COMMAND AND STAFF TRAINING INSTITUTE

BANGLADESH AIR FORCE

Individual staff Studies Programme (ISSP)

PROFESSIONAL SUBJECT-1 : METEOROLOGY
PHASE-8 : PART-I

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PHASE-8 : PART-I

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CONDUCT OF THE PHASE

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	e.	Storm Warning Signal Number	1	
	f.	Meteorological Communications	1	
	g.	Weather Briefing Procedures	2	
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6.	**Fundamentals of Meteorology**			
	a.	Divisions of Meteorology	1	6
	b.	Earth-Sun Relationship	3	
	c.	Methods of Heat Transfer	1	
	d.	Radiation (Heat) Balance in the Atmosphere	1	
7.	**Atmosphere**			
	a.	Layers of Atmosphere	2	2

Ser No	Topic		Period Distr	Total Period
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INTRODUCTION TO THE PHASE

Scope of the Phase

1. This phase deals with professional study materials on the subject of Meteorology which has been divided into two parts Part-I and Part-II. The materials contained in this volume constitute Part-I of the phase. The individual topic has been so presented as to help you gain theoretical background leading to its practical utilization in forecasting.

Guidance on Methods of Study.

2. In addition to this phase note you should study different manuals and Publications pertaining to this subject to improve your knowledge.

3. Self assessed exercises of different tasks are given in the phase note. Your study during the period is vital and your exercise results will reflect how much benefit you have derived forms it. You should try to solve some problems those come up during your study especially with Dynamic and Synoptic Meteorology.

SECTION – 1 : FORMATION OF METEOROLOGICAL SQUADRON

TASK-1 : TYPE OF METEOROLOGICAL SQUADRON

Introduction

1. To provide meteorological facilities required for Air Force Operations a meteorological branch has been organised in Bangladesh Air Force. In the national network, though technically assisted by Bangladesh Meteorological Department, the branch functions under the entire control of the Chief of Air Staff, Bangladesh Air Force. A Directorate of Meteorology has been established under the Assistant Chief of Air Staff (Operations and Training) at Air Headquarters to formulate and implement plans and policies regarding meteorological facilities in Bangladesh Air Force. In the international field of Meteorology, airforce meteorological branch, is to maintain liaison as and when necessary, with the Director, Bangladesh Meteorological Department, who represents Bangladesh in the World Meteorological Organisation (WMO) and International Civil Aviation Organisation (ICAO). Bangladesh became member of WMO on 24 Aug 73 and ICAO on 21 Jan 73.

Meteorological Squadron

2. In the chain of meteorological branch a few squadrons have been formed to function in the field of meteorology for the sake of operational requirements. Considering the size, scope and operational activities the squadrons have been marked as follows :

a. Squadron having the status of Main Meteorological Office (MMO) where round the clock forecasting watch is maintained will be known as Main Meteorological Squadron.

b. Squadron having the status of Dependent Meteorological Office (DMO) where restricted forecasting watch is maintained will be known as Dependent Meteorological Squadron.

c. Squadron having the status of Supplementary Meteorological Office (SMO) which functions under the directives from its controlling office will be known as Supplementary Meteorological Squadron.

3. The squadron will be commanded by the officer-in-charge meteorological squadron (OIC Met Sqn) who will remain responsible to the Base Commander through Staff Operations Officer for proper functioning of the squadron. Each squadron will consist of the following four flights :

a. **Analysis, Prognosis and Forecasting Flight.** This flight will be commanded by the officer next to OIC Met Sqn and will also perform the duties of duty forecasting officer as and when required. He will be known as the Chief Analyst and Forecaster (CAF). He will be responsible to the OIC Met Sqn for his duties.

b. **Climatology and Research Flight.** This flight will be commanded by a Flight Lieutenant. In addition to his assignments as duty forecasting officer he will remain responsible to the officer-in-charge meteorological squadron for all other duties concerning their flight.

c. **Instrument and Observation Flight.** This flight will be commanded by one of the forecasting officers. In addition to his forecasting duties, he will be responsible to the officer-in-charge meteorological squadron for the duties pertaining to this flight.

d. **Admin and Tele-Communication Flight.** This flight will be commanded by a Master Warrant Officer/Warrant Officer who will be responsible to the Officer-in-Charge meteorological squadron for the duties concerning correspondence in respect of administrative and tele-communication matter of the squadron as a whole.

Consolidation Exercise on Task–1

Q1. What is the purpose of organizing the meteorological branch in BAF ?

Q2. Under which PSO the meteorological branch is established ?

Q3. What is the name of similar organization outside, which is extending technical assistance to BAF Met ?

Q4. Who is representing Air Force Meteorological Branch in World Meteorological Organization ?

Q5. What is ICAO ?

Q6. What is the name of that Meteorological Squadron which maintains dawn to dust forecasting watch ?

Q7. How many flights are there in a Main Meteorological Squadron ?

Q8. How the OIC Analysis, Prognosis and Forecasting Flight be designated ?

Q9. What is the rank of the officer who will command climatology and Research Flight ?

Q10. Can a MWO/WO command Met Admin and Telecom Flight ?

Answer to Consolidation Exercise – 1

A1. To provide meteorological facilities.

A2. Assistant Chief of Air Staff (Operations & Training).

A3. Bangladesh Meteorological Department.

A4. Director of Bangladesh Meteorological Department.

A5. International Civil Aviation Organization.

A6. Dependent Meteorological Squadron.

A7. Four.

A8. Chief Analyst and Forecaster.

A9. Flight Lieutenant.

A10. Yes.

TASK-2 : DUTIES AND RESPONSIBILITIES OF OIC MET SQN

1. OIC Met Sqn will remain responsible to the Base commander through OC Ops Wg for the following duties:

a. He will analyze the 0000UTC charts and will ensure continuity in the analysis of other charts.

b. He will keep himself informed of the latest developments in analysis and forecasting techniques.

c. He will carry out Met brfg of VVIP flights.

d. He will ensure timely issue of Met warnings.

e. He will scrutinize forecasts and warnings issued by the Sqn.

f. He will carry out morning mass met brfg at least once in a week.

g. He will arrange/deliver the weather familiarization lectures to pilot or navigators.

h. He will maint liaison with the op units to find out their requirements from time to time.

j. He will be responsible for smooth and efficient functioning of the different flights forming the Met Sqn.

TASK-3 : DUTIES AND RESPONSIBILITIES OF OIC CLIMATE AND RESEARCH

1. In addition to his assignments as DFO, OIC Climate & Research will remain responsible to the OIC Met Sqn for the following duties:

a. He will study and carry out climatological research on any subject as assigned to him by OIC Met Sqn under the directives from Air HQ.

b. He will ensure preparation and submission of the following climatological returns:

(1) Monthly met and aviation current weather registers.

(2) Monthly met summaries.

(3) All aerological returns.

c. He will supply non-routine met information for aviation and other interests.

d. He will assist OIC Met Sqn in the scrutiny of forecasts.

e. He will prepare/deliver weather familiarization lectures to aircrews.

f. He will supervise the maint of met library.

TASK-4 : DUTIES AND RESPONSIBILITIES OF DUTY FORECASTING OFFICER

1. Duty Forecasting Officer(DFO) will remain responsible to the OIC Met Sqn for the following duties:

a. Check (EM DFO) previous night whether there is any requisition of route forecast. Arrive in the Sqn half an hour before collection time of the route forecast.

b. Analyze the following charts:

(1) Surface synoptic charts for 0000, 0600 and 1800 UTC.

(2) Upper Air charts for 0000, 0600 and 1800 UTC.

(3) 24 hours change charts.

(4) Constant pressure charts for 0000 UTC.

(5) T-Q grams.

c. Ensure continuous forecasting watch & timely issue of Met Wng and tx to concerned agencies.

d. Ensure timely issue of fol local forecasts:

Ser No	Reriod	Time of Issue
a.	0100-0800 UTC	0300 UTC
b.	0700-1400 UTC	0630 UTC
c.	0000-0100 UTC	2300 UTC

e. Issue route/flight forecast (if any) and trend forecast (hourly).

f. Carry out Met brfg as & when reqr.

g. Maintain close liaison with ATCO for issue of Met Wng.

h. Inform OIC Met about any VVIP/VIP movements.

j. Maint proper handing/taking over procedure & be updated about present wx condition.

k. Look after the safety and sy of the Met Instr while on duty & report imm to OIC about U/S.

l. Ensure updating of met web page in LAN/WAN especially during VVIP/VIP movement.

m. Remain standby (Afternoon DFO) for issue of Met Wng at night.

n. Carryout Scientific review/Map discussion every month.

p. DFOs' will comply with any other task assigned by OIC Met Sqn.

q. Check Sat image & Radar picture and info OIC Met if there is any sig wx.

r. Check BDWS and info OIC Met if there is any sig.

s. Check website of IMD and be updated with latest wx info.

TASK-5 : ACTIVITEIS AND ESTABISHMENT OF BAF MET SQUADRON

Met Sqn, BAF Base Bashar

1. **Introduction.** "Forecast for operational safety" with this motto, Met Sqn, BSR remains in operation round the clock. BSR Met Sqn provides Met Warning, Local Forecast and Route Forecast to all BAF and BA ac/hel operating Tej Airfield. This Sqn also issues international route forecast for BAF aircraft going abroad. BSR Met Sqn provides all kinds of weather information to all other Met Sqn of BAF and concerned agencies through Tel/Fax/LAN/WAN. This Sqn is also equipped with Radar Link from BMD Wx Radar for collection of 3 hourly Radar Image which is an important forecasting tool for issuing timely Wx Warning. This Sqn is having 3xWx Satellite receivers through which DFO receives colored real time cloud picture from Wx Satellite receivers. The Sqn now provides latest satellite images to pilots specially in case of VIP/VVIP missions. The Sqn uses highly technical software "Digital Atmosphere" to collect and analyze met data, which helps the forecasters to predict the wx pattern within very short time. The Sqn regularly updates the weather web page and all the user of LAN/WAN can see the updated Wx info at their end opening the Wx page.

2. **Role and Task.** The role and task of the Met Sqn are:

a. To provide all kinds of wx sp to ac op from the Base, this includes Army Aviation and friendly forces op in the country.

b. To maint round the clock watch on wx.

c. To issue round the clock local forecast and Met Warnings for Tejgaon airfield & 20 miles around and BAF Base PKP.

d. To carr out Met Brfg on routine basis at different Flg Sqns.

e. To issue Route forecast including VIP/VVIP Route forecast

f. To conduct 3 level, 5 level and 7 level OJT for airmen.

g. To provide Met trg facilities for different agencies like FCTU, FSI, Flg Sqns & AMI.

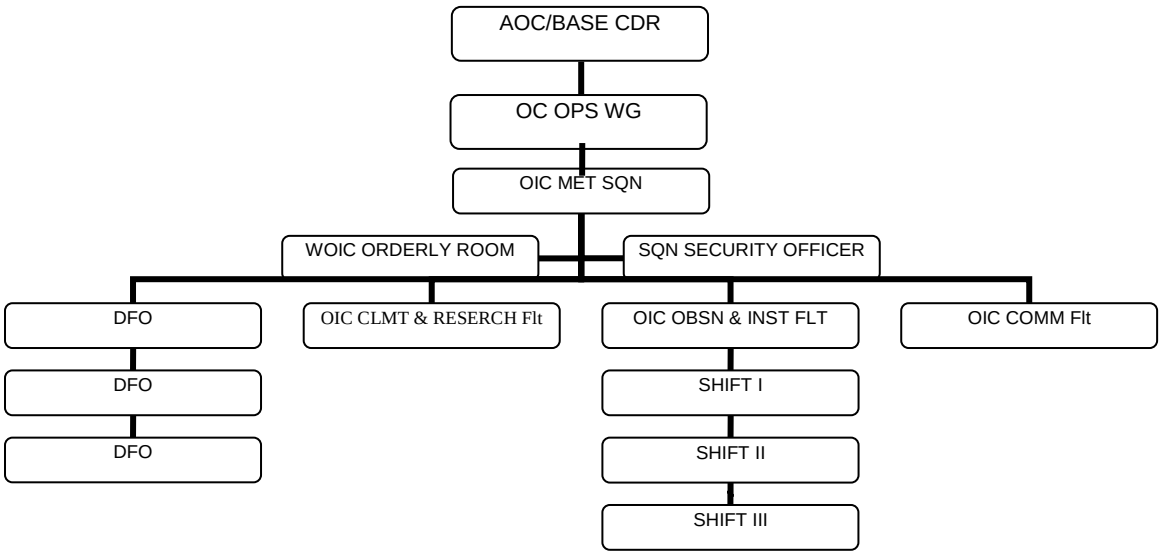
h. To collect, interpret and dispatch Radar Obsn, as and when required for other Met Sqns.

j. To maint liaison with Civil Met for smooth reception/ transmission of Met data, rectification of instrumental faults, quick reception of cyclonic signals.

k. To practice Met Contingency plan with Civil Met for national forecasting duties in case of strike to cater the national emergencies.

l. To fulfil addl wx related tasks given by the Base and Air HQs.

3. **Organogram.** The organogram of this Sqn is as below:



4. **Flts of Met Sqn.** With the above role and task, the Sqn comprises the fol 04 flts:

a. **Analysis, Prognosis and Forecasting Flt.** 01 x sr DFO is detailed as CAF (Chief Analyst & Forecaster), who looks after the forecasting job.

b. **Climatology and Research Flt.** 01 x offr of the rank of Sqn Ldr is in charge of this flt.

c. **Instrument and Obsn Flt.** One of the DFOs of the rank of Flt Lt acts as OIC of this Flt.

d. **Admin & Tele-Comm Flt.** WOIC/NCOIC of this Sqn looks after this Flt.

5. **Estb.**

a. **Officers**

APPOINTMENT	ESTB	
	RANK	STR
OIC Sqn	Wg Cdr	1
OIC Climate & Research	Sqn Ldr	1
DFO	Flt Lt & below	3
Total		05

b. **Airmen & Others**

APPOINTMENT	ESTB	
	RANK	STR
WOIC Sqn	MWO/SWO	1
NCOIC Sqn, Ops & Shifts	WO	4
Shift Workers	Sgt & below (Met Asst)	23
Computer Operator	Sgt & below (Clk GD)	1
Balloon Maker (Class-III)	Balloon Maker	4
Class IV	Peon/ Laskar	3
Total		36

6. **Activities.**

a. Daily mass brfg at Flg Wg HQ/Flg Sqn, Tejgaon.

b. Night Flg brfg at Tejgaon.

c. Fortnight brfg.

d. Issue & Exchange of Local Forecast.

(1) For period 0700 F - 1400 F at 0630 F.

(2) For period 1300 F - 2000 F at 1230 F.

(3) For period 1900 F - 0700 F at 1830 F.

e. Issue and Transmission of Met Wrng as per AFO 105-6A.

f. Transmission of Cyclonic Wrng as per AFO 105-6A.

g. Issue of Route Forecast (pictorial & non-pictorial) for BAF & other Flg org.

h. Plotting & Analysis of Charts.

(1) 3 x Synop charts at standard synoptic for the hr of 0000, 0600 & 1800 UTC.

(2) 3 x Upper air charts as of the same time above.

(3) 1 x Constant pressure chart at 0000 UTC.

(4) 1 x Changes Chart (P_{24}, P_{48}, Max, Min Temp & Pressure departure etc.).

(5) Tephigram of Dhaka & Calcutta.

j. Observation & Transmission.

(1) Half hourly/hourly METAR, SPECI, TREND Forecast & CRASH obsn as & when required.

(2) Preparation & Supply of Climate data as and when reqr by Air HQ.

7. **Eqpt.**

Nomenclature/Name of Eqpt	Quantity
Barometer	02 Ea
Stevenson Screen	01 Ea
Thermometers (incl Min & Grass Min)	04 Ea
Electrical Anemometer (Munro)	01 set
Barograph	01 Ea
Thermograph	02 Ea
Hygrograph	03 Ea
Nephoscope	01 Ea
Whirling Phychrometer	01 Ea
Sun Shine Recorder	01 Ea
Rain Gauge (Hyetograph)	01 set
Facsimile Receiver, FURUNO	01 set
Computer Control HF Receiver (RTT)	01 set
Microwave Data Link System	01 set
Extended Microwave Data Link	01 set
Radar Link System	01 Set
Wx Satellite Receiver System	01 Set
Auto Weather Station	01 Set
Electronic Anemometer (Microcomm)	01 Set
Electronic Anemograph (Microcomm)	01 Set

Met Sqn, BAF Base Zahurul Haque

8. **Introduction.** BAF Base Zahurul Haque is loc in the Karnphuli estuary near the funnel of Bay of Bengal. Base experiences diff types of wx because of her unique posn. Land breeze and sea breeze are prominent due to hill range along the coast. Summer monsoon is the most active in this area of Bangladesh with max amount of rainfall. The number of rainy days is max over this Base. Base also experiences dir thrust of cyclone unlike other BAF Bases due to her loc, funneling shape of Bay of Bengal and shallow depth of sea water along the coast. Met Sqn ZHR plays an important role for keeping watch on wx and forecasting rd the clock with a view "*Forecast for Operational Safety*".

9. **Role and Task.** Role and Task of the Sqn are as fol:

a. Maint round the clock obsn/forecasting watch.

b. Fulfill op reqr iro wx for all Flg Sqns/Units of the Base.

c. Op and maint of diff Met eqpt/instr used for su/upper air obsn and telecomm.

d. Carr out all routine / non-routine op wx brfg and de-brfg to the plt and navigators.

e. Help all Flg Sqns/Units to impart trg on Met.

f. Prep diff climate returns and dispatch the same to Air HQ.

g. Collect, compile and record Met data for climate research and Long Range Forecast as and when reqr.

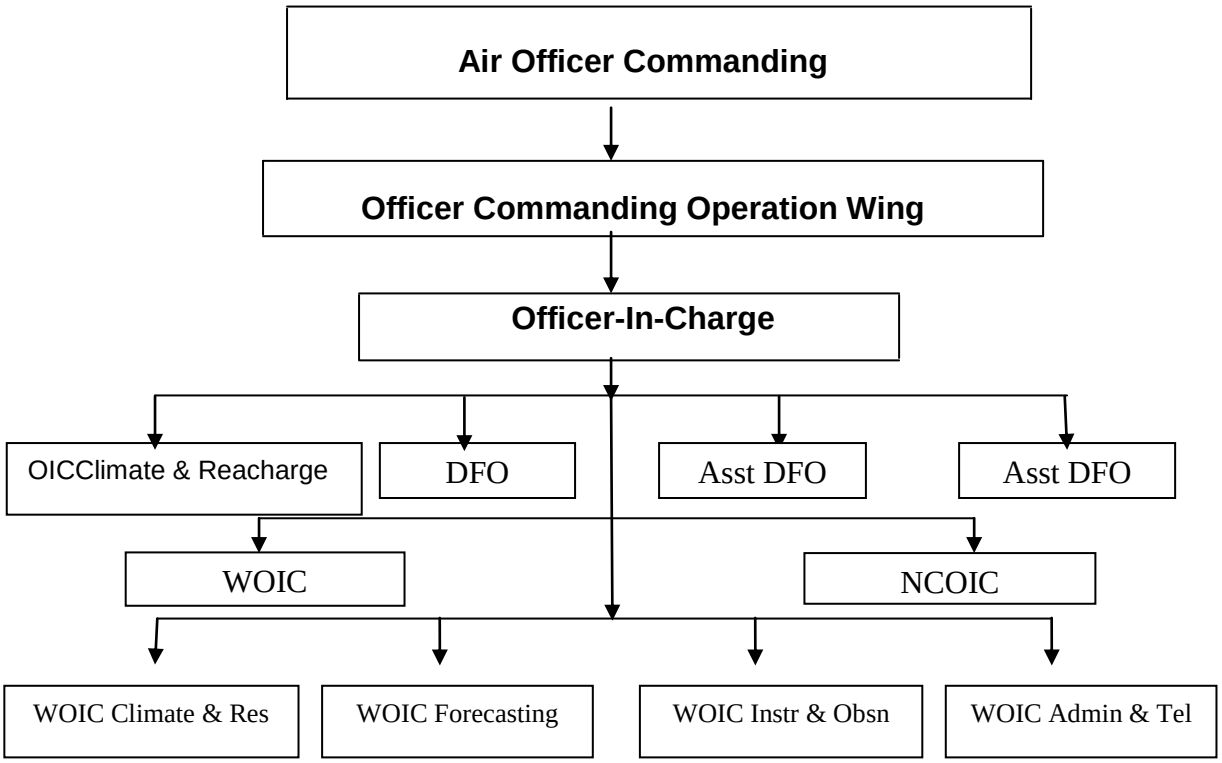
h. prep wx forecast for the op msn in Ctg Hill Tracts area.

j. Issue route forecast as and when reqr for local/International.

k. Issue route forecast for VIP/VVIP flt.

l. Meet any climatological query.

10. **Organogram.** The Org chart of Met Sqn is shown below:



11. **Estb.**

a. **Offrs.**

Appt	Rank	Estb
OIC Met Sqn	Wg Cdr	1
OIC Climate & Research	Sqn Ldr	1
Duty Forecasting Officer	Flt Lt & below	3
Total		5

b. **Airmen.**

Rank	Estb
MWO/SWO	1
WO	4
Sgt & below	21
Clk GD (Sgt & below)	1
Total	27

c. **Civ.**

Rank	Estb
BM	4
Peon/Lascar	3
Total	7

12. **Activities.**

a. **Routine Job.**

(1) Maint obsn watch round the clock.

(2) Carr out daily/weekly/fortnightly/ni flg brfg.

(3) Tx and collection of METAR/SPECI, Met Wng, Upper Wind, and other Met Info to all concern agencies incl other Bases.

(4) Issue of route forecasts as and when reqr for home and abroad.

(5) Issue and tx Met wng and cyclone sig to concerned agencies as per AFO 105-6A, dt 04 Oct 94.

(6) Prep wx forecast for msns of CHTs area as and when reqr.

(7) Recording and maint METAR Register, Climate Register and Special Wx Bulletin Register.

(8) Checking serviceability of all the Met instr.

(9) Updating hrly various Met Info in BAF Customize Software through BAF LAN/WAN.

b. **Issue of Local Forecasts.**

(1) Period 0700F-1400F; Issued at 0630F.

(2) Period 1300F-2000F; Issued at 1230F.

(3) Period 1900F-0700F; Issued at 1830F.

c. **Plotting and Analysis of Wx Charts.**

(1) 3 X Synop Charts (0000 UTC, 0600UTC &1800UTC).

(2) 3 X Pilot Charts (0000 UTC, 0600UTC &1800UTC).

(3) 1XConstant Pressure Chart (0000UTC).

(4) Tephigram of Dhaka or Chittagong or Calcutta (0000UTC), if aval.

(5) 2XPressure Changes Charts (0000UTC& 1200UTC) during cyclone.

(6) 2XPressure Departure Charts (0600UTC, 1800UTC) during Cyclone.

d. Delivery of lecture on “Met forecasting in BAF” for the MS students pursuing Atmospheric Science incl professors of Chittagong University.

e. Delivered lecture on Nor'wester and its precaution (Mar 2010).

f. Delivered lecture on Cyclone at the beginning of the cyclone pd .

13. **Eqpt.**

a. 3xWx Satellite Receiver Systems.

b. Hydrogen Generator.

c. Digital Auto Wx Station.

d. Barometer.

e. Electrical Anemometer.

f. Digital Atmosphere.(Software)

g. Theodolite.

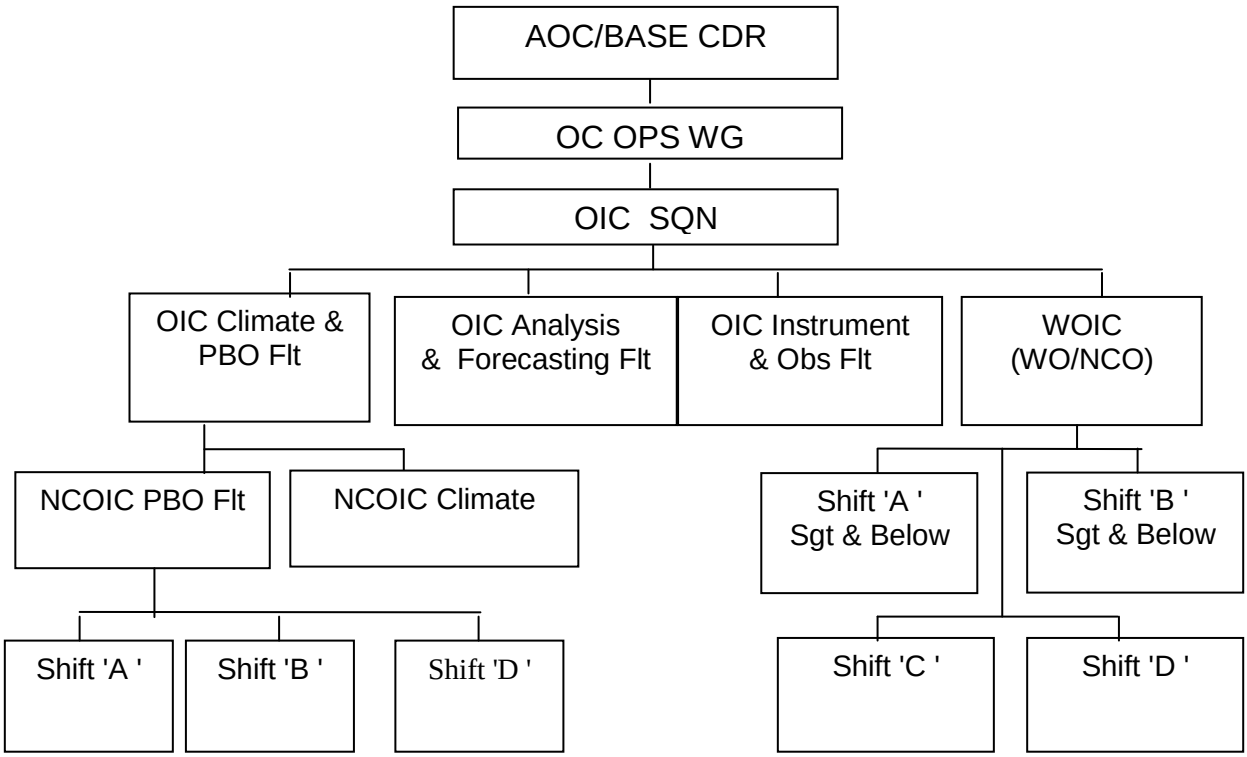
h Lightning Detector.

j. Fax.

Met Sqn, BAF Base MTR

14. **Introduction** The Met Sqn was established with the status of Main Meteorological Office (MMO) and handed over to BAF by BMD on 12 Dec 77 as per mutual agreement vide Air HQ/17098/Admin dt 12 Oct 77 and MOD letter No. 1/150376/D-IV/484 (1) dt 02 Sep 77.

15. **Organogram**



16. **Estb.**

a. **Officer**

Appt	Rank	Estb
OIC Met Sqn	Wg Cdr	01
OIC Climate & Research	Sqn Ldr	01
Duty Forecasting Officer	Flt Lt	03
Total		05

b. **Airmen**

Rank	Estb
MWO/SWO	01
WO	04
Sgt & below	27
Clk GD	01
Total	33

c. **Civilian**

Rank	Estb
Balloon Maker	04
Peon	02
Lascar	01
Total	07

17. **Activities.**

a. Daily Met Briefing to pilots to keep updated the on going Wx activities.

b. Timely issue and dissemination of Met Warning to recipient.

c. Fortnightly Met Briefing to all officers to plan and prepare Flg activities.

d. Deliver Nor'wester briefing to all Base Personnel to create awareness about the erratic behaviour of severe weather and take precautionary measures.

e. Carry out seasonal weather briefing to all person of the sqn like Monsoon, Cyclone and winter weather to recapitulate.

f. Post commission Offrs' professional training.

g. Met briefing and forecasting course of WO/SWO/MWO.

h. Wx satellite receiver maintenance course twice in a year.

j. Basic Computer Training Course

k. Training of Balloon Makers as and when required.

l. Scientific review by Officers'.

m. Conduct classes of Army and Navy offr at 18 Sqn, BAF

n. Conduct classes of ATC Flt Cadets.

p. Conduct classes of 41 QFI course at FIS, BAF

q. Intermediate Professional Course of Met at OTS, BAF

r. QFI course at FIS, BAF.

s. Flt Cadets of ATC

t. BN Offrs at 18 Sqn, BAF

u. BA Offrs Basic Hel Conversation Course at 18 Sqn, BAF

v. OJT for one year of 01 X Cpl of 7 level & 03 X AC of 3 level.

w. Publish Nor'wester slogans through BRO's

x. Arrange training on Satellite receiver twice in a year.

y. **Issue of Local Forecasts.**

(1) Period 0700F-1400F; Issued at 0630F.

(2) Period 1300F-2000F; Issued at 1230F.

(3) Period 1900F-0700F; Issued at 1830F.

z. **Plotting and Analysis of Wx Charts.**

(1) 3 X Synop Charts (0000 UTC, 0600UTC &1800UTC).

(2) 3 X Pilot Charts (0000 UTC, 0600UTC &1800UTC).

(3) 1XConstant Pressure Chart (0000UTC).

(4) Tephigram of Dhaka or Chittagong or Calcutta (0000UTC), if aval.

(5) 2XPressure Changes Charts (0000UTC& 1200UTC) during cyclone.

(6) 2XPressure Departure Charts (0600UTC, 1800UTC) during Cyclone.

SECTION-2 : FUNCTIONS OF METEOROLOGICAL SQUADRONS

TASK-6 : METEOROLOGICAL OBSERVATION PROCEDURES

Introduction

1. An observation is the evaluation of one or more meteorological element(s) either as a sensor observation estimated by experience only or as an instrumental observation made with the help of one or more measuring instruments or sensor-indicator systems, inclusive of necessary reductions, corrections and calculations connected therewith. To ensure that the observations all over the world are comparable, the observational practices and methods of applying corrections and obtaining derived data have to be uniform and in conformity with standard international practices.

2. The accuracy with which meteorological parameters should be measured varies with the specific purpose for which it is required. The various Technical Commissions of the World Meteorological Organisation have laid down the accuracy requirements for the measurements of the meteorological parameters in regard to their specific branch of meteorology.

3. Duty Met officer must check the accuracy of meteorological observations. It is desirable that under marginal/bad weather conditions the conditions as seen from the tower and obtained from aircraft in flight should be compared with the current weather reports from the Met Section. The observer must avoid parallax errors.

Current Weather Observations

4. At airfields, current weather observations are made primarily to cater to flying activities. As such when the meteorological conditions are different in different directions over the airfield and its immediate vicinity, due care must be taken to report the conditions representative of the area which are of direct interest to flying, viz. approach, landing, take-off, climb-out and circuit. The time of observation will be the time at which pressure reading is taken. The process of observation should start at least 10 minutes before the time of observation.

5. **Routine Observations**. METAR is the abbreviation of ‘Aviation Routine Weather Report’. It is generally issued hourly/half hourly on routine basis. Whether required or not by aircrew, the METAR is issued round the clock throughout 24 hours each day by Met Offices in the code form. The METAR code is given below:

METAR CCCC GGgg dddff/$f_m f_m$

VVVV $RV_RV_RV_RV_R/D_RD_R$ WW $N_sCCh_sh_sh_s$

or

CAVOK

TT/T_dT_d $P_HP_HP_HP_H$

TTTT GGgg HR dddff/$f_m f_m$

or

NOSIG

Decoding of METAR Message

6. The specifications of the above symbolic letters (or groups of letters) are given below:

GGgg = Time of observation in hours and minute UTC(Universal Time Coordination).

CCCC = International four letter ICAO location indicator, name of the station; eg VGJR=Jessore, VGEG=Chittagong etc.

ddd = Direction in degrees from which wind is bellowing, rounded off to the nearest 10°. The direction shall refer to the true north and not to the magnetic north.

ff = Wind speed in knots.

$f_m f_m$ = Maximum wind speed in knots at surface, the speed of 100 kts or more are given in 3 figures.

VVVV = Horizontal visibility at surface, in meters up to and including 9 km. 9999 indicates visibility of 10 km and above.

R = The RVR is preceded by R.

$V_R V_R V_R V_R$ = Runway visual range in meter.The RVR report should apply to a measurement from a location along runway about 300 meters from the threshold.

$D_R D_R$ = Number of Runway to which the RVR refers.
WW = Significant present weather.

$P_H P_H P_H P_H$ = QNH value in whole mbs.

TT = Air temperature in whole degrees Celsius. For negative values TT is preceded by the letter M.

$T_d T_d$= Dew point temperature in whole degrees Celsius. For negative values $T_d T_d$ is preceded by the letters M.

N_s = Amount of individual cloud layers of Genus CC.

CC = Genus of cloud according to abbreviation.

$h_s h_s$ = Height of the base of cloud layer whose genus is indicated by CC.
CAVOK = CAVOK (CLoud And Visibility OK or Ceiling And Visibility OK) is used whenever the following conditions occur simultaneously at the time of observation and used in place of groups ‘VVVV $RV_R V_R V_R V_R/D_R D_R$ WW $N_s CCh_s h_s h_s$’:

Visibility : 10 km or more.

Cloud : No cloud below 1,500 meter.

Weather : No precipitation and no thunderstorm.

An example of METAR message is given below:

METAR 170900Z VGJR 22010G20KT 6000 05HZ 3SCT007 2FEW025 6BKN120 25/19 1001

7. **Non-routine Observations**. Notwithstanding para 5, the observations shall be made on the following occasions:

a. When requested by the ATC in connection with aircraft take-off, holding or making an approach to land. Such reports will be logged in the Enquiry Log and also be entered in the current weather register in chronological order.

b. As soon as the Met section comes to know of an aircraft accident on the airfield or within its local flying area. Such reports will be annotated as ‘Crash Observation’ in the current weather register and underlined in red.

TASK-7 : SELECTED SPECIAL WEATHER REPORT

Introduction

1. Besides half-hourly/hourly aviation routine weather reports (METAR) and other casual METAR reports issued on requisition from any authorised agency including the report on the occasion of an aircraft incident/accident (Crash Observation), selected special weather reports (SPECI) are also issued when certain adverse weather conditions such as poor visibility, abnormal change in wind direction and speed, coverage of sky with very low stratus cloud, thunderstorm, dust/sand storm etc occur at an airfield. These are issued on both deterioration and improvement of adverse weather. When deterioration of one weather element is accompanied by an improvement of another element a single appropriate SPECI should be issued. SPECI reports are of vital importance for aviation.

Selected Special Weather Report(SPECI)

2. SPECI means 'Aviation Selected Special Weather Report'. When certain weather elements are expected to deteriorate to a certain critical value, a weather warning is issued. If that deterioration actually exists, then SPECI is issued. SPECI is made during the intervals between the routine observations. It is made in accordance with the criteria specified in Table 10A**.** For SPECI actual time of observation is maintained. It is issued in METAR code except temperature and pressure groups. There are two types of SPECI:

a. SPECI for deterioration.

b. SPECI for improvement.

3. When a deterioration of one weather elements is accompanied by an improvement in another element, eg lowering of clouds and an improvement in visibility, a single SPECI report shall be issued. As soon as the conditions for which SPECI for deterioration was issued improve or ceases, a fresh SPECI is issued indicating the improved condition. The SPECI message has the precedence of 'IMMEDIATE'. Improvement SPECI is not issued if the dangerous condition exists. If weather deteriorates in 1 hour then improvement SPECI should not be issued.

Criteria for the Issue of SPECI Reports

4. There are two types of SPECI issued as special reports. One is issued for deterioration and another is issued for improvement. Only four main meteorological elements are considered for issuing of SPECI in Table 5.1.

Table 5.1 : SPECI

Elements	Special Report to be made for Deterioration	Special Report to be made for Improvement
Surface Wind Speed	1st SPECI: Speed ≥ 15 kts 2nd SPECI: Speed ≥ 25 kts 3rd SPECI: Speed ≥ 35 kts	1st SPECI: Speed ≤ 35 kts 2nd SPECI: Speed ≤ 25 kts 3rd SPECI: Speed ≤ 15 kts
Low cloud: when the height of base of lowest cloud of an amount >4 oktas	1st SPECI: Height ≤ 1000 ft (300m) but not < 500 ft (150m) 2nd SPECI: Height ≤ 500ft (150m) but not < 200 ft (60m) 3rd SPECI: Height ≤200 ft (60m)	1st: SPECI: Height ≥ 200 ft but not > 500 ft 2nd SPECI: Height ≥ 500 ft but not >1000 ft 3rd SPECI: Height 1000 ft or more
Horizontal Visibility	1st SPECI: ≤ 5000 m but not < 1500 m 2nd SPECI: ≤ 1500 m but not < 800 m 3rd SPECI: ≤ 800 m	1st SPECI: ≥ 800 m but < 1500 m 2nd SPECI: ≥ 1500 m but < 5000 m 3rd SPECI: ≥ 5000 m
Present Weather	Thunderstorm when started Hail when started Squall when started Dust Storm when started	Thunderstorm when ceased Hail when ceased Squall when ceased Dust Storm when ceased

TASK-8 : WARNING FOR METEOROLOGICAL PHENOMENA

1. **Weather Phenomena.** Meteorological warnings are issued for the following weather phenomena either individually or jointly for more than one phenomenon at time as and when expected to occur:

a. Poor visibility.
b. Low cloud.
c. Strong wind.
d. Gusty wind.
e. Thunderstorm.
f. Squall/Nor'wester.
g. Hail.
h. Heavy rain.
j. Dust storm.

2. **Classification.** Meteorological warnings[1] are classified as 'Red' ie Red Meteorological Warnings (RMW) and 'Yellow' ie Yellow Meteorological Warnings (YMW) indicating severity of the expected weather phenomena mentioned in paragraph 11.

3. **Criteria.** Criteria for the issue of weather warnings of the phenomena mentioned in paragraph 11 above are given in Table 5.2.

Table 5.2 : Criteria for the Issue of Weather Warnings.

Ser	Subject of Warning	Yellow Meteorological Warning (YMW)	Red Meteorological Warning (RMW)
1	Poor Visibility	When visibility is expected to reduce to 5 km or less but not below 900m.	When visibility is expected to reduce to less than 900m.
2	Low Cloud	When the height of base of lowest cloud of an amount greater than 4 oktas is expected to lower between 450-150 meters (1500-500 feet).	When the height of base of lowest cloud of an amount greater than 4 oktas is expected to lower below 150 meters (500 feet) AGL.
3	Strong Wind/Gale	When the mean wind speed is expected to exceed 15 kts but not to exceed 28 kts.	When the mean wind speed is expected to exceed 28 Kts (gale force).
4	Gusty Wind	When the wind is expected to be gusty and wind force in individual gusts is expected to reach 15 to 28 kts.	When the wind is expected to be gusty and the wind force in individual gusts is expected to exceed 28 kts.
5	Thunderstorm	When a thunderstorm not accompanied by squall is expected to occur.	When a thunderstorm accompanied by squall is expected to occur.
6	Squall/ Nor'wester		When squall/Nor'wester is expected to occur.
7	Hail		When hail is expected to occur.
8	Heavy Rain		When rainfall of intensity 2 inch per hour or more is expected to occur.
9	Dust Storm		When dust storm is expected to occur.

4. **Area Covered.** Weather warning will be effective for an area covering 20 miles (30 km) around an airfield.

5. **Period of Validity.** The period of validity of a warning is to be as short as practicable preferably for 1 hour. Under any circumstances initially it should not exceed two hours. It may, however, be extended, if necessary.

6. **Amendments.** An amendment is to be issued under the following circumstances:

a. When the intensity of weather is expected to change, the criteria for the warning from Yellow to Red or vice versa.

b. When the weather is expected to develop earlier or later than the period indicated in the original warning.

7. **Cancellation.** Meteorological warning is to be cancelled as soon as the hazard is no longer expected to occur within next one hour.

8. **Forms of Message.** The text of the message is to consist of the following:

a. The word 'YELLOW/RED' at the beginning.

b. The phenomena or phenomenon together with details and intensity.

c. Area likely to be effected.

d. Period covered (date and time of commencement and cessation in UTC).

e. Percentage of probability.

9. **BAF Form No.** Form 10275 of appropriate colour will be used for all Met Warnings. BAF Form 10275A (Yellow colour) and BAF Form 10275B (Red colour) will be used for YMW and RMW respectively.

10. **Gale Warnings**. Warnings in respect of strong and gusty surface winds, gale, squall, thunderstorm and dust storm are essential for taking precautionary measures for the protection of parked and moored aircraft. Such warnings, will therefore, be termed as 'Gale Warnings' when issued for this purpose. The gale warning a shall be issued when the mean speed of the surface wind is expected to exceed 34 knots.

TASK-9 : ALTIMETER SETTING

Introduction

1. Altimeter,setting is a pressure value used in setting an altimeter which is an instrument fitted in aircraft for measuring altitude. It is found by adding to the observed station pressure a correction determined by the weight of a column of air extending from station to sea level whose temperature distribution is that of the standard atmosphere. The altimeter when set to this reading indicates the elevation of an airfield above sea level when the aircraft is on the ground and approximate height of the aircraft above sea level when the aircraft is in flight.

2. The value of QNH is reported to the second place of decimal in inches and millimeter and first place of decimal in milibars. The reportable values are found in the following numerical figures in group :

a. Inches..... ..... 4 figures.

b. Millibar..... ..... 4 figures (3 figures pressure is below 1000 mbs).

c. Millibmeter..... 5 figures.

Determination of QNH

3. The procedure for determining altimeter setting are detailed below :

a. Determine cistern level pressure (observe barometric pressure and reduce it to the cistern level).

b. Reduce the cistern level pressure to ten feet above the official airfield level (QFE).

c. Find the pressure altitude(QNE) in feet from the Standard Atmospheric Table (as stated below) corresponding to the value obtained in b above.

d. From this pressure altitude subtract algebraically the official airfield elevation.

e. Find the pressure in the standard atmospheric tables equivalent to the altitude found in d. If the sign is negative this altitude is considered to be below sea level. This Pressure isthe QNH value for the airfield.

STANDARD ATMOSPHERIC TABLE

4. An example is given below :

a. Cistern level pressure (cistern 5 feet above official airfield level) is 990.0 mb.

b. Pressure reduced to official airfield level plus ten feet ie QFE is 989,8 mb.

c. Pressure atitude corresponding to b ie QNE is 646 feet .

d. Pressure altitude minus airfield elevation (Say, 1150 feet) is equal to -504 feet.

e. QNH is pressure corresponding to d is 1031.9 mb.

TASK-10 : STORM WARNING SIGNAL NUMBER

Introduction

1. Storms generally occur in Bangladesh in the months of April-May and October-November. The Meterological Department uses separate codes of signals for storm warnings at maritime and river ports. These codes are given below in abbreviated forms. It should be noted that the signal numbers in the two codes do not carry the same significance and, in particular, that higher signal numbers within the danger and great danger maritime groups indicate differences in storm location not difference in strom intensity.

Storm Warning Signals for Use at Maritime Ports.

2. **Distant Cautionary Signal No.One.** There is a region of squally weather in which a storm may be formed.

3. **Distant Warning Signal No.Two.** A storm has formed.

4. **Local Cautionary Signal No.Three.** The port is threatened by squally weather.

5. **Local Cautionary Signal No.Four.** The Port is threatened by a storm, but danger not yet sufficiently great to justify extreme precautionary measures.

6. **Danger Signal No.Five.** The port will experience severe weather from a storm of slight or moderate intensity and the storm is expected to cross the coast to the south of the port.

7. **Danger Signal No.Six.** The port will experience severe weather from a storm of slight or moderate intensity and the storm is expected to cross the coast to the north of the port.

8. **Danger Signal No.Seven.** The port will experience severe weather from a storm of slight or moderate intensity and the storm is expected to cross over or near the port.

9. **Great Dander Signal No. Eight.** The port will experience severe weather from a storm of great intensity and the storm is expected to cross the coast to the south of the port.

10. **Great Dander Signal No. Nine.** The port will experience severe weather from a storm of great intensity and the storm is expected to cross the coast to the north of the port.

11. **Great Dander Signal No. Ten.** The port will experience severe weather from a storm of great intensity and the storm is expected to cross the coast over or near the port.

12. **Failure of Communication Signal No.Eleven.** Communications with Met Warning Centre have broken down due to storm weather.

Storm Warning Signals for Use at River Ports.

13. **Cautionary Signal No.One.** Area threatened by squally winds. Look out for further developments.

14. **Warning Signal No.Two.** A storm or Nor'wester is likely to strike the area.

15. **Danger Signal No.Three.** A storm will soon strike the area. All vessels seek shelter immediately.

16. **Great Dander Signal No. Four.** A violent storm will soon strike the area.

TASK-11 : METEOROLOGICAL TELECOMMUNICATIONS

Introduction

1. An efficient and reliable telecommunication system is the life-line of an efficient meteorological service. Weather does not recognise the political boundaries, hence met information has to be collected and exchanged on a Global basis within a stipulated time frame. For this purpose, a Global Telecommunication System (GTS) has been developed under the World Weather Watch (WWW) programme by the WMO. BMD has established National Meteorological Communication Centre (NMCC) for the functional control of Meteorological Communication in Bangladesh. Under this centre, an extensive Telecommunication Network connecting National and International Meteorological centres is maintained, for collection and distribution of meteorological information (basic data and processed information) over the Globe. Air Force also maintains its own Telecommunication Network for exchange of aviation met data among the Air Force airfields to meet the operational requirements.

Regional Telecommunication Hub

2. Under the Global Telecommunication System (GTS) organised as part of the World Weather Watch plan of WMO, New Delhi is functioning as a Regional Telecommunication Hub on the Main Telecommunication Network (MTN) connecting the two World Meteorological Centres, Moscow directly and Washington via Tokyo. The automated centre of RTH, New Delhi is thus the principal Meteorological Telecommunication Centre in South Asia and its zone of responsibility extends from Saudi Arabia in the West to Thailand in the east and the adjoining sea areas. It collects observational data from these areas and feeds them on to the Global Telecommunication Network for Global and Regional exchange. Other Meteorological services in the Middle East and South East Asia also depends for their data requirement on RTH, New Delhi. Accordingly it maintains telecommunication circuits with Moscow, Tokyo, Cairo, Jeddah, Beijing, Bangkok, Colombo, **Dhaka**, Tehran, Karachi, Male, Yangoon and Kathmandu. BMD collects observational data from all Meteorological stations of Bangladesh and feeds them to the Global Telecommunication Network through RTH.

Air Force Met Communication Channels

3. The Meteorological Services in the BAF provide necessary met information for ensuring safety of aircraft in the air and on the ground for efficient planning and safe execution of Air Operations. The basic requirement to meet this objective is to have an efficient communication system for the exchange of met data. To meet the operational requirements of Air Force, following communication facilities are available at most of the Met Sqns :

a. Broadband Internet Connection
b. Satellite Receiver System.
c. Radar link and Data link
d. LAN/WAN
e. Fax
f. RT/ Walkie-talkie

Met Data Exchange System :

4. The following met data are transmitted among different Met Sqns :

a. Hourly METAR and SPECI.

b. Weather Warning.

c. SYNOP.

d. PILOT.

e. RAREP.

5. SYNOP, PILOT and TEMP data are received from internet source as well as from Digital Atmosphere. All other information, message or signal from BMD is received through FAX. METAR/SPECI, SYNOP and PILOT data are transmitted among the Met Sqns and other users through telephone, Fax and LAN/WAN. Met Sqn, MTR has already been connected with the network of Met Data Acquisition Sub System (MDASS) under the Global Telecommunication System(GTS) and other Met Sqns are in the process of the network so as to collect all Met data. RAREPs are received through Radar link as well as telephone. Recently BAF KTL is connected with Composite Radar Imagery of ZIA through optical fibre link. Weather Warnings are transmitted among transmission channel telephone and Walkie-talkie. All Met Sqns have own Satellite receiver system through which it can receive satellite picture directly from MTSAT and FY-2 satellite.

TASK-12 : WEATHER BRIEFING PROCEDURE

Met Briefings

1. **Introduction**. Meteorological briefing and documentation is to be provided by the Met Section at an airfield for all aircraft operations conducted from that airfield. Meteorological charts used for the briefing are to cover an area sufficient to show the meteorological situation in relation to the area and missions expected to be flown.

2. **Occasions of Met Briefings.** The Met Section is expected to brief aircrew and other personnel of the station connected with flying activity on the following occasions: -

a. Mass Briefing held every day in the morning or as specified by AOC before commencement of planned day/night flying.

a. For cross country flights and route forecast.

b. For any specified mission /exercise, as required.

3. **Mass Briefings**. Met briefing for routine planned local flying will be a part of the station mass briefing, conducted once in a day before the commencement of flying activity. The purpose of the met briefing is to help the aviators to carry out Op task safely. This briefing is to be conducted at Flg Sqn's Briefing Room or a place designated for the assembly of aircrew and others connected with flying. The information must be brief and clear. Only vital and relevant information required by the aircrew for local flying or a particular operation is to be presented.

4. Met briefings for cross country flight and any specific mission are to be conducted at met section. The venue of exercise briefing will be decided by AOC as the case may be.

5. **Preparation**. Duty met officer conducting the briefing must be familiar with the following:-

a. The general plan and nature of flying/exercise/mission profiles to be carried out during the forecast period. Ops staff should provide this information to the met section for effective met briefing.

b. Area and routes concerned.

c. Aircraft involved and their performance limitations.

d. Topography and climatology of the region, local peculiarities and main adverse weather period.

e. Professional background of the persons being briefed.

6. There should be thorough preparation before the briefing. The Met Officer should systematically analyse the latest charts, satellite imageries, inferences and weather bulletins, radar reports, study the relevant current weather observations, TRENDs etc., and prepare the meteorological charts, forecasts and diagrams for the mass briefing. It should be ensured that the latest current weather reports of base and diversionaries are available. He should precisely plan the text and sequence of the met briefing, anticipating the questions from the aircrew and provide proactive, unequivocal advice. Comparison of previous day's weather profile with that expected for the day, creates more impact on the aircrew. Weather aspects on which you require de-brief should be clearly specified for a meaningful dialogue. Vague phrases covering large spans of time and phenomena should be avoided. For example, a forecast like "Fair to Cloudy, Tempo Rain/TSRA" should be avoided. The expected changes are to be mentioned using specific time blocks.

7. **Standard Templates**. Current weather info and local forecasts should be prepared as standard templates and used in briefing without significant variations. The slides meant for projection must be neat, accurate and clear, arranged in the correct sequence. This uniformity will help the out-station crew to appreciate the met briefing better. Greatest visual effect is achieved by using primary colors. To avoid obscuring the material, pointers are to be used for indicating systems/figures etc.

8. Mass briefings must be well modulated, with proper pauses and emphasis where it is due and audible to the full assembly. The material displayed must be clearly visible to every member of the audience. Font size >14 should be used for text.

9. **Display Material.** Following information should normally be displayed for briefing:-

a. Pressure Pattern of the latest synoptic hour.

b. Latest satellite imageries.

c. Streamlines Patterns at selected levels with expected wind and temperature

d. Current Weather observations of base and neighbouring airfields and describe weather warnings, TRENDs with emphasis on primary diversions in pre-monsoon and monsoon seasons.

e. Latest RAREP plot.

f. Local/Area forecast for the relevant period.

g. Climatological information, Sun – Moon data etc.

10. **Sequence.** To sustain the interest of the aircrew the briefing should be task oriented. Emphasis on expected aviation hazard and 'Significant Weather Event' should be its main plank. It should conclude with met information pertaining to the op task of the day, highlighting the fluctuations of met parameters. Following sequence is recommended in the briefing:

a. Summary of past weather.

b. Synoptic Situation as on the latest chart and the forecast development. Important features such as depressions, cyclones, jet streams and their movement must be clearly brought out.

c. Satellite imageries.

d. Upper air patterns. Highlight significant changes in profile leading to turbulence.

e. Latest current weather and trend of base and neighbouring/diversionary airfields, together with latest radar reports (plotted on a polar diagram) and in-flight reports, if any. Weather warnings, if any at base and diversionaries and their period of validity.

f. Local forecast for the next 6 to 12 hours for area 50km around, giving details of winds and temperature for various altitudes, variations of different elements, freezing level, mintra level, CAT, icing, mountain waves etc. If low flying and cloud flying areas are outside this area, detailed forecasts for such areas also should be spelt out separately.

g. Climatological information and clarification of doubts, if any.

11. **Briefing Aids**. Generally an overhead projector or PC based projector is used for briefing.

12. **Record of Mass Briefing**. All units are to maintain a record of the material prepared for Mass Met Briefing in the register for “Synoptic Situation, Forecast and Verification”. The synoptic situation and forecast (Local/Area /Diversionary and Forward Areas) as briefed at the mass briefing are to be written in the register.

Met Briefing For Cross Country Flights

13. Briefing or consultation is to be provided, on request to flight crew. The Captain/ Co-Pilot/Navigator of aircraft on a cross-country flight originating from the base will report to the Met Section and obtain current and expected weather in respect of route, airfield of departure, destination and alternate airfield prior to the filing of the flight plan for clearance. The captain of the ac transmitting through the base will make own arrangements to obtain the met briefing. Its purpose is to provide the latest available information on existing and expected meteorological conditions along the route. Met briefing is to be done by the Duty Met Officer. This briefing is to include a written forecast.

14. **Pre-Flight Information**. Notification of a flight will be given to the Met Section as early as possible to enable the necessary information to be prepared. In case of operational necessity like CASEVAC or rescue, the notice period may be waived. In such a case, the Met Section is to provide as much information as possible in the time available.

15. When the notification of a proposed flight is received, the following information is to be obtained: -

a. Type of aircraft.

b. ETD, route, flight-profile, destination, alternate(s) and ETA.

c. Nature of flight and special requirements, if any.

d. Time of briefing.

16. **Information at Briefing**. The meteorological information used for briefing and consultation is to include any or all of the following, as required: -

a. Latest Synoptic charts for the surface and upper air together with appropriate previous charts and diagrams.

b. Flight, route and area forecasts as applicable.

c. Aerodrome forecasts (TAF) as applicable.

d. Latest available current weather (METAR/SPECI/SPECIAL) reports.

e. Weather warning relating to the local airfield and diversions.

f. Meteorological satellite imageries or mosaics and/or neph-analysis.

g. Ground based weather radar information from nearest radar location.

17. **Documentation.** Documentation provided for flights shall contain: -

a. **Upper Wind and Upper Air Temperature Information**. It is to be supplied in a tabular form or in a chart form. The levels depicted are to correspond to the standard isobaric levels same as for upper air charts.

b. **Significant Weather**. Information on expected significant en-route weather phenomena is to be provided. It should include: -

(1) Thunderstorm/Hailstorm.

(2) Tropical Cyclone.

(3) Severe squall lines.

(4) Moderate or severe icing.

(5) Moderate or severe turbulence.

c. **Clouds.** The procedure for representing clouds is given below:

(1) **CB Cloud**. The abbreviation EMBD (embedded) any be added to any one of the three abbreviations to indicate cumulonimbus cloud that are contained in layers of other clouds or concealed by poor in flight visibility conditions. In all forms and documentation cumulonimbus cloud should be indicated using following abbreviations: -

(a)	ISOL	for individual CBs	(Isolated)
(b)	OCNL	for well separated CBs	(Occasional)
(c)	FRQ	for CBs with little or no separation	(Frequent)

(2) **Other Clouds**. All other clouds should be depicted using the abbreviations based on ground/sky contact most of the time (FEW), for nearly 50% of the time (SCT), for less than 20% of the time (BKN) and no contact at all (OVC).

(3) Type of clouds should be indicated as follows: -

(a)	**High Clouds:**	Cirrus -	'CI'
		Cirrocumulus -	'CC'
		Cirrostratus -	'CS'
(b)	**Medium Clouds** :	Altocumulus -	'AC'
		Altostratus -	'AS'
(c)	**Low Clouds** :	Nimbostratus -	'NS'
		Stratocumulus-	'SC'
		Stratus -	'ST'
		Cumulus -	'CU'
		Cumulonimbus-	'CB'

(4) On tabular form, the base and top of cloud only relevant to the flight is to be indicated. The height of the base of the lowest clouds should always to be given.

(5) On pictorial cross section the base and top of cloud associated with significant weather should be given. Additionally, the height indication of the base of the lowest cloud should be given, if required for operation.

(6) On both forms and documents, a progressive change in cloud height through the section, when significant, should be shown by two sets of figures for height indication, separated by word 'becoming' or by the word ' then' in the case of an abrupt change in space. Occasional variations should be indicated in the same way, employing the abbreviation OCNL. If the word 'becoming' refers to a change in time, stating the time at which the changes expected should indicate this. The unit in which height indications are expressed should be clearly indicated on the form.

(7) In the cross section the cloud types should be depicted at appropriate levels with cloud top forecasts drawn as accurately as possible. TCU, CBs and areas of precipitation should be highlighted.

d. **0° Celsius Isotherm**. The 0°C isotherm for the route should be drawn in thick black. If the air temperature is 0°C at more than one level, all such levels be similarly marked.

e. **Upper Winds and Temperature**. The wind and air temperature should be given at each of a series of upper levels, as required. The wind and air temperature at the lowest of these levels should be entered on the lowest line with those for the higher levels in ascending order above. The wind or air temperature given for any level should be the mean value over the section of the route at that level unless it is necessary to give the means over smaller distances than the whole section, in which case the successive mean values, separated by the word 'becoming', should be given in the order in which the aircraft is expected to encounter them. If "becoming" refers to a change in time, stating the time at which the change is expected should specifically indicate this. In specifying wind, the direction should be given first in three digits indicating degrees true, to the nearest 10°, followed by an oblique stroke and then the value of the speed in knots or kmph per hour in at least two digits rounding off to the nearest five knots or 10 kmph as appropriate. Air temperature should be expressed by two figures giving the value in degrees Celsius, preceded by the appropriate sign (M for minus) eg. –5.0 as M5 except for 0°, which should be given only by "00".

f. **Lowest Pressure at Mean Sea Level**. When required for the operation, the lowest value of pressure at mean sea level expected to occur in each section should be given in hectopascals (hPa).

g. **Supplementary Information**. Supplementary information comprising any other aeronautical meteorological information not previously specified should be given whenever relevant for the operation. Cloud cover for photo, vertical visibility, mountain waves, gustiness of winds etc.

18. **Updating of Information**. If there is any delay in the flight from the ETD or expiry of validity, the documents are to be suitably updated as necessary, prior to their issue, on the basis of latest charts/current weather reports etc. The operators are to intimate the changes in the ETD to the concerned Met section directly or through ATC. The Met Section preparing flight forecast shall keep the forecast under continuous review and issue amendments as necessary. If any amendments are found necessary to the forecasts subsequent to the briefing, they are to be communicated to the captain of the aircraft directly or though the OC Ops /DATCO. If transiting ac approach the Met Section for updating the information without any notice, the following info should be provided and logged in the briefing register:

a. Latest available METAR/SPECIs.

b. TAF is any.

c. RAREP if any.

d. Answer the queries within forecasting watch hours.

19. **Criteria for Issue of Amendments**. Amendments to forecast are to be issued, when any one or more of the following changes are expected:

a. **Upper Winds**. Change in direction of 30° or more, provided the wind speed is 60 Km/h (30 kt) before or after the change, change in speed of 40 km/h (20 kt) or more.

b. **Upper Air Temperature**. Change of more than 5° C.

c. **Significant En-route Weather.** New expectation or Occurrence no longer expected.

TASK-13 : FORECAST FOR VVIP/VIP FLIGHT

1. Whenever a requisition for route forecast for a VVIP/VIP flight is received, the person receiving the requisition is to inform the duty meteorological officer who should ensure that the information is passed on to officer -in-charge meteorological squadron immediately.

2. Officer in-charge meteorological squadron is to personally issue the forecast. The period of the route forecast shall be one hour before the actual time of departure and one hour after the estimated time of arrival at the destination.

3. Meteorological briefing to the aircrew for the V-VIP flight will be carried out by the officer in-charge meteorological squadron himself at the time and Place designated for this purpose. Briefing for VIP flight may be carried out by any officer detailed by the officer in-charge meteorological squadron.

4. Route forecast for VVIP flight shall be prepared in triplicate a copy of which is to be forwarded to Air Headquarters within 48 hours of its issue. Air Headquarters copy of the forecast should accompany the following information :at Actual meteorological conditions of the route obtained from debriefing to the pilots/navigators if available. or . as obtained after studying the charts.

a. Actual weather of the destination air fields which will be obtained through debriefing to the pilots/navigators, if available, or as obtained after studying the charts.

b. Actual weather of the destination air fields which will be obtained through de-briefing to the pilots/navigators and/or observed by the meteorological squadron at the landing time.

5. If the VVIP/VIP flight is from a BAF airfield where no briefing facilities can be provided, the forecast covering the entire route alongwith all QFZ is to be issued by the meteorological squadron wherein the requisition was made.

SECTION-3 : TYPE OF FORECASTS

TASK-14 : CLASSIFICATION OF FORECAST

Classification of Forecast

1. The term 'Forecast' first applied in meteorology by Admiral Fitz Roy, which signifies a statement of anticipated metrological conditions for a specified place (or area, route etc) and period of time. A forecast is a statement of expected meteorological conditions for a specified period and for a specified area or portion of air space.

2. Owing to unavoidable limitations due to the variability over very short intervals of time and space and the inadequacies of forecast techniques of met parameters, the specific values of the elements indicated in the forecast are to be understood to be necessarily approximate and representing the most probable mean of a range of values which the element may assume during the period of forecast and over the areas or in the air space concerned. Similarly, the time of occurrence or time of change in the value of element in a forecast has to be interpreted as representing the most probable mean of a range of time. The issue of a new forecast by a Met Section, such as Local, TAF or TREND forecast automatically supercedes any forecast of same type previously issued for the same place for the same period of validity or part thereof. Therefore the dissemination of met forecasts and warnings are to be given the highest priority on communication links so that the operators receive these products with minimum time lapse.

3. A three-fold classification of forecasts, in terms of the period covered, is recognized:

a. **Short-Period**. Short-period forecast covers part or whole of a 24-hour period, often with a 'further outlook' for the following 24 hours.

b. **Medium-Range**. Medium-range forecast covers some 2 to 5 days.

c. **Long-Range**. Long-range forecast covers a period longer than about 5 days ahead, eg a month or season.

4. The short-period forecast generally contains information concerning wind velocity, weather (state of sky, precipitation, fog, thunder, frost etc) and temperature (relative to seasonal normal). For special purposes, additional information is given-for example, upper winds for aviation. In medium-range and more especially long-range forecasts the information given is in more general terms and is often confined to precipitation and temperature.

5. In short-period forecasting, the methods of synoptic meteorology are normally used to anticipate changes in surface pressure distribution and positions of lows and highs (and fronts), on which together with an appeal to physical reasoning and to precedent, the forecast is based. Alternatively, the changes in pressure distribution are derived by numerical methods. Purely statistical methods of short-period forecasting are applied to a small extent. In medium-range forecasting, the synoptic method predominates, with concentration of attention on the dominant circulation features. In long-range forecasting, significant but limited success has been achieved with synoptic methods in which time-averaging of the pressure and circulation patterns is employed, and with a Synoptic Analogue method.

6. The main two types of forecasts terminology, Area & Route and Local (time), are:

a. **Area and Route Forecast Terminology.**

Isolated (ISOL)	Upto 25% of the whole area (at one or two places)
Scattered (SCTD)	26% to 50% of the whole area (at few places)
Fairly Wide Spread (FWD)	51% to 75% of the whole area (at many places)
Wide Spread (WD)	76% to 100% area (at most places)

b. **Local Forecast Terminology.**

Temporary	1 to 2 times, duration less than 1 hour each time
Occasional	2 to 3 times, duration less than 1 hour each time
Intermittent	3 to 4 times, duration less than 1 hour each time
Continuous	4 times or one for few hours

TASK-15 : LOCAL AND AREA FORECASTS

Local and Area Forecasts

1. Local and area forecasts are statements of expected meteorological conditions over a given airfield, flying sector or a range for a specified period, for the use of the Operational and Air Traffic Control authorities. The Met Section responsible for the issue of such forecasts shall keep the forecasts under continuous review so as to ensure that necessary amendments are issued promptly. Local forecasts issued in the morning are to be reviewed, as soon as the latest inputs of satellite pictures and charts are available. Necessary amendments whenever warranted should be issued to the concerned agencies promptly. Such amended forecasts shall be identified in plain abbreviated language as AMD FCST and shall apply for the remaining period of validity.

2. **Area Covered**. Local forecasts shall cover a radius of 30 km round the airfield for which they are issued. If the low flying area, cloud flying area, firing range, etc. fall outside the 30 km radius, a separate area forecast shall be issued for such areas on an as required basis. In the BAF, coverage of area for local and area forecasts in 30km and 100 km respectively.

3. **Frequency of Issue and Period of Validity.** All Met Sections with forecasting watch will issue 3 forecasts every day. There shall be a certain amount of time overlap between two successive forecasts. The time of origin and period of validity of each forecast shall normally be shown below:

TOO of Local forecast	Period of Validity
a. 0630 BST	01 to 08 UTC
b. 1230 BST	07 to 14 UTC
c. 1830 BST	13 to 01 UTC

TASK-16 : ROUTE/FLIGHT FORECASTS

Route/Flight Forecasts

1. A route forecast is the forecast for the route of a planned flight valid for the entire period of the forecast for the whole route where as a flight forecast is valid only for the time the aircraft is expected to be over the specific portion of the route. For the en route phase of the flight, the forecast shall cover the route from the aerodrome of departure to the final aerodrome. A statement or other indication of conditions expected between the final aerodrome and one alternate aerodrome also shall be provided when requested for as per details provided by the captain of the aircraft.

2. Route forecast is a different form of flight documentation. This forecast is the area forecast for a specific route and period of validity and shall contain upper winds, upper air temperatures, en-route significant weather phenomena and associated clouds. Other elements may be added as required. This information shall cover the flight operations for which they are indented in respect of time, altitude and geographical extent.

3. Met sections preparing route forecasts are to keep the forecast under continuous review and issue amendments as necessary.

4. With the availability of LAN/WAN in the station, these forecasts can be exchanged between the different Met sections. This form of forecasts can also be used for routine air mission or relief operation where the operation takes place over the same flight envelope. However these forecasts are to be updated and communicated to the operators at least one hour before the expiry of the previous one.

TASK-17 : TERMINAL AERODROME FORECAST (TAF)

Terminal Aerodrome Forecast (TAF)

1. TAF consists of the expected meteorological conditions at a given aerodrome for a specified period of time. A TAF shall be the forecast prepared by the Met Office of the aerodrome or the Met Office designated for the issue of such forecasts. The office of issue shall keep the forecasts under constant review. It is to ensure that necessary amendments are issued promptly.

2. **Area Covered**. Area covered by a TAF will be the aerodrome and its vicinity. Vicinity in this context will mean landing, take-off, climb-out, approach and circuit areas.

3. **Period of Validity**. The period of validity of routine TAFs shall not be less than 9 hours nor more than 18 hours. TAFs valid for 9 hours should be issued every 3 hours and those valid for 12 hours or more, at least every 6 hours.

4. **Procedure for the Air Force.** AF Met Sections issue TAFs as follows: -

Type of Met Section	TOO BST	Based on Chart (UTC)	Period of Validity (UTC)
24 hour	1030 1630 0530	00 06 18	0600-0600 1200-1200 0000-2400
Amendments shall be issued as warranted			

Consolidation Exercise – 2

Q1. What do you mean by SPECI ?

Q2. What is the name of that METAR report which is recorded immediately after accident/incident of an aircraft ?

Q3. When deterioration of one weather element is accompanied by improvement of another element, how many SPECI reports are required to be issued ?

Q4. Cloud amount is 5/8 and its height of base is 1000 feet; does it warrant to issue a SPECI report ?

Q5. In deteriorated weather conditions, in addition to the amount what is the cloud height at which the last SPECI is issued ?

Q6. Will you issued a SPECI for the visibility at 880 yards when the runway visual range for the same is given ?

Q7. When the second SPECI is issued for changing of wind direction with speed changed to 21 knots from 16 knots; is it an improvement weather condition or a deterioration report ?

Q8. Does it warrant to issue a SPECI if thunder is heard without any precipitation ?

Q9. After receipt of a SPECI report what responsibility lies with ATC.

Q10. What is the maximum number of SPECIs can be issued in case of deterioration of visibility ?

Answer to Consolidation Exercise – 2

A1. SPECI is an aviation special weather report. It is issued both for deterioration and improvement of hazardous weather.

A2. Crash Observation.

A3. Appropriately one.

A4. Yes.

A5. 200 feet or below.

A6. No.

A7. Deterioration.

A8. Yes.

A9. To pass this report to all aircrafts in flight.

A10. Three only.

SECTION-4 : ANALYSIS OF WEATHER CHARTS

TASK-18 : SURFACE CHART ANALYSIS

Introduction

1 . A large number of observations are Plotted on the surface synoptic chart. The observations are the scientific facts upon which the analysis of the synoptic charts is based. If the ana*lysts* were expert and experienced and if the data Plotted on the chart was accurate and complete, the differences in the, individual analysis would probably be quite small.

Steps in Analysis

2. The basic analysis of the surface synoptic chart may comprise of two major steps given below. These steps may not be followed rigidly in this order.

a. The frontal Analysis.
b. The construction of the pressure pattern.

3. After these two steps have been accomplished there are a number of secondary steps which must be taken in order to extract the maximum amount of information from the available data.

Frontal Analysis

4. The nomenclature of various fronts or frontal systems is given below :

a Warm front.

b. Cold front.

c. Warm type occlusion.

d. Cold type occlusion.

e. Back-bent seclusion.

f. Quasi stationary for waves.

5. Continuity of the frontal pattern is of paramount importance in analysing charts. The position of the front should be extrapolated making use of the advection rules that warm fronts and warm occlusions move:-with about two-third of the geostraphic wind speed in the warm air, and cold fronts and cold occlusions)move with. nearly geostrophic speed. Warm fronts may move, Somewhat faster over the ocean.

Warm and Cold Fronts

6. The two fundamental properties which identify an air mass are its temperature and dew point. The other elements of observation although less fundamental, also give valuable information about the air mass. The identifying features of warm and cold air masses which are immediately adjacent to each other are given in the table I and table II respectively.

TABLE - I

IDENTIFICATION OF A WARM FRONT

Weather Element	**Observation in the Warm Air**	**Observation in the Cold Air**
Pressure	Does not identify directly although a trough in the pattern may assist the identification	Does not identify directly although a trough in the pattern may assist in identification.
Air Temperature	Warmer behind the front.	Colder ahead of the front.
Sea Minus Air Temperature	Less behind the front.	Greater ahead of the front.
Wind Direction	Blows from a point several degrees veered from the wind in the cold air.	Blows from a point several degrees backed from the wind in the warm air.
Dew Point	Higher in the warm air.	Lower in the cold air.
Dew Point Depression	Often less than in the cold air	Often greater than in the warm air, except in precipitation, when it may be about the same as or even less than in the warm air.
Pressure Tendency	Falls less sharply than in the cold air, occasionally rises slowly.	Falls, or falls more sharply than in the warm air.
Weather	Overcast sky, except inland in summer occasionally rain and particularly drizzle, which may be heavy on coasts exposed to the wind, fog on exposed coasts and covering hills.	Usually continuous rain or snow, but sometimes only light and intermittent; occasionally no weather particularly
Cloud Amount	Usually 8/8 low cloud, sometimes broken low cloud inland in summer.	8/8 low cloud in precipitation; occasionally only broken low cloud inland in summen usually 8/8 medium and high cloud.
Cloud Type	Stratiform clouds.	High, medium and stratiform clouds, nimbostratus in precipitation.
Visibility	Often good but poor on coasts exposed to the wind and elsewhere in drizzle and fog.	Often good but poor in precipitation.

TABLE - II

IDENTIFICATION OF A COLD FRONT

Weather Element	Observation in the Cold Air	Observation in the Warm Air
Pressure	Does not identify directly although a trough in the pattern may assist to identify.	Does not identify directly although in the pattern may assist to identify.
Air Temperature	Colder behind the front.	Warmer ahead of the front.
Sea Minus Air Temperature	Greater behind the front.	Less ahead of the front.
Wind Direction	Blows from a point several degrees veered from the wind in the warm air	Blows from a point several degrees backed from the wind in the cold air.
Dew Point	Lower in the cold air.	Higher in the warm air.
Dew Point Depression	Greater than in the warn air except in precipitation.	Less than in the cold air.
Weather	Continuous precipitation near fronts; further behind front, showers of rain, hail or snow, broken sky, occasionally thunderstorms.	Continuous precipitation near front; overcasts sky, except inland in summer; occasional drizzle, which may be heavy on coasts exposed to the wind; fog, on exposed coasts and covering high ground.
Pressure Tendency	Rises rapidly or more rapidly than in the warm air, sometimes continuous to fall, but at a slower rate than in the warm air.	Falls, or rises more slowly than in the cold air.
Cloud Amount	Broken low cloud, but 8/8 in precipitation.	Usually 8/8 low cloud; occasionally only broken cloud inland in summer; usually 8/8 medium and high cloud near front.
Visibility	Very good except in precipitation	Often good but poor in precipitation and on coasts exposed to the wind, and elsewhere in drizzle and fog.

7. The criteria given for identification of warm and cold fronts may not always be available on charts. Temperature and humidity observations reported in the nearest radio zone ascents will be found useful in such cases. Storm warning radar reports are also a help in locating cold fronts.

Occlusion

8. The triple point at which the occlusion starts may be identified by following the warm and cold fronts to the point where the warm air vanishes at the surface. There are larger falls of barometric pressure at the triple point than elsewhere along the front. Small separate depression occasionally form at these point and subsequently break away from the parent. Once the triple point has been found the remainder of the occlusion can be traced to the centre of the depression. If there is a well marked trough in the cold air in the rear of a depression centre the occlusion may bend round and the traced \down the through and is called a back-bent occlusion.

Secondary Front

9. Both warm and cold type secondary fronts may exist but the secondary cold front is more frequent. The secondary warm front is usually formed in a weak through in the isobars of the warm air between the main front and the following cold front.

Quasi-Stationary Front

10. A front tends to become quasi-stationary when the pressure gradient along it and the isallobaric gradient across it, become weak or disappear altogether or geostrophic and isallobaric component of the wind normal to the front act with equal strength in opposite directions. this generally occurs during the final stage of the life of a front.

Young Waves

11. Waves may form on both warm and cold fronts. A warm front wave is often translated along the warm front without much deepening. Such a wave can be identified by an area of falling barometric tendencies, and a bulge in the belt of precipitation marking the warm fronts.

12. The formation of cold front waves is more frequent. They are distinguished by an area of falling pressure particularly on the cold side of the front where the pressure should be expected to be rising and also by a bulge in the precipitation areas in the directions of motion of the waves.

The Isobars

13. Isobars are usually drawn at 2 millibars interval on the charts of scale 1 : 10, 0000. Even numbered intervals are generally used. The interval maybe of less than 2 millibars if situation demands.

14. The surface wind direction provides a valuable guide to accurate drawing of isobars provided the wind speed is at least 7 knots and pressure tendencies are not large. The isobars should continuously intersect an imaginary line drawn tangent to the wind direction at an angle of 12° to 15° over the sea a greater angle over the land. the wind should blow towards the low pressure. On ocean area isobars may be spaced in accordance with wind scales depending upon the geostrophic or gradient wind equation.

15. The isobaric fields will normally be separated into regions of low and high pressure which may be described as follows :

a. **Depression**

(1) A depression is a part of the atmosphere where pressure is lower than the surroundings. It is bounded by a series of closed isobars. The wind speed in any part of this area does not exceed 38 mph (33 knots). The deficiency of pressure at the centre is of the order of 3-4 mb.

(2) Some depressions are deeper than others. The terms 'shallow depression' and 'deep depression' are therefore used. A shallow depression is one in which the pressure at the centre is not very much lower than the surroundings. It is sometimes also called a low or an area of low pressure. A deep depression is one in which the pressure is very much lower near the centre than on the outside (as compared with a depression) and/or wind reported from different parts of the depression may reach such high values as 38 mph.

(3) The depressions of temperate latitudes generally move from west to east and have well marked sectors with air masses of different origins and properties.

(4) In depressions of tropical areas the air masses in different sectors are not easily distinguishable from each other. They move, at least in their initial stages, from east to west. Isolated squatty weather is occasionally met within the disturbed weather area of such depressions.

(5) The winds in all types of depressions which affect our country blow in counter clockwise direction round their centres.

b. **Tropical Storm**

(1) The natures of a tropical depression and a tropical storm are essentially alike, but the wind force associated with tropical storms exceeds 38 mph and may go upto 73 mph (63 knots).

(2) On the basis of wind speed associated with the tropical storms there are two terms used in Bangladesh the tropical storms and the severe tropical storms.

(3) **Tropical Storms.** When wind sped in any part of its closed circulation (observed or in its absence inferred from isobaric gradient) is 39 mph (34 knots) to 54 mph (47 knots).

(4) **Severe Tropical Storm.** When the wind speed in some part of its field reaches 55 mph (48 knots) to 73 mph (63 knots).

c. **Cyclone.** The cyclone is a tropical storm of great intensity. Its diameter it sometime less than 25 miles and sometimes as great as 600 miles. The minimum pressure at its centre is sometimes lover than 900 mb; but usually of the order of 950 mb. The winds in the centre are nearly calm but round the calm centre there is a ring of high winds reaching 73 mph or more. When the cyclone reaches phenomenal intensity and wind speed cannot ordinarily be measured it is called a severe cyclone.

d. **Western Disturbance (Extra Tropical Depression).** Disturbed weather conditions moving towards the country from the west are termed “Western Disturbance”. They usually approach as waves of low pressure or shallow depressions in the temperate latitude weather systems originating from Mediterranean Sea or the Middle East. At times they are 3 to 4 mb deep, when they may be called “Western Depression”. Such Western Disturbances are most frequent in the winter and spring seasons and are sometimes associated with well-marked warm and cold fronts.

e. **Secondary Depression.** It is a small depression within the circulation of a large one. it circulates around the primary depression with the general air stream. Sometimes the secondary becomes well developed when the primary gets filled up.

f. **The Orographic or Lee Depressions.** An area of low pressure usually occurs to the lee or a mountain range when the gradient wind is strong. A lee depression usually takes up an irregular shape.

g. **Anti-Cyclone.** When the isobars close around a central high pressure region, the pattern is called an anti-cyclone. In an anti-cyclone pressure decreases outwards from the centre. The winds blow clock-wise in then northern hemisphere and anti-clockwise in the southern hemisphere. At 2,000 feet the wind direction is parallel to the isobars, but near the ground level it blows outward across the isobars form the central region. The pressure gradient is never very steep;’ but the wind speed is greater compared to straight isobars having the same gradient.

h. **Trough.** A trough of low pressure is usually found to coincide with the position of a front. All such troughs are marked by V-shaped or at least by chinked isobars. Occasionally a cold front or occlusion moves more rapidly than the trough in which it originally lay. The isobars will then be rounded as they cross the trough line.

j. **Ridge.** The ridge is simply an elongated area of high pressure which usually connects two anti-cyclones.

k. **Wedge.** The wedge of high pressure takes the form of a long tongue which pushes outward from the anti-cyclone centre.

l. **Col.** The col is a neutral area lying between adjacent anti-cyclones and depressions.

Isobars over High Ground and Oceans

16. It may be noted that the pressures plotted on the surface charts are reduced to mean sea level, if the altitude of the station is below 800 gpm (2600 feet approximately). The pressure tendency reported by a ship is composed of the change caused by the ships motion normal to the pressure field and the change of pressure with time.

Symbolic Presentation of Analysis on Charts

17. the significant isobaric patterns, fronts and some important weather phenomena are to be marked or hatched.

Ser No	Nomenclature	Symbolic Presentation on Working Charts
1.	Cold Front	a. Continuous blue line when on surface. b. Broken blue lines when above surface.
2.	Warm Front	a. Continuous red line when on surface. b. Broken red line when above surface.
3.	Quasi-Stationary	a. Alternate Red & Blue continuos line when on surface. b. Alternate Red & Blue broken line when above surface.
4.	Occluded Front	a. Continuous purple line when on surface. b. Broken purple line when above surface.
5.	Temperate Front or Sub-tropical discontinuity	Brown broken line.
6.	Inter-tropical discontinuity or Inter-tropical Front.	Alternate red and green broken lines.
7.	Shear-line	Black.
8.	Trough	T (in black lead pencil).
9.	Low	L (Red)
10.	Depression	D (Red)
11.	Tropical Storm	S (Red)
12.	Cyclone	(Red)
13.	Zone of Continuous precipitation.	Cross hatching in green with appropriate hydrometer symbol distributed.
14.	Zone of Intermittent precipitation.	Single hatching in green with appropriate hydrometer symbol distributed.
15.	Areas of Thunderstorms, showers.	Distribute large symbols showers (in green) and thunderstorms (in red) for appropriate element over the affected area (s).
16.	Areas of Fog.	Yellow shading of affected area (s).
17.	Areas of Dust storms, Sandstorms and Dust-Haze.	Brown shading together with distribution of appropriate 'ww' symbols, over the affected area (s)

Notes :

1. The hatching or shading is not to obliterate the plotted data.

2. Appropriate 'ww' symbols are to be superimposed on he shaded/hatched area (s) to indicate the nature of weather in the area (s).

3. The extent of the affected area (s) is/are to be delineated with thin boundary line.

Consolidation Exercise on Task- 18

Q1. What are the two major steps in the analysis of surface synoptic charts ?

Q2. How continuity of the frontal pattern is maintained ?

Q3. What fundamental properties help you for identifying an air mass ?

Q4. How pressure tendency helps you in identifying a warm front ?

Q5. What type of clouds appear with a warm front ?

Q6. Storm warning ---reports are also a ----------in locating ----------fronts.

Q7. In a frontal system where do you expect the largest fall of pressure ?

Q8. At what intervals isobars are drawn a surface chart ?

Q9. How wind direction helps in drawing the isobars ?

Q10. In a depression of tropical areas, air masses in different sections are easily distinguishable from each other. (True/False).

Q11. In what respect a tropical depression differs from a tropical storm ?

Q12. What is the wind speed expected in s severe tropical storm ?

Q13. What is the diameter of a cyclone ?

Q14. when cyclone is called severe one ?

Q15. what is the pressure gradient in an anti-cyclone ?

Q16. the wind speed in an anti-cyclone is ----------compared to straight --------having the ----------gradient.

Q17. What is a COL ?

Q18. what pressure is plotted on the surface chart ?

Answers to Consolidation Exercise on Task- 18

A1. a. the frontal analysis.

b. The construction of the pressure pattern.

A2. By “Advection Rules”.

A3. Its temperature and dew point.

A4. Falls less sharply than in cold air, occasionally rises slowly.

A5. Stratiform clouds - cirrus, cirrostratus, altostratus, stratocumulus and nimbostratus in precipitation.

A6. Radar, help, cold.

A7. At the triple point.

A8. Isobars are usually drawn at 2 millibars interval may be of less than 2 millibars if situation demands.

A9. the isobars should continuously intersect an imaginary line drawn tangent to the wind direction at an angle of 12 to 15° over the sea and a greater angle over the land.

A10. False.

A11. It differs in respect of wind speed. The wind force associated with tropical storms exceeds 38 mph (33 knots) and may go upto 73 mph (63 knots).

A12. 55 mph (48 knots) to 73 mph (63 knots).

A13. It is sometimes less than 25 miles and sometimes as great as 600 miles.

A14. when a cyclone reaches phenomenal intensity and wind speed cannot ordinarily be measured it is called a severe cyclone.

A15. Not very steep.

A16. Creater, Isobars, Same.

A17. It is a neutral area lying between adjacent anti-cyclones and depressions.

A18. Pressure reduced to mean sea level, if the altitude of the station is below 80-geopotential metres.

TASK-19 : UPPER-AIR CHARTS AND THEIR ANALYSIS

Introduction

1. As important as the surface chart is in providing a picture of weather over an area, it is one-dimensional. The surface chart, in conjunction with upper-air charts, provides us with the most complete picture possible of the three-dimensional distribution of wind and temperature in the atmosphere.

2. An accurate and complete analysis of all data (surface and upper air) does not guarantee a successful prognosis or forecast, but it definitely improves one's chances. As an analyst, you are much more than one who draws charts. You must be able to think, reason, and deduce from your products. Relating the weather aloft to that occurring at the surface is absolutely essential in understanding the processes working within the atmosphere.

Upper-Air Analysis

3. The upper-air analyst is responsible for recognising and resolving erroneous reports; extrapolating upper-air data from surface reports; drawing isopleths for various elements such as heights, temperatures, wind speeds, etc.; deriving upper-air information from satellite pictures; and relating the various levels analysed.

Evaluation of Data

4. Today's upper-air equipment is far better than that used only a few years ago, and it permits far more accurate readings of pressure, temperature, humidity, and wind. You must be aware, however, that the same type of errors and unrepresentative data that exists in surface reports also exists in upper-air reports. To a large extent these errors are attributable to the method used in determining the data. In many cases erroneous reports can be resolved into useable data. Common errors that sometimes can be corrected are communications and plotting errors, computation errors, and in the case of aircraft reports, erroneous position reports. You must exercise discretion in correcting such errors; however, do not throw away or disregard data unless you are absolutely sure it is in error and uncorrectable.

Data Priority

5. Observed data should be plotted according to the following priority:-

   a. Radiosonde and Rawinsonde observations.

   b. Winds aloft observations by pilot balloons (Pibals).

   c. Weather reconnaissance aircraft observations (Reccee).

   d. Other aircraft observations (Pireps).

   e. Satellite-derived information.

6. **Radiosondes and Rawinsondes**. These are the most all-encompassing methods of gathering upper-air information and also the most accurate. Probable errors associated with sondes are listed in table 2.1.

7. **Winds aloft Observations (PIBALs)**. The two biggest contributors to this data's being questionable are 'a' the assumed-constant ascension rate of the balloon and (b) the time lag in the observer's reading of elevation and azimuth angles. These errors become magnified in areas of high winds or large vertical wind shears.

8. **Reccees and Pireps**. Flight altitude data is reasonably accurate and useful. Dropsonde data is considered somewhat less accurate than data gathered by balloon-borne sondes. Position errors make these observations stand out in analysis, because they fail to fit into the height pattern.

9. **Satellites**. Satellite pictures of Earth allow us to verify the existence, intensity, and position of weather systems. In sparse-data areas, they are our primary means of completing an analysis.

Data Accuracy

10. Tests conducted to evaluate sonde accuracy have shown the data to be satisfactory if the observers have been fully trained in equipment operation and data evaluation.

11. **Temperature**. Under controlled conditions, comparisons of sonde-recorded temperatures to those measured by thermometer show the sonde temperatures to be accurate within 1°C over 90% of the time.

12. **Pressure**. The average sonde pressure error is from 2 to 4 hPa. The absolute maximum error evaluated was 5 hPa, and this occurred in only one percent of the sondes tested.

13. **Humidity**. This element is accurate to within 5% up to 700 hPa, but maybe in error by as much as 20% at 300 hPa. Because this element is recorded with respect to water (never ice) when a sonde passes through an ice crystal cloud layer the relative humidity computes at 70 to 80 percent. This is an accurate reading. A very rough estimate of humidities in below-freezing temperatures is obtained by decreasing the humidity 10% for every 10°C decrease in temperature.

14. **Upper Winds**. The reliability of upper-wind data is dependent on the manner in which the data is obtained. Rawinsonde winds are for the most part very accurate. Winds obtained by radar tracking are the most accurate. See probable errors listed in table 2.1.

Contour (Isoheight) Analysis

15. Today, few stations do manual analysis. Computers have for the most part replaced individual analysts. They are undoubtedly faster at deciphering reports, evaluating data for continuity and accuracy, and producing a myriad of products worldwide. However, there are times when computer generated products aren't available. At such times, you may be called upon to analyse upper level data. For this reason, and to better acquaint you with constant-pressure chart features, you should be familiar with analysis procedures. Just as there are recommended analysis procedures for the surface chart, there are similar procedures for constant-pressure charts. A recommended procedure is as follows:-

a. Review past history.

b. Extrapolate heights in sparse data areas.

c. Sketch and label contours.

d. Sketch in troughs.

e. Evaluate slope of upper systems and their orientation.

f. Harden in troughs.

g. Harden in contours.

h. Label low and high height centres.

Table 2.1. Probable Errors in Upper Air Data

Parameter	Probable error	Remarks
Roab temperatures	± 1ºC to 400 hPa ± 2ºC above	
Roab heights 1000 hPa	± 6 metres per 305 metres of station elevation	Different temperature parameter used for reduction to 1000 hPa than to msl which results in inconsistencies of the order of 120 metres in extreme cases. In order to circumvent this, we directly convert the reported msl pressure to 1000 hPa.
850 hPa	± 9 metres	
700 hPa	± 12 metres	
500 hPa	± 21 metres	
400 hPa	± 30 metres	
300 hPa	± 49 metres	
200 hPa	± 70 metres	
150 hPa	± 90 metres	
Thicknesses: 1000 – 700 1000 – 500 500 –300	 ± 12 metres ± 21 metres ± 27 metres	
Tropopause Heights	± 10 hPa	
Wind aloft directions	± 5 degrees	Due in part to rounding off to nearest 5 degrees in coding.
Wind aloft speeds	± 10 knots up to 500 hPa for winds up to 50 – 75 kt	This error increases rapidly, especially for winds over 100 kt, usually due to low elevation angles of recording equipment. Also varies considerably with different types of equipment.

Past History

16. One basic consideration in the approach to all types of map analysis is that of history or continuity. Upper-level features do not change radically in short periods of time. Consequently, a valuable aid in contour analysis of any given pressure level is the past history of the contours at that level. The study of previous maps is essential, both as a key to the present situation and as a method of determining future movement and change in atmospheric systems.

17. Your first step in the analysis should be to check previous charts for accuracy, rationality, and any changes made to previous analyses based on information received after the analyses were completed. Fronts, troughs, and height centres do not normally appear and/or disappear in the 12 hours between analyses and any such occurrence should be viewed with suspicion. The past position of all height centres should be entered on the current chart for at least 24 hours. These positions are normally entered in black ink with an X circumscribed with a circle and connected with a dashed line. The time and date are entered above the circle. The corrected positions of all troughs and ridges should be transposed onto the current chart in yellow pencil. Knowing the past positions of features is your first clue in locating their present positions. When an upper-level feature moves into an area containing few or no reports, you may have to extrapolate its movement, construct the upper-level field from surface data, and/or determine the new position from satellite pictures, if possible. Constructing the upper-level field from surface data is widely used in computer-generated products.

Extrapolating Upper-Level Heights

18. A common analysis practice is extrapolation of upper heights from sea-level reports. The scarcity of upper-air-reporting stations in many regions of the world and the absence of upper-level data from stations that do report require that this procedure be used. This is a common practice in computer-analysed constant-pressure charts. Extrapolated heights are plotted enclosed in parentheses.

19. The thickness of a stratum or height of an upper level is computed using a known sea-level pressure and temperature and an assumed mean virtual temperature for the stratum. Tables and nomograms, derived from the hydrostatic equation, are also used for this purpose. Figure 1.1 contains a nomogram for computing the height of the 700- or 500-hPa level using a known surface temperature and an estimated upper-level temperature. The upper-level temperature is usually estimated from past analysis and compensated for any changes which may have occurred since the last analysis; i.e., any cold or warm air advection. A step-by-step extrapolation procedure follows:

a. Estimate the upper-level temperature.

b. Determine the height of the 1000-hPa level.

c. Determine the thickness of the stratum, following nomogram directions.

d. Algebraically add the 1000-hPa height and the thickness of the stratum obtained in step ‘c’. This is the height of the upper level above sea level.

20. The 1000-hPa height must be determined, because tables and nomograms use 1000 hPa as the standard surface-pressure value. To compute its height, we assume 7½ hPa equals 60 metres of height, or 8 metres per hPa. Take the difference between the actual sea-level pressure (SLP) and 1000 hPa and multiply this figure by 8. For example, a ship reports a sea-level pressure of 1015.0 hPa. The difference between the reported value and 1000 hPa is 15. Multiply this difference by 8. 15 x 8 = 120. The height of the 1000-hPa level is 120 metres above sea level. SLP (hPa) – 1000 hPa x 8 m/hPa = 1000-hPa height Minus (–) values indicate 1000-hPa heights below mean sea level, and plus (+) values indicate 1000-hPa heights above mean sea level. Given the following parameters, compute the height of the 700-hPa level, using the nomogram shown in fig 2.1: Estimated 700-hPa temperature – 5.0°C; sea-level temperature, 25.5°C. Remember—the nomogram contains 700-hPa heights and 500-hPa heights. The 700-hPa heights are to the left of the centerline.

21. In step ‘d’, algebraically add the thickness of the stratum just computed and the height of the 1000-hPa level. For computational purposes, use the 120-metre height previously computed. The thickness of the 1000-700-hPa stratum as computed from the above information should read approximately 2,957 metres. Because the reported sea-level pressure in this example is greater than the standard, you should have added the 120 metres to the height of the 1000-700-hPa stratum. Your answer should read 3,077 metres. If the reported sea-level pressure is less than 1000 hPa, subtract the 1000-hPa height from the height of the stratum.

22. Since we are working with assumed or estimated temperatures and not those of an actual upper-air sounding, inversions anywhere in the stratum or non-representative temperatures at the surface or upper level will result in incorrect height computations. In the case of marked inversions of any type, the estimated height will be less than the "true" height, because the computed mean virtual temperature will be less (colder) than the true mean virtual temperature. Compensate for such inversions by using a higher estimate of the upper-level temperature. Higher estimates may be required in the following situations:-

a. In the vicinity of high-pressure cells where subsidence inversions are present

b. Where surface inversions are indicated by stable weather phenomena such as fog

c. When a frontal surface exists below the level to be extrapolated

23. A study comparing the true thickness of the 1000-700-hPa and 1000-500-hPa stratums to extrapolated thicknesses using temperature averaging showed the extrapolated thicknesses to be within 30 metres for the 1000-700-hPa stratum and within 60 metres for the 1000-500-hPa stratum in 90 percent of the cases conducted.

Sketching and Labeling Contours

24. Contours are the upper-air equivalent of isobars on surface charts. They connect points of equal height on constant-pressure charts. The primary contours (isoheights) are spaced at 30-, 60-, and 120-metre intervals. The 30-metre interval is used on charts below 500 hPa; the 60-metre interval, on charts between 500 and 300 hPa; and the 120-metre interval, on charts at 300 hPa and above. Primary contours are represented by solid black lines. Some of the primary contours drawn on constant-pressure charts are as follows:

850 hPa	700 hPa	500 hPa	30 hPa	200 hPa
1410 m	2910 m	5400 m	8760 m	11,400 m
1440	2940	5460	8880	11,520
1470	2970	5520	9000	11,640
***[1500**	**3000**	**5580**	**9120**	**11,570]**
1530	3030	5640	9240	11,880
1560	3060	5700	9360	12,000
1590	3090	5760	9480	12,120

**The bracketed contours are closest to the standard heights*

25. The above listing is not all inclusive; you may have to draw heights higher or lower than those listed. Intermediate contours may be used when greater definition is needed. They are one-half the primary contour interval for the level in question. For example, the primary contours on the 500-hPa chart are drawn for every 60 metres. The intermediate contours would be drawn at 30-metre intervals. Intermediate contours are represented by dashed black lines.

26. Contours should first be sketched lightly, using a black pencil, according to the reported heights and winds. Contours parallel the wind direction and are drawn following downwind, extrapolating between station height plots as necessary. The contours should conform to the wind direction. However, since most plotters do not plot wind directions with the aid of a wind rose or protractor, wind directions tend to be the least reliable of the plotted data. Be aware of the tens digit plotted at the end of the wind shaft. It is not uncommon to see the plotted wind direction differ from the reported value by as much as 20 degrees. For example, a 270° wind may get plotted anywhere from 250° to 290°. See fig 2.2.

27. While you are constructing the contour pat-tern, continually strive to accurately depict the wind field. Contour spacing is inversely proportional to wind speed. Only in areas of dense height reports where the winds are weaker (sub-gradient) or stronger (super-gradient) than the gradient within which they appear is there any justification for drawing contours that do not conform to the reported wind. For stationary troughs and ridges, cyclonically curved contours are usually spaced more closely (tighter gradient) than anti-cyclonically curved contours of the same wind speed. Use geostrophic wind scales to aid in spacing contours in sparse-data areas.

28. When you sketch preliminary contours, make smooth sweeping lines, bringing your entire arm into motion. Keep your eyes just ahead of the pencil. This will enable you to anticipate contour direction changes. Each contour will eventually form a loop or go off the chart. In no case do contours cross or touch contours of different values. The following discussion of rules for drawing contours is illustrated by fig 2.3 and 2.4.

a. Two contours of the same value will never exist between adjacent highs and lows. See fig 2.3.

b. There will always be two contours with the same value between two adjacent highs and two adjacent lows. See fig 2.4.

c. Adjacent contours of the same value will always flow in opposite directions. Some typical errors made by inexperienced analysts are illustrated in fig 2.5, to assist you in correctly drawing contours. Contours are labeled in decimetres. Use the thousands, hundreds, and tens digits. For example, the 3060-metre contour on the 700-hPa chart is labeled 306. The unit digit is dropped. On the 200-hPa chart, the ten thousands digit is also dropped. Like isobars, contours are labeled wherever they end. If a contour extends from one side of a chart to another, it will be labeled at both ends. Closed contours are broken at a convenient spot to permit entry of the label. The heights should be labeled neatly and the labeling be of uniform size.

29. Upper-level contours form closed centres and wavelike patterns. The upper-level trough is an elongated area of low heights. Its axis is denoted by a trough line, which is sketched in black. Upper-level ridges are elongated areas of high heights. A black zigzagging line is used to denote the axis of a ridge. Additional information on troughs and ridges is discussed later in this chapter.

Evaluating the Location and Slope of Pressure Systems and Fronts

30. The mechanics of constant-pressure analysis require that all levels interrelate; vertical consistency between levels is a must. The procedure used to determine vertical consistency is one of overlaying charts. Upper-level analyses are superimposed on lower-level analyses to assure a consistent slope to the various features with height. This permits visual determination of how systems stack. In this way, violations of internal consistency are prevented. For example, by overlaying a 1200 UTC, 850-hPa chart over the surface chart of the same day and time, you'll see that some pressure systems stack vertically, while others have a distinct slope. Lows normally slope upward toward colder air (usually westward and pole-ward), and highs toward warmer air (usually westward and equatorward). Fronts slope upward toward colder air. These spatial relations are an absolute requirement for a proper three-dimensional representation of pressure systems and fronts.

31. Although computer-generated surface and constant-pressure charts do not depict fronts, fronts do intersect upper levels. A fast-moving cold front with a slope of 1:40 intersects the 850-hPa level approximately 35 miles to the rear of the surface position. A slow-moving cold front (1:100) is found no more than 90 miles behind the surface position. These same cold fronts intersect the 700-hPa level 70 and 175 miles respectively to the rear of the surface position. Warm fronts have a more gradual slope (1:150) and may not intersect the 700-hPa level. At the 850-hPa level, expect to find them no less than 135 miles ahead of their surface positions. If warm fronts do intersect the 700-hPa level, do not look for them within 250 miles of their surface position.

32. A good policy to follow in locating fronts is to first locate them aloft, then use the surface data to determine their exact positions. When upper-air information is sufficiently complete, only fronts meeting the following two criteria are ordinarily significant enough to be carried: Fronts that are supported by the temperature and wind patterns at the 850-hPa level (700-hPa level over mountainous regions); and fronts that can be identified in upper-air soundings.

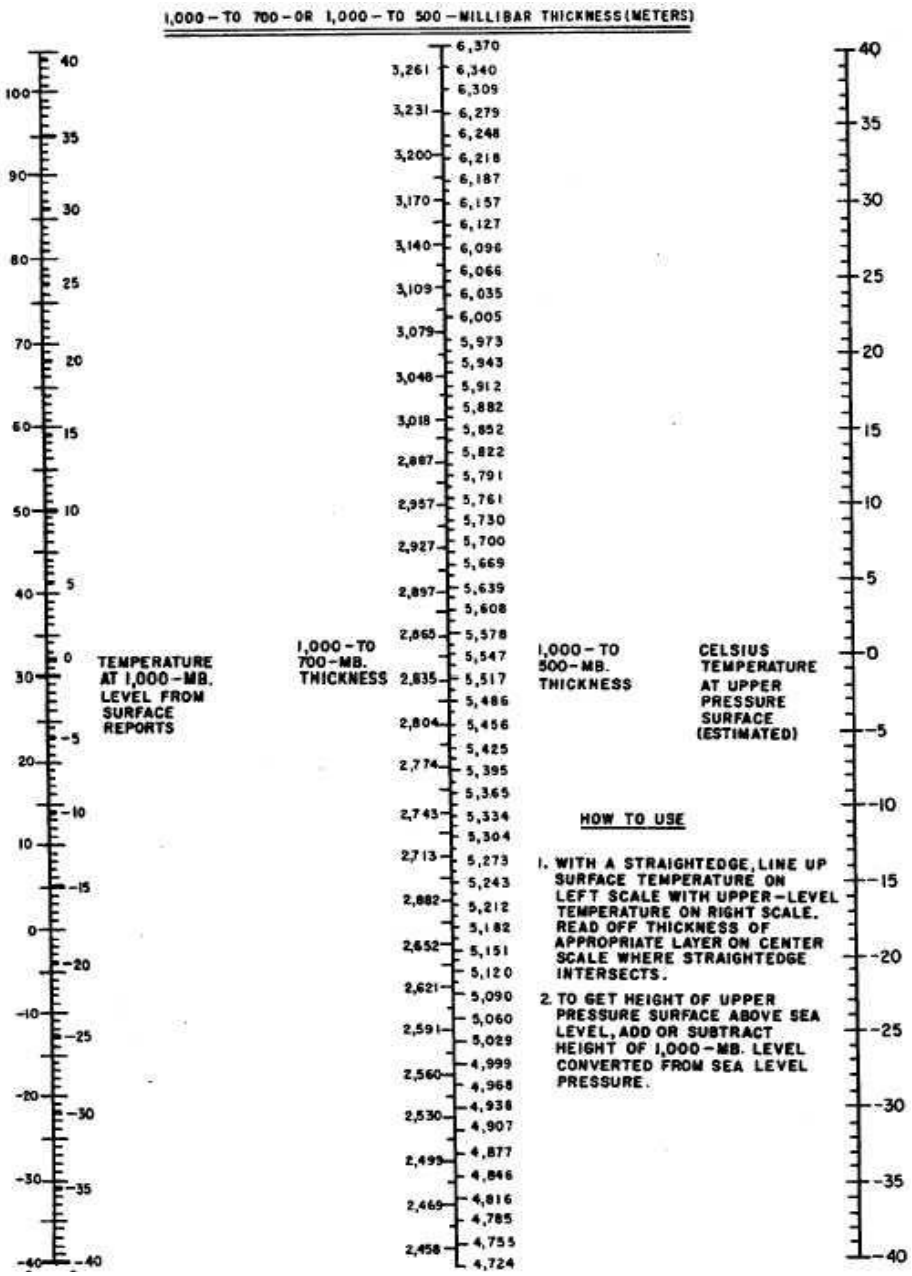


Fig 2.1. Nomograms for computing height of the 700-hPa and 500-hPa levels

Fig 2.2. Example of an incorrectly plotted wind direction

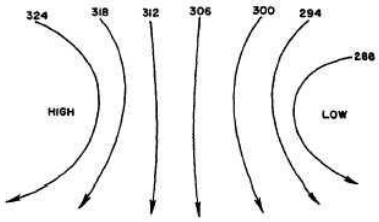


Fig 2.3. Contour pattern between a high and a low (700-hPa heights in m)

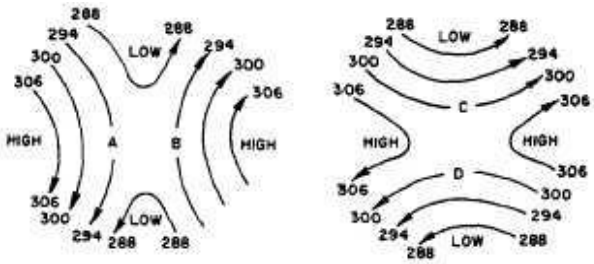


Fig 2.4. Contour pattern between adjacent highs and lows (700-hPa heights in metre)

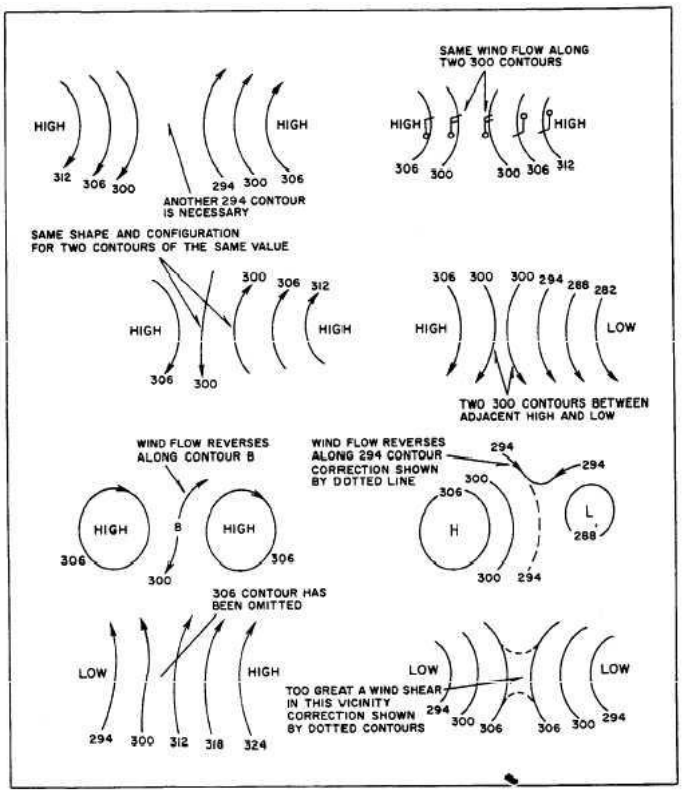


Fig 2.5. Common errors in contour analysis (700-hPa chart)

Finalising the Contour Analysis

33. After vertical consistency between levels is checked and any necessary adjustments made, the contours can be darkened in. This is usually done using felt-tip markers. High and low height centres are denoted by the letters **H** and **L**, respectively.

Isotherm Analysis

34. The most common upper-air pattern consists of alternating troughs and ridges. They form a series of waves which encircle each hemisphere. Occasionally, closed lows exist in the troughs and closed highs in the ridges (fig. 1.6). The lows are normally poleward and highs equatorward of the basic wind flow. All of these features reflect the vertical extent of features at lower levels, sea level in particular. Note the axes of the systems shown in figure 1.7. They are not vertical. As stated earlier, lows or troughs slope upward toward colder air, and highs and ridges slope toward warmer air. To determine the location of the colder and warmer air aloft, we do an isotherm (temperature) analysis for each level.

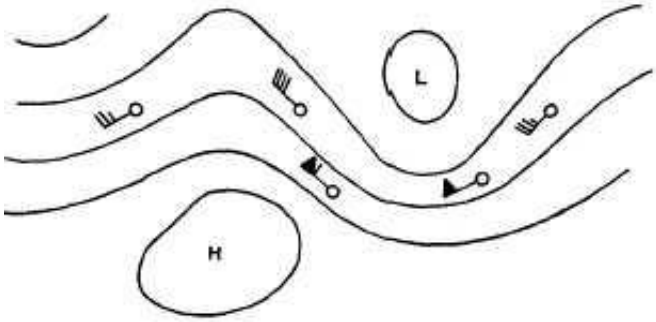


Fig 2.6. Common upper-air patterns

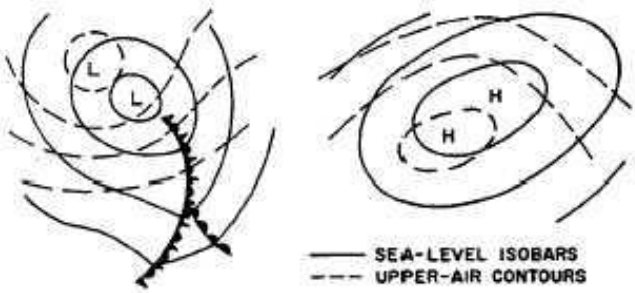


Fig 2.7. Slope of surface pressure systems with height. Isotherm Patterns

35. Isotherm patterns at lower levels usually consist of tongues or pockets of warm and cold air that move across the map with reasonable continuity from day to day. There is a correlation between isotherm patterns and contour (isoheight) patterns.

36. Dynamically, warm tongues in the troposphere are related to pressure ridges. This relationship is due to the sinking and adiabatic warming of air, created by horizontally converging air at a higher level in the atmosphere. At the same time the air in the troposphere is sinking and warming, the convergence causes the air in the lower stratosphere to rise and cool. Intensifying upper-level ridges or highs are characterized by warming in the troposphere and cooling in the stratosphere. If a ridge builds (intensifies) and attains sufficient amplitude, the northern portion may cut off, forming a separate upper-level high.

37. Cold tongues are related to pressure troughs in the upper troposphere. This relationship is due to upper-level divergence and the resulting lifting and adiabatic cooling of air in the lower and middle troposphere. An additional consequence of this divergence is the sinking and adiabatic warming of air in the lower stratosphere. Deepening lows tend to be associated with intensifying cold tongues in the troposphere and warm tongues in the stratosphere.

Drawing Isotherms

38. Isotherms (lines of equal temperature) are usually drawn at 5°C intervals. They are drawn as solid red lines. They are sketched according to reported temperatures. Use their previous positions (past history) as a guide. Isotherms are labeled in the same manner as contours—at the end of each line and in a small break near the top of closed loops.

39. In regions of sparse data an estimate of the isotherm pattern becomes necessary. Integrating past history (heights and temperatures) with the latest surface-pressure pattern aids greatly in determining the pattern aloft. As we discussed earlier, temperatures at selected points are frequently used in extrapolating the heights of various upper levels. Because wind is the advecting mechanism of warm and cold air, you should be aware of its effect and how it impacts the thermal pattern.

40. **Wind-Temperature Relationship**. Wind determines the pattern isotherms take and their speed of movement. Their speed is somewhat less than the wind speed. The factors working against the advection of isotherms with the speed of the wind are as follows:

a. The addition or subtraction of heat.

b. Adiabatic changes due to lifting or subsidence.

41. As warm air is advected toward a cold region, it tends to be cooled, and cold air advected toward warm regions tends to be warmed. In the case of cold air spreading southward over warmer regions, it tends to sink (being more dense), which results in adiabatic warming. At the same time, instability results. Both processes slow the advance of the cold air. Cold air moving offshore over warm ocean currents can be slowed by as much as 50 percent. When warm air is advected over cold regions, it tends to be lifted. This results in adiabatic cooling. The lifting process is more important at intermediate levels aloft; however, both lifting and subsidence work against the advection of isotherms with the speed of the wind.

42. The temperature pattern should explain temperature changes at individual stations. Because wind is the advecting mechanism, when there is a change of wind with height, the isotherm pattern must be adjusted. The isotherms are oriented to conform to the shear vector between the isobaric layers where the wind changed. The shear vector is derived from the wind speed and direction at the top and bottom of the layer.

43. **Wind Shear**. The vectoral rate of change of wind with respect to altitude is called vertical wind shear. It is determined by taking the vector difference between the reported wind at the top and bottom of the layer and dividing by their vertical separation. On the other hand, the vector difference between geostrophic winds at two levels is called the thermal wind. The thermal wind is not a wind that actually blows in the atmosphere; rather, it is the vector difference between winds at two levels. For example, if the 700-hPa geostrophic wind is southwest at 50 knots and the 500-hPa geostrophic wind is west at 80 knots, the vector difference, or thermal wind, is from the northwest at 58 knots. See fig 2.8.

44. In that example, the mean isotherms between 500 hPa and 700 hPa would be oriented in a northwest to southeast direction, with colder air to the north. In general, thermal winds parallel mean isotherms in a given layer, with colder air to the left as you look downstream (the direction toward which the wind is blowing). The spacing of the isotherms is made to conform to the magnitude of the shear vector. The greater the shear vector, the closer the spacing of the isotherms (tighter gradient) and the more rigorously the direction of the isotherms conforms to the direction of the shear vector.

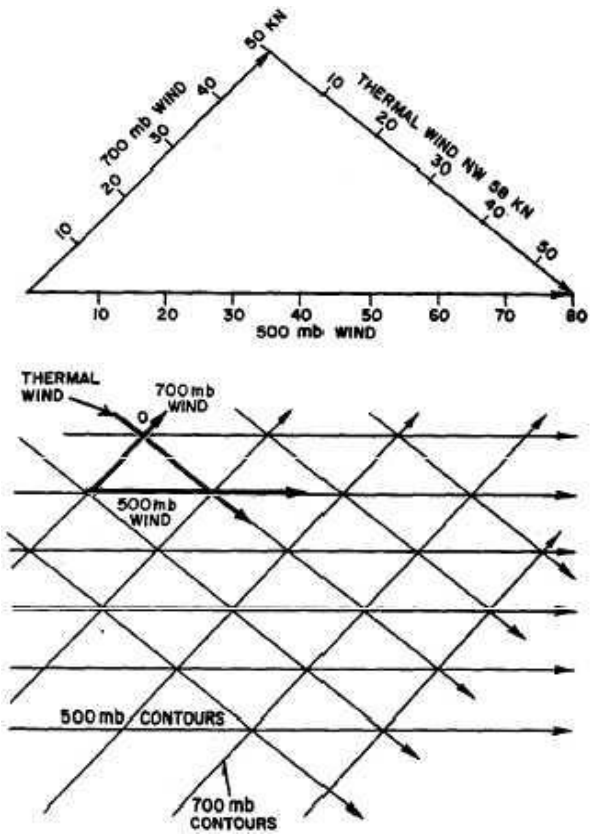


Fig 2.8. Thermal wind between two pressure surfaces

45. Over the oceans, computed shear vectors are of considerable value in drawing isotherms. Speeds of less than 10 knots may not be significant, but when the shear vector exceeds this value, it is of particular use in the analysis. In the free atmosphere the vertical wind shear is largely controlled by the temperature field. In areas where no temperature data is available, an isotherm analysis can still be carried out provided that the variation of wind with height is known. The basic relationships for the Northern Hemisphere are summarised as follows:

a If wind speed increases with increasing height but does not change direction, contours and isotherms are parallel, with cold air to the left facing downstream.

b. If wind speed decreases with increasing height but does not change direction, contours and isotherms are parallel, with cold air to the right facing downstream.

c. If there is no change in wind speed or direction with height, the air temperature is uniform throughout the layer.

d. If the wind veers with increasing height, the isotherms cross the contours in such a way that advection of warmer air takes place.

e. If the wind backs with increasing height, the isotherms cross the contours in such a way that advection of colder air takes place.

Frontal Analysis

46. The thermal gradient is by far the most important guide in locating fronts. The 850- and 700-hPa isotherm analyses are used as aids in determining the location, strength, and vertical extent of fronts. Isotherms generally parallel fronts, with the tightest packing (gradient) in the cold air (fig. 2.9). On upper-level charts that do not show fronts, isotherms are continuous lines. On those showing fronts, the isotherms may be discontinuous.

47. The thermal gradient and pattern in relation to fronts give an indication of a front's strength. The weaker the gradient (in the cold air), the weaker the front and the greater the probability that the front has a shallow slope. The tighter the gradient, the stronger the front.

48. Isotherms may parallel cold fronts for long distances; however, somewhere to the north the isotherms may cross these fronts. Any appreciable crossing of these fronts by the isotherms indicates the front is occluded. Secondary cold fronts may also show an isotherm pattern that is more or less perpendicular to them. This indicates little air-mass contrast and a weaker front.

Isotherm-Thickness Relationship

49. The isotherms of a constant-pressure level located near the middle of an isobaric layer are assumed to be representative of the mean isotherms (thickness lines) of the layer. For example, let's use the isobaric layer between 1000 hPa and 500 hPa. The constant-pressure level closest to the middle of the 1000-500-hPa layer is 700 hPa. The 700-hPa isotherms are assumed to be representative of the mean temperature and thickness of the 1000-500-hPa layer. Put another way, the 700-hPa isotherm pattern is similar to the 1000–500-hPa thickness pattern. The isotherm-thickness relation-ship applies to other layers. For example, the 850-hPa isotherms are representative of the mean isotherms of the 1000-700-hPa layer.

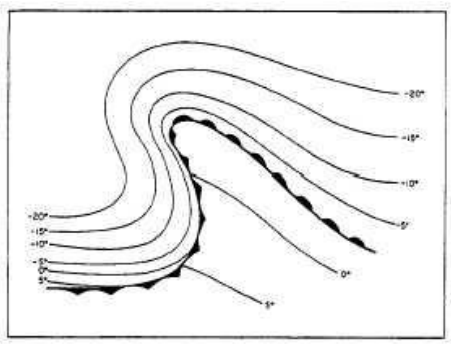


Fig 2.9. Isotherm packing at a warm and cold front aloft

Isotach Analysis

50. An isotach analysis provides a visual representation of the wind field at a given level. Isotachs are lines connecting points of equal wind speeds. They are drawn at 20-knot intervals. They form elongated ellipses that localise areas of highest wind speeds (fig. 2.10). These areas are known as centres of wind speed maxima in the overall isotach pattern. These centres move from west to east at speeds less than that of the winds themselves but greater than that of the waves in the long wave pattern. Their speed approximates that of the short waves. They move around the long wave troughs and ridges as these features move eastward. Occasionally, centres appear nearly stationary in the base of a trough or crest of a ridge, but they have never been known to retrogress upstream. Isotach maxima on any constant-pressure chart represent the intersection of that level with a jet stream (jet).

51. Whatever level you analyse, begin the analysis in an area of dense reports. Sketch in the 60-knot isotach. Isotachs are drawn as a series of dashes. Begin at a point representing 60 knots and follow it downwind, interpolating between reported wind speeds. The isotachs will parallel, more or less, the height con-tours. However, at low speeds, isotachs cross contours at large angles, and where isoheights converge (upstream from speed maxima), isotachs tend to cross from high to low heights.

52. The reverse takes place downstream, where isoheights diverge. Sketch in the remaining isotachs at 20-knot intervals and identify the centres of speed maxima. The centres are labeled with a "J" followed by the estimated maximum speed; e.g., J120. Speed minima (centres of minimum wind speeds) are labeled with an "S".

53. Computing wind speeds in sparse-data areas is accomplished using gradient or geostrophic wind scales. For reasons mentioned previously we use the geostrophic wind scale, and only in the case of cyclonically curved isoheights would you need to correct geostrophic wind to gradient wind.

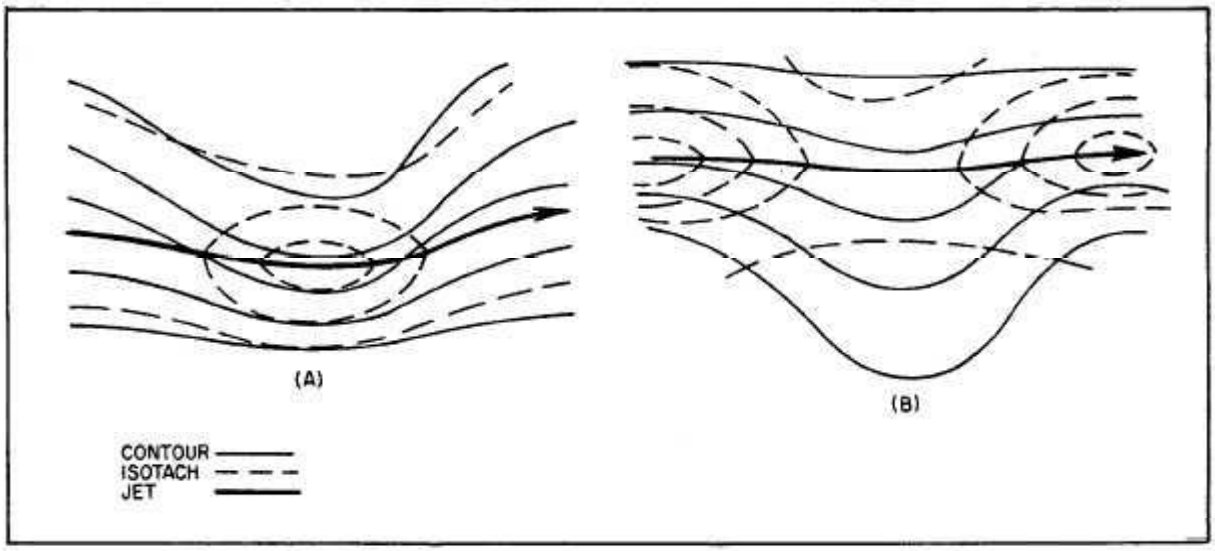


Fig 2.10.Common contour and isotach patterns.(A) Speed maximum at long-wave trough line; (B) Speed maximum at ridge line

Jet Stream Analysis

54. A jet is defined as a narrow stream of relatively strong winds. On upper-level charts two such jets are often depicted. Polar-front jets are the most predominant and are associated with polar fronts of middle and sub-polar latitudes. Like polar fronts, these jets can vary greatly in position and strength from day to day. The other jet that is often distinguishable is the subtropical jet. It is located at the poleward sides of the tropics, between 20 and 30 degrees latitude. To be classified as a jet, the wind speeds must equal or exceed 50 knots. However, an observation of high wind speed does not by itself warrant use of the term jet stream. As the word stream implies, the core must possess considerable length. The WMO defines it as normally thousands of kilometres in length, hundreds of kilometres in width, and some kilometres in depth.

55. The principal jet axis is marked by a heavy red line, with arrowheads indicating the flow direction. Secondary jets and jet fingers are depicted using dashed red lines with arrowheads. The jet axis, like isotachs, follows height contours. At 500 hPa, it is located within 60 metres (plus or minus) of the 5,610-metre contour. At 300 hPa, look for it between the 8,960- and 9,240-metre contours.

56. The polar-front jet lies vertically above the maximum temperature gradient of the middle troposphere. Because the 500-hPa chart is representative of the mid troposphere, locate the maximum temperature gradient (isotherm packing) on this chart. The jet is normally found above and just south of this thermal band. This isotherm concentration is most often associated with a polar front, and the jet axis at 500 hPa seems to coincide with the – 17°C isotherm on the warm side of the maximum temperature gradient.

57. The jet fluctuates vertically (up and down) and latitudinally (north and south). It usually lies between the 300- and 200-hPa levels. It is nearer the 200-hPa level at lower latitudes and 300 hPa at higher latitudes. It also fluctuates seasonally. It is at a lower altitude in winter (300 hPa) than in summer (200 hPa).

58. The 300- and 200-hPa charts give the best representation of the jet, but it is often well defined down at the 500-hPa level. This level is very important in analysing the jet, because it normally provides much better coverage (reports).

59. Upper-level charts allow us to locate jet streams and see their width and length. Another aid in locating their position is satellite pictures. The satellites play a key role over the oceans where upper level reports are very sparse. The combination of upper-level- wind observations and satellite pictures has given us a much better understanding of the various jet streams that exist within the atmosphere. There will be more on jet streams later in this chapter.

60. In summary, the isotach and jet stream analyses go hand in hand. Isotach patterns from 500 to 200 hPa outline centres of wind speed maxima and their associated jet streams. The jet streams are rivers of fast-flowing air (50 knots or more) and extend for thousands of miles around Earth, are hundreds of miles wide, and have a variable depth of only a few miles. The jet core is usually located between 300 and 200 hPa, but the entire stream fluctuates vertically and horizontally.

61. A combination of upper-level-wind reports and satellite pictures provides us with a means of locating the jets occurring within our atmosphere.

Tropopause Analysis

62. Unless you operate as a member of an upper air team taking raobs and Rawinsonde, you will most likely never do a tropopause analysis. The main things to remember are the relationship between the tropopause and the troposphere, and the criteria an analyst uses in determining where the troposphere ends and the tropopause begins. The tropopause is a transition boundary between the troposphere and the stratosphere. The analysis of this boundary layer is carried out on adiabatic charts, using temperature data obtained from atmospheric soundings (raobs and Rawinsonde). The tropopause is characterised by an abrupt change in the temperature lapse rate. The change is from a lapse rate marked by decreasing temperature through the troposphere to one where the temperature decreases much more slowly, becomes isothermal (constant), or even shows a slight increase with height through the tropopause.

63. There are at least three distinct tropopauses, which form leaflike or overlapping structures within Earth's atmosphere. The three most generally accepted are the subtropical tropopause, found at 25° latitude near 18,290 metres (approximately 100 hPa); the mid-latitude tropopause, at 35° to 40° latitude near 12,190 metres (approximately 200 hPa); and the sub-arctic tropopause, near 9,145 metres (300 hPa). In general, each tropopause is found at greater heights in summer than in winter. Because the thickness of the troposphere increases from the poles to the equator, each tropopause slopes upward toward the equator. For a short distance, the subtropical tropopause tends to overlap the mid-latitude tropopause, and the mid-latitude tropopause tends to overlap the sub-arctic tropopause. Fig 1.11 illustrates the overlapping of the mid-latitude and subtropical tropopauses. Each tropopause is characterised not only by height and pressure but also by potential temperature. In winter, the potential temperature of the subtropical tropopause is 390 ± 10ºK; the mid-latitude tropopause, 350ºK; and the sub-arctic, 310ºK. Potential temperatures are used to locate tropopauses from atmospheric soundings with many inversions or irregular lapse rates with no inversions.

64. The variation in temperature structure through the tropopause led to many different ideas on how to define and analyse it. The present WMO definition does not state what a tropopause is. Instead, the WMO defines an objective technique (selection criteria) for locating tropopauses from a plotted atmospheric sounding. The significance of WMO's definition is the standardisation the definition has brought about. It permits the same height to be consistently selected by all technicians from a given sounding, and other atmospheric phenomena can be empirically (through experience and observation) related to it.

65. Within the WMO definition, provision is made for identifying two or more tropopauses on a sounding, which is necessary because of the regions where overlapping exists. The definition is in two parts:

a. The "first tropopause" is defined as the lowest height at which the lapse rate decreases to 2°C per kilometre or less, provided also that the average lapse rate between this height and all higher altitudes within 2 kilometres does not exceed 2°C per kilometre.

b. If, above the first tropopause, the average lapse rate between any height and all higher altitudes within a 1-kilometre intend exceeds 3°C per kilometre, then another tropopause is defined by the same criteria as under 1 above. This second tropopause may be within or above the 1-kilometre layer.

66. There are also two qualifying remarks attached to the selection criteria. They are as follows:

a. A height below the 500-hPa level is not designated as a tropopause unless the sounding reaches the 200-hPa level and the height is the only height satisfying the above definitions.

b. When the second or higher tropopauses are being determined, the 1-kilometre interval with an average lapse rate of 3°C per kilometre can occur at any height above the conventional tropopause and not only at a height more than 2 kilometres above the first tropopause.

Supplementary Upper-Air Analysis

67. The basic upper-air analysis is the constant-pressure analysis. In conjunction with this basic analysis it is sometimes necessary, and at all times beneficial, to conduct concurrent supplementary types of analyses of upper-air properties in order that the fullest use be made of upper-air information to lead to the end product, the forecast. Most of these charts are constructed from either reported or derived data from upper-wind and upper-air reports. It is not feasible to list or explain all the types of upper-air charts currently being produced by the National Meteorological Centre. Only the space differential (thickness) analysis, advection, and time differential charts are covered here.

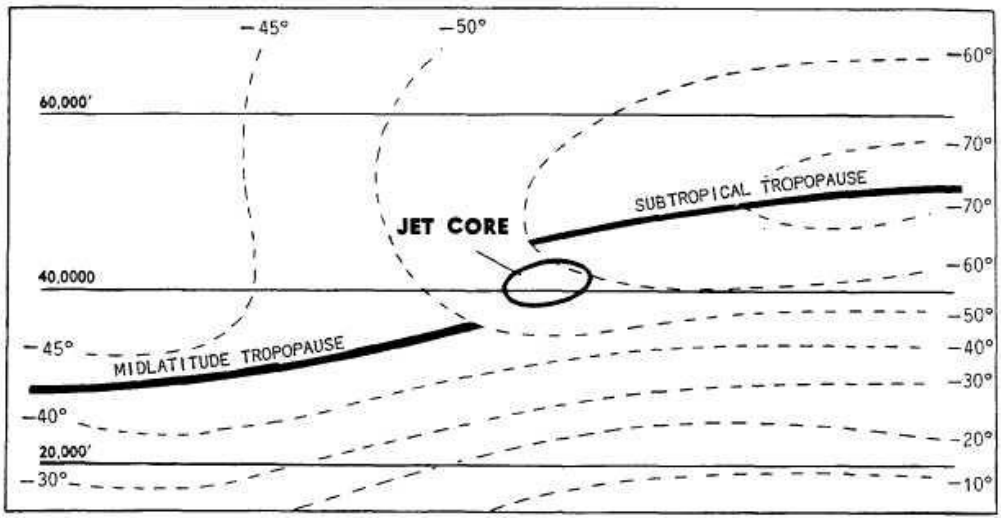


Fig 2.11. Overlapping of subtropical and mid-latitude tropopauses

Space Differential (Thickness) Analysis

68. For a truly three-dimensional analysis of the free atmosphere, it is necessary to analyse not only the individual levels within the atmosphere (850 hPa, 700 hPa, etc.) but also the various layers of it. The most commonly analysed layers are the 1000-700-hPa, 1000-500-hPa, 700-500-hPa and 500-200-hPa layers. Layer, or differential, analysis ensures vertical consistency between the individual levels and agreement within the limits of the hydrostatic equation.

69. Know the heights of any two constant-pressure levels and you can determine the thickness (vertical distance) of the layer separating them. It's simply a matter of subtraction. Space differential charts are commonly referred to as thickness charts, since they represent the difference in height between two constant-pressure levels. Manually, they are constructed by graphically subtracting the heights of one analysed constant-pressure chart from those of another.

70. **Procedure for Analysis**. If the need should ever arise whereby you must do such an analysis, here's a recommended procedure:-

a. Obtain the analysed constant-pressure charts for the levels bounding the layer to be analysed.

b. Place an acetate over one of these charts and trace the isoheights onto the acetate with a grease pencil. Be sure to label the contours.

c. Place the same acetate over the other chart and trace and label the isoheights of this level, using a different colour grease pencil.

d. Graphically subtract the lower contours from the upper and connect the points of equal thickness. It may prove helpful if you perform the mathematical subtraction of heights at a few intersections to aid you in getting the analysis started. Thickness lines are drawn in dashed black.

e. Place the acetate under a clean chart and trace the thickness lines onto the chart with a black felt-tip pen. Label the thickness lines.

71. There are several rules that you must follow in constructing the thickness pattern:-

a. Thickness lines cannot touch or cross.

b. Thickness lines cross isoheight contours at the intersection points of the two levels only.

c. Thickness lines must always pass from lower to higher contours or vice versa at both levels.

d. Between any two consecutive thickness lines an isoheight of either pressure surface must exist.

e. Between any two consecutive isoheights a thickness line or an isoheight of the other pressure surface must exist.

72. **Thickness Patterns**. Fig 2.12 illustrates most of the important details of the 1000-500-hPa thickness pattern in relation to fronts. Adherence to these features of the thickness model insures the proper slope of systems between 1000 and 500 hPa, the proper relationship between surface fronts and polar jet, and surface frontal analyses that portray a meaningful picture of the three-dimensional temperature structure. The most important features of the pattern are as follows:

a. The concentration of thickness contours is on the cold side of frontal systems. The stronger the front, the greater the concentration.

b. The spacing of thickness contours in the cold air ahead of warm fronts is greater than in the cold air behind cold fronts.

c. The horizontal distance between the maximum thickness gradient and cold fronts is less than with warm fronts. The maximum gradient is usually located horizontally in the same position as the 500-hPa jet stream.

d. Thickness contours are anticyclonically curved in advance of warm fronts and cyclonically curved behind cold fronts.

e. The location of the cold trough in the thickness contours lies to the rear of the surface low, halfway between the surface low and the next upstream ridge or high.

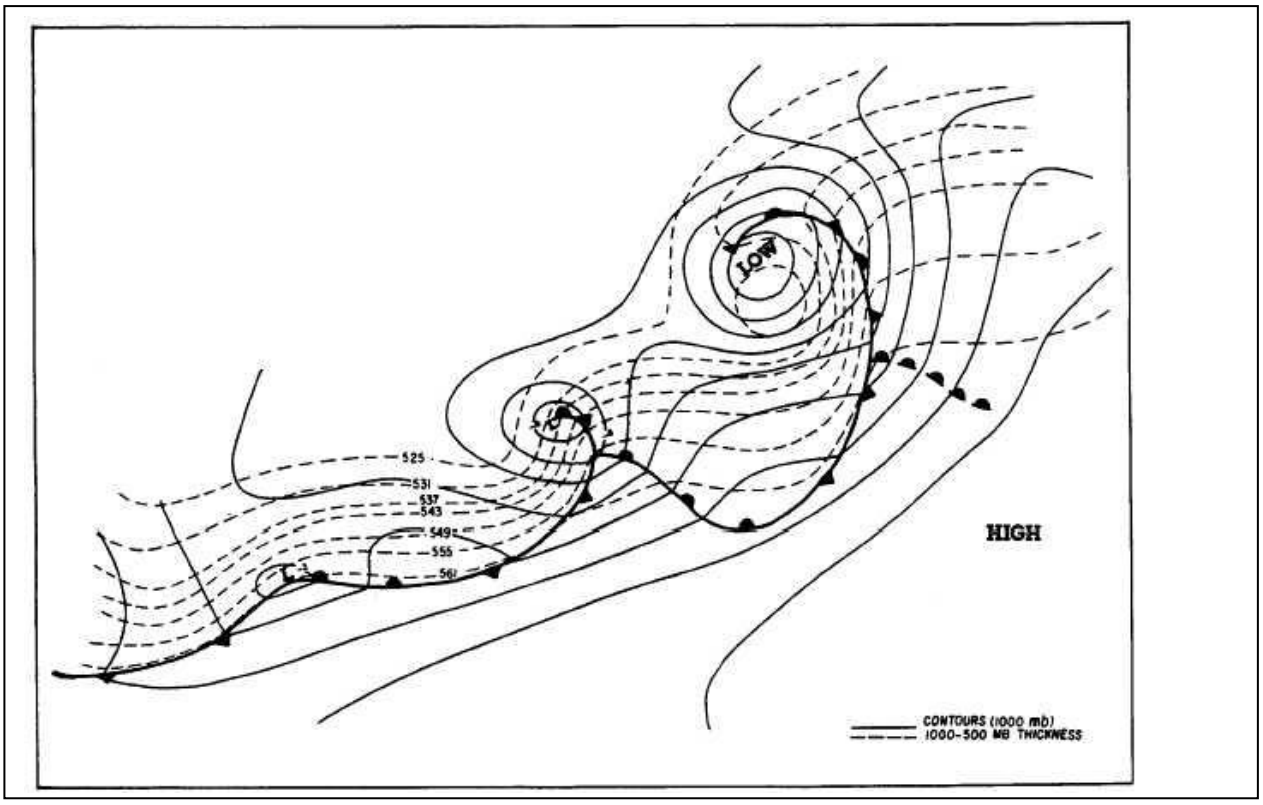


Fig 2.12. Illustration of the relation of thickness patterns to fronts

Advection Analysis

73. In meteorology, advection refers to the horizontal transport of heat or other properties. Advection charts, like thickness charts, are constructed between any two desired constant-pressure levels. In fact, they are usually constructed on thickness charts. Cold or warm air advection is indicated at the same intersections used to compute thickness. Advection arrows indicate the mean direction of flow in the layer. They are, for the most part, perpendicular to the thickness lines. Blue arrows indicate cold air advection and red arrows warm air advection. If the flow is such that it crosses thickness lines from higher height values to lower height values, the advection is warm; and from lower to higher values, it's cold. The thumb rule to follow when constructing advection arrows is that when the contour of the lower pressure level is to the left looking downstream, advection is cold; but when it is to the right, advection is warm. See fig 2.13.

74. A derivative of the thermal wind equation and advection arrows is the thermal wind rule. It simply states that in the Northern Hemisphere if the wind backs with height, cold advection is indicated; and if the wind veers with height, warm air advection is indicated.

Time Differential Analysis

75. Time differential charts show the amount and direction of change of a meteorological quantity over a given period of time. They are used to track upper-height centres. They are usually drawn at 24-hour intervals, vice every 12 hours, to minimise diurnal effects.

76. Construction is as follows: Take two charts, 24 hours apart and of the same level, and lay the most recent over the other. Over these lay a clean acetate or blank chart. Using a light table, algebraically subtract the contour values of the most recent chart from those of the earlier chart. This is done where the contours of the two charts intersect. Lines are then constructed connecting like height differences. Falling height lines are drawn in red, rising heights in blue, and lines of no height change are drawn in purple. These lines are labeled in decimetres. The centres of rising and falling heights are then transposed onto a blank chart (if acetate was used). These centres are then tracked in the same manner as are the pressure centres on constant-pressure charts.

Summary of Upper-Air Analysis Rules

77. The following list is by no means all inclusive, but it does provide a guide for avoiding some typical and often repeated errors made by inexperienced analysts.

a. Always check the previous analysed map before starting the current analysis.

b. Isoheights (contours) are drawn parallel to winds where possible. This is not always possible, because of observation errors and non-geostrophic and/or non-gradient winds. Always check the plotted wind shaft for the number indicating direction.

c. Contours are drawn following down the wind; therefore, wind direction cannot change discontinuously along a contour.

d. Do not over-emphasise cyclonic curvature at troughs in the form of kinks. This implies a trough is a front.

e. Continue analysis into areas of no data. Use wind scales, history, and common sense to get central heights of highs and lows when no data is available.

f. Use geostrophic wind scales to determine correct spacing of contours. The spacing will be less than the observed wind indicates in areas of cyclonic curvature and greater than the observed wind where anticyclonic curvature is occurring.

g. The isotherm-contour pattern at 500 hPa is normally one of cold lows and warm highs. A closed isotherm will be nearly coincident with height centres. Long-wave troughs are cold, ridges warm. The opposite is true for short waves.

h. Marked changes in the configuration of troughs should be doubted.

j. Insure vertical consistency:-

(1) Troughs and lows must slope toward coldest air.

(2) Ridges and highs must slope toward warmest air.

(3) Cold lows have little or no slope.

(4) Warm lows at lower levels become short-wave (warm) troughs aloft.

(5) Frontal waves at sea level become short waves aloft.

(6) Occluded lows become cold or cut-off lows aloft.

k. Strive for a professional-looking product.

l. Avoid jagged, ragged or nervous isolines.

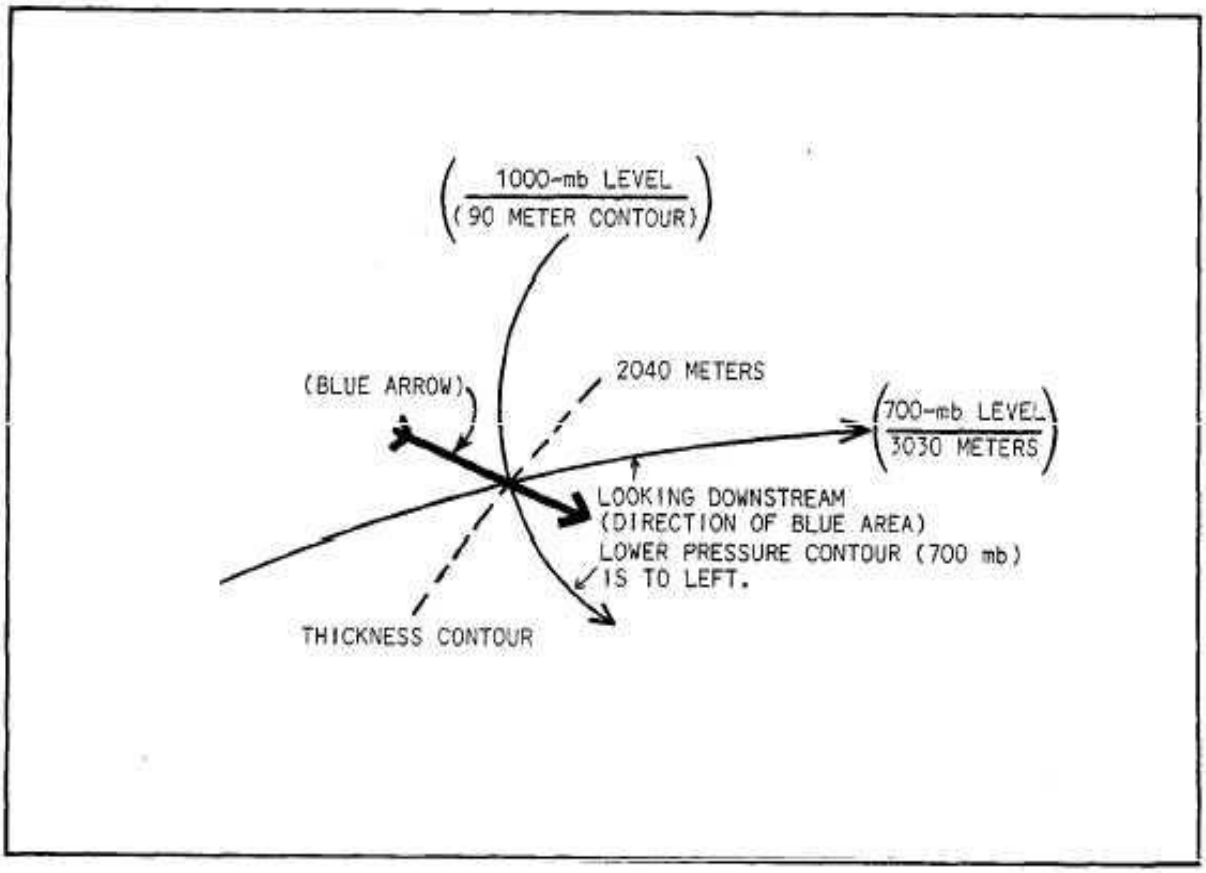


Fig 2.13. Explanation of advection arrow construction

TASK-20 : USE OF CONSTANT PRESSURE CHARTS

Constant-Pressure Charts

1. Upper-air charts are termed Constant-Pressure Charts, because they depict conditions at levels (heights) within the atmosphere where the pressure is the same (constant).

2. Constant-pressure charts are produced for standard levels. These levels are the 1,000-, 850-, 700-, 500-, 400-, 300-, 250-, 200-, 150-, 100-, 70-, 50-, 30-, 20-, 10-, 7-, 5-, 3-, 2-, and 1-hPa levels. However, the most commonly produced charts are for the 1000-, 850-, 700-, 500-, 300-, 200-, and 100-hPa levels.

3. Atmospheric soundings show that pressure changes most rapidly when the temperatures are cold and least rapidly when they are warm. Remember, pressure is a function of the weight of the atmosphere, and the atmosphere's weight is dependent on its density. Cold air is more dense than warm air; therefore cold air is heavier and exerts more pressure at a given altitude. Assuming that two columns of air (one cold, one warm) exert the same pressure at the surface, the column containing the warm air has to extend to a greater height. Fig 3.3 illustrates the pressure-height differences in cold and warm air. Also, note the vertical spacing (thickness) between the constant-pressure levels.

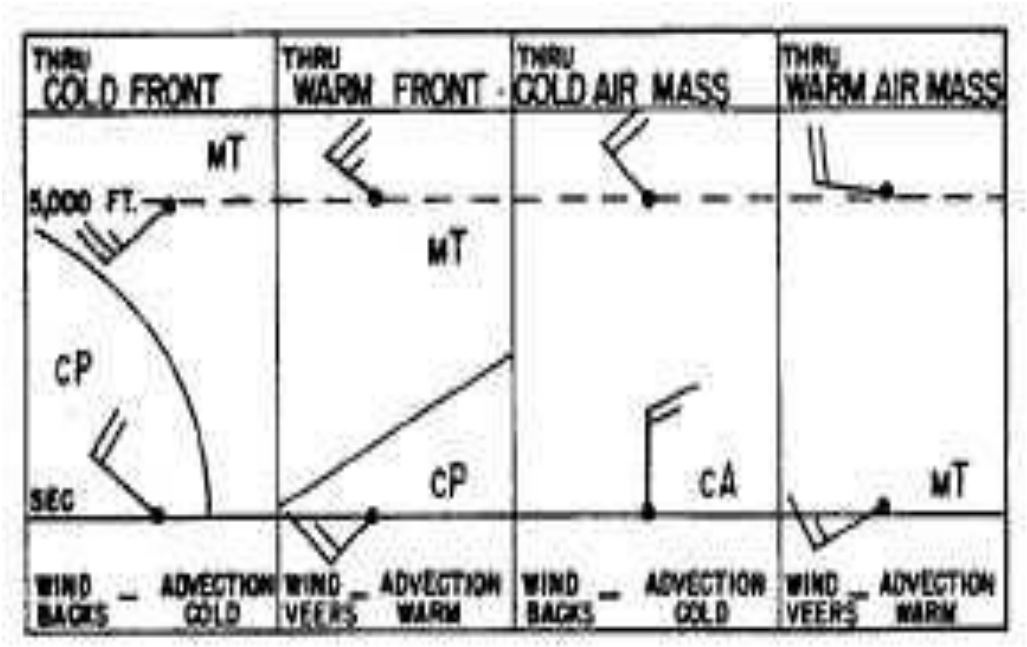


Fig 3.1 The thermal wind rule (Northern Hemisphere)

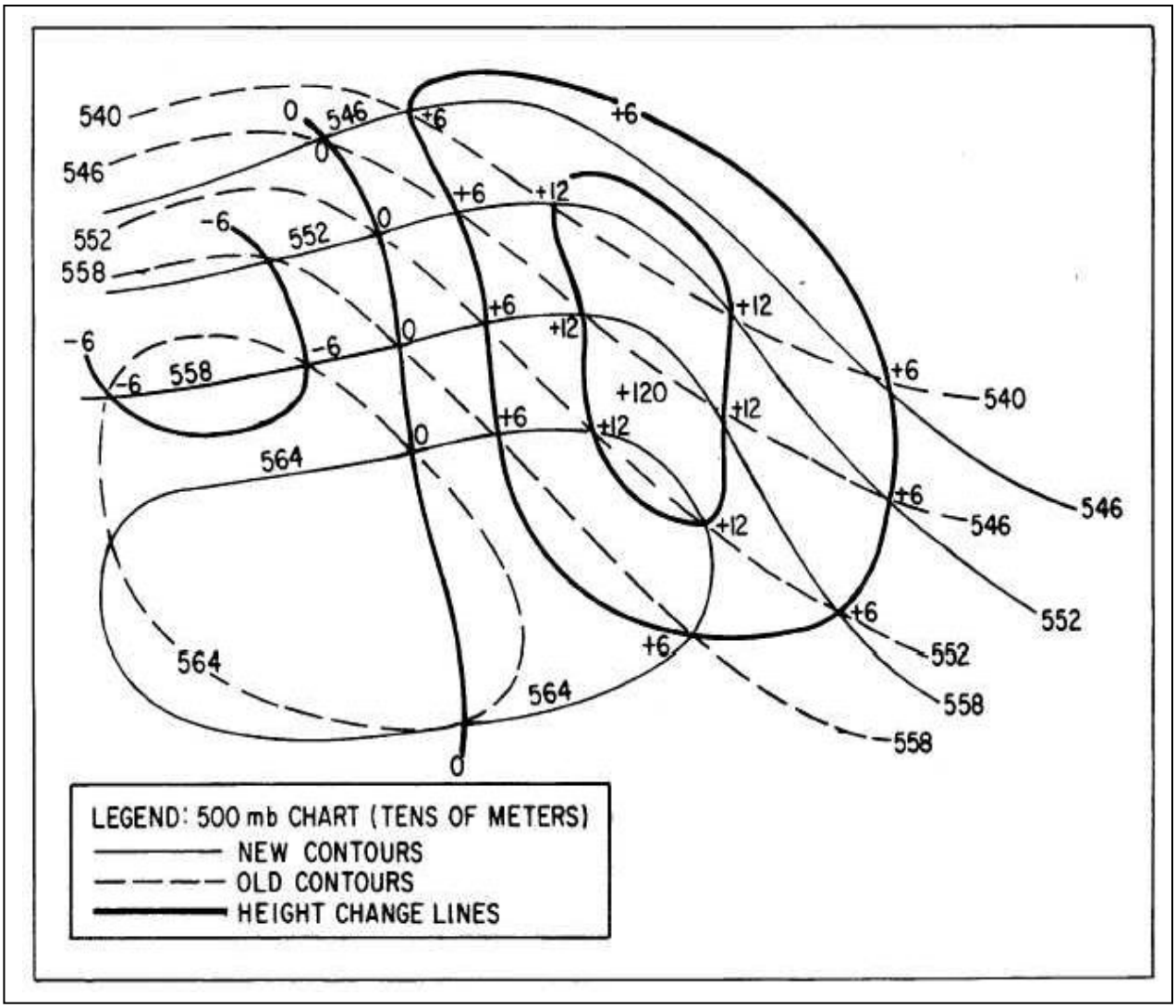


Fig 3.2 Time differential chart

4. Constant-pressure charts are produced for standard levels. These levels are the 1,000-, 850-, 700-, 500-, 400-, 300-, 250-, 200-, 150-, 100-, 70-, 50-, 30-, 20-, 10-, 7-, 5-, 3-, 2-, and 1-hPa levels. However, the most commonly produced charts are for the 1000-, 850-, 700-, 500-, 300-, 200-, and 100-hPa levels.

5. Atmospheric soundings show that pressure changes most rapidly when the temperatures are cold and least rapidly when they are warm. Remember, pressure is a function of the weight of the atmosphere, and the atmosphere's weight is dependent on its density. Cold air is more dense than warm air; therefore cold air is heavier and exerts more pressure at a given altitude. Assuming that two columns of air (one cold, one warm) exert the same pressure at the surface, the column containing the warm air has to extend to a greater height. Fig 3.3 illustrates the pressure-height differences in cold and warm air. Also, note the vertical spacing (thickness) between the constant-pressure levels.

6. As the temperatures in the atmosphere change, so do the heights of the constant-pressure levels. Based on the U.S. standard atmosphere, the approximate heights of the more common constant-pressure levels are as follows:-

Pressure level	Height	
(hPa)	(metres)	(feet)
1000	110	370
850	1,460	4,780
700	3,010	9,880
500	5,570	18,280
400	7,180	23,560
300	9,160	30,050
200	11,790	38,660
150	13,620	44,680
100	16,210	53,170

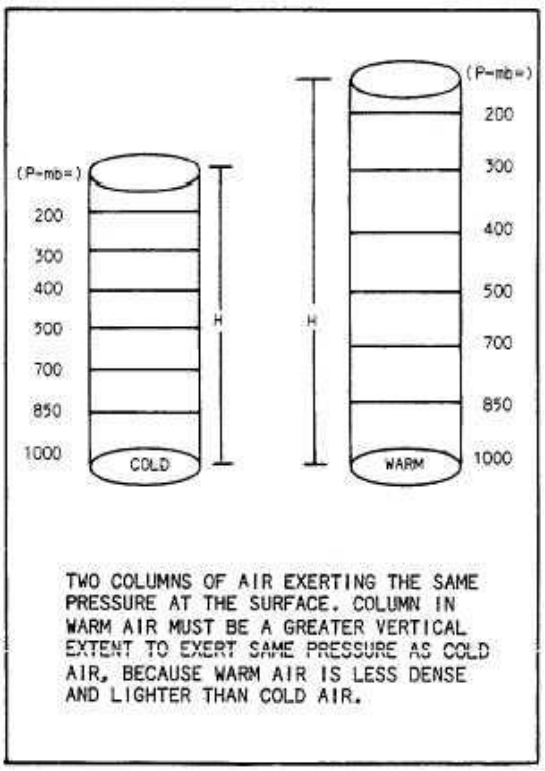


Fig 3.3 Pressure-height differences in cold and warm air

7. Constant-pressure charts are primarily used as an aid in weather forecasting. When they are used in conjunction with surface synoptic charts, the following determinations may be made:

a. Movements of weather systems

b. Areas of cyclonic and anticyclonic windflow

c. Types of air masses

d. Location of moist and dry areas within the atmosphere

e. Formation, intensification, and dissipation of pressure systems

f. Actual slopes of fronts

g. Vertical extent of pressure systems

h. Location and strength of jet streams

8. The following is a brief summary of the principal uses of constant-pressure charts commonly prepared and displayed in most weather offices.

The 1000-hPa Chart

9. This chart indicates the height of the 1000-hPa level above and below sea level. When below sea level, it is indicated by negative height values. For reasons previously discussed, 1000-hPa height values are not very accurate in mountainous areas. Use them with caution.

10. A 1000-hPa chart is constructed from a surface chart by assuming that 7½ hPa equals 60 metres for temperatures between 30°F and 70°F; that 8½ to 9 hPa equals 60 metres for temperatures below 30°F; and that 6½ hPa equals 60 metres for temperatures above 70°F. These ratios give valid approximations of 1000-hPa heights; however, heights from radiosonde soundings should be used whenever available.

11. The principal use of 1000-hPa chart is in constructing space differential (thickness) charts. The 1000-hPa chart serves as the base level for the 1000-700- and 1000-500-hPa charts.

The 850-hPa Chart

12. The principal uses of the 850-hPa chart are to locate surface frontal positions, to determine the representativeness of surface winds and temperatures, to determine the depth of moisture patterns in winter, and to serve as the surface chart in mountainous and plateau areas where the mean elevation is around 5,000 feet.

13. Temperature and moisture analyses should be made in close conjunction with the surface chart whenever possible. A complete and careful isotherm analysis at this level in conjunction with the wind and height analysis will lead to the correct placement of fronts both at this level and the surface. A thumb rule to guide you in locating most fronts is to look for the 850-hPa warm front roughly 2½ to 3 degrees latitude ahead of the surface front and cold fronts ¾ to 2 degrees latitude behind the surface front. An isotherm analysis also serves as a good indication of the 1000-700-hPa thickness pattern.

The 700-hPa Chart

14. The 700-hPa chart is used mostly to determine the vertical extent and structure of fronts and pressure systems, or to play the role of the 850-hPa chart over areas where the mean elevation is around 10,000 feet. It is also used to analyse moisture patterns in summer, when moist tongues extend to greater heights than in winter, because of convective activity. Other uses are in forecasting (steering currents for certain shallow pressure systems are determined at this level) and differential analysis.

15. Short waves are a predominant feature of this chart. Because of their influence on cloudiness, frontal intensity, precipitation areas, etc., these wave features are carefully studied and tracked. The isoheight interval is the same as that for the 850-hPa chart-30 metres.

The 500-hPa Chart

16. The 500-hPa chart is the most widely used of all upper-air charts. Primary features are the warm highs and cold lows, with their associated ridges and troughs. Long waves are identifiable at this level, but most short waves have lost their identity.

17. For various reasons, the 500-hPa level comes closest to representing the mean state of the atmosphere at observation time. Since this level approximately divides the atmosphere with respect to mass, the 500-hPa chart is often used, in conjunction with the 1000-hPa chart, to provide a layer analysis of the lower half of the atmosphere.

18. This chart also provides winds at a common flight level for piston-engine aircraft, gives a fair approximation of the horizontal position of the jet stream when no 200- or 300-hPa chart is available, and provides an important base upon which to construct higher-level analyses. The importance of this last point is based on the rapid decrease in available data above 500 hPa. The 500-hPa chart is also used extensively in forecasting the movement and development of sea level systems and fronts. Contour spacing is 60 metres.

The 300-hPa Chart

19. The primary features of the 300-hPa chart are the permanent and semi-permanent highs and lows, certain dynamic lows, long waves, the polar jet stream in winter, and the tropopause, especially the arctic and mid-latitude tropopause in winter.

20. Its primary uses are in forecasting; determining the characteristics of long waves; analysing and forecasting jet streams; analysing the tropopause in winter; determining vorticity distribution; and in the case of tropical lows that do not show a closed circulation at this level, steering currents. It is also an indispensable tool in planning jet aircraft operations.

21. The contour interval is normally 120 metres, but a 60-metre interval maybe used in areas where a finer degree of delineation is required.

The 200-hPa Chart

22. The operational use and contour interval of the 200-hPa chart are the same as those of the 300-hPa chart. In fact, the 200-hPa chart is used as an adjunct to the 300-hPa analysis. In summer, it plays the same role, with respect to the jet stream, that the 300-hPa chart does in winter. In winter, its principal use is in estimating changes in the temperature advection pattern in the stratosphere.

The 150-, 100-, 50-, and 25-hPa Charts

23. The 150-, 100-, 50-, and 25-hPa charts are normally prepared at major centres and are used primarily for research purposes. Data at these levels is so scanty that their construction is almost solely based on extrapolation of data from lower levels. As the operational ceilings of jet aircraft increase, it can be anticipated that practical uses of the 150- and 100-hPa charts will also increase.

TASK-21 :CIRCULATION PATTERNS ON UPPER-AIR CHARTS

Circulation Patterns on Upper-Air Charts

1. The patterns on constant-pressure charts are much the same as those patterns delineated by isobars on surface charts. However, the pattern becomes smoother and less complex on upper-level charts. The 850-hPa chart, for example, may show many closed centres, but by the time the 200-hPa level is reached, there are few, if any, closed centres. Instead, the contours present a wavelike pattern. These waves, like their ocean counterparts, have definite properties by which they can be identified.

Long and Short Waves

2. Waves are classified according to their length, amplitude, and speed. Wavelength is the measured distance (in degrees longitude) between successive waves. The measurement is usually taken from trough to trough, ridge to ridge, or from any point on one wave to the same corresponding point on the next wave. The amplitude is one-half of the wave's total range, which is measured in degrees latitude from the peak of the ridge to the base of the trough. Fig 3.4 illustrates the measurement of wavelength and amplitude on a long wave. Also, note the short wave on the long wave. The speed of waves is usually governed by their length. The longer the waves, the slower they move, and vice versa.

Long Waves

3. A significant feature of the westerlies in both hemispheres, long waves vary in length from 50° to 120° longitude, have large amplitudes, and are slow moving. In the overall hemispheric pattern there are normally four or five long waves in existence at any one time. However, there are times when there are as many as seven or as few as three. The pattern is a persistent feature, and waves do not appear or disappear rapidly. A change in the number of waves in the pattern is significant. The fewer the number, the more progressive are the weather patterns at the surface. The greater the number, the more stagnant the weather patterns. It is during these periods that prolonged good or bad weather affects a region. The number of waves and pattern changes are often discussed at briefings for meteorologists. New long waves form from short waves or a changing synoptic situation, and their development is associated with the development of new intense circulations at lower levels.

4. Because some short waves have large amplitudes, it is often difficult to distinguish them from long waves. Also, it is virtually impossible to identify wave types (long or short) on a single chart. A series of charts over a 3- to 5-day period is best for this. This is usually enough time for most short waves to move through the slower long-wave pattern, thereby distinguishing between the two types. The long waves have a normal movement at 40°N of about 2° longitude per day in the spring to less than 1° per day during the fall. They can also become stationary or even retrogress.

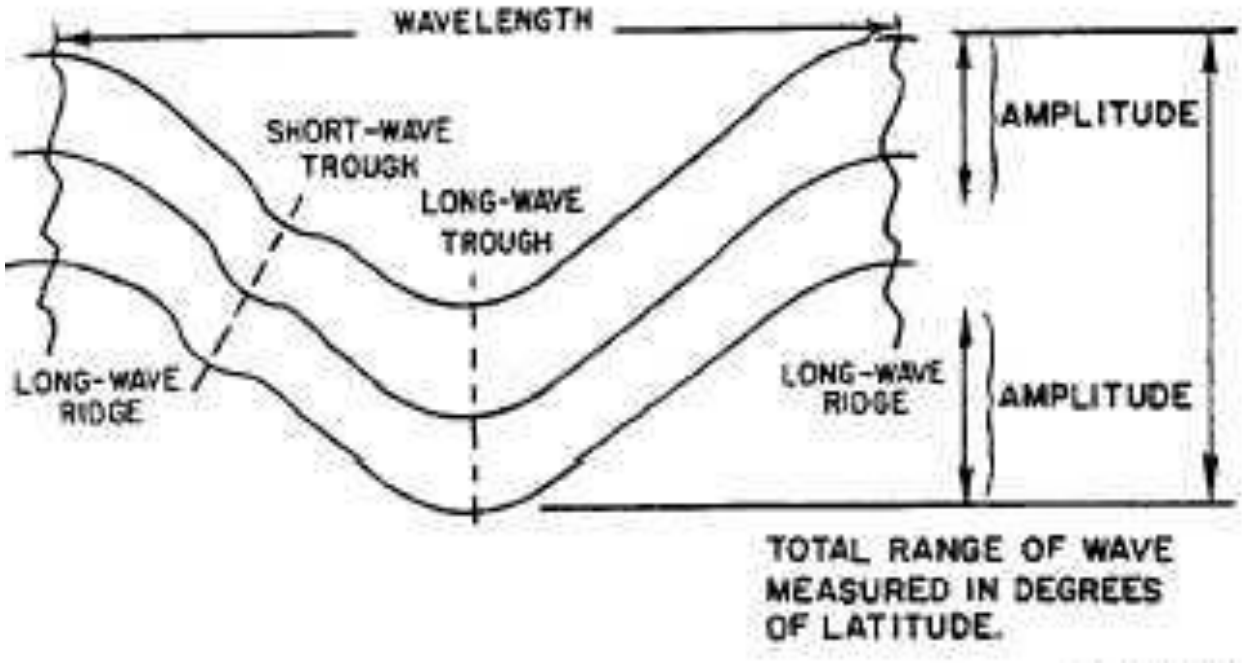


Fig 3.4. A long & short wave and the measurement of length & amplitude of a long wave

5. Because a long wave's amplitude increases with height within the troposphere (greater at 300 hPa than at lower levels) the long-wave pattern is best identified at the 300-hPa level. Here, the wave contours are approaching their maximum amplitude, and the overall pattern is smooth (no short wave distortion). The increase in amplitude with height also distinguishes long waves from short waves. Short waves often disappear with height and may not be detectable above 500 hPa. This is attributable to the temperature patterns associated with the two types of waves. With long waves, the troughs are cold and the ridges warm; the opposite holds true for short waves.

6. Synoptically, long waves are related to a number of weather occurrences. Fig 3.5 illustrates many of the relationships. Simply stated, the weather between the long-wave trough and the downstream ridge (trough sector) is more apt to be bad than the weather between the trough and the upstream ridge (ridge sector).

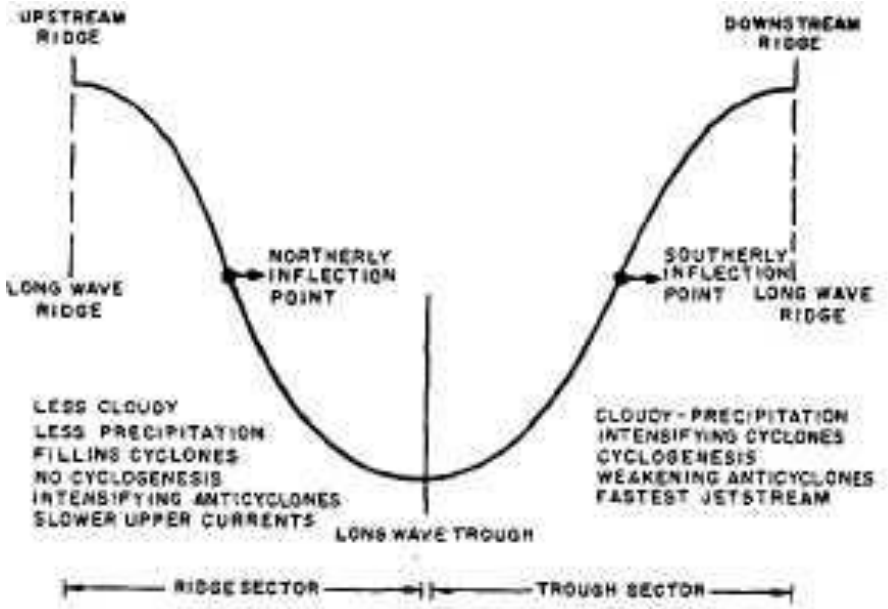


Fig 3.5. Long waves and related weather

Short Waves

7. Superimposed on the long-wave contours of a given upper-air chart, say 500-hPa, are numerous short waves. Ten or more short waves are present in the hemisphere most of the time. They have shorter wavelengths and smaller amplitudes and move faster than long waves. They move in the same direction as the current in which they are embedded. Their eastward motion is very near that of the 700-hPa flow. Their normal movement is on the order of 8° longitude per day in summer and 12° per day in winter. Short waves are progressive and never retrograde. Their troughs are warm and their ridges cold; therefore, they do not extend to great heights and are most predominant in the lower half of the troposphere (500 hPa and below).

8. Short waves have a great effect on long waves. They dampen (flatten) long-wave ridges as they move across them, and at the same time, the short wave is weakened. As a short wave approaches a long-wave trough, the short wave strengthens and the long-wave trough intensifies. This latter occurrence often results in the formation of a surface low-pressure system (cyclogenesis). The location of short waves coincides with the small closed height fall centres (troughs) and height rise centres (ridges) of a 700- or 500-hPa time-differential chart.

Wave Movement

9. We've discussed the relationship between waves and their associated temperature patterns. That is, long waves have cold troughs and warm ridges, while short waves have the opposite. The location and strength of warm and cold air in relation to troughs and ridges give an indication of their present and future movement. Locating and determining the strength of waves is done through a comparison of the isotherm and contour patterns on constant-pressure charts. The isotherms are considered either in-phase or out-of-phase with pressure troughs and ridges. In phase, the thermal troughs and ridges coincide with the pressure troughs and ridges. Fig 3.6, cases A through C illustrate the in-phase relation-ships. The only difference in the three in-phase patterns is the amplitude of the isotherms as compared to that of the contours.

10. When the isotherms and contours are in-phase and parallel (have the same amplitude), the wave stagnates, because there is no temperature advection taking place across the wave. When the isotherm amplitude is less than the amplitude of the contours (case B), colder air is advected into the west side of the trough and warm air into the eastern side. Where the temperatures are falling (in this case, the western side), the pressure should fall. Since systems move from high to low pressure, we would expect such a wave to move west (retrograde).

11. When the isotherms have a greater amplitude than the contours have (case C), warm air is advected into the western side of the trough and colder air into the eastern side. Therefore, pressures fall in advance of the trough and rise behind it. When this occurs, the trough moves slowly eastward toward the falling pressures (is slowly progressive).

12. The last two cases deal with out-of-phase isotherm-contour relationships and are associated with short waves. See fig 3.6, cases D and E. These isotherms are classified as being 90° or 180° out-of-phase. If they are in-phase, the coldest air is in the troughs and the warmest air in the ridges. For isotherms to be classified as 180° out of phase, the exact opposite must occur. When 180° out of phase, the waves are fast moving, and their speeds exceed that of the gradient wind within them. When 90° out of phase, the waves move with a speed equal to that of the gradient wind within the wave. In both out-of-phase cases, the temperature advection taking place is significant and the pressure changes are great downstream.

13. In all the above relationships, the effects of convergence, divergence, and dynamic deepening and filling on temperature are not taken into account. Therefore, these rules are used only to approximate a wave's vector movement.

Upper-Level Highs and Lows

14. In addition to the wave patterns on upper-level charts, closed circulations (lows and highs) also exist. The vertical extent and slope of these systems have already been discussed, and at this time it might help if you quickly review that material. Basically, these highs and lows are classified according to the vertical variation in their temperature patterns.

a. The semi-permanent highs (warm core) and lows (cold core) maintain their closed circulations well into the upper troposphere. They are generally stationary with nearly vertical axes.

b. Tropical cyclones and thermal lows are classified as warm-core systems, while the major high-pressure systems of Canada and Siberia are cold core. These warm-core systems are very shallow with the exception of mature tropical cyclones, and their closed circulations are confined to the lower half of the troposphere, disappearing with height.

c. The dynamic migratory systems, like the semi-permanent systems, also retain their closed circulations to appreciable altitudes. The lows slope upward toward the coldest tropospheric air (usually northwest of the surface low), and the highs slope toward the warmest tropospheric air (usually southwest of the surface high). In their final stages of development, those dynamic lows that fully occlude become cold-core with practically vertical axes. The intensification process of

dynamic highs is similar to that of the lows, although we don't classify it as an occluding process. It results in a vertically stacked warm-core system.

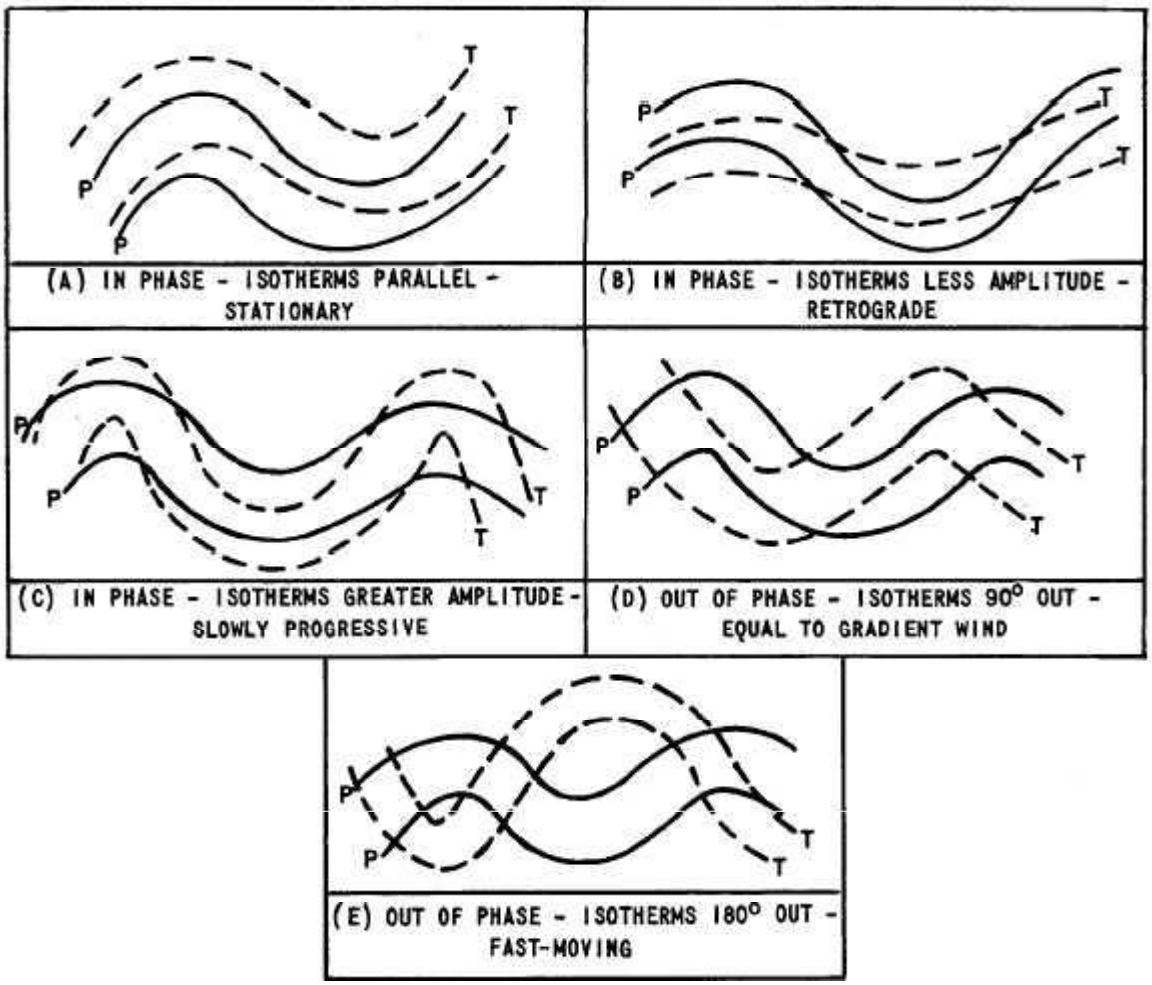


Fig 3.6 Isotherm-contour patterns

15. These dynamic systems also have a relationship with the strongest belt of westerly winds. Dynamic lows are normally poleward of the strongest westerlies, while the dynamic highs are normally equatorward of these winds. Occasionally, this situation gets reversed and a dynamic low ends upon the equatorward side and a high on the poleward side. Highs and lows in this abnormal position are termed cut-off centres.

Cut-off Highs

16. Cut-off highs occur when warm tropical air is advected poleward into the crest of a steep long-wave ridge. This warm air, and the high that it develops, ends up on the poleward side of the strongest westerlies. In this position, it is "cut off" from receiving additional tropical air.

Cut-off Lows

17. Cut-off lows take on far more importance than their counterpart highs because of the bad weather that accompanies them. In the Northern Hemisphere, they occur most frequently along the southwest coastal areas of the United States and northwest coastal areas of North Africa. They form when cold polar air is advected equatorward into the base of a deep long-wave trough. This pool of cold air, and the low it develops, ends up on the equatorward side of the strongest westerlies. Fig 3.7 shows the typical stages in the development of a cut-off low. The latter stages are often associated with occluding low-pressure systems at the surface; however, cut-off lows are noted for their production of bad weather without frontal or cyclonic circulations at the surface. In the meridional flow of which they are a part, they are the cold valleys between mountains of warm air. On the 500-hPa chart, the warm ridge to the west is very sharply oriented southwest to northeast. To the northeast, an intense warm stationary high or ridge Blocks the normal path of migratory systems.

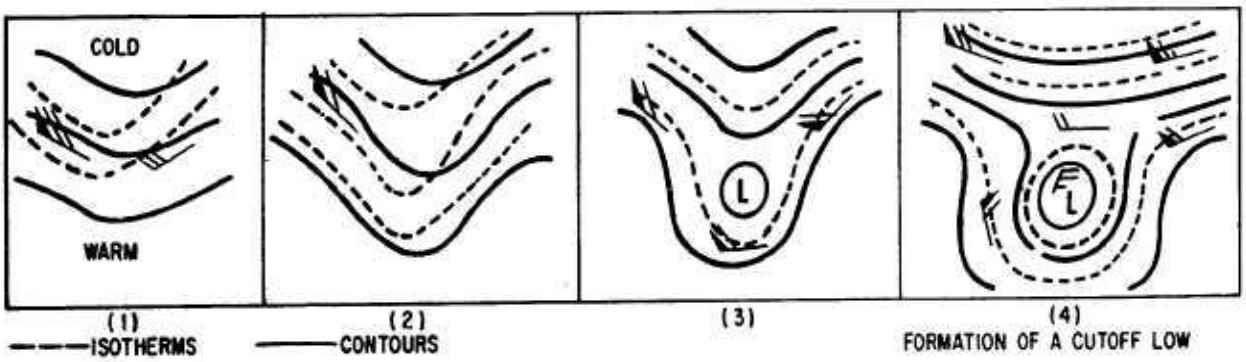


Fig 3.7 Development of cut-off low

Blocks

18. .Blocking is the obstructing of the normal west to east progress of migratory systems. Like cut-offs, blocks are associated with pronounced meridional flow in the upper levels, occur most frequently in spring and least often in autumn, and tend to form in the same geographical regions. In the Northern Hemisphere, they form most frequently in the eastern North Atlantic and eastern North Pacific oceans.

19. Blocks are warm long-wave ridges or upper- level highs that take up residence in higher latitudes and move very slowly, if at all. As a block sets up and intensifies, it tends to move west (retrograde). Figure 1.8 shows three types of blocks that occur in the circulation pattern. Blocking highs are either warm-core or dynamic systems, but in either case, they cause a split in the westerlies. The split causes the migratory systems to divert from their normal paths. It is at these times that prolonged periods of good or bad weather occur.

20. In the winter of 1976-77, a block developed over the western United States. Basically, it lasted from 15 Oct 1976 to 20 Feb 77. To the west of this block, warm air was transported far north; Alaska basked in balmy weather. Meanwhile to the east of the block, the eastern half of the United States had one of the worst winters on record. Cold arctic air was advected from over the North Pole southward to the Bahamas. The Ohio basin was particularly hard hit and suffered one of its coldest winters on record. The Chesapeake Bay of Virginia and Maryland froze over, and icebreakers were required to

keep the shipping lanes open. The citrus industry of Florida suffered severe losses, and the list goes on. In the western half of the United States, drought-like conditions existed, because the block prevented moisture-laden air of the Pacific from reaching the coast. Granted, this block was far from normal, but it serves to show a block's effect on weather patterns.

Zonal and Meridional Flow

21. Climatic studies show hemispheric pressure patterns differ in a characteristic fashion depending on whether zonal (east-west) or meridional (north-south) flow dominates within the mid-latitudes. Since winds are pressure generated, a numerical zonal index based on horizontal pressure differences between 35° and 55° latitude was developed to measure the strength of these westerly winds. The higher the index, the greater the zonal component. The lower the index, the greater the meridional component. A particular index may remain nearly stagnant for several weeks, especially in winter, or last for only a few days. Today, zonal indices are seldom computed; merely estimated. The estimate is based on the current circulation and weather patterns. Since reference is made to zonal index, you must have an understanding of what is implied by high, low, and changing zonal indices.

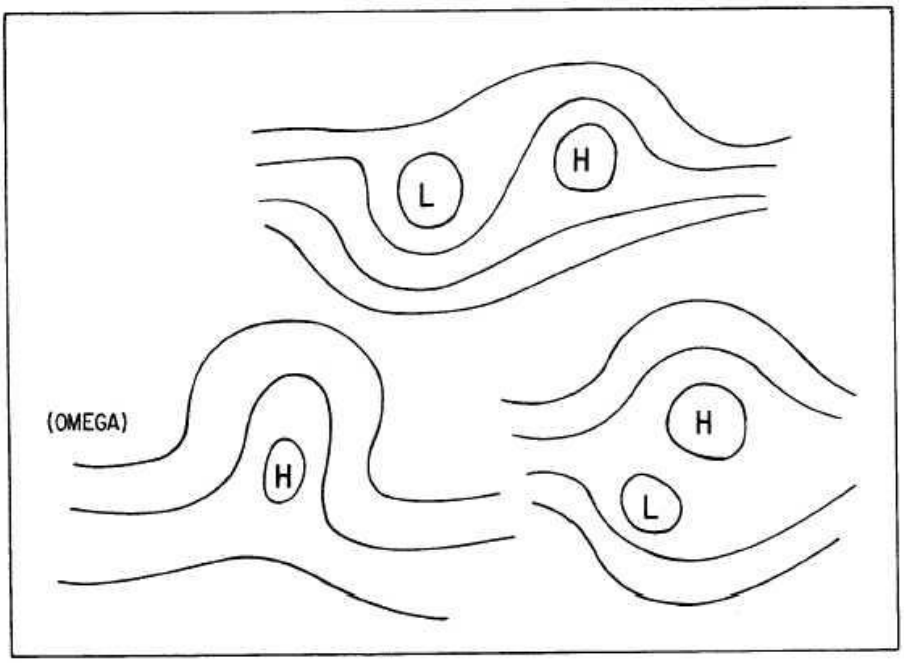


Fig 3.8 Types of blocks

High Zonal Index

22. With a high zonal index, long-wave ridges and troughs are weaker (have less amplitude) and fewer in number. The Icelandic and Aleutian lows are well developed and are at, or slightly north of, their normal positions. Their axes and the orientation of their associated troughs are east-west. The Atlantic and Pacific subtropical highs are north of their normal positions, and their orientation is strongly east-west. The Great Basin and Siberian highs are present. There's little westward extension to the high over the Great Basin. (The Great Basin encompasses all of Nevada, the western one-third of Utah, and portions of eastern California, southern Oregon and Idaho.) Highs are absent at higher

latitudes. Fronts are well north and predominantly oriented east-west. They and their associated lows move rapidly eastward. The highs of mid-latitudes are moderately developed and also progress east at a rapid pace. There are fewer polar outbreaks; therefore, the polar regions get colder, while mid-latitude temperatures are moderate. The weather is generally fair in the mid-latitudes. The stormiest weather is along 60°N.

Low Zonal Index

23. With a low zonal index, long-wave ridges and troughs are very steep (have great amplitude), and there are more of them. Cut-off centres are common. Short waves have larger amplitudes than normal and are a predominant feature of the 700-hPa chart. The Icelandic and Aleutian lows are weak, are split into two cells, and are oriented north-south. The Atlantic and Pacific subtropical highs are weak, split, oriented north-south, and are centreed farther south than normal. The polar highs merge and are strongly developed. Frontal systems are more common, with sharp temperature contrasts across them. The fronts are oriented north-south. Stormy weather is frequent in low latitudes, while high latitudes experience storm-free weather and mild temperatures.

Changing Zonal Index

24. Hemispheric weather patterns are, for the most part, always changing. As the pattern changes, so does the zonal index. A pattern change from a high-index situation to a low, or vice versa, is simply one of transition. It doesn't happen overnight. A changing index is one that is either increasing or decreasing. Increasing or decreasing indices are also based on the circulation and weather pattern.

25. **Increasing Zonal Index**. With an increasing zonal index, the number of long waves in the weather pattern decreases. Cut-off centres weaken. Migratory systems intensify and speed up, especially in higher latitudes, resulting in a more east-west orientation of associated frontal systems. The eastern cells of the Icelandic and Aleutian lows and subtropical highs weaken while moving eastward. The western cells of these systems move northeastward toward their normal positions. A polar high stagnates over the Great Basin.

26. **Decreasing Zonal Index**. With a decreasing zonal index, the number of long waves in the weather pattern increases. Cut-off centres are more likely to develop. Migratory systems slow down, especially in the higher latitudes. Frontal systems gradually shift from a east-west orientation to one that is more north-south. The Aleutian and Icelandic lows and subtropical highs move southward and begin to split. Polar highs intensify, and outbreaks of cold polar air into lower latitudes take place.

Jet Streams

27. Winds in the upper-level circulation pattern reach maximum speeds in narrow streams that meander in wavelike fashion above both hemispheres. By definition, when these streams of high-speed winds are thousands of miles long, hundreds of miles wide, and a few miles deep (vertical extent), they are termed jet streams. Jet streams are three-dimensional features. They have length, width and depth. Isotach analyses done on upper-level constant-pressure charts provide us with a view of two of the dimensions. They outline a jet stream's axis and show its width latitudinally and length horizontally.

28. These analyses also show that jets are not continuous around the globe; they stop, start, split, merge, and can exist side by side within a few hundred miles of one another or be thousands of miles apart. The third dimension (depth) is best determined from vertical wind profiles developed from wind information obtained from radiosonde, Rawinsonde, and Pilot reports. However, you can obtain a crude picture of a jet's depth by stacking upper-level charts. Three-dimensional studies also reveal a core of higher speed winds existing within each jet stream. The winds in the jet core differ from those elsewhere in the stream in that they are stronger and have a constant velocity. In other words, their direction and speed are unchanging. The importance of this is related to wind shear, experienced in and around jet streams. If there is no change in wind speed and direction in the core, there can be no wind shear there. Outside of the core, however, wind shear can be significant.

Consolidation Exercise on Task 19, 20 & 21

Q1. What is a streamline ?

Q2. What is an isotach ?

Q3. Which are the isopleths which complete the analysis of the field of motion ?

Q4. What is an isogon ?

Q5. According to V Bjerkens and C E Palmer what are names of the points where isogons meet ?

Q6. What is indicated by the streamlines tending to merge ?

Q7. The gradient concept employed in contour analysis is entirely inapplicable in streamline analdysis, why ?

Q8. The most exact means for determination of quantitiatve instantanwous horizontal divergence and vorticity are offere by ----------

Q9. What is the the wind speed at the singular point ?

Q10. Other speed ----------are found where the ----------have theri sharpest----------.

Q11. At what intervals isotachs are drawn ?

Answers to Consolidation Exercise on Task 19, 20 & 21

A1. This is a line which gives instantaneous wind direction.

A2. th line joining the places having same wind speed.

A3. Superimposing of the stremlines and isotachs complets the analysis of the filed of moition.

A4. An isogon is a line joining points of the same wind direction.

A5. According to V Bjerkens : Singlular points, critical points or nodal points. According to CE Palmer : Positive points “ for highs and “Negative Points” for lows and “Neutral Points: for Cols.

A6. When streamlines merge, fit merely indicates that the flow directions are rapidly changing for a given small area.

A7. the streamlines every where indicate the instananeous flow direction and do not indicate speed.

A8. Streamlines and isotachs.

A9. Wind speed is zero at these points.

A10. Minima, streamlines, curvature.

A11. For every 5 knots in Tropics and for every 10 knots as you approach the higher latitudes to avoid crowding of the isotachs.

Consolidation Exercise on Task 19, 20 & 21

Q1. From what layer the analysis of constant pressure charts starts ?

Q2. What is the second step in the process of CP charts analysis ?

Q3. How 850 mb chart is made ?

Q4. How contours of higher levels are drawn ?

Q5. How the addition of a thickness chart to a contour chart is done ?

Q6. How 1000 mb chart is produced ?

Q7. At what temperature interval isotherms are drawn ?

Q8. On which CP chart dew-point isopleths are drawn ?

Q9. 850 mb isotherms compares closely to what thickness pattern ?

Q10. To drawn isotherms on 500 mb chart what winds are used ?

Q11. What is Garvin's technique ?

Answers to consolidation Exercise on Task 19, 20 & 21

A1. From lowest layer ie from 1000 mb layer.

A2. Construction of various thickness charts ie 1000-850 mb, 850-750 mb, 700-500 mb etc.

A3. By adding 1000-850 mb thickness to 1000 mb contour obtain 850 mb chart.

A4. Contours are drawn in accordance with the reported winds and heights.

A5. This is done by the method of graphical addition.

A6. It is produced with the help of mean – sea – level pressure by using the relation between temperature, pressure and height. Contour interval is 20 gpm.

A7. At the intervals of 5°C.

A8. On 850 mb chart.

A9. 1000-700 mb thickness pattern.

A10. Shear winds between 15,000 feet and 20,000 feet are utilized.

A11. A very height correlation exists between temperatures at 500 mb and the thickness 500 – 300 mb.

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TASK – 22 : STABILITY AND INSTABILITY OF ATMOSPHERE

Introduction

1. The atmosphere has a tendency to resist vertical motion. This is known as stability. The normal flow of air tends to be horizontal. If this flow is disturbed, a stable atmosphere resists any upward or downward displacement and tends to return quickly to normal horizontal flow. An unstable atmosphere, on the other hand, allows these upward and downward disturbances to grow, resulting in rough (turbulent) air. An example is the towering thunderstorm that grows as a result of a large intense vertical air current.

2. Atmospheric resistance to vertical motion (stability), depends upon the vertical distribution of the air's weight at a particular time. The weight varies with air temperature and moisture content. As shown in figure 1.4, in comparing two parcels of air, hotter air is lighter than colder air; and moist air is lighter than dry air. If air is relatively warmer or more moist than it's surroundings, it is forced to rise and is unstable. If the air is colder or dryer than its surroundings, it sinks until it reaches its equilibrium level and is stable. The atmosphere can only be at equilibrium when light air is above heavier air-just as oil poured into water rises to the top to obtain equilibrium. The stability of air depends a great deal on temperature distribution and to a lesser extent on moisture distribution. Since the temperature of air is an indication of its density, a comparison of temperatures from one level to another can indicate how stable or unstable a layer of air might be—that is, how much it tends to resist vertical motion.

The Adiabatic Process

3. The adiabatic process is the process by which a gas, such as air, is heated or cooled, without heat being added to or taken away from the gas, but rather by expansion and compression. In the atmosphere, adiabatic and nonadiabatic processes are taking place continuously. The air near the ground is receiving heat from or giving heat to the ground. These are nonadiabatic processes.

4. However, in the free atmosphere somewhat removed from Earth's surface, the short-period processes are adiabatic. When a parcel of air is lifted in the free atmosphere, pressure decreases. To equalise this pressure, the parcel must expand. In expanding, it is doing work. In doing work, it uses heat. This results in a lowering of temperature as well as a decrease in the pressure and density. When a parcel of air descends in the free atmosphere, pressure increases. To equalise the pressure, the parcel must contract. In doing this, work is done on the parcel. This work energy, which is being added to the parcel, shows up as an increase in temperature. The pressure and density increase in this case also.

Terms

5. In discussing the adiabatic process several terms are used that you should understand.

6. **Lapse Rate**. In general, lapse rate is the rate of decrease in the value of any meteorological element with elevation. However, it is usually restricted to the rate of decrease of temperature with elevation; thus, the lapse rate of the temperature is synonymous with the vertical temperature gradient. The temperature lapse rate is usually positive, which means that the temperature decreases with elevation.

7. **Inversion.** Inversions describe the atmospheric conditions when the temperature increases with altitude, rather than decreases as it usually does. Inversions result from the selective absorption of Earth's radiation by the water vapour in the air, and also from the sinking, or subsidence, of air, which results in its compression and, therefore, heating. Either effect alone may cause an inversion; combined, the inversion is stronger.

8. When air is subsiding (sinking), the compressed air heats. This frequently produces a subsidence inversion. When subsidence occurs above a surface inversion, the surface inversion is intensified. Such occurrences are common in wintertime high-pressure systems. The air in the inversion layer is very stable, and the cold air above the inversion acts as a lid trapping fog, smoke, and haze beneath it. Poor visibility in the lower levels of the atmosphere results, especially near industrial areas.

9. An inversion is a frequent occurrence (especially at night) in the Tropics and in the Polar regions. For night conditions all over the world, polar and tropical regions included, it may be said that low-level inversions are the rule rather than the exception.

10. **Isothermal**. In the isothermal lapse rate, no cooling or warming is noted and the rate is neutral with height—no change in temperature with height.

Adiabatic Heating and Cooling

11. Air is made up of a mixture of gases that is subject to adiabatic heating when it is compressed and adiabatic cooling when it is expanded. As a result, air rises seeking a level where the pressure of the body of air is equal to the pressure of the air that surrounds it. There are other ways air can be lifted, such as through the thermodynamic processes of a thunderstorm or mechanically, such as having colder, denser air move under it or by lifting as it flows up over a mountain slope.

12. As the air rises, the pressure decreases allowing the parcel of air to expand. This continues until it reaches an altitude where the pressure and density are equal to its own. As it expands, it cools through a thermodynamic process in which there is no transfer of heat or mass across the boundaries of the system in which it operates (adiabatic process). As air rises, it cools because it expands by moving to an altitude where pressure and density is less. This is called adiabatic cooling.

13. When the process is reversed and air is forced downward, it is compressed, causing it to heat. This is called adiabatic heating. (See fig. 1.1) Remember, in an adiabatic process an increase in temperature is due only to compression when the air sinks or subsides. A decrease in temperature is due only to expansion when air rises, as with convective currents or air going over mountains. There is no addition or subtraction of heat involved. The changes in temperature are due to the conversion of energy from one form to another.

Lapse Rates

14. Earlier it was shown that temperature usually decreases with altitude and that the rate at which it decreases is called the lapse rate. The lapse rate, commonly expressed in degrees Fahrenheit per 1,000 feet, gives a direct measurement of the atmosphere's resistance to vertical motion. The degree of stability of the atmosphere may vary from layer to layer as indicated by changes of lapse rate with height. (See table 1.1 and fig. 1.4)

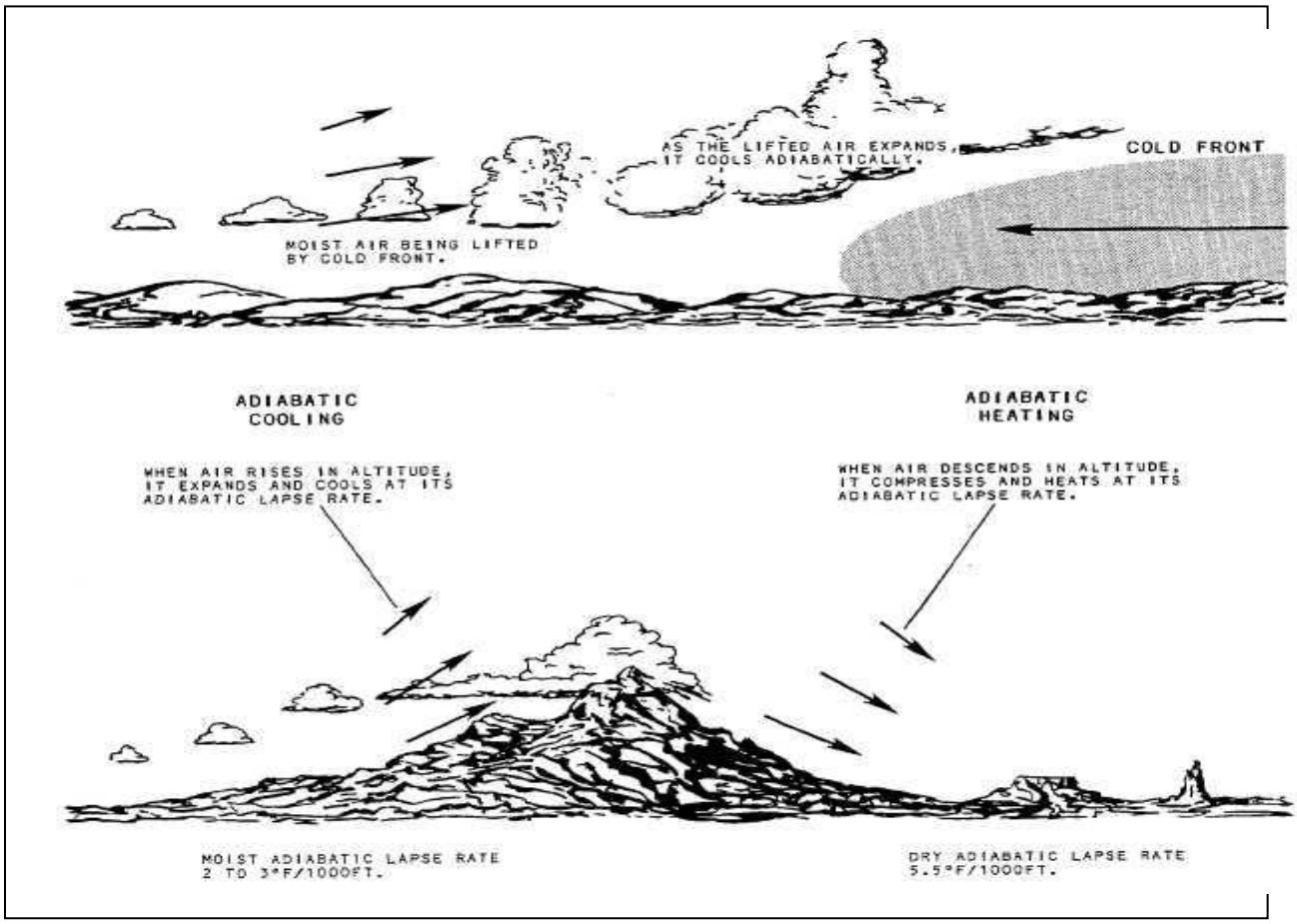


Fig 1.1 Adiabatic cooling and heating process

15. **Dry Adiabatic Lapse Rate**. If a parcel of air is lifted, its pressure is decreased, since pressure decreases with height, and its temperature falls due to the expansion. If the air is dry and the process is adiabatic, the rate of temperature fall is 1°C per 100 metres of lift (10°C per km), or 5½°F per 1,000 feet of lift. If that parcel descends again to higher pressure, its temperature then increases at the rate of 1°C per 100 metres or 5½°F per 1,000 feet. This is known as the dry adiabatic lapse rate.

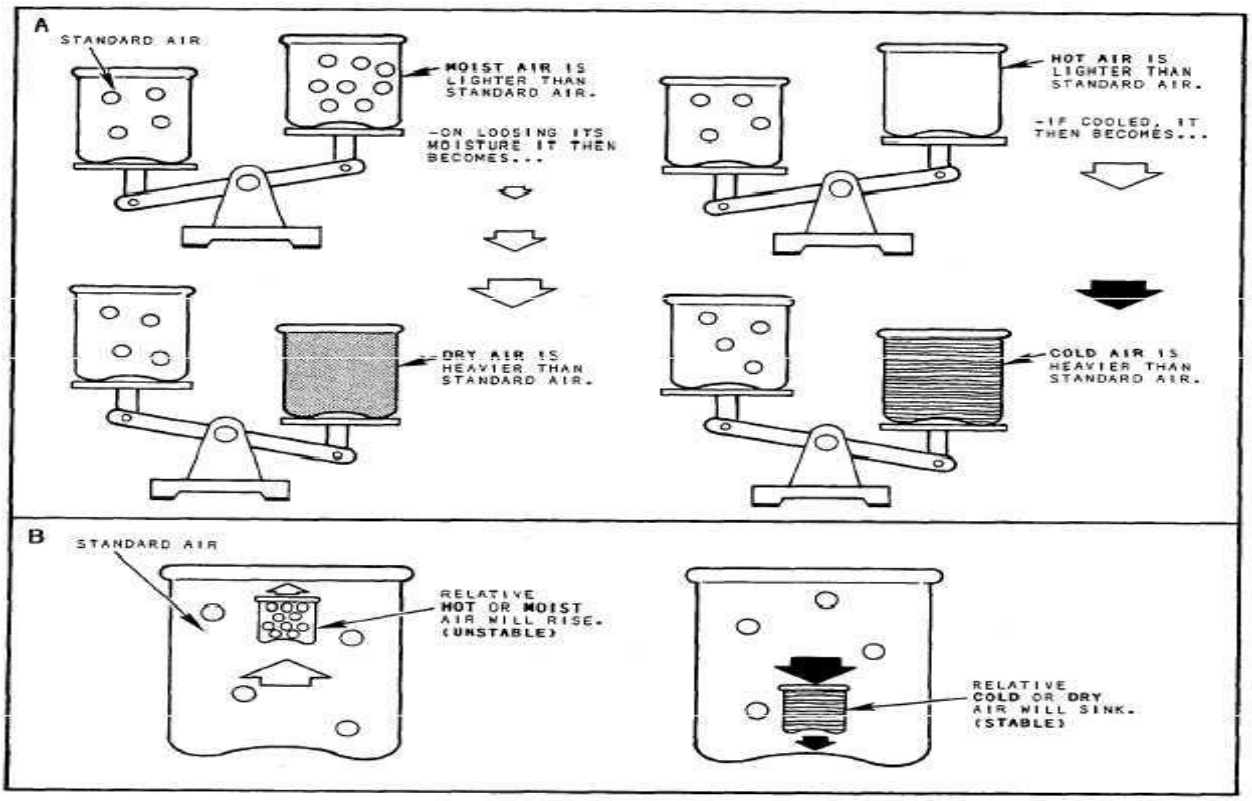


Fig 1.2 Moisture content and temperature determines weight of air

Table 1.1 Lapse Rates of Temperature

Lapse Rate	Per 1000 ft	Per 100 meters
Dry adiabatic	5½ ºF	1 ºC
Saturation (moist) adiabatic	2.3 ºF	0.55 ºC
Average	3.3 ºF	0.65 ºC
Superadiabatic	5½ - 15ºF	1 – 3.42 ºC
Autoconvective	More than 15ºF	More than 3.42ºC

Moist (Saturation) Adiabatic Lapse Rate.

16. When a mass of air is lifted, it cools at the dry adiabatic lapse rate of 5½°F per 1,000 feet as long as it remains unsaturated (relative humidity below 100 percent). If the original moisture is being carried along with the mass as it ascends and it cools to its saturation temperature, the relative humidity reaches 100 percent. Condensation takes place with further cooling. For each gram of water condensed, about 597 calories of heat are liberated. This latent heat of condensation is absorbed by the air, and the adiabatic cooling rate is decreased to 2° to 3°F per 1,000 feet instead of 5½°F per 1,000 feet. The process during the saturated expansion of the air is called the saturation adiabatic, the moist adiabatic, or the pseudoadiabatic process. The pseudoadiabatic process assumes that moisture falls out of the air as soon as it condenses.

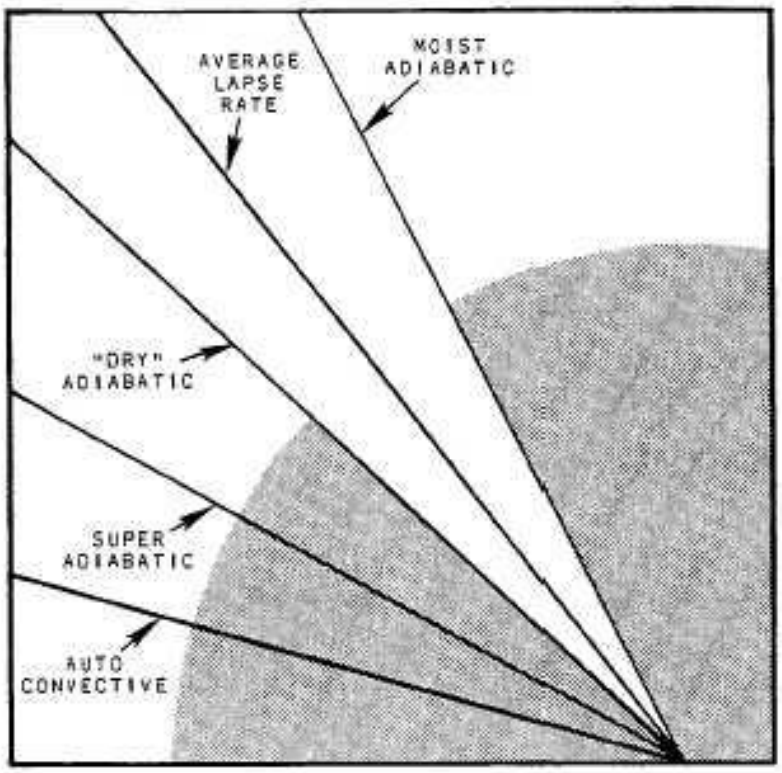


Fig 1.3 Adiabatic Lapse Rates

17. How the temperature of a parcel of air changes in response to these processes was illustrated in chapter 1 and because of its importance, it is illustrated again now. Assume that a saturated parcel of air having a temperature of 44°F is at 5,000 feet and is forced over a 12,000-foot mountain. Condensation occurs from 5,000 to 12,000 feet so that the parcel cools at the moist adiabatic rate (3°F per 1,000 ft) and reaches a temperature of approximately 23°F at the top of the mountain. Assuming that the condensation in the form of precipitation has fallen out of the air during the ascent, the parcel heats at the dry adiabatic rate as it descends to the other side of the mountain. When it reaches the 5,000-foot level, the parcel has descended 7,000 feet at a rate of 5½°F per 1,000 feet. This results in an increase of 38.5°F. Adding the 38.5°F increase to the original 12,000 feet temperature of 23°F, the parcel has a new temperature of 61.5°F.

18. **Average Adiabatic Lapse Rate.** The average lapse rate lies between the dry adiabatic and the moist adiabatic at about 3.3°F per 1,000 feet.

19. **Superadiabatic Lapse Rate**. The super-adiabatic lapse rate is a decrease in temperature of more than 5½°F per 1,000 feet and less than 15°F per 1,000 feet.

20. **Autoconvective Lapse Rate**. The autoconvective lapse rate is the decrease of more than 15°F per 1,000 feet. This lapse rate is rare and is usually confined to shallow layers.

Types of Stability

21. In figure 2.9 a bowl is set on a flat surface with a ball placed inside it. The ball rests in the bottom of the bowl; but, if you push the ball in any direction, it seeks out the bottom of the bowl again. This is referred to as absolute stability (fig. 1.4). Turn the bowl upside down, position the ball anywhere on the bowl's bottom surface (fig. 1.4) and the ball starts moving on its own without any other force being applied. This is a condition of absolute instability. If you now remove the bowl and place the ball on the flat surface (fig. 1.4), you have neutral stability - that is, if a force is applied to the ball, it moves; but if the force is removed, the ball stops. Air in the atmosphere reacts in a similar manner when moved up or down. If it is moved up and becomes more dense than the surrounding air, it returns to its original position and is considered stable. If it becomes less dense than the surrounding air, it continues to rise and is considered unstable. When density remains the same as the surrounding air after being lifted, it is considered neutrally stable, with no tendency to rise or sink.

Equilibrium of Dry Air

22. The method used for determining the equilibrium of air is the parcel method, wherein a parcel of air is lifted and then compared with the surrounding air to determine its equilibrium. The dry adiabatic lapse rate is always used as a reference to determine the stability or instability of dry air (the parcel).

23. **Absolute Instability**. Consider a column of air in which the actual lapse rate is greater than the dry adiabatic lapse rate. The actual lapse rate is to the left of the dry adiabatic lapse rate on the Skew-T diagram (fig. 1.5). If the parcel of air at point A is displaced upward to point B, it cools at the dry adiabatic lapse rate. Upon arriving at point B, it is warmer than the surrounding air. The parcel therefore has a tendency to continue to rise, seeking air of its own density. Consequently the column becomes unstable. From this, the rule is established that if the lapse rate of a column of air is greater than the dry adiabatic lapse rate, the column is in a state of absolute instability. The term absolute is used because this applies whether the air is dry or saturated, as is evidenced by displacing upward a saturated parcel of air from point A along a saturation adiabat to point B. The parcel is more unstable than if displaced along a dry adiabat.

24. **Stability**. Consider a column of dry air in which the actual lapse rate is less than the dry adiabatic lapse rate. The actual lapse rate is to the right of the dry adiabatic lapse rate on the Skew-T diagram (fig. 1.6). If the parcel at point A were displaced upward to point B, it would cool at the dry adiabatic lapse rate; and upon arriving at point B, it would be colder than the surrounding air. It would, therefore, have a tendency to return to its original level. Consequently, the column of air becomes stable. From this, the rule is established that if the actual lapse rate of a column of dry air is less than the dry adiabatic lapse rate, the column is stable.

25. **Neutral Stability**. Consider a column of dry air in which the actual lapse rate is equal to the dry adiabatic lapse rate. The parcel cools at the dry adiabatic lapse rate if displaced upward. It would at all time be at the same temperature and density as the surrounding air. It also has a tendency neither to return to nor to move farther away from its original position. Therefore, the column of dry air is in a state of neutral stability.

Equilibrium of Saturated Air

26. When saturated air is lifted, it cools at a rate different from that of dry air. This is due to release of the latent heat of condensation, which is absorbed by the air. The rate of cooling of moist air is known as the saturation adiabatic lapse rate. This rate is used as a reference for determining the equilibrium of saturated air.

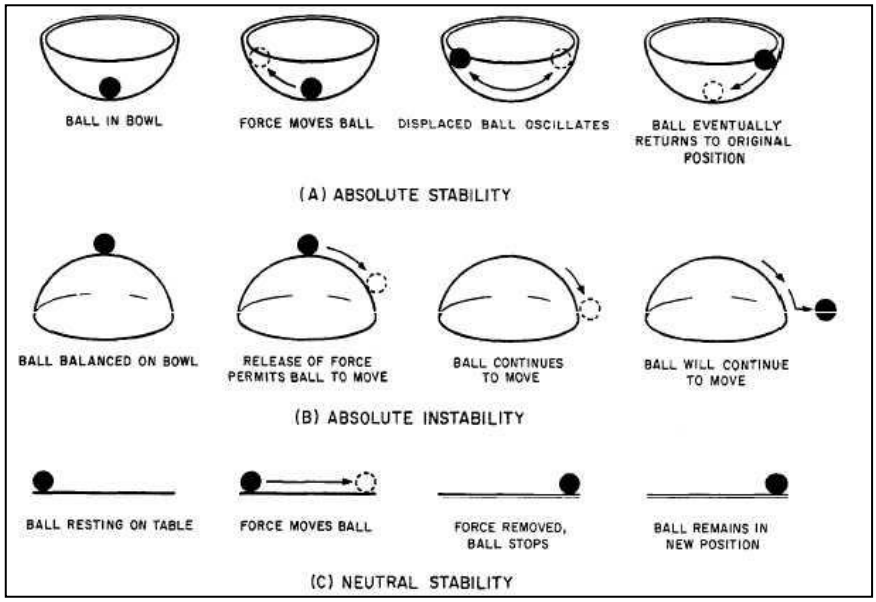


Fig 1.4 Analogy depiction of stability

27. **Absolute Stability**. Consider a column of air in which the actual lapse rate is less than the saturation adiabatic lapse rate. The actual lapse rate is to the right of the saturation adiabatic lapse rate on the Skew T diagram (fig. 1.5). If the parcel of saturated air at point A is displaced upward to point B, it cools at the saturation adiabatic lapse rate. The air upon arriving at point B becomes colder than the surrounding air. The layer, therefore, would be in a state of absolute stability. From this, the following rule is established: If the actual lapse rate for a column of air is less than the saturation adiabatic lapse rate, the column is absolutely stable and the parcel would return to its original position. Dry air cools dry adiabatically and is also colder than the surrounding air. Therefore, this rule applies to all air, as is evidenced when an unsaturated parcel of air is displaced upward dry adiabatically to point B. Here, the parcel is more stable than the parcel displaced along a saturation adiabat.

28. **Instability**. Consider now a column of air in which the actual lapse rate is greater than the saturation adiabatic lapse rate (fig. 1.8). If a parcel of moist air at point A is displaced upward to point B, it cools at the saturation adiabatic lapse rate. Upon arriving at point B the parcel is then warmer than the surrounding air. For this reason, it has a tendency to continue moving farther from its original position. The parcel, therefore, is in a state of instability.

29. The following rule is applicable. If the actual lapse rate for a column of saturated (moist) air is greater than the saturation adiabatic lapse rate, the column is unstable.

30. **Neutral Stability**. Consider a column of saturated air in which the actual lapse rate is equal to the saturation adiabatic lapse rate. A parcel of air displaced upward cools at the saturation adiabatic lapse rate and is at all times equal in temperature to the surrounding air. On that account, it tends neither to move farther away from nor to return

to its original level. Therefore, it is in a state of neutral stability. The rule for this situation is that if the actual lapse rate for a column of saturated air is equal to the saturation adiabatic lapse rate, the column is neutrally stable.

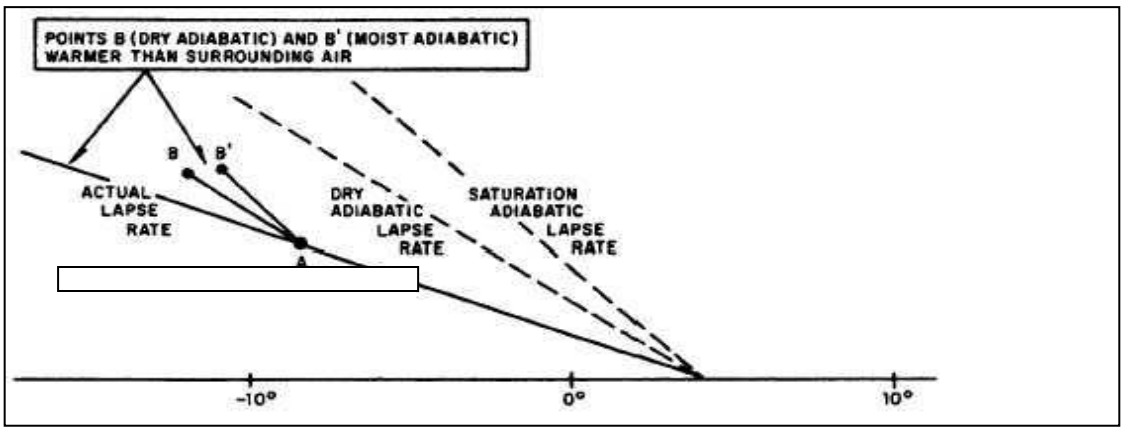


Fig 1.5 Absolute instability (any degree of saturation)

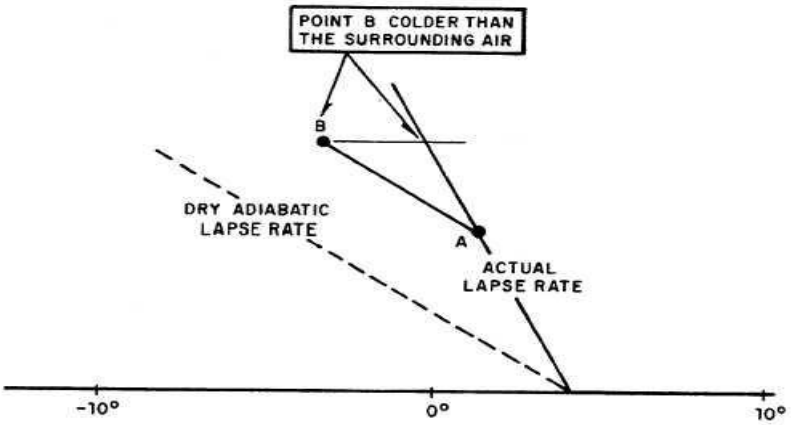


Fig 1.6 Stability (dry air)

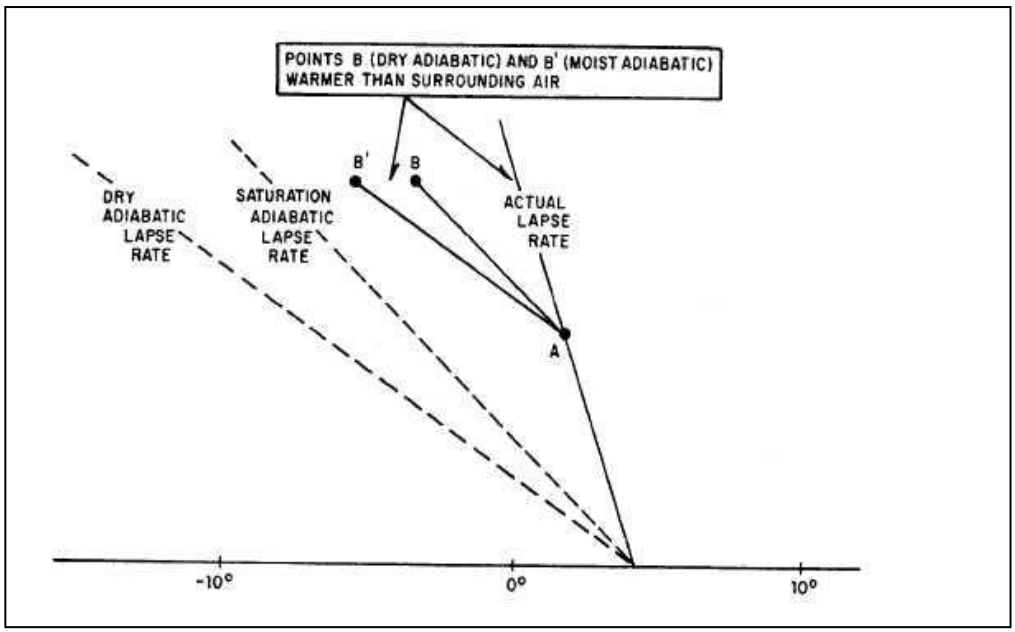


Fig 1.7 Absolute stability (any degree of saturation)

Conditional Instability

31. In the treatment of stability and instability so far, only air that was either dry or saturated was considered. Under normal atmospheric conditions natural air is unsaturated to begin with, but becomes saturated if lifted high enough. This presents no problem if the actual lapse rate for the column of air is greater than the dry adiabatic lapse rate (absolutely unstable) or if the actual lapse rate is less than the saturation adiabatic lapse rate (absolutely stable). However, if the lapse rate for a column of natural air lies between the dry adiabatic lapse rate and the saturation adiabatic lapse rate, the air may be stable or unstable, depending upon the distribution of moisture. When the actual lapse rate of a column of air lies between the saturation adiabatic lapse rate and the dry adiabatic lapse rate, the equilibrium is termed conditional instability, because the stability is conditioned by the moisture distribution. The equilibrium of this column of air is determined by the use of positive and negative energy areas as analysed on a Skew-T, Log P diagram. The determination of an area as positive or negative depends upon whether the parcel is being lifted mechanically (by a front or orographic barriers) or by convective means and whether the environment is colder or warmer than the ascending parcel. Positive areas are conducive to instability. Negative areas are conducive to stability.

32. **Types of Conditional Instability**. Conditional instability may be one of three types. The real latent type is a condition in which the positive area is larger than the negative area (potentially unstable). The pseudo-latent type is a condition in which the positive area is smaller than the negative area (potentially stable). The stable type is a condition in which there is no positive area. Fig shows an example of analysed positive and negative energy areas as they would appear on a Skew T- Log P diagram.

Autoconvection

33. Auto-convection is a condition started spontaneously by a layer of air when the lapse rate of temperature is such that density increases with elevation. For density to increase with altitude, the lapse rate must be equal to or exceed 3.42°C per 100 meters. (This is the auto-convective lapse rate.) An example of this condition is found to exist near the surface of the earth in a road mirage or a dust devil. These conditions occur over surfaces that are easily heated, such as the desert, open fields, etc.; they are usually found during periods of intense surface heating.

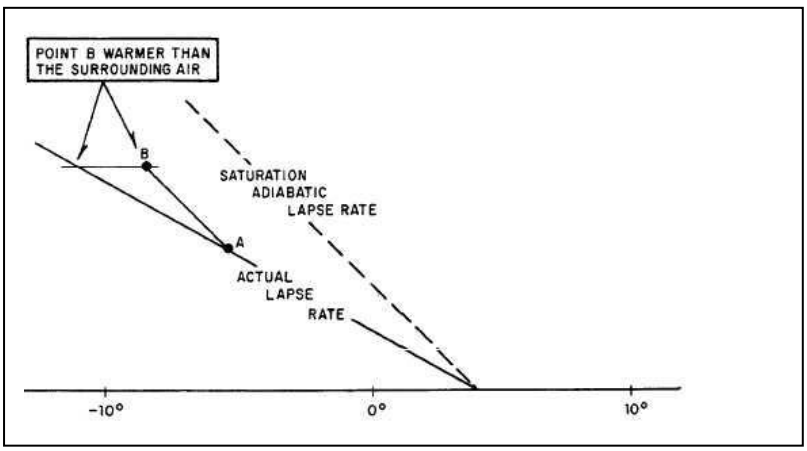


Fig 1.8 Instability (saturated air)

Convection Stability and Instability

34. In the discussion so far of convection stability and instability, parcels of air have been considered. Let us now examine layers of air. A layer of air that is originally stable may become unstable due to moisture distribution if the entire layer is lifted.

35. Convective stability is the condition that occurs when the equilibrium of a layer of air, because of the temperature and humidity distribution, is such that when the entire layer is lifted, its stability is increased (becomes more stable). Convective instability is the condition of equilibrium of a layer of air occurring when the temperature and humidity distribution is such that when the entire layer of air is lifted, its instability is increased (becomes more unstable).

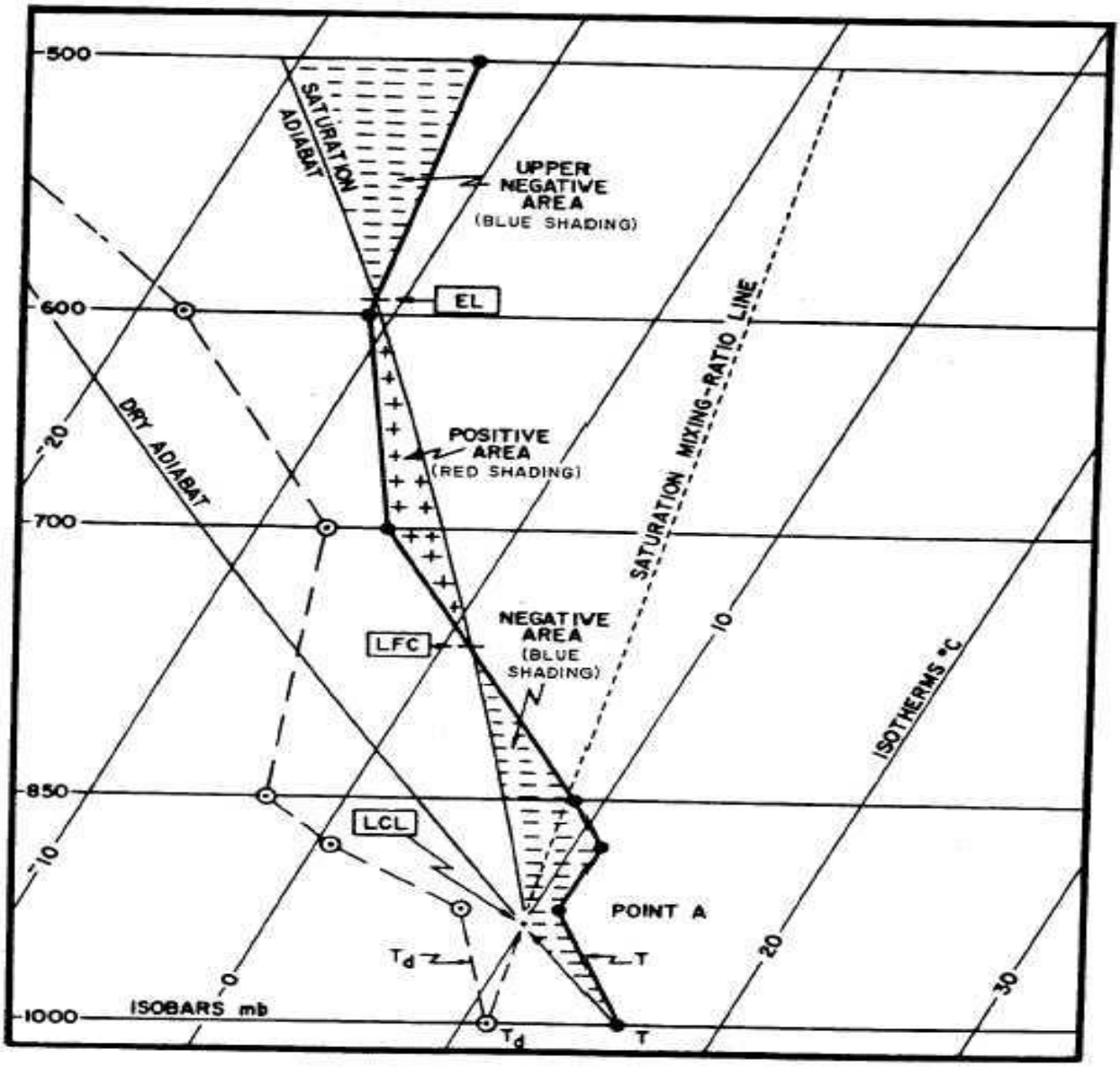


Fig 1.9 Example of positive and negative energy areas (mechanical lifting)

36. **Convective Stability**. Consider a layer of air whose humidity distribution is dry at the bottom and moist at the top. If the layer of air is lifted, the top and the bottom cool at the same rate until the top reaches saturation. Thereafter, the top cools at a slower rate of speed than the bottom. The top cools saturation adiabatically (0.55°C per 100 meters), while the bottom continues to cool dry adiabatically (1°C per 100 meters). The lapse rate of the layer then decreases; hence, the stability increases. The layer must be initially unstable and may become stable when lifting takes place.

37. **Convective Instability**. Consider a layer of air in which the air at the bottom is moist and the air at the top of the layer is dry. If this layer of air is lifted, the bottom and the top cool dry adiabatically until the lower portion is saturated. The lower part then cools saturation adiabatically while the top of the layer is still cooling dry adiabatically. The lapse rate then begins to increase and instability in-creases. To determine the convective stability or instability of a layer of air, you should first know why you expect the lifting of a whole layer. The obvious answer is an orographic barrier or a frontal surface. Next, determine how much lifting is to be expected and at what level it commences. Lifting of a layer of air close to the surface of the Earth is not necessary. The amount of lifting, of course, depends on the situation at hand. Fig illustrates the varying degrees of air stability that are directly related to the rate at which the temperature changes with height.

Determining Bases of Convective Type Clouds

38. You have seen from our foregoing discussion that moisture is important in determining certain stability conditions in the atmosphere. You know, too, that the difference between the temperature and the dewpoint is an indication of the relative humidity. When the dewpoint and the temperature are the same, the air is saturated and some form of condensation cloud may be expected. This lends itself to a means of estimating the height of the base of clouds formed by surface heating when the surface temperature and dewpoint are known. You know that the dewpoint decreases in temperature at the rate of 1°F per 1,000 feet during a lifting process. The ascending parcel in the convective current experiences a decrease in temperature of about 5½°F per 1,000 feet. Thus the dewpoint and the temperature approach each other at the rate of 4½°F per 1,000 feet. As an example, consider the surface temperature to be 80°F and the surface dewpoint 62°F, a difference of 18°F. This difference, divided by the approximate rate the temperature approaches the dewpoint (4½°F per 1,000 ft) indicates the approximate height of the base of the clouds caused by this lifting process (18 ÷ 4½) x 1000 = 4,000 feet). This is graphically shown in fig.

39. This method cannot be applied to all cloud types. It is limited to clouds formed by convection currents, such as summertime cumulus clouds, and only in the locality where the clouds form. It is not valid around maritime or mountainous areas.

Stability in Relation to Cloud Type

40. The degree of stability of the atmosphere helps to determine the type of clouds formed. For example, fig shows that if *stable* air is forced to ascend a mountain slope, clouds will be layer like with little vertical development and little or no turbulence. *Unstable air,* if forced to ascend the slope, causes considerable vertical development and turbulence in the clouds. The base of this type of cloud can be determined by mechanical lifting as analysed on a Skew-T.

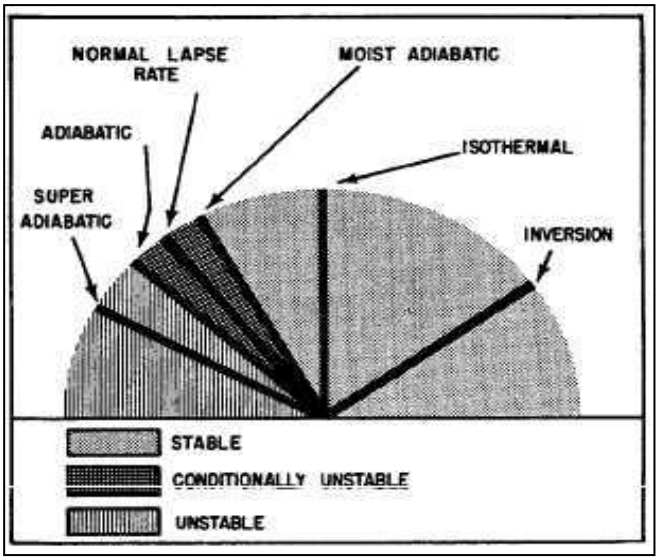


Fig 1.10 Degrees of stability in relation to temperature changes with height

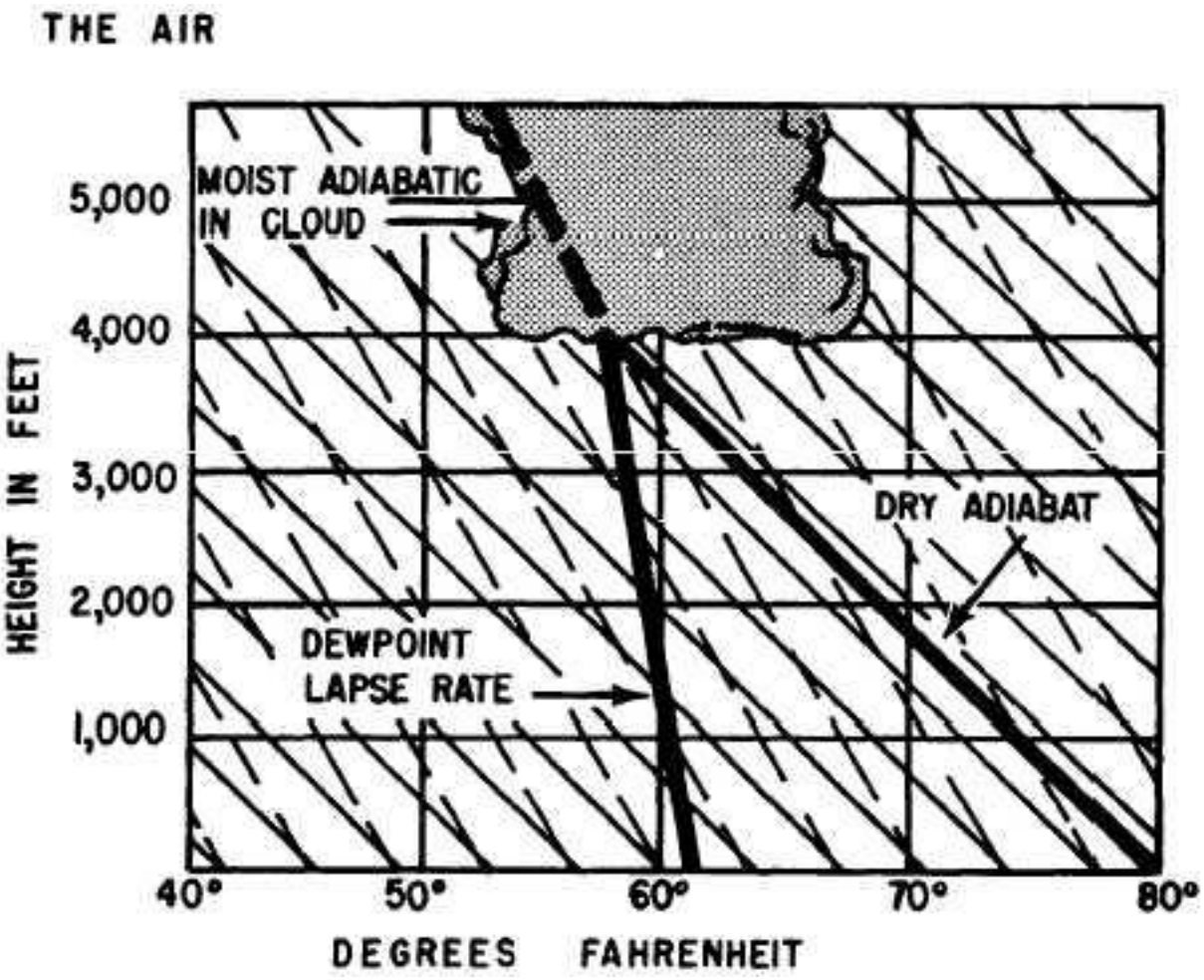


Fig 1.11 Determination of cloud's base when the dewpoint & temperature are known

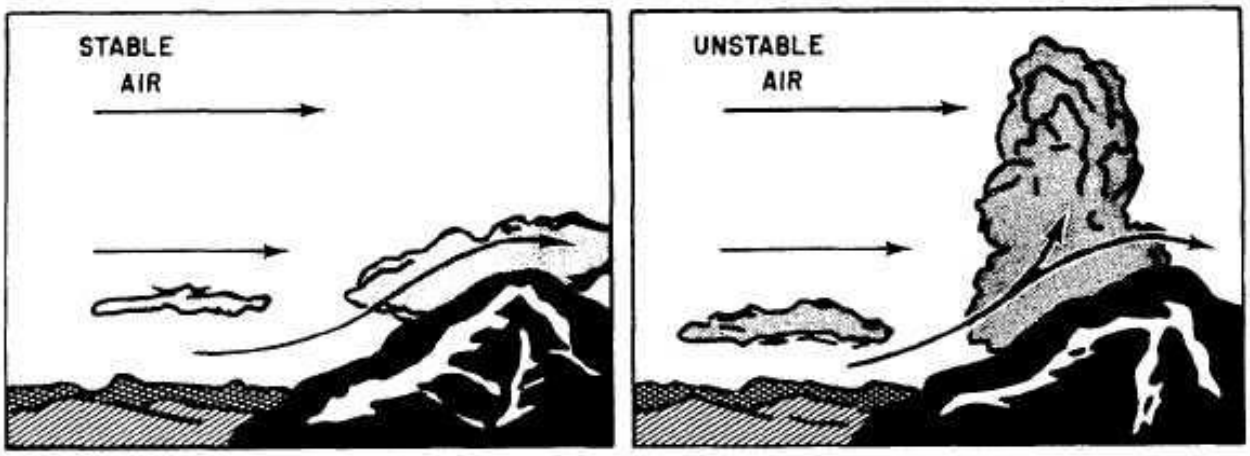


Fig 1.12 Illustration showing that very stable air retains its stability ever when it is forced upward, forming a flat cloud. Air which is potentially unstable when forced upward becomes turbulent and forms a towering cloud

TASK – 23 : TEPHIGRAM ANALYSIS

After reading this chapter you should be able to

- Understand the thermodynamic diagrams.
- Understand the determination of Derived Elements from T- Ø gram.
- Understand the analysis of vertical time section.

Introduction

1. There was a time when forecasters in Bangladesh and other countries had only surface air data to guide them, supplemented occasionally by some hydro-meteorological and nephoscopic observations. A notable advance was the introduction of pilot balloon observations that provided the forecaster with additional information regarding the horizontal currents in the upper air. Subsequently, with the advent of radiosonde observations (aerological data) the Indian Meteorology entered a new epoch in the early part of the last century.

2. A thermodynamic diagram is a convenient grid for the representation of these aerological data. A proper diagram should lend itself for the easy and quick deduction of those significant elements of the air mass - the basic data (potential temperature, entropy, specific humidity, mixing ratio, equivalent temperature, solenoids, etc.), which are to guide the forecaster in the art of weather analysis and forecasting. One of the aerological diagrams, which has found extensive application and has been adopted in the Indian Scenario, is the Tephigram.

3. Vertical cross-sections of the atmosphere, similar to horizontal sections of the atmosphere which we normally analyse, provide us with the vertical perspective. These help us to appreciate better three-dimensional and even the horizontal structure of the atmosphere. One of the principal advantages of such diagrams is that they bring out the tropopause structure very clearly.

Thermodynamic Diagrams

4. A thermodynamic diagram is a chart or graph on which isopleths of various thermodynamic variables (pressure, temperature, water vapor) or their functions are drawn such that equation of state, Clausins-Claeyron equation and the first law of thermodynamics for adiabatic and saturation or pseudo-adiabatic processes are satisfied. The thermodynamic diagrams used in meteorological offices represent energy by area and are basically used to represent graphically the effect of the processes which a parcel of air may be subjected to. These processes act as major controls on the weather and are of fundamental importance in the formation of clouds, fog and other condensation processes.

Energy and Thermodynamic Diagrams

5. Thermodynamic diagrams have the inherent requirement of representing energy by area and are therefore transformations of α - p diagrams the characteristic curve of a gas, subjected to a thermo dynamical process and brought back to its original state is represented by a closed curve on such a diagram. The area enclosed by this curve is directly proportional to the energy given out or absorbed by the gas during the cycle. Because of this characteristic, such diagrams are also known as *energy diagrams.* A suitable diagram is the T –*Ø gram*

Co-Ordinate System Of *T- Ø* Gram

6. The T Ø gram has been named as such because the co-ordinates are temperature (T) and entropy (Ø). The diagram comprises of a grid of isopleths of temperature, pressure, saturation_Ratio, potential temperature (dry-adiabats) and wet-bulb potential temperature (wet or saturated adiabats). The lines of the T Ø gram are shown on fig 2.1.

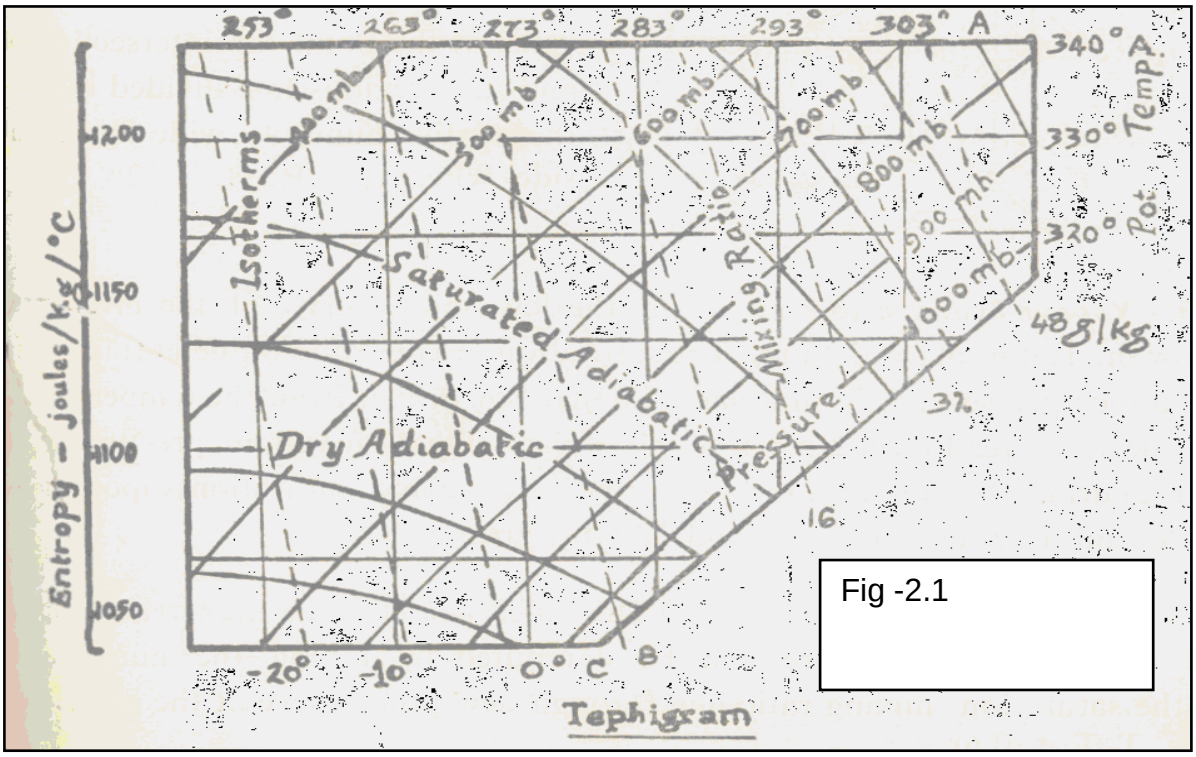


Fig -2.1

Fig 2.1 Tephigam

Normand Theorem

7. For many purposes it is necessary to know the variation of the wet bulb temperature along the vertical. Wet bulb temperature can be calculated from the values of temperature and dew point temperature by means of tables. However, the Tephigram provides a simple graphical method of determining the wet bulb temperature at any level. This method is based on a celebrated theorem formulated by Sir Charles Normand who was former Director General of Observatories in India. It states that if we produce the dry adiabat from the dry bulb temperature, the saturated adiabat from the wet bulb temperature and the iso-hygric from the dew-point, all three meet at a point called LCL or “Normand point” and the line joining such points is the Normand Curve. This curve is conservative with respect to evaporation, condensation, adiabatic descent and ascent of a parcel of air. It is also useful in distinguishing frontal inversions from subsidence and

radiation inversions. The frontal inversion becomes conspicuous in the condensation curve whereas the curve remains rather unaffected with subsidence and radiation inversions. It is also useful in tracing the thermal history of an air mass and identifying layers where convergence and divergence have taken place.

Graphical Method of Determining Wet Bulb Temperature

8. The graphical method referred to above follows easily from the theorem: “Draw the dry adiabat from the plotted temperature point and the isohygric the plotted dew-point at the given pressure level. From the point where two meet, follow the saturated adiabat towards higher pressure until the given pressure level is reached. The temperature at which this saturated adiabat cuts the initial pressure line is the wet bulb temperature at the level”. Actual practice the lines required for determining the Normand point are first drawn lightly in pencil and then erased after the wet bulb temperature has been determined. After some experience is gained the wet bulb temperature can also be located by inspection without actually drawing the lines.

9. Points representing the wet bulb temperature are joined by a continuous red curve. This curve is intermediate between the temperature curve and the dew-point curve; all three coincide when the relative humidity of the layer is 100%.

Determination of Temperature at Different Heights

10. One of the important uses of the Tephigram is the determination of temperature at any required height. This is done by a process of simple interpolation between the appropriate pair of consecutive plotted points against which heights above sea level are indicated in meters. A simplified example is given here. Let us assume that on a plotted Tephigram two of the consecutive plotted points are at 3000 meters and 5000 meters *asl* at which the temperature are +8°C and +2°C respectively. If the temperature at 4000 meters asl is required, it is easily determined by simple interpolation mentally as +5^{0}C. In actual practice the reported heights are not in such round figures and arithmetical calculation may become necessary.

11. For purposes of flight forecasts for cross country flying the temperatures are required in respect of pressure altitudes (flight levels) and not in respect of actual altitudes. These are easier to determine from a plotted Tephigram. As an example, let us assume that the temperature at flight level 25,000 ft is to be determined. Now flight level 25000 ft is the same as pressure altitude 25,000 ft. The latter corresponds to a pressure of 376 hpa as can be seen from tables of the ISA. From the plotted Tephigram on which the temperature curve is drawn the temperature at which this curve intersects the pressure line for 376 hpa is easily determined.

12. It may be mentioned that temperatures determined in this way may differ by more than 2 to 3°C from those determined for identical values of actual altitudes, especially at higher levels. These differences arise because the pressure altitude is rarely equal to the actual altitude. For certain types of jet aircraft temperature errors of this order may lead to incorrect settings of rpm and consequent flame-out of engines in flight. Hence, for purposes of aviation reports and forecast temperatures are to be determined from a Tephigram with reference to pressure altitudes only. Table of the ISA should be readily available for this purpose

Determination of Levels at which Specified Temperatures Occur

13. For many purposes it is necessary to know the level at which a specified temperature occurs. This is found out by the reverse of methods explained above. Thus, to find out the flight level at which the temperature is say, 0°C find out from the Tephigram the pressure at which this temperature occurs. Then by reference to tables of ISA, find out the pressure altitude corresponding to this pressure.

14. Height bands in which there is potential hazard of air-frame icing can be determined in this way. It must be remembered that free air temperature determined in this way are useful in pre-flight planning, but in actual flight the indication of OAT gauge are more reliable.

Determination of Altimeter correction or 'Alticor'

15. The Tephigram can be used to calculate the correction that has to be applied to the indicated altitude (ie altitude indicated by an ICAN altimeter whose subscale is set to 1013.2 hpa) to obtain true altitude when an aircraft is flying at any flight level in the vicinity of the station. As an example if the aircraft is flying at flight level (ie indicated altitude) 38, 000ft, it is seen from tables of the ISA that this corresponds to a pressure of 200 hpa. From the current plotted Tephigram of the station the true altitude corresponding to the pressure of 200 hpa is extracted. The altimeter correction can then be computed easily as difference in the values of true altitude and indicated altitude. "Alticor" can also be computed in a similar way.

Determination of the Tropopause

16. For tropical stations the tropopause easily shows up on a Tephigram by a sharp change from a fairly steep lapse rate to an inversion at fairly high levels (above 50,000 ft ie 150 mb). The level at which this sharp change occurs can be located in terms of pressure, pressure altitude or equal altitude.

17. For stations in sub tropical latitudes eg Delhi in winter, the Tephigram may show, two types of tropopauses. The lower one which is at about 40000- 45,000 ft is not sharp. There is no inversion but only a marked decrease in lapse rate. The, higher tropical type of tropopause with an inversion may show up at some higher level.

Determination of Derived Element from T- Ø gram.

18. **Mixing Ratio and Saturation Mixing Ratio (w /w_s).** The isohygric correspon-ding to the dew point temperature gives the mixing ratio (w) and that corresponding to the dry bulb temperature gives the saturated mixing ratio (ws) for the parcel illustrated in the fig 2.2, Mixing Ratio (w) is 8.75 g/kg and Saturation Mixing Ratio (ws) is 17.5 g/kg.

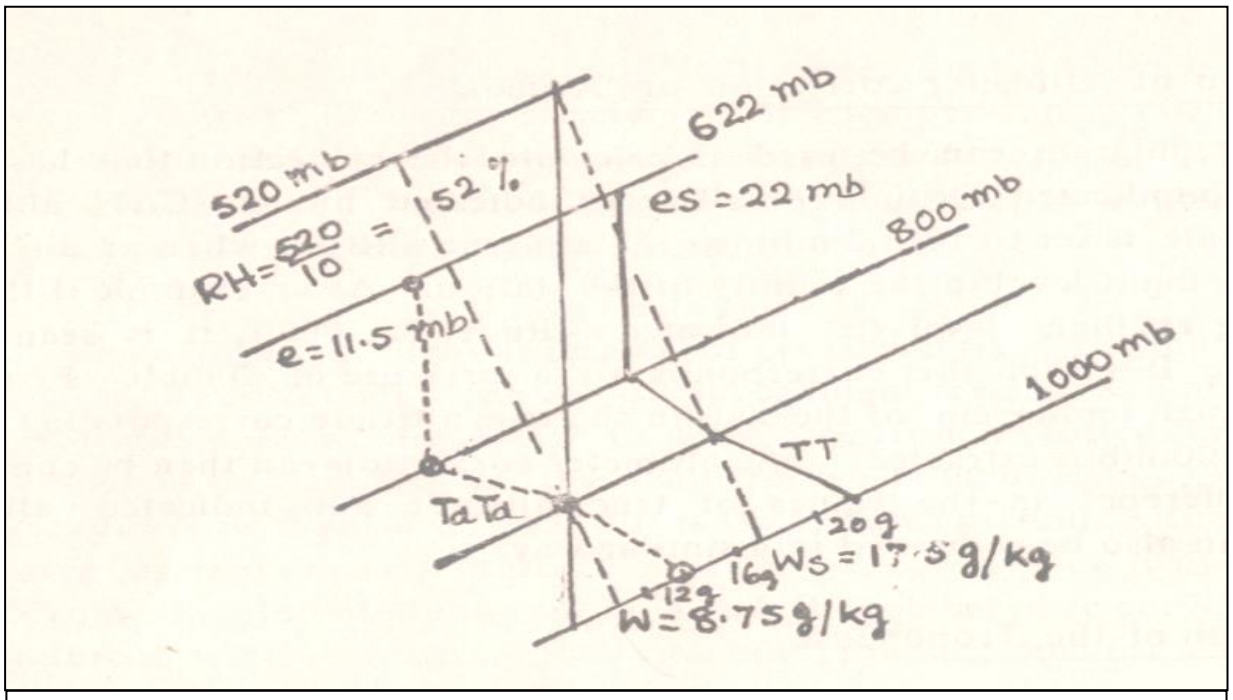


Fig- 2.2

19. **Relative Humidity (RH).** This can be calculated either from the ratio w/ws or graphically as follows. From the dew point of the given level follow the; saturation mixing ratio line to 1000 mb, level. From this point, at 1000 mb, draw a line parallel to isotherms. From the dry bulb temperature at the same level draw another line parallel to the saturation mixing ratio line. The pressure value at the point of intersection of this and the previous line divided by 10 gives the relative humidity, vide fig 2 along side where the R. H. is 52%.

20. **Vapour Pressure (e/e_s).** From the dew point curve, at the given pressure follow the isotherm to 622 hPa. The saturation mixing ratio value at this point gives the vapour pressure, e, in hPa. Similar line drawn from the temperature curve and the value read at 622 hPa level gives the saturation vapour pressure, es, in rob (vide fig 2.2). In our example vapour pressure and saturation vapour pressures for 800 hPa level are 11.5 hPa and 22 hPa respectively.

21. **Virtual Temperature(T_v).** The difference between the virtual temperature and dry bulb temperature can be computed by taking the numerical value of the saturation mixing ratio line through dew point curve at the given pressure since, T-Tv =0.6r.θ

22. **Convective Condensation Level (CCL).** It is located at the intersection of the sounding with the isohygric line for the average mixing ratio of the lower layers (vide fig 2.3). This is the expected height of base of cumuliform clouds due to surface heating. CCL in the example is at 830 hPa.

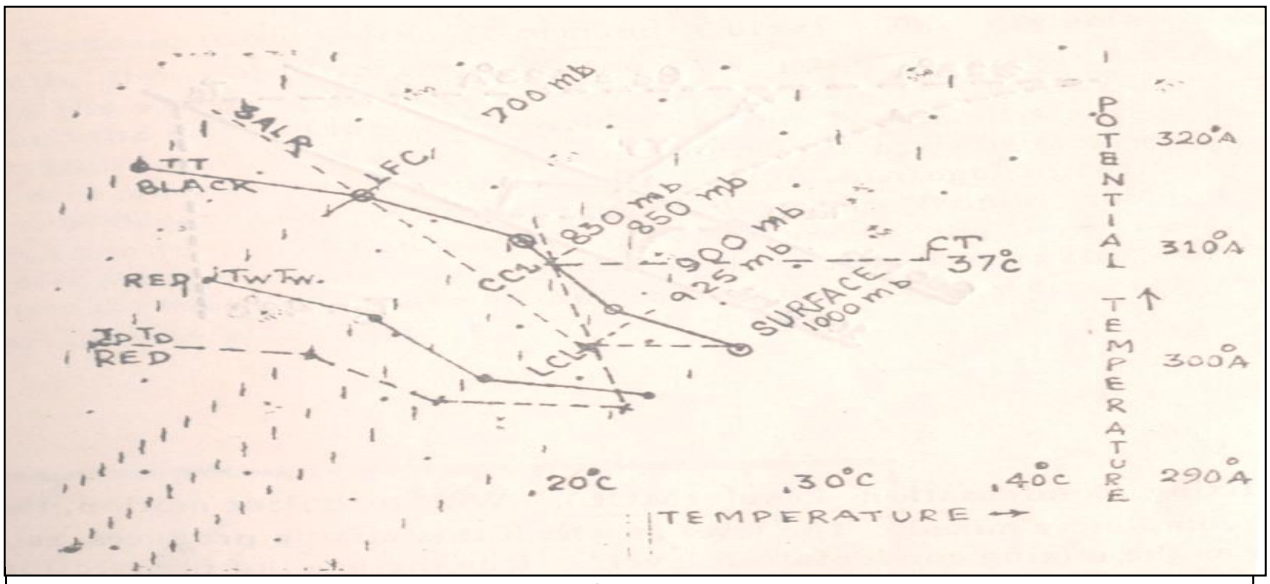


Fig – 2.3

23. **Convection Temperature**. It is the surface temperature which must be attained if cumulus clouds are to form due to surface heating only. It is the temperature obtained by extending the dry adiabat from the CCL to the surface pressure (vide fig 2.3). This temperature in the example is 37°C.

24. **Lifting Condensation Level (LCL)**. It is the height at which a parcel of air, lifted dry adiabatically would become saturated. It is located at the intersection of the isohygric through the surface dew point temperature and the dry adiabat through the surface temperature. LCL is usually located at a lower pressure than CCL. In our example LCL is at 940 hPa (fig 2.3).

25. **Level of Free Convection (LFC).** The level from which a parcel of air will start to rise spontaneously (i.e. warmer than the environment) is known as the level of free convection. The point of intersection of the saturation adiabat through LCL with the environmental temperature curve gives the height of LFC. It is desirable to use the wet bulb temperature corresponding to the average moisture content of the lower layer of the atmosphere for obtaining LFC.

26. **Potential Temperature (θ).** The value of the potential temperature can be read directly from the ordinate .

27. **Wet Bulb Potential Temperature (θw).** From the LCL, come along the saturation adiabat to the desired pressure level to obtain the wet bulb temperature. The value of the saturated adiabat brought down to the 1000 mb level is the wet bulb potential temperature.

28. **Equivalent (TB) and Equivalent Potential(θe) Temperatures**. Find the LCL, proceed upwards along the saturation adiabat where it becomes parallel to the adiabat. From this point follow the dry adiabat downwards to the original pressure. The corresponding temperature of this point gives T E. The corresponding potential temperature value (read along the ordinate scale) gives θe. (fig 2.4).

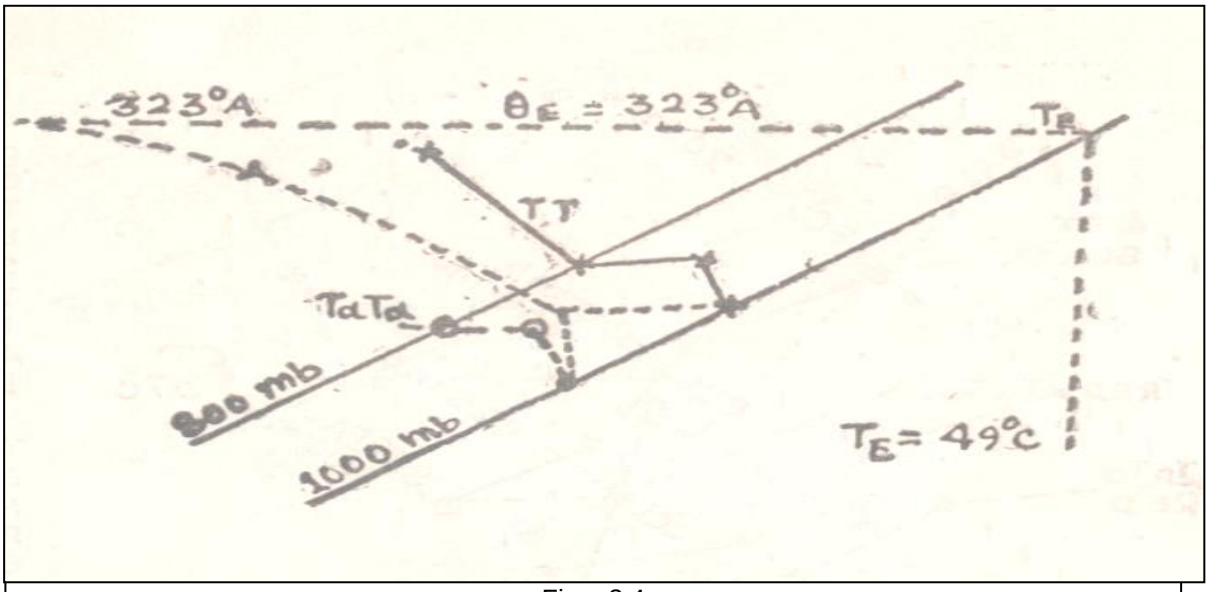


Fig – 2.4

29. **Mixing Condensation Level' (MCL).** With turbulent motion, the layers often get completely mixed. The level at which this mixing produces saturation is known as the mixing condensation level. It is the level of intersection of the average saturation mixing ratio of the mixed layer with the mean dry adiabat of the mixed layer. In order to find this an estimate of the top of the mixed layer is necessary. This is done empirically. The procedure for determining this level is shown in fig 2.5. In the example the top of the mixing layer is assumed to be 850 hPa. MCL is also found at this level.

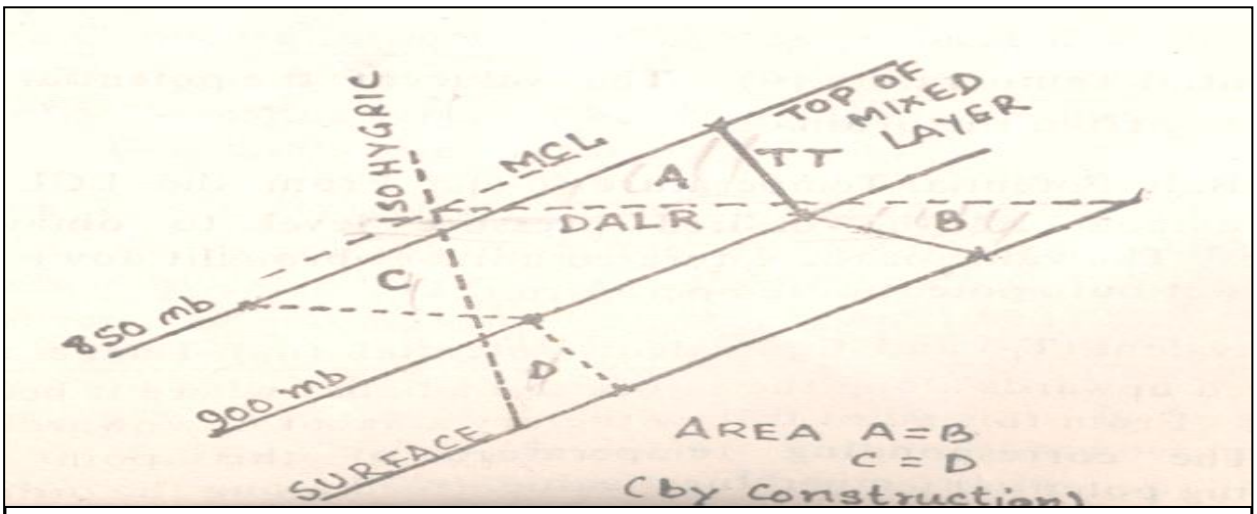


Fig – 2.5

30. **Thermal History.** Altitude markers placed at evenly placed intervals on the Normand curve can be utilized to provide information regarding the processes which a parcel of air has been subjected to, viz:

a. Markers close together or even merge into one - complete mixing. In case of non-saturation, this indicates that the parcel has moved over rough but dry terrain or was subjected to turbulent mixing due to strong winds.

b. The Normand curve closely following the saturated adiabat with the markers close together- the air has travelled over seas under strong wind conditions or colder air has moved over warmer seas causing turbulent mixing and humidification.

c. Markers far apart - frontal surfaces or inversion.

d. Normand curve follows dry adiabatic curve and markers close together at lower portion - mixing due to insolation.

e. Normand curve lies along the mixing ratio and the markers are far apart at the lower levels - radiation cooling.

f. Separation of markers (markers move upwards along the Normand Curve) - subsidence or condensation.

g. Separation of markers (markers move downwards, while the Normand curve remains unaffected) - convergence or evaporation.

Analysis of Cross-Section Charts

31. Horizontal distance and - log p usually form the abscissa and the ordinate of vertical cross-sections respectively. The vertical scale is considerably exaggerated. The exaggeration varies, but a vertical scale 250 times the horizontal is usual. The horizontal base is selected along a suitable direction and the available soundings along this line are projected to form the cross section. While projecting the stations, it is necessary to observe the distance of the station from the selected line of reference. Though no arbitrary limit has been set, it is desirable that the station should be as near to the line as and generally not away by more than 3 to 5° latitude/longitude.

Vertical Time Section

32. This type of analysis is used in the tropics extensively for operational and research purposes. Vertical time section shows the distribution of various parameters above a station over a period of time based on radiosonde and/or rawin data. Winds are plotted at various levels. The six hourly surface synoptic observations are also plotted at the bottom. For the study of systems moving from east to west these are plotted from left to right so that troughs, ridges and vortices appear on the time section like they do on horizontal synoptic charts. Temperatures, dew points and heights may also be plotted. To indicate the depth of the moist layer the height of 5g/kg moisture surface, during the rainy season, and 3g/kg moisture surface, during dry season, may also be plotted as calculated from T -Ø grams. Time section are used for

a. To identify incorrect or non-representative upper wind reports.

b. To locate and determine the thickness of transition layers between easterly and westerly flow regime.

c. To locate and assess the movement of troughs, ridges etc in the upper air.

d. Extrapolation and finding trend (only to a limited extent).

Analysis of Vertical Time Section

33. **Wind Directions**. Isogons may be drawn on the time section in the same manner as on horizontal charts with dots replacing the station circles 'The isogons patterns on time section are similar to those on synoptic maps, closed curves and singular points occurring in the field. Identifying these features on the time scale and comparing them with the synoptic wind patterns gives a better insight into the three dimensional wind structures. The isogons of primary interest are the 360/180 line, separating Easterly and Westerly winds, and 090/270 isogons, to locate singular points. The time section singular points represent the intersection of the sloping vertical axes of moving singularities in the horizontal wind field with the plane of the time-section. Whenever possible, each singular point on time section should be identified with the corresponding singular point on the horizontal streamline chart to more easily visualize their vertical continuity.

34. **Wind Speed**. Isotachs are drawn in the same manner as on horizontal wind charts, at 5, 10, or 20 kts speed intervals, to locate wind speed maxima and minima. At some stations the wind maxima are associated with cloud and weather variations.

35. **Moisture.** The moisture analysis can be done in a variety of ways viz dew points (at 5°C interval), dew point spread or departure of dew point from normal (at 2°C interval). Tile moisture changes are often abrupt rather than gradual.

36. **Temperature/Heights**. Isopleths of temperature and/or heights (Or their departure from normal) could be analysed. However, this analysis is of not much use in tropics.

Vertical Space Cross-Section

37. These are similar to time section charts but represent the distribution of various parameters along a selected section - say Srinagar, Delhi, Jodhpur, Bombay and Trivandrum. Analysis is similar to that of time section. The Stations data are plotted at separations proportional to the horizontal distances between the stations. Space cross-sections may be used as briefing aids.

Conclusion

38. The result of the aero logical soundings furnish information related to the Vertical distribution of pressure, temperature and moisture content in the atmosphere. In our scenario these diagrams are known as Tephigram. It is an extremely useful tool a Met forecaster. The requirement is to understand and bring the atmosphere on this diagram so as to derive desired benefits.

SECTION-5 : WEATHER

TASK – 24 : CLOUD

Introduction

1. Clouds are signposts of the sky. They are visible evidence of what is occurring in the atmosphere is doing in terms of motion and water content. By observing the shape, size and structure of cloud the degree of atmospheric instability can be understood. For the pilots the knowledge of clouds, their type, classification and names, how they are formed and their significance is particularly important in the planning and conducting of a safe flight because clouds gives a clue to flying conditions many hours in advance or hundreds of miles ahead. Cloud differs form fog only in that the base of fog must be within 50 feet of the ground. Clouds can be composed of water vapour and ice crystals or solely of ice crystals but fog is generally composed of water droplets.

Aim

2. To provide knowledge on clouds in broad aspects.

Definition

3. Clouds are countless millions of minute water droplets and/or ice crystals depending on the temperature within them. According to WMO the definition of cloud is ‘a visible aggregate of minute particles of water or ice or both in the free air’. Cloud is also defined as an aggregate of very small water droplets, ice crystals, or a mixture of both, with its base above the earth’s surface.

Composition of Clouds

4. The cloud particle has got the diameter of the order 200μ (microns) or 0.2mm, larger drops than this comprising drizzle (0.2mm-0.5mm) or rain (>0.5mm). With the exception of certain rare types (Nacreous and Noctilucent) and the occasional occurrence of cirrus in the lower stratosphere, clouds are confined to the troposphere. They are formed mainly as the result of vertical motion of air, as in convection, or in forced ascent over high ground, or in the large-scale vertical motion associated with depressions and fronts. Cloud may result, in suitable lapse rate and moisture conditions, from low-level turbulence and from other minor causes. When the temperature range is 0^0C to -15^0C, they are composed largely of super cooled water droplets and below –15^0C, they are almost ice crystals. The cloud droplets are very small but they are clustered together to be visible as clouds. Condensation of water vapour into liquid water drops appears to require a suitable solid nucleus eg smoke, dust, salt particles from sea spray. The atmosphere contains a plentiful supply of these nuclei and so saturation quickly leads to cloud or fog formation. Ice crystals also require a nucleus, but of a different kind; these are far from plentiful and the result is that water drops are reluctant to freeze at temperature below 0^0C. Water drops frequently exist in the super cooled, liquid state down to near -40^0C, below that temperature freezing is virtually spontaneous. The following table, Table 1, gives a rough guide of constitution of clouds.

TABLE 1: CONSTITUTION OF CLOUDS WITH DIFFERENT TEMPERATURE RANGE

Temperature	Constitution
Below -40^{0}C	Ice crystals almost invariably
-40^{0}C to -20^{0}C	Ice crystals predominate, mixed with some small super cooled water drops
-20^{0}C to -10^{0}C	Small super cooled water drops predominate, mixed with some ice crystals
-10^{0}C to zero	Medium or large sized super cooled water drops almost entirely
Above zero	Water drops, melting snowflakes, hail (snow can persist down to 1,500 feet below the 0^{0}C level)

Formation of Cloud

5. When air is saturated or supersaturated it can no longer hold all of its water vapour; clouds are formed by the condensation of a part of water into visible droplets, snow or ice crystals. The following three conditions are essential for cloud formation:

a. Sufficient water vapour must be present.

b. There must be a cooling process.

c. There must be condensation nuclei, or core particles, around which the droplets can form.

6. The cause of condensation to water drops is the reduction of air temperature below the dew-point. In nature this may be caused in any of the following ways:

a. Convective cooling by expansion, ie heating from below.

b. Mechanical cooling by expansion, ie forced ascent along hill slopes or fronts.

c. Loss of heat by radiation.

7. **Common Methods of Cloud Formation.** The common method of cloud formation is the adiabatic cooling by reduction of pressure, which is almost entirely associated with vertical motion. The different types of cloud formed by various modes of upward motion may be classified as follows:

a. Mechanical or frictional turbulence; forms layer cloud like St, Sc.

b. Convection, heating from below; forms heap cloud like Cu, Cb.

c. Orographic ascent, over hills; forms Ac (lenticular).

d. Slow and widespread ascent, mass lifting; associated with cyclone, fronts; forms Cs, As and Ns.

8. **Cloud Physics.** The study of the physical processes which governs the formation, nature, size, size distribution and number (per unit volume) of the individual particles which together constitute cloud, fog or precipitation.

9. **Structure of Cloud.** When the clouds form, the degree of stability or instability determines the size, shape and structure of clouds, but in unstable atmosphere cumuliform or heap type of clouds are formed.

Cloud Classification

10. Clouds are classified in various ways. There are mainly 10 types of cloud, *cloud genera*, observed in lower atmosphere. They are:

a. Cirrus(Ci).

b. Cirrocumulus(Cc).

c. Cirrostratus(Cs).

d. Altocumulus(Ac).

e. Altostratus(As).

f. Nimbostratus(Ns).

g. Stratocumulus(Sc).

h. Stratus(St).

j. Cumulus(Cu).

k. Cumulonimbus(Cb).

11. Other classifications of the clouds are:

a. **According to International Cloud Atlas.** In the publication 'International Cloud Atlas', division is made into cloud genera (10 basic characteristic forms); with subdivision as required into:

(1) Cloud species (clouds shape and structure).

(2) Cloud varieties (cloud arrangement and transparency).

(3) Supplementary features and accessory clouds-like Incus, Mamma, Virga, Praecipitatio, Arcus, Tuba, Pileus, Velum and Pannus.

(4) Growth of a new cloud genus from a 'mother-cloud', indicated by the addition of 'genitus' to the new cloud and mother-cloud genera, in that order, if a minor part of the mother-cloud is affected, and of 'mutatus' if much or all of the mother-cloud is affected, eg stratocumulus cumulogenitus, or stratus stratocumulomutatus.

b. **Cloud Level.** A classification is made in terms of the level high, medium or low at which the various cloud genera are usually encountered. In temperate at regions the approximate limits are:

High	5-13 km (16,500-45,000 feet); Ci, Cc and Cs.
Medium	2-7 km (6,500-23,000 feet); Ac, As and Ns; Ns may be low cloud.
Low	Earth's surface-2 km (0-6,500 feet); Sc, St, Cu, Cb and Ns; the Cu and Cb also reaching middle and high levels.

c. **Less Formal Classifications.** Less formal classifications are made:

(1) In terms of the physical processes of cloud formation, notably into Heap Clouds and Layer Clouds (or sheet clouds).

(2) In terms of cloud composition, namely Ice-Crystal Clouds, Water Droplet Clouds and Mixed Clouds.

12. For synoptic purpose, a nine-fold cloud classification is made in each of these three latter divisions of cloud genera, the corresponding codes being designated C_H, C_M and C_L respectively. The purpose is to report characteristic states of the sky rather than individual cloud types.

Height of Base of Cloud

13. Height of the cloud base is determined by estimation by trained observers. The height of base of cloud can be measured by releasing hydrogen-filled balloon with known rate of ascent, by aircraft, by ceilometers or search light.

14. **Classification.** Classification of different of clouds in terms of height in tropical regions is given in Table 2.

TABLE 2: CLASSIFICATION OF CLOUD IN TERMS OF HEIGHT.

Family	High clouds	Medium clouds	Low clouds	Clouds with vertical development
Mean upper level Mean lower level	60,000 feet 20,000 feet	25,000 feet 6,500 feet	6,500 feet Close to ground	Cirrus level 1,500 feet
Genus	Cirrus=Ci Cirrocumulus=Cc Cirrostratus=Cs	Altocumulus=Ac Altostratus=As Nimbostratus =Ns	Stratocumulus=Sc Stratus=St	Cumulus=Cu Cumulonimbus=Cb

During darkness an observer has difficulties in identifying cloud types following the on set of precipitation, so the following table, Table 3, can be used as guide to the cloud types which may be present from the nature of the precipitation. Precipitation (pptn) is a term given to water drops or ice particles formed at a higher level and following towards the grounds and includes rain, drizzle, sleet, snow, hail, ice pellets etc.

TABLE 3: TYPE OF PRECIPITATION FORM DIFFERENT TYPES OF CLOUD

Precipitation	**Cloud type**					
	As	Ns	Sc	St	Cu shower)	Cb (shower)
Rain	+	+	+		+	+
Drizzle				+		
Hail						+
Snow	+	+	+	+	+	+
Ice pellets	+	+				

15. **Cloud Base.** That lowest zone in which the type of obscuration perceptibly changes from that corresponding to clear air or haze to that corresponding to water droplets or ice crystals. (Conference of Directors of Members of the International Meteorological Organization, 1947). Height of cloud base is reported as height above ground level.

16. **Cloud Searchlight.** Light projected vertically, by remote control, from a searchlight at distance L (about 1,000 feet) from an observer causes a spot of light to be thrown on the lowest cloud overhead. The observer measures the angle of elevation (E) of the light spot by means of an Alidade[2] and deduces the cloud base (h) from the relationship, Figure 1:

$$h=L.\tan E \qquad (1)$$

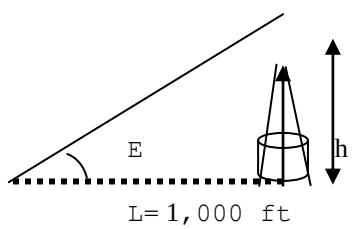


Figure 1: Cloud searchlight.

Cloud Conditions

17. **Cloud Amount.** Amount of sky estimated to be covered by a specified cloud type (partial cloud amount), or by all cloud types (total cloud amount). In either case the estimate is made to the nearest Okta(eighth) and is reported on a scale which is essentially one of the 'nearest eighth', except that figures 0 and 8 on the scale signify a completely clear and cloudy sky, respectively, with consequent adjustment to other figures near either end of the scale. Thus when half of the sky is covered, the amount is given as 4 oktas.

18. **Cloudiness.** Amount of sky covered by cloud, irrespective of type, ie total 'cloud amount'.

19. **Day of Clear Sky.** In a resolution adopted at the International Meteorological Meeting at Utrecht in 1874, a 'day of clear sky' was defined as one on which the average 'Cloudiness' at the hours of observation is less than two-tenths of the sky. On 01 January 1949 Oktas were first adopted, and since then a 'day of clear sky' has been defined in Great Britain as one on which the average cloudiness at hours of observation is less than two oktas.

20. **Cloudy Day.** Cloudy day is defined as a day on which the average cloudiness at the hours of observation is more than six OKTAS (prior to 01 January 1949 the criterion was based on an average cloudiness greater than eight-tenths of the sky). Such days have sometimes been described in Great Britain as 'overcast days'.

21. **Cloud Burst.** A popular term for a very sudden and very heavy shower, often accompanied by thunder and hail. It is associated with strong upward and downward currents.

22. **Cloud Discharge.** A lightning flash confined within a thundercloud.

23. **Cloud Seeding.** The attempted modification of the physical processes occurring within natural clouds, by injecting the clouds with one or other seeding agent:

a. Dry ice (solid carbon dioxide) at very low temperature to cause local cooling to below -40^{0}C and spontaneous freezing.

b. Silver iodide to act as Ice Nuclei.

c. Hygroscopic salt nuclei or a spray of fine water drops to stimulate coalescence.

Injection of the seeding agent into the clouds has been carried out from aircraft, from balloons and from the ground. In general, the purpose of the cloud seeding has been to stimulate precipitation. Attempts have also been made to clear stratus clouds and to inhibit hail and thunderstorms. Some success has been claimed in at least the first two aims, but the existence of a method of clouds seeding of commercial value has not yet been established.

Other Types of Clouds

24. Except the clouds of Table 2 the following clouds are also observed:

a. **Mamma.** Hanging bulges on the under surface of a Cb cloud, looking like the udders, indicates severe weather.

b. **Lenticular Clouds.** Lens shaped clouds seen at times near mountain tops on the Lee-side.

c. **Castellanus.** When Ac or Sc has a turreted structure, it is known as castellanus. It is indicative of instability at higher level.

d. **Line and Squall Clouds.** Roll clouds of dark colour in the shape of an arch, slightly shed of long line of Cb clouds. Their approach indicates impending severe weather.

e. **Rotor Cloud.** Roll type of clouds which sometimes form on the lee side of a mountain in a zone of severe turbulence.

Flying in Clouds

25. Flying in clouds has to be done under instrument flight rules (IFR) unless the clouds are thin or of patchy nature. Before entering cloud, aircrew are to be thoroughly sure of the kind of cloud, its approximate thickness and horizontal coverage. Flying in cloud is associated with the following hazards:

a. **Poor Visibility.** In cloud, the vertical as well as horizontal visibility is poor. The horizontal visibility ranges from 1 kilometer in cirrus clouds to less than 10 metres in well-developed cumulus or cumulonimbus. In general, rain giving clouds, which have a concentration of larger water drops, are associated with much less visibility than the non-precipitating types.

b. **Turbulence.** All clouds are associated with vertical motion of air, because this is a pre-requisite for their formation. The vertical motion may be in the form of columns of rising or falling air or in the form of smaller eddies with irregular random motions. When their sizes are comparable to the dimensions of an aircraft, they cause bumpiness in the motion of the aircraft; the turbulence may range from slight to severe type. In general, cumuliform clouds give more turbulence than stratiform clouds. Clouds associated with instability give rise to severe turbulence.

c. **Ice Accretion.** Ice may form on the aircraft surface disturbing the aerodynamic properties, control surfaces and in the carburettor.

d. **Cloud Ceiling.** While landing, the pilot has to keep in view the airfield and the runways so that he can descend, approach and align himself with the runway in use. In many of the blind landing systems, the pilot is brought to an altitude, known as break-off altitude, and then he is left on his own, for the final landing. Even during take-off, it is essential that in case of any emergency he should be able to land back safely. When clouds with low base are present these operations are naturally affected. Hence the pilot has to be given an accurate picture of the clouds over the base as well as terminal, and in addition when low critical heights are involved, at the break off area of the runway in use since any cloud below the aircraft on the approach path would obstruct his visual reference.

Observations of Cloud

26. The 10 genera of clouds are identified with the following description given in WMO Cloud Atlas:

a. **Cirrus.** Detached clouds in the form of white, delicate filaments or white or mostly white patches or narrow bands. These clouds have a fibrous (hair-like) appearance.

b. **Cirrocumulus.** Thin, white patch, sheet or layer of cloud without shading, composed of very small elements in the form of grains, ripples, etc., merged or separate, and more or less regularly arranged; most of the elements have an apparent width of less than one degree.

c. **Cirrostratus.** Trans- parent, whitish cloud veil of fibrous (hair-like) or smooth appearance, totally or partly covering the sky, and generally producing halo phenomena.

d. **Altocumulus.** White or grey, or both white and grey, patch, sheet or layer of cloud, generally with shading, composed of laminae, rounded masses rolls, etc., which are sometimes partly fibrous or diffuse and which may or may not be merged; most of the regularly arranged small elements usually have an apparent width of between one and five degrees.

e. **Altostratus.** Greyish or bluish cloud sheet or layer of striated fibrous or uniform appearance, totally or partly covering the sky, and having parts thin enough to reveal the sun at least vaguely as through ground glass. Altostratus does not show halo phenomena.

f. **Nimbostratus.** Gray cloud layer, often dark, the appearance of which is rendered diffuse by more or less continuously falling rain or snow, which in most cases reaches the ground. It is thick enough throughout to blot out the sun.

g. **Stratocumulus.** Gray or whitish, or both grey, and whitish, patch sheet or layer of cloud which almost always has dark parts, composed of tessellations, rounded masses, rolls, etc, which are non fibrous (except for virga) and which may or may not be merged; most of the regularly arranged small elements have an apparent width of more than five degrees.

h. **Stratus.** Generally grey cloud layer with a fairly uniform base, which may give drizzle, ice prisms, or snow grains. When the sun is visible through the cloud, its outline is clearly discernible. Stratus does not produce halo phenomena except possibly at very low temperatures. *Sometimes stratus appears in the form of ragged patches.*

j. **Cumulus.** Detached clouds, generally dense and with sharp outlines, developing vertically in the form of rising mounds, domes, or towers, of which the bulging upper part often resembles a cauliflower. The sunlit parts of these clouds are mostly brilliant white; their base is relatively dark and nearly horizontal. *Sometimes cumulus ragged.*

k. **Cumulonimbus.** Heavy and dense cloud, with a considerable vertical extent, in the form of a mountain or huge towers. At lest part of its upper portion is usually smooth or fibrous, or striated, and nearly always flattened; this part often spreads out in the shape of an anvil or vast plume.

Conclusion

Virtually all weather problems that confront a pilot are associated in one way or another with clouds or fog and he should never fly into any cloud without knowing what weather elements he is likely to encounter. Cloud is the visible aggregate of minute particles of water droplets or ice crystal or both suspended in the free air. Clouds are the signposts of the sky. They are visible evidence in the atmosphere. There are mainly 10 types of cloud that fall under mainly low, medium and high level. According to thickness of the clouds, they are of cumulus and stratus types. Cumulus type clouds have got more thickness while stratus types of clouds are of sheet type. For formation of clouds sufficient water uapour is required with the cooling process and condensation nuclei. Mechanical or frictional turbulence, convection, orographic ascent, and slow and widespread ascent are the common methods of cloud formation. There may be maximum 8 oktas of cloud, but 1 or 2 oktas of cb or cu cloud may be dangerous for flying. Poor visibility, turbulence, icing and low ceiling are the main be weather in clouds.

TASK 25 : VISIBILITY

1. **Definition.** Visibility is defined as the greatest distance at which an object of specified characteristics can be seen and identified with the unaided eye in any particular circumstances, or in the case of night observations, could be seen and identified if the general illumination were raised to the normal daylight level. Lower visibilities are expressed in metres or yards and higher visibilities in kilometres or miles. Reports generally refer to a visibility based on all directions; where there is marked variation with direction, the lowest visibility is recorded for synoptic purposes, with an appropriate entry in a 'special phenomena' group. 'Visibility objects' by day are ideally confined to black or nearly black objects which appear against the horizon sky. Night visibility objects comprise mainly unfocused light of moderate and known intensity at known distances.

2. **Importance of Visibility**. Although modern developments in radio and radar have made flying possible without ever looking outside the cockpit, still visibility remains a factor of great importance in all ordinary aircraft operations both civil and military. Visibility is a measure of the degree of transparency of the atmosphere. A pilot's interest in visibility arises because he wants to know how far he will be able to see various things, land marks, targets, obstructions, beacon lights, other aircraft, runway etc, while in flight or when he is about to make an approach for landing. A pilot should be thoroughly familiar with the prevailing visibility in different seasons over the airfields on which he operates and the incidents of phenomena which render visibility poor. Visibility observations should be made on all runways intended for use during periods of reduced visibility and in particular on:

a. Precision approach runways.

b. Runways used for take-off and having high intensity edge lights and/or centre line lights.

The RVR observations should be made and reported throughout any period when either the horizontal visibility or the RVR is observed to be less than 1500 meter.

3. **Types of Visibility.** There are three types of visibility that affect aviation, shown in Fig 3.5. They are:

a. **Horizontal Surface Visibility.** Horizontal surface visibility refers to the ability of an observer on the surface to see other objects on the surface.

b. **Air-to-Air or Flight Visibility.** Air-to-air visibility refers to the ability of an observer aloft to see other objects aloft. This is reported by pilots.

c. **Oblique or Slant Visibility.** Oblique visibility, or 'slant visibility' is the greatest distance at which a given object can be seen and identified with the unaided eye along a line of sight inclined to he horizontal. Oblique visibility in a downward direction, an important element in aircraft operation, is generally different from the visibility measured at the earth's surface due:

(1) To height variations of atmospheric Extinction Coefficient[3] in the layer concerned. In relation to Visibility, scattering is much the more important of the two extinction processes.

(2) To the fact that objects are then viewed against a terrestrial background.

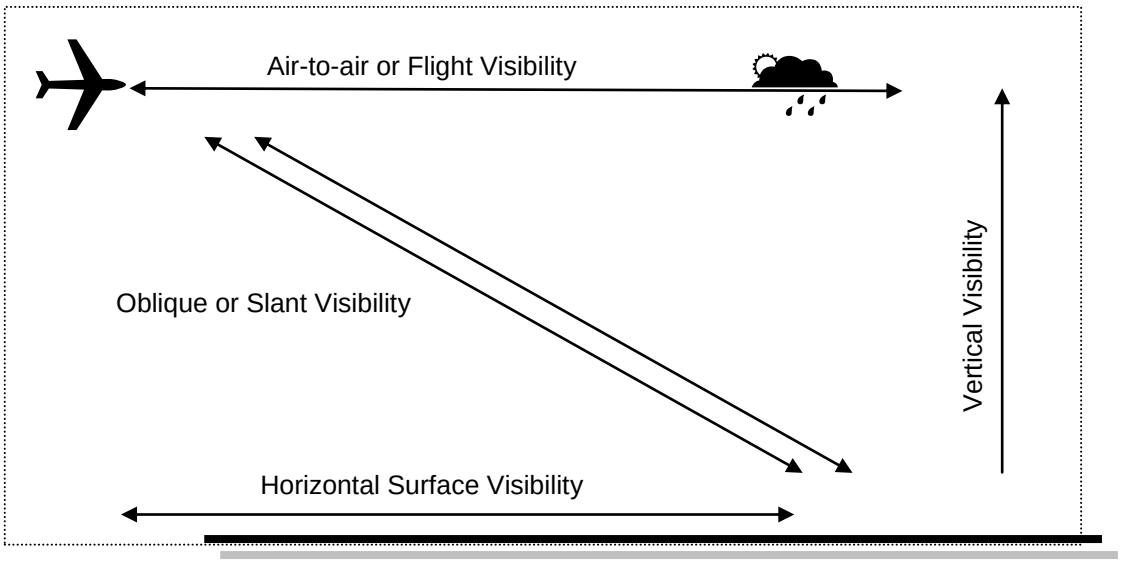


Fig 3.5 Different types of visibility.

d. **Vertical Visibility.** The greatest distance at which a given object can be seen and identified in the vertical plane of the observer. This element, required in synoptic observations on occasions when the sky is obscured by fog, etc. may be measured by pilot balloon and theodolite, the vertical visibility being taken as *h.cosecE* where h is the height of the balloon and E its angular elevation at the moment of its disappearance from view.

4. **Descriptive Terms of Visibility.** Visibility in terms of range is classified as:

a.	Poor visibility	:	1,500m or less.
b.	Moderate visibility	:	More than 1,500m but <5km.
c.	Good visibility	:	More than 5km but <9km.
d.	Very good or excellent visibility	:	More than 10km.

5. **Causes of Atmospheric Obscurity.** The distance at which an object can be seen depends on the position and characteristics of the observer and the object, as well as on the obscurity of the atmosphere between the two. The condition determining the obscurity may be classified as follows:

a. Fog and mist caused by water droplets.

b. Cloud and precipitation caused by water droplets or ice crystals or both.

c. Wind blown spray from sea caused by water droplets.

d. Smoke caused by solid impurities from combustion.

e. Dust and smoke also caused by solid impurities thrown out from active volcanoes or by raised dust or sand from ground on desert or semi desert regions in dry season.

6. **Common Weather Phenomena Reducing Visibility.** Common weather phenomena which reduce visibility are given below:

Table 3.2

Weather Phenomena	Visibility (m)
Haze	1000-5000
Mist	1000-5000
Fog	30-1000
Drizzle	<1000
Rain	<1000
Snow	<300
Blowing snow	<50

TASK - 26 : PRECIPITATION - RAIN AND SHOWERS

Objectives

After reading this chapter, you should be able to:-

- Understand the mechanism of Precipitation Formation
- Understand the theory of Formation and Growth of Ice Crystals.

Forms of Precipitation

1. Precipitation composed entirely of drops a little larger than this commonly falls in damp weather from low, shallow, layer clouds and is called drizzle. Rain constitutes of larger drops having radii upto about 2 mm, is produced by layer clouds some kilometers deep as are associated with fronts and depressions. The heaviest rains composed of even larger drops fall from cumulus clouds whose depth may reach 10 km, and which contain powerful upcurrents of several metres per second. Precipitation from these clouds is sporadic, for their horizontal extent is only a few kilometers and the active life of individuals is less than one hour. These rains are described as showers.

2. The upper parts of the cloud systems which extend well above the 0°C level contain ice particles. In stratiform clouds, these will usually be snow crystals. These join together to form snow flakes which fall at speeds upto about 1 m/s and either melt on crossing the 0°C level, in cold weather, reach the ground as snow. In shower clouds, the ice particles are usually in the form of hail pellets which may often melt before reaching the ground. However, very deep, vigorous clouds may produce very large hail stones which, in hot climates, are occasionally as large as oranges.

3. The occurrence of precipitation is strongly controlled by the motion of the cloud air in motion, during the formation of the clouds in combination with the abundance and properties of those aerosols (airborne particles) it contains and which act as condensation and freezing nuclei, determines the concentration, initial size distribution, and nature of the cloud elements. As soon as these have formed, the processes of condensation and aggregation allow some particles to grow preferentially and the production of precipitation elements is now under way. Because the air motion governs the dimension, water content, and duration of the cloud, it controls not only the rates of these processes, but the period during which they operate and thus the maximum size which the largest cloud particles can attain. If precipitation should result, μ is again the air motion which determines the maximum rate of precipitation and its duration. The most important factors are therefore the air motion and its aerosol content, and from specification of these it should be possible, in principle, to calculate the course of cloud and precipitation development. Unfortunately, we understand rather little about the motion of air, and the laws governing the growth and aggregation of cloud particles are not yet firmly established. Moreover, the large variations in the concentration and properties of atmospheric aerosols, and the great complexity of atmospheric motions (as revealed by the great variety in the pattern of clouds development), add to the difficulty of construction a detailed, general theory of precipitation development. However, considerable progress has been made with calculations, based on simple models of the air motion of the growth of individual rain drops and hail stones and as we should see, these give a reasonable qualitative explanation of formation of precipitation in different kinds of cloud.

Role of Condensation

4. In droplet clouds the condensation process alone is ineffective in producing rain. The size which droplets attain by condensation is mainly determined by their concentrations and the quantity of water vapour made available by the ascent of the cloud air. In the lower and middle troposphere, where the droplet concentrations established during the formation of clouds are usually of order 100 per cm^3 and the quantity of water vapour condensed is limited to about 7 g per cm^3, the average radius of cloud droplets can not exceed 30μm. Droplets concentrations arising during condensation is very clean air at high levels may be of order of 10 per cm^3, but the amount of vapour to be condensed is also greatly reduced, and so the conclusion that condensation alone is unlikely to produce droplets of average radius greater than 30 μ is not affected. Droplets of this size evaporates completely after falling a few metres in unsaturated air, and so are incapable of reaching the ground as precipitation. Condensation on giant hygroscopic nuclei may produce a few larger droplets but these will attain radii of 100 μ by condensation only after several hours. In the later type clouds which last this long the vertical air velocities are considerably less than 1 m per sec, so that the droplets would fall out of them before reaching even this size. On the other hand, the orographic and cumulus clouds which contain updraughts capable of sustaining these drops do not provide more than an hour for drop growth. Consequently condensation by itself is not capable of causing precipitation from droplet clouds.

5. The central problem is then to explain how precipitation particles, at least one million times greater in volume than typical cloud droplets, are produced within about one hour of the cloudy air first becoming saturated.

Precipitation Theory

6. Several valid theories have been formulated in regard to the growth of raindrops. The theories most widely accepted today are treated here in combined form.

7. Raindrops grow in size primarily because water exists in all three phases in the atmosphere and because the air is supersaturated at times (especially with respect to ice) because of adiabatic expansion and radiational cooling. This means that ice crystals coexist with liquid water droplets in the same cloud. The difference in the vapour pressure between the water droplets and the ice crystals causes water droplets to evaporate and then to sublimate directly onto the ice crystals. Sublimation is the process whereby water vapour changes into ice without passing through the liquid stage. Condensation alone does not cause droplets of water to grow in size. The turbulence in clouds permits and aids this droplet growth process. After the droplets become larger, they start to descend and are tossed up again in turbulent updrafts within the cloud. The repetition of ascension and dissension causes the ice crystals to grow larger (by water vapour sublimating onto the ice crystals) until finally they are heavy enough to fall out of the cloud as some form of precipitation. It is believed that most precipitation in the mid-latitudes starts as ice crystals and that most liquid precipitation results from melting during descent through a stratum of warmer air. It is generally believed that most rain in the tropics forms without going through the ice phase.

8. In addition to the above process of droplet growth, simple accretion is important. In this process, the collision of ice crystals with supercooled water droplets causes the droplets to freeze on contact with the ice crystals. As the droplets freeze on the ice crystals, more layers accumulate. This process is especially effective in the formation of hail.

9. There are other factors that explain, in part, the growth of precipitation, but the above processes are the primary ones.

10. **Cloud Formation**. To be able to thoroughly understand clouds, the meteorologist must know the physical processes that form clouds. Three conditions must be met before clouds can form as a result of condensation— presence of sufficient moisture, hydroscopic or sublimation nuclei in the atmosphere, and a cooling process. Moisture is supplied to the atmosphere by evaporation and is distributed horizontally and vertically by the winds and vertical currents. The first task is to consider the hydroscopic and sublimation nuclei. Hydroscopic nuclei are particles of any nature on which condensation of atmospheric moisture occurs. It can be said that hydroscopic nuclei have an affinity for water or that they readily absorb and retain water. The most effective hydroscopic nuclei are the products of combustion (sulfuric and nitric acids) and salt sprays. Some dust particles are also hydroscopic, but not effectively so. The presence of hydroscopic nuclei is a must; water vapour does not readily condense without their presence. Air has been supersaturated in laboratories to over 400 percent before condensation began when there were no hydroscopic nuclei present. On the other hand, condensation has been induced with relative humidities of only 70 percent when there was an abundance of hydroscopic nuclei.

11. The condensation which results when all three mentioned conditions are fulfilled is usually in the form of mist, clouds, or fog. Fogs are merely clouds on the surface of Earth.

12. In our industrial cities, where byproducts of combustion are abundant, the distinction between smoke, fog, and haze is not easily discernible. A combination of smoke and fog gives rise to the existence of the so-called smogs characteristic of these industrial areas.

13. Little is known about the properties of sublimation nuclei, although it is believed they are essential for sublimation to occur at all. It is assumed sublimation nuclei are very small and very rare, possibly of a quartz or meteoric dust origin. All cirriform clouds are composed of ice crystals and are believed to be formed as a result of direct sublimation.

14. In the atmosphere, water clouds, water and ice crystal clouds, and pure ice crystal clouds may coexist at the same time.

15. Next under consideration is the cooling process that may induce condensation. There are several processes by which the air is cooled: convective cooling by expansion, mechanical cooling by expansion, and radiational cooling. Any of the three methods may work in conjunction with another method, making it even more effective. The methods are as follows:

a. **Convective Cooling**. The ascent of a limited mass of air through the atmosphere because of surface heating is called thermal convection. If a sample of air is heated, it rises (being less dense than the surrounding air) and decreases in temperature at the dry adiabatic lapse rate until the temperature and dew point are the same. This is the saturation point at which condensation begins. As the parcel of air continues to rise, it cools at a lesser rate—called the moist/saturation adiabatic lapse rate. The parcel of air continues to rise until the surrounding air has a temperature equal to, or higher than, the parcel of air. At this point convection ceases. Cumuliform clouds are formed in this way. Cloud bases are at the altitude of saturation and tops are at the point where the temperature of the surrounding air is the same as, or greater than, the temperature of the parcel of air.

b. **Mechanical Cooling**. Orographic and frontal processes are considered mechanical means of cooling which result in cloud formation.

(1) **Orographic Processes**. If air is comparatively moist and is lifted over mountains or hills, clouds may be formed. The type of cloud depends upon the lapse rate (the rate of decrease in temperature with increase in height, unless otherwise specified) of the air. If the lapse rate is weak (that is, a low rate of cooling with an increase in altitude), the clouds formed are of the stratiform type. If the lapse rate of the air is steep (that is, a high rate of cooling with increasing altitude), the clouds formed are of the cumuliform type.

(2) **Frontal Processes**. Earlier you learned that, at frontal surfaces, the warmer, less dense air is forced to rise along the surfaces of the colder air masses. The lifted air undergoes the same type of adiabatic cooling as air lifted orographically. The type of cloud formed depends on the lapse rate and moisture of the warm air and the amount of lifting. Lifting is determined by the slope of the front; when the slope is shallow, the air may not be lifted to its saturation point and clouds do not form. When the slope is steep, as with a fast-moving cold front, and the warm air is unstable, towering cumuliform clouds form.

c. **Radiational Cooling**. At night Earth releases long-wave radiation, thereby cooling rapidly. The air in contact with the surface is not heated by the outgoing radiation, but rather is cooled by contact with the cold surface. This contact cooling lowers the temperature of the air near the surface, causing a surface inversion. If the temperature of the air is cooled to its dew point, fog and/or low clouds form. Clouds formed in this manner dissipate during the day because of surface heating

Initiation of Rain in Non-freezing Clouds.

16. Most of the world's precipitation falls to the ground as rain, much of which is produced by clouds whose tops do not extend to temperatures colder than 0°C. The mechanism responsible for precipitation in these "warm" clouds is coalescence among cloud droplets. The dominant precipitation-forming process in the tropics, coalescence is also effective in some mid-latitude cumulus clouds whose tops may extend to subfreezing temperatures.

17. A central task of precipitation physics is to explain how raindrops can be created by condensation and coalescence in times as short as 20 minutes. This is often quoted as the interval observed between the initial development of a cumulus cloud and the first appearance of rain. During this time a cloud population, consisting of the order of 100 droplets per cm^3 averaging 10 μm in radius, evolves into a raindrop population of 1000 drops per m^3 with typical diameters of 1 mm. Although there are still some uncertainties about details, it is generally agreed that collision and coalescence of droplets account for nearly all of this 50-fold increase in radius, but that these events do not occur in significant numbers until some of the droplets grow to a radius of about 20 μm. Smaller droplets have small collision cross-sections and slow settling speeds and hence have little chance of colliding with one another. Coalescence can only become significant after the droplet spectrum evolves to include a spread of sizes and fall speeds, with some droplets reaching 20 μm or so. The rate of collisions that a droplet of this size experience increases rapidly with size, in proportion to at least the fourth power of the radius, so that coalescence proceeds at an accelerating pace once it begins. By the time some droplets reach a radius of 30 μm in a developing cloud, coalescence is likely to be the dominant growth process. A typical raindrop of 1 mm diameter may be the result of the order of 10^5 collisions. Before these can begin, some other process must account for the production of a few droplets (perhaps only one in 10^5 droplets, or one per litre of cloud volume) as large as 20 μm in radius.

18. it may be determined that a cloud droplet can grow by condensation to a radius of 20 μm in 10 minutes under conditions of constant ambient saturation ratio if the super-saturation is about 0.5%. For typical droplet concentrations, this super-saturation would require a sustained updraft of 5 m/s or greater. Such special conditions would only be approximated in developing cumulus clouds of considerable vertical extent, but in these clouds it appears plausible that condensation in an adiabatically ascending cloudy parcel can produce the droplets needed to initiate coalescence in realistic time.

Droplet Growth by Collision and Coalescence

19. Collisions may occur through differential response of the droplets to gravitational, electrical or aerodynamic forces. Gravitational effects predominate in clouds. Large droplets fall faster than smaller ones, overtaking and capturing a fraction of those lying in their paths. The electrical and turbulent fields required to produce a comparable number of collisions are much stronger than those thought usually to exist, although the intense electric fields in thunderstorms may create significant local effects. As a drop fall it will collide with only a fraction of the droplets in its path because some will be swept aside in the airstream around the drop. The ratio of the actual number of collisions to number for complete geometric sweep-out is called the collision efficiency, and depends on the size of the collector drop and the sizes of the collected droplets.

20. Collision does not guarantee coalescence, when a pair of drops collide several types of interaction are possible:

a. They may bounce apart.

b. They may coalesce and permanently united.

c. They may coalesce temporarily and separate, apparently retaining their initial identities.

d. They may coalesce temporarily and then break into a number of small drops.

21. The type of interaction depends upon the drop sizes and collision trajectories, and is also influenced by the existing electrical forces and other factors. For sizes smaller than 100 μm in radius, the important interactions are ‘a’ and ‘b’ in the preceding list.

22. The ratio of the number of coalescence to number of collisions is called the coalescence efficiency. The growth of a drop by the collision-coalescence process is governed by the collection efficiency, which is the product of collision efficiency and coalescence efficiency. Laboratory studies of small colliding droplets indicate that the coalescence efficiency is close to unity if the droplets are charged or an electric field is present. Because weak fields and charges exist in natural clouds, theoretical studies of droplet growth by collision-coalescence usually make the assumption that the collection efficiency equals the collision efficiency.

23. Observations show that rain can develop in warm clouds of the cumulus type in times as short as about 15 minutes after the cloud begins to form. It is generally agreed that the process responsible for this development must be gravitational coalescence among the droplets, so that the droplet populations most likely to produce rain in a short time are those with broad enough spectra to have a high rate of collisions. A serious impediment to coalescence growth is the fact that collection efficiencies between smaller droplets are extremely small. Moreover, the condensation-diffusion process, which dominates droplet growth initially, leads to a narrowing of the spectrum, seemingly complicating the coalescence problem. The theoretical task is therefore to explain raindrop development in reasonable times in spite of the small collection efficiencies and the approximate parabolic form of the diffusional growth law.

24. It is now recognized that statistical effects are crucial in the early stages of coalescence, so that the stochastic equation should be used to describe this process. Even so, coalescence alone is not sufficient to account for rain development in reasonably short times, starting with realistic droplet spectra. Several mechanisms have been postulated for broadening the spectrum, thus paving the way for rapid coalescence. There is no agreement on which of these is the most important, although each may be effective under certain conditions. Rather than spectral broadening, it has been shown that the additional effect which can account for rain development, at least in some conditions, is continued condensation growth. This seems strange at first since condensation-diffusion, even the kinetic corrections, leads to a narrowing of the droplet spectrum. Though the spectrum narrows, the rate of coalescences increase because the collision efficiency increases rapidly as the droplets in the spectrum grow. Definitive calculations have not yet been made which account for rain development under various conditions of updraft speed, temperature, initial droplet spectrum, and entrainment mixing. Results from simple models are encouraging, however, indicating that theory may be on the verge of explaining the observations.

Formation and Growth of Ice Crystals

25. Once a cloud extends to altitudes where the temperature is colder than 0°C ice crystals may form. Two phase transition can lead to ice formation: the freezing of a liquid droplet or the direct deposition (sublimation) of vapour to the solid phase. Both are nucleation processes, and in principle homogeneous and heterogeneous nucleation are possible.

26. A newly formed ice crystal in a cloud of liquid droplets is in a favourable environment to grow rapidly by diffusion. The vapour in the cloud is essentially saturated relative to liquid water and hence supersaturated relative to ice. In a time of only a few minutes, such a crystal can grow to a size of many tens of micrometers in linear dimension. A crystal of this size falls with a velocity of a few tens of centimetres per second. It may eventually reach the ground as an individual crystal, or it may collide with supercooled droplets to form a rimed crystal, or with other crystals to form a crystal aggregate or snowflake.

27. The growth processes are thus the same as for a droplet, namely diffusion followed by coagulation. For the crystal, however, diffusional growth is more significant than for the droplet because of the difference in saturation vapour pressure over water and ice.

Nucleation of the Ice Phase

28. It is convenient to consider first the homogeneous phase transitions that can lead to the formation of ice. Homogeneous freezing of a pure liquid drop occurs when statistical fluctuations of the molecular arrangement of the water produce a stable, ice like structure that can serve as an ice nucleus. Just as for the homogeneous nucleation of liquid in the vapour, two considerations determine the conditions for homogeneous nucleation of freezing: the size of the stable nucleus and the probability of occurrence of embryonic ice nuclei by random rearrangement of water molecules. These quantities depend on the surface free energy of a crystal/liquid interface, which is analogous to the surface tension at a liquid/vapour interface. The numerical value of the surface free energy is not known accurately, but is accepted to be close to 2.0×10^{-2} N/m^2 (20 ergs/cm^2). Consistent with experimental data on the freezing of pure water, this value inserted in the equations predicts that droplets smaller than 5 μm will freeze spontaneously at a temperature of about –40°C. Larger droplets are predicted to freeze at slightly warmer temperatures, also in agreement with most observations. In natural clouds, few liquid drops are thought ordinarily to exist at temperatures as cold as –40°C. Larger droplets are predicted to freeze at slightly warmer temperatures, also in agreement with most observations. In natural clouds, few liquid drops are thought ordinarily to exist at temperatures as cold as –40°C, implying that heterogeneous freezing has occurred at temperatures warmer than –40°C. However, occasional reports of aircraft icing clouds at temperatures near –40°C suggest that droplets sometimes may not freezing until the homogeneous threshold is reached.

29. Some liquid in clouds, as cold as –20°C, is not at all uncommon. This resistance to freezing is contrary to common experience, which indicates that water freezes when the temperature falls below 0°C. Our experience is based on observations of bulk water, in which a single nucleation event anywhere suffices to cause the entire mass to freeze. A cloud is an unusual system in which the water mass is distributed over a large number of very small drops, each one of which must experience a nucleation event before the cloud can be entirely frozen.

30. Homogeneous deposition occurs when vapour molecules from a stable ice embryo by chance collisions. Although the surface free energy of a crystal/vapour interface is poorly known, theory predicts that homogeneous nucleation of deposition should only occur for extreme conditions of supersaturation. More than twenty-fold supersaturation with respect to ice is required at a temperature a few degrees below 0°C, and still higher supersaturations at colder temperatures. Experimental confirmation of the theory of homogeneous deposition seems out of the question because liquid water droplets should always nucleate homogeneously before the supersaturation reaches the higher values required for ice. These droplets will freeze spontaneously at temperatures colder than –40°C, making it possible to recognize ice crystals that might be formed by deposition. In spite of the experimental uncertainties, it is clear that homogeneous deposition cannot occur in the atmosphere, where the necessary extreme supersaturations never exist.

31. Ice crystals usually appear in a cloud in appropriate numbers when the temperature drops below about –15°C, signifying heterogeneous nucleation. Water in contact with most materials freezes at temperatures warmer than –40°C, and deposition occurs on most surfaces at supersaturations and supercoolings less than the homogeneous nucleation values. Thus the nucleation of ice in supercooled water or a supersaturated environment is aided by the presence of foreign surfaces or suspended particles.

32. The foreign material provides a surface or substrate on which water molecules can impinge, stick, bond together, and form aggregates with an ice like structure. The larger the aggregate, the more likely is to be stable and continue to exist. The probability of the heterogeneous nucleation of freezing or deposition depends strongly on the properties of substrate material as well as on the supercooling and supersaturation. The more tightly-bound the water molecules are to the substrate, the greater will be the probability of ice nucleation. In addition, if the crystal structure of the substrate closely resembles that of an ice crystal plane, it will increase the chances of ice nucleation. When the binding and the matching of the crystal lattice are good the supersaturation or supercooling required to nucleate ice on a substrate may be much lower than that for homogeneous ice nucleation.

33. Supercooled clouds in the atmosphere develop and exist in the presence of vast number of aerosol particles, a small fraction of which serve as ice nuclei at temperatures considerably warmer than –40°C threshold for homogeneous freezing.

Precipitation from shower clouds composed of droplets

34. Showery precipitation from cumuliform clouds is generally of greater intensity and short duration than that from layer clouds, the elements usually being of larger mass. The particles which fall from vigorous shower clouds and thunderstorms are usually large rain drops and hailstones, while snow and small pellets of soft hail are usually associated with weak or decaying clouds. The large vertical displacements and correspondingly high liquid water content of air which forms the upper parts of tall clouds favour rapid growth of the precipitation elements by the accretion of cloud water. Moreover, the characteristically strong updraughts tend to keep the growing precipitation particles suspended in these regions of high cloud water content. On the other hand, the strength

of the updraughts is such that the individual cloud masses may reach their level of maximum development and be exposed to mixing with clear air and evaporate before the accretion processes have the opportunity to produce precipitation particles. Evidently it is these features – the rate of the accretion processes (governed largely by the concentration of cloud water), the thickness of the clouds, and the strength of the updraughts which principally govern the formation of shower rains. The great variation on the size of the clouds which produce showers suggests that in many clouds the favourable combination of conditions is only just realized, and in many other only narrowly missed.

35. Bowen and Ludlam investigated the formation of shower by the droplet-coalescence process using a very simplified model of cumulus cloud structure. Ludlam assures that near the base of the clouds a small proportion of droplets, formed upon giant hygroscopic nuclei, attain radii of 20 – 40 μ and are then carried up in an updraught of constant speed when they grow by sweeping up smaller cloud droplets of uniform sizes whose radius is determined by their concentration and the cloud-water content. The latter is assumed to be that corresponding to adiabatic ascent of the air from cloud base.

36. In summary, the elementary calculations made by Ludlam probably describe quite well the relation between updraught, cloud temperature and minimum depth of cloud necessary for shower production, and accord quite well with observations, but only because, on the one hand, they underestimate the growth rates of incipient precipitation elements by treating coalescence and accretion as continuous rather than as stochastic processes, and, as the other hand, they overestimate the liquid-water concentrations of the cloud by assuming the adiabatic values. Moreover they beg the question of how droplets of radius 20 – 40 μ appear at cloud base in the first place. There is a need to revise these calculations using the stochastic approach to the growth process, using more recent and reliable computations of collection efficiency, and cloud models in which the updraught and liquid-water content vary with height in a realistic manner.

<u>The Release of Showers by the Growth of Ice Particles</u>.

37. It is believed that ice crystals in concentrations significant for shower formations (of order 1/1) form in the super cooled parts of cumulus when temperature has fallen to between -10 and -15°C, but that this threshold temperature varies considerably from day today and fro place to place. These variations are attributed to changes in the concentration and properties of atmospheric ice nuclei. Very large variations are observed in the concentrations of crystal which appear when samples of outdoor air are introduced into a supercooled cloud formed in a cloud chamber, but it is not known exactly how these may be related to the concentrations which could occur when the air is involved in natural cloud formation and when crystals may be produced by the secondary processes described.

38. It has sometimes been assumed that shower formation occurs when cumulus summits reach a level at which ice crystals are present in the requisite concentration of about 1000 / m^3 , but clearly some additional development is required if the crystals are to reach a size which will ensure their continued growth inside the cloud into precipitation elements. By analogy, with thiscriteria for shower production by the growth of water drops, Ludlam considers that ice particles must atleast reach a size such that during their growth they have acquired falling speeds exceeding 1 m/s and can fall through several hundred metres of unsaturated air without significant evaporation.

39. The size at which these conditions are fulfilled depends upon the size and structure of water vapour until they reach a diameter of about 100 μ beyond which these are able to collect the cloud droplets with increasing efficiency. At temperatures around -15°C this first stage is accomplished in about 4 min and thereafter the capture and freezing of supercooled droplets leads to the formation of a roughly spherical aggregate containing many air enclosures. The density of such pellets of soft hail usually lies between 0.1 and 0.3 g / cm^3 . For such densities the particle must attain radii of 500 and 300 μ respectively for the conditions listed above to be fulfilled. In a cold cloud with base temperature -10°C and having an average liquid water content of 0.4 g / m^3, growth to such a size takes an additional 10 min, at the end of which the cloud summit will have reached a level where the temperature is as low as -20 or -25°C. The particle may subsequently grow, in the next 10 – 15 min to a radius exceeding 1 mm, fall out of the cloud and reach the ground as a pellet of soft hail. This type of precipitation commonly falls from cold shower clouds in winter times. If the cloud base temperature is well above 0°C such particles will usually melt before reaching the ground. In warm vigorous clouds containing high concentrations of liquid water, the ice particles are likely to develop into true hailstones. In these warm clouds, precipitation is also more likely to be released by the coalescence process. But, in many clouds both processes may contribute precipitation elements to a shower formed inside a cloud of more than minimum size, in which cases, the complete description of shower formation and development must be very complex..

40. Indeed, enough has been said to indicate that even a qualitative theory of shower production is complicated. The formation of a shower requires a favourable combination of large scale and small scale properties to ensure that the growth of precipitation elements is accomplished within the useful life of the cloud. The size, spped and distribution of cloud updraughts, the cloud base temperature, the degree of mixing between the cloud and its surroundings, the distribution of humidity, temperature and wind in the environment, the concentration and nature of the atmospheric aerosol, are all factors which are important and which are subject to great natural variation. Perhaps it not surprising that a quantitative theory of shower rain has not yet been attempted.

Precipitation Processes within Warm Clouds.

41. Warm clouds occur entirely beneath the 0°C isotherm, so that the only comprise water droplets in the stable phase. In middle and high latitudes they can by definition, therefore, be of only limited vertical extent. In tropical areas the processes which produce precipitation from such clouds may extend higher into the atmosphere, so that we find that the more appreciable precipitation amounts and intensities produced by warm cloud tend to be confined to lower latitudes and warmer seasons where warm clouds may attain greater depth. Production of precipitation on all such warm clouds is thus by means of coalescence. Once the 0°C isotherm is reached cloud droplets will become supercooled, and there is thus an increasing likelihood of ice particles being present and subsequent accretion, or operation of the Bergeron-Findeisen process taking place.

42. Coalescence of drops may occur between drops of different sizes which possess different cloud velocities. In the simplest case, and one which is illustrated here, imagine two cloud drops, one large (radius R) and are appreciably smaller (radius r). their geometric centres are separated by the distance y, the “impact parameter”. The larger drop is called the collector drop of sweeping drop, since it will be faster moving of the two. We now consider the likelihood of coalescence. Clearly if y is so great that the geometric centres of the two drops are separated by significantly more than (R+r) then no collision can take place. Equally clearly collision is normally certain if the two centres lie on exactly the same path. Between these two extremes four special conditions may be imagined, tow of which (ii & iii below) stem from the two theories, collision and Bergeon Findeisen process:-

a. Where Y<(R+r) but the size differential is considerable (r<<R), the smaller drop may become caught up in the flow of air around the larger drop and may be swept around the larger, so that coalescence will not occur.

b. If the two drops are of very similar size, and close the “wake effect” may cause the two to be drawn together and coalescence may occur even though y>(R+r)

c. Under geometrics similar to case (ii), the possession by adjacent drops of unlikely electrical charges will produce a similar effect

d. When y is very slightly less than (R+r), but a thin layer of air is trapped between the two drops, collision may again be averted.

43. The efficacy with which collision may occur between two adjacent drops is measured by collision efficiency (E). The mathematical relationship indicating the collision efficiency between adjacent water drops is not a perfect one, since collision may be encouraged or constrained by any one of the above constraints. It can however by estimated by

$E = \frac{Y_o^2}{(R+r)^2}$ where Y_o is the critical clue of y separating collision from deflection. The value of Y_o is dependent on prevailing temperature and pressure which have an impact on air density and viscosity.

44. A further significant problem which causes theoretical derived efficiencies to diverge strongly from lab obtained one is that even if collision seems likely, coalescence does not necessarily occur. The smaller drop may simply bounce off the larger, or even calve a number of smaller drops as a result of the impact of the collision. This may be the result of the situation outlined in (d) above

45. Thus we may invoke a further index, the coalescence efficiency which simply expresses the proportion of collision resulting in coalescence. This coalescence efficiency decreases markedly as the size of the two drops (reach) approach one another. As in the case for the collision efficiency, the coalescence efficiency is extremely difficult to verify experimentally. The combined effect of the two indices, known as the collection efficiency, determines the rate of drop growth within a warm cloud, and is clearly very considerably influenced not merely by drop size and speed, but also by relative drop trajectories (very few will conventionally fall in parallel) and therefore, again, the nature of within-cloud air movement. Of course we must remember that in a typical cloud there are considerable more than two water drops. Further, the drop size distribution within a cloud is also of great importance.

46. Precipitation production by a warm clouds is, however, in spite of the apparently obvious and clear-cut nature of the process described above, a difficult process. By definition warm clouds are shallow clouds, for if they attain any appreciable vertical development, even in the tropics, the 0°c isotherm will be reached and other processes will begin to dictate particle growth above that level, and have a knock-on impact at lower elevations also. However, the opportunity for drop growth to precipitation size is increased where there is greater cloud depth. The likelihood collisions is increased where there are marked up and downdraughts. If such currents exist then it is in turn likely that the cloud will attain considerable thickness, and in turn probable that at least a part of the cloud will exist above the 0°C isotherm. So far precipitation to be produced by collision within a warm cloud it is most likely in the absence of strong vertical currents. The greater opportunity for collisions will also occur in those clouds with a broad range of drop sizes. This however is further complicated by the tendency for many warm clouds whose droplets have grown purely by condensation, initially to contain a rather narrow range of droplet sizes.

Precipitation Process within Cold Clouds

47. Cold clouds include all clouds or portions of clouds above the level of the 0°C isotherm, thus indicating clouds of both the mixed and cold types once the cloud temperature falls below 0°C cloud particles (either solid or super cooled liquid down to -40°C) may grow to produce precipitation-sized entities by one of two further collision processes. The temperature band between -40°C and 0°C is , one which may be associated with rather special characteristics, since a cloud of such a temperature may contain both solid and super cooled liquid elements. Clearly the processes will also apply to collision between two ice particles, the process of aggregation, whereby the ice particles combine directly to form progressively larger particles until these become heavy enough to fall from a cloud as precipitation. However, because we may have both solid and liquid elements in these “warmer” cold clouds we may have both solid and liquid elements in these “warmer” cold clouds we may also have collision and growth by means of accretion: the collection by an ice particle of super cooled water drops by collision. Accretion is again subject to the same dynamic processes as those governing coalescence and aggregation, although it should be noted that in the accretion process the problem of particles bouncing off one another, encountered for coalescence and aggregation does not occur.

48. Whilst the initial formation of ice particles within clouds is still inadequately understood, once formed, crystalline ice may grow, although rather slowly, because it finds itself in a cloud environment which is effectively saturated with respect to water. Maximum rates of growth are determined by the local temperature and pressure environment in a cloud, but in the lower atmosphere say between the surface and 500 mb, maximum rates occur at around -14 to -17°C.

49. The ice crystals which are formed may assume a wide variety of different shapes (habits) which are apparently related to the temperatures at which crystal growth is taking place. There are two basic types: prism-like or plate-like. It is interesting, however, that the temperature range at which the most complex forms dominate (-10 to -20°C) also contains the range of temperatures at which growth is most rapid.

50. The further combination of ice crystals by aggregation within a cloud is complicated by two factors when compared with growth of water drops by coalescence. First the terminal velocities of ice particles tend to be very slow, and for the mere complex and platforms, varies very little with increasing size. Even the remaining simple, columnar forms, adopt slow-terminal velocities since their size is normally very small. The corresponding range of terminal velocities, too, is very small. The corresponding range of terminal velocities, too, is very small. Generally the terminal velocity of pure ice crystals is less than about 0.1 m/s, and is commonly around 0.05 m/s. This narrow range and the slow progress of these pure ice structures limits opportunities for growth by aggregation. Second, the solid nature of particles naturally acts to cause colliding crystals to bounce off one another, although this may be compensated for in the case of complex dendrite forms since the overall crystal form may cause colliding crystals to interlock. The opportunities for cloud particle growth to precipitation sized entries by aggregation are therefore, somewhat limited.

51. Growth beyond the small crystalline stage involving collision may be considerable assisted by the existence of a very thin water film on the surface of an ice particle. This film will occur normally wherever both ice particles and supercooled water drops coexist in clouds resulting from the different saturation vapour pressures over water and ice and indicate that ice particle growth is taking place at the expense of adjacent supercooled water drops. Collision between two such ice particles will trap the thin layer of supercooled water between their surfaces. This will almost instantaneously freeze, cementing the two ice particles together. The efficiency with which this process may occur is again a function of temperature and it appears to be most effective at the higher sub-zero temperatures, notable between -4 and 0°C. The production of snow flakes occurs by this process, so that the largest snow flakes are produced in the warmer regions of a cloud. Thus we find that when it is snowing the size of the flakes reaching the ground generally decreases with decreasing temperature. The very largest ("warm snow") occur when the cloud temperatures are just below freezing and surface temperatures are at or a degree or two above freezing.

52. The process outlined above leads us conveniently into a discussion of the accretion process. Although the terminal velocities of ice (crystal) particles are small in magnitude and range, differential air motion within a cloud of mixed ice and supercooled water will still result in collision between the tow. This is therefore an efficient means of particle growth to particles of precipitation size. Within the cold portion of the cloud these particles are frozen, since the collision between an ice particle and a supercooled water drop often results in the almost instantaneous freezing of dry growth, where all the supercooled water is frozen on to the ice particle as it is collected. When sufficiently large, of course, such frozen particles may pass into portions of the cloud above the 0°C isotherm, begin to melt, and often reach the ground as a liquid drop. Further the particles so produced, particularly the more complex forms, are very fragile, so that small splinters of ice are easily broken away. These may now act as further freezing nuclei, so accelerating the process of growth of precipitation within a cloud. Similar small splinters may be produced when freezing is rapid and the bulk of water to be frozen is comparatively large. The outer portion of the drop will freeze first, so that subsequent freezing of the water within the drop results in the rupture of this initial ice casing, since on freezing, water expands. The extruded ice splinters are thus shed as small fragments, which may again accelerate the precipitation production process.

53. Clearly a collector ice particle on its passage through a cloud may gather up super cooled water in its path at a wide range of rates. The rapid gathering of drops will result in rapid growth, and in clouds which possess a high water content the total volume of water collected and frozen on a particle may be considerable under these circumstances the water drops may have a chance to combine before freezing, so that layers of clear ice will build up around the original nucleus. The resultant particle may be quite large and particularly dense, commonly producing a form of hail. However, if the amount of water collected is very large and the initial temperature is high enough, then the quantity of latent heat released on freezing may be sufficient to raise the particle temperature near to freezing point. The remaining water lands to be held by the complex shape of the ice particles so that the resultant ice-water combination is often called ‘spongy ice’ formed by the process of ‘wet growth’. Ultimately, as long as the particle temperature or correctly its wet bulb temperature remains at or below freezing point, and when fewer super cooled drops are encountered, it becomes solid ice. However, under certain conditions, a chain reaction may be started and some of this water is later thrown off to produce new super cooled drops.

54. Where the cloud possesses a much lower water content, so that the drops are more sparsely distributed, and the rate of accretion is much slower, water drops collected may freeze individually. This is the process of ‘riming’. The relatively large number of individual drops swept up in this way will trap air between them, so that the resultant particles, as well as tending to be small, because of the slow growth rate, comprise ice which is opaque due to the entrapped air. Conglomeration of such small frozen drops are termed ‘graupel’. These particles are relatively fragile and quite soft, and are of appreciable lower density than their clear ice counter parts.

The Bergeron – Findeisen Process

55. Although the processes of precipitation formation in cold clouds outlined in the previous section are important components in the production of precipitation, it is now generally accepted that a still more important means of obtaining precipitation – sized particles involves the B-F process. A large majority of precipitation clouds extend upward above O°C isotherm and, crucially, contain appreciable thickness between O°C and -40°C where both ice and super cooled water may exist together. Further shower activity often occurs from cumiliform clouds which have glaciated into the cumulonimbus stage, rather than the original cumulus, and where the upper cirriform portions may 'seed' the lower cumuliform cloud with ice particles. In an alternative scenario precipitation may be produced beneath multi-layered stratiform clouds existing at a variety of heights and possessing different physical make-up : some are entirely of ice; others, mixtures; and the lowest are liquid. In this case, again, ice particles from the upper, colder, layers may seed mixed or warm clouds beneath with ice particles. A similar process using frozen CO_2(dry ice) or certain chemical compounds, is used in cloud seeding, in an attempt to induce clouds to produce precipitation.

56. The importance of ice particles to the production of precipitation in clouds was considered to be important even when the science of meteorology was in its infancy. Alfred Wegener, in 1911, proposed that a very efficient means of particles growth in a mixed super cooled liquid/solid cloud environment could be postulated involving preferential growth of ice particles at the expense of nearby super cooled water drops, due to the differences in saturation vapour pressures over plane water and ice surfaces.
57. The idea was developed later by Bergeron (1930) & Findeisen (1935) so the process is known after their names. Although initially the process was thought capable of explaining all precipitation, subsequent observation and development of the theory out side cool, temperate Europe and N America has illustrated that precipitation also occurs from warm clouds, particularly in the tropics. The process is, however now generally acknowledged to be largely instrumental in producing the more intense types of precipitation, such as that produced by cb clouds. The type, form and intensity of precipitation produced naturally depends on the detailed nature of the cloud environment itself. Very large ice particles may develop in an environment where initially they are few in number, and in most cases particle growth will be completely rapid. It is estimated that under typical conditions precipitation – sized particles may develop after about 10 to 30 min.

57. Accepting that different saturation vapour pressures apply over ice and super cooled water below O°C, then the process is best understood by considering step by step what happens to two adjacent particles, one solid and other super cooled liquid. Let us assume that the ambient temperature within a cloud is -10°C, so that the saturation vapour pressure over the ice is 2.60 mb and over the water, 2.86 mb. We shall, for the purposes of simplicity ignore the impact on these values of the small radius of curvature of the drop. Now, if the vapour pressure in the cloud environment is in fact 2.60 mb, then the air is unsaturated with respect to water, but saturated with respect to ice. This means that evaporation will take place from the super cooled water drop until the drop is in equilibrium with the air around it, and results in turn in the air becoming super saturated with respect to ice. Because of this, vapour will now be deposited directly on the ice particle until once again the air is saturated with respect to the ice. Once again we have the initial situation, with evaporation taking place from the super cooled water drop, so that the mass of the water drop is once more decreased. The process will continue until the water drop has ceased to exist.

58. The process is probably at its most effective where the temperature is between about -10 and -30°C, where both ice particles and super cooled water drops are numerous, although in theory the process will operate throughout the range 0 to -40°C. Above about -10°C, however, there will be relatively few ice particles, and below about -30°C there will be too small a liquid water contents. Most convectional cumiliform clouds of appreciable vertical extent will possess such mixtures. In a very large Cb, and in situations where several stratiform layers exists, such as in temperate frontal systems, the higher cloud layers seed the cloud layers beneath, which 'feed' on this meal of particles to produce precipitation-sized drops. Bergeron termed these two groups of clouds 'releaser' clouds (typically Cs and As, or the Ci anvil of a Cb) and 'spender clouds' (Ns or St, or the base of a Cb). The mechanism is today frequently referred to as the 'seeder-feeder' mechanism.

59 In very broad terms, the vast majority of clouds produce no precipitation for the following reasons:-

a. They are too short lived. In order for cloud water droplets or ice particles to become sufficiently large a considerable residence time is necessary before they become large enough to fall from the base of the cloud.

b. They are too shallow. A reduced cloud depth means that there is little vertical motion, and vertical motion affords the opportunity for cloud droplet growth by collision.

c. They occur too high in the atmosphere. High and medium level cloud suffer from three major problems. Firstly, they are found at a level in the atmosphere where temperatures are very low, so that moisture availability is small. Second, with the exception of convectional clouds with considerable vertical development through all levels, the degree of vertical motion is small at the medium or high levels. Any clouds that form therefore tend to be tenuous and/or thin. Third, any precipitation falling from the base of medium-or high clouds must fall through a considerable depth of atmosphere. Often considerable thicknesses of this are unsaturated, so that there is a greater chance of evaporation or sublimation of the falling drop or particle.

60. Conversely those which do produce precipitation possess are or more of the following characteristics:-

a. They have existed for some considerable time, thereby increasing opportunities for multiple collisions, and are probable more dynamically active and contain considerable different vertical motion.

b. They are of significant depth: again affording greater opportunity for multiple collisions, and possessing considerable differential air motion, particularly in the vertical. In addition this will increase the likelihood that the cloud will include an appreciable thickness in the crucial 0 to -40°C temperature range.

c. They contain high liquid water content, if above 0°C.

Precipitation Types

61. The final means of classifying precipitation commonly combines the general characteristics of precipitation with its mode of occurrence, but is essentially an expression of origin: precipitation type. We may consider three main types of precipitation: conventional, cyclonic and orographic. These are all terms that have close relationships between intensity, duration and scale of occurrences themselves functions of the processes discussed earlier, provide conversant means of subdividing precipitation. We also find that, because precipitation form and mode at the ground are closely linked with the processes which went into the development of the precipitation in the first place, the three different precipitation types are often quite closely matched with different forms and modes of precipitation.

Convectional Precipitation

62. It is produced as a result of rapid uplift in the atmosphere, and is associated with Cu and cb clouds. It operates generally at the small and medium scale, typically forming cells of more intense precipitation over areas measuring tens or at most, hundreds, of square kms. These cells may occur individually as discrete thunderstorms or showers. They may be grouped at the mesoscale to form complexes of numerous intense rainfall cells, and these clusters may be organized in a linear fashion, or they may occur, still as discrete cells, but over a much wide area, associated with perhaps a tropical storm / cyclone. Individually, their total lifespan is also of limited extent, since the thermals which produce them directly (as with a large day time thunderstorm) or indirectly (where the convection is forced) are often confined to times when insolation is strong. The range of life span is thus typically between about 30 min and 12 hours. Cells which develop in situ and then may decay, either again more or less in situ, or follow a track determined by the general atmospheric circulation. In the former case a considerable amount of high intensity precipitation may result over a comparatively small area, and in the latter the high intensity precipitation will produce smaller point totals, but spread along a long but relatively narrow ground track, typically less than about 10 km. Their origins are therefore varied, and not always simply the result of free convection. Any organisation into linear bands (as for example, along ‘squall lines’ or ‘sea breeze fronts’ or within temperature depths) or spiral arms (as in tropical cyclones may be the result of larger-scale dynamic processes active within the atmosphere, or perhaps the consequence of localised convergence of air near the ground. There is thus an area of overlap between them and the more widespread precipitation associated with depressions or cyclones. This overlap is an important one, and the incorporation of numerous convection type intense rain cells within many larger precipitation producing disturbances in fact provides the key to an understanding of many larger precipitation producing disturbances in fact provides the key to an understanding of many observed mesoscale variations of rainfall within the general rain areas associated with temperate depressions or tropical cyclones. Precipitation is usually produced as a result of the B-F process, since the clouds producing the precipitation possess considerable vertical development, so that high intensity precipitation is produced. Some of the more intense precipitation reaching the ground is often in the form of hail or ice pellets.

Cyclonic Precipitation

63. Cyclonic type precipitation is produced primarily as a result of the circulation of the atmosphere itself at the meso and macroscale, and includes precipitation from disturbances which range in size or magnitude from small low pressure area, through temperate latitude frontal depressions, to the very active tropical depressions and cyclones, and produce large amounts of rainfall over wide areas, although the total rain area associated with many temperate latitude frontal depressions. The prime process involved in all these systems is that of horizontal convergence taking place on a considerable scale within the troposphere. The impact of convectional activity, is however important in producing high-intensity bursts of precipitation. Overall, precipitation areas are typically of the order of hundreds to, very occasionally tens of thousands of square kms. Precipitation intensity is rarely high over large areas, and the precipitation may be intermittent and of virtually any form, dependent on atmospheric conditions at the time.

64. The total life span of such precipitation events is considerably more than the case for convectional events, being measured in days rather than hours. A typical temperate latitude frontal depression may retain its identity as a discrete system, for example, for upto five days or a week. Some tropical cyclones may last longer than this. An important feature is of course that they may move considerable distances in their life time.

Orographic Precipitation

65. The final category, orographic precipitation, is commonly assigned a type to itself mainly because the precipitation produced is tied to a particular topographic barrier, and therefore the precipitation is not spatially mobile, and considerable amounts may accumulate in a very restricted area. Precipitation may produced on either the windward side of the barrier, or, much less commonly, to its lee as a result of lee wave activity. Precipitation intensity will vary according to the magnitude of the processes involved, which in turn will depend on the nature of the local lower tropospheric circulation and its stability. A sustained and deep, moist flow against a relief barrier produces the most significant orographic rainfalls. Such conditions prevail in tropical and temperate areas where a moist onshore flow is impeded and uplifted by mountain ranges near the coast, for example, the temperate west coasts of parts of Europe and North America, the South Island of New Zealand (Griffiths & MCSaveney,1983), or the temperate and tropical rain forest areas along the eastern edge of the Dividing Range in Australia (Hobbs, 1971; Gentilli, 1972). In temperate regions prolonged warm sectors in frontal depressions can be very important and yield copious precipitation amounts, though of moderate intensity, when uplifted by relief (Douglas & Glasspoole, 1947), whilst mesoscale intense rainfall may also be triggered orographically (Harrold, 1973; Hobbs, 1978), and persist downward or the higher ground (Harrold, 1973).

66. Where there are pronounced seasonal or shorter-term changes in lower tropospheric airflow then rainfall distributions around a topgraphic barrier will shift accordingly (see for example, Coutts, 1969; Nieuwolt, 1968; Nordo, 1972; Sawyer, 1956; Sumner, 1975, 1983; Sumner & Bonell, 1986). The scale and extent of orographic precipitation if of course closely governed by the height and longitudinal extent of the relief barrier, but even comparatively low hills (only tens of metres in height) may produce consistent and notable increases in precipitation (Bergeron, 1968). The form of precipitation may include intercepted for and leaf drip as well as the range of 'normal' precipitation types. Most commonly, however, intensities are low to moderate, being of drizzle, rain or snow.

67. The task is now to uncover the detailed nature of precipitation areas both three-dimensionally, and in terms of the precipitation produced at the ground using precipitation process, form, characteristics and type as guides. Since type and process may be linked together in many cases, and since the precipitation characteristics of intensity, duration and areal extent are so closely interlinked and may also be linked to process and type, the task may be logically approached by studying precipitation areas based on their scale of operation. Chapter four thus deals with the workings of precipitation areas at the small and mesoscale, including conventional storms. Convectional processes, and the small but intense precipitation areas they produce, are also key features within precipitation-producing systems at larger scales, so that the processes laid down in chapter Four are fundamental to an understanding of many aspects of the larger-scale systems. The very largest systems of all are extremely active and dynamic features of the atmospheric circulation involving the exchange and movement of considerable quantities of energy and moisture. These are subdivided on the basis of where they occur, so that Chapter Five deals with temperate latitude frontal depressions and Chapter Six with tropical systems. Intermediate in size between the smaller convectional elements and these larger systems are a number of precipitation-producing elements, involving the localized and regional effects of differential surface heating and orography.

TASK 27 : NOR' WESTER

Introduction

1. Thunderstorms form all over the world specially along the equatorial and tropical areas. Some areas are more susceptible to thunderstorms but some areas are not. During the pre-monsoon season, there are some local severe thunderstorms form over Bangladesh, West Bengal and Assam, these severe thunderstorms are commonly known as Nor'wester. Though they occur locally, their violence and destruction often become very significant. The Nor'wester does not approach always from the same direction and their time of occurrence is not always the same. However, the majority of the Nor'wester usually starts from West Bengal and Chotonagpur in the early afternoon and proceeds in a Northwest-Southeast direction. There could be some variation with respect to the origin of Nor'wester to a certain extent depending on the Synoptic Situation.

Aim

2. The aim of this chapter is to provide the knowledge on Nor'wester in detail.

Definition

3. In the month of March, April and May, ie during pre-monsoon period thunderstorms that usually originates in West Bengal and Chotonagpur, some of which reach severe thunderstorm or tornado violence, are termed as Nor'wester because of their pro-tendency to move from north-west.

4. In Bengali Nor'wester are popularly known as 'Kal Baishakhi' due their black appearance and period of formation in the Bengali month Baishakh.

Climatology of Nor'wester

5. Nor'wester activities in the region of Bangladesh, West Bengal and adjoining areas are directly linked up with the apparent movement of the sun towards north, from winter season to pre-monsoon season, causing steady rise of temperature over southern India and gradually extending to the north. Such a situation becomes increasingly prominent from March and prolongs up to the end of May. Frequency of Nor'westers usually reaches its maximum in April. Whereas it is comparatively less in May and minimum in March. Though the frequency of Nor'wester is less but intensity is more in March. There are occasions when Nor'wester has been observed to occur in late February and early June. The occurrences of Nor'westers in late February can be attributed to the early withdrawal of winter from Bangladesh, Assam, Bihar, West Bengal and adjoining area, while those in early June are due to delay in the onset of Southwest Monsoon over the region. The Nor'wester forms over West Bengal and Chotonagpur in the early afternoon and moves gradually towards southeast, and most of the Nor'wester visits Bangladesh in between 1700 hours and 2100 hours.

Causes or Favourable Conditions for Nor'wester

6. The following are the necessary condition favourable for Nor'wester:

a. A low-level humid and warm layer of air extending from surface to 5,000 feet or 7,000 feet.

b. An upper level dry and cold layer of air, which will enable the lower ascending air to ascend further to higher level.

c. One or more of the following initial lifting/triggering action:

(1) Insolation.

(2) Inflow of moist air in the lower level.

(3) Convergence of air or katabatic flow to enable the lower layers atmosphere to ascend.

(4) Eastward passage of Western Disturbance (WD).

7. Koteswaram and Srinivasan (1958) have shown in their investigation that the Nor'westers fail to occur in the Gangetic West Bengal and by inference over Bangladesh and Assam in the absence of southerly winds up to at least 3,000 feet in spite of other conditions being fulfilled.

Classification of Nor'wester

8. According to the place of origin, movement and frequency Nor'westers are classified as Type 'A', Type 'B', Type 'C' and Type 'D'. The different Types of Nor'wester are shown in Figure 1 in the next page.

a. Type'A'. Type 'A' Nor'wester occurs simultaneously over a large area and generally in the afternoon. 70% to 80% Nor'wester are of this type. They usually start in West Bengal and Chotonagpur in the afternoon and proceed from northwesterly direction with a speed of 48-64 kph.

b. Type'B'. They originate in the sub-mountainous districts of North Bengal and move southwards mostly during the night and early morning. They move slowly at a speed of 16-32 kph (10-20 mph) to Meghna estuary from north. About 10% Nor'wester are of this type.

c. Type'C'. They originate over hills of Nagaland, Manipur and Mizoram and travel westward. They are very rare and come from northeasterly direction.

d. Type'D'. They are very similar to Type 'B' but their place of origin is near the Khashi hills. They move usually from north to south. They are about 5% only.

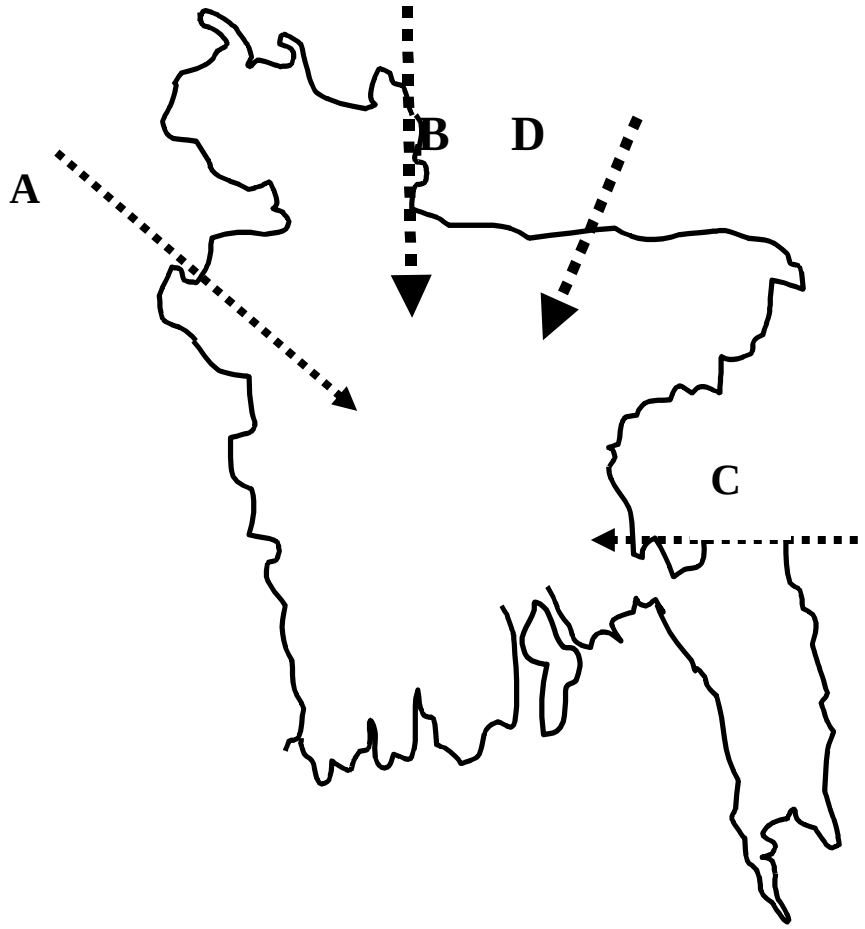


Figure 1: Different types of Nor'wester

Mechanism of Formation

9. During winter season northern hemisphere remains colder as sun shines obliquely over it. With the advance of season, the sun apparently moves toward north and northern hemisphere gets more heat from the sun. As the specific heat of land is smaller than that of the water, so land becomes hotter quickly than the sea area. As a result, low pressure forms over land and high pressure remains in sea area. Thus, during the pre-monsoon period a low or trough of low lies over Gangetic West Bengal which causes to flow humid/moist and warm winds from south (Bay of Bengal) to the low-pressure area at the lower level. During winter season Subtropical Westerly Jet blows from west to east over India Sub-continent which is, of course, dry and cold. The depth of the moist layer in the lower atmosphere increases as the season advances. During this pre-monsoon period conditional instability exists. The word *conditional instability* refers that if the atmosphere is stable up to a certain height and the parcel could be moved .

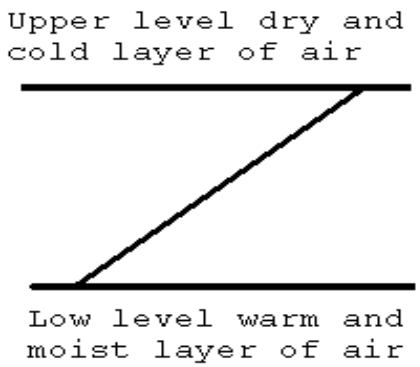


Fig 2: A gap in between the low-level warm & moist layer and upper level dry & cold layer.

upward to the level of free convection (LFC), then it would result the instability. There is a gap between these lower level moist and warm layer of air and upper level dry and cold layer of air which acts as a barrier between them. If any external force or triggering action breaks the barrier or gap then the moist-warm air and dry-cold air start mixing. It happens when the moist-warm air is pushed upward by any of the triggering action. When the moist-warm air rises up and crosses the LFC, then it continuously goes up and when it reaches the freezing level then it produces saturation and ultimately to condensation to form clouds in a deep layer. These vertical developed cumulus (cu) and cumulonimbus (cb) clouds producing thunderstorms, some times tornado, are called Nor'wester.

Duration of Nor'wester

10. Duration of Nor'wester depends on:

a. Strength of the triggering actions worked behind the development.

b. Intensity of the vertical instability.

11. **Frequency of Nor'wester with Duration.** Normal duration with frequency of the Nor'westers are as follows:

a. In 30% cases, duration ranges from 1 to 1.5 hours.

b. In 20% cases, duration ranges from 1.5 to 2 hours.

c. In 40% cases, duration ranges from 2 to 4 hours.

d. In rest 10% cases, duration ranges more than 4 hours.

Weather Associated with Nor'wester

12. The following weather are observed in Nor'wester:

a. **Moderate to Heavy Rainfall.** The average rainfall associated with Nor'wester is only 12 mm but in some cases it may range from nil to 50 mm or more.

b. **Moderate to Strong Gusty/Squally Winds.** Majority of Nor'wester are associated with squalls. The most common wind speed is 25 to 50 knots. In few cases, wind speed may reach 100 knots or more.

c. **Moderate to Severe Hail Storms.** Some of the Nor'wester are accompanied by hail with sufficiently large size to damage the aircraft and other installations. Although the period involved in transiting the hail area of a thunderstorm may be relatively short, damage from large hailstones can be considerable, especially to radomes, transparencies, upper and leading surfaces including deicer equipment. The greater is the aircraft's speed, the greater is the damage. Small hailstones cause only superficial damage but large one may make holes on the body of aircraft.

d. **Moderate to Severe Icing.** Moderate to severe icing is possible in a highly developed Nor'wester.

e. **Vertical and Horizontal Wind Shear.** The speed of updraft, the vertical current, in Nor'wester may be as high as 30 to 40 feet per seconds.

f. **Moderate to Severe Lightning.** Aircrafts are very often struck by lightning. Moderate to severe lightning may cause:

(1) Damage of aerials, hinge bearings and denting

(2) Background crackle on the radio receiver.

(3) Damage of electrical and compass systems.

(4) Temporary blindness of pilot.

g. **Low Cloud.** The height of the base of the lowest cloud may come down as low as 500 feet or below with overcast sky condition.

h. **Thickness of Cb Cloud.** Top of the Cb cloud may reach as high at 40,000 feet. In some cases top may reach upto 60,000 feet.

Forecasting Technique of Nor'wester

13. The area over which Nor'wester occurs varies usually from one day to other mostly depending on the synoptic situation at the surface and upper level. Identification of this area with positive threats of the storms is one of the most difficult problems faced by forecaster. To see the basic favourable conditions being fulfilled, a forecaster within a short span of time has to adopt certain quick techniques to make a decision about occurrence or non-occurrence of Nor'westers. The techniques are:

a. To determine the stability indices.

b. To locate the dynamic heat low over the vulnerable area like north Orissa, Bihar, Gangetic West Bengal or south-western part of Bangladesh.

c. To find out the middle and upper-level jet shear.

d. To see that the positive area is greater than the negative area in the thermodynamic chart.

e. To find out the 12-hours surface pressure falls.

f. To see the low-level moisture influx upto at least 3000 feet (1 km) form pilot balloon chart.

g. To locate the area of low-level convergence from pilot balloon charts.

h. To carefully interpret and follow the radarscope observations.

Conclusion

14. Nor'wester is one of the atmospheric monsters. It causes great damage to men and materials both in the air and on the surface. Since it cannot be denied, precaution should be taken to minimize the effects of this. With the advent of Nor'wester period we should take more care about the day-to-day weather warning issued by the Meteorological Squadron during the approach of Nor'wester, which can safe lives and properties from destruction.

TASK-28 : SOUTH WEST MONSOON

Introduction

1. The name South West Monsoon is used both for the phenomena of rains & south-westerly surface winds & the period during which they occur. Though the Arabic root word 'Mausam' simply means 'season' in meteorological point of view monsoon has come to mean the seasonal reversal of wind (the prevailing wind direction shifts by at least 120° between January and)July) & such changes take place even in higher latitudes and stratospheric winds. Over most of India, Bangladesh & South - West Asia colossal differences are noticed from preceding or following months or the winter (also called by analogy North-East Monsoon). The distribution of rain fall shows that more than 75% of the annual rain fall is received by the country during South-West Monsoon period of June to September & for the rest of the year only 25% or less. Winds are south-westerly over the Bay & the Arabian sea in July compared to North-easterly in January. The monsoon air mass is Maritime & moist in great depth as against the winter dry continental air. Temperature in the troposphere decrease to north in winter, while monsoon reverses this gradient. The Westerly Jet Stream of the other seasons is replaced by the easterly jet Stream. most of the annual rainfall of the densely populated areas of the world viz. India, Bangladesh, South-East Asia, Japan & parts of China is due to the phenomena of the South-west Monsoon. So meteorologists spared no efforts to fully unrevel its various facts.

Monsoon Circulation

2. The term 'monsoon' is derived from the Arabic word 'mausim', which means season. Since early times, the term monsoon has been used to signify any annual climate cycle with a dominant seasonal wind reversal. Over vast oceanic areas, the tropical circulation undergoes very little seasonal variation, except for some minor latitudinal shifts and intensity changes. On the contrary, the circulation varies substantially and displays a distinct seasonal rhythm over the tropical continents. Over the oceans, evaporation consumes a high proportion of the incident radiation, which is also rapidly absorbed by the water surface and spread over greater depths by waves and turbulence, and dissipated to other latitudes by ocean currents. But over the continents the incoming radiation is mostly used to warm the earth's surface, so that temperatures in these regions reach very high levels owing to the much lower heat capacity of the soil compared to water. This warming over the tropical continents in early summer produces thermal low-pressure areas which gradually take on some functions of the equatorial trough, thus forming a new region of convergence. The trade winds from the winter hemisphere cross the equator, slow down and create a minor area of convergence owing to their change in direction caused by the reversal of the Coriolis force. Subsequently, the air accelerates towards the low-pressure area over the continents. In winter, the continents experience relatively low temperatures and high surface pressure; winds are re-established towards the equator which are similar to the trade winds, though they are not stable in speed and direction.

Monsoon Areas

3. Thus the tropical continents and adjacent oceans experience a semi-annual reversal in wind direction characteristic of monsoons. Ramage (1971) formulated four simultaneous criteria to delineate the monsoon areas:

a. The prevailing wind direction shifts by at least 120 deg between January and July.

b. The average frequency of prevailing wind direction in January and July exceeds 40%.

c. The mean resultant wind in at least one of the months exceeds 3 metre per sec.

d. Fewer than one cyclone-anticyclone alternation occurs every two years in either month in a 5 deg latitude-longitude rectangle.

4. Based on these criteria, Ramage delineated the monsoon region of the world as shown in fig 7.1, which is widely adopted. The monsoon region includes almost half of the African continent, South and East Asia and northern Australia. These areas are inhabited by more than half of the world's population for whom the monsoon rainfall is essential to their survival and prosperity.

5. To include in the definition of “monsoon region”, the areas where the surface position of ITCZ has a relatively small annual oscillation in positions like Eastern Pacific, Central and South America and Western Atlantic, Asnani (1993) proposed the definition as “It is the region which lies between the latitude 5 degree north of the northern most (July) surface position of ITCZ, and the latitude 5 degree south of the southern most (January) surface position of ITCZ, on climatological basis.”

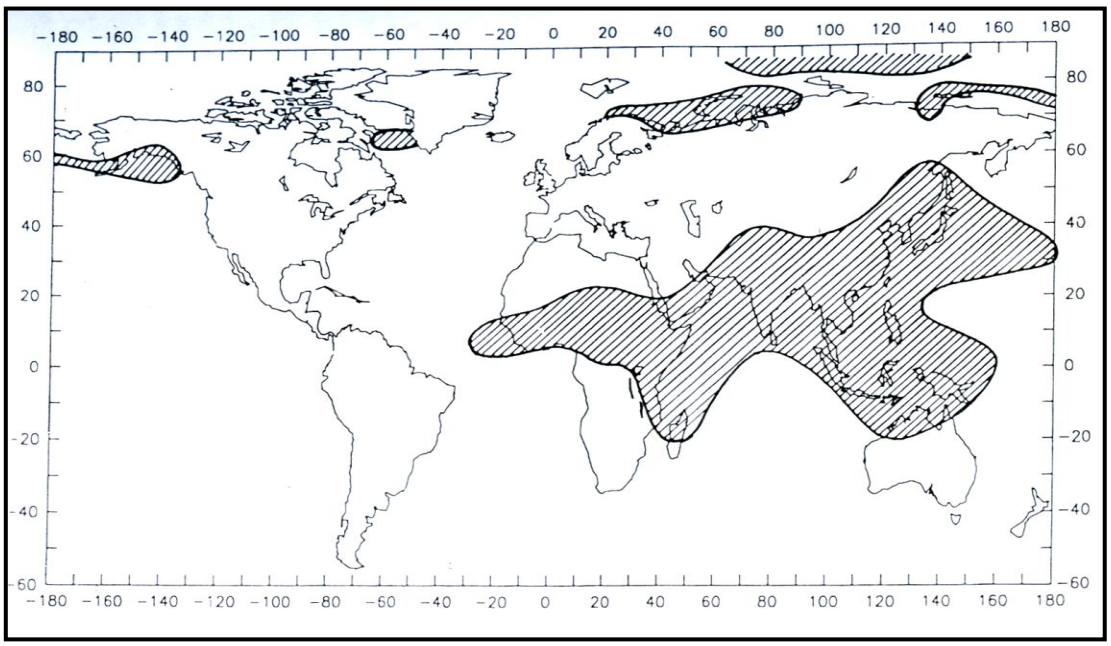


Fig 7.1 The monsoon regions of the world (After Ramage, 1971)

6. **The Asian Summer Monsoon**. Nowhere else on the globe is the annual reversal of wind and rainfall regimes as spectacular as in the North Indian Ocean and the adjoining land areas in summer. Asia is the largest continent on the earth and its tropical zone has the right conditions for the circulation to develop with predominant winds of one direction in winter and of the opposite direction in summer. The monsoon circulation is most pronounced over a wide area, from Pakistan in the west to Japan in the east. It is now a well-established fact that the Himalayan mountain range plays a crucial role in the genesis and development of the Asian monsoons.

7. During the summer season, at lower levels in the atmosphere, the seasonal wind reversal and the associated south-to-north migration of the ITCZ is modified by the land ocean contrasts and orographic barriers. These features accentuate a vigorous monsoon activity over South Asia practically all through the summer. The equatorial trough migrates to its northernmost position (30 deg N) over South Asia during the northern hemispheric summer. This migration results in a pressure gradient from the equatorial region to the region of maximum heating and lowest pressure, which is associated with a quasi-geostrophic westerly current deflected by surface friction towards the low-pressure area in the subtropics. Thus, while the Asian summer monsoon is a consequence of the thermal differences between the land and the sea in general terms, it is primarily due to the seasonal shifting of thermally produced planetary belts of pressure and winds under continental influences.

Morphology of Monsoon Circulation

8. The south Asian Monsoon circulation is an important component of the global general circulation. It is by now generally recognised that the monsoons arise due to the land-ocean temperature contrasts during summer and winter. Global temperature and pressure fields for both summer and winter at the surface and at 400 hPa level reveal the following important points, especially regarding over northern hemisphere:-

a. Continents are hotter in summer and colder in winter compared to the oceans.

b. At the surface lower pressures prevail over the warmer regions while higher pressures prevail over colder regions, relatively speaking. At upper levels the reverse is true.

c. Over the Afro-Asian land mass region the low and high pressure systems, at the surface during summer and winter respectively, are truly continental in scale.

d. The position of the surface temperature maxima or minima do not coincide exactly with the position of pressure minima and maxima respectively. However the reverse association between surface temperature maps and pressure maps is so striking that we can safely conjecture that the differential temperature field is the casual factor for the pressure field.

e. The temperature gradients are strong both in the north-south and in the east-west directions. Over the tropics the north-south temperature gradient reverses with seasons. Over the middle latitudes east-west temperature gradients show reversal with seasons.

9. The mean sea level pressure fields during January and July over Asia and neighbourhood (eastern hemisphere) show the lowest pressure occurs in July over northwest India-Pakistan. In January the highest pressure occurs over Siberia. Thus the annual cycle of the surface pressure has the largest amplitude over the Asian continents.

10. The wind field (streamlines and isotachs) at 850 hPa and 200 hPa during winter (December, January, February) and summer (June, July, August) show the strongest westerly jet stream is seen over Japan and neighbourhood in winter at 200 hPa. In summer we see the well marked anticyclone over Tibet called the Tibetan anticyclone and easterly jet stream to the south of it over south Asia and Africa, with the strongest winds over India. Thus we see that very large amplitude variations of wind in the upper troposphere occur over Asian continents.

11. The notable feature in the mean wind field over Indian region at 850 hPa and 700 hPa is the southwesterly monsoon winds over the Arabian sea, peninsular India and the Bay of Bengal. The shallow low pressure area lying over northwest India-Pakistan is called the heat low. The pressure trough of cyclonic shear zone extending from the heat low over NW India to the head Bay of Bengal at the surface and 850hPa is called the monsoon trough. The latitude-height section of the mean zonal winds averaged between 50°E and 100°E brings out the lower tropospheric westerlies (maximum 20 kts) and the upper tropospheric easterly jet stream (60 kts). A profile of zonal winds with height at Trivandrum for July-August (1963-1964) brings out the same features.

12. The precise definition of monsoon is difficult. However Kurashima (1968) adopted the following practical definition:

a. Monsoon is a part of the planetary wind system.

b. Monsoon occurs frequently during summers and winters and has sufficient stability to represent winds of the respective seasons.

c. Wind direction in winter and summer are nearly opposite.

13. Based on the above definition Kurashima prepared the map of geographical distribution of monsoon. Following evolved from the maps:-

a. Monsoons are indeed global phenomena. Over Asia monsoon occurs over a wide region extending from the Indian Ocean to Kamchatka region.

b. Monsoons are stronger over the Afro-Asia-European region than over the American region.

14. India is mostly within the tropics. Therefore India will be under the influence of axially symmetric monsoon due to north-south shifts of the Hadley cell which arise due to north-south temperature contrasts. During the monsoon season, the symmetric Hadley cell of the northern hemisphere is highly overshadowed by the symmetric circulation over the monsoon region. Reversal takes place of north-south currents from winter to summer. The meridional winds are of the order of 1 m per sec. During the monsoon season the usual Hadley cell exists over two-thirds of the tropics but over the monsoon region, a reverse Hadley cell extends even up to 30°N exists.

15. India will also be under the influence of the axially asymmetric monsoon due to the east-west temperature gradients produced by east-west land ocean contrast. Thus it is necessary for us to understand the physics of both the theories of symmetric and asymmetric monsoon.

16. The physics of the maintenance of this monsoon circulation and the energy sources for the monsoon wind system has been studied by (a) observational studies (b) theoretical studies and (c) numerical model studies.

17. Keshavamurty (1968) studied the balance of angular momentum in Indian monsoon region. He estimated the different terms in the equation for the region equator to 20°N and 50°E to 100°E (Table 7.1).

18. It is seen from these estimates that the zonal winds are maintained by the Coriolis term. In the lower troposphere the Coriolis term maintains the zonal winds against frictional; dissipation. In the upper troposphere the zonal momentum produced by the Coriolis term and the east-west pressure gradient is taken out of the region by mean flux. The implication is that the mean meridional circulation with southerlies in the low level and northerlies in the upper levels turns into the low level monsoon westerlies and the upper level easterly jet by Coriolis turning, because of earth's rotation.

Table. 7.1: Budget of Angular Momentum

(Units: 10^{25} gm cm^2 sec^{-2})	Lower Troposphere (Westerly Momentum)	Upper Troposphere (Easterly Momentum)
Ω-Transport or Coriolis Term	6.8	7.0
Frictional Torque	-7.0	****
Zonal Pressure Gradient Term	-0.4	2.6
Mountain Torque	2.1	****
Flux divergence		
East-West Mean Transient	-0.3	-5.0
	-0.4	0.5
North-South Transient Mean	0.3	-4.8
	-0.1	-0.5
Balance	1.0	-0.2

19. The monsoon circulation is basically a heat engine. The heating contrast of the Asian continent with respect to the Indian Ocean sets up a vertical Hadley type circulation with southerlies in the lower levels and northerlies in the upper levels. These result in the observed zonal winds because of Coriolis turning (as the earth is rotating). The basic factors are the differential heating and the rotation. In addition to the heating of the Asian continent, the Tibetan plateau acts as an elevated heat source. The monsoon current also imports moisture evaporated over the Arabian Sea and the Indian Ocean and copious rains are produced in the hilly regions of northeast India and in the low level convergent region of the monsoon trough over north and adjoining central India. Large amounts of latent heat are thus released and this heat enhances the north-south temperature gradient and hence the monsoon meridional circulation and the zonal winds. Thus the monsoon engine imports part of its fuel from large distances.

Characteristic Features of South Asian Summer Monsoon

20. The Asian summer monsoon is a unique feature of the tropical circulation, which has been visualized by some people as ‘breathing in’ during summer and ‘breathing out’ during winter, over the Asian continent. The unique physiographic setting in the South Asian longitudes, with the vast Asian continent spanning equatorial to polar latitudes in the northern hemisphere contrasted by the extensive water surface of the Indian Ocean spanning equatorial to Antarctic latitudes in the southern hemisphere, primarily helps in the development of intense thermal centres of action due to differential heating of land and water. The resultant pressure patterns and meridional circulation in summer are further accentuated by the presence of huge mountain massifs over South Asia, leading to the establishment of the southwest monsoon or Indian summer monsoon.

21. The summer monsoon circulation, which has an almost astronomical precision in the timing of its annual visit to the region, has completely transformed the seasonal variation of the climate over South Asia. Its importance to the tropical circulation and consequently to the general circulation of the atmosphere is well-recognized; in fact, there has been a suggestion that the ‘monsoon year’ (defined as a year starting shortly before the summer monsoon season) should be taken as the climatic year in the tropics (Yasunari, 1991). In this chapter, we will briefly summarise some important characteristic meteorological features which pervade the region during the summer monsoon season, in contrast to the features during other parts of the year.

Sea Level Pressure Patterns

22. The sea level pressure distribution over South Asia shows a gradual transition, during March to May, from the winter conditions to the characteristic patterns of the summer monsoon circulation. This period is known as the pre-monsoon season, which is marked by high temperatures and extensive heat lows over the land areas. The land low over South Asia is a part of the global-scale low extending from the Sahara to Central Asia across Arabia, Iran, Afghanistan, Pakistan, northwest India, and even up to Myanmar. By May, the continental low-pressure areas completely dominate North Africa and Asia. The main centre over South Asia lies over northwest India and adjoining Pakistan, with an extension as a trough into peninsular India, which becomes more marked in June. The lowest pressure for the whole belt from Africa to Asia is over the central parts of Pakistan. The progressive development of this heat low before and during the monsoon season is considered to be one of the major causative factors of the Indian summer monsoon circulation.

23. Monsoon activity reaches a peak in July when the low-pressure area extending from north Africa to northeast Siberia is most intense, with its main centre over north Baluchistan. A trough lies over north India with its axis running from northwest India to Head Bay (north coast of the Bay of Bengal) which is known as the 'monsoon trough'. As the monsoon becomes established over South Asia, the subtropical anticyclones over the Indian Ocean are strengthened, thereby creating strong pressure gradients north of the subtropical highs up to the monsoon trough. This facilitates large-scale cross-equatorial flow into the South Asian region. The pressure patterns over South Asia, south of the monsoon trough, are characterised by weak ridges in the Arabian Sea off the west coast of India and in Bay of Bengal off the Tennaserim coast and over Myanmar, and a weak trough over eastern peninsular India off the east coast. The intensity of the Afro-Asian low starts decreasing in August, with a consequent decrease in the pressure gradient south of the monsoon trough. Towards the end of the monsoon season, the trough over northern India shifts to the Bay of Bengal and the pressure field becomes flat over almost all South Asia and the winter conditions are gradually re-established.

The Heat Low

24. The heat low over the central parts of Pakistan and neighbouring regions, which is a very important causal factor of the monsoon, is generally linked to the regions of maximum heating which are out of reach of the maritime air mass. The tapering shape of peninsular India, the Himalayan barrier to the north and the Assam hills to the northeast, which ;make the maritime air mass pervade over most of South Asia, displace the centre of the low to the extreme northwest of the continent. Blocking of cold air incursions from the north by the Himalaya in the lower troposphere also makes the heat low more intense in this region. The existence of the lowest pressures of Afro-Asian low in this region, in spite of the relatively higher temperatures in the Sahara, is a result of the topographical configuration and the associated adjustments in the wind field.

25. The heat low is shallow, extending up to about 1.5 km and is overlain by a well marked ridge extending to the upper troposphere, which is part of the subtropical high pressure belt. The role of the upper ridge in maintaining the surface heat low is not clear. While the pressure distribution of the upper ridge is inimical to that of the surface low, it is argued that the subsidence in the upper ridge maintains the clear skies required for the heat low; however, this argument cannot hold in the pre-monsoon months when the subtropical ridge is well away from the heat lows over South Asia (Rao, 1976). When the western disturbances, which bring cold air in their wake, move north with the advance of summer, heating continues uninterruptedly in May in the absence of any rain or clouding over the area of the heat low.

26. The intensity of the heat low has been correlated with monsoon activity. Negative pressure anomalies in the heat low region and positive anomalies over peninsular India are regarded as favourable conditions for good monsoon activity.

Monsoon Trough

27. During the summer monsoon season, the most conspicuous signature of the monsoon circulation at the surface is a trough extending from the heat low over Pakistan southeastwards up to Gangetic West Bengal, termed the monsoon trough. The monsoon trough is a major semi-permanent feature of the summer monsoon circulation in the lower troposphere and exerts considerable influence on the summer monsoon activity in South Asia. The monsoon trough is regarded as a part of the equatorial trough of the northern summer in the Indian longitudes and indicates the separation between air of northern and southern hemispheric origin. The monsoon trough is flanked by westerly to southwesterly winds to the south and easterlies to the north. The air mass on the south of the trough line is derived from the Arabian Sea branch of the monsoon, while that on the north is derived from the Bay of Bengal branch. In the daily weather charts the trough can be located up to the 600 hPa level (about 6 km) during periods when the monsoon has advanced into the northern parts of India.

28. It is observed that the trough line tilts southward with height; the slope in the western sector is steep in the lower troposphere and less marked in the middle troposphere, while in the eastern sector the slope is moderate in the lower troposphere and increases appreciably in the middle troposphere. The temperature to the north of the trough is on average about 2°C higher than that to the south, which explains the southward slope of the trough axis with height (Joshi & Desai, 1985). The mean position of the monsoon trough during the month of July is from Ganganagar to Calcutta through Allahabad. The trough axis experiences considerable day-to-day variation in its position, which has a vital bearing upon the monsoon rainfall distribution in the region. No other semi-permanent feature has such a control on monsoon activity. This arises mainly from the different synoptic systems that prevail in association with different positions of the trough. During the break monsoon periods, when there is a temporary ‘lull’ in monsoon activity, the trough line shifts to the foot-hills of the Himalaya, rainfall over the central parts of India decreases considerably, and there is an increase in rainfall over north India along the Himalayan foot-hills. The monsoon depressions, which originate over the Head Bay of Bengal, move across the Gangetic plains in a northwesterly direction along the trough line. A southward swing of the trough line to the central parts of India is generally associated with the monsoon depressions. Table 18.2 indicates the normal positions of the monsoon trough. It can be seen that the trough is in the normal position only 30-40% of the time, indicating its high intra-seasonal variability. It is also seen that the western part of the trough is more often towards the north than towards the south, while the eastern part shows the opposite trend. This is due to the influence of the mid-latitude disturbances on the northwestern parts of the subcontinent and the formation of monsoon depression over the head of the Bay of Bengal (Srinivasan & Ramakrishnan, 1970). Energy balance studies in the monsoon trough region indicate that the vertical structure of the trough has a large convergence zone in the lower levels and a compensating outflow higher up (Anjaneyulu, 1969). Along the normal position of the trough, the rainfall distribution shows a minimum. This is due to the intense rainfall activity on the southern and northern sides of the trough axis, associated with its north-south excursions.

Table7.2 Mean Positions of Monsoon Trough during 1961-69 (After Srinivasan & Ramakrishnan, 1970)

Month	Longitudinal section (°E)	Normal position of trough (°N)	Percentage frequency of location of trough		
			South of normal	Normal Position	North of Normal
July	77	27-29	27	30	43
	81	25-27	27	45	28
	87	23-25	37	35	28
August	77	27-29	20	33	47
	81	25-27	20	47	33
	87	23-25	34	39	27

Surface Winds

29. During the monsoon season, the northern parts of South Asia, north of the monsoon trough, have weak easterlies at the surface. Southerlies occur over West Bengal and Bangladesh, while the rest of the subcontinent is dominated by southwesterlies and westerlies at the surface. The southwesterlies are relatively stronger over the southwestern Arabian Sea. Nearer the west coast of peninsular India, the winds are west-southwesterlies to westerlies, with speeds of 5-10 m per sec, while the mean speeds do not rise above 5 m per sec inland. This pattern persists throughout the active phase of the summer monsoon, and towards the end of September, as the monsoon withdraws from the subcontinent, there is a large-scale weakening of the wind field consequent to the weakening of the pressure gradient.

Upper Winds

30. The subtropical high-pressure belt, which passes over northern India throughout the year, greatly influences the upper-wind distribution. During the pre-monsoon months, the subtropical ridge over land around 18°N at the 850 hPa level and extends up to 700 hPa. At higher levels, the subtropical ridge gradually shifts southwards to 8°N at the 200 hPa level. At this level, the anticyclone from the east extends up to Sri Lanka. Westerlies strength with height over northern India, reaching maximum speeds of around 20 m per sec near 25°N at 300 hPa and 25-30°N at 300 hPa and 25-30 m per sec near 25-30°N at 200 hPa. The subtropical westerly jet stream in the upper troposphere is found a little north of Delhi with its core at the 200 hPa level. Above these levels, speed decreases slowly. Some upper-level easterlies are found over southern peninsular India and Sri Lanka, but they are generally weak during the pre-monsoon months and gradually start building up towards the beginning of the monsoon season.

31. As the monsoon becomes established over the whole subcontinent towards late June and early July, the lower tropospheric winds (up to 700 hPa) are characteristic of the monsoon trough, dominated by westerlies to the south of the monsoon trough and easterlies to its north. Westerly winds over the peninsula increase with height in the lower layers, reaching a maximum (10-12 m per sec) around 900 hPa in the west and 800 hPa in the east. The monsoon trough tilts southward with height and gradually loses significance around 500 hPa. Above 700 hPa, the subtropical high from the west over-rides the warm surface low over Pakistan and surrounding area. At 500 hPa, this ridge becomes better organized and is flanked by easterlies over northern India and a trough over southern peninsular India and the adjoining sea. However, winds at this level are generally weak. At 300 hPa and above, almost the whole subcontinent is dominated by easterlies. The subtropical westerly jet stream over north India weakens and its core is shifted north of the Himalaya. At levels between 200 and 100 hPa, another ridge (the Tibetan high) develops over northeast India and the easterlies strengthen, reaching a maximum (30-40 m per sec over southern peninsular India) at 100 hPa, becoming concentrated into a core of high winds known as the tropical easterly jet stream. These are the typical upper wind patterns which throughout the monsoon season with remarkable stability.

Temperature

32. The highest temperature over India during the pre-monsoon or hot weather season, which coincides with the spring season (March - May) of northern middle latitudes. During this season, the monthly mean surface air temperatures exceeds 33-35°C in the inland areas of northwest India and adjoining areas. The surface temperatures, particularly the daytime temperature, drops dramatically with the onset of the summer monsoon, the monthly means falling to less then 30°C. This is due to the extensive cloudiness and rainfall associated with the monsoon circulation.

33. During the pre-monsoon season, a thermal high develops at 850 hPa over central India, with temperatures decreasing in all directions. The thermal high shifts southwards and becomes weaker with height and is seen as a weak thermal high over southern peninsular India at about 300 hPa. The thermal field becomes flat at the 200 hPa level, with temperatures varying in the range -52 to -48°C. Above this level, the temperature gradient is reversed, with a marked increase in temperature from the central parts of the peninsula towards the north.

34. During the monsoon season, the thermal field at 850 hPa over south Asia is dominated by a ridge in the north extending form the thermal high over Iran, and two thermal troughs running along the west coast if India and the Myanmar coast, with an intervening ridge near the east coast of India. At 700 hPa and above, the troughs and ridge around peninsular India disappear and the thermal field is dominated by the ridge in the north, which becomes better organized at still higher levels and results in a prominent ridge over the Tibetan region at 200 hPa, which is a very important feature of the monsoon circulation.

Onset and Withdrawal of Summer Monsoon

35. The seasonal transition from the pre-monsoon to monsoon is so sudden that it is often termed the 'burst' of the monsoon over the Indian subcontinent. The most perceptible changes associated with the establishment if the monsoon circulations are surface winds blowing from the southwest, a sudden fall in the surface air temperature, and an increase in cloudiness and rainfall. The southwest monsoon over the Indian peninsula first arrives over the south Indian state of Kerala. While almost simultaneously the Bay of Bengal branch reaches West Bengal and the hills of Assam in northeast India. Kerala is widely known as the 'gateway' of the Indian summer monsoon: its onset over the south Kerala coast is one of the most important meteorological events in the region and is eagerly awaited every year by the public in general as well as the Indian meteorological community. This events heralds the rainy season for the region, ending the days of parching heat and bringing much-needed water for agricultural, industrial and domestic rains over other parts of the subcontinent, which heralds the start of agricultural operations for the main cropping seasons of the years known as *kharif*. The onset, advance and withdrawal of the monsoon are particularly critical to rain fed agriculture during the *kharif* season.

Normal Dates of Onset and Withdrawal

36**.** Although the four month period of June to September is termed the Indian summer monsoon season in a general large-scale sense, the actual rainy period differs widely over different parts of the subcontinent. A sustained increase in rainfall and cessation of rainfall activity have been traditionally used to demarcate the beginning (or onset) and end (or withdrawal) of the monsoon circulation, respectively. The calendar dates of these seasonal demarcations also have considerable inter-annual variability, of the order of 1-2 weeks. The standard deviation of the date of onset of the monsoon over the west coast of India is about 6-7 days (Ramdas *et al.,* 1954) while that around Delhi is 7-8 days (Bhullar, 1952). The mean picture of the onset and withdrawal of the monsoon over different parts of the subcontinent can be obtained by examining long-term mean daily or pentad (5 day) rainfall at individual stations spread over the subcontinent and locating the dates of sharp increases or decreases in rainfall. However, this procedure runs into difficulties in places where there is substantial pre-monsoon thunderstorm activity at the time of onset, such as at Kerala in southern India. In view of this, identifying the dates of onset and withdrawal in individual years and then averaging the dates may give a more reliable mean picture.

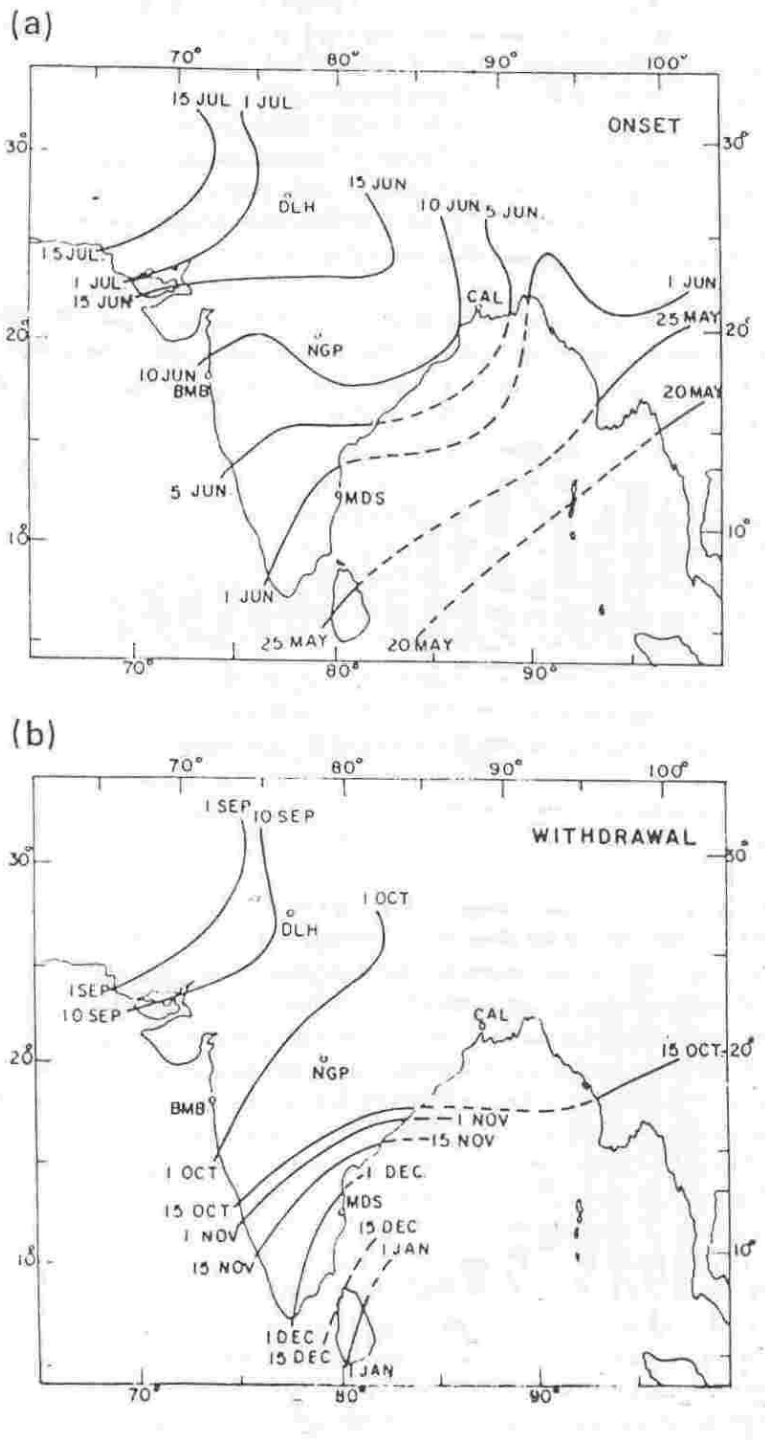


Fig 7.2 Normal dates of onset (a) and withdrawal (b)of the summer monsoon over India

37. Fig 7.2 a, b show isolines of the mean dates of monsoon onset and withdrawal prepared on the basis of long-period data by the India Meteorological Department (IMD, 1943). These dates have been derived from normal pentad rainfall data at different stations using data up to 1940; the middle date of the pentad representing an abrupt rise in rainfall was taken as the onset date. These diagrams, published more than half a century ago, are still widely used as a standard source of reference in Indian as well as in international meteorological literature. Although the approach of identifying the onset dates from normal pentad rainfall has several limitations (Soman, 1993), and despite some attempts (Subbaramayya & Bhanu Kumar, 1978; Subbaramayya *et al*., 1984, 1990) to revise the onset diagram, these diagrams continue to be used, perhaps indicating the controversial nature of the problem and the difficulties involved in identifying a unique set of dates of onset and withdrawal of the summer monsoon. The isochrones (Figure 18.2a) show that the monsoon rains commence around the third week of May over Sri Lanka and the Andaman Islands in the Bay of Bengal, while the monsoon enters the Indian mainland on 01 June over the south Indian state of Kerala. The onset of the monsoon brings with it a dramatic change in the weather situation, associated with a conspicuous cloud cluster over a large area near the western part of the southern tip of the Indian Peninsula. Ananthakrishnan *et al.,* (1981) analysed the pentad rainfall data of six stations in the Andaman Nicobar group of islands for the period 1953-78 and studied the onset of the summer monsoon rainfall over the southeast Bay of Bengal. Their study suggests that the onset dates are ahead of the dates interpolated from the normal onset dates from the men charts. In the island stations the onset of the monsoon from south to north occurs progressively from the last week of April to the first week of May. It normally takes the monsoon a period of about 1½ months to reach northwest India and Pakistan. It proceeds gradually northwards and by the middle of July the whole of the Indian subcontinent comes under the grip of the monsoon. However, the northward progress of the monsoon is not a smooth affair and takes place in surges, interspersed with periods of weakening or stagnation of monsoon activity. The northward advance is usually associated with synoptic disturbances and there is a pronounced tendency for the formation of low-pressure systems at the leading edge of the monsoon current. This is also termed the ‘onset vortex’. Ananthakrishnan *et al.* (1968) found that, on about 75% of occasions, the advance of the monsoon is associated with either a feeble trough in the low level, a depression or a cyclonic storm. Subbaramayya *et al.* (1984) distinguish three phases in the advance of the monsoon over India, interspersed with periods of stagnation: the first affects the southern peninsula, the second reaches the northern peninsula and central India, and the third penetrates to the central parts of north India. Joshi *et al*. (1990), using satellite data, have shown that the onset of the monsoon is preceded by an increase in the tropospheric temperatures over almost the entire region, and these temperature changes are more prominent over the heat low and Tibetan plateau region, compared to other neighbouring areas.

38. The withdrawal of the monsoon begins in the western parts of the; northwest Indian state of Rajasthan in early September (Figure 18.2b). Thus, the effective duration of the southwest monsoon rains over this area is only about 1½ months. The southward retreat of the monsoon rains continues rapidly until about the middle of October, by which time it withdraws completely from the northern half of the Indian peninsula. The withdrawal phase of the monsoon is associated with the equatorward motion of the ITCZ, causing heavy rainfall in its wake (Subbaramayya *et al.,* 1977). Over the southern part of the peninsula, the withdrawal phase becomes mixed up in a transition to the northeast monsoon type of circulation and cannot be located precisely from rainfall variations. Thus, it is not appropriate to identify the much later decrease of rainfall in south India as the withdrawal of the southwest monsoon.

Onset of Summer Monsoon over Kerala Coast

39. The announcement of the date of arrival of the monsoon over Kerala, though a subjective decision, is based on an overall judgement taking into account the changes in circulation features in the lower and upper troposphere which indicate a seasonal reversal of wind regimes, and a sustained increase in rainfall over Kerala and the island stations over the southeast Arabian Sea. The specification of objective criteria for fixing the onset has several difficulties owing to the considerable inter-annual variation of the meteorological features associated with the onset. Furthermore, the onset is accompanied by significant changes in circulation features, the vertical distribution of moisture, cloud characteristics, the state of the sea etc., which are difficult to quantify in terms of criteria for onset. The problem is further confounded by the fact that Kerala frequently witnesses widespread rainfall activity due to pre-monsoon thundershowers which may be difficult to differentiate from the; monsoon rains. Therefore, the experience and studied judgement of the forecaster contribute to a large extent to the declaration of the date of onset.

40. Since the early days of Indian meteorology, an essential requirement for declaring the; monsoon onset has been a sustained increase of rainfall at observatory stations over Kerala and the Arabian Sea islands. Ananthakrishnan *et al.* (1968) made a pioneering study of the criteria for declaring the date of onset of the Indian summer monsoon over Kerala. Their study revealed considerable differences between the real-time dates issued by the IMD and those refixed by a post-mortem examination of rainfall sequences. This has necessitated a re-examination of past data to decide on the onset date based on some objective criteria, in order to make the onset dates useful for scientific investigations. Although the use of upper-air and satellite data has considerably reduced the subjective errors in deciding on the dates of onset, one has to rely on the rainfall data alone to generate long-period series of onset dates.

41. The onset of the summer monsoon over Kerala is characterized by a transition in the nature of rainfall from light- to heavy-spell category. This can be seen every year, despite appreciable inter-annual variations. The general impression that the pre-monsoon thunderstorm rains merge with the monsoon rains and confound the onset phase of the monsoon, as stated earlier, is mainly drawn from an examination of mean rainfall sequences. However, this is not the case in individual years. The merging occurs mainly because the averaging of calendar date rainfall data causes dispersal in the onset dates over the period of averaging, blunting the abrupt rainfall changes associated with the onset. Ananthakrishnan & Soman (1987) devised some objective criteria for fixing the onset dates in individual years based on the analysis of 80 years data (1901-80) of daily areal mean rainfall series for south and north Kerala. They considered the date of the onset as the first day of the transition from light to heavy rainfall category, with a provision that the average daily rainfall during the first 5 days after the transition should not be less than 1 cm. They also demonstrated the abruptness with which the monsoon sets in Kerala by superimposing the daily rainfall amounts relative to the onset dates (figure 18.3) identified using this criterion. Here, the onset dates are labelled as zero for every year and the rainfall amounts for days 0 and ± n (n = 1, 2, 3,….) are averaged over the 80 year period. The superimposed epoch analysis clearly shows that the rainfall jumps abruptly from about 0.5 - 0.6 cm per day during the pre-monsoon months to over 1.7 cm on the onset day.

42. Based on this objective method, Ananthakrishnan & Soman (1988, 1989) have prepared long-term series of onset dates for south (1891-1990) and north (1870-1990) Kerala. They reported that the mean date of onset for south Kerala is 30 May, with a standard deviation of 8.5 days, while the mean onset date for north Kerala is 01 June, with a standard deviation of 8.4 days. The frequency distribution of the onset dates over south Kerala during the 100 year period 1891-1990 is shown in Figure 18.4. The onset has the maximum frequency in the 3 day interval 1-3 June and the frequency distribution has a skewed character (Soman, 1993). Although the onset of the monsoon over Kerala may appear to be of local character, it is generally considered to be a pointer for advancement of the monsoon over India. For example, Deshpande *et al.* (1986) reported that the anomalies in the dates of onset were similar at Kerala and Bombay on 70% of occasions. An examination of the time series plot of onset dates of the southwest monsoon, as deviation from long-term mean, over south Kerala (Figure 18.5) suggests considerable inter-annual variability. During the last 100 years there have been extremes in the dates of monsoon onset over Kerala of as much as three weeks from the normal. However, no significant long-term trend in the time series of onset dates has been observed. However, the monsoon onset was more often in June than in May during the period 1901-40 while the reverse occurred during 1941-80. Figure 18.5 also shows the long-term changes in the onset date by means of a smoothed curve obtained from the 9-point Gaussian low-pass filtering of the anomalies of onset dates over south Kerala. The smoothed curve shows a prominent bunching of late onset dates for a few decades around 1900 and of early onset around 1960.

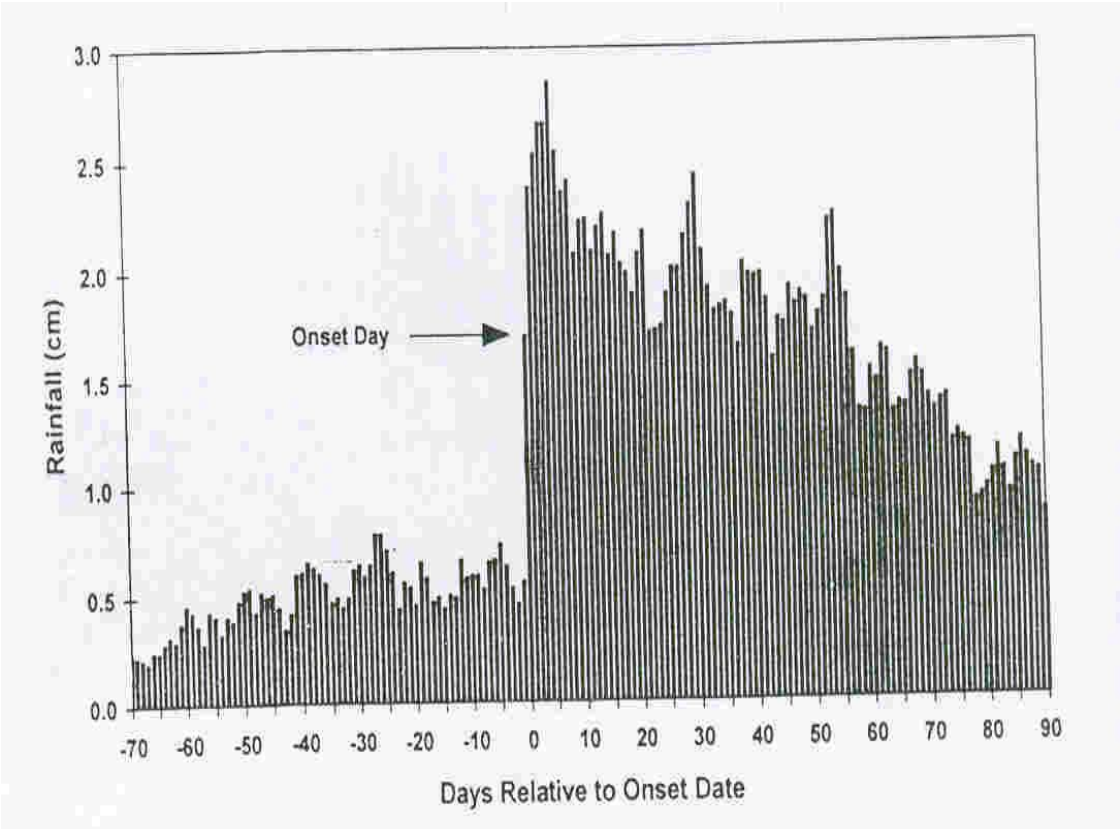


Fig 7.3 Average daily areal mean rainfall for south Kerala obtained by superimposing the onset dates.

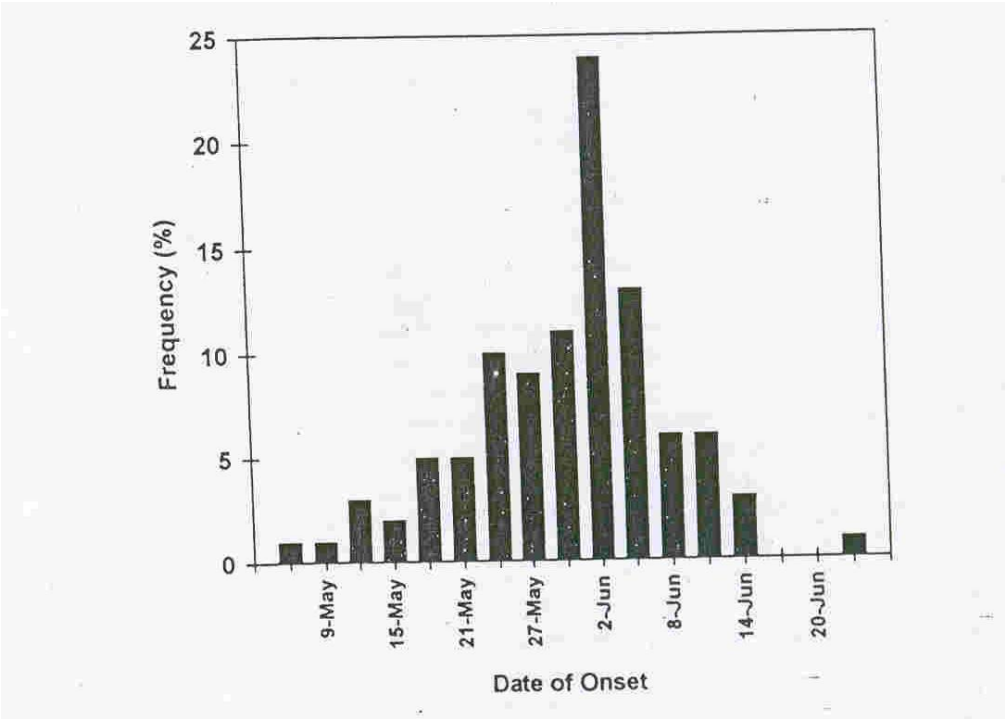


Fig 7.4 The frequency distribution of the onset dates of the southwest monsoon over south Kerala at 3 day intervals for the period 1891-1990.

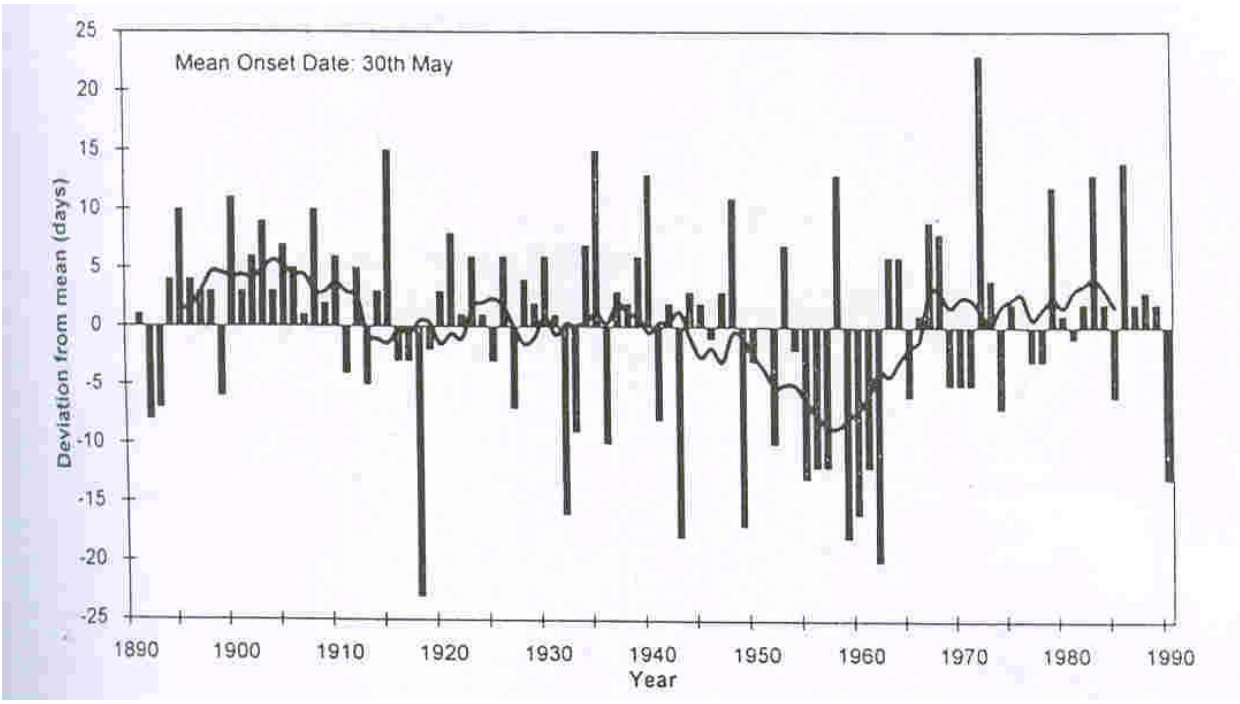


Fig 7.5 Time series of the deviation from the mean onset (30 May) over south Kerala for period 1891-1990.The smoothed curve indicates the 9-point low-pass filtered series

43. Soman & Krishna Kumar (1993) examined the circulation and moisture changes over India associated with onset of the southwest monsoon over south Kerala, by compositing the meteorological parameters such as rainfall, wind, relative humidity, vertically integrated zonal moisture transport and outgoing long-wave radiation (OLR) at several stations. The study is based on 80 years (1901-80) of daily rainfall data and 15 years (1971-85) of daily aerological data at a well-distributed network of stations in India. The following are some of the main features associated with the onset of monsoon as brought out by their study:

a. The rainfall composites at most of the Indian peninsula stations, except some on the east coast, showed an abrupt increase with respect to onset over Kerala, with an appropriate lag based on the normal date of onset at these stations.

b. Subtropical westerlies weaken and shift poleward and tropical easterlies strengthen and spread towards the north with the onset of the monsoon.

c. The composite streamline charts depict a trough in the mid-tropospheric levels between 600 and 400 hPa. This could be regarded as the manifestation of the onset vortex noticed in some years over the eastern Arabian Sea during the onset.

d. Vertical distribution of relative humidity shows rapid deepening of the moist layer a few days before the onset at the respective stations. This large-scale moisture build-up over the Indian landmass before the strengthening of the monsoon flow is similar to the increase noticed over the Arabian Sea.

e. The OLR composites show a convective area developing near the equator in the vicinity of 70°E about 5 days before the onset over south Kerala. The intensification and northward movement of this convection brings the first monsoon rains over Kerala.

Monsoon Depressions/ Low Pressure Systems

44. Monsoon depressions are important synoptic-scale disturbances in the hierarchy of tropical circulation systems and make major contributions to the monsoon circulation in organizing the low-level convergence. The low-pressure systems and depressions during the monsoon season move along the axis of the monsoon trough, towards the northwest. The depressions are low-pressure areas having two to three closed isobars at 2 hPa intervals covering an area of about 5° latitude by 5° longitude. Monsoon depressions normally form in the Bay of Bengal north of 18°N latitude and move west-northwest across the central and northern parts of India giving widespread rains, with relatively heavy rainfall in the southwestern quadrant of the system. These low-pressure systems are referred to as ‘depressions’ when the surface wind speeds are between 8-16 m per sec and as ‘cyclonic storms’ when the speeds are above 16 m/s. in addition to providing beneficial rainfall along and near their tracks, these systems transport heat and moisture upwards and maintain the activity of the monsoon trough. Table 18.3 shows the number of depressions and cyclonic storms during the monsoon season over the South Asian region during the period 1891-1970. Some of the systems in early June, usually

associated with the advance of the monsoon, and also in September are not typical of monsoon depressions, particularly in the Arabian Sea. The number of monsoon depressions and cyclonic storms during the course of a single season shows considerable inter-annual variability. While there have been several years without a single depression or cyclonic storm throughout the monsoon season, there have been years which have witnessed as many as 12-15 depressions and/or cyclonic storms in a single season. Monsoon depressions rarely grow into cyclonic storms; they do not acquire hurricane intensity during the summer months as they are not long over oceanic areas before reaching land, and the large-scale vertical wind shear in the troposphere inhibits local accumulation of latent heat release over the disturbance (Cadet, 1970). Cyclonic storms of very severe intensity are formed in the South Asian seas only during the post-monsoon season.

Table7.3 Number of Depressions & Cyclonic Storms during the Monsoon Season (1891-1970) (After Rao, 1976)

Region of Formation	Depressions				Cyclonic Storms			
	Jun	Jul	Aug	Sep	Jun	Jul	Aug	Sep
Bay of Bengal	71	107	132	141	35	38	26	32
Arabian Sea	18	9	2	9	15	3	2	5
Land Areas	12	39	42	21	1	1	0	1

45. Most monsoon depressions form over the warm waters of the northern parts of the Bay of Bengal in association with a series of low-pressure systems and easterly waves that move over the region during the monsoon season across Myanmar. They generally develop out of three types of situations (Rao, 1976):-

a. In almost 50% of cases, a diffuse pressure field develops over the northern By of Bengal and adjoining areas, associated with a southward swing of the monsoon trough, where the pressure gradient to the south of the monsoon trough is fairly strong as a normal feature of the monsoon season.

b. About one-third of the depressions are generated from the diffuse low-pressure systems travelling across Myanmar into the northern Bay of Bengal., which are remnants of the typhoons of the China Seas.

c. About 15% of the monsoon depressions are seen initially as closed circulations in the middle troposphere, which gradually descend to lower levels leading to the formation of surface lows.

46. The frequency of monsoon depressions formed in the Bay of Bengal is about 80% of the total number of depressions forming in the South Asian monsoon region. Relatively few monsoon depressions form in the east Arabian Sea and over land in the monsoon trough region. The average annual frequency of monsoon depressions is seven, of which one occurs in June and two each in July, August and September.

47. The monsoon depressions normally take a west-northwesterly course during the peak monsoon months of July and August, while they move in a northwesterly direction during the transition periods in early June and late September. On average, a monsoon depression travels at the rate of about 300-400 km per day. The depressions generally weaken after crossing the central parts of the country, owing to the cut-off in moisture supply, then move further northwest and merge in the seasonal low over west Rajasthan and adjoining Pakistan, Sikka (1977) found that one-third of the depressions fill up on crossing 85°E and nearly half on crossing 80°E. On a few occasions, when the depressions are fed by fresh moisture supply from the Arabian Sea branch of the monsoon, the depressions may retain their intensity and take a westerly course to reach Gujarat state (India), causing very heavy rains in the region. Quite often, the monsoon advance over northwest India during the latter part of June occurs in association with the movement of a monsoon depression over that region. The anomalies in the frequency and tracks of the monsoon depressions substantially contribute to the spatial and temporal variability in monsoon rainfall and are believed to be associated with the large-scale circulation features of the monsoon system.

48. The surface winds are stronger to the south of the centre of monsoon depressions as a result of the superimposition of the Westerlies, caused by the depression perturbation south of its centre, on the prevailing basic flow of moderate to strong Westerlies. The intensity of the wind circulation is strongest around the 700hPa level and decreases upwards as well as downwards. The cyclonic becomes very weak and generally disappears at around the 300 hPa level. Monsoon depressions are generally cold-core systems below 700hPa and have a warm core higher up; on the rare occasions when they intensify to become cyclonic storms, they have a warm core throughout their depth. The axis of the depression joining the centres are different levels slopes south-westwards with height. The heaviest rainfall associated with a monsoon depression occurs in its south-western sectors (Pisharoty & Asnani, 1957; Koteswaram & George, 1958).

49. When a monsoon depression is located over the head of the Bay of Bengal, almost the whole Indian subcontinent experience widespread rainfall activity. This situation is generally associated with the development of a trough of low pressure along the northern parts of the west coast of India, inducing increased rainfall. Bhalme & Mooley (1980) and Mooley & Parthasarthy (1983) have shown that the monsoon depressions have greater westward penetration during years of excess monsoon rainfall over the Indian region than during years of deficient rainfall. The rainfall associated with monsoon depressions has less intensity than that associated with cyclonic storms however, it covers a much larger area, particularly over the land regions.

50. The cyclonic vortices, lows and depressions embedded in the monsoon flow play a notable role during the monsoon season by helping in organizing the monsoon flow and producing rainfall over a wider area through convergence and associated vertical motion. Owing to the transport of heat and moisture upwards over the lows and depressions, the periodic passage of these lows across the country maintains the normal location and activities of the monsoon trough, which are condusive to good rainfall distribution over a large area. The number of low-pressure systems during good monsoon years is generally large and they traverse central India in succession,

contributing subcontinent. There is a year-to-year variation in the number of storms and depressions during the monsoon season over the region of South Asia. There is apparently no direct relationship between the number of these cyclonic systems and the monsoon seasonal rainfall over the region (Mooley & Shukla, 1989). This is partly to the varying intensity and rain-producing potential of these systems. However, Pant *et al.,* (1988) identified a low-frequency signal common to the time series of all-India summer monsoon rainfall and the number of storms and depressions, suggesting the possible influence of some slowly varying large-scale climatic anomalies on the number of monsoon depressions and cyclonic storms during the period 1891-1980 over the Indian land area, with the highest number of 200 being over the head of the Bay of Bengal.

Off-shore Trough along West Coast of India

51. During the summer monsoon season, particularly in the onset and advance phase, the existence of a weak sea level trough off and along the west coast of India is a common feature seen in the daily weather charts. Small vortices develop within this trough, known as off-shore vortices (George.1956) which are shallow zones of convergence causing enhanced rainfall activity along the coastal belt. These systems have a horizontal extent of about 100 km and a vertical extent up to the 600 hPa level. The off-shore troughs form more often near coastal Karnataka, though they may also appear and disappear in situ over any area along the west coast. They often move northward along the coast, with associated northward movement of the belt of heavy rainfall. Pressure gradient increases to the south of the trough, particularly as it shifts to the north. Upper winds are affected only in the lower troposphere, often below one km. Nearly half of the active to vigorous monsoon situations in Konkan and three-quarters of such events in coastal Karnataka are associated with the off-shore trough (Rao, 1976). Heavy rainfall generally occurs in the southern portion of the trough. But the intensity and distribution of rainfall along the coast may vary widely in association with the trough.

Break Monsoon Situations

52. Although the mid-monsoon months of July and August contribute most of the seasonal monsoon rainfall, the rainfall distribution is not spatially or temporally uniform over the subcontinent even in these two months. The rainfall undergoes significant variations associated with changes in the synoptic patterns. There are occasions when the monsoon activity abruptly weakens and dry weather prevails over most parts of South Asia. These situations are called ‘break monsoon periods’ and are characterized by certain distinct circulation features. The breaks occur with varying intensities and durations and are mostly associated with the north-south excursions of the monsoon trough. When the monsoon trough shifts close to the foot-hills of the Himalaya, a sudden decrease in rainfall ensues over most parts of peninsular India but there is a considerable increase along the foot-hills of the mountains in India and Nepal. this is sometimes associated with an increase in rainfall in the southernmost parts of the Indian peninsula and Sri Lanka. During this period, situations characterized by cessation of rain and the disappearance of monsoon-like synoptic conditions may occur.

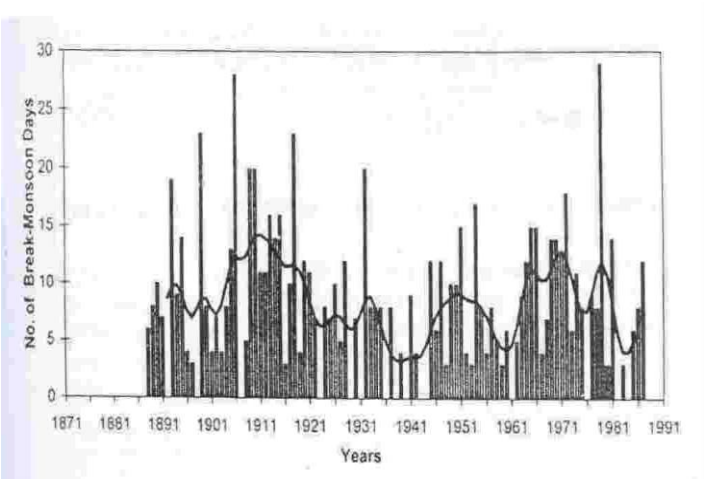


Fig 7.6 Time series of number of break monsoon days for the period 1888-1990; the smoothed curve indicates the 9-point Gaussian low-pass filtered series.

53. The number of break monsoon days in the months of July and August for the period 1888-1967 are shown in Table 7.4 (Ramamurthy, 1969). Ramamurthy (1969) adopted the following criteria for defining the occurrence of a break:

a. The monsoon trough is absent near the surface up to about the 850 hPa level.

b. The duration of such a synoptic situation is at least 2 days.

Table 7.4 Statistics of Break Monsoon Situations During Jul and Aug (1888-1967)

Month	No. of breaks	No. of break days	Average duration (days)	Longest break (days)	Most frequent duration (days)	No. of break-days in		
						First ten days	Second ten days	Remaining period
July	53	306	5.8	17	4	81	117	108
August	55	356	6.5	20	3	115	159	82

54. It is observed that the middle 10 day period of August has witnessed the most frequent occurrence of break monsoon situations, which are also of longer duration than in July. Ananthakrishnan & Pathan (1971) found a distinct minimum around 14-18 August in the normal pentad rainfall at several stations. Ramaswamy (1973) found that, during the period 07-15 August, the daily rainfall is less than the month's daily mean in the central and western parts of the country, while it is more in the Himalayan belt. He calls this the normal period of a large-scale break. During prolonged breaks the troposphere over the region as a whole gets warmer and it appears as if the monsoon has temporarily withdrawn from the region. The breaks in the monsoon should not, however, be confused with the active and weak spells which are seen in rainfall pattern, as well as the convective cloud bands which traverse the region from south to north. While the typical circulation features associated with a break are easily discernible, there are no consistent precursors to its development, which makes the forecast of a break extremely

difficult. The break usually ends with the formation of a monsoon depression over the head of Bay of Bengal or a low-pressure area along the west coast of India. In years when the break occurs in the middle of September, the monsoon may withdraw prematurely from the subcontinent.

55. Alexander *et al.* (1978) described the circulation anomalies over India during active and break monsoon by compositing six occurrences of each during the period 1965-73. Strong monsoons are characterized by an anomalous strong cyclonic circulation at low levels centered near 20°N over India and stretching eastward over to Myanmar and Indo-Chine. Break monsoons are characterized by an anticyclonic low-level circulation centered slightly further south and also elongated in an east-west direction. During active periods a cloud mass is present in the monsoon trough over central India and during break periods this northern cloud mass weakens and more cloudiness appears near the equator and over the southern tip of India. Pant (1983) described active and break phases of the monsoon and suggested a mechanism involving eddy dynamical processes to explain the slow northward propagation of anomalies associated with active and break phases of the monsoon.

56. The revival of the monsoon from a break condition perhaps represents the reorganization or restoration of the conductive synoptic situations. There are two distinct modes of transition from a break to an active phase. In the first, revival from the break condition occurs with the formation of a disturbance in the northern part of the Bay of Bengal and its subsequent westward movement over the monsoon zone. The second mode of revival involves northward movement of the oceanic tropical convergence zone on to the subcontinent.

Intra-Seasonal Variations in Monsoon Circulation

57. The large-scale monsoon rainfall is associated with the seasonal migration of the ITCZ. However, during the summer monsoon season, two convergence zones are often observed in the same longitudinal belt, one in the monsoon zone north of 15°N and the other appearing intermittently in the westerly regime over the equatorial Indian Ocean. As both these convergence zones cannot be termed ‘inter-tropical’, Gadgil (1988) suggested the use of the term ‘tropical’ convergence zone’ (TCZ), preferring to distinguish these zones by the large-scale convergence and organized precipitation associated with them rather than by the confluence of the surface winds. Thus, we have a continental TCZ and an oceanic TCZ prevailing in the same longitudinal belt. As mentioned earlier, within the Indian summer monsoon season, the large-scale monsoon rainfall fluctuates between active spells and break situations. During the active spells, the continental TCZ is almost continuously present over the monsoon zone north of 15°N, while during dry spells or intense breaks it complexly disappears from the monsoon zone. The break situation is usually followed by the northward propagation of the oceanic TCZ onto the continent, similar to the onset phase, leading to the revival of the continental TCZ (Gadgil, 1988).

58. It has been observed that the above sequence of break spells and revival of active spells occurs at intervals of about 30-50 days. Sikka & Gadgil (1980) presented detailed analysis of fluctuations in the cloud cover over the Indian monsoon region, based on satellite cloud photographs. They found organized progression of zonally oriented cloud band from the equatorial regions towards the foot-hills of the Himalaya with a periodicity

of around 40 days, which was associated with active and break phases of the monsoon (see also Yasunari, 1980). There has been considerable excitement over the detection of 30-50 day oscillation in the monsoon system, leading to a large number of studies to identify this oscillation in various surface and upper-air parameters of the monsoon circulation. However, analysis of long-period data revealed that the 30-50 day mode has a large amount of inter-annual variability (Singh & Kripalani, 1985; Mehta & Krishnamurti, 1988), in which ENSO as well as east-west propagations might be playing important roles.

59. in this connection, it may be noted that spectral analyses of monsoon circulation parameters have revealed both 10-20 day periodicities involving westward wave propagation (Krishnamurti & Bhalme, 1976), and 30-50 day periodicities involving northward propagation (Yasunari, 1979). The performance of the monsoon in a specific year is a result of the relative phases and amplitudes of these two dominant modes. Soman (1993) also found that, while the 30-60 day mode contributed the maximum variance in daily rainfall in the southern and central parts of India, there is a large inter-annual variability in its amplitude, periodicity and speed of northward propagation. In view of this, the practical predictive potential of this oscillation is limited.

SECTION-6 : FUNDAMENTALS OF METEOROLOGY

TASK 29 : DIVISIONS OF METEOROLOGY

Introduction

1. Meteorology is the science of weather. It is essentially an inter-disciplinary science because the atmosphere, land and ocean constitute an integrated system. The three basic aspects of meteorology are observation, understanding and prediction of weather. Weather plays an important role in all facets of life and is a vital factor in civil as well as military aviation. Meteorological phenomena and weather processes occurring in the atmosphere are of an infinite variety. Changes in pressure, temperature, humidity and wind flow result in major synoptic systems, clouds, precipitation, thunderstorm and its associated weather hazards etc. Aviation Meteorology deals with weather requirements of aviation related to the present and forecast conditions at and around an operating area and en-route. Knowledge of weather conditions likely to be encountered during a specific flight enables an aviator to plan his flight with a view towards economy of fuel, operational efficiency and flight safety. Therefore, there is a need for accurate prediction of weather phenomena such as thunderstorms, heavy rain, clear air turbulence, icing, low level wind shear, mountain waves, duststorms, squalls, gale, hailstorm, fog etc. which have the potential to adversely affect aviation activities.

Definition of Meteorology

2. Meteorology is the branch of wider science of physics, which deals with the atmosphere and the physical processes occurring in it. In other words, we can say ‘meteorology is the study of weather processes in the atmosphere’. We live in the ocean of air that is termed as ‘atmosphere’. But there occurs striking physical differences from time to time and from place to place. These changes are termed as ‘Weather’. Weather at a certain place and time is the result of prevailing state and motion of atmosphere. So meteorology is the study of atmospheric conditions such as pressure, temperature, wind, visibility, humidity etc and their change of states that gives weather like fog, snow, rain, thunderstorm etc.

Divisions of Meteorology

3. From the theoretical point of view meteorology may be divided into the following divisions:

4. **Synoptic Meteorology.** Weather observations, taken on the ground or on ships, and in the upper atmosphere with the help of balloon soundings, represent the state of the atmosphere at a given time. When the data are plotted on a weather map, we get a synoptic view of the world’s weather. Hence day-to-day analysis and forecasting of weather has come to be known as synoptic meteorology. It is the study of the movement of low pressure areas, air masses, fronts, and other weather systems like depressions and tropical cyclones.

5. **Climatology.** Climatology is a study of the climate of a place or region on the basis of weather records accumulated over long periods of time. The average values of meteorological parameters derived from a data base that extends over several decades are called climatological normals. Different regions of the world have different characteristic climates. However, it is now recognized that climate is not static and issues such as climate change and global warming are receiving increasing attention.

6. **Dynamic Meteorology.** This particular branch of meteorology attempts to describe the atmospheric processes through mathematical equations which together are called a numerical model. After defining the initial state of the atmosphere and ocean, the equations are solved to derive a final state, thus enabling a weather prediction to be made. Dynamic meteorology deals with a wide range of hydrodynamical equations from a global scale to small turbulent eddies. The process of solving the equations is very complicated and requires powerful computers to accomplish.

7. **Physical Meteorology.** In physical meteorology we study the physical processes of the atmosphere, such as solar radiation, its absorption and scattering in the earth-atmosphere system, the radiation back to space and the transformation of solar energy into kinetic energy of air. Cloud physics and the study of rain processes are a part of physical meteorology.

8. **Agriculture Meteorology.** In simple terms, agricultural meteorology is the application of meteorological information and data for the enhancement of crop yields and reduction of crop losses because of adverse weather. This has linkages with forestry, horticulture and animal husbandry. The agrometeorologist requires not only a sound knowledge of meteorology, but also of agronomy, plant physiology and plant and animal pathology, in addition to common agricultural practices. This branch of meteorology is of particular relevance to India because of the high dependence of our agriculture on monsoon rainfall which has its own vagaries.

9. **Applied Meteorology.** Like agriculture, there are many human activities which are affected by weather and for which meteorologists can provide valuable inputs. Applied meteorologists use weather information and adopt the findings of theoretical research to suit a specific application; for example, design of aircraft, control of air pollution, architectural design, urban planning, exploitation of solar and wind energy, air-conditioning, development of tourism, etc.

10. **Aeronautical Meteorology.** Aeronautical meteorology deals with the application of meteorology to the problems of aviation. High altitude meteorology is included in this division.

11. **Marine Meteorology.** Marine meteorology is related to marine navigator in the same manner as Aeronautical meteorology is related to air navigation.

12. **Medical Meteorology.** Medical meteorology deals with the influence of weather and climate on the human body and remedial action.

13. **Hydro Meteorology.** Hydro Meteorology deals with meteorological problems relating to water supply, flood control, irrigation etc.

14. **Aerology.** Aerology deals with the conditions of the free atmosphere on the basis of direct observation.

System of Measurement

15. To work in the field of meteorology, you must have a basic understanding of the science of measurement (metrology). When you can measure what you are talking about and express it in numerical values, you then have knowledge of your subject. To measure how far something is moved, or how heavy it is, or how fast it travels, you may use a specific measurement system. There are many such systems throughout the world today. The Metric System (CGS, centimeter-gram-second) has been recognised for use in science and research. Therefore, that system is discussed in the paragraphs that follow, with brief points of comparison to the English System (FPS, foot-pound-second).

16. The metric system is easy to learn as it is based on decimals. Because metrics are widely used in the field of meteorology, they are used throughout the notes.

17. As the metric system uses centimeter-gram-seconds (CGS) to describe physical events. These units measure length, weight, and time, respectively. The derivation of those units are described briefly.

Length

18. To familiarise you with the conventional units of metric length, start with the metre. The meter is slightly larger than the English yard (39.36 inches *vs* 36 inches). Prefixes are used in conjunction with the meter to denote smaller or larger units of the meter. Each larger unit is ten times larger than the next smaller unit. (See table 1.1)

19. Since the C in CGS represents centimeters (cm) you should see from table 1.1 that the centimeter is one-hundredth of a meter, 0.01 M, or 10^{-2} M. Conversely, 1 M equals 100 cm. To describe a gram, the G in the CGS system, you must first have a familiarisation with area and volume.

Table 1.1. Common Prefixes used in the Metric System

Prefix*	Symbol	Decimal Value	Scientific Notation
Kilo	K	1000	10^{3}
Hecto	H	100	10^{2}
Deca	D	10	10^{1}
Deci	d	0.1	10^{-1}
Centi	c	0.01	10^{-2}
Milli	m	0.001	10^{-3}

* These prefixes are used with all metric units such as meters, grams, liters, and seconds (e.g., kilometers, hectometers, centimeters, millimeters)

Area and Volume

20. A square has four equal sides and it is a one-plane figure-like a sheet of paper. To determine how much surface area is enclosed within the square you multiply the length of one side by the length of the other equal side. If the sides were 1 centimeter (cm) in length the area of the square would be 1 cm x 1 cm = 1 square cm, or 1 cm^2

21. Now, if squares having an area of 1 cm^2 were stacked on top of each other until the stack was 1 cm tall, you would end up with a cube whose sides were each 1 cm in length. To determine the volume of the cube you simply multiply the length by the width and height. Because each side is 1 cm you end up with a volume of 1 cubic centimeter (cm^3) (1 cm x 1 cm x 1 cm = 1 cm^3).

22. More simply stated, multiply the area of one side of the cube by the height of the cube. Once you understand how the volume of a cube is determined, you are now ready to review the G in the CGS system.

Weight

23. The conventional unit of weight in the metric system is the gram (gm). You could use table 1.1 and substitute the word gram for meter and the symbol (gm) for the symbol (M). You would then have a table for metric weight. The gram is the weight of 1 cm^3 of pure water at 4°C. At this point it may be useful to compare the weight of an object to its mass. The weight of the 1 cm^3 of water is 1 gm. Weight and mass are proportional to each other. However, the weight of the 1 cm^3 of water changes as you move away from the gravitational centre of Earth. In space the 1 cm^3 of water is weightless, but it is still a mass. Mass is expressed as a function of inertia/acceleration, while weight is a function of gravitational force. When we express the movement of an object we use the terms mass and acceleration.

Time

24. Time is measured in hours, minutes, and seconds in both systems. Hence, the second need not be explained in the CGS system. With knowledge of how the CGS system can be used to express physical entities, you now have all the background to express such things as density and force.

Density

25. With the previous explanation of grams and centimeters, you should be able to understand how physical factors can be measured and described. For example, density is the weight something has per unit of volume. The density of water is given as 1 gram per cubic centimeter or 1 gm per cm^3. By comparison, the density of water in the English system is 62.4 pounds per cubic foot or 62.4 lb per ft^3

Force

26. Force is measured in dynes. A dyne is the force that moves a mass of 1 gram, 1 centimeter per square second. This is commonly written as gm cm per sec^2, gm cm per sec per sec or gm per cm per sec^2. The force necessary for a gram to be accelerated at 980.665 cm per sec^2 at 45° latitude is 980.665 dynes.

TASK 30 : EARTH-SUN RELATIONSHIP

Introduction

1. The Sun is a great thermonuclear reactor about 93 million miles from Earth. It is the original source of energy for the atmosphere and life itself. The Sun's energy is efficiently stored on Earth in such things as oil, coal, and wood. Each of these was produced by some biological means when the Sun acted upon living organisms. Our existence depends on the Sun because without the Sun there would be no warmth on Earth, no plants to feed animal life, and no animal life to feed man.

2. The Sun is important in meteorology because all natural phenomena can be traced, directly or indirectly, to the energy received from the Sun. Although the Sun radiates its energy in all directions, only a small portion reaches our atmosphere. This relatively small portion of the Sun's total energy represents a large portion of the heat energy for our Earth. It is of such importance in meteorology that every meteorologist should have at least a basic knowledge about the Sun and the effects it has on Earth's weather.

Sun

3. The Sun may be regarded as the only source of heat energy that is supplied to Earth's surface and the atmosphere. All weather and motions in the atmosphere are due to the energy radiated from the Sun.

30. The Sun's core has a temperature of 1,50,00,000°K and a surface temperature of about 6,000°K (10,300°F). The Sun radiates electromagnetic energy in all directions. However, Earth intercepts only a small fraction of this energy. Most of the electromagnetic energy radiated by the Sun is in the form of light waves. Only a tiny fraction is in the form of heat waves. Even so, better than 99.9 percent of Earth's heat is derived from the Sun in the form of radiant energy.

Solar Composition

4. The Sun may be described as a globe of gas heated to incandescence by thermonuclear reactions from within the central core.

32. The main body of the Sun, although composed of gases, is opaque and has several distinct layers. (See fig. 1.1) The first of these layers beyond the radiative zone is the convective zone. This zone extends very nearly to the Sun's surface. Here, heated gases are raised buoyantly upwards with some cooling occurring and subsequent convective action similar to that which occurs within Earth's atmosphere: The next layer is a well-defined visible surface layer referred to as the photosphere. The bottom of the photosphere is the solar surface. In this layer the temperature has cooled to a surface temperature of 6,000°K at the bottom to 4,300°K at the top of the layer. All the light and heat of the Sun is radiated from the photosphere. Above the photosphere is a more transparent gaseous layer referred to as the chromosphere with a thickness of about 1,800 miles (3,000 km). It is hotter than the photosphere.

5. Above the chromosphere is the corona, a low-density high temperature region. It is extended far out into interplanetary space by the solar wind—a steady outward streaming of the coronal material. Much of the electromagnetic radiation emissions consisting of gamma rays through x-rays, ultraviolet, visible and radio waves, originate in the corona.

6. Within the solar atmosphere we see the occurrence of transient phenomena (referred to as solar activity), just as cyclones, frontal systems, and thunderstorms occur within the atmosphere of Earth. This solar activity may consist of the phenomena discussed in the following paragraphs which collectively describe the features of the solar disk (the visual image of the outer surface of the sun as observed from outside regions). (See fig. 1.2.)

Solar Prominences/Filaments

7. Solar prominences/filaments are injections of gases from the chromosphere into the corona. They appear as great clouds of gas, sometimes resting on the Sun's surface and at other times floating free with no visible connection. When viewed against the solar disk, they appear as long dark ribbons and are called filaments. When viewed against the solar limb (the dark outer edge of the solar disk), they appear bright and are called prominences. (See fig. 1.2) They display a variety of shapes, sizes, and activity that defy general description. They have a fibrous structure and appear to resist solar gravity. They may extend 18,500 to 1,25,000 miles (30,000 to 2,00,000 km) above the chromosphere. The more active types have temperatures of 10,000°K or more and appear hotter than the surrounding atmosphere.

Sunspots

8. Sunspots are regions of strong localised magnetic fields and indicate relatively cool areas in the photosphere. They appear darker than their surroundings and may appear singly or in more complicated groups dominated by larger spots near the centre. (See fig. 1.2.)

9. Sunspots begin as small dark areas known as pores. These pores develop into full-fledged spots in a few days, with maximum development occurring in about 1 to 2 weeks. When sunspots decay the spot shrinks in size and its magnetic field also decreases in size. This life cycle may consist of a few days for small spots to near 100 days for larger groups. The larger spots normally measure about 94,500 miles (1,20,000 km) across. Sunspots appear to have cyclic variations in intensity, varying through a period of about 8 to 17 years. Variation in number and size occurs throughout the sunspot cycle. As a cycle commences, a few spots are observed at high latitudes of both solar hemispheres, and the spots increase in size and number. They gradually drift equatorward as the cycle progresses, and the intensity of the spots reach a maximum in about 4 years. After this period, decay sets in and near the end of the cycle only a few spots are left in the lower latitudes (50 to 100).

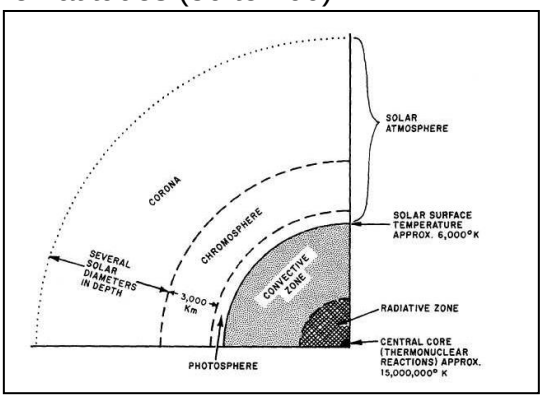


Fig 1.1. One-quarter cross-section depicting solar structure

Plages

10. Plages are large irregular bright patches that surround sunspot groups. (See fig. 1.2) They normally appear in conjunction with solar prominences or filaments and may be systematically arranged in radial or spiral patterns. Plages are features of the lower chromosphere and often completely or partially obscure an underlying sunspot.

Flares

11. Solar flares are perhaps the most spectacular of the eruptive features associated with solar activity. (See fig. 1.2) They look like flecks of light that suddenly appear near activity centres and come on instantaneously as though a switch were thrown. They rise sharply to peak brightness in a few minutes, and then decline more gradually. The number of flares may increase rapidly over an area of activity. Small flares like brightening are always in progress during the more active phase of activity centres. In some instances flares may take the form of prominences, violently ejecting material into the solar atmosphere and breaking into smaller high-speed blobs or clots. Flare activity appears to vary widely between solar activity centres. The greatest flare productivity seems to be during the week or 10 days when sunspot activity is at its maximum.

12. Flares are classified according to size and brightness. In general, the higher the importance classification, the stronger the geophysical effects. Some phenomena associated with solar flares have immediate effects; others have delayed effects (15 minutes to 72 hours after flare).

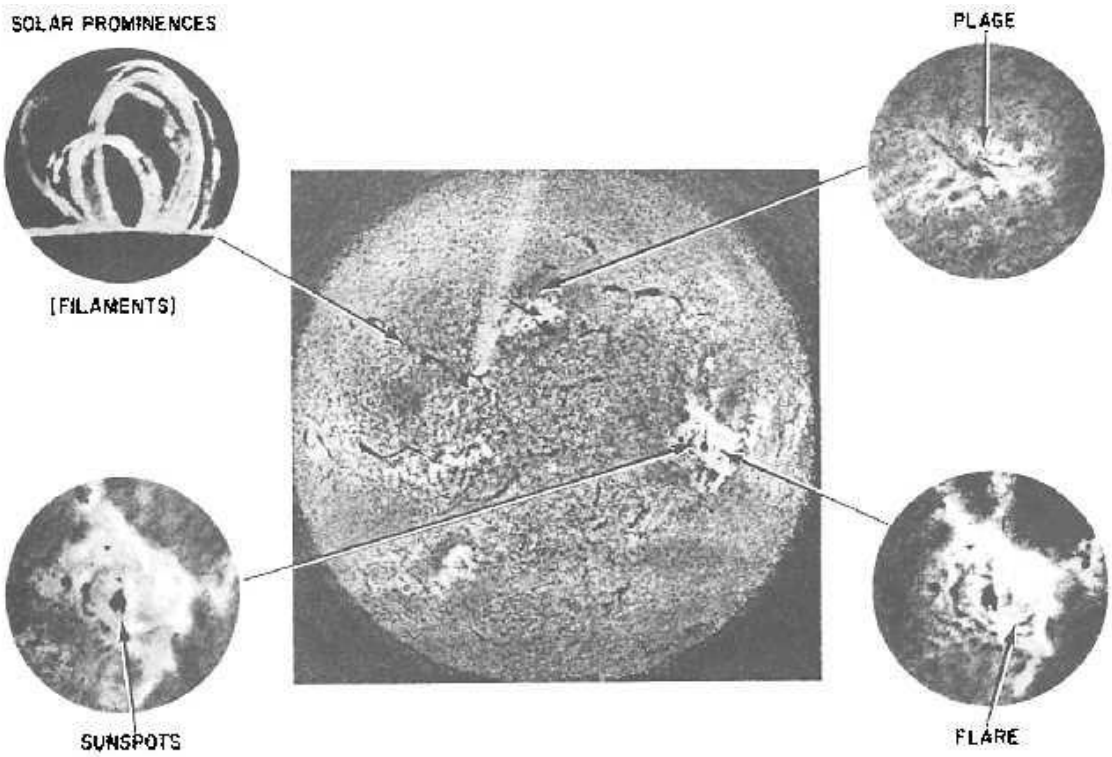


Fig 1.2. Features of the solar disk

13. Solar flare activity produces significant disruptions and phenomena within Earth's atmosphere. During solar flare activity, solar particle streams (solar winds) are emitted

and often intercept Earth. These solar particles are composed of electromagnetic radiation which interacts with Earth's ionosphere. This results in several reactions such as: increased ionization (electrically charging neutral particles), photo chemical changes (absorption of radiation), atmospheric heating, electrically charged particle motions, and an influx of radiation in a variety of wavelengths and frequencies which include radio and radar frequencies.

14. Some of the resulting phenomena include the disruption of radio communications and radar detection. This is due to ionization, incoming radio waves, and the motion of charged particles. Satellite orbits can be affected by the atmospheric heating and satellite transmissions may be affected by all of the reactions previously mentioned. Geomagnetic disturbances like the aurora borealis and aurora australis result primarily from the motion of electrically charged particles within the ionosphere.

Earth

15. Of the nine planets in our solar system, Earth is the third nearest to (or from) the Sun. Earth varies in distance from the Sun during the year. The Sun is 94 million miles (150,400,000 km) in summer and 91 million miles (145,600,000 km) in winter.

Motions

16. Earth is subject to four motions in its movement through space: rotation about its axis, revolution around the Sun, processional motion (a slow conical movement or wobble) of the axis, and the solar motion (the movement of the whole solar system with space). Of the four motions affecting Earth, only two are of any importance to meteorology.

17. The first motion is rotation. Earth rotates on its axis once every 24 hours. One-half of Earth's surface is therefore facing the Sun at all times. Rotation about Earth's axis takes place in an eastward direction. Thus, the Sun appears to rise in the east and set in the west. (See fig. 1.3)

18. The second motion of Earth is its revolution around the Sun. The revolution around the Sun and the tilt of Earth on its axis are responsible for our seasons. Earth makes one complete revolution around the Sun in approximately 365 1/4 days. Earth's axis is at an angle of 23½° to its plane of rotation and points in a nearly fixed direction in space toward the North Star (Polaris).

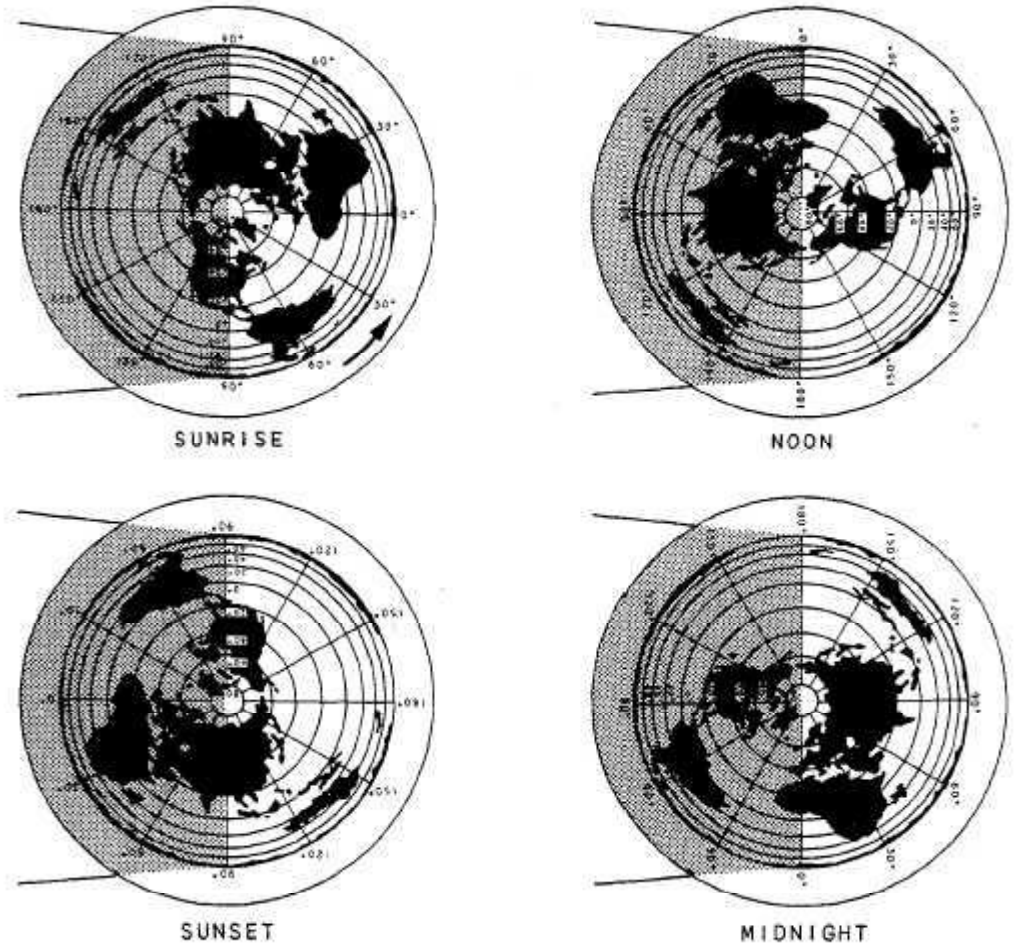


Fig 1.3. Rotation of Earth about its axis (during equinoxes)

Solstices and Equinoxes

19. When Earth is in its summer solstice, as shown for June in figure 1.4, the Northern Hemisphere is inclined 23½° toward the Sun. This inclination results in more of the Sun's rays reaching the Northern Hemisphere than the Southern Hemisphere. On or about June 21, direct sunlight covers the area from the North Pole down to latitude 66½°N (the Arctic Circle). The area between the Arctic Circle and the North Pole is receiving the Sun's rays for 24 hours each day. During this time the most perpendicular rays of the Sun are received at 23½°N latitude (the Tropic of Cancer). Because the Southern Hemisphere is tilted away from the Sun at this time, the indirect rays of the Sun reach only to 66½°S latitude (the Antarctic Circle). Therefore, the area between the Antarctic Circle and the South Pole is in complete darkness. Note carefully the shaded and un-shaded area of Earth in figure 1.4 for all four positions.

20. At the time of the equinox in March and again in September, the tilt of Earth's axis is neither toward nor away from the Sun. For these reasons Earth receives an equal amount of the Sun's energy in both the Northern Hemisphere and the Southern Hemisphere. During this time the Sun's rays shine most perpendicularly at the equator. In December, the situation is exactly reversed from that in June. The Southern Hemisphere now receives more of the Sun's direct rays. The most perpendicular rays of the Sun are received at 23½°S latitude (the Tropic of Capricorn).

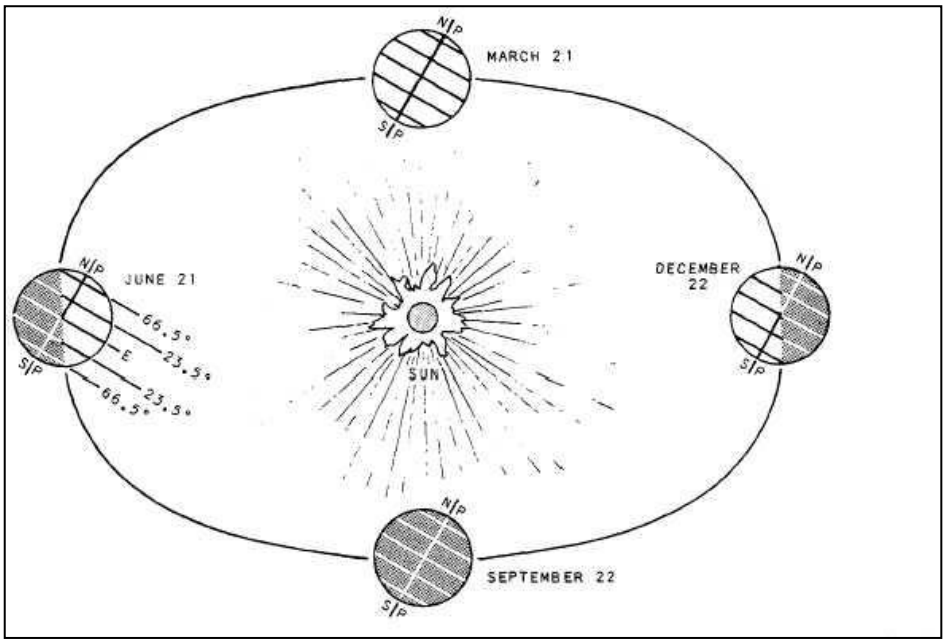


Fig 1.4. Revolution of Earth around the Sun

21. The southern polar region is now completely in sunshine; the northern polar region is completely in darkness.

22. Since the revolution of Earth around the Sun is a gradual process, the changes in the area receiving the Sun's rays and the changes in seasons are gradual. However, it is customary and convenient to mark these changes by specific dates and to identify them by specific names. These dates are as follows:-

a. **March 21**. The Vernal Equinox, when Earth's axis is perpendicular to the Sun's rays. Spring begins in the Northern Hemisphere and fall begins in the Southern Hemisphere.

b. **June 21**. The Summer Solstice, when Earth's axis is inclined 23½° toward the Sun and the Sun has reached its northernmost zenith at the Tropic of Cancer. Summer officially commences in the Northern Hemisphere; winter begins in the Southern Hemisphere.

c. **September 22**. The Autumnal Equinox, when Earth's axis is again perpendicular to the Sun's rays. This date marks the beginning of fall in the Northern Hemisphere and spring in the Southern Hemisphere. It is also the date, along with March 21, when the Sun reaches its highest position (zenith) directly over the equator.

d. **December 22**. The Winter Solstice, when the Sun has reached its southernmost zenith position at the Tropic of Capricorn. It marks the beginning of winter in the Northern Hemisphere and the beginning of summer in the Southern Hemisphere.

23. In some years, the actual dates of the solstices and the equinoxes vary by a day from the dates given here. This is because the period of revolution is 365 ¼ days and the calendar year is 365 days except for leap year when it is 366 days.

24. Because of its 23½° tilt and its revolution around the Sun, Earth is marked by five natural light (or heat) zones according to the zone's relative position to the Sun's rays. Since the Sun is always at its zenith between the Tropic of Cancer and the Tropic of Capricorn, this is the hottest zone. It is called the Equatorial Zone, the Torrid Zone, the Tropical Zone, or simply the Tropics.

25. The zones between the Tropic of Cancer and the Arctic Circle and between the Tropic of Capricorn and the Antarctic Circle are the Temperate Zones. These zones receive sunshine all year, but less of it in their respective winters and more of it in their respective summers. The zones between the Arctic Circle and the North Pole and between the Antarctic Circle and the South Pole receive the Sun's rays only for parts of the year. (Directly at the poles there are 6 months of darkness and 6 months of sunshine.) This, naturally, makes them the coldest zones. They are therefore known as the Frigid or Polar Zones.

Radiation

26. The term 'radiation' refers to the process by which electromagnetic energy is propagated through space. Radiation moves at the speed of light, which is 1,86,000 miles per second (2,97,600 km per second) and travels in straight lines in a vacuum. All of the heat received by Earth is through this process. It is the most important means of heat transfer.

27. Solar radiation is defined as the total electromagnetic energy emitted by the Sun. The Sun's surface emits gamma rays, x-rays, ultraviolet, visible light, infrared, heat, and electromagnetic waves. Although the Sun radiates in all wavelengths, about half of the radiation is visible light with most of the remainder being infrared. (See fig. 1.5)

28. Energy radiates from a body by wavelengths which vary inversely with the temperature of that body. Therefore, the Sun, with an extremely hot surface temperature, emits short wave radiation. Earth has a much cooler temperature (15°C average) and therefore reradiates the Sun's energy or heat with long wave radiation.

Insolation

29. Insolation (an acronym for incoming solar radiation) is the rate at which solar radiation is received by a unit horizontal surface at any point on or above the surface of Earth. In this manual, insolation is used when speaking about incoming solar radiation.

30. There is a wide variety of differences in the amounts of radiation received over the various portions of Earth's surface. These differences in heating are important and must be measured or otherwise calculated to determine their effect on the weather.

31. The insolation received at the surface of Earth depends upon the solar constant (the rate at which solar radiation is received outside Earth's atmosphere), the distance from the Sun, inclination of the Sun's rays, and the amount of insolation depleted while passing through the atmosphere. The last two are the important variable factors.

TASK 31 : METHODS OF HEAT TRANSFER

1. In meteorology, one is concerned with four methods of heat transfer. These methods are conduction, convection, advection, and radiation. Heat is transferred from Earth directly to the atmosphere by radiation, conduction, and advection. Heat is transferred within the atmosphere by radiation, conduction, and convection. Advection, a form of convection, is used in a special manner in meteorology. It is discussed as a separate method of heat transfer. As radiation was discussed earlier, this section covers conduction, convection, and advection.

2. **Conduction**. Conduction is the transfer of heat from warmer to colder matter by contact. Although of secondary importance in heating the atmosphere, it is a means by which air close to the surface of Earth heats during the day and cools during the night.

3. **Convection**. Convection is the method of heat transfer in a fluid resulting in the transport and mixing of the properties of that fluid. Visualise a pot of boiling water. The water at the bottom of the pot is heated by conduction. It becomes less dense and rises. Cooler and denser water from the sides and the top of the pot rushes in and replaces the rising water. In time, the water is thoroughly mixed. As long as heat is applied to the pot, the water continues to transfer heat by convection. The transfer of heat by convection in this case applies only to what is happening to the water in the pot. In meteorology, the term convection is normally applied to vertical transport. Convection occurs regularly in the atmosphere and is responsible for the development of air turbulence. Cumuliform clouds, showers and thunderstorms occur when sufficient moisture is present and strong vertical convection occurs. Vertical transfer of heat in the atmosphere (convection) works in a similar manner. Warmer, less dense air rises and is replaced by descending cooler, denser air, which in turn, acquires heat.

4. **Advection**. Advection is really a form of convection, but in meteorology it means the transfer of heat or other properties horizontally. Convection is the term reserved for the vertical transport of heat. The words convection and advection are used to mean the vertical and horizontal transfer of atmospheric properties, respectively. Horizontal transfer of heat is achieved by motion of the air from one latitude and/or longitude to another. It is of major importance in the exchange of air between polar and equatorial regions. Since large masses of air are constantly on the move somewhere on Earth's surface and aloft, advection is responsible for transporting more heat from place to place than any other physical motion. Transfer of heat by advection is achieved not only by the transport of warm air, but also by the transport of water vapour that releases heat when condensation occurs.

Depletion of Solar Radiation

5. If the Sun's radiation was not filtered or depleted in some manner, our planet would soon be too hot for life to exist. We must now consider how the Sun's heat energy is both dispersed and depleted. This is accomplished through dispersion, scattering, reflection, and absorption.

6. **Dispersion**. Earlier it was learned that Earth's axis is inclined at an angle of 23½°. This inclination causes the Sun's rays to be received on the surface of Earth at varying angles of incidence, depending on the position of Earth. When the Sun's rays are

not perpendicular to the surface of Earth, the energy becomes dispersed or spread out over a greater area (fig. 1.6). If the available energy reaching the atmosphere is constant and is dispersed over a greater area, the amount of energy at any given point within the area decreases, and therefore the temperature is lower. Dispersion of insolation in the atmosphere is caused by the rotation of Earth. Dispersion of insolation also takes place with the seasons in all latitudes, but especially in the latitudes of the polar areas.

7. **Scattering**. About 25 percent of the incoming solar radiation is scattered or diffused by the atmosphere. Scattering is a phenomenon that occurs when solar radiation passes through the air and some of the wavelengths are deflected in all directions by molecules of gases, suspended particles, and water vapour. These suspended particles then act like a prism and produce a variety of colours. Various wavelengths and particle sizes result in complex scattering affects that produce the blue sky. Scattering is also responsible for the red Sun at sunset, varying cloud colours at sunrise and sunset, and a variety of optical phenomena. Scattering always occurs in the atmosphere, but does not always produce dramatic settings. Under certain radiation wavelength and particle size conditions all that can be seen are white clouds and a whitish haze. This occurs when there is high moisture content (large particle size) in the air and is called diffuse reflection. About two-thirds of the normally scattered radiation reaches Earth as diffuse sky radiation. Diffuse sky radiation may account for almost 100 percent of the radiation received by polar stations during winter.

8. **Reflection**. Reflection is the process whereby a surface turns a portion of the incident radiation back into the medium through which the radiation came. Some insolation is reflected by a substance. This means that the electromagnetic waves simply bounce back into space. Earth reflects an average of 36 percent of the insolation. The percent of reflectivity of all wavelengths on a surface is known as its albedo. Earth's average albedo is from 36 to 43 percent. That is, Earth reflects 36 to 43 percent of insolation back into space. In calculating the albedo of Earth, the assumption is made that the average cloudiness over Earth is 52 percent. All surfaces do not have the same degree of reflectivity; consequently, they do not have the same albedo. Some examples are as follows:-

a. Upper surfaces of clouds reflect from 40 to 80 percent, with an average of about 55 percent.

b. Snow surfaces reflect over 80 percent of incoming sunlight for cold, fresh snow and as low as 50 percent for old, dirty snow.

c. Land surfaces reflect from 5 percent of incoming sunlight for dark forests to 30 percent for dry land.

d. Water surfaces (smooth) reflect from 2 percent, when the Sun is directly overhead, to 100 percent when, the Sun is very low on the horizon. This increase is not linear. When the Sun is more than 25° above the horizon, the albedo is less than 10 percent. In general, the albedo of water is quite low. When Earth as a whole is considered, cloud surfaces are most important in determining Earth's albedo.

9. **Absorption**. Earth and its atmosphere absorb about 64 percent of the insolation. Land and water surfaces of Earth absorb 51 percent of this insolation. The remaining 13 percent is directly absorbed by ozone, carbon dioxide, and water vapour.

These gases absorb the insolation at certain wavelengths. For example, ozone absorbs only a small percentage of the insolation. The portion or type the ozone does absorb is critical since it reduces ultraviolet radiation to a level where animal life can safely exist. The most important absorption occurs with carbon dioxide and water vapour which absorb strongly over a broader wavelength band. Clouds are by far the most important absorbers of radiation at essentially all wavelengths. In sunlight, clouds reflect a high percentage of the incident solar radiation and account for most of the brightness of Earth as seen from space. There are regions, such as areas of clear skies, where carbon dioxide and water vapour are at a minimum and so is absorption. These areas are called atmospheric windows and allow insolation to pass through the atmosphere relatively unimpeded.

Greenhouse Effect

10. The atmosphere conserves the heat energy of Earth because it absorbs radiation selectively. Most of the solar radiation in clear skies is transmitted to Earth's surface, but a large part of the outgoing terrestrial radiation is absorbed and reradiated back to the surface. This is called the Greenhouse effect. A greenhouse permits most of the short-wave solar radiation to pass through the glass roof and sides, and to be absorbed by the floor, ground or plants inside. These objects reradiate energy at their temperatures of about 300°K, which is a higher temperature than the energy that was initially received. The glass absorbs the energy at these wavelengths and sends part of it back into the greenhouse, causing the inside of the structure to become warmer than the outside. The atmosphere acts similarly, transmitting and absorbing in somewhat the same way as the glass. If the greenhouse effect did not exist, Earth's temperature would be 35°C cooler than the 15°C average temperature we now enjoy, because the insolation would be reradiated back to space.

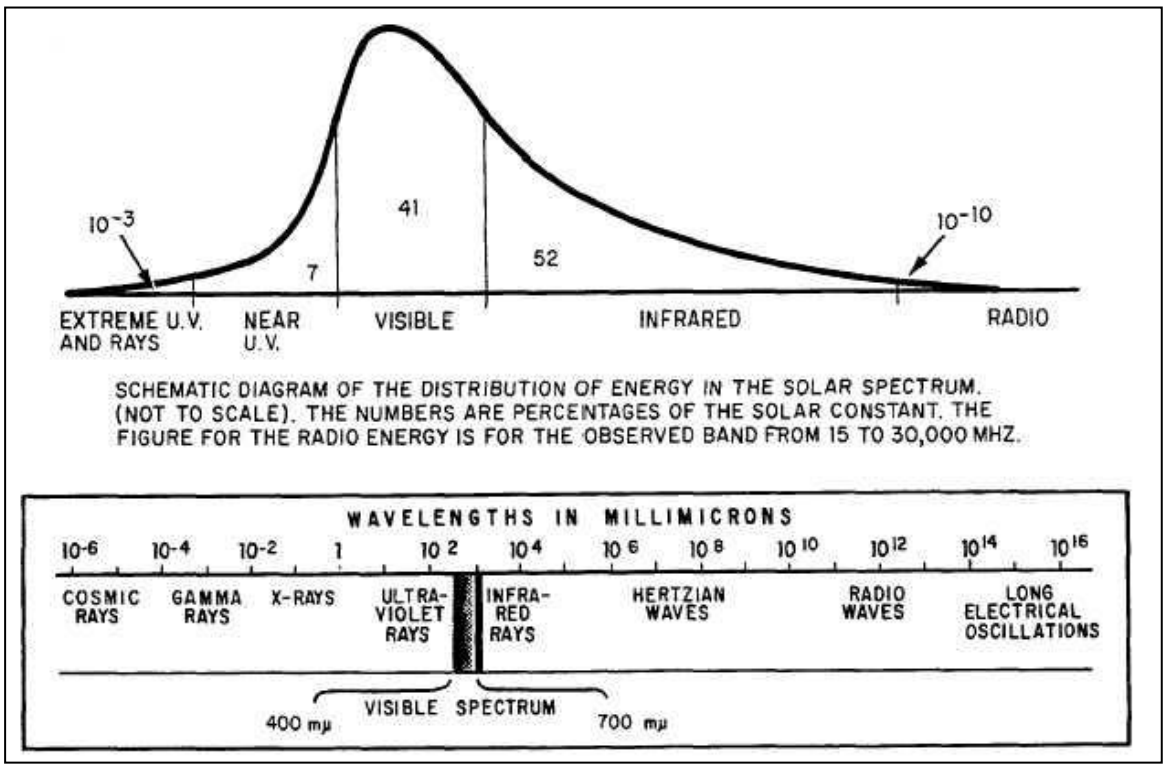


Fig 1.5. Electromagnetic Spectrum

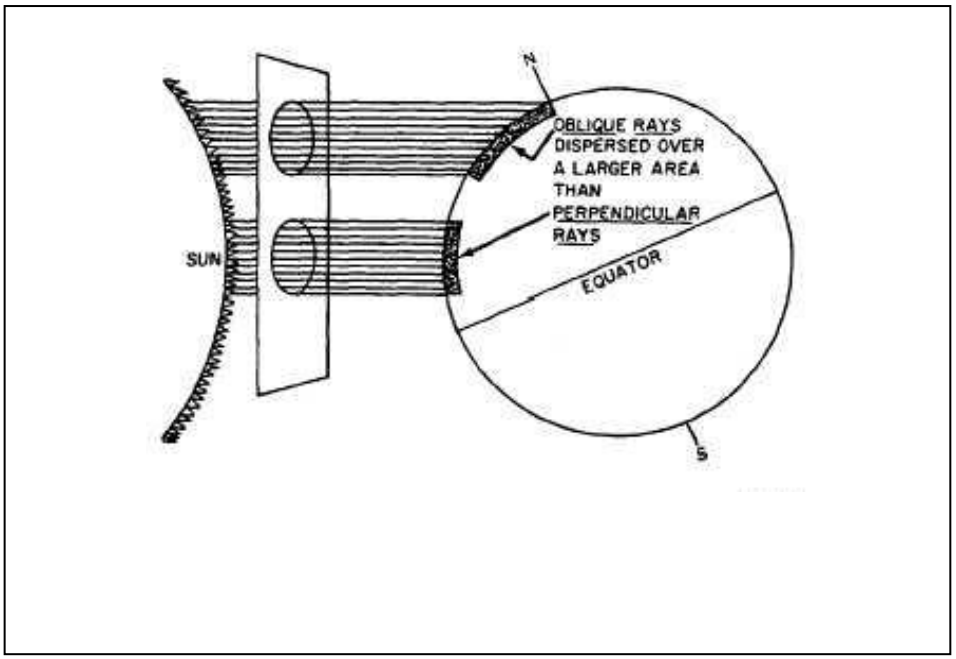


Fig 1.6. Dispersion of Insolation

11. Of course, the atmosphere is not a contained space like a greenhouse because there are heat transport mechanisms such as winds, vertical currents, and mixing with surrounding and adjacent cooler air.

TASK 32 : RADIATION (HEAT) BALANCE IN THE ATMOSPHERE

1. The Sun radiates energy to Earth, Earth radiates energy back to space, and the atmosphere radiates energy also. As is shown in fig 1.7, a balance is maintained between incoming and outgoing radiation. This section of the lesson explains the various radiation processes involved in maintaining this critical balance and the effects produced in the atmosphere.

2. We have learned that an object reradiates energy at a higher temperature. Therefore, the more the Sun heats Earth, the greater the amount of heat energy Earth reradiates. If this rate of heat loss/gain did not balance, Earth would become continuously colder or warmer.

Terrestrial (Earth) Radiation

3. Radiation emitted by Earth is almost entirely long-wave radiation. Most of the terrestrial radiation is absorbed by the water vapour in the atmosphere and some by other gases (about 8 percent is radiated directly to outer space). This radiant energy is reradiated in the atmosphere horizontally and vertically. Horizontal flux (flow or transport) of energy need not be considered due to a lack of horizontal temperature differences. The vertical, upward or downward, flux is of extreme significance.

4. Some of this radiation is carried aloft by convection and turbulence. Water vapour, undergoing the condensation-precipitation-evaporation cycle (hydrological cycle), carries the remainder into the atmosphere.

Atmospheric Radiation

5. The atmosphere reradiates to outer space most of the terrestrial radiation (about 43 percent) and insolation (about 13 percent) that it has absorbed. Some of this re-radiation is emitted earthward and is known as counter-radiation. This radiation is of great importance in the greenhouse effect.

Heat Balance and Transfer in the Atmosphere

6. Earth does not receive equal radiation at all points as was shown in fig1.8. The east-west rotation of Earth provides equal exposure to sunlight but latitude and dispersion do affect the amount of incident radiation received. The poles receive far less incident radiation than the equator. This uneven heating is called differential insolation.

7. Due to this differential insolation the tropical atmosphere is constantly being supplied heat and the temperature of the air is thus higher than in areas poleward. Because of the expansion of warm air, this column of air is much thicker and lighter than over the poles. At the poles Earth receives little insolation and the column or air is less thick and heavier. This differential in insolation sets up a circulation that transports warm air from the Tropics poleward aloft and cold air from the poles equatorward on the surface. (See fig. 1.8)

Summary

8. This is the account of the total radiation. Some of the radiation makes several trips, being absorbed, reflected, or reradiated by Earth or the atmosphere. Insolation comes into the atmosphere and all of it is reradiated. How many trips it makes while in our atmosphere does not matter. The direct absorption of radiation by Earth and the atmosphere and the re-radiations into space balance. If the balance did not exist, Earth and its atmosphere, over a period of time, would steadily gain or lose heat.

9. Although radiation is considered the most important means of heat transfer, it is not the only method. There are others such as conduction, convection, and advection that also play an important part in meteorological processes.

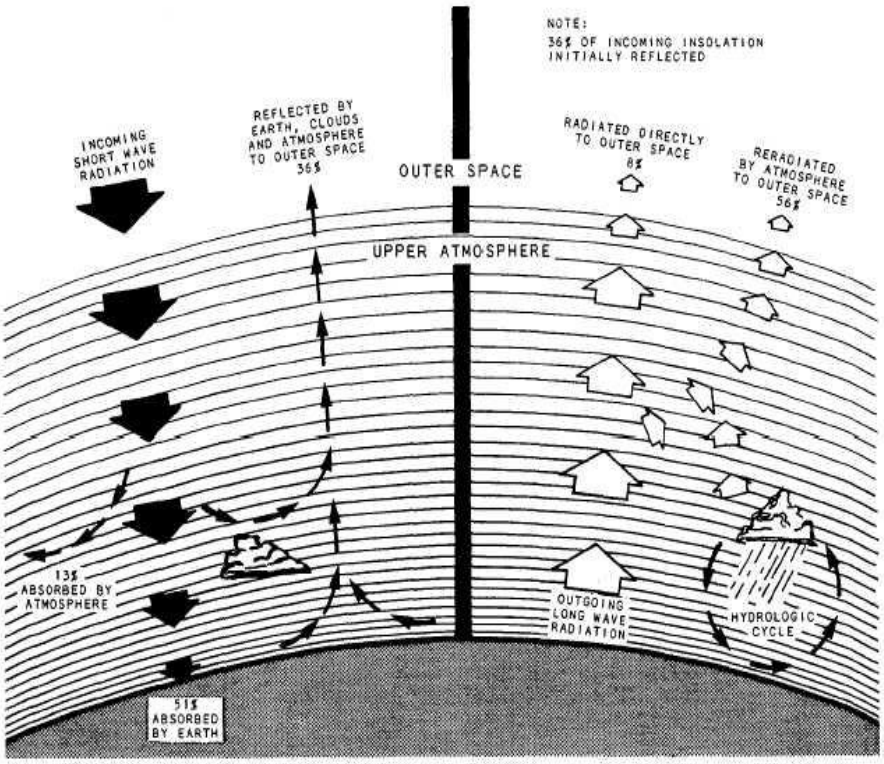


Fig 1.7. Radiation Balance in the Atmosphere

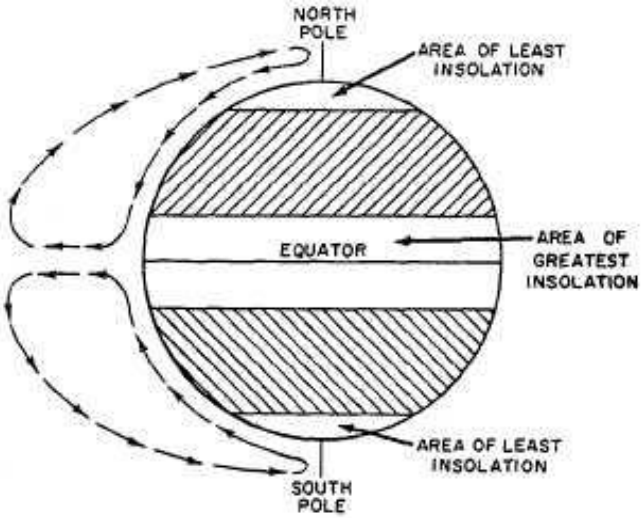


Fig 1.8. Beginning of a Circulation

SECTION-7 : ATMOSPHERE

TASK 33 : LAYERS OF ATMOSPHERE

Introduction

1. Troposphere is defined as the gaseous envelope or blanket surrounding a plant. The study of the Earth's atmosphere, termed meteorology, goes back thousands of years. Present evidence suggests that no other planet has the exact mixture of gases or the heat and water conditions necessary to sustain life as we know it. In fact, Steven Hawking, a well-known physicist, believes that the chance of a planet developing an atmosphere like Earth's are less than a million to one. The gases that make up the atmosphere and the systems which impact the atmosphere are vital to our lives. Atmospheric changes occur all the time, and if we alter or change our atmosphere too greatly it may impact our environment, drastically changing our lives.

Layers of Atmosphere

2. The envelope of gas surrounding the Earth changes from the ground up. Five distinct layers have been identified using:

a. Thermal characteristics (temperature changes).

b. Chemical composition.

c. Movement.

d. Density.

3. Each of the layers are bounded by "pauses" where the maximum changes in thermal characteristics, chemical composition, movement, and density occur.

4. **Troposphere**. The troposphere is the layer of air enveloping Earth immediately above Earth's surface. It is approximately 5½ miles (29,000 ft or 9 km) thick over the poles, about 7½ miles (40,000 ft or 12.5 km) thick in the mid-latitudes, and about 11½ miles (61,000 ft or 19 km) thick over the Equator. The figures for thickness are average figures; they change somewhat from day to day and from season to season. The troposphere is thicker in summer than in winter and is thicker during the day than during the night. Almost all weather occurs in the troposphere. However, some phenomena such as turbulence, cloudiness (caused by ice crystals), and the occasional severe thunderstorm top occur within the tropopause or stratosphere. The troposphere is composed of a mixture of several different gases. By volume, the composition of dry air in the troposphere is as follows:-

a. 78 percent nitrogen, 21 percent oxygen, nearly 1 percent argon, and about 0.03 percent carbon dioxide. In addition, it contains minute traces of other gases, such as helium, hydrogen, neon, krypton, and others.

b. The air in the troposphere also contains a variable amount of water vapour. The maximum amount of water vapour that the air can hold depends on the temperature of the air and the pressure. The higher the temperature, the more water vapour it can hold at a given pressure.

c. The air also contains variable amounts of impurities, such as dust, salt particles, soot, and chemicals. These impurities in the air are important because of their effect on visibility and the part they play in the condensation of water vapour. If the air were absolutely pure, there would belittle condensation. These minute particles act as nuclei for the condensation of water vapour. Nuclei which have an affinity for water vapour are called hydroscopic nuclei.

d. The temperature in the troposphere usually decreases with height, but there may be inversions for relatively thin layers at any level.

5. **Tropopause**. The tropopause is a transition layer between the troposphere and the stratosphere. It is not uniformly thick, and it is not continuous from the equator to the poles. In each hemisphere the existence of three distinct tropopause is generally agreed upon—one in the subtropical latitudes, one in middle latitudes, and one in sub-polar latitudes. They overlap each other where they meet. The tropopause is characterised by little or no increase or decrease in temperature with increasing altitude. The composition of gases is about the same as that for the troposphere. However, water vapour is found only in very minute quantities at the tropopause and above it.

6. **Stratosphere**. The stratosphere directly overlies the tropopause and extends to about 30 miles (160,000 ft or 48 kilometers). Temperature varies little with height in the stratosphere through the first 30,000 feet (9,000 meters); however, in the upper portion the temperature increases approximately linearly to values nearly equal to surface temperatures. This increase in temperature through this zone is attributed to the presence of ozone that absorbs incoming ultraviolet radiation.

7. **Stratopause.** The stratopause is the top of the stratosphere. It is the zone marking another reversal with increasing altitude (temperature begins to decrease with height).

8. **Mesosphere**. The mesosphere is a layer approximately 20 miles (100,000 ft or 32 kilometres) thick directly overlaying the stratopause. The temperature decreases with height.

9. **Mesopause**. The mesopause is the thin boundary zone between the mesosphere and the thermosphere. It is marked by a reversal of temperatures; i.e., temperature again increases with altitude.

10. **Thermosphere**. The thermosphere, a second region in which the temperature increases with height, extends from the mesopause to the exosphere.

11. **Exosphere**. The very outer limit of Earth's atmosphere is regarded as the exosphere. It is the zone in which gas atoms are so widely spaced they rarely collide with one another and have individual orbits around Earth.

12. **Electrical Classification**. The primary concern with the electrical classification is the effect on communications and radar. The electrical classification outlines three zones—the troposphere, the ozonosphere, and the ionosphere.

13. **Troposphere**. The troposphere is important to electrical transmissions because of the immense changes in the density of the atmosphere that occur in this layer. These density changes, caused by differences in heat and moisture, affect the electronic emissions that travel through or in the troposphere. Electrical waves can be bent or refracted when they pass through these different layers and the range and area of communications may be seriously affected.

14. **Ozonosphere**. This layer is nearly coincident with the stratosphere. As was discussed earlier, the ozone found in this zone is responsible for the increase in temperature with height in the stratosphere.

15. **Ionosphere**. The ionosphere extends from about 40 miles (200,000 ft or 64 kilometers) to an indefinite height. Ionization of air molecules in this zone provides conditions that are favourable for radio propagation. This is because radio waves are sent outward to the ionosphere and the ionised particles reflect the radio waves back to Earth.

16. **Vertical Profile**

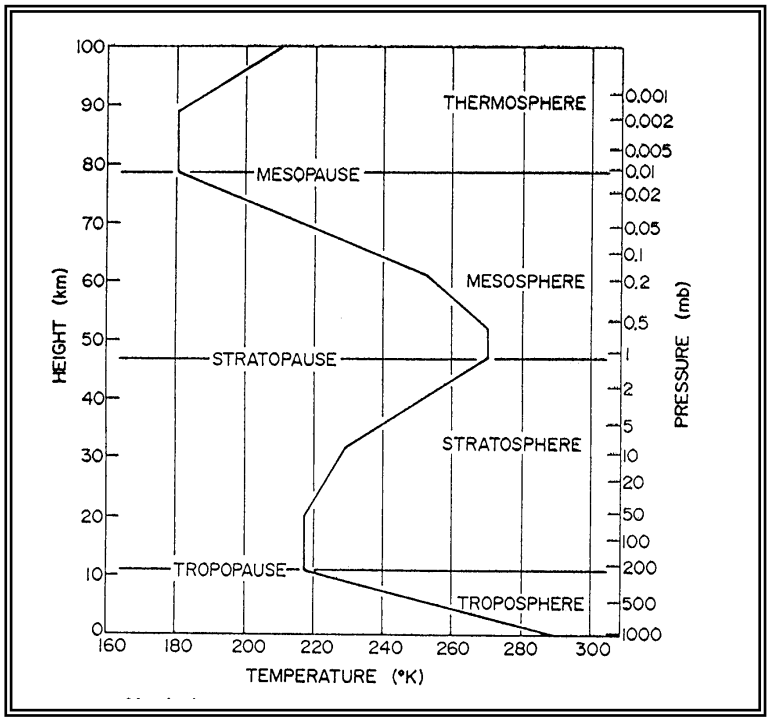


Fig 2.1 Vertical Temperature Profile

Troposphere	Rather well-mixed layer
	Relatively linear decrease in temperature with height up to the **tropopause**
Stratosphere	Layered structure
	Temperature almost constant with height in the lower stratosphere and then increases up to the **stratopause**
Mesosphere	Middle atmosphere
	Temperature decreases with height up to the **mesopause**
Thermosphere	Temperature increases with height

Heat Transfer

17. The atmosphere is constantly gaining and losing heat. Heat is constantly being transported from one part of the world to another by wind movements. It is due to the inequalities in gain and loss of heat that the air is almost constantly in motion. The motions and heat transformations are directly expressed by wind and weather.

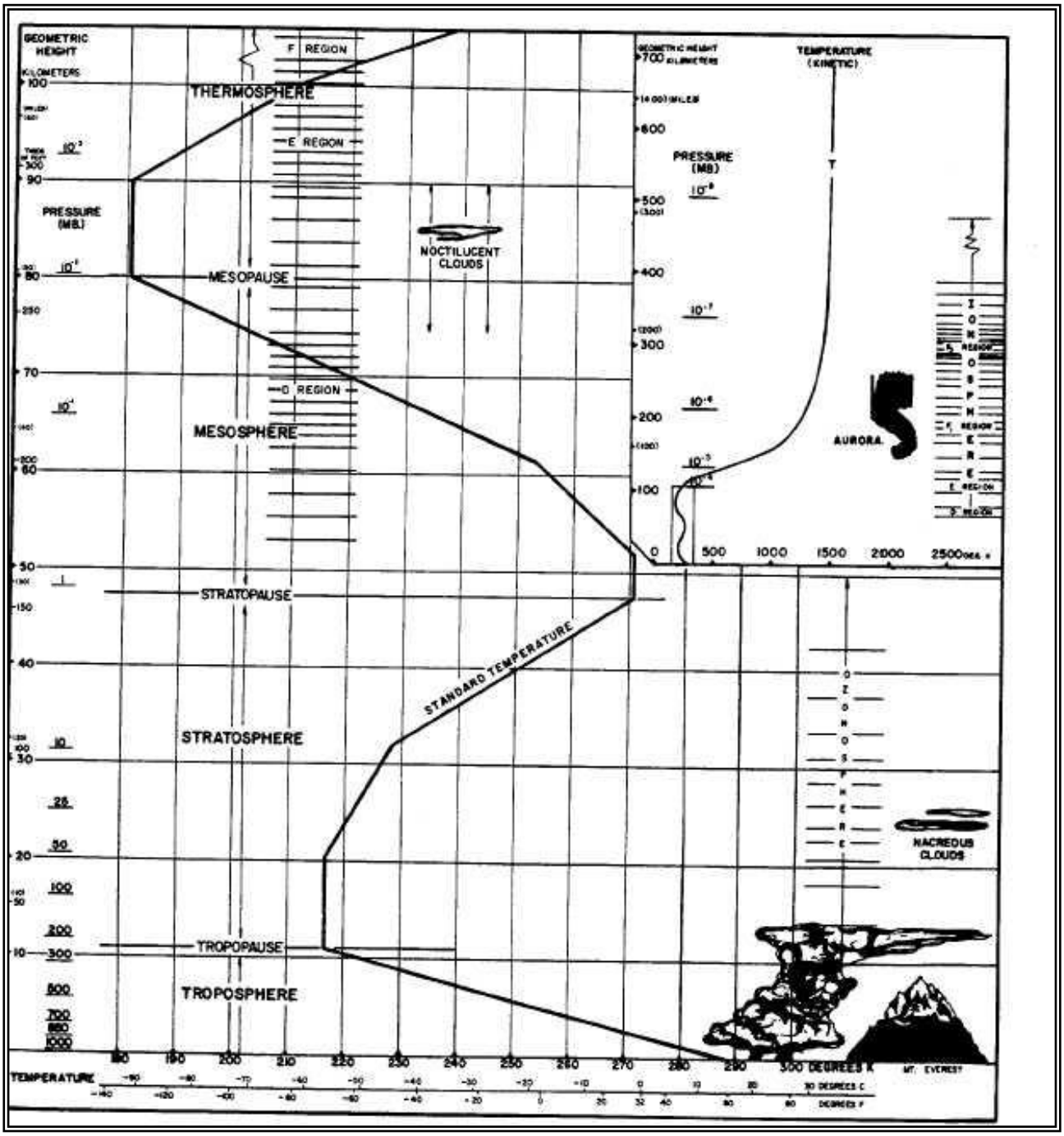


Fig 2.2. Earth's Atmosphere

SECTION-8 : METEOROLOGICAL ELEMENTS AND PHENOMENA

TASK 34 : IMPORTANCE OF METEOROLOGICAL ELEMENTS IN AVIATION

Importance of Various Meteorological Elements

1. Weather is a phenomenon of the atmosphere. Aircraft operate in this medium. Hence knowledge about the happenings in this medium is essential for safe aircraft operation. Some elements like pressure, temperature, density etc govern the operational efficiency of the aircraft. Some weather phenomenon like thunder storm, rain, fog etc restrict their operations. Weather and weather elements play a very vital role in aviation. Wirght brothers' aircraft toppled during the trials due to strong gust. This incident at the very dawn of aviation demonstrated the importance of meteorological support for safe conduct of air operations. Early development in aviation meteorology was in response to demands of military aviation and air mail services. Subsequently its growth in the post second world war period has been predominantly driven by the phenomenal growth of commercial aviation. "Military aviation is different from that of civil aviation in that it is not take-off and landing-centric. Military aircraft are on a mission. It is not enough if the conditions are conducive for take-off and landing. The weather should be conducive for the pilot to accomplish his mission".

2. **Surface Winds.** Surface wind is an important factor during the take off and landing phases of a flight. Aircraft take off and land into the wind. Direction of the prevailing winds determines the runway to be used. The lift of an aircraft depends on the component of surface wind along the runway. The drift and controllability of an aircraft in the take-off or landing run depend upon the cross-wind component of the wind. Hence the wind direction, speed and gusts if any are to be reported accurately and the latest values passed on to the aircraft. Accurate surface winds are important for para drop operations. For example, attempting drops when surface wind speeds are more than 10 kt may lead to disaster. The direction is important in confining the drops to the required area and applying correction for drift.

3. **Head and Tail Wind Components.** The tail winds increase the take off and landing distances. For the tail wind components of 10% of the landing/take off speed, roughly 15 kt in case of most ac, there is an increase of 21% in landing distances. Gustiness is more crucial, especially at round off stage and unsticking or lift off stage. There is an increase in the stall speed because of increase in the angle of attack. Horizontal gusts can cause the ac to float or sink as per increase in head or tail wind component. The minimum flying speed of an ac is 15 % higher than the stall speed. Sudden decrease in the head wind component at the short finals stage can push the ac into stall. Reporting max wind speed along with mean speed deserves special attention on the part of met officers.

4. **Wind Shear.** Another parameter which is required by high speed aircraft, particularly if they are making use of automatic landing devices, is the vertical wind shear from ground to say 100 to 300 m. At present we have no satisfactory method of providing this information. Its effect can be visualised through an example. When the surface wind is calm or light, the aircraft may be approaching with a tail wind which decreases with decreasing height. This would result in a constant increase in the lift of the aircraft and consequently it may overshoot the runway. Conversely, if there is a head wind decreasing with decreasing height, there may not be sufficient lift during the final approach and undershooting may be the result. If there is a cross-wind shear, it will become difficult to maintain the alignment with the runway. Thus, vertical wind shear assumes importance during the approach and landing phase and also in the take off and climb-out phase and affect the performance and controllability of aircraft over the runway during take off and landing.

5. **Temperature.** The indirect importance of temperature in aviation is clear from the fact that temperatures are in many ways directly related to the development of weather. Apart from the forecasting aspect, the aircraft manufacturers must allow for all possible variations in temperature upto the ceiling height of the aircraft in connection with aircraft performance and cooling systems. Engine performance and cooling systems depend on the variation of temperature in the atmosphere. Higher temperature implies lower density and so has an adverse effect on engine performance. This effect is usually greatest during take-off, but it should also be considered at other stages of flight, especially for jet aircraft. The efficiency of a jet engine depends on the difference between the outside air temperature and the maximum temperature attainable in the combustion chamber, which for safe running must not exceed a certain limit. When the air temperature increases above a certain value, depending on the altitude, both efficiency and true airspeed fall off (other things being equal) and the aircraft's operation height is reduced at the cost of an increase in fuel consumption per air kilometer. The air temperature again is intimately related to the risk of ice accretion during flight. Details of performance in terms of temperature, pressure, altitude, all-up weight etc are given in the appropriate aircraft flight manual; thus, for flying, approved operational requirements regulate the maximum weight at which an aircraft shall operate at take-off, en-route and on landing, for altitudes and temperature concerned. Aircraft performance charts are based on the standard atmosphere, more precisely, the ISA. Hence when the atmospheric temperature varies from the standard there is a variation in the efficiency.

6. **Density.** Density of air in the atmosphere depends on Temperature, pressure and humidity. Their dependency is as follows. If pressure is more than standard atmosphere for a given altitude then density is high. If temperature is high density is low. If humidity is high density is low. Minimum density may occur with exceptionally low pressure, exceptionally high temperature or with high humidity or with combination of all. In tropics the effect of temperature is usually more important. Variation during the course of the day arise mainly from the diurnal variation of temperature, the lowest densities occurring in early afternoon and the highest at night.. Density decreases by about 1 percent for every 3 deg c rise of temp or 10 hPa fall of press. It is another important Met element that affects an aircraft performance. The level of maximum efficiency, lift, drag, ceiling height and air speed – all to a large extent depend upon air density. At surface, if the density is low, lift reduces and aircraft will require longer runway for both take off as well as landing. Runway lengths being fixed this puts a limit on the “All up weight” or in other wards the load of the air craft. In respect of fighter aircraft the restrictions can be in terms of weapon system that can be carried or the fuel. In respect of commercial aircraft this imposes a restriction on the cargo/passengers. In regard to conditions at an aerodrome, the average and minimum air density occurring in any month may be provided to the operator since they indicate the average and the most adverse effects on take-off and landing speeds and on load. Such information is commonly given in terms of density altitude.

7. **Upper Winds and Temperature.** Information regarding the winds and temperature at higher levels is crucial to a aviator. The true air speed in cruise will depend entirely on the direction and speed of wind at the level of flight. Knowledge of the actual wind conditions is necessary to calculate the fuel load to be carried. Wind is also used in navigation to calculate the time elapsed and position. Strong head winds (of the order of 100 kt or more in the jet streams), if not taken into account at the time of flight planning, may mean running out of fuel before reaching the destination. Upper air temperatures have a critical effect on the performance of turbine engines. In some circumstances the fall in power caused by high ambient temperatures could reduce the efficiency of turbo-jets by as much as 10%. In case of jet engines, faulty power setting due to inaccurate temperature values may even lead to flame-outs. In case of jet engines, faulty power setting due to inaccurate temperature values may even lead to flame-outs.

8. **Pressure.** The altimeters in the aircraft work on the principle of decrease of pressure with height. This naturally means that the altimeter will read correctly only if the pressure setting is correct. For setting the altimeters before landing and take off, correct pressure values are required

TASK 35 :METEOROLOGICAL ELEMENTS

Pressure

1. **Definition of Pressure**. Pressure is one of the most important parameters in meteorology. Knowledge of the distribution of air and the resultant variations in air pressure over the earth is vital in understanding Earth's fascinating weather patterns. Pressure is the force per unit area. Atmospheric pressure is the force per unit area exerted by the atmosphere in any part of the atmospheric envelope. Therefore, the greater the force exerted by the air for any given area, the greater the pressure. Although the pressure varies on a horizontal plane from day to day, the greatest pressure variations are with changes in altitude. Nevertheless, horizontal variations of pressure are ultimately important in meteorology because the variations affect weather conditions. Pressure is force, and force is related to acceleration and mass by Newton's second law. This law states that acceleration of a body is directly proportional to the force exerted on the body and inversely proportional to the mass of that body. It may be expressed as

$$a = F/m \quad \text{or} \quad F = m\,a$$

where "**a**" is the acceleration, "**F**" is the force exerted, and "**m**" is the mass of the body. This is probably the most important equation in the mechanics of physics dealing with force and motion.

2. **Standards of Measurement.** Atmospheric pressure is normally measured in meteorology by the use of a mercurial or aneroid barometer. Pressure is measured in many different units. One atmosphere of pressure is 29.92 inches of mercury or 1,013.25 hPa. These measurements are made under established standard conditions.

3. **Standard Sea Level Pressure.** The establishment of a standard atmosphere was necessary to give scientists a yardstick to measure or compare actual pressure with a known standard. In the International Civil Aeronautical Organization (ICAO), the standard atmosphere assumes a mean sea level temperature of 59°F or 15°C and a standard sea level pressure of 1,013.25 hPa or 29.92 inches of mercury. It also has a temperature lapse rate (decrease) of 3.6°F per 1000 feet or 0.65°C per 100 meters up to 11 kilometers and a tropopause and stratosphere temperature of – 56.5°C or – 69.7°F.

4. **Vertical Distribution of Pressure.** Pressure at any point in a column of water, mercury, or any fluid, depends upon the weight of the column above that point. Air pressure at any given altitude within the atmosphere is determined by the weight of the atmosphere pressing down from above. Therefore, the pressure decreases with altitude because the weight of the atmosphere decreases. It has been found that the pressure decreases by half for each 18,000-foot (5,400-meter) increase in altitude. Thus, at 5,400 meters one can expect an average pressure of about 500 millibars and at 36,000 feet (10,800 meters) a pressure of only 250 hPa, etc. Therefore, it may be concluded that atmospheric pressures are greatest at lower elevations because the total weight of the atmosphere is greatest at these points. There is a change of pressure whenever either the mass of the atmosphere or the accelerations of the molecules within the atmosphere are changed. Although altitude exerts the dominant control, temperature and moisture alter pressure at any given altitude-especially near Earth's surface where heat and humidity, are most abundant. The pressure variations produced by heat and humidity with heat being the dominant force, are responsible for Earth's winds through the flow of atmospheric mass from an area of higher pressure to an area of lower pressure.

Temperature

5. **Definition of Pressure**. One of the most important properties of the atmosphere is its ability to absorb and lose heat. The heating and cooling of the atmosphere exerts a tremendous influence on the processes that determine the weather. Consequently, temperature is one of your principal concerns. It is necessary to know the meaning of temperature, the scales and instruments used in its measurement, and the important temperature values. Temperature may be regarded as a measure of molecular motion. Its intensity is determined from absolute zero (Kelvin scale), the point at which all molecular motion stops. Temperature is the degree of hotness or coldness, or it may be considered as a measure of heat intensity.

6. **Temperature Scales.** Long ago it was recognised that uniformity in the measurement of temperature was essential. It would be unwise to rely on such subjective judgments of temperature as cool, cooler, and coolest; therefore, arbitrary scales were devised. Some of them are described in this section. They are Fahrenheit, Celsius, and absolute (Kelvin) scales. These are the scales used by the meteorological services of all the countries in the world.

7. **Fahrenheit Scale.** The Fahrenheit scale was invented by Gabriel Daniel Fahrenheit about 1710 AD. He was the first to use mercury in a thermometer. The Fahrenheit scale has 180 divisions or degrees between the freezing (32°F) and boiling (212°F) points of water.

8. **Celsius Scale.** The Celsius scale was devised by Anders Celsius also during the 18th century. This scale has reference points with respect to water of 0°C for freezing and 100°C for boiling. It should be noted that many publications still refer to the centigrade temperature scale. Centigrade simply means graduated in 100 increments, and has recently and officially adopted the name of its discoverer, Celsius.

9. **Absolute Scale (Kelvin).** Another scale in wide use by scientists in many fields is the absolute scale or Kelvin scale. It was developed by Lord Kelvin of England. On this scale the freezing point of water is 273°K and the boiling point of water is 373°K. The absolute zero value is considered to be a point at which theoretically no molecular activity exists. This places the absolute zero at a minus 273° on the Celsius scale, since the degree divisions are equal in size on both scales. The absolute zero value on the Fahrenheit scale falls at minus 459.6°F.

10. **Scale Conversions.** Two scales, Fahrenheit and Celsius, are commonly used. With the Celsius and Fahrenheit scales, it is often necessary to change the temperature value of one scale to that of the other. Generally a temperature conversion table is used or a temperature computer. If these are not available, you must then use one of the following mathematical methods to convert one scale to another. It is important to note that there are 100 divisions between the freezing and boiling points of water on the Celsius scale. There are 180 divisions between the same references on the Fahrenheit scale. Therefore, one degree on the Celsius scale equals nine-fifths degree on the Fahrenheit scale. In converting Fahrenheit values to Celsius values the formula is: **C = (F – 32) (5/9).** In converting Celsius values to Fahrenheit values the formula is:-

$$F = (9/5)\ C + 32$$

One way to remember when to use 9/5 and when to use 5/9 is to keep in mind that the Fahrenheit scale has more divisions than the Celsius scale. In going from Celsius to Fahrenheit, multiply by the ratio that is larger; in going from Fahrenheit to Celsius, use the smaller ratio. Another method of converting temperatures from one scale to another is the decimal method. This method uses the ratio 1°C equals 1.8°F. To find Fahrenheit from Celsius, multiply the Celsius value by 1.8 and add 32. To find Celsius from Fahrenheit, subtract 32 from the Fahrenheit and divide the remainder by 1.8. To change a Celsius reading to an absolute value, add the Celsius reading to 273° algebraically. For example, to find the absolute value of – 35°C, you would add minus 35° to 273°K algebraically. That is, you take 273° and combine –35° so you use the minus (–) function to arrive at 238°K. To change a Fahrenheit reading to an absolute value, first convert the Fahrenheit reading to its equivalent Celsius value, which is then added algebraically to 273°. Consequently, 50°F is equivalent to 283° absolute, arrived at by converting 50°F to 10°C and then adding the Celsius value algebraically to 273°.

11. **Vertical Distribution.** Earth's atmosphere is divided into layers or zones according to various distinguishing features. (See fig. 1.9) The temperatures shown here are generally based on the latest "U.S. Extension to the ICAO Standard Atmosphere" and are representative of mid-latitude conditions. The extension shown in the insert is speculative. These divisions are for reference of thermal structure (lapse rates) or other significant features and are not intended to imply that these layers or zones are independent domains. Earth is surrounded by one atmosphere, not by a number of sub-atmospheres.

Moisture

12. More than two-thirds of Earth's surface is covered with water. Water from this extensive source is continually evaporating into the atmosphere, cooling by various processes, condensing, and then falling to the ground again as various forms of precipitation.

13. The remainder of Earth's surface is composed of solid land of various and vastly different terrain features. Knowledge of terrain differences is very important in analysing and forecasting weather.

14. The world's terrain varies from large-scale mountain ranges and deserts to minor rolling hills and valleys. Each type of terrain significantly influences local wind flow, moisture availability, and the resulting weather.

15. Moisture in the atmosphere is found in three states—solid, liquid, and gaseous. As a solid, it takes the form of snow, hail, ice pellets, frost, ice-crystal clouds, and ice-crystal fog. As a liquid, it is found as rain, drizzle, dew, and as the minute water droplets composing clouds of the middle and low stages as well as fog. In the gaseous state, water forms as invisible vapour. Vapour is the most important single element in the production of clouds and other visible weather phenomena. The availability of water vapour for the production of precipitation largely determines the ability of a region to support life.

16. The oceans are the primary source of moisture for the atmosphere, but it is also furnished by lakes, rivers, swamps, moist soil, snow, ice fields, and vegetation. Moisture is introduced into the atmosphere in its gaseous state, and may then be carried great distances by the wind before it is discharged as liquid or solid precipitation.

Water Vapour Characteristics

17. There is a limit to the amount of water vapour that air, at a given temperature, can hold. When this limit is reached, the air is said to be saturated. The higher the air temperature, the more water vapour the air can hold before saturation is reached and condensation occurs. (See fig. 10) For approximately every 20°F (11°C) increase in temperature between 0°F and 100°F (–18°C and 38°C), the capacity of a volume of air to hold water vapour is about doubled. Unsaturated air, containing a given amount of water vapour, becomes saturated if its temperature decreases sufficiently; further cooling forces some of the water vapour to condense as fog, clouds, or precipitation.

18. The quantity of water vapour needed to produce saturation does not depend on the pressure of other atmospheric gases. At a given temperature, the same amount of water vapour saturates a given volume of air. This is true whether it be on the ground at a pressure of 1000 hPa or at an altitude of 17,000 ft (5,100 meters) with only 500 hPa pressure, if the temperature is the same. Since density decreases with altitude, a given volume of air contains less mass (grams) at 5,100 meters than at the surface. In a saturated volume, there would be more water vapour per gram of air at this altitude than at the surface.

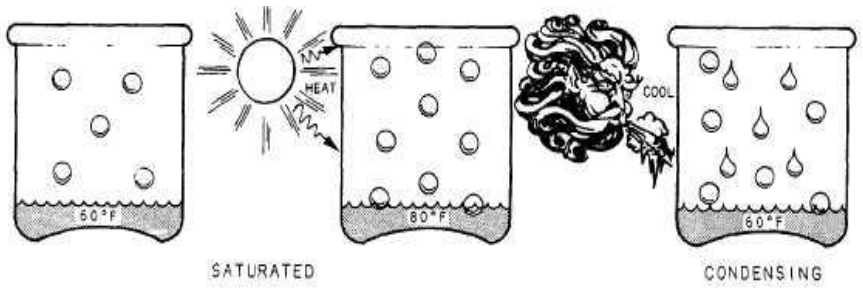


Fig 3.1 Saturation of air depends on its temperature

19. Although the quantity of water vapour in a saturated volume of atmosphere is independent of the air pressure, it does depend on the temperature. The higher the temperature, the greater the tendency for liquid water to turn into vapour. At a higher temperature, therefore, more vapour must be injected into a given volume before the saturated state is reached and dew or fog forms. On the other hand, cooling a saturated volume of air forces some of the vapour to condense and the quantity of vapour in the volume to diminish.

20. Condensation occurs if moisture is added to the air after saturation has been reached, or if cooling of the air reduces the temperature below the saturation point. As shown in figure 1.11, the most frequent cause of condensation is cooling of the air and often results when; (a) air moves over a colder surface, (b) air is lifted (cooled by expansion), or when (c) air near the ground is cooled at night as a result of radiational cooling.

21. The actual amount of water vapour contained in the air is usually less than the saturation amount. The amount of water vapour in the air is expressed in several different methods. Some of these principal methods are described in the following portion of this section.

Humidity

22. **Relative Humidity.** Although the major portion of the atmosphere is not saturated, for weather analysis it is desirable to be able to say how near it is to being saturated. This relationship is expressed as relative humidity. The relative humidity of a volume of air is the ratio (in percent) between the water vapour actually present and the water vapour necessary for saturation at a given temperature. When the air contains all of the water vapour possible for it to hold at its temperature, the relative humidity is 100 percent. (See fig. 3.1) A relative humidity of 50 percent indicates that the air contains half of the water vapour that it is capable of holding at its temperature. Relative humidity is also defined as the ratio (expressed in percent) of the observed vapour pressure to that required for saturation at the same temperature and pressure. Relative humidity shows the degree of saturation, but it gives no clue to the actual amount of water vapour in the air. Thus, other expressions of humidity are useful.

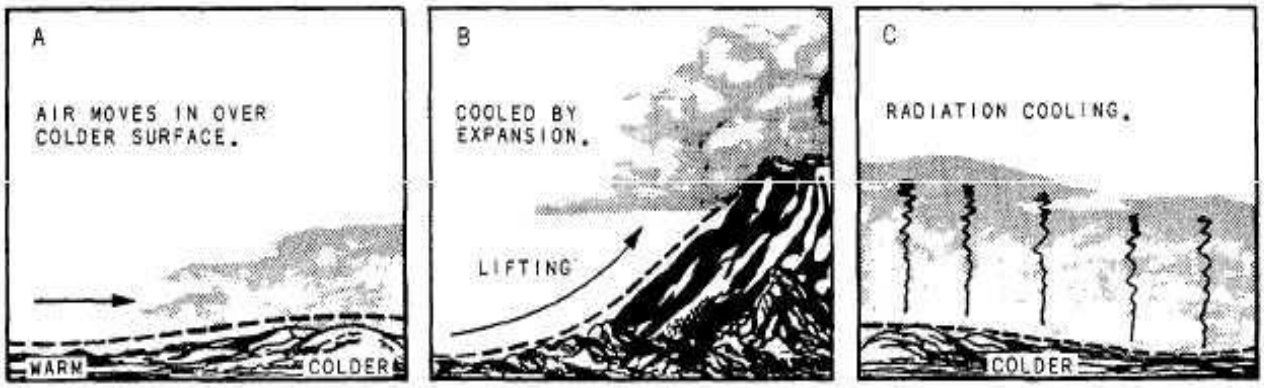


Fig 3.2 Causes of Condensation

23. **Absolute Humidity.** The mass of water vapour present per unit volume of space, usually expressed in grams per cubic meter, is known as absolute humidity. It may be thought of as the density of the water vapour.

24. **Specific Humidity.** Humidity may be expressed as the mass of water vapour contained in a unit mass of air (dry air plus the water vapour). It can also be expressed as the ratio of the density of the water vapour to the density of the air (mixture of dry air and water vapour). This is called the specific humidity and is expressed in grams per gram or in grams per kilogram. This value depends upon the measurement of mass, and mass does not change with temperature and pressure. The specific humidity of a parcel of air remains constant unless water vapour is added to or taken from the parcel. For this reason, air that is unsaturated may move from place to place or from level to level, and its specific humidity remains the same as long as no water vapour is added or removed. However, if the air is saturated and cooled, some of the water vapour must condense; consequently, the specific humidity (which reflects only the water vapour) decreases. If saturated air is heated, its specific humidity remains unchanged unless water vapour is

added to it. In this case the specific humidity increases. The maximum specific humidity that a parcel can have occurs at saturation and depends upon both the temperature and the pressure. Since warm air can hold more water vapour than cold air at constant pressure, the saturation specific humidity at high temperatures is greater than at low temperatures. Also, since moist air is less dense than dry air at constant temperature, a parcel of air has a greater specific humidity at saturation if the pressure is low than when the pressure is high.

Mixing Ratio

25. The mixing ratio is defined as the ratio of the mass of water vapour to the mass of dry air and is expressed in grams per gram or in grams per kilogram. It differs from specific humidity only in that it is related to the mass of dry air instead of to the total dry air plus water vapour. It is very nearly equal numerically to specific humidity, but it is always slightly greater. The mixing ratio has the same characteristic properties as the specific humidity. It is conservative (values do not change) for atmospheric processes involving a change in temperature. It is non-conservative for changes involving a gain or loss of water vapour. Previously it was learned that air at any given temperature can hold only a certain amount of water vapour before it is saturated. The total amount of vapour that air can hold at any given temperature, by weight relationship, is referred to as the saturation mixing ratio. It is useful to note that the following relationship exists between mixing ratio and relative humidity. Relative humidity is equal to the mixing ratio divided by the saturation mixing ratio, multiplied by 100. If any two of the three components in this relationship are known, the third may be determined by simple mathematics.

Dewpoint

26. The dewpoint is the temperature that air must be cooled, at constant pressure and constant water vapour content, in order for saturation to occur. The dewpoint is a conservative and very useful element. When atmospheric pressure stays constant, the dew point reflects increases and decreases in moisture in the air. It also shows at a glance, under the same conditions, how much cooling of the air is required to condense moisture from the air.

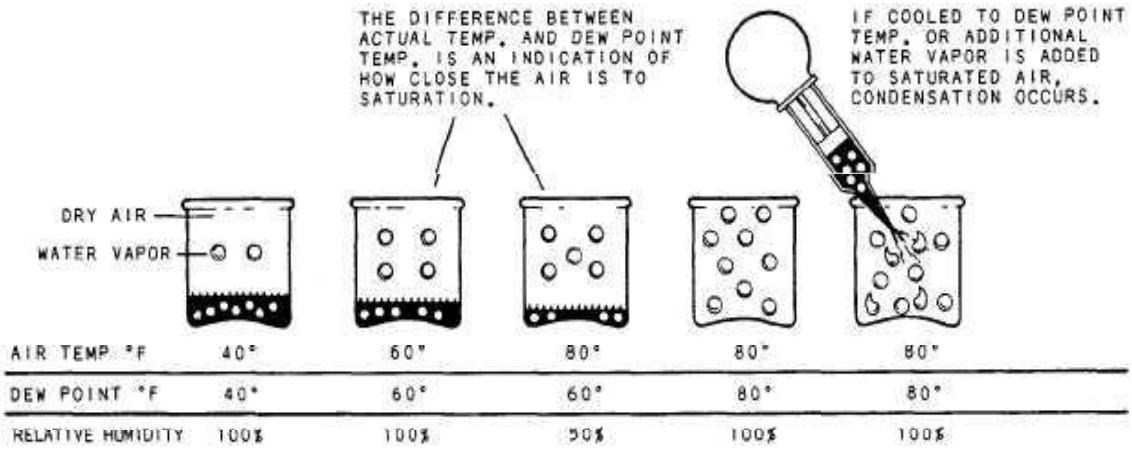


Fig 3.3 Relative humidity and dewpoint

Wind

27. **Definition**. Wind is defined as *horizontal flow of air*. Vertical flow of air is called current. For describing wind, we are to specify both speed and direction of the air flow. Wind speed is usually expressed in knots and wind direction either in 16 points of compass or in degrees from true north, the direction given is always that from which the wind is blowing. For example, a north wind or a wind direction of 360^0 means that wind is blowing from north to south, ie northerly wind. Anemometer is used to measure the wind speed and wind vane is used to measure the wind direction.

28. **Veering and Backing.** The terms veering and backing are used to describe changes of wind direction with height. A wind is said to 'veer' when its direction changes in a clockwise direction with height. Veering of wind is associated with good or fair weather. A wind is said to 'back' when its direction changes in an anti-clockwise direction with height. Backing of wind is associated with bad weather. The veering and backing of wind are shown in Fig 3.4

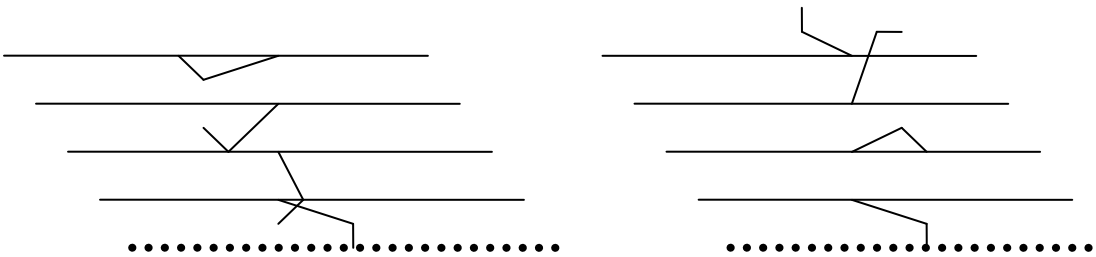


Fig 3.4a: Veering of wind. Fig 3.4b: Backing of wind.

Some times in an airfield surface wind blows at an angle to the runway. The component of the wind of right angles to the runway in use is known as 'Cross wind component'. Such winds are dangerous for flying as aircraft tend to swing on take-off or landing.

29. **Causes of Wind.** There are several factors that cause the wind, but the basic causes of wind are:

a. Pressure gradient force that caused by the different pressure by unequal heating of the atmosphere.

b. The Coriolis force that caused by earth's rotation.

c. Friction up to 2,000 to 3,000 feet above ground levels (AGL) that reduces the wind speed and deflects the direction.

Clouds

30. Clouds are signposts of the sky. They are visible evidence of what is occurring in the atmosphere is doing in terms of motion and water content. Cloud differs form fog only in that the base of fog must be within 50 feet of the ground. Clouds can be composed of water vapour and ice crystals or solely of ice crystals but fog is generally composed of water droplets. Clouds are countless millions of minute water droplets and/or ice crystals depending on the temperature within them. According to WMO the definition of cloud is ‘a visible aggregate of minute particles of water or ice or both in the free air’. Cloud is also defined as an aggregate of very small water droplets, ice crystals, or a mixture of both, with its base above the earth’s surface. It differs from fog in that it does not reach the surface of Earth.

Visibility

31. Visibility is defined as the greatest distance at which an object of specified characteristics can be seen and identified with the unaided eye in any particular circumstances, or in the case of night observations, could be seen and identified if the general illumination were raised to the normal daylight level. Lower visibilities are expressed in metres or yards and higher visibilities in kilometres or miles. Reports generally refer to a visibility based on all directions; where there is marked variation with direction, the lowest visibility is recorded for synoptic purposes, with an appropriate entry in a ‘special phenomena’ group. ‘Visibility objects’ by day are ideally confined to black or nearly black objects which appear against the horizon sky. Night visibility objects comprise mainly unfocused light of moderate and known intensity at known distances.

TASK 36 : WEATHER PHENOMENA

Thunderstorm

1. A thunderstorm, also known as an electrical storm, a lightning storm, or simply a storm is a form of weather characterized by the presence of lightning and its acoustic effect on the Earth's atmosphere known as thunder. The meteorologically-assigned cloud type associated with the thunderstorm is the cumulonimbus. Thunderstorms are usually accompanied by strong winds, heavy rain and sometimes snow, hail, or no precipitation at all. Those which cause hail to fall are known as hailstorms. Thunderstorms may line up in a series or rainband, known as a squall line. Strong or severe thunderstorms may rotate, known as supercells. While most thunderstorms move with the mean wind flow through the layer of the troposphere in which they occupy, vertical wind shear causes a deviation in their course at a right angle to the wind shear direction. Thunderstorms result from the rapid upward movement of warm, moist air. They can occur inside warm, moist air masses and at fronts. As the warm, moist air moves upward, its cools, condenses, and forms cumulonimbus clouds that can reach heights of 10 km or more. As the rising air reaches its dew point, water droplets and ice form and begin falling the long distance through the clouds towards Earth's surface. As the droplets fall. they collide with other droplets and become larger. The falling droplets create a downdraft of air that spreads out at Earth's surface and causes strong winds associated with thunderstorms.

2. Thunderstorms can generally form and develop in any geographic location, perhaps most frequently within areas located at mid-latitude when warm moist air collides with cooler air. Thunderstorms are responsible for the development and formation of many severe weather phenomena. Thunderstorms, and the phenomena that occurs along with it, can produce numerous risks and hazards to populations and landscapes. Damages that result from thunderstorms are mainly inflicted by downburst winds, large hailstones, and flash flooding caused by heavy precipitation. Stronger thunderstorm cells are capable of producing tornadoes and waterspouts.

Lightning

3. Lightning is obviously the most spectacular of electrometers and is directly related to the thunderstorm even though classified independently. It is the bright flash of light accompanying a sudden electrical discharge. Most lightning has its beginning in clouds; however, it generates from high structures on the ground and mountains, although much less frequently. The thunderstorm changes the normal electric field, in which the ground is negatively charged with respect to the air above it. Because the upper portion of the thunderstorm cloud is positive and the lower part is negative, the negative charge induces a positive charge on the ground. The distribution of the electric charges in a typical thunderstorm is shown in figure 5.17. The lightning first occurs between the upper positive charge area and the negative charge area immediately below it. Lightning discharges are considered to occur most frequently in the area bracketed roughly by the 32°F and the 15°F temperature levels. However, this does not mean that all discharges are con-fined to this region; as the thunderstorm develops, lightning discharges may occur in other areas and from cloud to cloud, as well as from cloud to ground. There are four main types of lightning. All can do considerable damage to aircraft, especially to radio equipment.

a. **Cloud To Ground Lightning (CG)**. Lightning occurring between cloud and ground.

b. **Cloud Discharges (IC).** Lightning taking place within the cloud.

c. **Cloud To Cloud Discharges (CC).** Streaks of lightning reaching from one cloud to another.

d. **Air Discharges (CA).** Streaks of lightning passing from a cloud to the air that do not strike the ground.

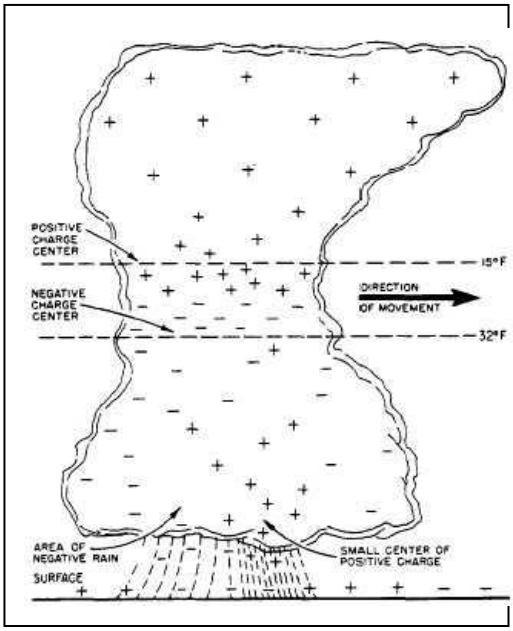


Fig 3.6 Location of electric charges inside a typical thunderstorm cell

Precipitation

4. Precipitation includes all forms of moisture that fall to Earth's surface, such as rain, drizzle, snow, hail, etc. Dew, frost, clouds, fog, rime, glaze, spray, tornadoes, and waterspouts are not forms of precipitation, although they are hydrometeors. Precipitation is classified according to both form (liquid, freezing, and solid) and size (rate of fall). The size of precipitation drops determines their rate of fall to a large extent.

Drizzle

5. Drizzle consists of very small and uniformly dispersed droplets that appear to float while following air currents. Sometimes drizzle is referred to as mist. Drizzle usually falls from low stratus clouds and is frequently accompanied by fog and reduced visibility. A slow rate of fall and the small size of the droplets (less than 0.5 mm) distinguish drizzle from rain. When drizzle freezes on contact with the ground or other objects, it is referred to as freezing drizzle. Drizzle usually restricts visibility.

Rain

6. Precipitation that reaches Earth's surface as water droplets with a diameter of 0.02 inch (0.5 mm) or more is classified as rain. If the droplets freeze on contact with the ground or other objects, the precipitation is classified as freezing rain. Rain falling from convective clouds is referred to as rain showers. Showers are usually intermittent in character, are of large droplet size, and change rapidly in intensity.

Showers

7. Precipitation of large drops for a short spells of time, usually from CU/CB clouds.

Hail

8. Ice balls or stones, ranging in diameter from that of a medium-size raindrop to two inches or more, are referred to as hail. Precipitation of small hails or pieces of ice (hailstones) with a diameter ranging from 5 to 50 mm (0.2 to 2.0 inch) or sometimes more. They may fall detached or frozen together into irregular, lumpy masses. Hail is composed either of clear ice or of alternating clear and opaque snowflake layers. Hail forms in cumulonimbus clouds, and it is normally associated with thunderstorm activity and surface temperatures above freezing. Determination of size is based on the diameter (in inches) of normally shaped hailstones.

Snow

9. Snow consists of white or translucent ice crystals. In their pure form, the ice crystals are highly complex, hexagonally branched structures. However, most snow falls as parts of crystals, as individual crystals, or more commonly as clusters and combinations of these. Snow occurs in meteorological conditions similar to those in which rain occurs, except that with snow the initial temperatures must be at or below freezing. Snow falling from convective clouds is termed snow showers.

Gusty Wind

10. If wind speed reaches 16 kts or more and lasts for less than 1 minute then the wind is called gusty wind.

Squally Wind

11. If wind speed reaches 16 kts and increases to 22 kts or more and lasts for at least 1 minute the wind is called squally wind.

Fog

12. Fog is a cloud that is in contact with the ground. Fog is a visible aggregate of minute water droplets or ice crystals or both from 0.01 mm to 0.1 mm in diameter suspended in the air. It reduces surface visibility to less than 1000 meter. If it is lifts up to a height of 50 ft or more then it is said to be cloud. In fog, Relative Humidity (RH) remains more than 90%. In industrial area, fog may be mixed with smoke and smog may be formed. Fog is distinguished from mist only by its density, as expressed in the resulting decrease in visibility: Fog reduces visibility to less than 1km, whereas mist reduces visibility to less than 5km. Fog is formed by either adding moisture to the air or dropping the ambient air temperature.

Mist

13. Mist is a suspension in the air of microscopic water droplets or wet hygroscopic particles, reducing the visibility to less than 5 km at the earth's surface In mist RH remains more than 75%. mist reduces visibility to less than 5km. Mechanism of formation of mist and fog is same but fog is distinguished from mist only by its visibility range. Mist is also formed by either adding moisture to the air or dropping the ambient air temperature.

Haze

14. Haze is a suspension in the air of extremely small dry particles invisible to the naked eye and sufficiently numerous to give the air an opalescent appearance. It may also be defined as the suspension of dust particles that reduces surface visibility from 5 to 8 km irrespective of the presence of cloud in the sky. If RH is less than 80% (generally less than 65%) and visibility is in between 1km and 5km that is in mist range, we can call the atmospheric obscurity as Haze. Haze is of two types:

a. **Dust Haze.** Dust haze is a suspension in the air of dust or small sand particles, raised from the ground prior to the time of observation by a dust storm or sandstorm.

b. **Moist Haze.** Occasionally a haze layer is found in a position which would be occupied by cloud if the air were sufficiently humid of it indicates a layer previously occupied by cloud which has been evaporated by descent and adiabatic warming.

Smoke

15. Smoke is fine ash particles suspended in the atmosphere. When smoke is present, the disk of the Sun at sunrise and sunset appears red, and during the daytime has a reddish tinge. Smoke at a distance, such as from forest fires, usually has a light grayish or bluish colour and is evenly distributed in the upper air.

Dust

16. Dust is finely divided solid matter uniformly distributed in the air. It imparts a tannish or grayish hue to distant objects. The Sun's disk is pale and colourless or has a yellow tinge during the day. Blowing dust consists of dust raised by the wind to moderate heights above the ground and restricting horizontal visibility to 5000 metre or less and RH less than 75%. When visibility is reduced to 500 m to less than 1000 metre and wind speed between 11 and 21 kt, it is classified as a light dust storm; when visibility is reduced to 200 m to less than 500 metre and wind speed between 22 and 40 kt, it is classified as a moderate dust storm; and, if less than 200 metre and wind speed greater than 40 kt, as a severe dust storm.

Sand

17. Fine particles of sand picked up from the surface by the wind and blown about in clouds or sheets constitute a troublesome lithometeors in some regions. Blowing dust consists of dust raised by the wind to moderate heights above the ground and restricting horizontal visibility to 5000 metre or less and RH less than 75%. When visibility is reduced to 500 m to less than 1000 metre and wind speed between 11 and 21 kt, it is classified as a light dust storm; when visibility is reduced to 200 m to less than 500 metre and wind speed between 22 and 40 kt, it is classified as a moderate dust storm; and, if less than 200 metre and wind speed greater than 40 kt, as a severe dust storm.

Dust Devils

18. Dust devils, or whirling, dust-laden air, are caused by intense solar radiation which sets up a steep lapse rate near the ground. They are best developed on calm, hot, clear afternoons and in desert regions. As the intense surface heating sets up a steep lapse rate, a small circulation is formed when the surrounding air rushes into fill the area of the rising warm air. This warm ascending air carries dust, sand, leaves, and other small material to a height of a few hundred feet.

Dew

19. A deposit of water on objects at or near the ground, produced by the condensation of water vapour from the surrounding clear air.

SECTION-9 : METEOROLOGICAL EQUIPMENT

TASK -37: WEATHER SATELLITE RECEIVER SYSTEM

Introduction

1. A satellite is something that moves around a planet like earth. Meteorological satellite is a spacecraft that can collect various meteorological information. We need satellite observations for global coverage, representativeness of observation and high spatial and temporal sampling. The main uses of satellite imagery are information for operational forecasters, analysis tool, especially for data sparse regions, aid to short period forecasting of cloud, rainfall and flood. The application of satellite imagery is many. However, the most common are monitoring cyclones and monsoon, cloud motion vector (CMV) winds, Water Vapour winds, outgoing long wave radiation (OLR), rainfall estimation, mesoscale features, flood/intense precipitation advisory, snow detection, crop discrimination, aerosols studies and temperature/humidity profile.

History

2. In late 1940, rockets were carrying cameras and at the end of 1957, satellite came to the reality. The first successful meteorological instrument named ‘Suomi Radiometer’ was flown on Explorer 7 on 13 October 1959. The TIROS-1 launched on 01 April 1960 and TIROS-8 launched on 21 December 1963, introducing Automatic Picture Transmission (APT) system. The second generation of satellite was launched in December 1976, called the Application Technology Satellite System (ATS). Nimbus-1was the first sun synchronous satellite, and Geostationary Operational Environmental Satellite-1 (GOES-1) was launched on 16 October 1975. Third generation of US Polar-Orbiting Met Satellite TIROS-N launched on 13 October 1978. In future, the Next Generation POES System (NPOESS) will be launched on 2012 for 100 times more data than POES.

Types of Satellite

3. There are two types of orbit:

a. **Geostationary Satellite.** A satellite that appears to remain in the same position above the earth is called a Geostationary Satellite. A satellite in a geosynchronous orbit goes around the earth once a day returning to its original position. Equatorial region is well covered by geostationary satellites. The objectives of geostationary satellite systems are:

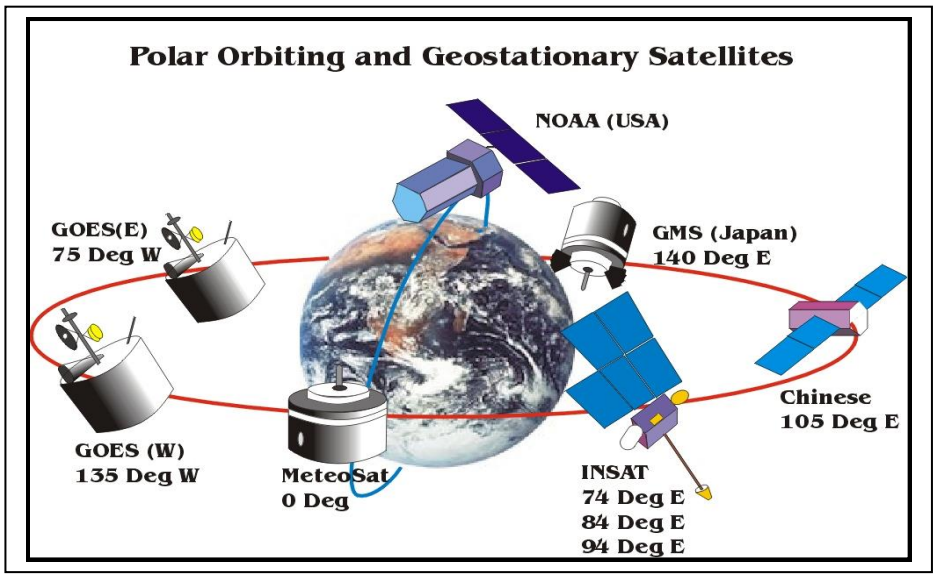
(1) High-resolution imaging of the Earth's surface and of its cloud coverage, in the visible and thermal infrared spectrum, and extraction from the image data of meteorological information such as cloud motion wind vectors, sea surface temperatures, cloudiness and cloud top heights.

(2) Dissemination of cloud covers images and other meteorological information to user stations.

(3) Collection and relay of environmental data from fixed or mobile Data Collection Platforms, either located on the Earth's surface or in the atmosphere.

b. **Polar Orbital Satellite.** An orbit with a inclination of 90^0, or close to it, is called a Polar Orbit. Because the earth is rotating as the satellite follows a polar orbit, the satellite can survey the whole of the earth's surface, including the poles, in a few days. Many observation satellites that need to cover the entire earth are in polar or near-polar orbits. These are called sun-synchronous orbit because the satellite's orbital plane and the Sun's direction are always the same. Polar orbiting satellite systems constantly circle the earth in an almost north-south orbit and pass close to both poles. The satellites operate as a pair and ensure that data for any region of the earth are no more than six hours old. Polar region is covered by polar orbital satellite only because geostationary satellites can not see obliquely up to poles.

4. **Geostationary Satellites and Polar Orbital Satellites.**



Imager Channel

5. The different imager channel with their spectral bands and pixel x lines values are:

Channel	Spectral Band	Pixels x Lines
Vis (visible)	0.4 – 1.1 µm	5000x5000
IR (infrared)	10.5-12.5 µm	2500x2500
WV (water vapour)	5.7-7.1 µm (6.7µm)	2500x2500

Types of Satellite Imagery

6. There are mainly three types of satellite imagery used in BAF Satellite Receiver Systems. They are:

a. Visible (VIS).

b. Infrared (IR).

c. Water Vapour (WV).

7. **Visible Imagery (VIS).** Visible images are obtained by using reflected sunlight at visible wavelengths, in the range 0.4 – 1.1 µm. Visible imagery is displayed in such a way that high reflectance objects, i.e. dense cirrus from CB clusters, fresh snow, nimbostratus etc. are displayed as white and low reflectance objects, e.g. much of the earth's surface is dark gray or black.

8. **Infrared (IR) Imagery.** IR images are obtained by sensing the intensity of the 'heat' emissions of the earth, and the atmosphere/atmospheric constituents, at IR wavelengths in the range 10.5-12.5 µm micrometers. The earth and its components radiate across a wide spectrum of wavelengths, but for many of these, the atmospheric gases, of which water vapour is an important constituent, absorb a significant proportion of such radiation. Thus so-called *window* need to be chosen to allow the satellite sensors to detect such radiation unhindered and the 10.5-12.5 µm band is one such. IR imagery is so presented that warm or high intensity emissions are dark gray or even black and low intensity or cold emissions are white. This convention was chosen so that the output would correspond with that from the VIS channels.

9. **Water Vapour (WV).** WV imagery is derived from emissions in the atmosphere clustered around a wavelength of 6.7 µm. In contrast to the IR channel, this wavelength undergoes strong absorption by WV in the atmosphere (i.e. this is not a window). So, it can be used to infer vertical distribution and concentration of WV-an important atmospheric constituent The main characteristics of WV channel are:

a. WV - imagery derived from water vapor emissions.

b. Most common wavelength is centered around 6.7 µm.

c. Always available.

d. Shades of levels differ depending upon humidity in upper to midlevel (WV).

e. Most of the radiation comes from 300 hPa and 600 hPa level (middle level).

f. Notice that highest clouds can be seen but surface features cannot be seen because this is not a window channel.

g. Bright and dark areas indicate rising and sinking motions respectively.

Cloud Matrix

10. The cloud matrix for visible and infrared channel are:

		Visible	
		Dark	**White**
Infrared	**White (cold)**	Thin Cirrus	Deep Convection
	Dark (warm)	No cloud	Low cloud

Gray Scale Matrix

11. The gray scale-infrared and gray scale-visible matrix are shown as:

a. **Gray Scale-Infrared.**

Infrared			
White	**Gray**	**Dark Gray**	**Black**
Cb, TCu, As, Cb Anvil, Thick Ci	**St, Sc, Ac, As, Thick Ci**	**St, Fair Wx Cu**	**Warm Sea**

b. **Gray Scale: Visible.**

Visible			
White	**Gray**	**Dark Gray**	**Black**
St, Sc, Ac, As, TCu, Cb	**Cb Anvil**	**Ci, Fair Wx Cu**	Warm Sea

Component Of Weather Satellite Receiver

12. The main 02 (two) components of Weather Satellite Receiver Systems are:

a. Hardware.

b. Software.

13. **Hardware.** The main hardware components of Weather Satellite Receiver Systems include:

a. **GOES Geostationary Satellite.**

(1) Parabolic Reflector Antenna (size - 3.8 meter).

(2) Integrated Feed.

(3) RG-58 Weather Satellite Receiver Signal Cable.

(4) Ingest Machine.

(5) Data Processing Server (Control Work Station).

(6) CPU (Work Station).

(7) LCD Monitor.

(8) HP Deskjet Printer.

b. **POES Satellite.**

(1) Parabolic Reflector Antenna (size - 1.8 meter).

(2) Azimuth Rotor.

(3) Elevation Rotor.

(4) POES Tracking Control Box with line Cable Integrated Feed

14. **Software.** The Weather Satellite Receiver System is operated on Linux (Suse)-9.2 or Linux (Suse)-10.0 version which is a multi-tasking and multi-user operating system. Moreover, the Linux (Suse) is used for high standard of processing the image like satellite Data. The other Softwares for processing the satellite images are:

a. **SuperLooper.** SuperLooper is used for processing/animating of GOES data like satellite images of MT SAT and FY-2. The SuperLooper is an easy-to-use, yet very powerful tool that allows us to do many things including enhance, analyze and annotate images or loops.

b. **RVT.** The Rapid Visualization Tool may be controlled by adjusting the position, altitude, angle and direction of navigation from which we view the earth. As the name implies, by using this Tool one is able to view the earth from above the surface rapidly.

c. **GD Viewer.** The Gridded Data viewer (or GDViewer) is used for POES Satellite data/images. This tool is known as the Gridded Data Viewer as the intermediate data set format that we use for the satellite images is called gridded data format. The GDViewer lets you view any gridded data format image.

Software Used for Processing/Animating the Satellite Images

15. The following 3 (three) software are used for processing and animation of the satellite images for the use of meteorologists:

a. The SuperLooper – for GOES satellite.

b. Rapid Visualization Tool (RVT) – for GOES satellite.

c. GD (Gridded Data) Viewer – for POES satellite.

Superlooper for GOES Satellite

16. **Introduction.** The GOES Box with its accompanying SuperLooper image processing and animation tools is not only a new product, but a new way of working with and distributing real-time satellite data. The SuperLooper is an easy-to-use, yet very powerful tool that allows you to do many things including enhance, analyze, and annotate images or loops; view different channels and areas; track storms; export images to be used in other programs; archive data; and print. The SuperLooper and GOES Box provide a new, easy-to-use and flexible way to work with the satellite data, making them valuable tools for meteorologists. The software SuperLooper will be discussed under the following main topics:

a. Running the SuperLooper.

b. Looping.

c. Tools.

d. The Time Bar.

e. The Enhancement Tool.

f. Enhancing a View.

g. The Annotation Tools.

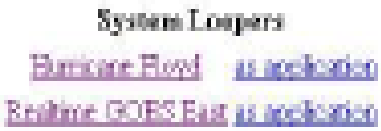
h. Archiving, Exporting and Printing Data.

17. **Running the SuperLooper.** Before attempting the procedures in this chapter ensure that your workstation has been setup to properly run the SuperLooper. If it has not you or your system administrator must follow the setup steps in the chapters “Super Looper Setup Windows/Linux” of the GOES Box manual.

a. Open either K Menu>Internet>Web Browser>Firefox or Firefox by clicking on the icon found on your desktop.
b. Go to the goesbox by typing in “http://goesbox” at the top of the browser's window.
c. At this page, click on “SuperLooper”. The way it appears on your screen is shown below.

d. Prompted to log in. Next to “Name” type in your user name. Next to “Password” type in your password.
You should notice that space below where you typed your user name and password, there should be a light gray box, shown below. If you do not see this box, then the page is still loading. Wait until you see this box with text in it before you click “login.”

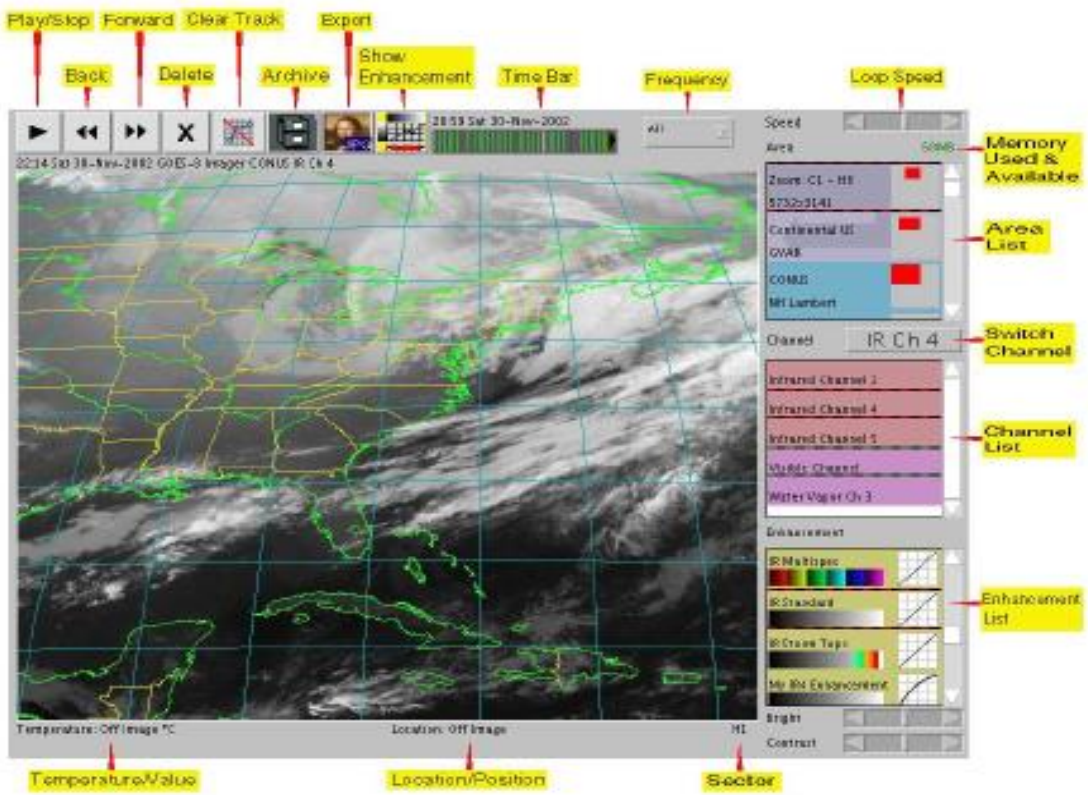
e. After successfully logging in, the window titled “Super Server Main Menu” should appear. Below this title you will see a menu, shown below. You may click on data sets in the left column.



You will normally click on the title of the looper you want to open and it will open the SuperLooper within your web browser with data from that resource. Click on "Realtime GOES" to begin viewing current (real-time) weather patterns.

f. When you click on one of the loopers, a new window will appear. It will be titled with the same name that you clicked on in the menu on the "Super Server Main Menu" page. You will notice that the window called "Super Server Main Menu" is still open.

18. **Looping.** The main function of the SuperLooper, as its name implies, is to loop. Looping is animating a time-lapsed series of images that are of the same type, cover the same area, and are of the same channel. Looping shows the motion and development of weather patterns. The SuperLooper screen is shown here:



Tools

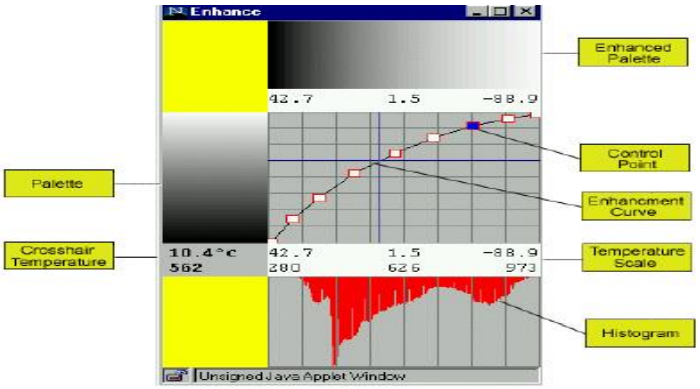
19. **The Time Bar.** The time bar is a very useful feature of the SuperLooper. The time bar is the horizontal bar with vertical stripes (shown below), located above an image in the SuperLooper. Each vertical line in the bar represents an image. The procedure to do this is described below, in the section "Selecting part of the Time Bar.

20. **Selecting part of the Time Bar.** To select a part of the time bar, a time span, to view, simply press your mouse button on the time bar where you wish to start, and drag it to the right, releasing where you wish your selection to end. Dragging the pointer beyond the time bar may in some instances result in the selection not working properly. Should this happen and the Time Bar does not display the area you attempted to select, re-drag your mouse from the first image you wish to select to no further than the right arrow.

21. **"Zooming out" with the Time Bar.** In order to "Zoom out," or have the time bar display a greater span of time, click once with the mouse button on the time bar. Clicking once takes you back to your previous setting on the time bar. You may repeat this procedure until the full time span of data available (represented by thevertical lines) are again displayed by the time bar. Double clicking on the time bar will take you back to showing the full time span of all the datasets available.

The Enhancement Tool

22. The Enhancement Tool is a very useful feature of the SuperLooper. It may be used to provide information about the temperatures in your images, it includes a histogram, it may be modified, and helpful enhancement curve settings may be saved. The Enhancement Tool is found at the top of the screen and may be shown by clicking on the icon for the Enhancement tool shown below. The picture below is the enhancement tool window with the key elements labelled it can be used as a guide to relate the terminology used in this chapter to the location of elements within the Enhancement Tool window.



23. **Enhancing a View**. After you have opened a loop, there are many types of enhancements you can use to highlight certain features or areas. The techniques to do this are explained in this section.

24. **Zooming In on a Region.** Zooming In is a feature of the SuperLooper that enables you to look more closely at a specific region. To select and view a specific region of the loop, press and hold the mouse button and drag a box around the area you wish to select. A rectangle will appear around the area that you have selected. When you release the mouse button, a menu will appear in which you have the option to select that area or cancel the selection. You may select the area by clicking "Zoom." If this menu does not appear, click the mouse button again. It should then appear. Selecting

"Cancel" will make the rectangle disappear and end the selection. You may continue to zoom in to smaller and smaller regions if you wish, up to the software's limit. Notice that as you zoom in, each area that you zoom in to is added to the "Area" list on the right side of your SuperLooper window.

25. **Zooming Out the Stripes.** Zooming Out is a feature of the SuperLooper that enables you to look at a larger region. To zoom out to a larger region, select one of the regions from the "Area" list on the right side of your SuperLooper window. This "Area" list contains the previous views to which you had zoomed in, and pre-defined areas. The previous views that you had zoomed in to are displayed at the top of the "Area" list. If you wish to return to your previous region, you may do so by clicking on one of the previously selected areas, displayed at the top of the "Area" list. Or, you may choose one of the pre-defined areas. When viewing a loop using one of the pre-defined areas you may not zoom out to any larger regions; the pre-defined areas are the largest regions you may view.

The Annotation Tools

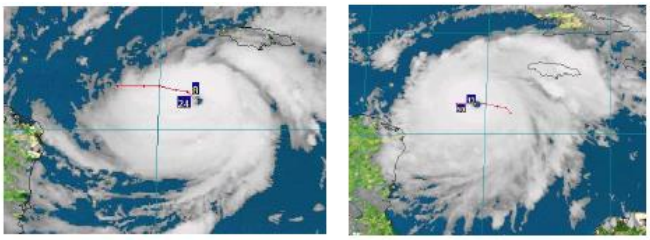
26. The Annotation Tools may be accessed by clicking on the SuperLooper screen. This will bring up the menu that is shown below.

27. The following tools are available from this menu as described below:

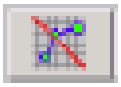
a. **Cancel.** "Cancel" will make the menu disappear if you decide that you do not want to use any of the Annotation Tools.

b. **Select**. "Select" will enable you to select an area to which you may zoom in. Selecting "Cancel" will make the box you selected disappear. Select "Zoom" to zoom in on the area in the selection box. If you have a selection shown on the screen, you may not access the annotations tool menu until you select either "Zoom" or "Cancel."

c. **Storm Tracker.** "Storm Tracker" is a feature of the SuperLooper that enables you to track the speed and distance at which a storm or a front moves. Selecting "Storm Tracker" will put a dot on your screen, as shown below. Normally, you will want to put this dot at the center of a cyclone. You may then wish to put dots on successive images on the spot to which the eye of the cyclone. As you place these dots, you will see them connect, as shown by the red line on the images below. As you play the loop, you will notice that at each dot you placed you will see two numbers. These represent the distance (miles) and speed (mph) that the system has moved. The lower number represents the distance. If you advance more than three images from the image on which you last placed a storm tracker dot, the storm track will not be displayed.



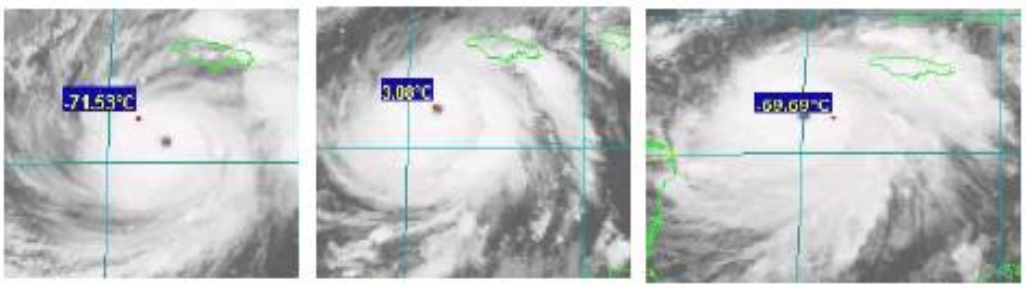
If you wish to delete the Storm Track, you may click on the “Delete Strom Tracker Selection” icon found at the top of the SuperLooper window, shown below. This will remove all of the dots and lines.



d. **Delete.** “Delete” enables you to remove an annotation. Select a point (such as a Storm Tracker dot, eBouy, or label) that you decide you do not want, click on that point, and select “Delete” from the menu. It will delete the object closest to the point at which the menu was brought up.

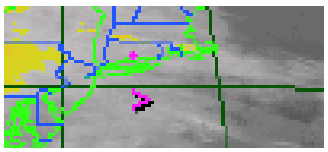
28. **On All Images/On This Image.** “On All Images” option means that for the tools displayed below it on the menu, what you do with those tools will be displayed on all of the images in your loop. You may switch between the settings “On All Images” and “On This Image” by clicking on it in the menu. Selecting “On All Images” will place the annotation on all images in the loop, while if you have selected “On This Image,” the annotation will only be placed only on the image you are currently viewing.

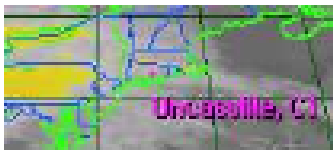
29. **eBouy.** “eBouy” gives you the temperature for the location at which you place the “eBouy”. If setting is “On All Images,” when you loop your images it will show you the temperature changes at that point. An example of this is shown below. As a storm moves from the east of the dot, over it, and to the west of it, in successive images (on the “On All Images” setting), one can see the temperature at that point change.



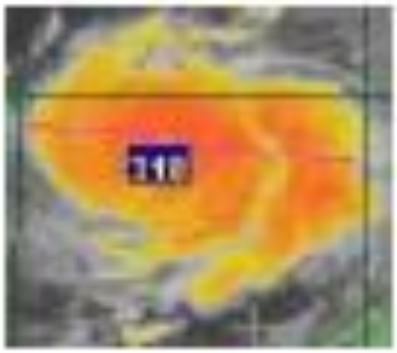
You may view the temperature in different units if you wish, as explained in the section “Changing Temperature Units” in the chapter “Enhancing a View.”

30. **Point Label.** “Point Label” enables you to identify a location on the map. Selecting “Point Label” will put a dot on your screen and a text prompt (the arrow), as shown in the picture on the left, below. At this prompt, you may begin typing the label you want for that point. When done, press the “Enter” key on your keyboard, resulting in something similar to the picture on the right.

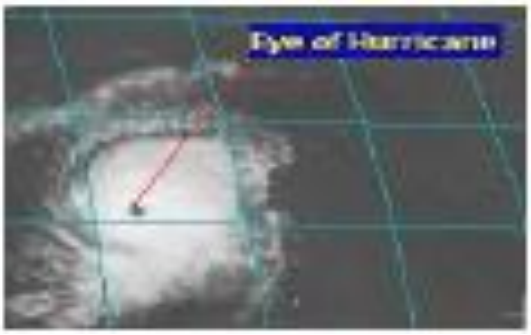




31. **Distance.** "Distance" is a feature of the SuperLooper that shows you the distance between two points, in miles. Click on the location from which you want to measure the distance and select "Distance" from the menu that appears. Drag the line out to the point to which you want to measure the distance and click the mouse button. You should now see two points connected with a line, and the distance of this line labeled, as shown below. Both the plot of the line and the distance shown is the great circle course and distance. Great circle distance is the shortest point along the curve of the earth between two points.



32. **Arrow Box.** "Arrow Box" is very similar to "Point Label." The difference is that "Arrow Box" allows you to put a label away from the point. This is often used instead of "Point Label" when you do not want the label of the point to cover the part of the image around this point. Click over the point you wish to label, and select "Arrow Box." Drag the line out to where you wish to put the label and click. Type in a name for the label and press the "Enter" key on your keyboard.



Exporting

33. Exporting is a tool of the SuperLooper that creates images in a standard JPEG image format. What you see on the screen (color, size, and enhancement) is what you will get in the export.

34. **How to Export.** To export, click on the icon that looks like the Mona Lisa, shown below. If you are running the loop, all the images in the loop will be exported. If you only want to export the image at which you are looking, you should not be looping when you press the export icon. Exporting takes about 3-10 sec/image. During this time you should not attempt to do other operations with the SuperLooper.

Once complete, a browser window will appear where you can enter a title. Type in a title at the prompt "Title for this Image Data:" and push "OK." This is shown below.

Once you click "OK," it will tell you that your image has been saved. To return to your SuperLooper window, click "Dismiss."

35. **Saving Exported Images.** You often want to save the image onto your hard drive to use it for the other purposes, such as those listed in the above section "Common Applications for Exporting." These next two procedures will help you to save images to your hard drive or removable media by two different methods that yield the same result.

36. **Saving an Opened Image.** Go to exports and select the user whose exports you wish to view. Select the title and image, such that the image is open in your browser. If you are using Explorer, right click on the image and select "Save Picture As" from the menu. . In this window you may select to where you want to save the image, then click "Save." The exported image is now saved to the location you selected.

37. **Saving a Loop of Images**. To save a loop of images to your hard drive, you must do this for each image. To save time, remember that you do not need to open up each image if you follow the procedure described in "Saving an Un-Opened Image." Fortunately this process is made quicker because the Save As Box of most browsers defaults to the same location subsequent times.

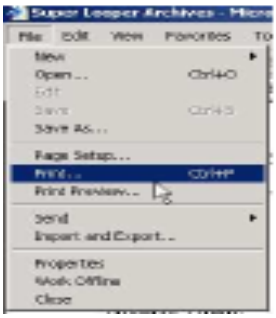
38. **Permission to View Exports.** Unlike archives, all exports are public and anyone with access to the system can view them; you can access the exports of any user, regardless of your own status. Only the user who created the export, and the administrator can delete the export.

Printing

39. Printing will allow you to obtain a hard copy of an image that was exported from the SuperLooper. Depending on your printer you may printout in color, or color-mapped to grayscale if your printer only prints in black.

Printing from the Web Browser

40. To print an image from the SuperLooper, it must first be exported. Remember, if you only want to print one image you need only to export that single image, not the entire loop. This is explained in further detail in the chapter “Exporting.” When you are viewing an exported image, you can use your browser's print function to print this image. On most browsers, “Print” is found in the “File” menu, as shown below in Explorer.



Rapid Visualization Tool (RVT)

41. The Rapid Visualization Tool (RVT) is discussed under the following main topics:

a. Navigation Animation.

b. Channels.

c. Interactive Controls.

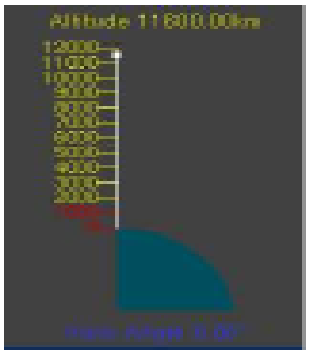
d. Overlays.

Navigation

42. Navigation in the Rapid Visualization Tool may be controlled by adjusting the position, altitude, angle, and direction from which you view the earth; each of these is described below. Through these controls, you are able to view the earth from above the surface, as though you were an observer looking out the window of a spaceship. With these controls, you may be at virtually any position to our desired balance of detail and area displayed.

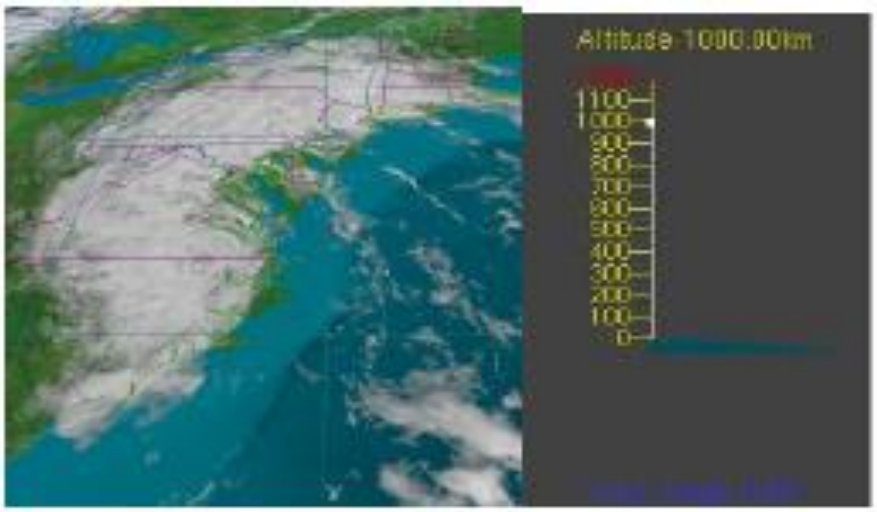
43. **Position.** A user of the Rapid Visualization Tool will often wish to view the weather satellite data of a specific region. The compass tool, shown below, may be used to do this. You will notice on the compass the directions North, East, South, and West are represented respectively with the letters N, E, S and W. To move in a certain direction, simply click on the compass in the direction you wish to move.

44. **Altitude**. As you use the Rapid Visualization Tool, you may need to view a larger region or take a closer look at a specific region. The altitude adjustment feature, shown below, enables you to control how high up you, the observer, are from the earth's surface.



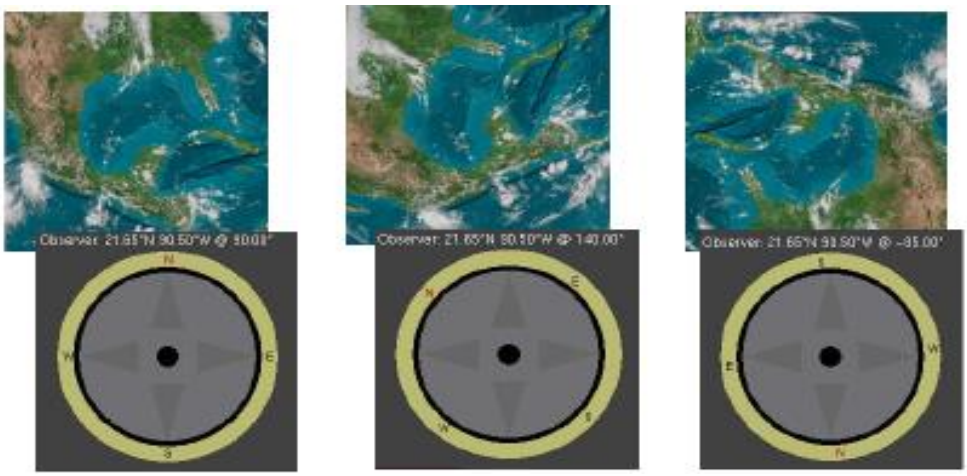
To adjust the altitude, simply click on the vertical line to the left of the number scale. Your current altitude is shown by the white dot on the vertical scale and is also numerically displayed in yellow above the scale. By adjusting the altitude, you may view the earth from as high as 12,000 km, down to just 100 km above the earth's surface. An example of the capabilities of the Altitude Adjustment Tool is provided below. Here's a view using the altitude adjustment set at 8000km view of the east coast or the US.

45. **Angle.** For some applications, the user may desire to change the angle at which she is looking at the earth. The angle may be adjusted using the Angle Adjustment Tool, the blue curve found below the Altitude Adjustment Tool.



You may have noticed that the altitude scale is red below 1200 km and yellow above that 1200 km threshold. It is only when you are below 1200 km that you may use the angle adjustment feature. Selecting too great of an angle at too high of an altitude would result in the user looking out into outer space, not at the earth. By allowing the user to adjust the angle only when below 1200 km, this scenario is avoided. To adjust the angle when you are below 1200 km in altitude, click on the rim of the blue curve. Clicking towards the right edge of the curve enables the user to view the earth at a greater angle.

46. **Direction.** When you start the Rapid Visualization Tool, by default the direction being faced is north. This may be changed using the compass tool. Clicking on the yellow outer circle of the compass sets which direction north is on the screen. The default setting is to have north at the top of the screen so the "N" on the compass likewise starts out facing the top of the screen. If, for example, you prefer to have the direction north at the bottom of the screen and south at the top, click the bottom of the yellow circle of the compass, positioning north at the bottom of the screen. The Cartesian coordinate system direction that North is pointing is displayed above the compass, next to the longitude and latitude values. An example of this feature is shown below, using images of the Gulf of Mexico. In the picture and corresponding image of the compass on the left, north is set to be at the top of the screen. In the picture on the right, north is set to be off to the upper right of the screen by clicking on the yellow circle in that desired direction.



Animation

47. Animation is a powerful feature of the Rapid Visualization Tool that enables you to animate successive data sets or areas of a Dataset to see how weather conditions are changing over time or position, facilitating the prediction of weather in the near future. The three types of animation you may use to do this are Looping, Slide Show and Fly Through

48. **Looping.** Looping is a feature of the Rapid Visualization Tool that enables the user to select a given location, including the position, altitude, angle, and direction. The user may then look at a time lapse series of data sets at this location, facilitating the understanding of a developing weather pattern for that given area.

49. **Fly Through.** Fly Through is a feature of the Rapid Visualization Tool that enables the user to define a path of varying positions, altitudes, angles, and directions. The user may then travel along this path to examine any data set she chooses. This

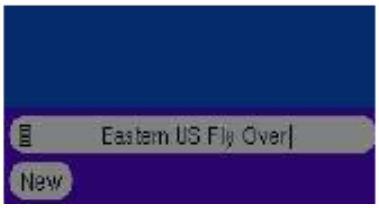
feature may be particularly useful when predicting weather conditions along heavily traveled routes, which may be defined as paths, as a user may look at then current satellite data along this saved Fly Through Path.

50. **Slide Show.** The Slide Show tool allows the user to rapidly view a wide variety of areas at different altitudes and angles. It provides a powerful quick look as to what is happening.

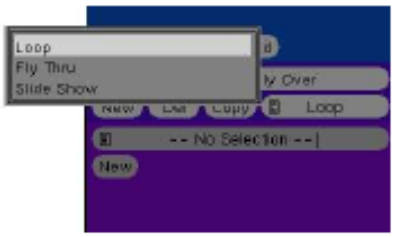
51. **Attribute Packages.** The various animation modes discussed above combined with attribute provides the flexibility of quickly being able to view in a definable manner both the data and the areas that your organization is responsible for.

Creating Paths

52. Paths consist of one or more points that you "teach" the RVT. The RVT stores these points under the path name and acts on this path in the defined manner when you push the Play button in the upper right of the RVT. You teach the RVT the path by simply moving to the location for that point adjusting altitude, angle, and direction, as appropriate and then adding that point to the path. In the case of fly through the points of a path are obviously the route that you will be flying through. For a Slide Show each point in the path is a slide. For a loop usually you will just have one point, the spot at which you want to view how the weather changes over time. You can however have multiple points in which case it will loop through the series of data that is loaded and then advance to the next point and loop through this series. To begin creating a path, click on the button labeled "New" in the lower right corner of the Rapid Visualization Tool window.



53. Upon selecting "New" as shown above, you will then be prompted to provide a name for your path, at the cursor, enter the name as shown below. You may find it helpful to choose a name that accurately reflects the region over which you want to create this path for. After naming the path, click either "Loop", "Fly Through", or "Slide Show" to set the type of path you will be creating.



54. Once you have typed in the name of this path and have selected the type of path you wish to create, adjust the view of the Rapid Visualization Tool to display the location you desire to have at the start of the path you are about to define.

When you have adjusted the Rapid Visualization Tool to display your desired starting position for the path you are creating, click the button “Add”, found just above the gray box listing the path names. Doing this will add your current position to the list of positions in your current path. Now that you have clicked on “Add”, you will notice that new buttons have been added to that lower right corner of the Rapid Visualization Tool, as shown below. These buttons will help you develop your path and will be explained later in this chapter.

55. You are now ready to define the next frame in your path. Adjust the position, altitude, angle, and direction to your satisfaction, and then click “Add.” You may continue adding frames to your path using the procedure described above until you have finished defining your path. At this point you may be wondering what the optimal distance is between frames in your path. If you are creating a Fly through loop, the Rapid Visualization Tool takes the positions along the path that you define and, when playing through the Fly Through the RVT automatically smoothes these transitions into a fluid animation. You therefore only need to define several of what you deem to be the more critical locations or Fly Through paths, and the Rapid Visualization Tool will smoothly interpolate between them when you play the fly through.

Playing your Loop, Slide Show, or Fly Through

56. To play through the data sets that you currently have loaded on the Rapid Visualization Tool starting from the first point in your selected path, click the green button labeled “Play”, located in the upper right part of the window.

57.Once you have pressed this green play button, the path you have selected will continue animating through its defined frames. Once the path is playing, the green play button is replaced by a red stop button. When you have finished viewing your path, simply click on the red stop button, as shown below, to stop on the current frame of the path.

58. The RVT also allows you to pause an animation and resume it from where you left off, After starting to Play an animation a pause button will appear as shown below, when paused it will change appearance to be a resume button. Depending on the path and data set you are currently using, you may prefer to animate the frames of your path at a faster or slower speed. Adjusting the number of frames per second (fps) may be done by clicking on the light yellow down and up arrows in the lower right corner of the Rapid Visualization Tool window, as shown below.

59. The Rapid Visualization Tool also gives you the option to go through the points of your path manually, by clicking on the gray arrows in the lower right corner. Note that the current frame number is displayed in red to the right of these arrows.

To go to a previous or subsequent frame, click on the corresponding gray arrow in the lower right corner of the Rapid Visualization Tool. Note that the number of the current frame is is displayed to the right of these arrow keys.

60. When playing a loop it will only include in the loop those datasets where there is data under the cursor location; in this way if you are receiving data from a source whose area coverage is heterogeneous it will not include those datasets that are not at least partially within the current view.

Redefining Positions for your Loop, Slide Show, or Fly Through

61. As you define paths, there will likely come a time when you realize a frame needs to be inserted into a path, needs to be changed, or should be omitted. Making these changes to an already existing path is simple.

Inserting a Frame.

62. If you are animating through one of your paths and you realize that a necessary frame is missing, stop animating through the path and use the gray arrow keys to view the frame just before the one you want to insert. For example, let's say that you are viewing a 5frame path and realize that between the 4th and 5th frame, an important position was not defined in that path. If you are current animating through the path, press the red button to stop. Then, because you want to insert a frame after the 4th one, use the gray arrows to scroll through the frames, stopping at the 4th frame, as shown below.

63. Continuing with this example of inserting another frame into a path, now that you have displayed the frame just before the one you wish to insert, you should now adjust the position, altitude, angle, and direction such that the screen displays the view you want for this new frame. Then when you are ready, click "Ins" to insert that position as another frame into the path. For this example, the inserted frame would become the 5th one, and the one that was previously the 5th will automatically become the 6th frame in the path. All frames before the one that you inserted will not be changed, and all frames after the inserted one will be shifted back.

64. **Changing a Frame**. Changing a frame of a Fly Through path is much like inserting one. Select the Fly Though path that you want to change and scroll through the frames until you get to the one that you wish to alter. Readjust the position, altitude, angle, and direction until you are satisfied, and then click the button labeled "Chg" to update that frame. When you do this, none of the other previous or subsequent frames will be affected.

65. **Deleting a Frame**. Select the Fly Though path that you want to alter and scroll through the frames until you are on the one that you want to delete. Click the button labeled "Del" to remove that frame. When you do this, none of the other previous or subsequent frames will be affected.

66. **Exporting Data.** The RVT can automatically export the views you define as PPM imagery. An external export processor will then convert this exported data into pictures and/or video and store it in a certain hierarchy. Export processors can have -very different behaviors depending on the customers needs. The basic export processor included with the RVT facilitates generation of standard JPEG or other image formats in a specific hierarchy. To tell the RVT to include an attribute package in the export generation process simply select either Pics, Video, or Pics+Video from the menu in the lower right corner. The RVT will only export data when put into the Auto Export mode by pressing the F12 key. You may press this key again to return to the normal mode. When a loop is exported, the exported data is sent to a file with the same name as the attribute package with which the data was exported. Note that data exported in this matter will be deleted after the export sweep time has passed (which by default is set to be 7 days). Normally after exported data is about 7 days old you will not have any reason to use it; it will be too old to help in the analysis of current data so this sweep will automatically remove these old exports from your hard drive. There may, however, be special situations in which you would want to save an old set of exported data, such as if there are unique weather patterns or storms. If you want to save a set of exported data for some reason, you need to move those images outside of the RVT export processor image export directory (your administrator can tell you which directory that is). Only the RVT export processor image export directory is scanned to clear

out old images every 7 days, so putting those files in another directory will preserve them.

Channels

67. The Rapid Visualization Tool has the ability to display the weather satellite data on a variety of channels.

Changing Channels

68. The channel currently being displayed is shown in the upper left corner. Clicking on the name of the current channel will bring up a popup menu that displays the names of all the channels. Clicking on the name of a channel will allow you to view it for your current data set.

You will notice that in the far upper left corner of the Rapid Visualization Tool there is a button labeled with the letter "A." Clicking on it will change it to the letter "B." You may set A and B to whichever channels you want to look at, and toggle back and forth between these two channels simply by clicking that button.

69. The different channels are:

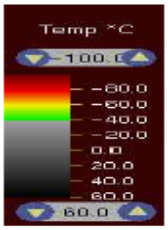
a. Visible Channel.
b. Infrared Channel.
c. Water Vapor Channel.
d. Surface Channel.
e. Short Wave Infrared Channel.
f. 12 µm Infrared Channel.
g. CO_2 Infrared Channel.
h. Cloud Mask.
j. Fog Channel.
k. Rain Rate Channel.
l. Rainfall 3 Hours Channel.
m. Sea Surface Temperature Channel.
n. Fire Channel.
p. Dirty Infrared Channel.
q. Long wave - Shortwave Infrared Channel.

Setting Enhancement

70. An enhancement is a definition of how the range of temperatures or other calibrated measurement is mapped to colors. For each channel a number of standard enhancements are available, these represent enhancements that have been found useful in the analysis or presentation of data in that channel. The menu button next to the channel selection menu button allows you to choose the desired enhancement.

Channel Settings

71. For each of the channels, there is a value to color mapping displayed to the right of the map in a maroon colored box. Note that you can adjust this range using the arrows above and below the color map, allowing you to select the values you wish to view in greater detail. You normally will not need to make such adjustments to view the data for a given channel.



72. For some channels, you may find it helpful to click on the “Transparent” key in the upper right corner of the Rapid Visualization Tool window. This will toggle your current setting between “Transparent” and “Opaque.” The generally preferred setting for a given channel is always displayed as the default, but you may change this if you desire. Oftentimes having the “Opaque” setting is helpful to prevent any of the data from blending in with or being obscured by the land, while other times you may prefer “Transparent” so that you can clearly see land features relative to the satellite data you are currently viewing.

Interactive Controls

73. The Rapid Visualization Tool contains several other features to enhance ability to observe and forecast weather conditions with the following:

a. **Relief.** The relief in the Visible channel is a realistic raising of the imagery to the elevation estimated through the temperatures in the long wave infrared data which are related to cloud top height. It is possible to display Visible channel data on the Rapid isualization Tool as flat, or showing its relief. This setting may be controlled using the button labeled “Relief ON” found on the top control bar of the Rapid Visualization Tool. Pressing this button enables you to toggle this setting. This Relief option applies only to the Visible Channel as for this channel it elevates the cloud tops to the altitude they are predicted to be at, based upon data from the infrared channels and shown in the cloud heights channel.

b. **Transparency.** The transparency of the background map may be adjusted. Adjusting this setting may be necessary to clearly view some data on certain channels. This setting may be turned on or off using the button labeled “Transparency” found on the top control bar of the Rapid Visualization Tool. The level of the threshold above which the image will be made transparent may be adjusted using the arrows to the right of it.

Transparent: ON
Transparent: OFF
Level of Transparency Controls

Overlays

74. The overlay of the Rapid Visualization Tool is the set of longitude and latitude lines, used to facilitate the identification of locations. While the presence of these lines is often helpful, they may occasionally obstruct data if you are looking at an image from a very low altitude. In these cases, you may wish to hide these lines. This may be done using the button labeled "Overlay ON" found on the top control bar of the Rapid Visualization Tool. Clicking this button will make the longitude and latitude grid lines disappear; clicking this button again will make the lines reappear. Note that the state of this overlay does not affect the user defined overlays of points, lines, and labels.

THE GRIDDED DATA VIEWER FOR POES SATELLITE

The Gridded Data Viewer

75. This tool is known as the Gridded Data Viewer (or GDViewer) as the intermediate data set format that we use for the satellite images is called gridded data format. The GDViewer lets us view any gridded data format image. It is a tool designed to look at a single data set at a time. Because the GDViewer is most appropriately used to look at a single image at a time rather than loop a series of time lapsed images. it is an effective tool to use with data from the polar orbiting satellites.

Capabilities

76. **Resolution.** Gridded data format files contain the image information- from the satellite at full or reduced resolution and at its full bit depth. With the GDViewer, these images may be displayed. The GDViewer can display gridded data format files of any size at ¼, ½ or full resolution.

77. **Channels.** The GDViewer allows the user to look at data from any channel in the gridded data file.

78. **Navigation.** The location is usually navigated in both forward and reverse. In forward navigation, from the pixel the latitude and longitude may be obtained. In reverse navigation the latitude and longitude are the basis for determining on which pixel to display the data.

89. **Enhancements and Tools.** The GD Viewer has several features that allow the user to enhance and analyze the data including:

a. The ability to toggle back and forth between any two channels.

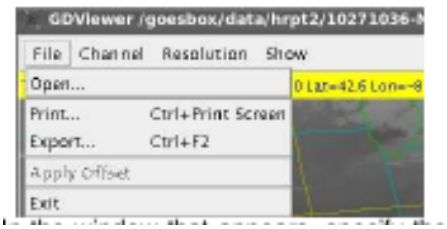
b. The ability to overlay one channel on top of another and adjust the transparency of the overlaid channel.

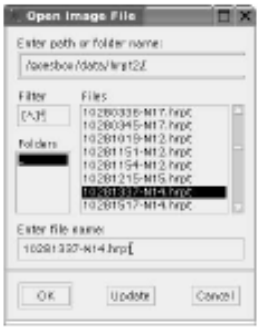
c. The option to adjust the positioning of the overlay.

d. The Enhancement Tool allows the user to adjust the albedo (or temperature) to colour mapping to adjust the detail over the range of values.

80. **Exporting and Printing.** The GD Viewer is able to print on a color printer and provides the user with several printing options. From the GD Viewer, an image may be exported as a jpg file.

81. **Loading an Image.** To open a file in the GD Viewer, from the File Menu select "Open." In the window that appears, specify the location and name of the file you wish to open. Upon entering the location and name of the file, click "OK."



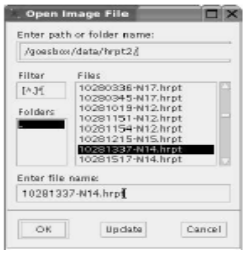


In this example, the user typed in "*/goesbox/data/hrpt2*" for the name of the folder path in which the image he wants to view is stored. Upon typing in this path name, pressing the "Enter" key on the keyboard made the list of files in that folder appear. Here, clicking on the name "10281337-N14.hrpt" highlighted that image name. Clicking the "OK" key in the lower left corner of the window opens the selected file in the GDViewer.

Menu Options

82. **The File Menu.** Clicking on the File menu in the upper left hand corner of the GDViewer screen brings up the menu shown below:

83. **Open.** To open a file in the GDViewer, you must enter the path and folder name, and the file name, in the appropriate boxes as shown below:

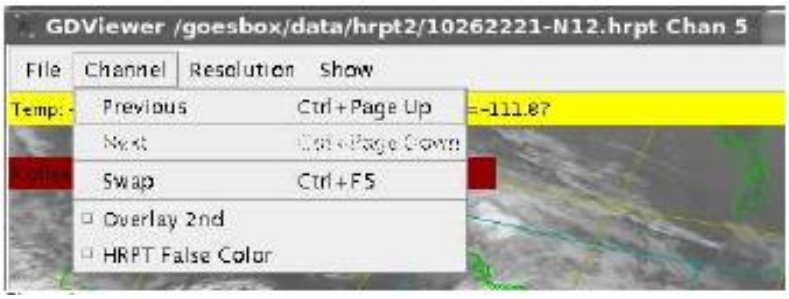


84. **Export.** The "Export" option from the File menu exports the image that you currently see as a minimally compressed jpg image. Upon selecting "Export" a dialog box will appear enabling you to select the file name and the location to which you wish to save the file. Note that you may also access the Export tool through the key stroke or simultaneously pressing ″Ctrl′ and "F2.'

85. **Apply Offset.** In some situations, you may need to adjust the overlay by several pixels to better align with the geographical features in the satellite data. To save your overlay offset settings, select "Apply Offset" from the File menu.

The Channel Menu

86. Clicking on the Channel menu in the upper left hand corner of the GDViewer screen brings up the following menu.



a. **Previous.** There are a couple of ways to change the channel in which the data is being displayed. The "Previous" option from the Channel menu also enables the user to view the previous channel.

b. **Next.** To view the next channel, simply click on the "Page Down" key on the keyboard. The "Next" option from the Channel menu also enables the user to select the next channel that is available to view.

c. **Swap.** The "Swap" option from the Channel menu enables the user to swap between two channels.

d. **Overlay 2nd.** With the Swap command you can quickly and easily toggle back and forth between two channels.

HRPT False Colour

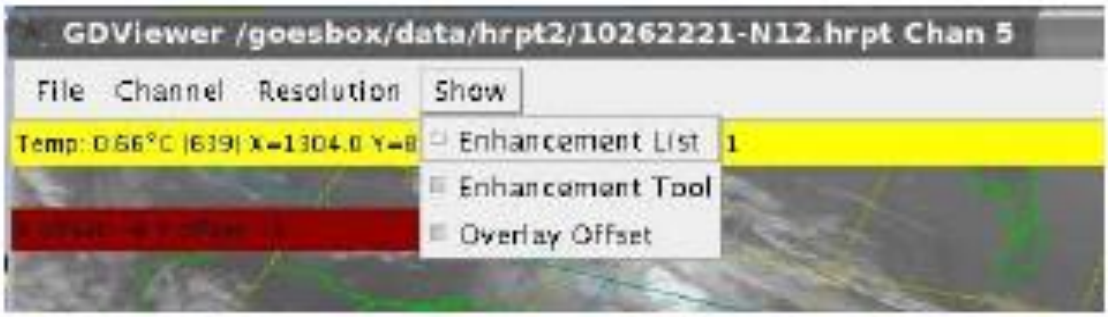
87. The HRPT False Color option takes an hrp data set and using the visible data attempts to match real colors to the image.

88. **The Resolution Menu.** Clicking on Resolution in the upper left hand corner of the GDViewer screen brings up the following menu:

User will notice that in this menu there are three options: Quarter, Half, and Full. These refer to the level of resolution in the image currently being displayed. The level of resolution at which you want to view an image will depend upon your objective. To view a larger area at once, *;ybu* will likely want to select Quarter resolution, whereas to view a small area in great detail, Full resolution may be a better choice.

<u>The Show Menu</u>

89. The Show Menu will have the following menu:



a. **<u>Enhancement List</u>**. Default enhancements for various channels are displayed.

b. **<u>Enhancement Tool.</u>** As described in SuperLooper.

c. **<u>Overlay Offset</u>.** The Overlay Offset delineates the geographical and political boundaries.

<u>Conclusion</u>

90. Meteorological satellite is intended for global coverage of meteorological information particularly for the use of operational forecasters. Monitoring cyclone and monsoon, cloud motion vectors, rainfall estimation etc. are the main uses of the meteorological satellite. Three softwares are used to process, animate and navigate the satellite images. With the installation of weather satellite receiver system forecasters take the facility to see the cloud height, observe the brightness of the clouds in different colours, zoom into a narrow area, calculate the movement of the cloud system with intensification/decay etc. with almost half-hourly interval. The different channels available in the systems allow us to justify the different layers of clouds with specific moisture content. To keep pace with the fast moving modern world, BAF Met Branch is rightly equipped with the Weather Satellite Receiver System, which has made all Met personnel to forecast the weather phenomena and issue the weather warning with more confidence and accuracy. With the use of this useful forecasting tool, DFOs are better able to apprehend the likely weather approach to the operational airfields which will make the operational activity safer and smoother.

TASK-38 : RADAR LINK AND DATA LINK

Introduction

1. Bangladesh Air force has long been trying to accumulate sufficient weather information for more accurate weather forecasting. In this consequence BAF Met Sqn BSR has been connected with Bangladesh Meteorological Department (BMD) with a Data Link and Radar Link connection. Data Link is a 100kbps dedicated communication line with BMD for getting Satellite pictures , Synoptic data, WAFS charts, Storm warnings , Numerical weather Charts etc. Radar link is a dedicated link with BMD for getting real-time Radar images.

Working Principle

2. Microwave link is a technology for transmitting information/data by radio wave over a distance that should be able to share data with other users. Radio waves are attenuated by trees and cannot easily pass through buildings, therefore the theoretical maximum range is severely shortened if there are obstacles in the. The short range microwave links are described as 'line of sight' so that it should be possible to see from one end of the link to the other. However there should also be a region around the direct line between the ends of the link that needs to be clear; this is known as the Fresnel zone. The Fresnel zone is largest at the centre of the link, getting smaller towards either end, and corresponds to approximately 5 metres all around the centre line for a 2 km long link. To achieve this clear Fresnel zone normally requires the aerials to be mounted high up so that the ground does not interfere. Any link is affected by several factors:

a. How much power is output by the bridge or access point.

b. How much power is lost from the cable connecting the bridge to the aerial.

c. How much extra power (gain) is provided by the aerial (by focussing the radio waves in one direction).

d. How much loss is experienced travelling the distance through the air.

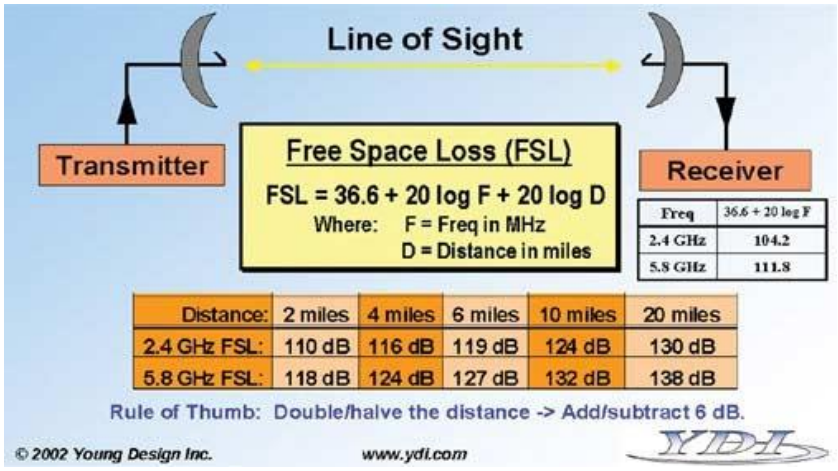
e. How much loss is experienced through obstacles in the way.

f. How much gain is provided by the receiver aerial.

g. How much loss is experienced through the cable between the aerial and the receiving bridge.

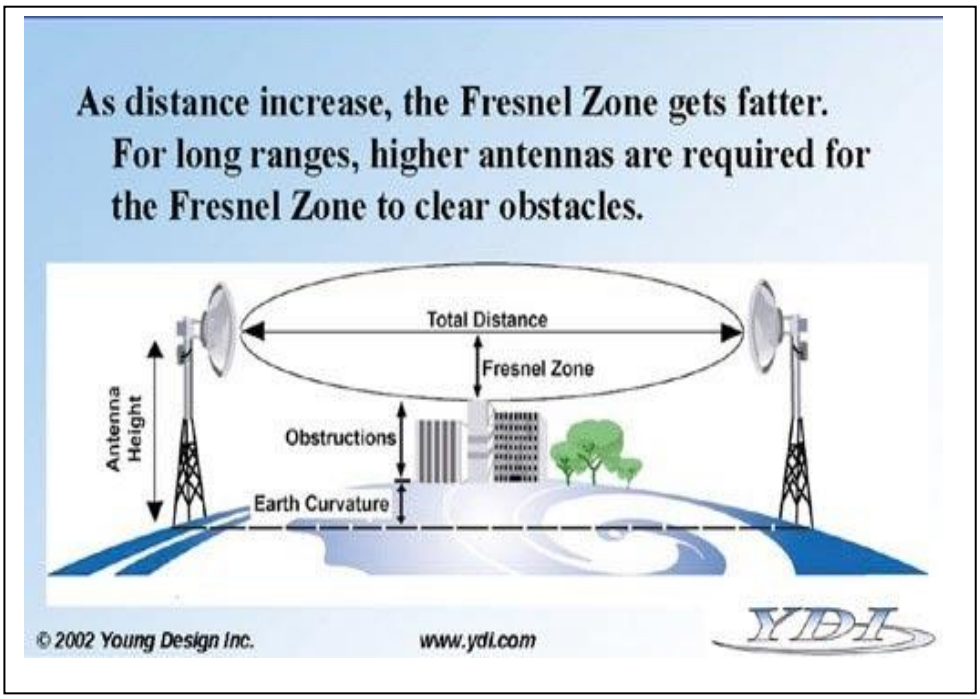
h. How sensitive is the receiver in the bridge.

3. So changing any of the above effects the link, i.e. if you have higher gain aerials you can have a longer link with more loss. Equally if the aerial cables are cheap, the workable link distance will be reduced. If there is an obstacle in the path you need higher gain aerials or reduce the distance of the link. As an example a typical oak tree will halve the working range of a link.



<u>Block Diagram of Microwave Data Link System</u>

4. <u>The block diagram of microwave data link system is shown below:</u>



Block Diagram of Radar Link System

5. The block diagram of radar link system is shown below:

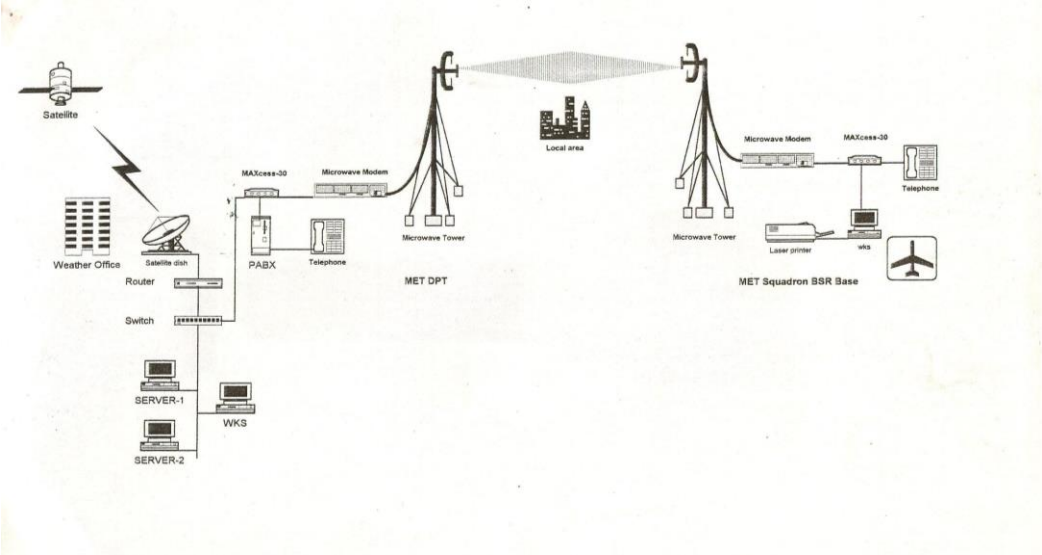
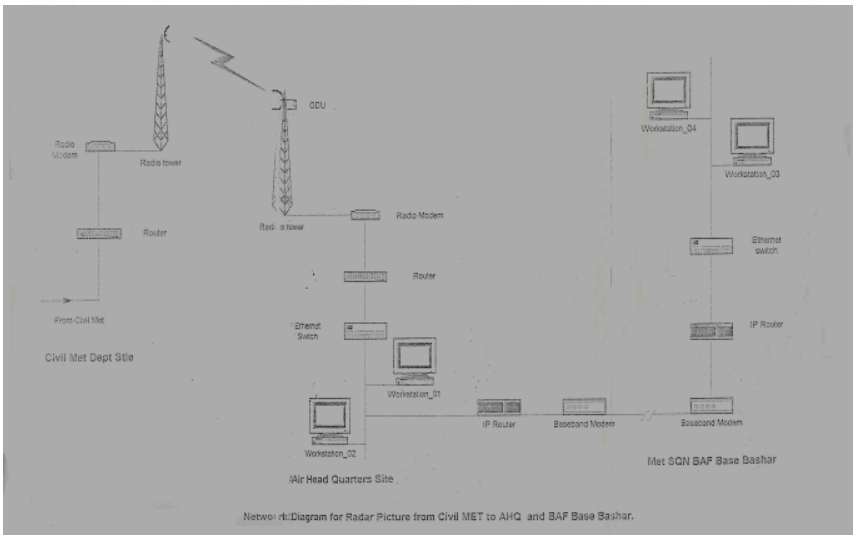


Figure1: Microwave Link form metrological department of Bangladesh to MET Squadron BSR Base of Bangladesh Air force.



Installation of Data Link System

6. To install a microwave link the following items are required:

   a. Radio Modem.

   b. Antenna (24 DBI semi parabolic guide antenna).

   c. LDF 5-50A complete with N connectors length 50 ft.

   d. Tower (height 10 metre).

   e. Multiplexer & Router with Ethernet port.

f. PC with color monitor.

g. UPS.

h. Internal antenna

i. Software: Windows-98 or Windows NT.

Installation of Radar Link System

7. To install a Radar link the following items are required:

a. Radio Modem.

b. Antenna (24 DBI semi parabolic guide antenna).

c. LDF 5-50A complete with N connectors length 50 ft.

d. Tower (height 10 metre).

e. Multiplexer and Router with Ethernet port.

f. PC with color monitor.

g. UPS.

h. Internal antenna.

i. Base band modem with IP routers and network accessories.

j. Software: Windows NT.

Operating Procedure of Data Link

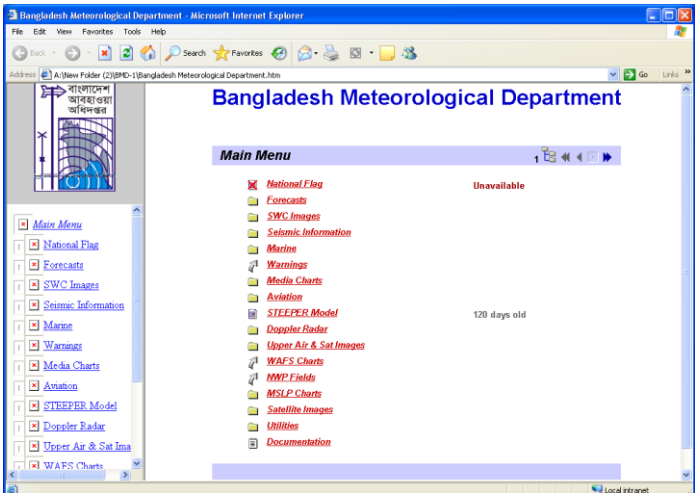
8. The operating procedure of Data Link is as follows:

a. Turn on the computer for Data Link.

b. Double click the icon for internet browser.

c. Web page of BMD as given bellow will be seen.

d. Select any link as per requirement.



Operating procedure of Radar Link

9. The operating procedure of Radar Link is as follows:

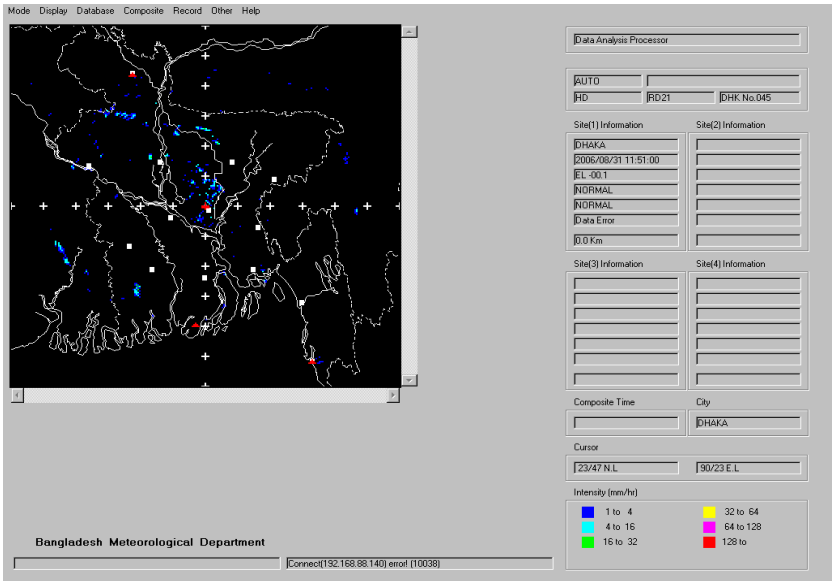
a. Turn on the computer for Radar Link.

b. Press Ctrl+Alt+Delete to log on.

c. Type user name “--------” and password “-----”.

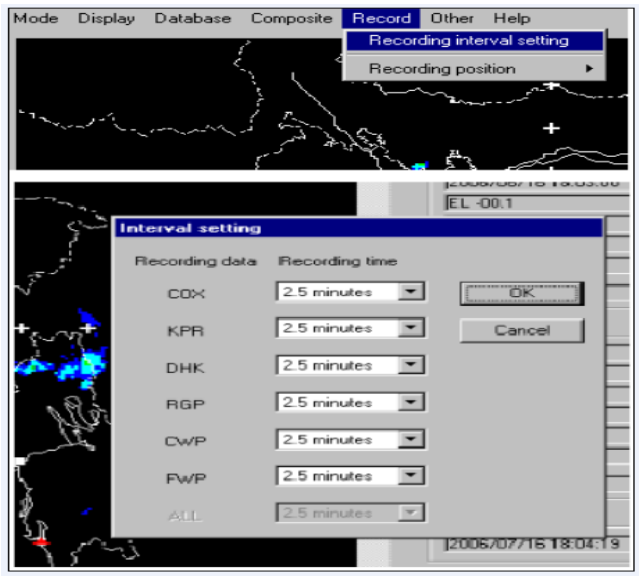
d. Double click the icon “Shortcut to Bangl”.

e. If link connection is OK then picture will automatically come to screen whenever transmitted by BMD.



Procedure of data Recording

10. Click on Record go to recording interval setting click. Set Recording time then click ok.



Procedure of Animation play Radar Picture

11. The procedure of animation play are;

a. Click on Mode, go to Mode change then click on replay.

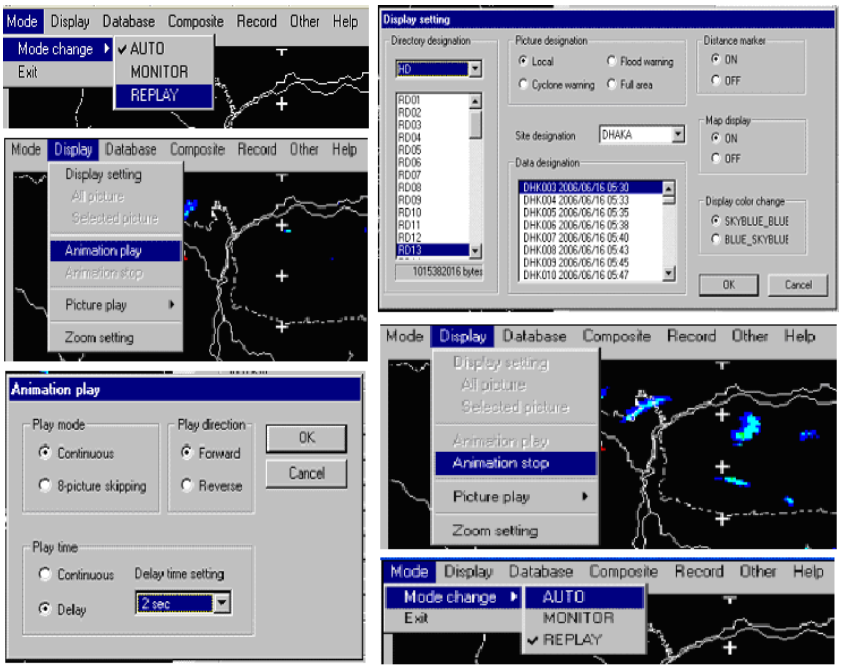
b. In site designation select Location like Dhaka / Cox's Bazar, Area, click ok.

c. Click on display go to animation play.

d. Select play mode, play direction & Play time click ok.

e. For animation stop click Display go to animation stop & Click.

f. To see current picture Click on Mode go to Mode change then click on Auto.



Copying procedure of Rader picture

12. The procedure of copying the latest radar observation from radar link is as follows:

a. Press print screen button in your keyboard.

b. Click on start button in "Task Bar".

c. Go to program > Accessories > Paint and Click.

d. Click on Edit (Menu Bar) and click on Paste.

e. Click on File (Menu Bar) and save.

f. Select a Drive (D or E) and save the file in that particular drive.

g. Open sub-folder under a Folder and save the files of daily obsn in the sub-folder.

g. Click on start button in "Task Bar".

j. Go to program > ACD System > ACD See and Click.

k. Double click on latest saved picture.

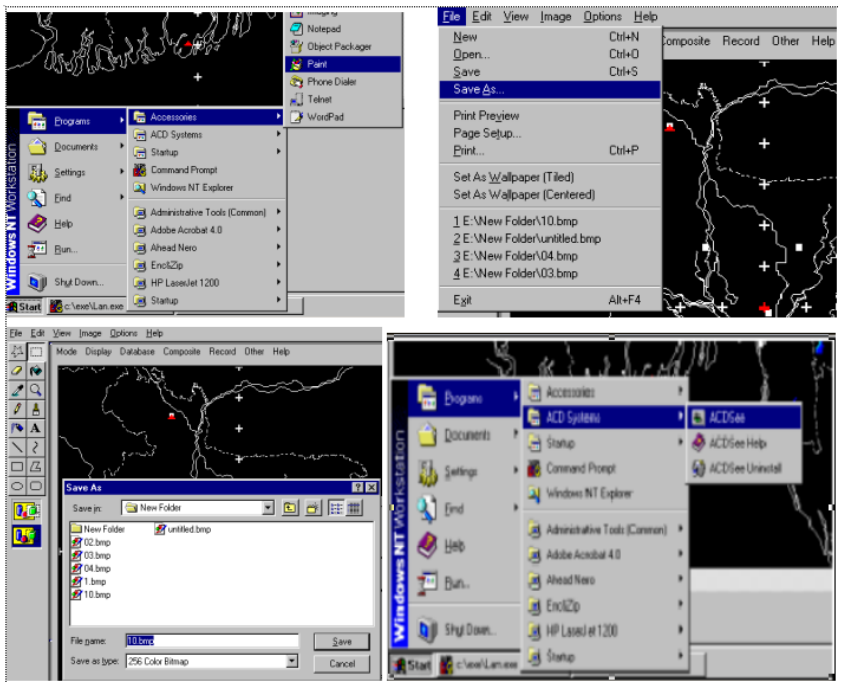
l. Click on File (Menu Bar) > save as.

m. In the save as type box select GIF and click on save.

n. Click on File (Menu Bar) > save as.

p. Right click on latest saved GIF picture.

q. Send to Floppy disk / CD.



Conclusion

13. Microwave link is a technology for transmitting information/data by radio wave over a distance that should be able to share data with other users. Met Sqn of BAF Base Bashar is linked with Bangladesh Met Dept for reception of satellite pictures, synoptic data, WAFS charts, storm warning signals, numerical weather charts etc and real-time radar images. With the installation of link Duty Forecasting Officers are surely able to better forecast for safe flying.

TASK -39 : DOPPLER WEATHER RADAR

Chapter Objectives

After reading this chapter you should be able to:-

- Understand the basic principle of a Doppler radar.
- Know about the primary data products of a Doppler radar.
- Know about the Doppler weather radar system features and architecture.
- Know about the display of various products.
- Operating characteristics of a C band Doppler weather radar.

Introduction

1. The modern Doppler weather radar has evolved by utilizing the vast experience gained in the development and use of conventional; weather radars, but differs in the important and fundamental aspect that it can directly measure many parameters associated with air motion. The Doppler weather radar is coherent radar, i.e. it measures the phase of the echo signals in addition to their amplitude. According to the Doppler principle, the motion of the scattering target (s) results in a phase shift of the scattered signal. The rate of change of phase of the echo signal relative to that of the transmitted signal appears as a frequency shift called the Doppler Shift or Doppler Frequency. It is there fore possible to estimate motion related parameters of the target (s). Doppler weather radar is inherently capable of determining only the radial component of the motion parameters associated with atmospheric phenomena. This fact constitutes a basic and major limitation of Doppler weather radars. This drawback notwithstanding, the Doppler weather radar is still a very useful sensor and is of great value in aviation weather surveillance.

Basic Principle and Limitation

2. According to the Doppler principle, the motion of the scattering target(s) results in a phase shift of the scattered signal. The rate of change of phase of the echo signal relative to that of the transmitted signal appears as a frequency shift called the Doppler shift or Doppler frequency. It is therefore possible to estimate motion-related parameters of the target(s) by appropriately processing the phase information in the echo signal. The Doppler frequency f_d due to a scatterer, however, depends only on the radial component V_r of the scatterer velocity relative to the radar:

$$f_d = -\left(\frac{2}{\lambda}\right)\mathrm{v}_\mathrm{r} \quad \text{..... .....Equation1}$$

where λ is the radar wavelength. The negative sign in eqn. 1 indicates that a positive range rate of the scatterer, corresponding to a radially outward or receding scatterer velocity, causes a negative Doppler shift relative to the carrier frequency. The Doppler shift due to a moving scatterer is insensitive to the components of scatterer motion perpendicular to the radial from the radar. Doppler weather radar is therefore inherently capable of determining only the radial component of the motion parameters associated with atmospheric phenomena. This fact constitutes a basic and major limitation of

Doppler weather radars, and any system designed with such radars as sensors must take this limitation into account. Such a drawback notwithstanding, the Doppler weather radar is still a very useful sensor for atmospheric motion parameters, and is of great value in aviation weather surveillance..

Atmospheric Wind Tracers for Doppler Radar

3. Wind velocity measurement using radars requires the existence of tracers of air motion in the atmosphere. Air molecules per se are not sensible by weather radars. It is therefore necessary that there be a significant number of radar scatterers which are airborne and move at the same speed as the local air, so that estimating the velocity parameters of such scatterers amounts to the estimation of the velocity parameters of the air that carries them. Such scatterers are called tracers of wind speed. Hydro meteoric particles, airborne insects, dust and debris, and eddies with refractive index irregularities or inhomogeneities are the common sources of radar scattering in the atmosphere.

4. **Primary Data Products**. The primary data products include wind velocity related data regarding each resolution volume in its field of view, besides data on the reflectivity distribution and frequency spectrum. Typically the velocity related data generated by weather radar consists of the mean and the spread of the radial wind speeds within each resolution volume. These data, together with reflectivity, are obtained by suitably processing the amplitudes and phases associated with batches of echo pulses received by the radar. The nature of the data products and their correspondence with weather parameters are readily visualized by considering the signal structure in the frequency domain. The frequency spectrum is obtained by taking the Fourier transform of the complex time series representing the successive returns from the volume. Based on this the three basic products are;

a. **Reflectivity**. The radar reflectivity of the scatterers in each resolution volume is derived directly from the power associated with the spectrum of echo signals from that volume. The power is simply given by the area under the spectral density plot, which corresponds to the zeroth moment of the spectrum. The reflectivity can be calculated from the echo power by using the radar range equation. The reflectivity measured by Doppler weather radars is physically the same quantity as the reflectivity obtained from conventional weather radars, though different signal processing circuitry and algorithms may be employed in the two systems, and the accuracy of the estimates may vary between them. Therefore the reflectivity factor derived from Doppler weather radars can be used to estimate rainfall rates and draw inferences regarding the nature of weather scatterers.

b. **Mean Radial Velocity**. The mean Doppler frequency f_{dm} of the weather spectrum is obtained from the first moment of the spectrum by normalizing it with respect to the area under the spectrum curve, i,e. the power associated with the spectrum. The mean radial velocity can be obtained from the Doppler frequency and is given by

$$v_{rm} = - (\lambda / 2) f_{dm}.$$

Physically the mean radial velocity represents the motion of the scatters due to the average radial component of the wind occurring over the resolution volume. Hence a positive sign would indicate movement towards the radar and negative, away from the radar.

c. **Doppler Velocity Spectral-width**. The width of the Doppler frequency spectrum provides a measure of the differential motion of the scatterers within a resolution volume. The spread of the Doppler frequency of individual scatterers is given by the Doppler spectrum width αd, which is the square of the second moment of the power normalized spectrum about the mean Doppler frequency. The following are the significant causes of Doppler spectral broadening:

(1) Turbulence within the resolution volume, which imparts to the scatterers random motion relative to one another in three-dimensional space, having a random radial component with respect to the radar

(2) Systematic wind gradients or wind shear over the resolution volume, which cause scatterers across the volume to move, on average, at different radial speeds relative to the radar

(3) Differing fall speeds of raindrops and/or other hydro meteors of varying sizes, shapes and densities, to the extent that these fall speeds have a radial component when the radar beam is not horizontal

(4) Vibration of hydrometeors, involving oscillatory fall paths and/or pulsating or random change in shape and orientation of nonspherical particles, which causes the radar cross-sections of the particles to vary

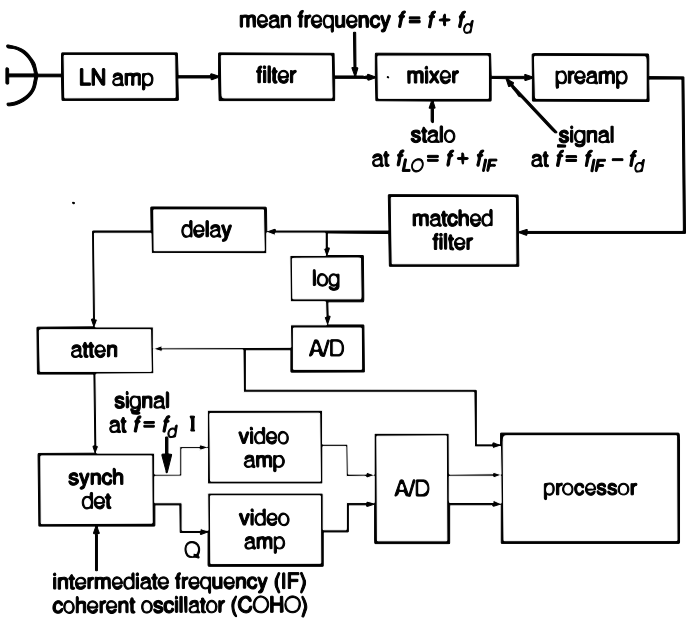
(5) The scanning or sweeping motion of the radar beam, which causes each resolution volume to shift continuously during the sample collection period, resulting in a variable weighting of the scatterers from pulse to pulse.

5. **Doppler Weather Radar System Features and Architecture**. The Doppler weather radar has all the principal subsystems of the .conventional weather radar (as indeed most other types of radar) such as the transmitter, antenna, receiver, signal processing and display. However, being coherent radar, it has special requirements with regard to the phase shift and frequency characteristics of its subsystems. Further, its signal processing circuitry has the capability of handling signals in complex form, preserving their amplitude and phase information. Complex signals are represented in coherent radar receivers through their in-phase and quadrature components (the so-called I and Q components).

6. An important requirement of modern weather radar is a high dynamic range. Dynamic range is an important system parameter of a radar which indicates the spread between the strongest and the weakest signals it can detect. Because of the inherent nature of atmospheric scatterers, the dynamic range requirements of modern Doppler weather radars are very demanding. As mentioned before, clear-air phenomena of meteorological interest may exhibit reflectivity factors of the order of -15 dBZ or less, while the reflectivity factor of intense rain with hail may reach 65 dBZ. This represents a

spread of >80 dB in the target reflectivity, calling for a high dynamic range of the receiver.

7. It is normally desirable that radar receiver-amplifiers be linear to preserve the relative strengths of targets in the signal domain. However, logarithmic receivers are often preferred where the dynamic range requirement is high. Receivers with logarithmic response characteristics provide high gain, and hence high sensitivity, at low signal levels, and yet do not get easily saturated as the input signal strength increases. It is possible to achieve dynamic ranges of the order of 80 dB with well designed logarithmic amplifiers (Taylor, 1990).



Simplified block diagram of a generic Doppler weather radar (LN Amp: low-noise amplifier; STALO: stable local oscillator; Preamp: preamplifier; Atten: attenuator; Log: logarithmic amplifier; AID: analog-digital converter; Synch Det: synchronous detector; IF: intermediate frequency, I: in-phase signal, Q: quadrature signal).

8. It is possible to use logarithmic amplifiers in conventional weather radars to avoid receiver saturation and obtain the required dynamic range. However, in the case of Doppler weather radars the use of a nonlinear device such as the logarithmic receiver-amplifier causes distortion of the spectrum, which affects the accuracy of spectral moment estimation. Modern Doppler weather radars therefore commonly employ linear receivers and utilize automatic gain control (AGC) circuitry to achieve high dynamic ranges. However, since an estimate of the original signal power is necessary for deciding the gain setting of the AGC, the control signal for the AGC circuit itself is often derived from a logarithmic amplifier. The block diagram of a generic Doppler weather radar receiver incorporating this principle is given below.

9. To estimate the spectral moments accurately, the transmitted signals of Doppler weather radars must be coherent from pulse to pulse. This means that the phase angles associated with successive transmitted pulses must be either the same or controlled in a known and precise manner. The requirement of pulse-to-pulse Phase coherence makes

klystron amplifiers the preferred device for the high-power elements of the transmitters of modern Doppler weather radars.

10. The antenna is typically a centre-fed paraboloidal reflector type, generating a narrow conical or pencil beam. A fan beam may occasionally be used if the weather function is combined with other functions, such as in the case of airport surveillance radars. A full-circular azimuthal scan capability of the antenna is common, with maximum scan rates of several revolutions per minute. The antenna pedestal and drive mechanisms usually permit scan along the elevation angle as well as varying the elevation tilt for performing the azimuthal scan. Programmable antenna scan cycles for conducting volume scans are also a common feature of modern Doppler weather radars.

11. The wide variability of the scattering strength of weather phenomena imposes severe limitations on the permissible side lobe levels of the antenna. The effects of side lobes become particularly apparent or disturbing while observing regions of high-reflectivity gradients. If the antenna has significant side lobes, areas of strong reflectivity viewed through a side lobe may be comparable to, or even stronger than, the feature in the main lobe at the same range. When the two are comparable, the side lobe feature will be superimposed on the main lobe feature, interfering with the observation of the latter. It may be noted here that all signals received by a radar are assumed to be from targets along its boresight (or main beam) and are so treated by the radar processor and display. When the feature in the side lobe is much stronger than that observed in the main lobe, the radar processor or observer will assume the former to be in the position of the latter. The scanning of the radar beam will cause attenuated replicas of strong features to be formed at locations separated by angular intervals equal to the angular separation between the main lobe and the strong side lobe(s). The factor of attenuation equals the side lobe ratio; hence the need to keep the side lobe ratios low. The requirement of a 'clean' pattern results in a significant tapering of the illumination function of the antenna feed over the reflector. For fixed-polarization radars, a horizontal polarization is more common, but a circular polarization is employed, at least as an option, in some cases.

Display of Basic Products

12. As in the case of conventional weather radars, to obtain area coverage of the geographical sector under weather surveillance, the plan position indicator (PPI) is the most commonly used display in modern weather radars. However, there are profound differences between the PPI displays of conventional and modern radars. The most significant difference arises from the fact that the modern Doppler weather radar generates and displays multiple parameters for each resolution volume, while the conventional radar displays only the reflectivity. Thus while the conventional weather radar has only one PPI display, the Doppler radar typically needs three PPI scopes to display the basic products or spectral moments (reflectivity, radial velocity and Doppler velocity spectrum width).

13. Another major characteristic of modern Doppler weather radars that influences the nature of displays is that the displayed parameters are the product of significant amounts of computation. The displays are therefore naturally of a computer-compatible type, in contrast with the circular-faced cathode ray tube displays of older generations of conventional radars with centre-originating radial traces. Computer-compatibility permits

a wide variety of commercial and special-purpose display devices to be used, depending on the desired size, resolution, reliability and cost considerations. Computer control also provides a high level of flexibility in the display format. Typical facilities provided on modern weather radar displays include zooming, choice of full-circle or sector displays, centre relocation on the screen, and colour scheme changes including a grey-scale display.

14. Modern weather radar displays are generally in full colour to efficiently convey the most possible information regarding the phenomenon being displayed. This is especially important in aviation weather surveillance systems where the time available for data assimilation and inference generation is very short.

15. In parametric displays such as those showing the three basic Doppler weather radar data products and a variety of higher-level products, the parameter being displayed is quantized into a number of levels, usually a power of two, and a uniform colour is assigned to each level. The parametric displays are therefore essentially colour-coded contour plots, but by choosing a sufficiently high number of quantization levels and assigning incrementally varying shades of colour to neighboring quantization levels, an effect approximating a continuous picture of the parameter variation may be created. To make instinctive sense, higher values of a given parameter, say reflectivity, are often assigned increasingly darker shades while areas with low values of the parameter are depicted in light shades. However, threshold values of the parameter which correspond to caution, warning or danger levels, or which must be otherwise emphasized, may be marked by abrupt changes in the assigned shade or intensity. The number of quantization levels and the display colour scheme for each parameter are very often kept operator-selectable (with suitable default options and built-in schemes for fast set-up) to maximize the visual impact of the display.

16. Aviation weather surveillance systems may also utilize non parametric displays for specific purposes. Typically these are used to depict complex scenes with multiple phenomena superimposed on geographic features, navigational facilities and other landmarks. The representation of features on such displays is usually in the form of symbols and icons, with numerical values displayed alongside where appropriate.

17. While the PPI is the most commonly used display format for weather radars, it does not provide a clear picture of the vertical structure of the phenomena being displayed. To display such a picture one makes use of the range-height indicator (RHI) mode of display. In this mode the radar antenna is made to scan over a sector in a vertical plane while being held at a constant azimuth angle. Each beam position of the radar is represented by a radial from the point corresponding to the radar position on the display surface, and the elevation angle of the radial line is kept proportional to the actual beam elevation. The returns from the various resolution volumes along each beam position are intensity-modulated or colour-modulated on the radial.

18. Another useful display mode is the velocity-azimuth display (VAD) which shows the Doppler or radial wind components as the radar beam performs a conical scan about a vertical axis. Ina way, the VAD scan is the counterpart of the RHI scan, because the former involves varying the beam azimuth angle at a constant elevation while the latter consists of scanning the beam in elevation at a constant azimuth. A layer of uniform horizontal wind would cause a sinusoidal variation of the radial component of the wind

over the corresponding range interval as the beam completes one azimuthal scan. By performing a harmonic analysis of the Doppler variation over the scan cycle corresponding to each range it is possible to obtain the uniform horizontal wind component as a function of height, and continuation of this process in time yields the evolution of this vertical wind profile. The two-dimensional depiction of the height-time variation of horizontal winds is a more common mode of display in the VAD.

Operating Characteristics C Band DWR

19. The system operates in the frequency band of 5500-5700 MHz, meant for weather surveillance. It would be capable of detecting and estimating parameters of synoptic and mesoscale weather events, like severe thunderstorm, meso cyclones and related phenomena, which are aviation related hazards.

20. a. Parameters to be Measured

(1) Reflectivity (Z).

(2) Radial Velocity (V) hereafter referred to as velocity.

(3) Spectrum Width (σ).

b. Product Range

(1) Reflectivity :500 km (operational range of 250 Km.)

(2) Radial Velocity :250 km.

(3) Spectrum Width :250 km.

c. Spatial Resolution

(1) Reflectivity : 300 m

(2) Velocity and spectrum width : 150m

d. Product Generation. The System should be capable of generating the following types of products:

(1) Base Products.

(2) Primary Products.

(3) Derived Products.

(4) Aviation Products.

(5) Hydrological Products

Products

21. The system is capable of generating the following products from the initial data output from the radar processor: -

a. **Base products**:

(1) The system generates PPI, RHI, Pictures for Z, (rainfall rates) V, after applying different corrections to raw data (like beam blockage, incomplete beam filling, attenuation effect, etc.).

(2) The raw data is archived with respect to geographical orientation (latitude /longitude), distance and angle from radar or other defined orientation point. GIS software is compatible.

(3) Provision is there to generate products offline using the archived raw data.

b. **Primary Products**:

(1) Plan Position Indicator.

(2) Range Height Indicator.

(3) CAPPI (Constant Altitude Plan Position Indicator). The System shall interpolate volume scan data set for a horizontal plane at user defined height and display it in a PPI type display.

(4) Pseudo CAPPI. The product is to be based on CAPPI product. Additionally, areas close to the radar and/or far from the radar shall be filled by interpolating data from adjacent elevations. Vertical Cross section, VSECT(Z,V, σ)

(5) Maximum Display. The System shall compute maximum values of base data elements (Z, V σ) from volume scan data in horizontal (East-west & North-South) and vertical columns (Top-Bottom) between user defined layers and display the resulting data in three-in-one image in a single frame.

(6) VCUT (Vertical Cut). The system shall interpolate volume scan data set for any vertical plane passing through any two user defined points and display the same in an RHI type image.

(7) EBASE (ECHO BASE). The system shall identify from the volume scan data set, the minimum height down to which the user defined threshold value for each base data exists and display the heights in a PPI type display.

(8) ETOP (ECHO TOP). The system shall identify from the volume scan data the maximum height up to which the user defined threshold value for each base data exists and display the heights in a PPI type display.

c. **Derived Products:**

(1) The system would recognize thunderstorm cell, cyclonic features, convergence, divergence and gust fronts, dust storm and generate and forecast their track.

(2) The system has the capability for converting selected data/products into coded messages in user specified formats for transmission over telecommunication circuits.

(3) The system would able to generate mesocyclones and Vergence products (divergence, convergence).

(4) The system should be able to provide an interactive method for locating storm centre by superimposing overlays.

d. **Velocity Products**.

(1) Velocity Azimuth Display (VAD). Radial velocity versus azimuth for a fixed elevation and a fixed slant range.

(2) Velocity Volume Processing (VVP). Analysis of the wind field, close to the radar site.

(3) Horizontal wind vectors. Estimation and display using Uniform Wind Technique algorithm in wind barbs notation at user defined grid points in PPI /CAPPI format. (Provision for including some other product as underlay shall be available.)

(4) Vertical time section of horizontal wind over the radar site in wind-barb notation. (Provision to display the same information in profile diagram and for computing and displaying Vergence product, shall also be available in this product).

(5) Combined Moment Display (CMD). Visualization of Z, V, σ data simultaneously. This is to be selectable as an overlay to other top projection radar images.

(6) Storm Relative Velocity (SRV). Estimation and display of velocity information relative to the moving storm cell.

(7) Spectrum Mean Velocity (SMV).

(8) Layer Mean Reflectivity (LMR). Estimation and display of the mean reflectivity at user selectable height.

(9) Severe Weather Analysis Display (SWAD). Display of Z,V, σ and shear information as separate windows over a selected geographical window area.

(10) Radial velocity for a fixed range in colour codes, in an azimuth verses height display.

e. **Hydrological Products**.

(1) Surface Rainfall Intensity (SRI). Rainfall intensity derived from reflectivity data using Z-R relationship in a user selectable surface layer at constant height above ground.

(2) Vertically Integrated Liquid (VIL). Liquid water content between two horizontal layers of the atmosphere obtained by vertical integration of reflectivity and converting the same into equivalent water content, in PPI format. Rainfall intensity histogram at selectable locations within radar coverage for a user defined time period.

(3) Precipitation accumulation (PAC) in a user definable time period, in PPI format.

(4) Rainfall amount in user defined basins for user defined time span, in PPI format.

(5) Rainfall amount for a place for any user defined past number of hours. Shall provide comparison between rainfall intensity derived from reflectivity and measured by rain gauge, within the radar coverage area.

(6) Rainfall Intensity Histogram (RIH). Display of rainfall intensity in mm/h over a user selectable time period.

f. **Aviation Products.**

(1) Shear. System is to be able to detect and identify Shear phenomena, which shall include Radial shear, Azimuth shear, Elevation shear, and 3D shear as well as Horizontal and vertical shear.

(2) Layer Turbulence. Evaluate and Display maximum turbulence within user defined atmospheric layer and display in top view format.

(3) The system shall also be able to generate warning product on microburst, mesocyclones, gust- fronts and thunderstorms for airfields with in useable range of radar for this purpose.

g. **Warning and Forecasting Products for Tropical Regions.**

(1) HAIL/DSD. System shall automatically generate hail thunderstorm and dust storm warning symbols at the places likely to get affected by hails, thunderstorm, dust storm using a reliable warning algorithms.

(2) The system shall be capable of providing interactive method for locating storm centre, superimposing 5º, 10º or 15 º soft spirals overlay as per operator's choice over the reflectivity image containing spiral bands of

the storm. The system shall also be able to measure the radius of maximum wind within user-defined grid of 5 – 60km around the storm centre.

(3) Storm Structure Analysis (SSA). Identify and extract storm characteristics such as volume, mass, tilt, location, base, top, maximum reflectivity/radial velocity/spectrum width including height.

(4) Microburst/Meso Cyclone Detection (MBD/MESC). Identify microburst conditions/precursors as well as meso cyclone patterns. (all Proven Algorithm to be implemented)

(5) Vergence Detection (VERC). Detect Vergence structures within atmospheric volume.

(6) Gust Front Detection (GUF). System shall be able to detect tornado and gust fronts associated with storms and issue visual and text warning message.(all Proven Algorithm to be implemented)

(7) System shall be capable of evaluating speed and direction of movement of weather systems.

(8) Severe Weather Indicator. System shall also be capable of warning if any of the conditions defined by the user are reached or fulfilled on reflectivity, velocity, VIL and wind shear.

(9) The system generates a storm relative velocity product e.g. PPI, PCAPPI removing the bias of storm motion velocity.

(10) Feature Combination (FCP). System is to be able to combine various features.

(11) Rain Tracking (RTR). Predict rainfall at user selectable geographical areas within user selectable time periods.

(11) Centroid Tracking (CTR). Storm tracking in terms of storm areas and storm cores. It is to be available in automatic and interactive modes.

(12) Radar network composite (MOSAIC).

h. **Dual Polarity Data Products.**

(1) Differential Reflectivity (ZDR).

(2) Specific Differential Phase Shift (KDP).

(3) Co-Polar Correlation Coherency Coefficient (Phv).

(4) CETP rain correction algorithm (ZPHI).

j. **Alphanumeric Products**. The system shall have provision for converting all products in image form to alphanumeric values and present them in tabular form giving numeric values for grid points, Azimuth/range, height and data with user defined resolution, in a 200 x 200 km field around the radar.

System Characteristics

22. **General.**

a. Frequency Range - A frequency band between 5500-5700 MHz. (Final frequency will be decided at the time of installation.)

b. Peak Power - Higher than 250 kW at transmitter output

c. Primary Power - 415 V ± 10% (3 Phase), 50 Hz ± 2%.

23. **Transmitter**.

a. Power Device - Klystron using Solid State modulator.

b. Tunability - Automatic and manual tunability within the Klystron specification.

c. Pulse Repetition- 250 to 1200 Hz, Frequency (PRF) variable, computer controlled within the duty ratio of Klystron.

d. Sector Blanking - Transmission should be off between selectable azimuth angles.

24. **Receiver.**

a. Frequency Range - A frequency band between 5500 – 5700MHz

b. System noise figure - Better than 3dB and consistent with the measurement accuracy requirements

c. Type of receiver: - Fully coherent receiver with digital IF (Digital Linear Receiver). The digital linear receiver has a dynamic range of 100 dB or better.

d. The total receiver from LNA input to the reflectivity data output should have a dynamic range, of 95 dB or better, and consistent with measurement accuracy. The lower value of dynamic range is to be as per detection on scope.

25. **Antenna System.**

a. Type - Horn feed onto parabolic solid surface reflector or equivalent. (With facility to reduce ground clutter to minimum, with state of the art technology).

b. Beam Width - 0.95 degree pencil beam at central frequency of Klystron measured at 3 dB points.

c. Polarisation - Linear Horizontal (Essential) / others desirable. Capability for dual polarization.

d. Side lobes - - 26 dB or better from main lobe to 12 degrees, -30 dB or better thereafter.

e. VSWR - 1.15: 1 maximum (with radome) at output of (Voltage Standing amplifier. Wave Ratio)

f. Antenna Gain - 45 dB or better.

26. **Antenna Scan Details.**

a. **Azimuth Movement:**

(1) Automatic Mode - 360 degrees continuous

(2) Manual Mode - Manually settable to any azimuth range

(3) Azimuth Rate - Variable from 0.5 to 6 RPM in steps of 0.5 RPM.

(4) Positioning - 0.1 degree or better Accuracy

(5) Azimuth data - 0.05 degree or better resolution

(6) Settling Time - Better than 1 sec

(7) Azimuth - 15º /S2. Acceleration

b. **Elevation Movement:**

(1) Automatic Mode- -1 degree to +90 degrees

(2) Manual Mode - -1 degree to +90 degrees

(3) Elevation speed - Variable up to 6 degrees per second in automatic mode in steps of 1º/sec

(4) Elevation speed - Variable from 1 to 6 degrees/sec in manual mode in steps of 1º/sec

(5) Elevation limit - Upper and lower limit switches for elevation limit protection with hard stops

(6) Elevation positioning- 0.1 degree or better. accuracy

(7) Elevation data - 0.05 degree or better. resolution

(8) Settling Time - better than 1 sec

(9) Elevation Acceleration - 15º / S2.

Scan Mode

27. Automatic Scan. The system shall be capable of performing the following types of scans, taking input from configuration files:

a. Full azimuth scan (0 to 360º) maintaining same elevation angle (input from file).

b. Sector scan in azimuth, taking central angle and sector-width as input (maintaining elevation angle).

c. Sector scans in elevation, taking central angle and sector-width as input (maintaining azimuth angle).

d. Multiple azimuth scans [as in (a) above] at different elevation (input from file - Max. 30 steps).

28. **Manual Scan**. All the above type of scans, as in para 18 above, shall be possible in manual mode, taking input from the operator in real-time.

Radome

29. The details of the radome are as follows:-

a. Type - Foam sandwich, rigid, spherical (equivalent).

b. Wind Load - up to 230 km/h

c. Transmission loss - Less than 0.2 dB (one way)

30. **Sensor & Data Integration.**

SAT - Satellite Image Integration

RG - Rain Gauge Data Integration

AWOS - Automatic Weather Observation System data integration.

LLWAI Integration - Low-level wind data integration.

NWP Interface - Two way integration with NWP model outputs.

TASK-40 : LIGHTNING DETECTOR

Chapter Objectives

After reading this chapter you should be able to:-

- Understand the theory of atmospheric electricity and lightning.
- Understand the physics of lightning detection.
- Understand the features of current operational lightning detecting systems.
- Analyse the features required for the systems to be bought for IAF.

Introduction

1. IAF Met Sections at the Stations are responsible for identification of hazardous severe convective weather phenomenon in the airfield environment to reduce severe weather risks during flying operations particularly in the landing and take off phases and also help protect critical Air Force activities and assets such as communication centers, radar sites and operation centers. At present there are no instrument inputs and the reporting of such hazardous severe convective weather phenomenon is achieved by naked eye. These severe convective weather phenomena such as thunderstorms, lightning, gale winds, showers and rain have profound effect on all types of flying operations. There are several instances where these weather events have resulted in incidents or accidents. Early detection of such severe weather events is very important not only from the point of view of safe flying operations but also for expensive AF assets. In the modern day advanced technology era, there are several options for early detection of such severe weather events. Lightning detector sensor system is one of the important options.

Atmospheric Electricity

2. On a clear day, when the atmosphere is clear of storm clouds, the primary source of electric charge creating an electric field on the surface of the earth is the ionosphere. This can be thought of as a large dome-shaped electrode high above the earth, which produces positive charges which contrast to the relatively negatively charged earth. This scenario creates what is termed a “fair weather” electric field due to the positive charge overhead. When thunderclouds form, however, processes within their vicinity cause the formation of negative electric charges (the opposite of the ionosphere) at the cloud base. As the charge builds, it creates a ‘bad weather’ electric field which grows and then begins to cancel out the ‘fair weather’ field. As it builds further, it becomes many times greater than the fair weather field. It is this ‘bad weather’ electric field which intensifies to the point that the air can no longer insulate the opposite charges. Finally, the positive and negative charges are drawn together suddenly via any convenient ‘weak spot’ which occurs in the atmosphere. This is the energetic discharge we call lightning.

3. It is the separation of positive and negative electric charges into large groups which creates the lightning hazard. These groups, of opposite polarity, are naturally attracted to each other but held apart by the atmosphere’s insulating properties. As these groups grow during the formation of a storm, the force of their attraction can exceed the

atmosphere's ability to keep them separated. Lightning is the sudden, intense electrical recombination of these groups which occurs when this point is reached. This is an over-simplified explanation of what is actually a very complex process. Interested readers may refer standard books on lightning.

4. **Cloud-to-Ground Lightning**. It is the most damaging and dangerous form of lightning. Although not the most common type, it is the one which is best understood. Most flashes originate near the lower-negative charge center and deliver negative charge to Earth. However, an appreciable minority of flashes carry positive charge to Earth. These positive flashes often occur during the dissipating stage of a thunderstorm's life. Positive flashes are also more common as a percentage of total ground strikes during the winter months.

5. **Intra-Cloud lightning**. It is the most common type of discharge. This occurs between oppositely charged centers within the same cloud. Usually the process takes place within the cloud and looks from the outside of the cloud like a diffuse brightening which flickers. However, the flash may exit the boundary of the cloud and a bright channel, similar to a cloud-to-ground flash, can be visible for many miles. The ratio of cloud-to-ground and intra-cloud lightning can vary significantly from storm to storm. Storms with the greatest vertical development may produce intra-cloud lightning almost exclusively. Some suggest that the variations are latitude-dependent, with a greater percentage of cloud-to-ground strikes occurring at higher latitudes. Others suggest that cloud-top height is a more important variable than latitude. Details of why a discharge stays within a cloud or comes to ground are not understood. Perhaps a flash propagates toward the Earth when the electric field gradient in the lower regions of the cloud is stronger in the downward direction. Depending upon cloud height above ground and changes in electric field strength between cloud and Earth, the discharge stays within the cloud or makes direct contact with the Earth. If the field strength is highest in the lower regions of the cloud a downward flash may occur from cloud to Earth.

6. **Inter-Cloud Lightning**. As the name implies, it occurs between charge centers in two different clouds with the discharge bridging a gap of clear air between them.

7. **Other Types of Lightning Discharge**. There are numerous names and descriptions of various types and forms of lightning. Some identify subcategories, and others may arise from optical illusions, appearances, or myths. Some popular terms include: ball lightning, heat lightning, bead lightning, sheet lightning, silent lightning, black lightning, ribbon lightning, colored lightning, tubular lightning, meandering lightning, cloud-to-air lightning, stratospheric lightning, red sprites, blue jets, and elves.

Physics of Lightning Discharge

8. With the initial breakdown of the air in a region of strong electric fields, a streamer may begin to propagate downward toward the Earth. It moves in discrete steps of about 50 meters each and is called a stepped leader. As it grows, it creates an ionized path depositing charge along the channel, and as the stepped leader nears the Earth, a large potential difference is generated between the end of the leader and the Earth. Typically, a streamer is launched from the Earth and intercepts the descending stepped leader just before it reaches the ground. Once a connecting path is achieved, a return stroke flies up the already ionized path at close to the speed of light. This return stroke releases tremendous energy, bright light and thunder. Occasionally, where a thunderstorm grows

over a tall Earth grounded object, such as a radio antenna, an upward leader may propagate from the object toward the cloud. This “ground-to-cloud” flash generally transfers a net positive charge to Earth and is characterized by upward pointing branches.

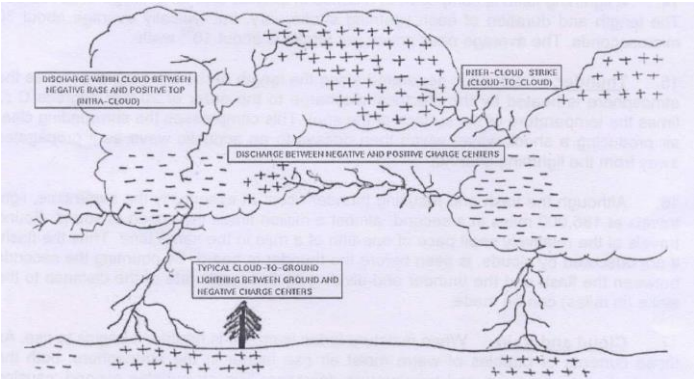


Fig.8.1. Charge distribution in CB Cloud (The lower part of a thundercloud is usually negatively charged. The upward area is usually positively charged. Lightning from the negatively charged area of the cloud generally carries a negative charge to Earth and is called a negative flash. A discharge from a positively-charged area to Earth produces a positive flash)

Characteristics of a Storm

9. **Lightning.** As the ice particles within a cloud (called hydrometeors) grow and interact, they collide, fracture and break apart. It is thought that the smaller particles tend to acquire positive charge, while the larger particles acquire more negative charge. These particles tend to separate under the influences of updrafts and gravity until the upper portion of the cloud acquires a net positive charge and the lower portion of the cloud becomes negatively charged. This separation of charge produces enormous electrical potential both within the cloud and between the cloud and ground. This can amount to millions of volts, and eventually the electrical resistance in the air breaks down and a flash begins. Lightning, then, is an electrical discharge between positive and negative regions of a thunderstorm. A lightning flash is composed of a series of strokes with an average of about four. The length and duration of each lightning stroke vary, but typically average about 30 microseconds. The average peak power per stroke is about 1012 watts.

10. **Thunder**. Sound is generated along the length of the lightning channel as the atmosphere is heated by the electrical discharge to the order of 20,000 degrees C (3 times the temperature of the surface of the sun). This compresses the surrounding clear air producing a shock wave, which then decays to an acoustic wave as it propagates away from the lightning channel. Although the flash and resulting thunder occur at essentially the same time, light travels at 186,000 miles in a second, almost a million times the speed of sound. Sound travels at the relatively snail pace of one-fifth of a mile in the same time. Thus the flash, if not obscured by clouds, is seen before the thunder is heard. By counting the seconds between the flash and the thunder and dividing by 5, an estimate of the distance to the strike (in miles) can be made.

11. **Cloud and Rain**. When moisture-laden warm air is heated, it begins to rise. As these currents or bubbles of warm moist air rise higher in the atmosphere, both the

surrounding air pressure and temperature decrease. The air bubbles expand, causing cooling of the moisture which eventually condenses to form clouds. As the cloud cools further, more moisture condenses and the water droplets making up the cloud grow and merge until some become so large and heavy that the air currents within the cloud can no longer support them. These water droplets begin to fall as rain.

12. **Hail.** Air currents in cumulonimbus clouds can be very violent. Even when lightning is not produced, pellets of ice may grow by the accumulation of liquid droplets. When the updrafts are very strong, the growing ice pellets can be suspended for long periods, allowing them to grow larger. Eventually some may become too large for a given updraft and begin to fall as hail. Diameters are typically 5 to 10 mm, although a 140 mm hailstone has been recorded.

Physics of Lightning Detection

13. **Cloud to Ground Lightning**. Both low frequency magnetic direction finding and low frequency time of arrival methods, work on the principle of detecting the electromagnetic signature of the Lightning flash. A Lightning flash releases energy right across the entire electromagnetic spectrum. As we know from AM radio transmissions, the length of the transmitting antenna relates directly to the electro-magnetic energy radiated. An antenna is typically designed to be of length one quarter wavelength at the radiated frequency for maximum performance. One can consider the process of a return stroke from a ground lightning stroke moving rapidly upwards along the ionized path created by the leader as being analogous to an AM radio transmission, with the ionized path effectively acting as an antenna. That path is where most of the stroke's energy is radiated and is approximately 8 to 10 km long. Considering an average length of a return stroke to be 9 km then the maximum energy is radiated at about 8 kHz. This is calculated from the formula:

$$c = n\nu$$

Where $1/\nu$ is the wavelength of the transmission, c is the velocity of light and n is the radiated frequency. Hence with an 'antenna' length of one quarter the wavelength, say 9 km, the frequency is calculated to be about 8 kHz.

14. **Cloud to Cloud Lightning (Intra & Inter Cloud Lightning)**. Now let us examine lightning events that do not come to ground and hence have no return stroke path of such high energy. We will classify these as inter-/intra- cloud (OLD) discharges. CLD events, whether of the inter- or intra-cloud variety have similar characteristics. As charge builds within a cloud due to various processes, there can be a "breakdown" between these charge centers. Should the charge centers be close together, then the stroke or 'spark' released by the "breakdown" is also short in length. Data collected by many scientists worldwide, show that such 'sparks' are extremely numerous in a cloud lightning event. In a single 'event' there can be many thousands of interconnected sparks, separated by a few microseconds or shorter. It is seen that electromagnetic radiation can occur at frequencies as high as a few Gigahertz, meaning a very short spark.

15. Let us examine the energy radiated at these frequencies by reviewing the signal amplitude shown in the above figure. From that figure, the peak energy of a return stroke to ground will be 1,000,000 micro-volts per meter for a 1 microsecond bandwidth. For higher frequencies, the energy level decreases rapidly, meaning that for the higher

frequencies shown on this graph the energy will be so low that the distance of radio-wave propagation will be negligible.

16. **The Current Measured in Lightning Strokes**. Much work has been performed on measuring the current in cloud-to-ground lightning (OG) events. The majority of this work has been carried out by measuring the lightning characteristics as the strokes connect with instrumented towers. Typical measurements show that the average current in a ground stroke is between 22 and 35 kilo-amps.

Types of Lightning Detection Sensing Technology

17. Lightning detector sensor is a passive device which senses the electromagnetic signatures of the Lightning strike. Lightning detector system is a general purpose Lightning/thunderstorm detection sensor employing Lightning detection sensing technology.

a. Lightning detection sensors employing low frequency magnetic direction finding and low frequency time of arrival sensing technology for finding direction and bearing of the lightning.

b. Lightning detection sensors employing Very High Frequency (VHF) interferometery technology which provides detection of intra / inter cloud lightning.

Current Operational Systems

18. The detection of lightning is a passive activity involving the use of radio receivers to detect wave fronts resulting from lightning. Data from individual detection sites may be distributed by any of the usual means including fixed links, telephone, Internet etc. The need by operational meteorologists for remote sensing of lightning activity is rapidly increasing. Customer requirements are developing in conjunction with developments in the use of weather radar and meteorological satellite products, and have a high priority given the need to automate surface weather observations in many developed countries. The reliable operation of these systems has clear links to considerations of public safety on land, sea and air. Provision of an effective forecast service impacts the efficiency of commercial and defence activities. The safety of engineers working on power lines and personnel handling explosive devices are examples of activities that benefit from effective lightning forecasts.

19. In current operational systems, the position of the lightning flash is either determined by measuring the direction of arrival of the associated spheric (atmospheric wave), or by measuring the time of arrival of the spheric or a combination of both. Measurements are normally made at more than three widely spaced sensing sites. The number of sites used in practice is usually larger than the minimum in order to improve the reliability of the reported locations. Time of arrival systems usually provide more accurate locations than direction finding systems when observing at ranges over several hundred kilometers. This is due to the direction of reception of sky waves sensed at the site, which usually differs slightly from the actual direction of the discharge, and will vary according to the state of the surface layers near the sensing site. Time of arrival systems usually rely heavily on GPS radio navigation signals to achieve the necessary time synchronization at the various sensing sites. All systems rely on cost effective, reliable

communications from the remote sites to the central processor. The radio frequency used to locate lightning activity varies according to the area of monitoring required and the specific purpose of the system.

20. Very long-range locations at ranges of several thousand kilometres are achieved operationally by observing frequencies centered at 10 kHz (2-15 kHz). In this system, the spherics are received at the remote outstations located around Europe with spacing of up to 2000 km apart. The spherics are Fourier analysed and time stamped at the sensor sites. The timed samples are immediately transmitted back to a central control station where the locations of the lightning discharges are computed from the differences in arrival times at the sites. Interference is extremely detrimental to the operation of the system and each outstation is equipped with adjustable notch filters to discriminate against local contamination.

21. The most widely used operational systems cover a more limited area in detail. In this case, the spherics are observed at higher frequencies centered around 200 kHz (the wideband receivers used are most sensitive in the middle of their range of 1 kHz to 350 kHz), and the sensing sites are usually spaced between 100 km and 400 km apart, depending on whether the emphasis is on cloud- to-ground or cloud-to-cloud flashes. At these higher frequencies, a discharge from the cloud-to- ground can be identified by a pronounced rise in amplitude defining a leading edge to the spheric. The arrival of this leading edge can be accurately timed. The times from the network sites are transmitted to a central processor and used to compute the positions of the discharges. In many cases, the network arrival time differences are operated in conjunction with magnetic direction finding systems installed in earlier years. In addition, in some areas it is necessary to observe all the electrical discharges associated with thunderstorm activity, both cloud-to-ground and cloud-to-cloud discharges. This is achieved by observing at very much higher frequencies (63 MHz and 225 MHz are used by the lightning detection and ranging (LDAR), while SAFIR uses 110 to 118 MHz).

Uses of Lightning Detectors

22. Lightning detectors are used the world over for improving nowcasting with early identification of hazardous convective weather as well as faster and more accurate tracking of thunderstorm development, intensity and dissipation. They are being put to more and more use for nowcasting, safety of the aircraft and asset Protection in the following fields:

a. **Meteorology**. To identify thunderstorms early to support severe weather forecast for aviation and Nowcasting.

b. **Air Traffic Management**. To reroute to avoid Lightning, Thunderstorms, gale etc.

c. **Ground Forces (Defence)**. To mitigate effects of lightning, thunderstorms, gale etc.

d. **Launch Facilities**. To protect critical activities

e. **Airports**. To protect critical activities

f. **Telecommunications Radars.** To protect and mitigate effects of lightning, thunderstorms, gale etc. on critical activities and assets.

Operational Characteristics and Features of the Lightning Detection

23. Lightning detection system comprising single point lightning detector sensors and Electric Field Mill Sensors is an effective modern sensor based equipment for continuous detection and automatic recording of lightning / thunderstorm occurrences as well as potential of lightning strike around the airfield up to a distance of at least 50 nm. Lightning detection systems is planned for all the AF airfields. Lightning detection system will help identify hazardous convective weather events in the airfield environment thus providing lightning and other severe weather management system. This will help to reduce severe weather risks not only during flying particularly in the landing and take off phases but also help protect Air Force assets and critical AF activities. The system will be integrated and configured with automatic weather stations that the Air Force is procuring. Live recordings and plotting of lightning / thunderstorm events around the airfield will be automatically transmitted and made available to all users in the station on LAN/WAN through central data acquisition computer in Met Section. The system will be capable of plotting lightning / thunderstorm data around the airfield up to a distance of at least 50 nm on a base map on PC monitor in three or more ranges. The design of the system is required to be compact and modular so that the critical components are field replaceable.

24. Lightning detection system will be capable of detection of current lightning / thunderstorm events as well as provide measure of potential for lightning strike over and in the vicinity of the airfield. Lightning detection system comprises single point lightning detector sensors and Electric Field Mill Sensors. Single point lightning detector sensor is a passive device and will provide distance and bearing of the lightning / thunderstorm events. Electric field mill (EFM) Sensors are used to determine likelihood of nearby lightning strike occurring. Lightning is caused by electrical charge separation in the atmosphere. Electric field mill (EFM) Sensor are employed to determine and monitor the potential level of electrostatic charge in the atmosphere in an effort to preempt any situation where lightning could directly impact sensitive Air Force operations / sites like refueling, takeoff/landing of the aircraft, radar sites, communication centers etc. It has been observed that electric fields associated with bad weather can reach values of well over 10,000 volts per meter at the ground thus disrupting communication/radar networks/centers. This technology is suited for very highly critical activities or areas. The system is to be deployed out in the open and therefore weather and environmental protection must be provided for the sensitive components so that the system is capable of operating unattended for extended periods of time.

Configuration of Lightning Detection System

25. Operational characteristics and features of the lightning detection system that the Air Force plans to procure are covered in the succeeding paragraphs. Each lightning detection system proposed at an AF Station will comprise the following:-

a. Single Point Lightning detector Sensor

b. Electric Field Mill (EFM) Sensor

c. Application Software and Hardware

d. Installation and other services

26. The lightning data from the sensor locations will be transmitted through wireless/land line to the signal processing unit (PC) in the Met Section. The application software will be capable of processing lightning data for computing number of strikes, intensity, density, bearing and range and potential (Probability) for lightning over or around the airfield etc. The software is required to be capable of plotting the exact location of the strikes, intensity, density, bearing and range on a base map on a LCD display with a detection efficiency of more than 90%. Data is to be updated once per minute.

27. **System Specifications**. The essential specifications of the Single Point Lightning Detector Sensor system and Electric Field Mill (EFM) Sensor are as follows:-

a. **Single Point Lightning Detector Sensors (60 Numbers)**

Ser	Item	Specification
1	Detect Lightning	(i) Cloud to Ground (ii) Intra/Inter Cloud
2	Resolution	(i) Range ± 1nm (ii) Azimuth ± 1 Degree
3	Accuracy	(i) Cloud to Ground(For different ranges) For More Than 200 nm. (ii) Intra / Inter Cloud (For different ranges) For at Least 30 nm
4	lightning Detection Location Accuracy	(i) Cloud to Ground (For different ranges) More Than 90% (ii) Intra / Inter Cloud (For different ranges) More Than 50 %
5	Sensitivity Controls	At Front End
6	Cloud lightning counts	Display
7	System Timing Accuracy	± 20 nsec
8	Timing Resolution	± 25 nsec
9	Display data on screen on different ranges	At Least Three Ranges
10	Calibration	All Parameters should be calibrated
11	Baud Rate	4800 Baud, 8NI or Better
12	Output Format	ASCII Characters
13	Power	220 ± 10 V AC
14	VHS Transmit and Receive unit	Fail Proof, Sufficient to Receive Data from Three Sensors at met section (60 Numbers)
15	Any additional Feature. Please list	(For The Vendors)

b. **Electric Field Mill (EFM) Sensor.** Electric field mill (EFM) Sensor are employed to determine and monitor the potential level of electrostatic charge in the atmosphere in an effort to preempt any situation where lightning could

directly impact sensitive Air Force operations / sites like refueling, takeoff/landing of the aircraft, radar sites, communication centers etc.

Ser	Item	Specification
1	Electric field mill	Digital
2	Range	+/- 20 kV/m Dynamic range
3	Data	RS – 232 polled data
4	Resolution	15 bit resolution
5	Display/Controller	LCD display, Two user adjustable thresholds, Addible alarms.
6	Power (input)	220 V +/- 5%, 50 Hz
7	Power Back up	Inverter/Battery backup up to 2 hours.
8	Cable	100m; to meet demand criteria as needed for system performance
9	Mounting Hardware	Hardware for downward looking installation

c. **Software/Application Software (60 Licenses)**

Ser	Item
1	Single Point Lightning Detector Sensors and Electric field mill (EFM) Sensor display, command and control software, Graphical display of data from boththe sensors with user definable notification (visual and audible, threshold deviation, data archiving for analysis
2	WINDOWS/Linux OS
3	Plot lightning strikes in real time over maps reflecting precise IAF facilities (Lat, Long plotting) over an area of 250/300 km radius (GPS based).
4	Provide all lightning characteristics such as type, intensity, polarity, signal strength.
5	Zoom on area of interest
6	Lightning density , Intensity and Probability of lightning in the local area Display
7	Automated alarm on Pre-selected ranges
8	Nowcasting capability
9	Storage capability for a year.
10	Facility for animations from stored data / pictures
11	Monitor / Display all critical parameters such as Power Supply Voltages, Timing Stability, Temperature etc.
12	Automatic Monitor System Performance
13	Remote Sensor self Diagnostics System
14	Lightning Mapping and Display Provision of Custom Map Background Display defined by IAF. Display to show real time Lightning Plots over Maps.

d. **Computer Hardware (60 Numbers)**

Ser	Item	Specification
1	CPU	Pentium D processor
2	Memory	1 GB RAM or More
3	Cache memory	1 MB cache or more
4	HDD	2 X 80 GB or more @7200 rpm
5	CD ROM drive	52 X DVD Combo
6	Key board	104 Keys
7	Mouse	Wireless, Three button
8	Monitor	17'' TFT Monitor
9	Speakers	320 watts with multimedia compatibility
10	RS 232 port (serial port)	2 Nos
11	Printer port (parallel port)	2 Nos
12	USB port	2 Nos (at the front panel)
13	LAN Card	10/100/100Mbps LAN card supporting TCP/IP
14	Mother board	INTEL with 945 chip set
15	PC Make	HP, IBM, Compaq
16	OS	LINUX / Latest WINDOWs version
17	UPS	APC 1 KVA

Note: Computer hardware is to be procured from within India.

e. **Environmental Requirements**.

Ser	Item	Specification
1	(a) Temperature range	–40ºC to +55 ºC for 2 Systems -10ºC to +55ºC for 4 Systems
2	(b) Humidity	0 – 100% RH
3	(c) Wind	To withstand up to 120 knots
4	(d) Tropicalisation	All electronics systems should be tropicalised for optimum performance in tropical conditions. Outer units shall have protection against saline atmosphere.
5	(e) Weather and environmental protection	Weather and environmental protection must be provided for the sensitive optical instruments

f. **Additional System Requirements**. Additional system requirements are as follows.

1	Fault diagnostic	BITE type maintenance terminal for:
2	Remote/Local 'ON'/'OFF'	Provision for switching on/off system from remote location or in the field independently
3	Safety device	Suitable safety device to prevent major damages due to electrical faults and also safety interlocks. Provision of protection against electrical surges and lightning.
4	Housing	The system is to be installed along AWS and configured with the AWS.
5	Replacement of modules	The system should be modular.
6	Standby power supply	Stabilized power supply through inverter capable for 2 hours backup in terms of current and voltage.
7	MTBF (Mean Time Between Failure)	More Than 30000 hours minimum
8	System	Quality certification: ISO 9001:2000
9	IMD / WMO certificate	For performance and accuracy of the system. .
10	System Software	The system is required to be integrated and configured with automatic weather stations software that the Air Force is procuring. Graphical Display of data.
11	Reporting of Data	Conformity to all ICAO and WMO requirements for reporting of data.
12	Data to Users	Lightning plots and other derived data is required to made available to all users in the station on LAN/WAN

Data Transmission

28. For Lightning Detection System comprising single point lightning detector sensors and Electric Field Mill Sensors, the installation site is required to be as freer as possible from EM interferences from other sources. Data transmission will be by both VHF link and land line from the sensor site to signal processing unit (PC) in the Met Section. Signal processing unit (PC) will process the data and make available lightning plots and other derived data. It will be the responsibility of the vendor to integrate the application software with that of the AF automatic weather station software for the purpose of display and dissemination to the users. Indian vendor is to produce a certificate from I Met D or any other accredited agency for Indian product for the performance and accuracy of Lightning detection system at the time of submission of Technical Tender. Foreign vendor can render a similar certificate from the Govt organisation of the country, which recognizes and certifies the Met services of that country. OEM must be ISO 9001:2000

certified. Protection against weather and environment is required be provided for the Lightning detection system so that the system is capable of operating unattended for extended periods of time. The system should be so designed that it is easily upgradeable on a future date. Firms are required to quote the life span of the system in their technical bids. Performance of the system should be independent of different climatic zones i.e. Desert, high altitude areas, coastal and cold region and various types of weather like sunshine, Rain and Fog etc.

Conclusion

29. Although predicting an actual lightning strike is difficult if not impossible no matter what technique is used, monitoring the local electric field along with some interpretation and experience can be one of the best ways to determine how likely it is for lightning to strike an area.

SECTION-10 : METEOROLOGICAL SOFTWARE

SECTION- 41 : WIND ROSE SOFTWARE

Introduction

1. A wind rose is a graphic tool used by meteorologists to give a brief and clear view of how wind speed and wind direction are typically distributed at a particular station. One can visually appreciate the frequency of the wind direction and wind speed from wind rose.

2. Presented in a circular format, wind rose shows the frequency of winds blowing from particular directions and the length of each "spoke" around the circle is related to the frequency that the wind blows from a particular direction per unit time. Each concentric circle represents a different frequency, emanating from zero at the center to increasing frequencies at the outer circles. The longest spoke shows the wind direction with the greatest frequency.

3. A wind rose plot contains additional information, in that each spoke is broken down into colour-coded bands that show wind speed ranges. Wind roses typically use 16 cardinal directions, such as north (N), NNE, NE, etc., although they may be subdivided into as many as 32 directions. Here, we have prepared wind roses using 16 cardinal directions.

Aim

4. The aim of this paper is to prepare a month wise wind rose that can briefly and clearly indicate how wind direction and wind speed are distributed at the Airfield.

How to Create Wind Rose?

The wind rose is the time honored method of graphically presenting the wind conditions, direction and speed, over a period of time at a specific location. To create a wind rose, average wind direction and wind speed values are logged at a site, at short intervals, over a period of time, e.g. 1 week, 1 month, or longer. The collected wind data is then sorted by wind direction so that the percentage of time that the wind was blowing from each direction can be determined. Typically the wind direction data is sorted into twelve equal arc segments, 30° each segment, in preparation for plotting a circular graph in which the radius of each of the twelve segments represents the percentage of time that the wind blew from each of the twelve 30° direction segments. Wind speed data can be superimposed on each direction segment to indicate, for example, the average wind speed when the wind was blowing from that segment's direction and the maximum wind speed during the logging period.

Data Used

5. Here the surface wind data (speed in knots) of Meteorological Squadron, BAF Base Zahurul Haque have been used for last 10 years. The daily average is made on the basis of at least 24 hourly observations including special observation. Climate Register is used as data source.

Software Used

6. The Windows based software Oriana (Version 3.02) is used to draw the wind roses. The Software is available at (http://www.kovcomp.co.uk/oriana/). One can get more detailed information, download detailed information in a PDF format, or download a fully working demo version of the Software. The demo version can be used only for 30 days; a registered version can be used for long time like "Registered Digital Atmosphere Software" that requires payment through credit card or other way.

Interpretation of Wind Rose

7. The wind roses for Meteorological Squadron, BAF Base Zahurul Haque, Chittagong have been constructed in the following way:

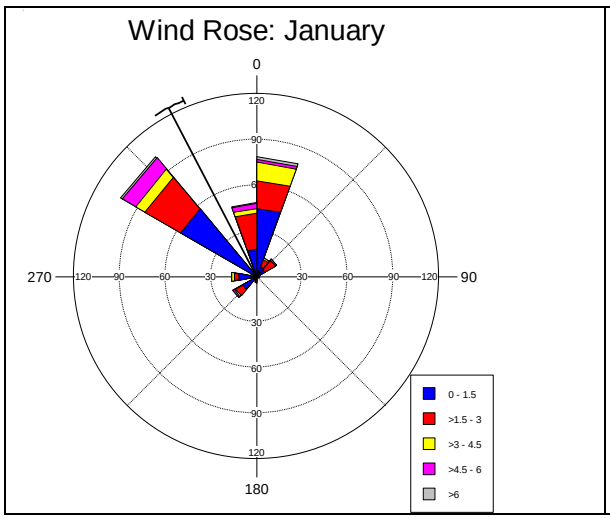
a. The 16 branches or cardinal directions are divided into segments of different thickness and colour, which represent wind speed ranges from that direction. In each case of the wind rose, the wind speed is divided into 5 ranges. The 1st, 2nd, 3rd, 4th and 5th ranges are depicted by the colours of blue, red, yellow, magenta and gray respectively.

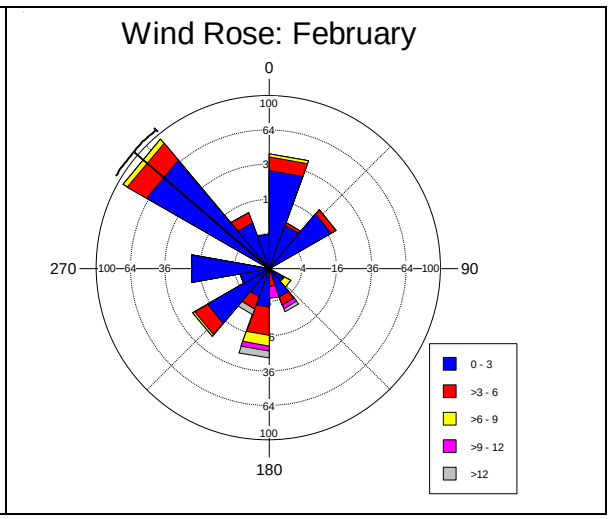
b. The percentage of calm conditions is represented by the size of the centre circle - the bigger the circle, the higher is the frequency of calm conditions.

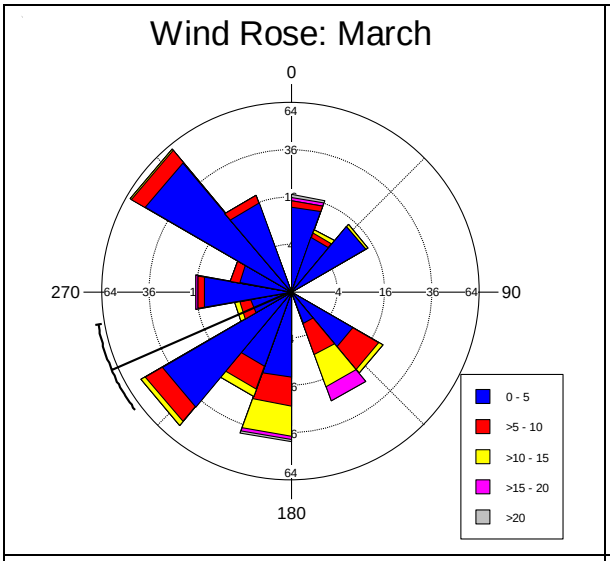
c. The black line with an arc outside the outermost circle indicates the average wind direction for the month.

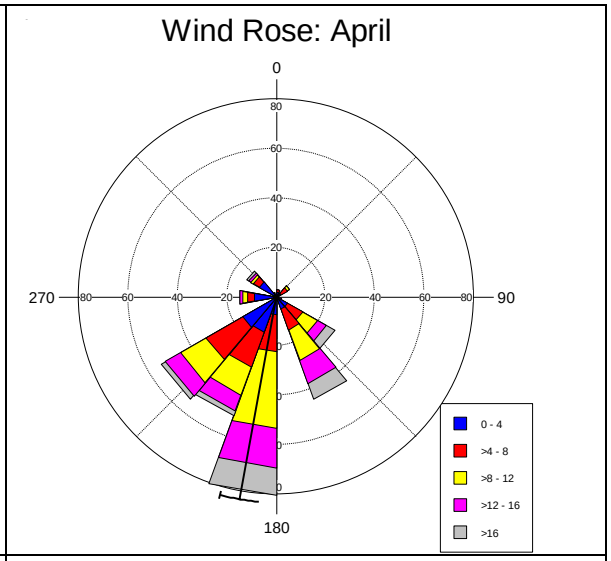
Graph of Monthwise Wind Roses

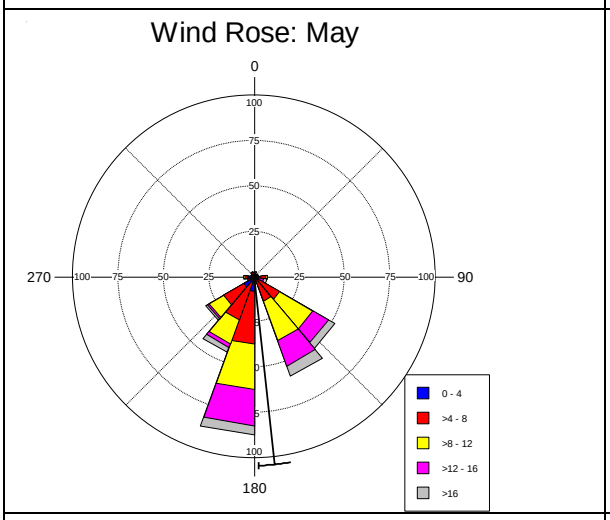
8. The graph of monthwise wind roses prepared with the dayswise data of wind (speed in knots) of last 10 years are shown as:

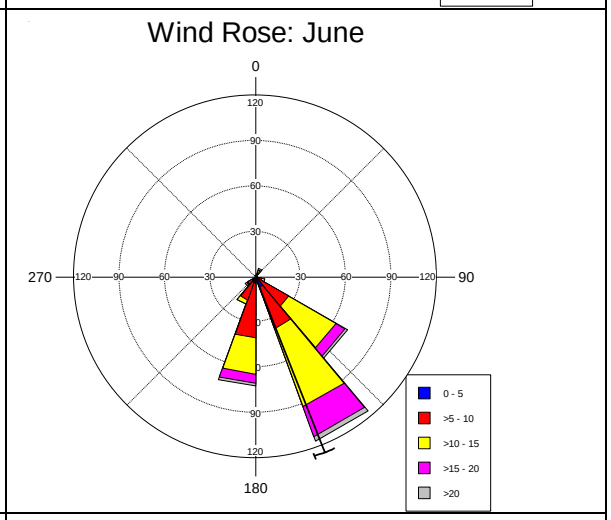


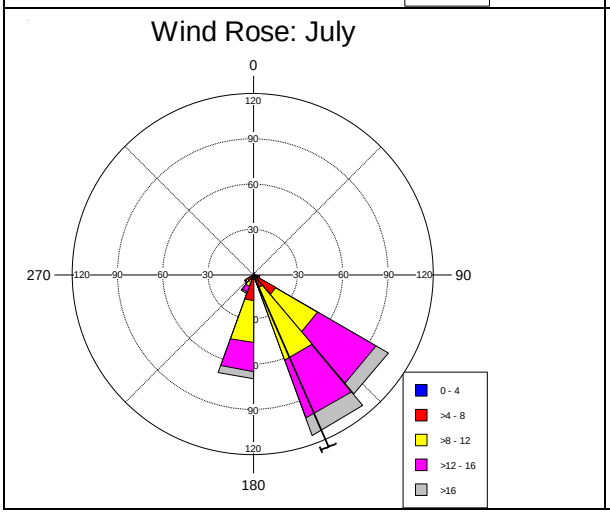


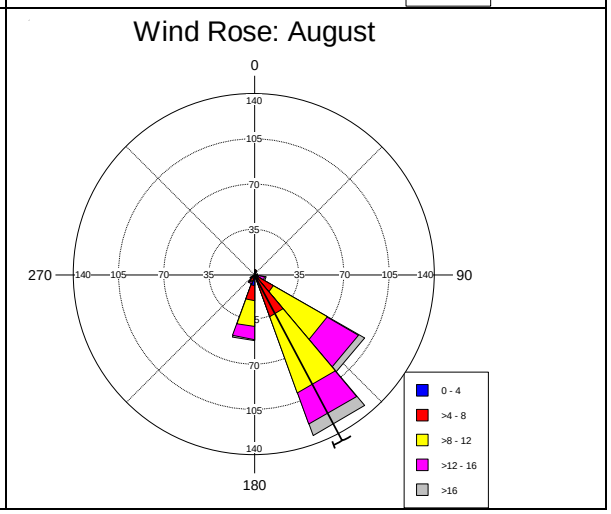

Wind Rose: March
0
90
180
270
0 - 5
>5 - 10
>10 - 15
>15 - 20
>20

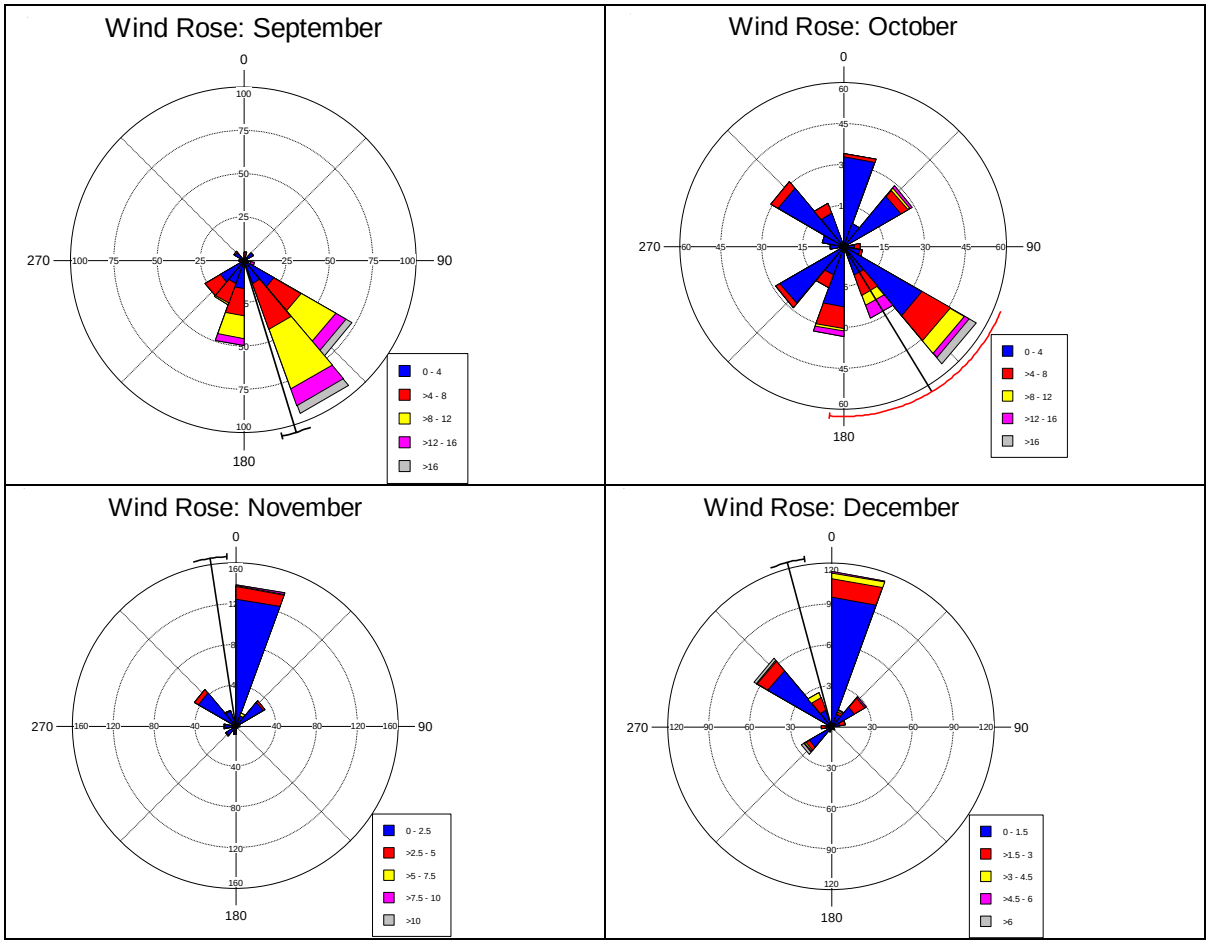

Wind Rose: April
0
90
180
270
0 - 4
>4 - 8
>8 - 12
>12 - 16
>16


Wind Rose: May
0
90
180
270
0 - 4
>4 - 8
>8 - 12
>12 - 16
>16


Wind Rose: June
0
90
180
270
0 - 5
>5 - 10
>10 - 15
>15 - 20
>20


Wind Rose: July
0
90
180
270
0 - 4
>4 - 8
>8 - 12
>12 - 16
>16


Wind Rose: August
0
90
180
270
0 - 4
>4 - 8
>8 - 12
>12 - 16
>16



Forecasting Value

9. We know, the average wind speed can easily be found out by arithmetic mean; and the direction of wind can not be averaged by any statistical method, but by graphical method. Therefore, the wind rose would be an important graph to visualize the wind direction with the frequency which could eventually be used for forecasting of weather and guiding BAF aircrafts for take-of and landing.

Limitation for the Preparation of the Wind Rose

10. The Oriana Software which was used to draw the wind rose was demo version valid for only 30 days. Within limited period of time, only 10 years' data was used for preparing the wind rose. Many of the features of the software could not be explored to optimally utilize the Software. If registered software is used with and available data with different time period of the day and the year to prepare the graph then it would be an excellent forecasting tool for forecasting the weather sea fog, and other weather associated with sea breeze and land breeze.

Use of Wind Rose

11. The wind rose is an important tool for meteorologist to clearly appreciate how wind speed and wind direction are typically distributed at a particular location. The following recommendations may be made after preparing the wind roses:

a. The month wise wind roses for last 10 years or more data may be used to forecast the surface wind of any Airfield.

b. Wind roses may be prepared on the basis of 30 years data or more with different features like different types of diagrams for different time period of day, week etc.

c. The Registered Software may be bought and circulated to all Meteorological Squadrons to plot the wind roses for respective Meteorological Squadrons for operational weather forecast.

d. Wind roses may be displayed both at Meteorological Squadrons to briefing the pilot and reply queries about surface wind, and at Air Traffic Control Tower to facilitate take-off and landing of BAF aircrafts with a view to appreciate the cross-wind component.

e. Wind roses of any Meteorological Squadron may be distributed to other Meteorological Squadrons to know the surface wind pattern of other Bases.

TASK-42 : DIGITAL ATMOSPHERE SOFTWARE

Introduction

1. Digital Atmosphere is a powerful and leading weather forecasting software program. It's powerful and rapidly expanding capabilities will let you monitor developing weather anywhere on earth or in your local area. Digital Atmosphere is essentially geographical display programs that ingest raw weather data and produces stunning plots and analyses of various charts.

2. The map/charts and other products are created with Digital Atmosphere are fully customizable. One can define the geographical area map and specify the map's resolution at his own and choose what weather data want to displayed. Whatever meteorological graphics needs, Digital Atmosphere can create exactly the map you desire, using only the parameters you desire.

Objective

3. The effective use of real time data and analyzed charts of Digital Atmosphere for day to day forecast.

Configuration of Area

4. The Generate Basemap panel is used to generate all **workcharts** from scratch. This is the primary way that new maps for new workchart areas can be created. The only alternate way to create such maps is to right-click on a map and choose **"Recenter map",** the workchart will be adjusted to the new center. Digital Atmosphere offers many different options, to provide the exact map position and scaling factors desired. To set up a map of area of our interest the following steps are to be followed:

a. Go to **Map > Generate**.

b. For **Projection**, choose Orthographic. You should use Orthographic for nearly all of your charts.

c. Set **Latitude** to **22**. The map will be centered on latitude **22** in the northern hemisphere, which is positive.

d. Set **Longitude** to **85** (positive eighty). The map will be centered on longitude **85**.

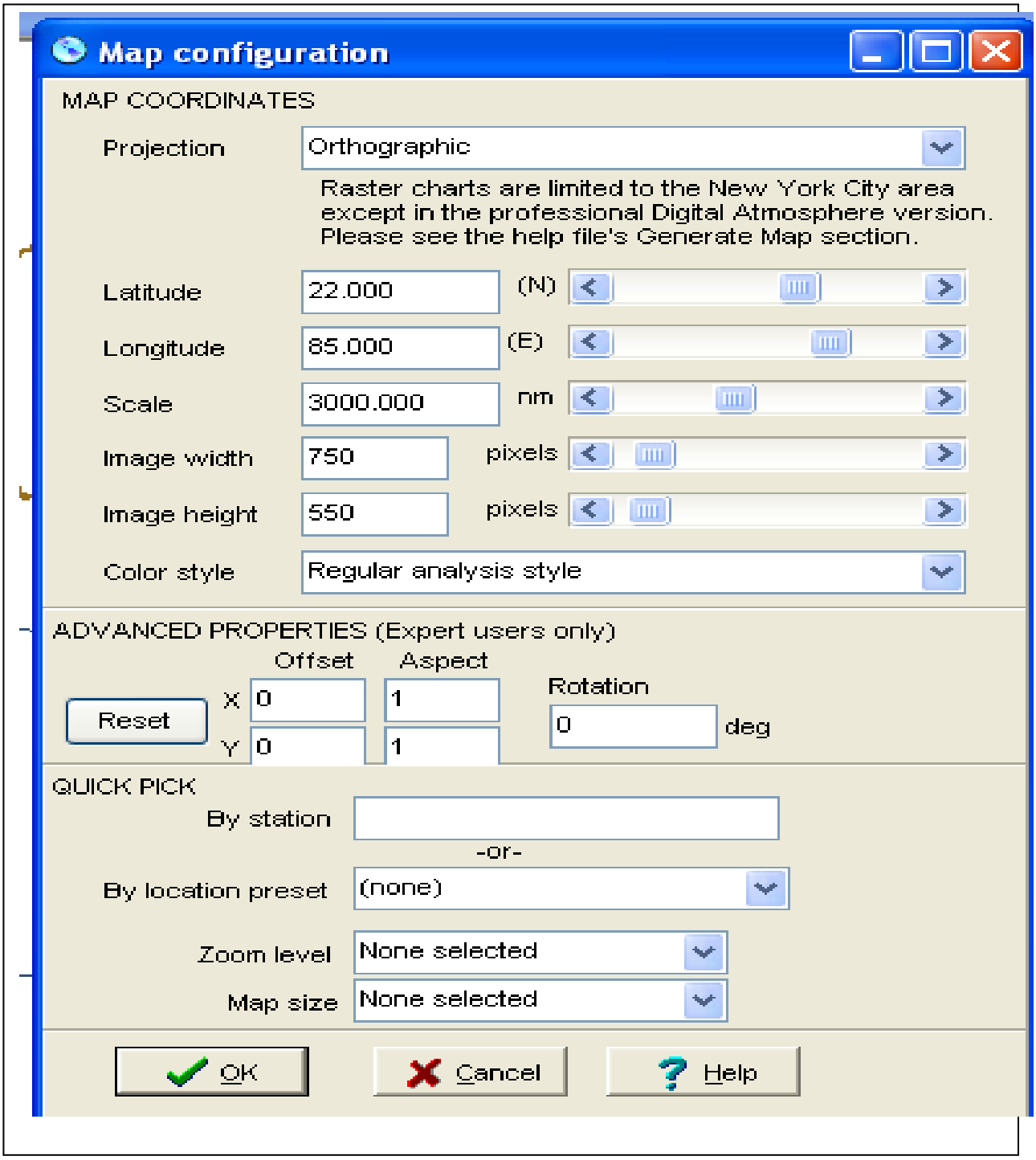
e. Set **Scale** to **3000** miles. The map width, hence, will be **3000** miles.

f. Set **Image Width** to **750** pixels.

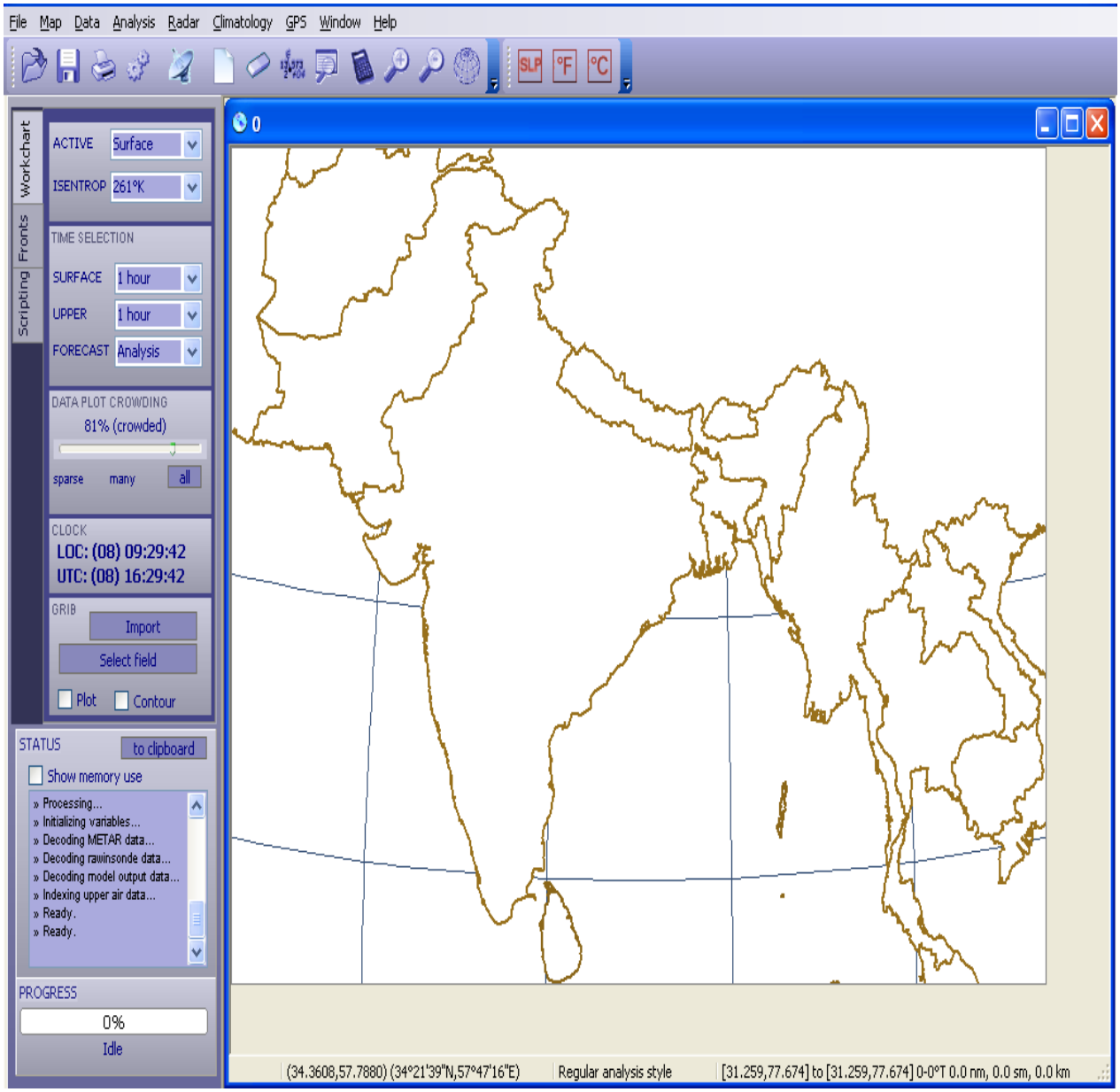
g. Set **Image Height** to **550** pixels.

h. Leave **Color Style** on "**Regular analysis style**". Likewise, make no changes to Advanced Properties.

j. Click **OK** and wait about **10 to 60** seconds while the map draws.



5. Once map coordinates are plotted the following work chart will appear:



Available Features

6. The main menu is where you issue most commands for Digital Atmosphere. This dropdown menu structure works just like most other Windows programs. Each main menu command will be described in the following chapters in this manual, so we won't discuss them in detail at this time.

7. **Main menu**

8. **Speed Buttons.** The speed buttons are provided as a convenient way of accessing frequently-used main menu commands. You can find the meaning of each one by simply resting the cursor on a button (a popup hint will appear). Each button corresponds to a main menu command.

Retrieve of Data

8. Retrieve of raw surface and upper air data is one of unique feature of digital atmosphere. Once you press Retrieve, the chosen products will be downloaded and stored in your data directory. Then you can use File, Import Directory to see the results. To retrieve data the following steps are to be followed:

a. Go to **Data > Retrieve data.** You will see an Internet retrieval panel pop up menu.

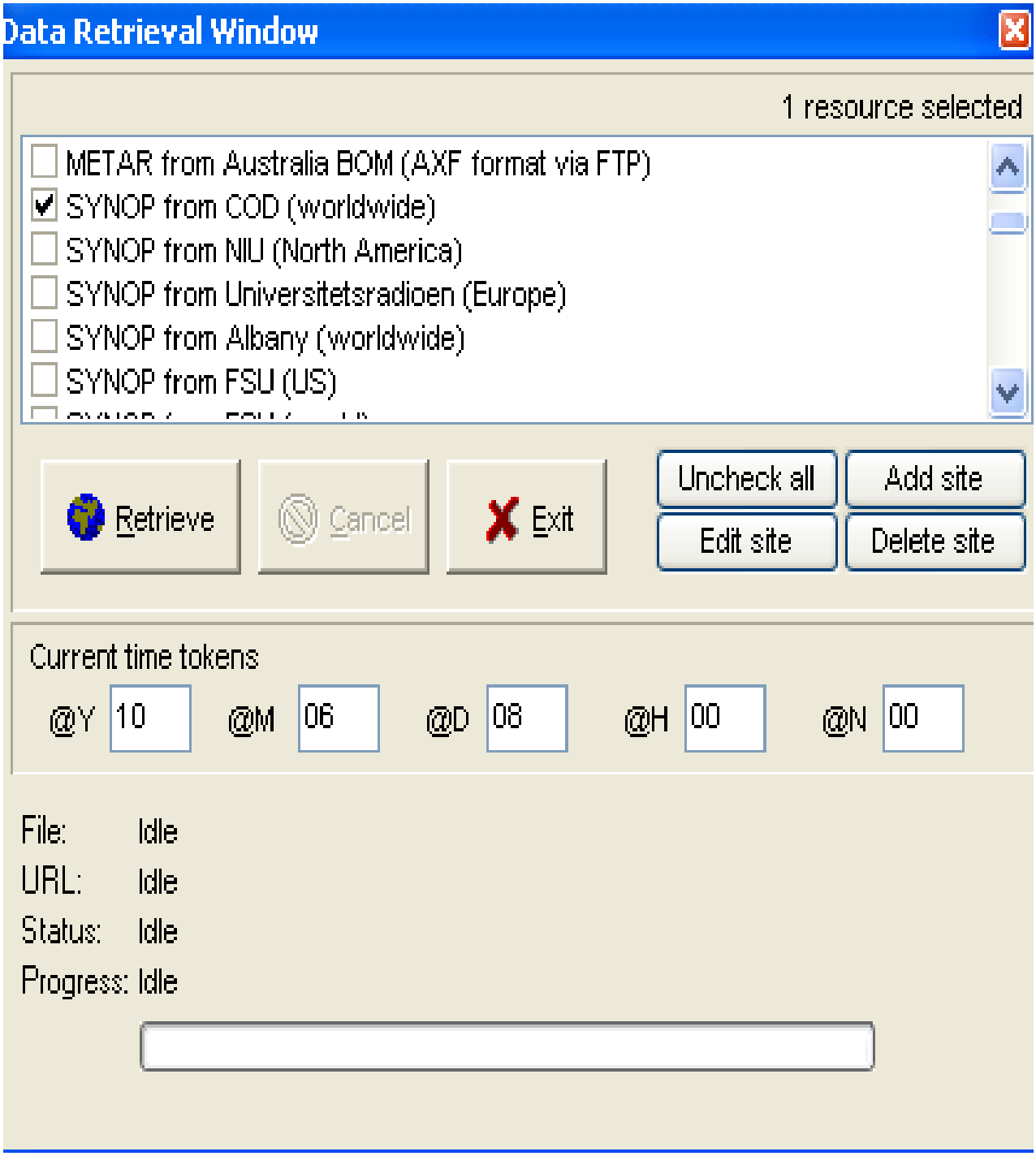
b. Make sure only the following item is checked:
SYNOP from COD (worldwide)

c. At the top right of the panel, it should show "**1 resource selected**". If it shows more than that, see if there are boxes you forgot to uncheck.

d. If you don't know the current **UTC** time, skip this step. If you do, check the **@Y, @M, @D, @H, @N** to see if it shows the correct year, month, day, hour, and minute value, respectively. If the difference is more than 10 minutes, check your Windows time and time zone settings.

e. Click **Retrieve.** Weather data will be retrieved from the College of **Albeny server** and will then be decoded and imported. This will take about **20** seconds on most computers.

9. The following retrieval window will be displayed:



10. **<u>View raw data.</u>**

a. To view raw data select file option, dropdown menu will appear, then select view raw data, all retrieved raw data will be displayed. This panel also a 'Find' option that lets you search for stations and keywords in the file.

11. **Validity of raw data.** Digital Atmosphere is a tool that lets you create weather charts using current raw data. Once you import data into Digital Atmosphere, the program will continue to work only with that data until you perform another import. In other words, the data will still be in Digital Atmosphere if you exit from the program and then run it again later. Once you perform a second import all the data from the first import is deleted and is no longer available.

Archiving of Data and Charts

12. Retrieved data can be archived in a directory/folder and can be imported and utilized for analyzing the charts instantly. Also, analyzed charts can be archived.

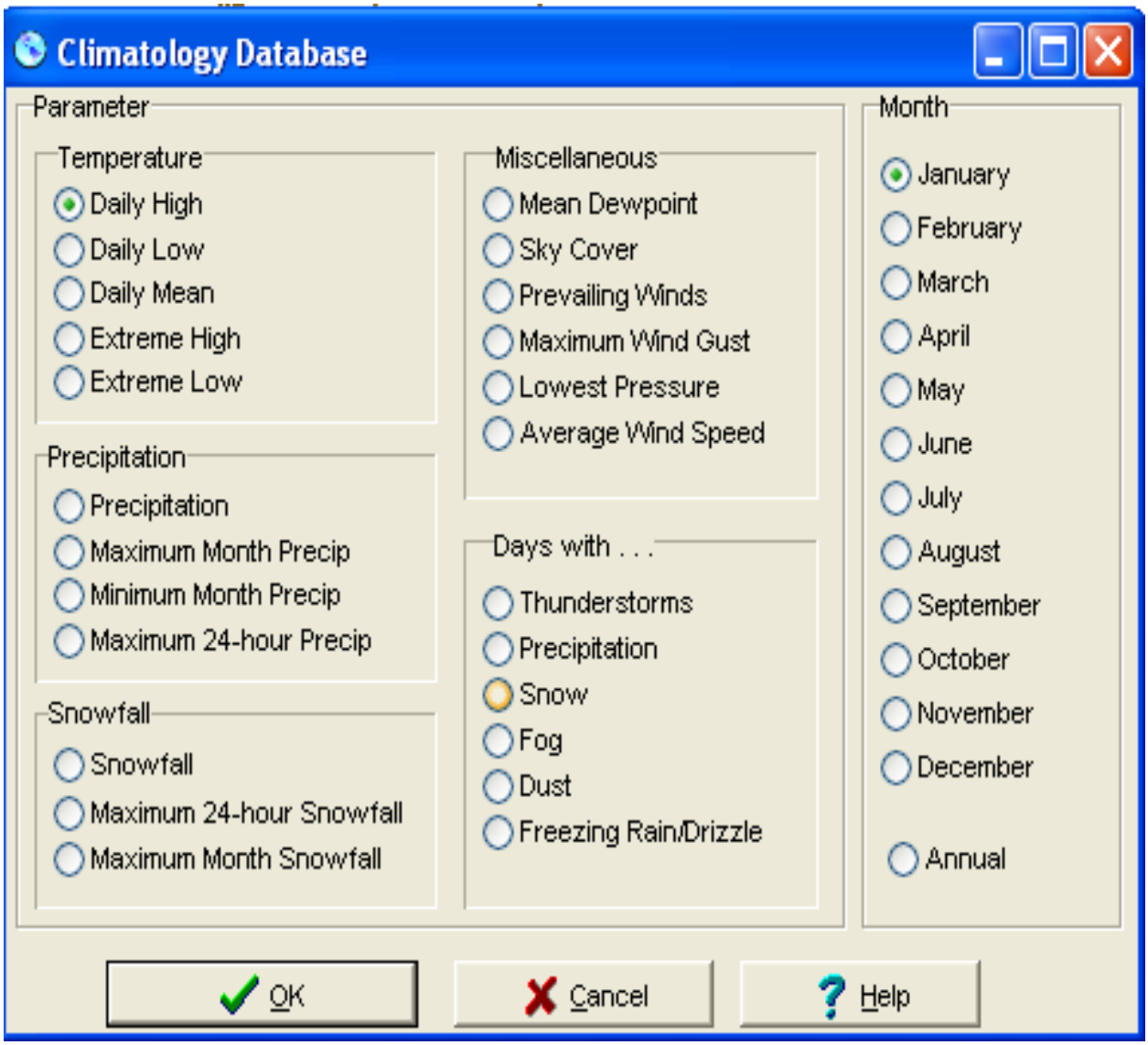
13. **Get Archived data.** If you have the Surface Archives or Upper Archives disc sets from Weather Graphics Technologies, you can use this option to retrieve data on the disc instantly. Digital Atmosphere will decompress and ingest the desired datasets, enabling you to plot maps. Once the “Import” item is selected, the data will be imported. You can then use commands such as Data > Plots and Analysis > Sea Level Pressure to view the data.

Analysis of Data

14. The Analysis commands comprise a powerful tool which can display isobars, isotherms, wind grids, and much more. All imported weather data is examined, objectively analyzed, filtered and smoothed, and then displayed graphically. Beginning with the Workstation series of Digital Atmosphere in 2004, users can now construct their own analysis fields and displays through a highly sophisticated scripting language. Users can also modify the predefined analysis commands available in the Analysis Menu by using Analysis > Edit analysis scripts or by directly editing digatmos.mnu.

Usage of Climatology

15. Digital Atmosphere maintains a database of numerous monthly weather parameters for over 2,000 weather stations across the world. Most of this archive spans a 30-year time period. This data can be viewed on a graph or plotted on your maps. Keep in mind that, as with most other meteorological data, the results may be affected by the observing station’s elevation or proximity to the ocean. This is why you may see significant variations in temperature along a coastal region, among other effects.



Limitations

16 Having various advantages, the Digital Atmosphere has got some limitations:

a. Erroneous data.
b. Scanty data.
c. Some features are not applicable for our area.
d. Internet problem.

Conclusion

17. Digital Atmosphere is a vast software programme. Within this short scope it is quite impossible to touch upon all the available features and yet there are many features need to be learnt in-depth for effective use in our day-to-day forecast. Despite some limitations the Digital Atmosphere one of the most resourceful, effective, user friendly and leading weather software programme.

TASK-43 : CYCLONE TRACK SOFTWARE " CYCLONE ATLAS"

Introduction

1. The Cyclone eAtlas – IMD is a fully menu driven software that could generate Tracks of Cyclones and Depressions that occurred over Indian seas during the period 1891-2007. The software can also generate large volume of statistics in the form of Maps, Charts and Tables on various aspects of Cyclones and Depressions of Indian seas.

2. The software has been developed and released by India Meteorological Department which is the National Weather Service of India and is responsible for monitoring, tracking and forecasting the movement of cyclones and depressions of North Indian Ocean. The development of the software was carried out at the Chennai centre of IMD, viz., Regional Meteorological Centre, Chennai which also distributes the software to the users.

View of Disturbances by Parameters

3. This is the main screen wherein the user passes various parameters and in various combinations to get the desired output. The user has three different type of query option for filtering the data:

a. Basic Options

b. Advanced Options

(1) Advanced Option 1

(2) Advanced Option 2

Display Options

4. The user can choose any one of the options or combinations of the options. But it is Mandatory for the user to invoke the Basic option.

View by Parameters - Invoking the Basic Options

5. On Clicking the NEW INPUT, the screen allows the user to enter his choice. At first, the software prompts the user to select the Basic Option which is mandatory.

a. First Year - Select the FROM Year (beginning Year) of the desired output from the combo box

b. Last Year - Select the TO Year (Ending Year) of the desired output from the combo box

c. First Month - Select the FROM Month (beginning Month) of the desired output from the combo box

d. Last Month - Select the TO Month (Ending Month) of the desired output from the combo box

6. Then Select the Basin where the storm has been formed. The user has the choice of Bay of Bengal or Arabian Sea or Land Area. The user can select ALL of the options or a multiple choice as he desires. The user is prompted to select the Intensity of the CD as Depression or Cyclonic Storm or Severe Cyclonic storm. The user can select all at the same time or a combination as the case may be. On selecting the Basic option, the user can go ahead to see the desired OUTPUT. For viewing the OUTPUT, the user can choose, if he wants to view the storms with markings or without markings.

7. To view the Desired OUTPUT, the user presses the VIEW OUTPUT Button. On clicking, the OUTPUT is displayed in another screen with the India Map.

Save Query

8. Save Query option enables the user to SAVE the existing query with a relevant name, so that he can review on a later date.

View Maps

9. VIEW INDIA MAPS 1 & 2 will display the India Map with the Latitude, Longitude and the Coastal Names.

CLEAR Option

10. CLEAR Option, will clear all the data that has been queried and enables the user to enter other queries of his desire. EXIT will exit / close the form. The desired Output will be as shown below: OUTPUT FORM. After viewing the Map, the user can SAVE the map in any of the Image format like Bitmap, Jpeg or gif. The Map can be saved in a default directory assigned by the software or it can be saved in any of the directories / location specified by the user. If the user requires the Raw DATA, he can export the data to the Text File or Excel File. The user can take a printout of the map through a local printer using the PRINT option.

Zoom-in, Zoom-out

11. The user has the option to view selected storms, Zoom-in, Zoom-out, etc., as explained under the heading “Options Features in the VIEW MAP / VIEW OUTPUT”. Click on EXIT button to exit from the MAP form and to VIEW the query form.

View by Parameters - Invoking the Advanced Option-1

12. The user can further refine his search by invoking the Advanced options. In the Advanced Options, the user has the option to choose one or more options as the case may be.

13. **Advanced Option 1.** The user first selects the Basic option. And on choosing the Advanced Option 1, the user is prompted to enter the following data. The user again has the option to view the C & Ds formed over a particular Latitude and Longitude or the C & Ds dissipated over the particular Latitude and Longitude or BOTH. Say for example, the user wishes to select both the options, the selection screen would look like as shown below:

a. When user selects the Formed Over option, the software allows the user to select the Longitude and latitude values.

b. The user selects the FROM and TO co-ordinates of the Latitude and Longitude of the CD that has formed over the particular region.

c. When user selects the Dissipated Over option, the software allows the user to select the Longitude and Latitude values. The user selects the FROM and TO co-ordinates of the Longitude and Latitude of the CD that has dissipated over the particular region. The user has the option to select the various Basins over which the CD has formed. The user can select one or multiple Basins as desired. The user has the option to view the OUTPUT with or without marking on the Map. After selecting all these options, the user can view the OUTPUT by pressing VIEW OUTPUT.

Save Query Option

14. Save Query option enables the user to SAVE the existing query with a relevant name, so that he can review on a later date. VIEW INDIA MAP will display the India Map with the Latitude, Longitude and the Coastal Names. CLEAR Option, will clear all the data that has been queried and enables the user to enter other queries of his desire.

Exit

15. EXIT will exit / close the form. The OUTPUT will be as shown in the following para.

Output Form

16. After viewing the Map, the user can SAVE the map in any of the Image format like Bitmap, Jpeg or gif. The Map can be saved in a default directory assigned by the software or it can be saved in any of the directories / location specified by the user. If the user requires the Raw DATA, he can export the data to the Text File or Excel File. The user can take a printout of the map through a local printer using the PRINT option. The user has the option to view selected storms, Zoom-in, Zoom-out, etc., as explained under the heading “Options Features in the VIEW MAP / VIEW OUTPUT”. Click on EXIT button to exit from the MAP form and to VIEW the query form.

View by Parameters - Invoking the Advanced Option-2

17. **"SEA TO LAND" Option.** Choosing the Basic option is mandatory for selection of the Advanced option-2. On clicking the Advanced option 2, the corresponding fields in the Option-2, tab is opened for the user to select or enter his choice. In the Advanced option-2, the user has again two choices to select his desired view. The user can select to view the storms that are crossing the "SEA TO LAND" or storms crossing from "LAND TO SEA". In both of these options, the user can select the already defined coastal belts or enter the Latitude and Longitude of the desired location. The user can select all the names in the coastal belt or can choose any number of desired coastal areas. On clicking the "Long & Latt" option, the user is allowed to enter his desired FROM and TO Latitude and Longitude of the location he desires to view. He can also give a name for the coastal Belt he desired to view by entering a name in the "Enter the Coastal strip Name". The user can view the desired OUTPUT with or without marking. After making all his selections, the user presses the VIEW OUTPUT, to view the output on the map. The Map output will be displayed as shown below:

a. SAVE QUERY option enables the user to SAVE the existing query with a relevant name, so that he can review on a later date.

b. VIEW INDIA MAP will display the India Map with the Latitude, Longitude and the Coastal Names.

c. CLEAR Option, will clear all the data that has been queried and enables the user to enter other queries of his desire. EXIT will exit / close the form.

Output Form

18. After viewing the Map, the user can SAVE the map in any of the Image format like Bitmap, Jpeg or gif. The Map can be saved in a default directory assigned by the software or it can be saved in any of the directories / location specified by the user. If the user requires the Raw DATA, he can export the data to the Text File or Excel File. The user can take a printout of the map through a local printer using the PRINT option. The user has the option to view selected storms, Zoom-in, Zoom-out, etc., as explained under the heading "Options Features in the VIEW MAP / VIEW OUTPUT". Click on EXIT button to exit from the MAP form and to VIEW the query form. The output shows two display boxes, one on the top left corner of the map and one at the top right corner of the map. On the top left corner of the map, the users query parameters are shown for the users reference. On the top right corner of the map, the desired output statistics are shown. (like the Month, Period, No of storms, the type of intensity and the system intensity)

View by Parameters - Invoking the Advanced Option-2

19. **"LAND TO SEA" Option**. The user has the option to select and view the storms crossing from "LAND TO SEA" Option. In this option, after selecting the Basic Option, the user clicks on the Advanced option-2 box. The usercan see all the storms crossing from "LAND TO SEA", by choosing the "Coastal Belt" option or "Long & Latt" option. On clicking the "Long & Latt" option, the user is allowed to enter his desired FROM and TO Latitude and Longitude of the location he desires to view. He can also give a name for the coastal Belt he desired to view by entering a name in the "Enter the Coastal strip Name". The user has the option to view his desired OUTPUT Display with or without Marking on the Map. On pressing the "VIEW OUTPUT" button the desired output is displayed as shown below.

a. SAVE QUERY option enables the user to SAVE the existing query with a relevant name, so that he can review on a later date.

b. VIEW INDIA MAP will display the India Map with the Latitude, Longitude and the Coastal Names.

c. CLEAR Option, will clear all the data that has been queried and enables the user to enter other queries of his desire. EXIT will exit / close the form.

Output Form

20. After viewing the Map, the user can SAVE the map in any of the Image format like Bitmap, Jpeg or gif. The Map can be saved in a default directory assigned by the software or it can be saved in any of the directories / location specified by the user. If the user requires the Raw DATA, he can export the data to the Text File or Excel File. The user can take a printout of the map through a local printer using the PRINT option. The user has the option to view selected storms, Zoom-in, Zoom-out, etc., as explained under the heading “Options Features in the VIEW MAP / VIEW OUTPUT” Click on EXIT button to exit from the MAP form and to VIEW the query form. The output shows two display boxes, one on the top left corner of the map and one at the top right corner of the map. On the top left corner of the map, the users query parameters are shown for the users reference -On the top right corner of the map, the desired output statistics are shown. (like the Month, Period, No of storms, the type of intensity and the system intensity)

Features in the View Map / View Output Screen

21. **Display of Storms**. Depression - is represented by dotted lines eg., Cyclone Storm - is represented by thin lines eg. Severe Cyclone Stone - is represented by thick lines eg.

22. **Display of Query.** The query is displayed in a 50 display grid with Longitude and Latitude markings. Moving the mouse, will display the current Longitude and Latitude position on the Map as seen in the picture. Eg., (68.3, 24.1) All the details of the query and the number of CD OUTPUT is denoted on the TOP RIGHT extreme corner.

Marking on the Storm

23. In the staring point of the storm the Month and year of the formation of the CD is displayed. In the circles 03 UTC and the Date is shown. The arrow indicates the direction of the storm at the time of the dissipation. Menu option on the Map. The menu has 4 options namely SAVE , PRINT, C & D and EXIT.

Save

24. The user has the option to save the Map in any of the Image format desired by the user. He can choose the desired location on the computer to save or the software automatically directs him to a default location. The user can save the query details in a EXCEL format or the user can save the query details in a TEXT format.

Print

25. The user has the option to print the OUTPUT to any default printer connected to the computer in Landscape or in Portrait format.

Cyclone & Depression

26. In the C & D option, the user can view the tracks of C & D displayed in various formats. The user has the option to select only few of the total C & D in the Output and display them. (as shown in the picture). After viewing the selection, if the user wishes to see all the storms that was originally queried, then he can choose “View all C & Ds”. The software will display all the C & Ds.

Display

27. If the user wishes to see a magnified view of the Map then, he can just double click on the Map. The Map will be in the magnifying mode and the user can scroll and view the C & Ds better and magnified. If the user wants to view the normal view of the Map, then he can choose the “Normal Display” option from the C & D menu. On pressing the EXIT option, the Map form will be closed.

View by Identifiers

28. In this screen, the user can view the DATA of a given particular Identifier. In order to locate the desired Identifier, a search option with multiple criteria is provided. The user can search for the desired Identifier by Year / Month / Season etc. The user selects the criteria from the “SEARCH BY” combo box. Then enters the relevant search sting in the “SEARCH KEYWORD” field and clicks on “OK” button to view the desired DATA. For Example, if the user selects the “SEARCH BY” criteria as “YEAR”. He will have to enter the desired year such as “1987” as shown in the picture. And on clicking the OK Button, the software displays the desired or matched DATA. The software displays all the Identifiers in the YEAR – 1987. Now the user can select the desired Identifier by clicking on the left grid, where the Identifier is located. The software displays the selected Identifier in the box below.

29. Click on the “DETAIL” button to get all the DATA (CD Details) relating to the particular Identifier. The user can scroll down to see all the rows for the particular Identifier. On Clicking the VIEW Button, the software displays the Map with the CD plotted on it as shown below.

30. CLEAR Option, will clear all the data that has been queried and enables the user to enter other queries of his desire. EXIT will exit / close the “VIEW BY IDENTIFIERS” form.

Output Form

31. After viewing the Map, the user can SAVE the map in any of the Image format like Bitmap, Jpeg or gif. The Map can be saved in a default directory assigned by the software or it can be saved in any of the directories / location specified by the user. If the user requires the Raw DATA, he can export the data to the Text File or Excel File. The user can take a printout of the map through a local printer using the PRINT option. The user has the option to view selected storms, Zoom-in, Zoom-out, etc., as explained under the heading “Options Features in the VIEW MAP / VIEW OUTPUT” Click on EXIT button to exit from the MAP form and to VIEW the query form.

Statistical Reports

32. **Monthly Frequency of C & Ds:** This SCREEN helps the user to view the Monthly Frequency of the three different kinds of C & Ds (Depression / Cyclone storm / Severe Cyclone Storm) over the range of years and for a particular month or for a range of months:

a. From Year - Select the Beginning year of the desired output from the combo

b. To Year - Select the Ending year of the desired output from the combo

c. From Month - Select the Beginning Month of the desired output from the combo

d. To Month - Select the Ending Month of the desired output from the combo

33. After making the query choices, click on the VIEW Button, to view the number of frequencies on the Map. The user can Click on RESET Button, to clear the selection. The user can again re-query his desired option. On pressing EXIT Button, the current form closes. The OUTPUT of the Query will be displayed as shown under.

Output Form

34. The OUPUT is displayed in the 2 ½ x 2 ½0 Lon / Lat Grid. The number indicates the number of frequencies of disturbances that has Formed or Dissipated as per the user choice. Three types of DATA can be read from each of the 2 ½0 Grid.

35. The number on top of the each 2 ½0 grid box denotes – the number of frequency with a combination of Depression + Cyclone Storm + Severe Cyclone Storm

36. The number on Middle of the each 2 ½0 grid box denotes – the number of frequency with a combination of Cyclone Storm + Severe Cyclone Storm

37. The number on Bottom of the each 2 ½0grid box denotes – the number of frequency of Severe Cyclone Storm

38. If there is a Blank, then it indicates that there were no corresponding values of C & D in that category. The OUPUT is displayed in the 2 ½ Grid. The number indicates the number of frequencies of disturbances.

39. After viewing the Map, the user can SAVE the map in any of the Image format like Bitmap, Jpeg or gif. The Map can be saved in a default directory assigned by the software or it can be saved in any of the directories / location specified by the user. If the user requires the Raw DATA, he can export the data to the Text File or Excel File. The user can take a printout of the map through a local printer using the PRINT option. The user has the option to view selected storms, Zoom-in, Zoom-out, etc., as explained under the heading “Options Features in the VIEW MAP / VIEW OUTPUT”. Click on EXIT button to exit from the MAP form and to VIEW the query form Monthly Frequency of Formation and Dissipation. This SCREEN helps the user to view the Frequency of the C & Ds.

40. Formed or Dissipated over the range of years and for a particular season or for a particular month. From Year - Select the Beginning year of the desired output from the combo:

a. TO Year - Select the Ending year of the desired output from the combo

b. From Month - Select the Beginning Month of the desired output from the combo

c. To Month - Select the Ending Month of the desired output from the combo

41. The user can view either the Formation or the Dissipation of the C & Ds by clicking the option button. After making the query choices, click on the VIEW Button, to view the number of frequencies on the Map. The user can Click on RESET Button, to clear the selection. The user can again re-query his desired option. On pressing EXIT Button, the current form closes. The OUTPUT of the Query will be displayed as shown under.

Output Form

42. The OUPUT is displayed in the 2 ½ x 2 ½ 0 Lon / Lat Grid. The number indicates the number of frequencies of C & Ds that has Formed or Dissipated as per the user choice. Three types of DATA can be read from each of the 2 ½ Grid.

43. The number on top of the each 2 ½ grid box denotes –frequency of DEPRESSIONS

44. The number on Middle of the each 2 ½ grid box denotes –frequency of CYCLONE STORM

45. The number on Bottom of the each 2 ½ grid box denotes –frequency of SEVERE CYCLONE STORM.

46. If there is a Blank, then it indicates that there were no corresponding frequency in that category. The OUPUT is displayed in the 2 ½ Grid. The number indicates the number of frequencies of C & Ds. After viewing the Map, the user can SAVE the map in any of the Image format like Bitmap, Jpeg or gif. The Map can be saved in a default directory assigned by the software or it can be saved in any of the directories / location specified by the user. If the user requires the Raw DATA, he can export the data to the Text File or Excel File. The user can take a printout of the map through a local printer using the PRINT option. The user has the option to view selected storms, Zoom-in, Zoom-out, etc., as explained under the heading “Options Features in the VIEW MAP / VIEW OUTPUT”. Click on EXIT button to exit from the MAP form and to VIEW the query form STATISTICAL REPORTS

Direction of Movement

47. This option helps the user to determine the direction of the movement of the C & D between two given years and between two Months. The user selects the desired period range from the “FROM YEAR” and “TO YEAR”. The user can select the same year, say for example “FROM YEAR”- 1991 and “TO YEAR” – 1991, if he wishes to view the storm for one particular year only. If he wishes to view for a multiple years, he can do so by giving a range of Years. The user can select the range of Months that he wishes to see for the selected YEAR. After selecting the criteria, he can click on VIEW Button to view the desired OUTPUT in the MAP format as seen below:

48. The user can Click on RESET Button, to clear the selection. The user can again re-query his desired option. On pressing EXIT Button, the current form closes. For example, if the user has selected a query such as FROM YEAR: 1991 and TO YEAR: 2005 and FROM MONTH: June and TO MONTH: September. The display will be as shown below:

Output Form

49. After viewing the Map, the user can SAVE the map in any of the Image format like Bitmap, Jpeg or gif. The Map can be saved in a default directory assigned by the software or it can be saved in any of the directories / location specified by the user. If the user requires the Raw DATA, he can export the data to the Text File or Excel File. The user can take a printout of the map through a local printer using the PRINT option. The user has the option to view selected storms, Zoom-in, Zoom-out, etc., as explained under the heading “Options Features in the VIEW MAP / VIEW OUTPUT”. Click on EXIT button to exit from the MAP form and to VIEW the query form STATISTICAL REPORTS

Scalar and Vector Mean Speed of Disturbances

50. From this SCREEN, the user can computer the Scalar and Vector Mean Speed of the C & Ds over a given period of Years and over a given period of Months. From Year - Select the Beginning year of the desired output from the combo:

a. To Year - Select the Ending year of the desired output from the combo

b. From Month - Select the Beginning Month of the desired output from the combo

c. To Month - Select the Ending Month of the desired output from the combo

51. After making the query choices, click on the VIEW Button, to view the Vector and Scalar Speed of the disturbances on the Map. The user can click on RESET Button, to clear the selection. The user can again re-query his desired option. On pressing EXIT Button, the current form closes. The OUTPUT of the Query will be displayed as shown under.

a. **Output Form.** The OUPUT is displayed in the 2 ½ x 2 ½ 0 Lon / Lat Grid. The number indicates the Direction of Motion, the Vector Speed and Scalar Speed of the CD for the given period of Years and Month. Three types of DATA can be read from each of the Grid.

(1) The number on top of the each 2 ½ grid box denotes the Direction of Motion in Degrees.

(2) The number on Middle of the each 2 ½ grid box denotes Vector Speed in KMPH

(3) The number on Bottom of the each 2 ½ grid box denotes Scalar Speed in KMPH

(4) If there is a Blank, then it indicates that there were no corresponding values of CD in that category. The OUPUT is displayed in the 2 ½ Grid. The number indicates the number of frequencies of C & Ds.

52. After viewing the Map, the user can SAVE the map in any of the Image format like Bitmap, Jpeg or gif. The Map can be saved in a default directory assigned by the software or it can be saved in any of the directories / location specified by the user. If the user requires the Raw DATA, he can export the data to the Text File or Excel File. The user can take a printout of the map through a local printer using the PRINT option. The user has the option to view selected storms, Zoom-in, Zoom-out, etc., as explained under the heading “Options Features in the VIEW MAP / VIEW OUTPUT”. Click on EXIT button to exit from the MAP form and to VIEW the query form STATISTICAL REPORTS.

Frequency of Re-Curvature of Disturbances

53. This screen helps to determine the number of disturbances that had re-curved towards North Eastern direction for a particular period, Basin and formed over the given Latitude and Longitude positions. From Year - Select the Beginning year of the desired output from the combo:

a. To Year - Select the Ending year of the desired output from the combo

b. From Month - Select the Beginning Month of the desired output from the combo

c. To Month - Select the Ending Month of the desired output from the combo Basin - The user has the option to choose ALL the basins or a combination of the basins (BOB – Bay of Bengal or AS – Arabian Sea or Land) Formed Over Longitude - Enters the FROM Longitude and TO Longitudes of the desired coordinates

d. Latitude - Enters the FROM Latitude and TO Latitudes of the desired coordinates

54. After making the query choices, click on the VIEW Button, to view the number of C & Ds on the Map. The user can click on RESET Button, to clear the selection. The user can again re-query his desired option. On pressing EXIT Button, the current form closes. The OUTPUT of the Query will be displayed as shown under.

Output Form

55. The OUPUT is displayed in the 2 ½0 Grid. The number indicates the number of C & Ds that has re-curved in the direction as per the user choice. The OUPUT is displayed in the 2 ½ Grid. The number indicates the number of frequencies of C & Ds. After viewing the Map, the user can SAVE the map in any of the Image format like Bitmap, Jpeg or gif. The Map can be saved in a default directory assigned by the software or it can be saved in any of the directories / location specified by the user. If the user requires the Raw DATA, he can export the data to the Text File or Excel File. The user can take a printout of the map through a local printer using the PRINT option. The user has the option to view selected storms, Zoom-in, Zoom-out, etc., as explained under the heading "Options Features in the VIEW MAP / VIEW OUTPUT". lick on EXIT button to exit from the MAP form and to VIEW the query form:

Statistical Reports of Disturbances Crossing the Coast Between two Stations

56. From this option, the user can attain the number of frequency of C & Ds that has crossed the coast between two given Latitude and Longitude points or stations. The user selects the desired query from the combo boxes as detailed below:

a. From Year - Select the Beginning year of the desired output from the combo

b. To Year - Select the Ending year of the desired output from the combo

c. From Month - Select the Beginning Month of the desired output from the combo

d. To Month - Select the Ending Month of the desired output from the combo

e. Basin - The user has the option to choose ALL the basins or a combination of the basins (BOB – Bay of Bengal or AS – Arabian Sea or Land) Formed Over

f. Latitude - Enters the FROM Latitude and TO Latitudes of the desired coordinates

g. Longitude - Enters the FROM Longitude and TO Longitudes of the desired coordinates

h. Intensity Type - The user has the option to select and intensity Type as Maximum or At Crossing

j. Intensity Options - Select any one of the Intensity option such as (D+CS+SCS or CS+SCS or SCS)

57. On selecting the desired query options, click on VIEW button to view the desired OUTPUT. The OUTPUT will be displayed in the MAP as shown below:

a. The user can Click on RESET Button, to clear the selection. The user can again re-query his desired option.

b. On pressing EXIT Button, the current form closes.

Output Form

58. The OUPUT is displayed as shown in the above figure. The number indicates the number of frequencies of C & Ds that has crossed the coastal stretch between the two marked stations. After viewing the Map, the user can SAVE the map in any of the Image format like Bitmap, Jpeg or gif. The Map can be saved in a default directory assigned by the software or it can be saved in any of the directories / location specified by the user. If the user requires the Raw DATA, he can export the data to the Text File or Excel File. The user can take a printout of the map through a local printer using the PRINT option. The user has the option to view selected storms, Zoom-in, Zoom-out, etc., as explained under the heading “Options Features in the VIEW MAP / VIEW OUTPUT”. Click on EXIT button to exit from the MAP form and to VIEW the query form STASTICAL REPORTS FREQUENCY OF C & Ds – BY TABLE. This SCREEN helps the user to get Vital statistics of the Frequencies of C & Ds over a period of Years, Various Basins and Intensity. The user has the option to view the statistics BY MONTH or BY SEASON. The same query OUTPUT can be viewed as a TABLE DATA or a BAR DIAGRAM. From Year - Select the Beginning year of the desired output from the combo:

a. To Year - Select the Ending year of the desired output from the combo

b. Basin - The user has the option to choose ALL the basins or a combination of the basins (BOB – Bay of Bengal or AS – Arabian Sea or Land)

c. Intensity Options - Select any one of the Intensity option such as Depression or Cyclonic Storm orSevere Cyclonic Storm or ALL

59. The user has the option to view his OUTPUT - BY SEASON or BY MONTH. If the user wishes to get the desired DATA in Table format, Select the option TABLE in the Radio Button. After making the query choices, click on the VIEW Button, to view the desired OUTPUT in Table format. The user can click on RESET Button, to clear the selection. The user can again re-query his desired option. On pressing EXIT Button, the current form closes. The OUTPUT of the Query will be displayed as shown under.

Output Form

60. The User can SAVE the DATA by clicking the SAVE Option. Click on EXIT to exit from the form. STATISTICAL REPORTS FREQUENCY OF C & Ds – BAR DIAGRAM. This SCREEN helps the user to get Vital statistics of the Frequencies of Disturbances over a period of Years, Various Basins and Intensity. The user has the option to view the statistics BY MONTH or BY SEASON. The same query OUTPUT can be viewed as a TABLE DATA or a Bar Diagram.

a. From Year - Select the Beginning year of the desired output from the combo

b. To Year - Select the Ending year of the desired output from the combo

c. Basin - The user has the option to choose ALL the basins or a combination of the basins (BOB – Bay of Bengal or AS Arabian Sea or Land)

d. Intensity Options - Select any one of the Intensity option such as Depression or Cyclonic Storm or Severe Cyclonic Storm or ALL. The user has the option to view his OUTPUT - BY SEASON or BY MONTH.

61. If the user wishes to get the desired DATA in as a Histogram format, Select the option Bar Diagram in the Radio Button. Select the month for which the Bar Diagram is to be drawn from the Combo named “Month”. After making the query choices, click on the VIEW Button, to view the desired OUTPUT in Excel Graph format. The user can click on RESET Button, to clear the selection. The user can again re-query his desired option.
On pressing EXIT Button, the current form closes. The OUTPUT of the Query will be displayed as shown under. As the graph is shown in the Excel sheet, all the properties like printing, changing color, Zooming, saving the graph to another file, saving as an Image file, Exporting etc can be done to the graph. The DATA with which the graph has been created is given in the excel sheet named “DATA” in the same excel file as seen the above picture.

Statistical Reports – in Table Monthly / Seasonal Variation Of C & Ds

62. This SCREEN helps the user to get statistics relating to the Monthly or Seasonal Variation of Frequencies of Disturbances over a period of Years and Various Basins. The user has the option to view the statistics BY MONTH or BY SEASON. The same query OUTPUT can be viewed as a TABLE DATA or a Bar Diagram. From Year - Select the Beginning year of the desired output from the combo:

a. To Year - Select the Ending year of the desired output from the combo

b. Basin - The user has the option to choose ALL the basins or a combination of the basins (BOB – Bay of Bengal or AS – Arabian Sea or Land)

63. The user has the option to view his OUTPUT - BY SEASON or BY MONTH. If the user wishes to get the desired DATA in Table format, Select the option TABLE in the Radio Button. After making the query choices, click on the VIEW Button, to view the desired OUTPUT in Table format. The user can click on CLEAR Button, to clear the selection. The user can again re-query his desired option. On pressing EXIT Button, the current form closes. The OUTPUT of the Query will be displayed as shown under.

Output Form

64. The OUTPUT can be saved to a text or EXCEL file by clicking on the SAVE Option. Click on the EXIT button to close the form.

Statistical Reports Monthly / Seasonal Variation of C & Ds – By Bar Diagram

65. This SCREEN helps the user to get statistics relating to the Monthly or Seasonal Variation of Frequencies of C & Ds over a period of Years and Various Basins. The user has the option to view the statistics BY MONTH or BY SEASON. The same query OUTPUT can be viewed as a TABLE DATA or a Bar Diagram. From Year - Select the Beginning year of the desired output from the combo:

a. To Year - Select the Ending year of the desired output from the combo

b. Basin - The user has the option to choose ALL the basins or a combination of the basins (BOB – Bay of Bengal or AS – Arabian Sea or Land)

66. The user has the option to view his OUTPUT - BY SEASON or BY MONTH. If the user wishes to get the desired DATA in as a Bar Diagram, Select the option Bar Diagram in the Radio Button. The user can further get more details by clicking his choice as FREQUENCY or PERCENTAGE FREQUENCY or as a PROBABILITY. Further Choose the combination intensity the user wishes to view. He can select combination such as D+CS+SCS or CS+SCS or only SCS from the combo. After making the query choices, click on the VIEW Button, to view the desired OUTPUT in HISTOGRAM format. The user can click on RESET Button, to clear the selection. The user can again re-query his desired option. On pressing EXIT Button, the current form closes. The OUTPUT of the Query will be displayed as shown under.

Output Form

67. As the graph is shown in the Excel sheet, all the properties like printing, changing color, Zooming, saving the graph to another file, saving as an Image file, Exporting etc can be done to the graph. The DATA with which the graph has been created is given in the excel sheet named “DATA” in the same excel file as seen the above picture.

Statistical Reports Table View Of Consolidated Listing of The C & Ds

68. From this option, the user can see all the C & Ds for a particular give year in a Table format. The user chooses the FROM YEAR and TO YEAR from the combo box. The user clicks on VIEW Button to all view the C & Ds in the Table format. On viewing the out put the user has the option to save the output in a text format or to an excel file. The user can Click on RESET Button, to clear the selection. The user can again re-query his desired option. On pressing EXIT Button, the current form closes. For example, if the user has selected a query such as FROM YEAR : 1891 and TO YEAR : 2005. The isplay will be as shown below:

Output Form

69. The user can SAVE the DATA in text or excel format. Click on EXIT to close the form.

System Requirements

70. Recommended minimum hardware environment :

a. Processor : Intel Pentium IV

b. Speed : 2.O0 GHz and above

c. Base memory : 256 MB and above

d. External disk drive : CD Drive
e. Hard disk drive : 15 GB and higher

f. Keyboard : 108 keys keyboard

g. Mouse : Two button

h. Monitor : 17” color monitor

j. Operating System : Windows 2000 and Higher

k. Packages : MS office suite 2000 or higher