MET 1 – THE ATMOSPHERE

CONVERSION FACTORS

- 1 nm = 6080 ft = 1.852 km
- 1 m = 3.28 ft (x3, + 10%)

COMPOSITION

- Atmosphere has no specific upper limit.
- Nitrogen (N_2) 78%
- Oxygen (O_2) 21%
- Argon (A) 0.93%
- Carbon Dioxide (CO_2) 0.03%

- Hydrogen (H) Trace
- Ozone (O_3) Filters and absorbs UV
- Water Vap (H_2O) Gas state of water
- Solid particles Pollution*

- Concentration % of gases remains constant with the exception of water vapour which decreases with altitude.

VARIATIONS WITH HEIGHT

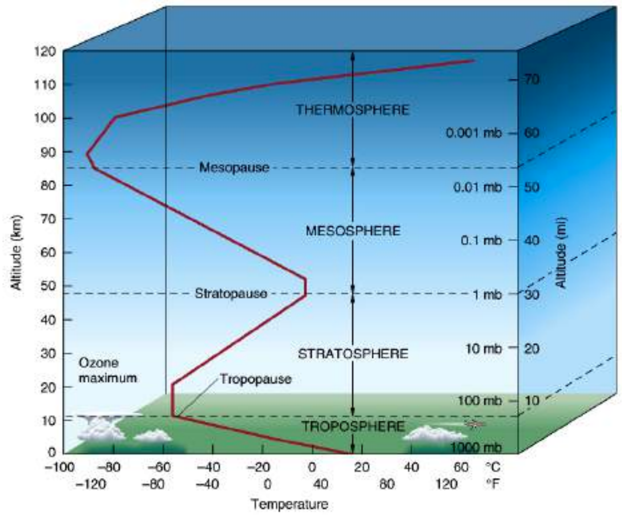
- Pressure decreases with height.
- Density decreases with height.
- Temperature varies with height.

ATMOSPHERIC PROPERTIES

- Air is a poor conductor of heat.
- The gases within the atmosphere obey the gas laws.

LAPSE RATES

- Normal +ve lapse rate. (Decreases approx 2^0C / 1000ft)
- Surface inversion, -ve lapse rate.
- Inversion aloft, +ve lapse rate
- Isothermal (no change with altitude)



TRPOPOSPHERE

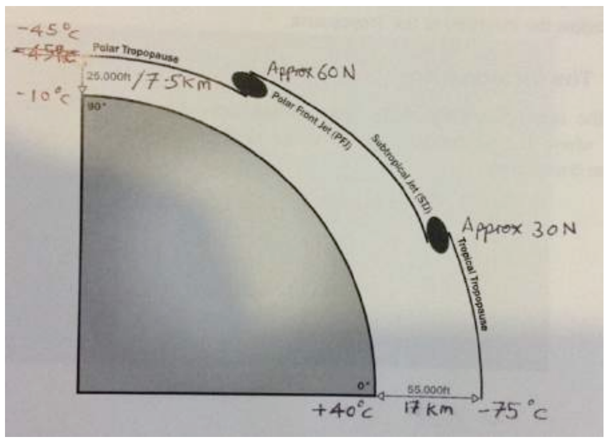
- Almost all water vapour within the atmosphere is contained here and hence this is where most of the weather occurs.
- +ve lapse rate

TROPOPAUSE

- Separates troposphere from stratosphere
- Marks the point where temperature stops falling (average -56.5 / 11km (36,000ft).
- Height varies with temperature.
- At poles: 25,000 ft / 7.5 km / Surface -10^0C / Tropo Temp -45^0C
- Equator: 55,000ft / 17 km / Surface $+40^0$C / Tropo Temp -75^0C
- The 'steps' in the tropopause give rise to strong upper winds (jet sreams)
- Higher in summer compared to winter.

STRATOSPHERE

- Isothermal then an increase with height due to Ozone layer heating.
- Only contains about 1% of atmospheres water vapour so is absolutely stable with very little weather.
- Stratosphere extends from 11 km – 50 km at mid latitudes.
- Reaches 0^0C at stratopause.



MET 3 – HEAT & TEMPERATURE

TEMPERATURE SCALES

- Celsius : Freeze 0 ^{0}C / Boil 100 ^{0}C
- Farenheight: Freeze 32 ^{0}F / Boil 212 ^{0}F
- Kelvin: Freeze 273 K / Boil 373 K

- C → F: $\left(C\ x\ \frac{9}{5}\right) + 32$
- C → K: +273 (Approx double, add 30)

- Celsius is used for meteorological purposes

REPORTING TEMPERATURE

- Temperature is **rounded** when reported.
- 2.2 becomes 2
- 2.5 becomes 3
- -2.5 becomes M2
- -0.5 becomes M0

MEASURING TEMPERATURE

- Measured with a **Stevenson Screen.**
- Measured at a height of **4ft AGL** (avoids ground heating).

NOCTURNAL / TERRESTRIAL RADIATION INVERSION

- Occurs with **weak winds** and **clear skies** at **night.**
- Creates a large outbound radiation and surface is cooled.
- Warmer air above leads to an inversion.

SOLAR RADIATION

- **Short wave** radiation
- Only occurs during **daytime**
- Only about **45%** of the radiation actually reaches the surface of the earth:
    - Absorbed by atmosphere and clouds
    - Scattered by atmosphere
    - Scattered and reflected by clouds
    - Reflected by earth (albedo effect – greatest snow / smallest rainforest)
- Heats the **surface of the earth** which then heats the air through conduction etc.

INSOLATION

- The amount of solar radiation incident on a **unit area** of the earth's surface.
- Affected by:
    - Angle of incidence (wider at poles)
    - Nature of surface (sand vs water)
    - Transparency of atmos. (cloud, dust)

RADIATION FROM EARTH

- **Long wave radiation**
- Occurs **24 Hrs**
- Negligible during day due to solar radiation.
- **Net outflow** of heat at night = **surface cools**
- Too high concentrations of carbon dioxide and water vapour **(greenhouse gases)** act like a blanket and can leading to warming.
- A calm and clear night will be cooler than a cloudy night as radiation from Earth's surface is allowed to slip into space.

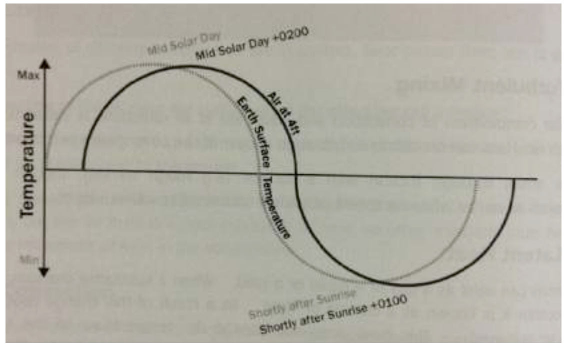
HEAT TRANSFER

- **Conduction**
- **Convection** (due density changes)
- **Advection** (horizontal movement of air)
- **Latent heat** (absorbed if melt / evaporate)

- Irregular mixing of convection and advection gives rise to **turbulence.**

DIURNAL VARIATION

- Daily changes of temperature = DV
- Max temp = **Noon + 2 Hrs**
- Min temp = **Sunrise + 30 mins**
- Factors affecting DV:
    - Wind – Strong wind reduces max + min
    - Cloud – Clouds reduces max + min
    - Surface – Oceans have very small DV, deserts have the max DV.
- Max DV occurs (inversion also likely) with:
    - Calm winds
    - Clear conditions
    - Over land (especially dry ground)

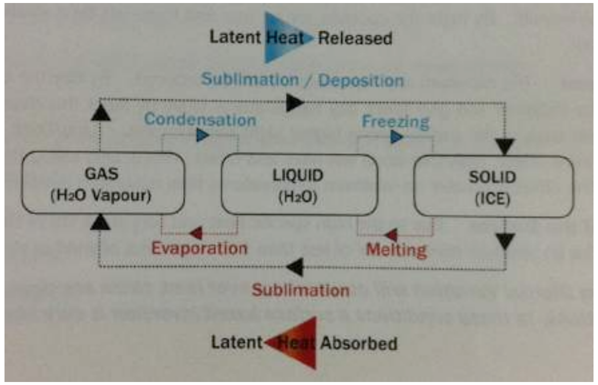


MET 2 – INTERNATIONAL STANDARD ATMOSPHERE

LATENT HEAT

Water Vapour
Liquid
Solid

- Going up the steps requires energy so latent heat is absorbed.
- Substance stays the same temperature but the temperature of the surroundings is changed.
- Convection and condensation contribute most to atmospheric waraming.

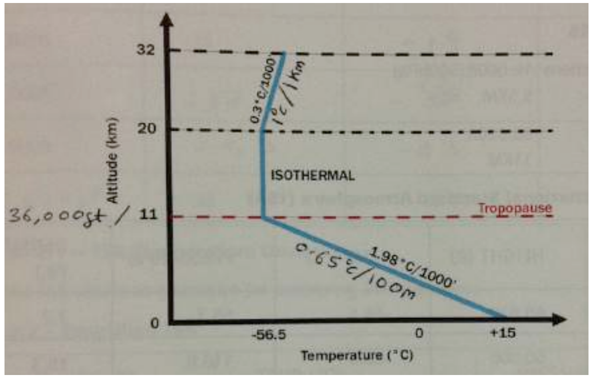


WHY ISA?

- International Standard
- Relate performance of a/c to know values
- Calibration of pressure instruments
- Manufacture and testing of a/c

ISA TEMPERATURE

- MSL Temp = +15 ^{0}C
- + ve Lapse Rate (MSL – 11km)
  - 1.98^{0}C / 1000 ft || 6.5^{0}C / 1 km
- Lapse Rate (11 – 20 km): -56.5 ^{0}C
- + ve Lapse Rate (20 – 32km)
  - 0.3^{0}C / 1000 ft || 1^{0}C / 1 km
  - A.K.A Inversion



- Polar 0^0 isotherm: 0 ft
- Temperate 0^0 isotherm: 6,000 – 10,000 ft
- Tropical 0^{0}C isotherm: 16,000 – 18,000 ft

JSA

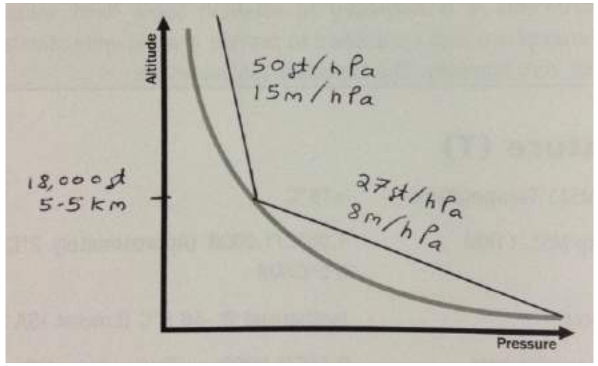
- Jet Standard Atmosphere
- Constant 2^{0}C / 1000 ft for planning

ISA DENSITY

- MSL Density = 1.225 kg / m^3
- Half Density = 20,000 ft

ISA PRESSURE

- MSL Pressure = 1013.25 hPa / 29.92 in Hg
- Lapse Rate (MSL – 5.5 km)
  - 27 ft/ hPa || 8 m / hPa
- Lapse Rate (5.5 km +):
  - 50 ft/ hPa || 15 m / hPa
- Half Pressure = 5.5 km / 18,000 ft
  - => Half the mass of the atmosphere can be found in the lowest 5.5 km (EASA use 5km sometimes)



ISA PRESSURE VALUES

- 30,000 ft 300 hPa
- 18,000 ft 500 hPa
- 10,000 ft 700 hPa
- 5,000 ft 850 hPa
- 0 ft 1013.25 hPa

ISA DEVIATION

- ISA Deviation = Ambient (OAT) - ISA

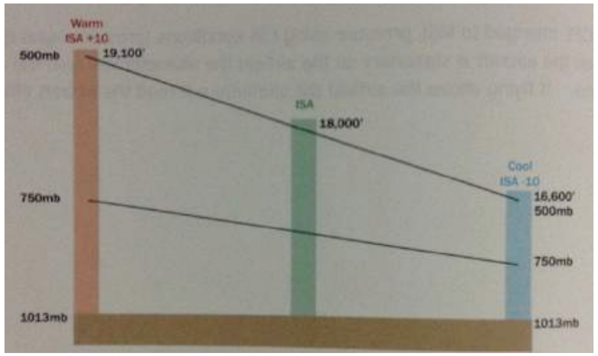
MET 4 – ATMOSPHERIC PRESSURE

VARIATION OF PRESSURE WITH HEIGHT

- The **rate of pressure decrease** will **reduce** as height increases.
- As altitude increases, the weight of the atmosphere above you will decrease.

PRESSURE VARIATION WITH TEMPERATURE

- **Cold air** is more dense so more rapid decrease in pressure with height.
- **Warm air** is less dense so slower decrease in pressure with height (compared to ISA).
- When flying from ISA to colder air, aircraft will descend but still show 18,000ft. **High to low, watch out below!**
- The pressure in a column of warm air is likely to be greater than the pressure at the same height in a cold column of air.



APLR

- **Ambient Pressure Lapse Rate**
- $APLR = \frac{96K}{P}$
- K = Mean temperature in Kelvin
- P = Mean pressure

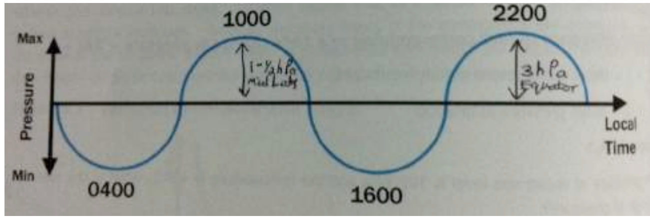
- *Pressure at MSL is 1000 hPa and temperature is +20 ⁰C. An aircraft is flying at the 910 hPa level where temperature is -6 ⁰C. What height is it flying at?*
- Mean pressure = (1000-910)/2 = 955 hPa
- Mean temperature = [(20)+(-6)]/2 = +7 = 280 K
- APLR = [(96x280)/955] = 28.15 ft / hPa
- Pressure difference is (1000 – 910) = 90 hPa
- 90 x 28.15 = 2533.5 ft AMSL

- An APLR **< 27' / hPa = Cold Air**
- An APLR **> 27' / hPa = Warm Air**

- Shortest distance between two pressure levels occurs when pressure increases and temperature decreases.

DIURNAL VARIATION

- Amplitude greatest at equator (~ 3 hPa)
- Mid Latitudes: ~ 0.5 – 1 hPa
- Poles: Negligible



PRESSURE MEASUREMENTS

- **QFE:** Pressure observed at a specific location with a datum of 0 ft.
- **QFF:** QFE changed to MSL pressure using APLR. Used on synoptic chart.
  - $\frac{Airfield\ Height}{APLR} +/- QFE = QFF$
  - Add if airfield is above MSL
- **QNH:** QFE changed to MSL pressure using ISA lapse rates.
  - $\frac{Airfield\ Height}{27} +/- QFE = QNH$
  - Add if airfield is above MSL

MET 4 – ATMOSPHERIC PRESSURE

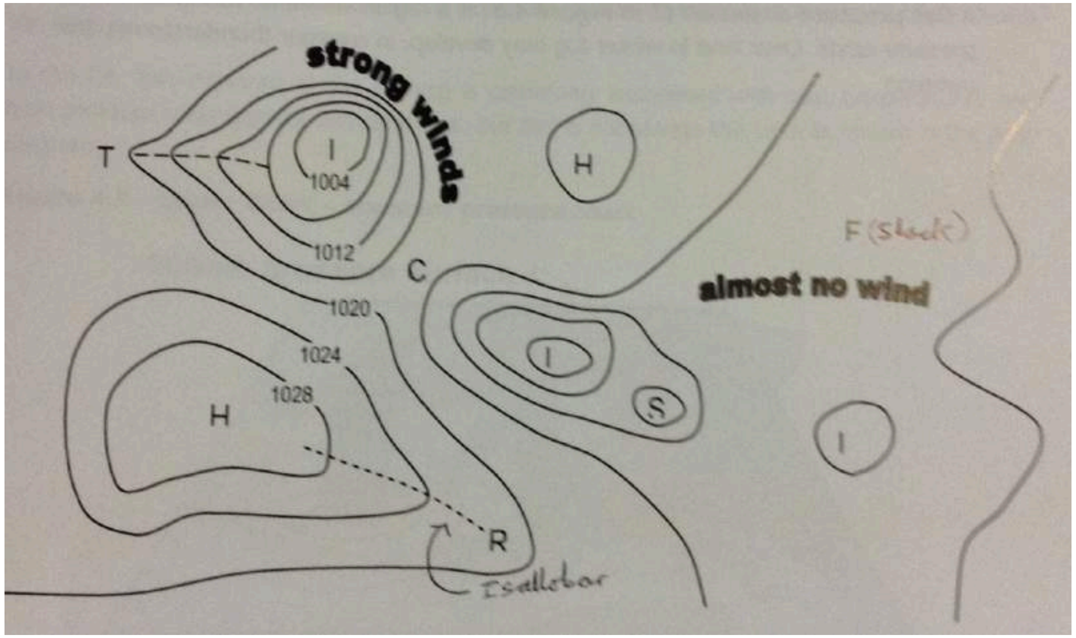
SURFACE PRESSURE CHART

- QFE's measured at each airfield.
- Converted to QFF's.
- **Isobars** join points of equal pressure.
- A high / low pressure area is determined by comparing the pressure of an area to that of the horizontal environments (surroundings)

- **Barometric Tendency** is the way and rate at which pressure is changing.
- **Isallobars** are lines showing equal change over a three hour period.

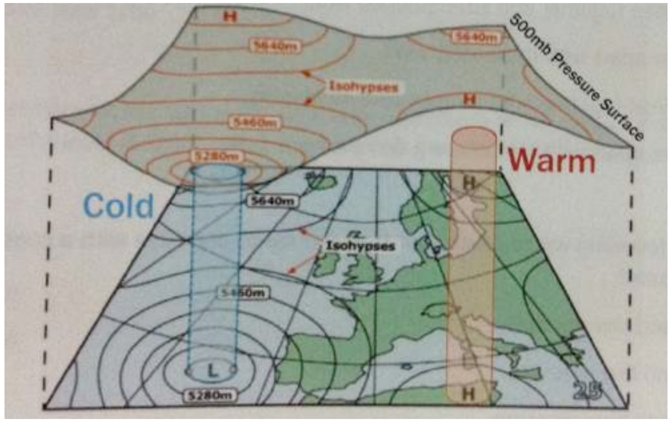
- **L = Low** (Depression / Cylone)
- **S = Secondary Depression**
- **T = Trough**
- **H = High (**Anticyclone)
- **R = Ridge**

- **C = Col** (Uniform pressure between two highs and two lows)
  - Winter = Fog
  - Summer = Thunderstorms
- **F = Flat** (No real pressure gradient)
  - Same seasonal wx as col



CONSTANT PRESSURE CHART

- **Isohypses** join points of equal pressure and true height AMSL
  - They indicate the true altitude of a pressure level.
- The heights are based on where the pressure level is that the chart is using.



MET 5 – DENSITY

DEFINITION

- **Density = Mass / Volume**

DENSITY RELATIONSHIPS

- Density ∝ Pressure
    - Higher Pressure = Higher Density
- Density ∝ 1 / Temperature
    - Lower Temperature = Higher Density
- Density ∝ 1 / Humidity
    - Humid air = Less Dense

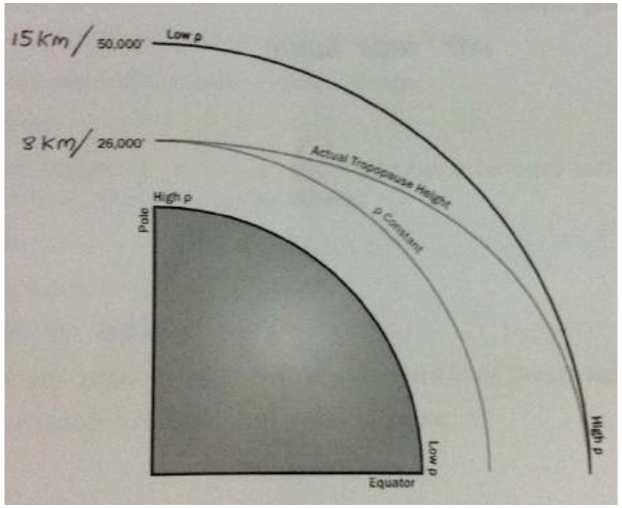
WITH INCREASING HEIGHT…

- Pressure Decrease = Density Decreases
- Temperature Decrease = Density Increase

- Proportional effects: P T H
- To change density by 1%
    - 10 hPa Change = 270 ft
    - 3 ^{0}C Change = 1500 ft
- Pressure therefore has the biggest effect and **density decreases with altitude.**

VARIATION WITH LATITUDE

- Due to higher pressure and lower temperature, **surface density is higher at poles** relative to equator.
- This 'head start' is quickly diminished as pressure reduces quicker in cold air.
- By **26,000ft (8 km) density is constant** at poles and equator.
- As this is the tropo height at the poles, the isothermal layer removes the effect of temperature changes on the density.
- Density therefore decreases at a **faster rate** at the poles above 8 km.
- By **50,000ft (15 km) density is lower over the poles** compared with the tropics.



DIURNAL VARIATION

- Opposite of temperature variation.
- Best (highest) density = Sunrise + 30 mins
- Worst (lowest) density = Noon + 2 Hrs

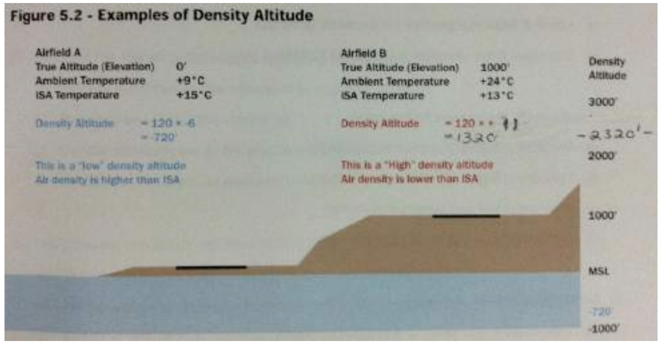
DENSITY AND PERFORMANCE

- Worst performance (highest density) occurs when **hot, high** and **humid.**

DENSITY ALTITUDE

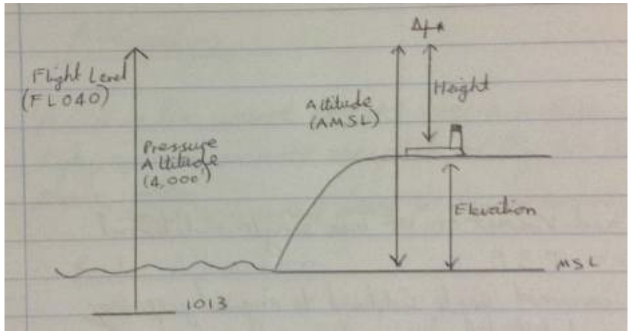
- **"Height in ISA which has a density corresponding to the actual ambient density."**
- Relative Density = Density Alt – Pressure Alt
- A high density altitude = lower density

- **Density Alt = Pressure Alt + (120 x ISA Deviation)**



MET 6 – ALTIMETRY

TERMINOLOGY



QNE

- **The height indicated on touchdown at an airfield using the 1013 datum.**
- Used when operating at very high airfields and altimeter cannot go below 950 hPa.

SPS

- **Standard Pressure Setting**
- 1013 hPa Datum
- “Flight Level”

RQNH

- **Regional QNH**
- Lowest forecast QNH within an ASR.
- Valid for 1 Hour.

WHY QNH VS QFF

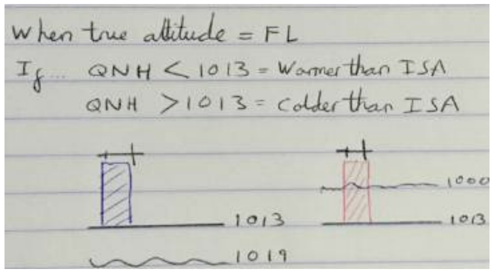
- QFF only used in the creation of synoptic charts.
- QNH used as the **altimeter is calibrated** to 27’ / hPa.
- Using the QFF would display incorrect readings at touchdown.

QFE / QNH / QFF SIMILARITIES

- QFE = QNH = QFF at **sea level only.**
- QFE = QNH at **sea level** or when perfect **ISA conditions** exist.

TRUE ALTITUDE VS ALTIMETER

- The difference in true altitude vs altimeter reading (due to temperature difference) **gets larger with an increase in altitude.**
- At high altitude, this is not a problem as everyone uses the same datum with the same error so are separated.
- On landing, the difference reduces to zero and so correct airfield elevation is obtained.



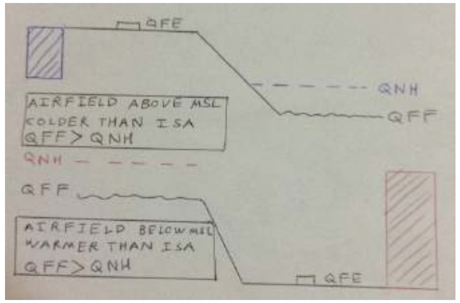
OVER / UNDER READ

- Over reads in cold air.
- Under reads in warm air.

- Can result in aircraft being at correct true altitude on ILS whilst the altimeter reads something else.

CALCULATING QNH LEVEL VS QFF

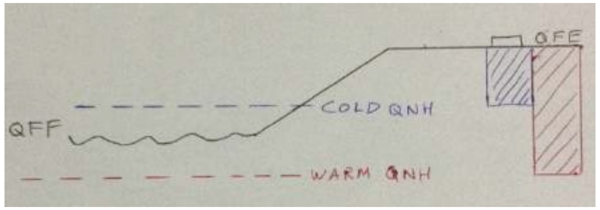
- The QNH level compared to the QFF level will depend on temperature.
- Draw either a small column of air (cold air) or large one (warm air) extending from the airfield to decide the QNH level.
- Remember, lower on the diagram is a **higher pressure** as you descend!!



MET 6 – ALTIMETRY

DITCHING

- Colder than ISA: Altimeter reads 0 ft when above the water.
- Warmer than ISA: Altimeter still reading positive when at sea level.



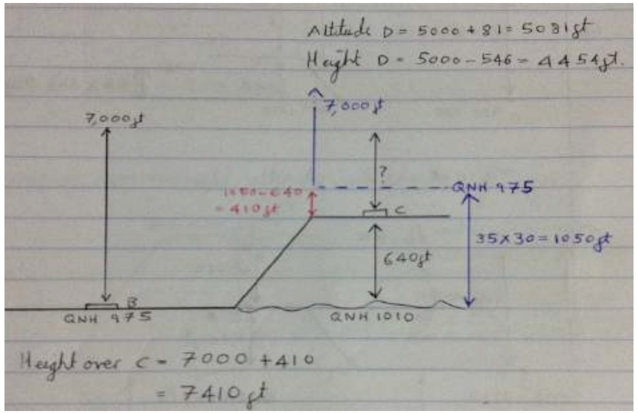
TEMPERATURE ERROR CORRECTION

$$Error = 4 \times \frac{Altitude}{1,000} \times ISA\ Deviation$$

- Altitude: 30,000 ft / OAT: -50^{0}C
  1. ISA Temp = 15 + (-2 x 30) = -45
  2. ISA Deviation = -5
  3. Error = 4 x 30 x (-5) = -600 ft
  4. True Altitude = 30,000 – 600 = 29,400 ft
  5. Check = altimeter over reads

PRESSURE QUESTIONS

- Always make a sketch with the pressure levels drawn on to visualise the changes.
- EG/ An aircraft flies from B to C and passed overhead B at 7,000 ft. B is at sea level and C is 640 ft above sea level. The QNH is 975 hPa at B and 1010 hPa at C. What height will the aircraft be over C? (Assume 1hPa = 30ft)



OVERNIGHT PRESSURE DROP

- Land at an airfield on QFE 1010
- Pressure drops to QFE 1000 overnight
- On returning to aircraft, altimeter still reads from the old 1010 datum and shows an increase in height.

TRANSITION ALT / LEVEL

- Set SPS passing **transition altitude** when climbing.
- Set QNH passing **transition level** when descending.
- **Transition layer** at least 500’ and not used for level flight.
- The lowest flight level (from MSA) depends on **lowest QNH and lowest temperature below ISA.**

MET 7 – LOW LEVEL WINDS

WHAT IS WIND?

- **The sustained horizontal movement of air.**
- Wind is caused by **variations in pressure.**
- Wind is a **vector** and has both direction and speed.

WIND DIRECTION

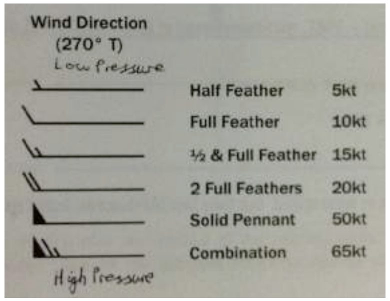
- Direction **from** which wind is blowing.
- Met Man gives **true** direction.
- ATC / ATIS give **magnetic** direction.
- Rounded to **nearest 10^0**

WIND SPEED

- 1 KT = 1.85 KMH = 0.52 MPS

WIND SYMBOLS

- Wind blows from the feather to the tip.
- Feathers will be on the side with low pressure.



WIND MEASUREMENT

- Speed measured with **anemometer**
- Direction measured with **wind vane**
- Measurement taken from **10m / 30 ft AGL**

GUST / LULL

- **Gust** = Increase in prevailing wind speed
- **Lull** = Decrease in prevailing wind speed
- Measured in **seconds**

SQUALL

- **An increase by 16 kts or more to become 22 kts or more for at least 1 minute.**

VEER / BACK

- **Veer** = Clockwise change (270 to 310)
- **Back** = Anti-clockwise change (310 to 270)
- Same in each hemisphere.

PRESSURE GRADIENT FORCE (PGF)

- The force that moves air from high to low pressure.
- A pressure gradient is said to exist when two points at the same level have a different atmospheric pressure.
- Size of force depends on isobar spacing.
  - Closely spaced = Steep PGF
  - Widely spaced = Slack PGF
  - Spacing also referred to as inclination

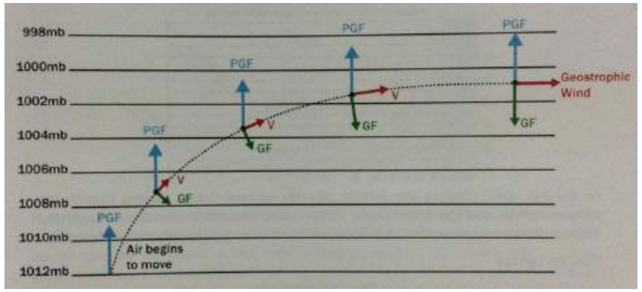
GEOSTROPHIC FORCE (GF)

- A.K.A Coriolis Effect
- Due to different rotational speeds of the earth at different latitudes.
  - Faster rotation at Equator
- Deflection **to the right** within the NH.
- $GF = 2\ \Omega\ \rho\ V \sin \emptyset$
  - Ω = Rotational Speed
  - ρ = Air Density
  - V = Wind Speed
  - $\emptyset$ = Latitude
- GF increases with wind speed
- GF increases towards the poles
- GF acts **perpendicular to wind direction**
- Negligible between **15 N and 15 S**

MET 7 – LOW LEVEL WINDS

GEOSTROPHIC WIND

- PGF increases velocity of the wind and GF begins to increase (acting perpendicular to wind direction).
- Geostrophic Wind is when **PGF and GF balance** and wind blows **parallel** to isobars.
- **Conditions required** for Geostrophic Wind:
    - Straight Isobars
    - Constant Pressure (equally spaced isobars)
    - Above friction layer (2000')
    - Above 15 N / S
- PGF increases velocity of the wind and GF begins to increase (acting perpendicular to wind direction).



GEOSTROPHIC WIND (LATITUDE VARIATION)

- $\boldsymbol{PGF = GF = 2\,\Omega\,\rho\,GW \sin \emptyset}$
- GW ∞ $1/\sin \emptyset$
- For the same pressure gradient, GW increases towards the equator.

BUY BALLOTS LAW

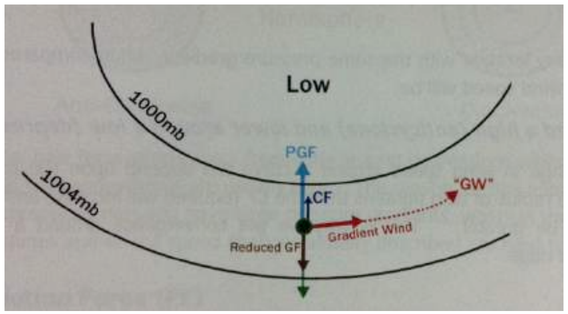
- **Back to the wind, low pressure on the left**
- Opposite in the southern hemisphere

GRADIENT WIND

- In reality, isobars are curved and there must be a **centripetal force (CF)** that gives wind its curved flow around LP / HP.
- Note that questions may sometime refer to centrifugal force. This acts in the opposite direction to centripetal force (away from centre of pressure system)
- Gradient wind will blow parallel to curved isobars.

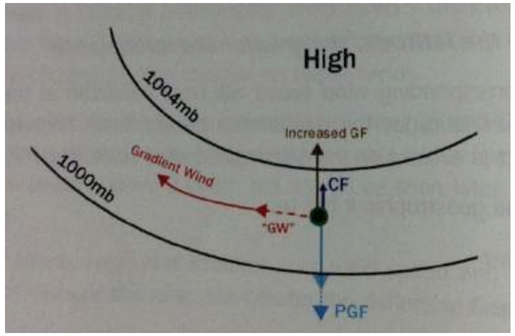
GRADIENT WIND – AROUND LP (NH)

- Around a depression (LP) in the NH wind flows **anti-clockwise.**
- **Geostrophic force reduces** to provide CF.
- **Velocity therefore decreases**
- **Sub-Geostrophic Flow** (Gradient Wind < Geostrophic Wind)



GRADIENT WIND – AROUND HP (NH)

- Around an anti-cyclone (HP) in the NH wind flows **clockwise.**
- **Geostrophic force increases** to provide CF.
- **Velocity therefore increases**
- **Super-Geostrophic Flow** (Gradient Wind > Geostrophic Wind)



GRADIENT WIND – LATITUDE VARIATION

- For the same pressure, the geostrophic wind and hence gradient wind, will be greater at lower latitude.
- In the NH, a high above a low can therefore have the same gradient wind speed.

MET 7 – LOW LEVEL WINDS

AIRFLOW AROUND PRESSURE SYSTEMS

- Any pressure system passing north of you will cause the wind to **veer.**
- Any pressure system passing south of you will cause the wind to **back.**
- Same in both hemispheres.

FRICTION LAYER

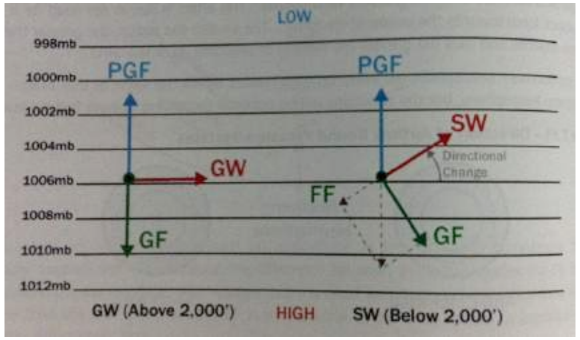
- Between 1,500 ft – 3,000 ft AGL (AVG 2K)
- Exceptionally can be up to 6,000 ft AGL
- Within this layer there is a **friction force** that causes wind to change speed and direction near the surface.
- A **thinner** layer is more effective.

CAUSES

- The friction force is due to **turbulence** present within the friction layer.
- This turbulence is caused by mechanical and thermal effects.
- **Mechanical** – Due to roughness of surface and obstructions. (Day + Night)
- **Thermal** – Surface heating makes air less dense and more easily deflected. (Day Only)

FRICTION FORCE

- The friction force acts **opposite to the wind**
- It causes the wind to **slow down** initially.
- **Geostrophic Force reduces** as a result.
- Unbalance of force now created and surface wind (SW) **turns towards low pressure.**
  - Backs in northern hemisphere
  - Veers in southern hemisphere

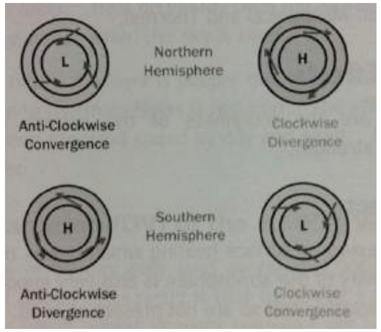


VALUES OF CHANGE

- **Over Land**
  - Backs 30^{0}
  - Speed Decreases 50%
- **Over Sea**
  - Backs 10^{0}
  - Speed Decreases 30%

- Veers in SH rather than backs.

SURFACE WIND AROUND HP / LP



COVERGENCE / DIVERGENGE

- Caused by frictional force at the surface.

ISOHYPSES

- Wind tends to follow isohypses above the friction layer because the geostrophic force (coriolis force) tends to balance with the horizontal PGF.

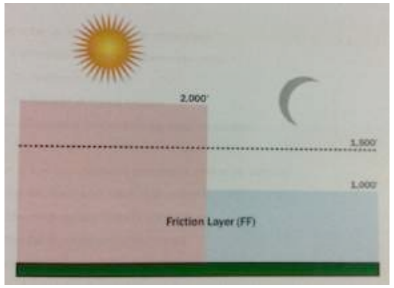
EYE OF PRESSURE SYSTEM

- Conditions in the centre of a high / low are relatively calm.

MET 7 – LOW LEVEL WINDS

DIURNAL VARIATION

- **Thinner at night** (more effective) as its just mechanical effects acting.
- Day to Night (NH): Backs and slows
- Night to Day (NH): Veers and speeds up
- Surface winds speeds are therefore likely to be highest during mid afternoon.



FACTORS AFFECTING DV

- **At sea / roughness of surface**, the mechanical effect is negligible so the layers will be thinner.
- **Cloud cover** will reduce surface heating and thermal effect so the layer is thinner.
- **Strong winds** decrease the thermal effect but increase the mechanical effect.
  - Night layer becomes thicker and day becomes thinner.
  - Less of a change from day to night.
- **Stability** of the air
  - Unstable leads to more mixing so frictional layer is thicker.

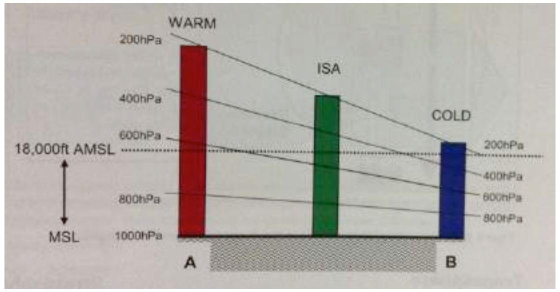
1,500 FT WIND

- Day to Night (NH): Veers and increases
- Night to Day (NH): Back and decrease

MET 8 – UPPER WINDS

CAUSE OF PRESSURE DIFFERENTIAL

- Temperature differences will create a pressure differential at altitude. For example at 18,000 ft, pressure drops from 600 hPa to 200 hPa.
- As the equator is hotter than the poles, there is a pressure differential set-up.

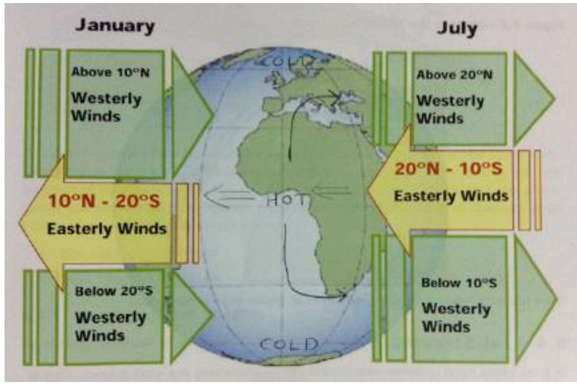


STRONGEST WINDS

- Located just below the tropopause

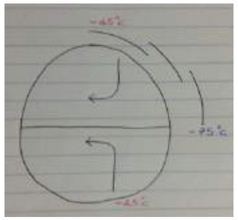
TROPOSPHERE UPPER WINDS

- **Mainly westerlies in troposphere** except between 15^0 N/S where no gradient force exists.
- The latitudes of this 'no gradient force area' vary in winter compared with summer.
- In this area, **weak easterlies** predominate.



STRATOSPHERE UPPER WINDS

- Lower temperature now exists at equator compared with poles.
- **Easterly winds predominate.**



WINDS EXPERIENCED DURING FLIGHT

- **UK to NY:** Westerlies / Easterlies (Stratosphere) / Westerlies
- **UK to Brazil:** Westerlies / Easterlies (Troposphere) / Westerlies

EFFECTS DURING WINTER

- A greater pressure gradient exists in Winter so **winds are stronger.**

JET STREAMS

- At about 60N and 30N there are 'steps' in the tropopause.
- The rapid horizontal temperature gradient at these points gives rise to strong winds.

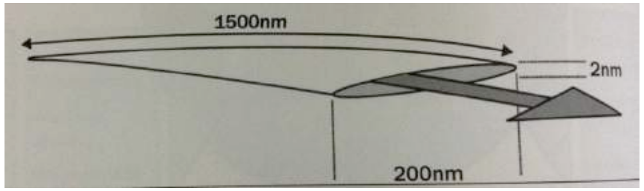
JET STREAM DEFINITION

- A strong narrow current concentrated along a **quasi-horizontal axis** …
- In the **upper troposphere** or **lower stratosphere** …
- Featuring strong vertical and lateral **windshears** featuring one or more **velocity maxima.**
- Wind speed must **exceed 60 kts**

MET 8 – UPPER WINDS

JET STREAM DIMENSIONS

- Ratio of horizontal to vertical is **100:1**
- **EASA: 1000 nm / 150 nm / 18,000 ft**



JET STREAM SPEEDS

- **Minimum:** 60 – 80 kts
- **Frequent:** 100 – 150 kts
- **Less Frequent:** 150 – 200 kts
- **Rare:** > 200 kts (can be up to 350 kts)
- Speeds are **greatest at the core**

JET STREAMS

- **Polar Jet Front**
- **Subtropical Jet Front**
- **Equatorial Easterly Jet**
  - NH Summer Only (20N – 10 N)
  - Burma to East Africa
  - Speeds may only reach 40 kts
  - A.K.A Tropical Jet
- **Artic Jet**
  - Winter Only
  - North of 55 N
  - Max speed 75 – 100 kts

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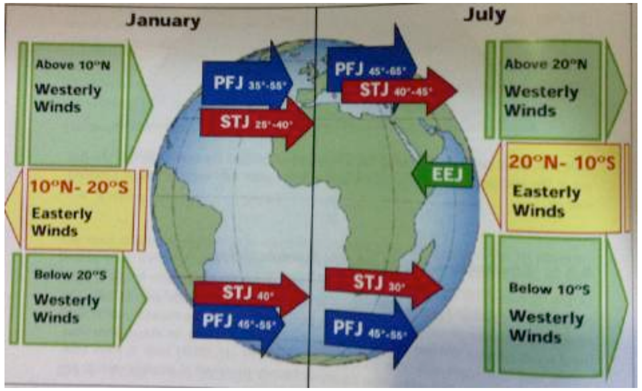
- **Polar Night Jet**
  - FL700
  - High Lats during permanent darkness
- **Low Level Jets**
  - As low as 5000 ft
  - Mountainous Regions
  - At night a PGF exists due to large temperature differences at the 850 hPa level.
  - 25 – 70 kts

LOCATIONS OF JET STREAMS

- Polar jet front **moves more** than subtropical jet front. (More lands mass)



JET STREAM HEIGHTS

- **Artic Jet (AJ):** 20,000 ft / 400 hPa
- **Polar Front Jet (PFJ):** 30,000 ft / 300 hPa
- **Subtropical Jet (STJ):** 40,000 ft / 200 hPa
- **Eq Easterly Jet (EEJ):** 45,000 ft / 150 hPa

WIND VARIATIONS

- SH upper winds are generally **weaker** than those in the north hemisphere (land mass).
- **Strongest winds occurs in winter**:
  - NH = January
  - SH = July

JETSTREAM AIR MASS

- Jetstreams are located in the **subtropical air mass.**
- **Appears** to be in polar air mass on charts.

JETSTREAM & FRONTS

- Jetstreams normally cross occluded fronts.
- Surface projection of jet stream 300 – 450 nm ahead of the warm front and 50 – 200 nm behind the cold front.
- Long streaks of CI cloud (on the equatorial side) can provide a visual indication of a Jet Front and associated CAT.
- Wind speed greatest in an area between a trough and a ridge.

MET 9 – TURBULENCE & WINDSHEAR

DEFINITIONS

- **Wind Shear –** Rate of change of the wind in a space as a vector.
- **Vertical Shear –** Change of the horizontal wind vector with height. (KT/100ft)
- **Horizontal Shear –** Change of the horizontal wind vector with distance. (KT/1000ft)

TURBULENCE VS WINDSHEAR

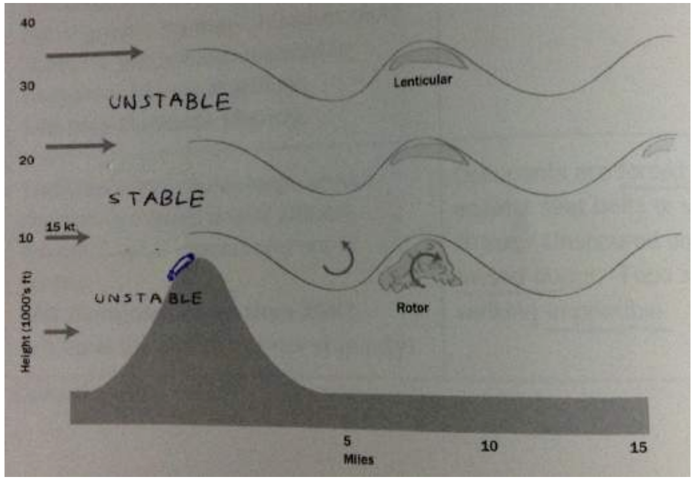
- **Wind Shear –** Abrupt displacement from flight path requiring substantial control action.
- **Turbulence –** Disruption to aircraft attitude but no significant effect on flight path.

MOUNTAIN (STANDING) WAVES

- **Conditions required:**
  - "Stable sandwich"
  - Wind blowing within 30^0 to the perpendicular of the ridge.
  - Min 15 kts wind, increasing with height.
- **Rotor (roll)** and **lenticular** clouds visible on thhe downwind side **only** when moisture is present.
  - Reversed flow often present at SFC
  - Cap clouds can also form on the upwind side.

AVOIDING MOUNTAIN WAVES

- Fly at **elevation x2**
- Fly **parallel to the ridge**



MOUNTAIN WAVES CAUTIONS

- **Flying low-level, upwind (into wind)** is worst as aircraft is out of phase.
- Can be **no visible indication.**
- With cloud present, **airframe icing** likely to be more severe (orographic intensification)
- **Jetstream** can cause more pronounced turbulence on the warm side.
- Can have a range of **50 – 100 nm** (even 500 nm has been recorded)

Intensity	IAS Effect	Effects
Light	**Fluctuates 5 – 15 Kts**	**Belts –** Slight Strain
		Objects – Displaced Slightly
		Food + Walk – No Difficulty
Light Chop	No IAS Fluctuations. Causes rhythmic bumpiness	
Moderate	**Fluctuates 15 – 25 Kts**	**Belt –** Definite Strain
		Objects - Dislodged
		Food + Walk - Difficult
Moderate Chop	Slight IAS Fluctuation. Rapid bumps / jolts without appreciable changes in altitude or attitude.	
Severe	**Fluctuates > 25 Kts**	**Belts –** Forced Violently
		Objects – Tossed About
		Food + Walk - Impossible

INCIDENCE

- **Occasional**
  < 1/3 of the time.
- **Intermittent**
  1/3 to 2/3
- **Continuous:**
  More than 2/3

MET 9 – TURBULENCE & WINDSHEAR

FRONTS

- At fronts, **a sharp change in wind direction** can occur.
- More pronounced at a **cold front**

CLEAR AIR TURBULENCE (CAT)

- Occurs **above the friction layer**
- Has **no visual indicator** (no clouds etc)
- Found with troughs / ridges, Jetstreams and outside of CB clouds.

CAT (TROUGHS AND RIDGES)

- **Sharp curves** in troughs and ridges can cause CAT / horizontal windshear.
- **Troughs** are more severe.

CAT (CONVERGENCE / DIVERGENCE)

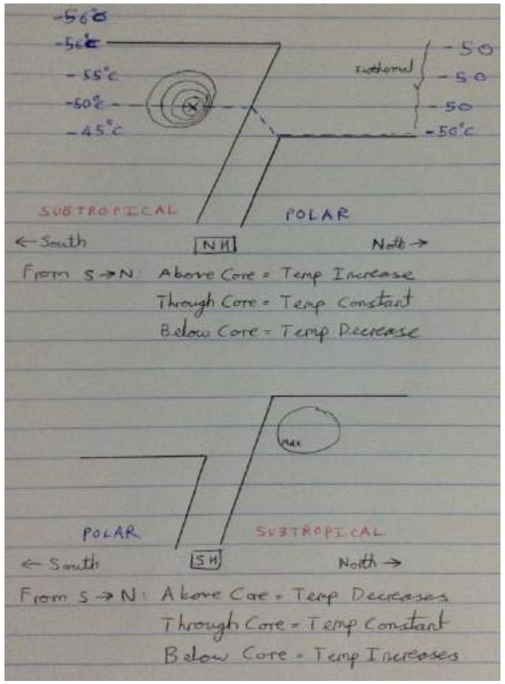
- When isohypses converge / diverge, CAT may form as a result of eddy formation.

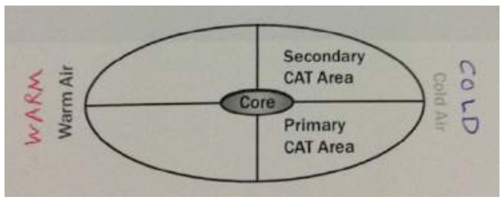
STABILITY AND TURBULENCE

- More turbulence with an unstable atmosphere.

CAT (JETSREAMS)

- There can be rapid changes of wind speed over a very short distance in, and close to, a Jetstream.
- Jetstream is always **located in the subtropical air mass.**
- **Isotechs** join points of equal speed.
- Maximum CAT will always be in the **bottom quadrant nearest the cold air (polar) side.**





CAT (JETSREAMS)

- Most frequent in the region **7000 ft below to 3000 ft above the tropopause.**
- Average depth of the layer is **2000 ft** (can be as shallow as 60 – 100 ft however)

- CI (Cirrus) cloud will move at high speed in a narrow band, **perpendicular** to the surface movement of the front.
- In the NH example (assuming front is moving north), it moves in direction of the wind which is coming out of the page.
  - "Back to wind, cold on the left"

- The core of a jet stream lies at a height where there is no horizontal temperature gradient and the slope of the pressure surfaces at the height of the core are at max.

MECHANICAL TURBULENCE

- Caused by friction of air flowing over the Earth's surface.
- Due to terrain and other obstruction interfering with the normal airflow.
- Increases when wind speed increases.

THERMAL TURBULENCE

- Due to vertical movements of air due to convection in unstable airmass.
- Greatest during early afternoon.

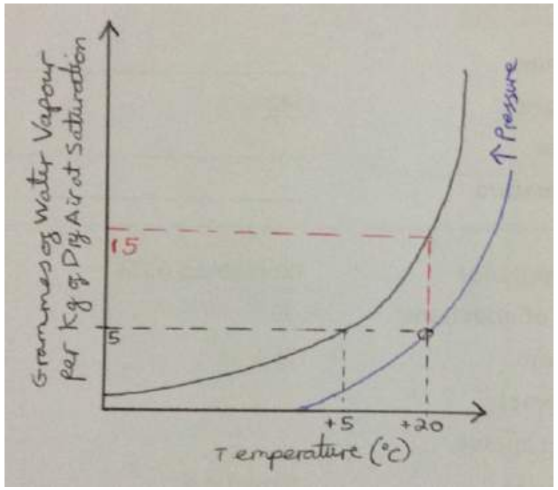
MET 10 - HUMIDITY

SATURATED AIR

- Air is saturated when it **cannot take on any more water vapour.**
- **Relative humidity = 100%**
- If air is not saturated, it can take on more water vapour through **evaporation.**
- When cooled, saturated air gives up water vapour through **condensation.**
  - Requires condensation nuclei to attach to (hygroscopic = affinity to water)
  - If not present, super-saturation occurs

HUMIDITY MIXING RATIO (HMR)

- HMR: Amount of grammes of water vapour per kg **before saturation.**
- The indicated parcel of air at +20^{0}C has a HMR of 5 gm / kg



SATURATION OPTIONS

- **Cool the particle** to +5^{0}C (higher altitude)
- Add more water vapour via **evaporation**
- **Increase pressure**

SATURATED MIXING RATIO (SMR)

- SMR is the **HMR when a parcel is saturated**.

DEW POINT

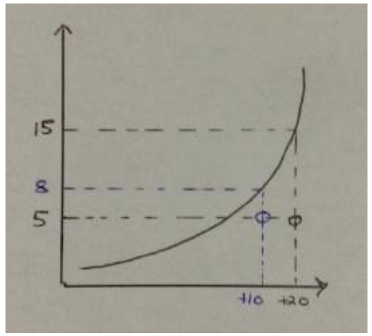
- **Temperature at which a volume of air must be cooled at constant pressure for saturation to occur.**
- If air is cooled to dew point it becomes **saturated.**
- Cooled **beyond dew point = condensation**
- Dew point can only be equal to, or lower, than the temperature of the air mass.
- Difference between DP and temp will be greatest in dry air.

COOLING BEYOND SATURATION

- Water vapour **condenses** into water droplets if nuclei present.
- **Latent heat released**
- **Clouds formed**

RELATIVE HUMIDITY (RH)

- **Expresses the % of saturation of the air.**
- Amount of water vapour in a unit mass of air *divided by* max amount of water vapour the unit mass of air could hold at same temperature and pressure *expressed as a percentage.*
- (HMR/SMR) * 100
- RH depends on the moisture content and temperature of the air.
- A particle at +20 will have RH of (5/15) x100% = 33%
- If cooled, the RH will increase to 67% (5/8)
- Methods of increasing humidity are same at saturation options.



EFFECT OF TEMPERATURE ON RELEASE OF LATENT HEAT

- Less water vapour is held at colder temps.
- When condensation occurs, less latent heat is released.

MET 10 - HUMIDITY

HMR

- Mass of water vapour contained in unit **mass** of dry air (gm/KG)

ABSOLUTE HUMIDITY

- Mass of water vapour contained in unit **volume** of dry air (gm/m^3)

HYGROMETER

- Used to **measure humidity.**
- **Two thermometers:**
  - One Normal (Dry Bulb)
  - One with muslin on the end (Wet Bulb)
- Unsaturated air will cause **evaporation** and absorption of latent heat.
  - Wet bulb will show lower temperature than dry bulb.
- Saturated air will result in **no difference**.
- **Other methods:**
  - Human Hair
  - Gold Beaters Skin

DV OF HUMIDITY

- Inverse of the temperature DV.
- As a particle is cooled, RH increases.
- Max RH is therefore at coolest temp.
- Min RH is therefore at max temp.

VAPOUR PRESSURE

- Vapour pressure is the amount of vapour that can be found in the air.
- Higher over a water surface than an ice surface.

MET 11 – ADIABTICS & STABILITY

RADIO SONDE BALLOON

- Used to obtain the **Environmental Lapse Rate.**
- By **comparing** this to a set of fixed lapse rates, we can **determine the stability** of the atmosphere.

WHY DOES AIR COOL WITH ALTITUDE?

- Consider a single parcel of air that's lifted.

1. Pressure Decreases
2. Volume Increases
3. Molecules Slow Down
4. **Adiabatic Cooling**

- The opposite process (on descent) results in **adiabatic warming.**
- This 'lifting' is done by **trigger factors**.

DRY ADIABATIC LAPSE RATE (DALR)

- Used for **unsaturated (dry)** air with a RH less than 100%. (99.9% is still dry)
- **3^0C / 1,000 ft**
- **1^0C / 100 m**

SATURATED ADIABATIC LAPSE RATE (SALR)

- Used for **saturated** air with a RH = 100%
- **1.8^0C / 1,000 ft**
- **0.6^0C / 100m**
- A saturated parcel of air when cooled will still cool at the DALR but it will also **release latent heat** during **condensation.**
- This 'extra warming' reduces the rate of cooling and hence SALR < DALR.

STABILITY

- **Neutral**
  - Parcel of air at same temperature than surrounding air.
  - Happy where it is.
- **Unstable**
  - Parcel of air warmer than surrounding air.
  - Will ascend to get to colder (once trigger is removed)
- **Stable**
  - Parcel of air colder than surrounding air.
  - Will descend to get to warmer (once trigger is removed)

ABSOLUTE INSTABILITY

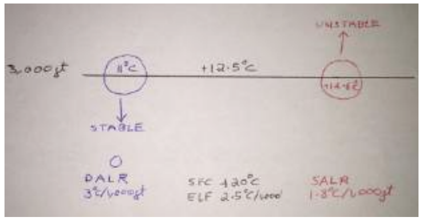
- **ELR > 3^0C / 1,000 ft**
- Both an unsaturated and saturated parcel of air will be **unstable.**

ABSOLUTE STABILITY

- **ELR <1.8^0C / 1,000 ft**
- Both an unsaturated and saturated parcel of air will be **stable.**

CONDITIONAL INSTABILITY

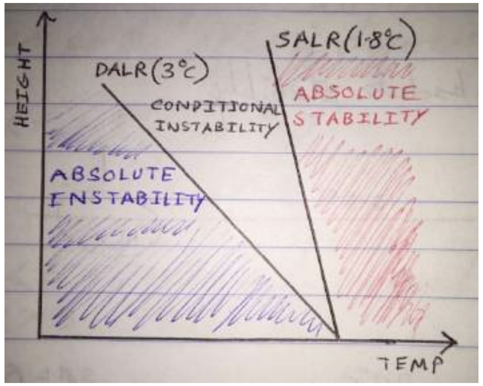
- **ELR 1.8^0C --> 3^0C / 1,000 ft**
- Unsaturated parcel is **unstable**
- Saturated parcel is **stable**



MET 11 – ADIABTICS & STABILITY

STABILITY GRAPH

- Plot the ELR on the graph.
- Consider whether the ELR is left / on / right of the DALR line (if dry air) or SALR (if saturated)
- If Right = Stable
- If Left = Unstable
- On Line = Neutral



DALR & SALR SPREAD

- At **lower temperatures, less latent heat** given off during condensation.
- Less warming of the atmosphere occurs at the poles so the **SALR is closer to DALR.**
- Also close together at high altitude where it is cold => CI Cloud

INVERSION STABILITY

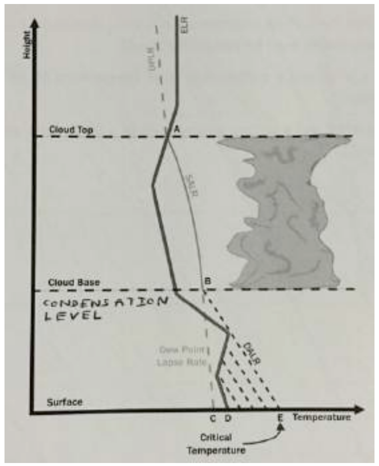
- With an inversion the ELR is +ve and to the right of the graph.
- An inversion is therefore **absolutely stable**

DEW POINT LAPSE RATE

- Rate of change of the dew point temperature in an unsaturated parcel of air.
- **0.5^0C / 1,000 ft**

TEPHI-GRAM: CRITICAL TEMP

- **Critical Temperature** – Temperature at the surface when the DALR first meets the dew point lapse rate.
- A **condensation level** will be present at this point where air becomes saturated and clouds start to form (cloud base).
- Parcel now cools at the SALR.
- A **neutral** atmosphere occurs when SALR = ELR and at this point the **cloud top** forms.
- **Other reasons** for a cloud top forming:
  - Run out of moisture
  - Tropopause forces the ELR to equal the SALR eventually.



ADIABATIC PROCESS

- When a gas is warmed due to compression or cooled due to expansion without receiving or giving energy to surroundings.

ISOTHERMAL LAYERS

- An unsaturated parcel rising through an isothermal layer will still cool at the DALR

ELR VARIATIONS

- The actual ELR varies daily.
- The average ELR is 2^0C / 1,000 ft

MET 12 – CLOUDS

STABLE STRATIFORM

Thin Layered | Cover Large Horizontal Area

LOW CLOUD

- Base: < 6,500 FT
- Water Droplets
- Grey From Below

- Stratus (ST)
- Stratocumulus (SC)

MEDIUM CLOUD

- Base: 6,500 – 23,000 FT
- Water Droplets + Ice Crystals
- Light Grey From Below

- Altostratus (AS)
- Altocumulus (AC) – Mackrell Sky

HIGH CLOUD

- Base: 23,000 FT +
- Ice Crystals
- White From Below

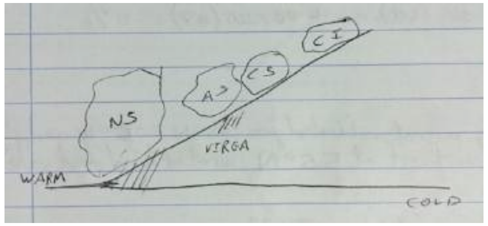
- Cirrus (CI) – Mare's Tail
- Cirrostratus (CS)
- Cirrocumulus (CC)

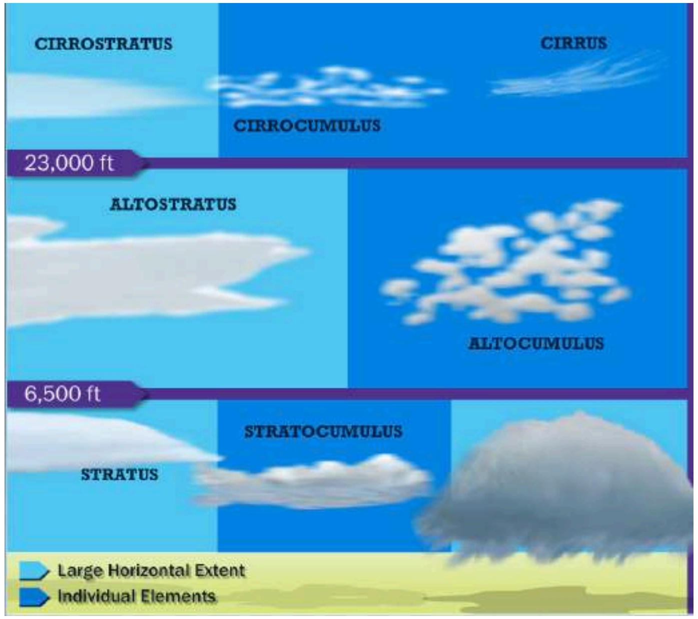
NIMBOSTRATUS (NS)

- Present in both low and medium heights.
- Nimbo = Rain bearing

WARM FRONT

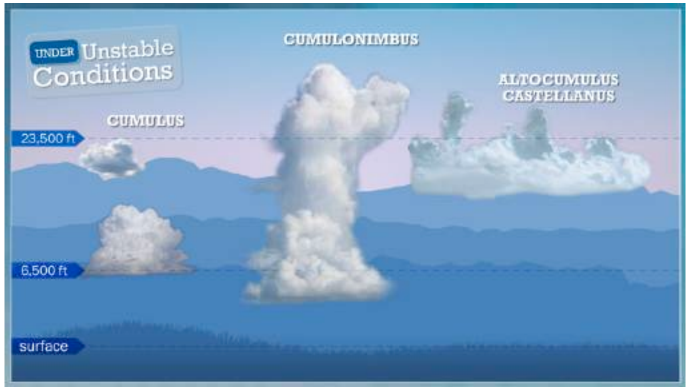
- Stable stratiform often found ahead of the surface position of a warm front.





UNSTABLE CUMULIFORM

Large Vertical Development



CUMULUS (CU)

- 3 Types of cumulus cloud.
- From SFC to 25,000 FT

CB & AC CAST

- **CB** – Cumulonimbus
- **AC CAST** – Altocumulus Castellanus (Medium level only)

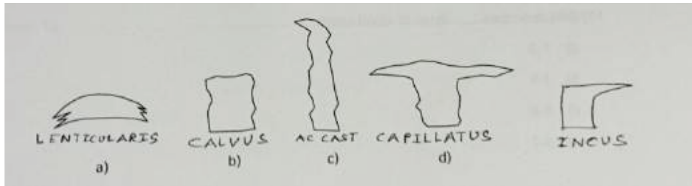
MET 12 – CLOUDS

SUPPLEMENTARY FEATURES

- Used to enhance descriptions.

- **Castellanus**
  - CI, CC, AC & SC
  - Turret shaped appearance
- **Lenticularis**
  - CC, AC, SC
  - Lens / almond shaped clouds
- **Fractus**
  - ST, CU
  - Broken / ragged appearance
- **Uncius**
  - CI
  - Like a comma / mares tail
- **Virga**
  - All clouds
  - Precipitation that does not reach SFC

CB CLOUD SPECIES



CONTRAILS

- Water vapour is a by-product of combustion
- Increases humidity of surrounding air, casing it saturate and condense.

WING TIP TRAILS

- Formed at extremities of the wing
- Low pressure from lift causes expansion
- Abiabatic cooling reduces it below dew point

CLOUD REPORTING

- 0 Octas = SKC
- 1 -2 Octas = FEW
- 3 – 4 Octas = SCT
- 5 – 7 Octas = BKN
- 8 Octas = OVC

CB REPORTING

- ISOL = Individual CBs
- OCNL = Well separated CBs
- FRQ = Little or no separation
- EMBD = Embedded

DEFINITIONS

- **Cloud Base** – Height of base above a particular level (usually airfield).
- **Cloud Ceiling** – Height of a BKN base (below 20,000 ft) above the ground or water
- **Operational Significance** – Cloud with a base below 5,000 ft or below highest MSA

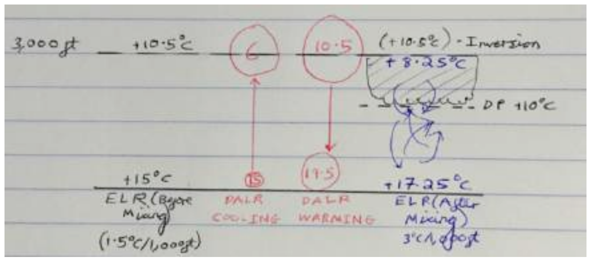
MET 13 – CLOUD TRIGGERS

6 TRIGGERS

- Turbulence (Stable, Wind ≥ 8 kts, DP)
- Convection (Unstable)
- Orographic Lifting
- Frontal Lifting
- Convergence
- Thin Layer Lifting (Unstable Sandwich)

TURBULENCE (ST / SC)

- **Conditions Required**
  - Stable Atmosphere (ELR < 1.8)
  - Wind ≥ 8 kts
  - Dew point within turbulent layer
- The **resultant ELR** approaches DALR (3^0)
  - Air forced to rise is mixed with that descending.
- **Cloud base** will form at the dew point level.
- **Inversion** present above turbulence layer
- **Flying Conditions**
  - Turbulent inside / under cloud
  - Smooth above cloud and in inversion
- **Icing**
  - Light / occasionally moderate rime if cloud above freezing layer.



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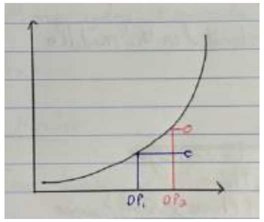
- **Increase SFC Temp = Higher Cloud Base**
  - Dew point occurs at a higher level
- **Increase Turbulent Layer = Higher Base**
  - Increases amount of mixing leading to a higher SFC temp.
- **Increase Humidity = Lower Base**
  - Dew point increases



CONVECTION (CU / CB)

- Convection cause by short wave radiation from sun so mainly **over land during day.**
- Assume a SFC temp of +15 at start of day.
  - Cools at DALR but hits ELR (neutral)
- SFC **temp increases to +20** due radiation
  - Saturated once DALR = DPLR (=base)
  - Cools at SALR
  - Neutral when SALR = ELR (= tops)
- SFC **temp increases to +25** due radiation
  - Base and top rise and TUC formed.
- SFC **temp increases to +30** due radiation
  - Base and top rise and CB formed

- Tops can also be formed due lack of moisture or tropopause forcing ELR and SALR to meet.

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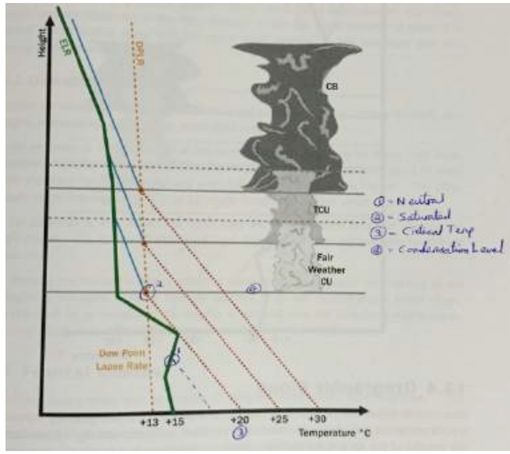
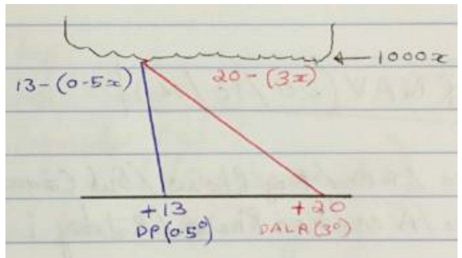


- Cloud base can be calculated by **equating the DALR and DPLR.**

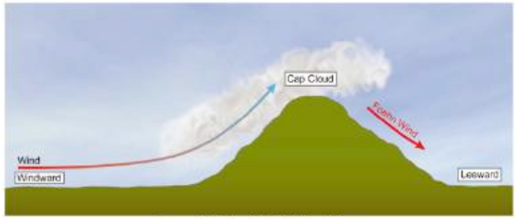
$$\mathit{Cloud\ Base} = \frac{\mathit{SFC\ Temp} = \mathit{DP\ Temp}}{2.5}$$



MET 13 – CLOUD TRIGGERS

OROGPRAHIC LIFTING - UNSTABLE

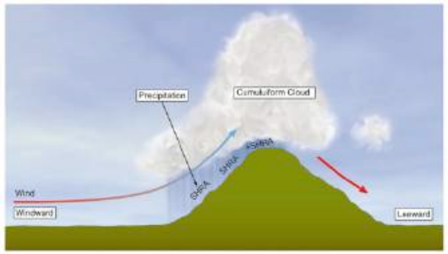
- Air forced to rise and cool adiabatically.
- **Stable** conditions will cause stratiform cloud to form on the windward side.
- Air descends once the trigger is removed and cloud also forms on the leeward side.
- Water vapour lost to precipitation or contact with the winward side of the hill causes a **higher base on the leeward side**.



Orographic Cloud – Stable Conditions

OROGPRAHIC LIFTING - UNSTABLE

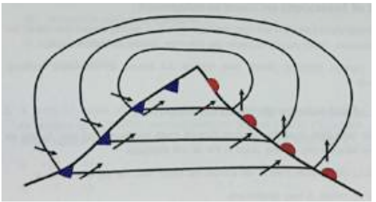
- Air continues rising and **cloud base forms above crest level.**
- **Very humid** conditions can cause base to form below crest level and tops to form above crest level – **obscuring high ground.**

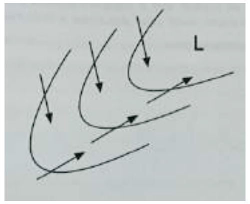


Orographic Cloud Forming in Unstable Conditions.

CONVERGENCE

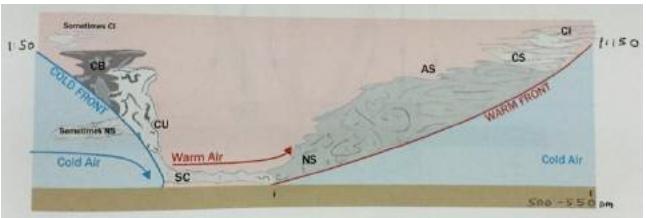
- Where there is a sharp change in wind direction, air comes together and rises.
- Occurs at **troughs** and **fronts** (esp. cold)





FRONTAL CLOUDS

- **Colder more dense air undercuts the warm air.**
- Cold Front = Unstable
- Warm Front = Stable



THIN LAYER LIFTING

- **Unstable air trapped between stable air.**
- Bell shaped AC / CC formed

EFFECT OF INVERSIONS

- **CU** vertical development could become trapped and **ST** formed.

EFFECT OF SUBSIDENCE

- Descending air warms adiabatically and any cloud in the air will **dissipate.**

MET 14 – VISIBILITY AND FOG

VISIBILITY MEASURING

- **Prevailing Vis –** Visibility reached within at least half the horizon circle / half the surface of the aerdrome.
- **Minimum Vis** – Reported with direction on METAR when < 1500 m or 50% of the prevailing visibility.
- Visibility is measured using a **visibility meter** which compensates for different types of precipitation.

OBSCURITY (VIS REDUCTION)

- **Less than 1000 m = Fog (FG)**
- **1000 m – 5 Km = Mist (BR)**
- **1000 m – 5 Km = Haze (HZ)**
  - Formed from solid particles

- **In order of decreasing vis:**
  - Hail
  - Rain
  - Drizzle
  - Sleet
  - Snow

- **Driving Snow** - Blown by wind when falling.
- **Drifting Snow** – Lifted less than 2m above surface after falling.
- **Blowing Snow** – Lifted more than 2m above surface after falling.

- **Shallow Fog** – Lifted less than 2m above surface.

TYPES OF FOG

RADIATION FOG

- **Conditions Required**
  - Over Land
  - Clear Sky (1 – 2 Oktas)
  - High Relative Humidity
  - Wind (5 kts)

- Radiation of the earth's heat at night causes cooling of the air in contact with the ground.
- Once cooled below the dew point and condensation occurs, a small amount of wind is required to lift it off the ground.
- Note that factors to produce max DV are required.
- Average height of 500 ft

- Can occur at anytime although **most likely in early morning (sunrise + 30).**
- **Cloud cover** will reduce heating and **rain** will keep air saturated, both causing radiation fog to persist.
- More likely with a high pressure system.

- **Dissipation Factors**
  - Sun (insolation)
  - Wind > 10 kts to lift it into ST / SC

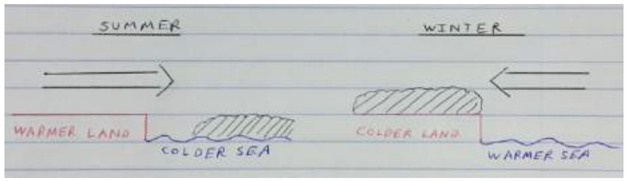
ADVECTION FOG

- Movement of **warmer air over a colder surface**.

- **Conditions Required**
  - Land or sea
  - High RH
  - Surface with temperature < DP
  - Wind (up to 15 kts / 20 kts over sea)

- Colder surface cools warmer air (at a high RH) below the dew point.
- Forms **over land in winter** (land cooler)
- Form **over sea in summer** (land warmer)

- Will often form slightly off shore as it takes a while to pick up moisture from sea.
- **Can also occur between two seas at different temperatures.**
- Can appear suddenly by day and night.



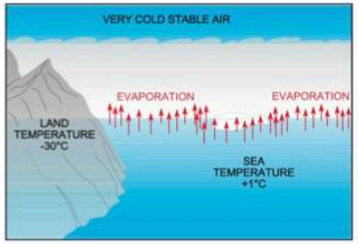
MET 14 – VISIBILITY AND FOG

HILL FOG

- The cap cloud produced by **orographic lifting** is fog for someone standing inside it.
- Has a visibility < 200 m

STEAMING FOG

- **A.K.A Artic Smoke**
- When **cold air moves over a warmer moist surface or sea.**
- The very low temperatures mean with just a little of moisture, air can become saturated.
    - Think about the HMR graph.
- This moisture is picked up from **evaporation.**



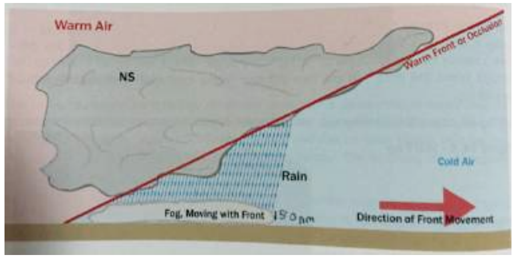
- Steaming fog occurs is air with cold mass properties.

VALLEY FOG

- Cold air runs down hill and mixes with moist air at the valley floor.
- This is a form of mixing fog.

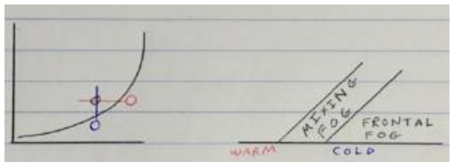
FRONTAL FOG

- Forms **ahead of the warm front (150nm)**
- **Precipitation from NS cloud saturates** (via evaporation of precipitation) the shallow layer of cold air underneath the front surface.
- Passes with passage of the warm front.



MIXING FOG

- Also known as **frontal fog.**
- Occurs in the **warm frontal zone** where warm and cold air mix.
- The resulting temperature after mixing is below it's saturation point.



FREEZING FOG

- Fog made of **water droplets** becomes **supercooled.**
- A solid object will act as a nuclei and droplets will freeze to it.

ICE FOG

- Normally found in **extremely cold artic air.**
- **Fog composed of ice crystals** instead of water droplets.

SOLID PARTICLES

SOLID PARTICLES

- **Smoke (FU)**
- **Volcanic Ash (VA)**
- **Dust (DU)** <0.08 mm
- **Sand (SA)** 0.08 – 0.3 mm

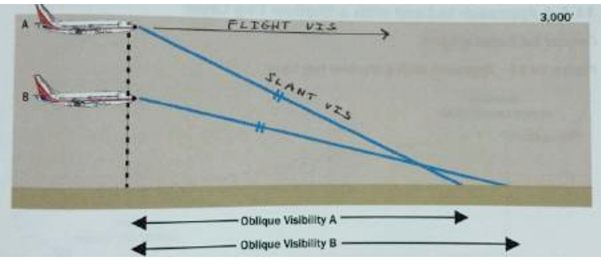
MET 14 – VISIBILITY AND FOG

FLIGHT VISIBILITY

- The only measurable visibility is **oblique visibility** which is the distance along the ground between a point directly beneath the aircraft and the furthest point on the ground a pilot can see.
- Into Sun / Up-Sun / Down-Moon = Worst
- Into Moon / Up-Moon / Down-Sun = Best

VIS WITHIN HAZE LAYER

- Slant vis remains the same regardless of altitude.
- **Oblique vis improves closer to the surface.**
- Climbing out of the haze layer will improve visibility.



SHALLOW FOG LAYER

- **Steeper approach** can be used to improve viz (stay out of it for longer)

MET 15 – PRECIPITATION

BERGERON (ICE CRYSTAL) THEORY

- When above the freezing level, both ice crystals and SCWDs may be present.
- The saturation vapour pressure of water is greater than ice so the water vapour sublimates onto the ice crystals.
- When heavy enough, ice crystals fall.
- If warm, falls as rain. If cold, falls as snow

COALESCENCE THEORY

- In clouds where temperature is above 0^0C and ice crystals are not present.
- Updrafts and downdrafts cause water droplets to collide and grow in size.
- Once droplets become sufficiently heavy, they fall as precipitation.
- Produces only DZ / -RN in the mid latitudes

PRECIPITATION TYPES

DRIZZLE (DZ) (Comma)

- **0.3 mm**
- Originates from **Stratus cloud**

RAIN (RN) (Full Stop)

- **Splashes when hits the ground**

SNOW (SN) *

- Will not form if less than -15^0C
- Snow Grains (SG) – Stratus / FG
- Snow Pellets
- Snow Flakes

SLEET (SN) *

- Mix of snow and rain
- RASN / SNRA
- Only settles when less than 4^0C

HAIL Δ

- **CB / TCU**
- **Most likely in continental regions at mid-latitudes** (High SFC temp and low temps at altitude => greater instability)
- **Small Hail (GS)**
- **Large Hail (GR)**

ICE PELLETS

- **Frozen raindrops <5 mm.**
- Ice crystals melt in warm air then re-freeze in colder air.
- Their presence **indicates freezing rain at higher altitude.**

FREEZING PRECIPITATION

- **Freezing Rain**
- **Freezing Drizzle**

REPORTING PRECIPITATION

DURATION

- **Showers**
  - CU / CB (Unstable Cumuliform)
  - Good vis after passing
- **Intermittent**
  - "From time to time"
- **Continuous / Steady**
  - NS (Stable Statiform)
  - Non-stop for at least 60 minutes

INTENSITY

- **Light**
- **Moderate**
- **Heavy**
  - NS/ CU / CB

MEASURING PRECIPITATION

- **Intensity** – Rate of rainfall device
- **Amount** – Rain gauge

PRECIPITATION EFFECTS

- **Lowers Temperature**
- **Increases Dew Point**

MET 16 – ICING

FROST POINT TEMPERATURE

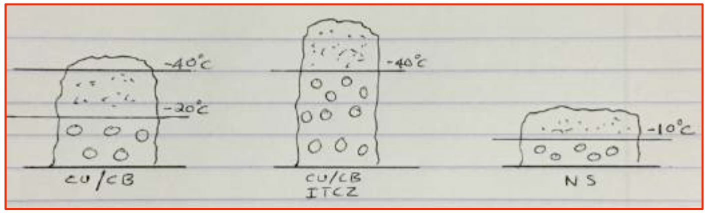
- When cooled below the frost point temperature, water vapour sublimates directly to ice.
- Frost will form on a solid surface of the same temperature when cooled below the frost point temperature.

ICING INTENSITY

- **Trace**
  - Ice becomes perceptible
  - No de-icing / anti-ice required (unless more than 1 hour)
- **Light**
  - Occasional use of de-icing / anti-ice
- **Moderate**
  - De-icing / anti-ice necessary
- **Severe**
  - De-icing / anti-ice fails to control the hazard

SCWD

- **Supercooled Water Droplets**
- Water droplets cooled below freezing but remain in liquid state.
  - Due to surface tension
- When surface tension is broken and they come into contact a surface they freeze.
- Large and small SCWDs are present in different parts of clouds.
- Only small SCWDs exist is ST / SC.



SCWD PROPORTIONS

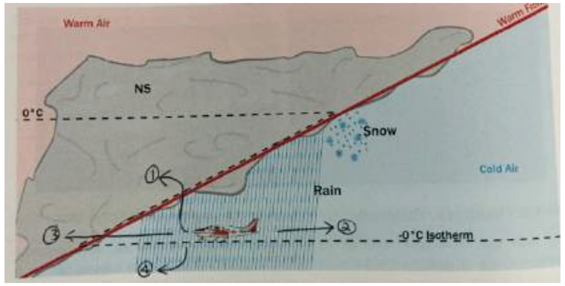
- For every degree below 0^0C, 1/80th of the drop will freeze instantly on impact.
- The rest will flow back over the wing.

AIRFRAME ICING

- **The following conditions are required for airframe icing:**
  - Below 0^0C
  - In cloud where moisture is present
- **Exception is freezing rain and hoar frost** which occur outside of clouds.

FREEZING RAIN / RAIN ICE

- **When flying below an inversion, when OAT less than 0^0C and rain is encountered.**
- Commonly occurs just ahead of a warm front.
- Can build up at a rate of 12 mm / min
- Escape options:
  - Climb / Turn Back / Speed Up / Descend
  - Turn Back is the book option of choice



HOAR FROST

- Occurs in clear air (cloud not required)
- Aircraft below zero comes into contact with warm moist air at temperatures > 0^0

Type	SCWD	Intensity	Notes
Impact / Rime / Opaque	Small	Light / Mod	Not serious
Clear / Flowback	Large	Mod/ Severe	Most severe at low temperatures (more flowback). Freezes gradually and is transparent.
Mixed / Cloudy	Small + Large	Mod / Severe	Combination of Impact & Clear

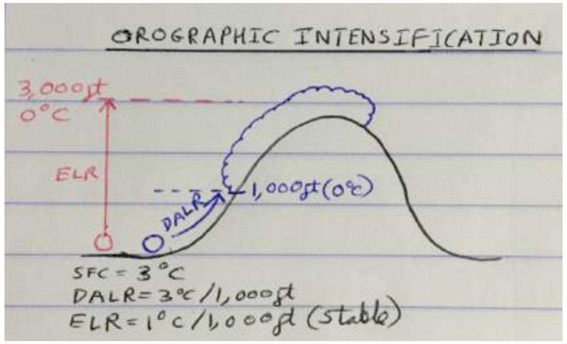
MET 16 – ICING

GROUND ICING

- Hoar Frost
- Freezing Drizzle
- Packed Snow
- Freezing Fog / Rime Frost
- Ice Fog
- Glaze Frost (Rain ice on surface)

FACTORS AFFETING ICING SEVERITY

- **Ascending / Descending**
    - Descending worse as a cold airframe enters more moist air.
- **Aerofoil Characteristics**
    - Thin aerofoil will up more icing.
    - "Thin before fat"
- **Airspeed**
    - Higher speeds result in more drops hitting per unit time => more severe
- **Kinetic Energy**
    - Airframe rises by temp of $(TAS/100)^2$
    - Requires very high speeds however to make a difference.
- **Cloud Density**
    - Precipitation reduces water content so icing likely to be less severe.
- **Cloud Base Temperature**
    - A cloud base at 0^0C will result in more icing than one at -10^0C due to warmer temperature holding more WV.
- **Orographic Intensification**
    - Freezing level in cloud is lower than the environment.



ICING EFFECTS / HAZARDS

- **Mass of Ice**
- **Aerodynamics**
- **Visibility**
- **Instruments**
- **Communications**
- **Systems**

ICE PROTECTION & REMOVAL

- **Anti-Ice:** Prevents Formation
- **De-Ice:** Removes ice accretion

- **Methods of anti-ice / de-Ice:**
    - Chemicals
    - Electrical Heating
    - Hot Air (Bleed) Heating
    - De-Icing Boots (De-Ice Only)

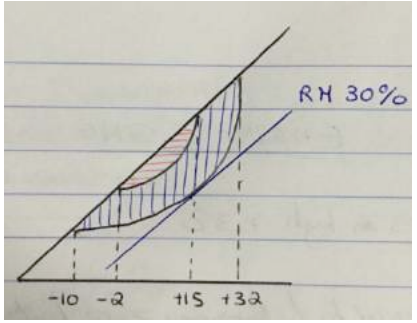
ENGINE ICING

PISTON ENGINES

- **Fuel Icing**
    - Water in fuel freezes in pipe bends
- **Oil Coring**
    - Congealing of oil at low temperatures
- **Impact Ice**
- **Carburettor Icing**
    - Throttle Ice
    - Fuel Ice

CARBURETTOR ICING SEVERITY

- **Can form anywhere between -10^0 and $+32^0$C with a RH > 30%**
- **Most severe between -2^0 and $+15^0$C in cloud, precipitation or fog at any power setting.**



TURBINE ENGINES

- Also subject to fuel icing like pistons.
- **Turbine icing most likely** to occur at high RPMs, with water droplets in cloud / fog up to + 10^0C

MET 17 – THUNDERSTORMS

CB'S VS THUNDERSTORMS

- Both CB's and thunderstorms have:
  - MOD / SEVERE Icing
  - MOD / SEVERE Turbulence
  - Hail
- Thunderstorms additionally have lightning.

REQUIREMENTS FOR TS FORMATION

- **Cloud Trigger**
- **Moisture**
- **Unstable Atmosphere**
  - When ELR > SALR

TRIGGERS

FRONTAL LIFTING TRIGGER

- CBs normally formed around a **cold front**.
- **Squall Line** – A big line of TS's that form ahead of cold / occluded fronts (I.E. In warm sector)

AIR MASS TRIGGERS

- **Orographic**
- **Convergence**
  - Particularly around a trough
- **Convection**
  - Land – Most common by day (large DV)
  - Sea – Both day and night (small DV)

CLASSIFICATIONS

TS CLASSIFICATIONS

- **Single – Cell (1 – 2 Hrs)**
- **Multi – Cell (3 – 4 Hrs)**
- **Super – Cell**
  - Lasts longest
  - Contains tornadoes

STAGES OF DEVELOPMENT

1. DEVELOPMENT STAGE

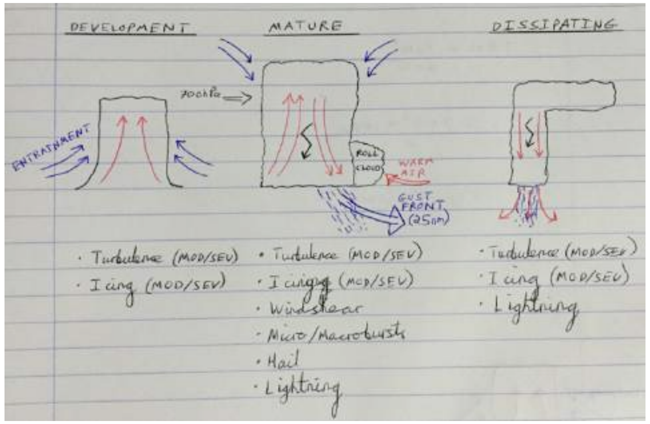
- **Takes approx. 15-20 mins**
- CU Humilis develops into CU Mediocris then CU Congestus.
- It is driven by **latent heat due to condensation**
- Characterised by **updrafts**
- **Entrainment** is the influx of dry air being drawn into the cloud.
  - Results in evaporation that could stop development if latent heat absorbed > latent heat given off from condensation.

2. MATURE STAGE

- **Takes approx. 15-20 mins**
- Characterised by **precipitation starting**
- Contains **updrafts and downdraft**
  - Downdraft from falling water droplets
- A **gust front** forms 25nm ahead
  - Descending air initially warms adiabatically.
  - Entrainment cools the air however and makes it more dense.
  - Spreads out when it reaches the surface
- Water droplets breaking up results in **static electricity** leading to **lightning**.
- **Roll cloud** can form on the bottom leading edge
- The TS will move with the **700 hPa wind**

3. DISSIPATING STAGE

- **Takes approx. 1 Hour**
- Contains **mainly downdrafts**
- **Precipitation continues**
- **Lightning possibility** still exists



MET 17 – THUNDERSTORMS

LIGHTNING

LIGHTNING

- Ice crystals (top of cloud) tend to be positive
- Water droplets (bottom) tend to be negative
- **Leaders** extend from both ground and cloud. When they meet there is a flow of current and lighting strike occurs.
- Most likely to experience lightning **5,000 ft either side of the freezing level => With temperatures between -10⁰C and +10⁰C**


Electrostatic Charge on a Thundercloud

SUPER-CELL THUNDERSTORMS

DIFFERENCES

- Characterised by **tornadoes**
- **Strong upper winds** result in separation of the updrafts and downdrafts.
  - They now do not tend to cancel each other out so the lifetime is extended.

TYPICAL CHARACTERISTICS

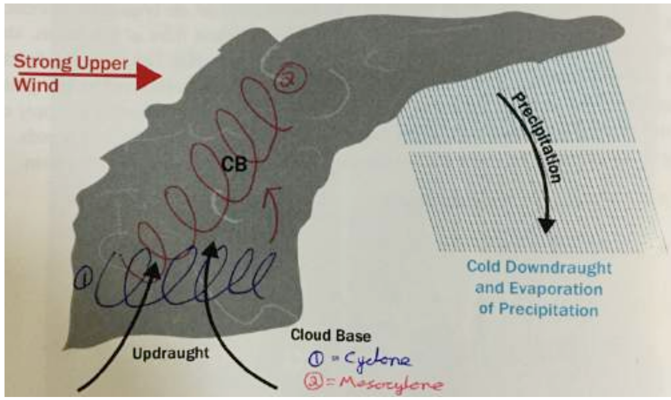
- Mainly occurs in **mid-west USA**
- Occur in **spring / early summer**
- **Hail can exceed 0.75 inches**
- **Gusts can exceed 50 kts**

1. INITIAL STAGE

- Same as a single-cell thunderstorm
- Updrafts develop.

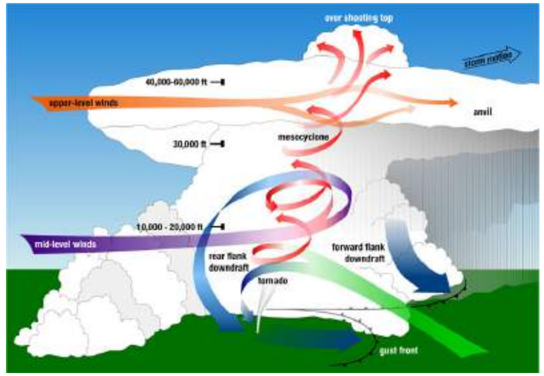
2. SUPER CELL

- **Windshear** will cause a **cylonic motion** to form in the horizontal plane.
- The updrafts will lift the cylone towards the vertical and a **mescocylone** is formed within the cloud.
- This has a **rotating centre**



3. TORNADO

- The lifecycle of the tornado can be further broken down into 3 parts.
- **1 Initial** – Precipitation drags down and area of quickly descending air creating a rear flank downdraft. The RFD pulls down the mesocylone and cloud and a **funnel starts to develop.**
- **2 Mature** – Eventually the **funnel reaches the surface.**
- **3 Dissipation** – Cold air from RFD surrounds the tornado and cuts off the warm moist air supply.



4. DISSIPATION

- Tornado dies out and thunderstorm follows.

MET 17 – THUNDERSTORMS

WATERSPOUTS

- Tornadoes over the sea are known as **waterspouts.**
- Only **20 – 30 ft in diameter** however and do not have the destructive power of tornadoes.

MICRO / MACRO BURSTS

- Included in the TS hazards.
- Only last for about **1 - 5 minutes.**
- **Microburst is less than 4 km**
- **Macroburst is greater than 4 km**

PRESSURE VARIATIONS

- Altimeter may vary by up to 1,000 ft in the vicinity of thunderstorms.

TS AVOIDANCE

- An airborne weather radar (AWR) will sense the concentration of water droplets.

- **If avoiding TS using the AWR:**
  - Avoid by 10 nm when below 20,000 ft
  - Avoid by 20 nm when above 20,000 ft
- **If avoiding TS visually, avoid by 10 nm at any altitude.**

- If you must overfly a TS then **overfly by at least 5,000 ft.**

PEARSON TORNADO SCALE		
Scale	**Windspeed (kts)**	**Damage**
0	30 – 60	Light
1	60 - 90	Moderate
2	90 - 130	Considerable
3	130 - 170	Severe
4	170 - 220	Well constructed houses are levelled
5	220 - 270	Strong frame houses are lifed from foundations.

TS CLASSIFICATION

- ISOL = Individual
- OCNL = Well separated
- FRQ = Little or no separation
- EMBD = Embedded

MET 18 – AIR MASSES

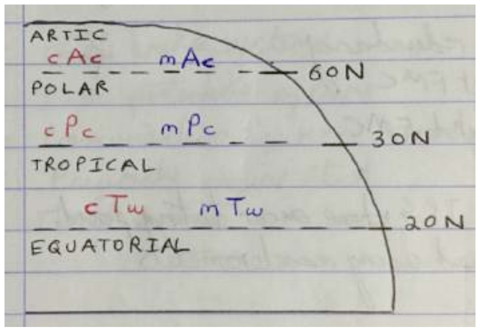
SOURCE CHARCTERISTICS

- **Large volume** of air (can be thousands of nm across).
- Slack pressure gradient => **Very slow moving**
    - Due to almost stationary nature, they take on the characteristics of the surroundings.
- **High Pressure & Stable**

SOURCE NAMING

- Air masses are named according to the **temperature and humidity (in the horizontal plane) at source.**
- Named either **Continental (Land) / Maritime**
- Named **Equatorial, Tropical, Polar or Artic** depending on its latitude.
- Equatorial & Tropical will be a **warm air mass** and Polar & Artic will be **cold air masses.**

- Tropical Continental (cTw) Sahara
- Tropical Maritime (mTw) "Azore's High"
- Polar Continental (cPc) "Siberian High"
- Polar Maritime (mPc)
- Artic Continental (cAc)
- Artic Maritime (mAc)



AIR MASS MODIFICATIONS

- As the air mass moves away from source, it's characteristics will change.

- A change in **latitude will affect temperature, stability and relative humidity.**
    - Move South = Warming from below = Stability Decreases & RH Decreases
    - Move North = Cooling from below = Stability increases & RH Increases

- The **surface it moves over will affect the absolute humidity.**
    - Over land = AH Decreases
    - Over Sea = AH Increases

CLOUD & PRECIP TYPES

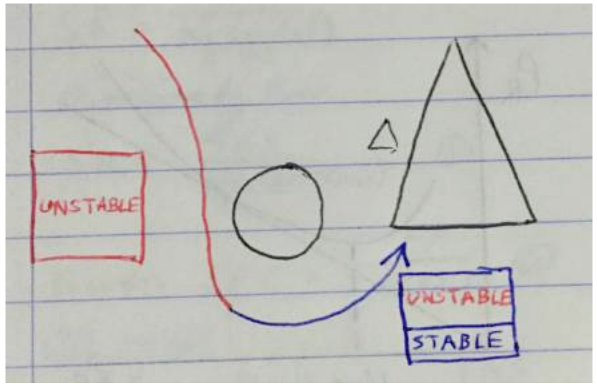
- **If stability has decreased => Unstable**
    - CU / CB / TS with showers
    - Vis good outside showers
    - Inland, the moisture dries out leaving clear skies.

- **If stability has increased => Stable**
    - ST/ SC with drizzle
    - Viz poor in haze

- If **continental air mass**, it will be dry so **no cloud forms and haze will be present.**
    - The exception is cPc with a sea track.
    - Added moisture gives ST / SC / CU with RA and SN.

RETURING POLAR MARITIME

- **Presence of a pressure system** will cause the mPc to head south of the sea initially then turn north towards the UK.
- On the **southern track,** temp increases and stability decreases.
    - CU / CB / TS forms out at sea
- On the **northern track towards the UK,** temp decreases and stability increase.
    - A lower layer of stable air forms.
    - Thickness of the stable layer depends on length of returning track.
    - ST / SC forms over the UK.
- Inland convection could cause the stable layer to be broken through.
    - CU / CB / TS could then form inland.



MET 18 – AIR MASSES

	mTw	mAc	mPc	cTw	cPc		mPw	
At Source	Stable Moist Warm	Stable Moist V Cold	Stable Cold Moist	Stable V Warm Dry	Stable V Cold Dry	SEA TRACK	Same as mPc (Over Sea)	Same as mPc (TRK TO UK)
Temp	↓	↑	↑	↓	↑	(Moisture added but since dry initially not enough to CBs etc)	↑	↓
Stability	↑	↓	↓	↑	↓		↓	↑
RH	↑	↓	↓	↑	↓		↓	↑
AH	↑	↑	↑	-	-	↑	↑	↑
Cloud	ST / SC	CU / CB/ TS	CU / CB /TS	-	-	ST / SC / CU	CU / CB / TS	ST / SC
Precip	DZ	SH	SH	-	-	RA / SN	SH	DZ
Viz	Poor in HZ	Good outside SH	Good outside SH	HZ	HZ	Good outside RA / SN	Good outside SH	HZ
UK Inland	Fog	Clear Skies, Very Cold	Clear skies, poss radiation fog at down	-	-	-	-	-
Other	Azores	Also cAC		Balklands / E Asia	Siberian High Extremely Cold			

SEASONAL VARIATIONS

- **Artic & mPw (Returning) – Winter Only**

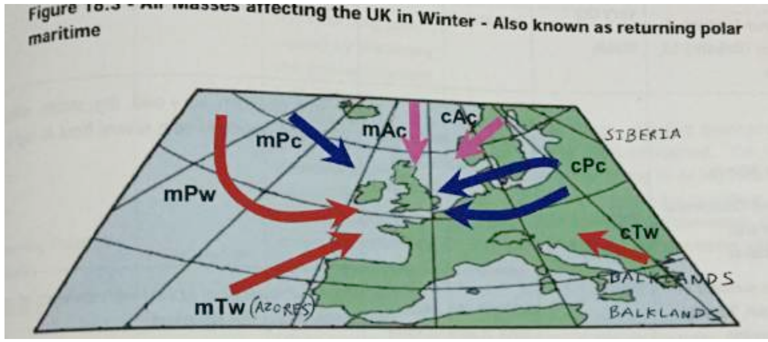


Figure [illegible] affecting the UK in Winter - Also known as returning polar maritime

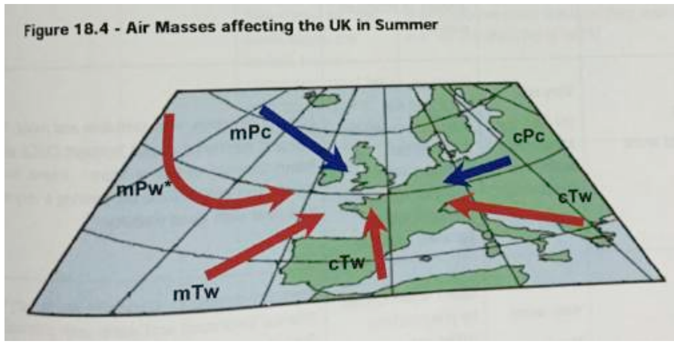


Figure 18.4 - Air Masses affecting the UK in Summer

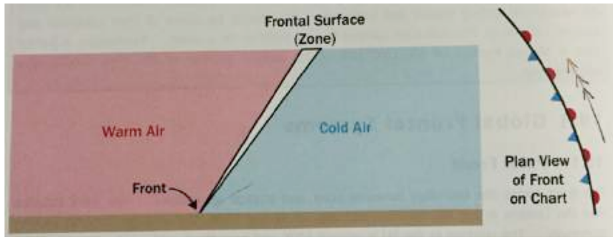
MET 19 – FRONTS AND POLAR FRONT DEPRESSIONS

WHAT IS A FRONT

- **When two air masses of different temperature and humidity meet.**
- The **cold air will always undercut the warm air** as it is **more dense.**
    - Slope always leans towards the cold mass.

QUASI-STATIONARY FRONT

- **Hardly any movement**
- Very little interaction between them so **no significant wx.**
- Wind flows from cold (HP) to warm (LP) and is deflected through 90^0 so **blows along the frontal zone.**

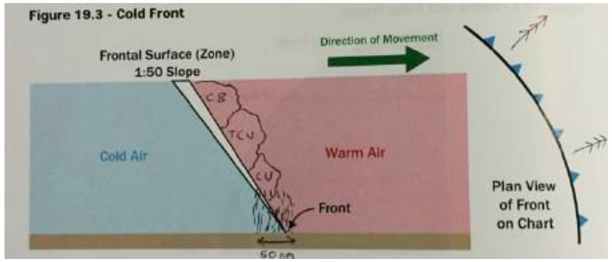


FRONTAL SPEEDS

- **Cold Front** – Full Geostrophic Wind Speed
- **Warm Front** – 2/3 Geostrophic Wind Speed

COLD FRONT

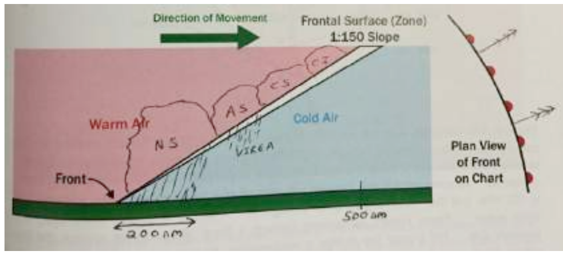
- **Cold air replaces warm air at the surface.**
- **Unstable CB / TCU / CU**
- **Precipitation 50nm wide both ahead and behind the front.**



- Due to its steep gradient, **surface friction** can cause a **nose overhang** to develop.
- A **squall** can develop if this collapses.

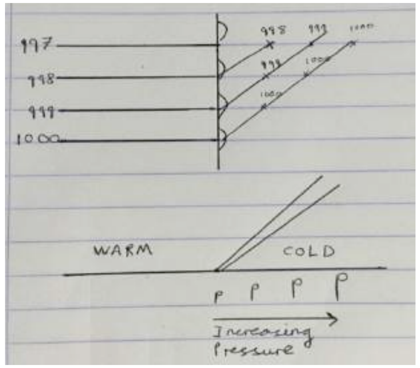
WARM FRONT

- **Warm air replaces cold air at the surface.**
- **Stable CI / CS / AS / NS**
- **Precipitation 200nm ahead of the front.**
    - Continuous and Moderate



ISOBARS

- The **isobars bend at the fronts** due to the change in pressure.
- As a warm front passes through, pressure decreases.
- As a cold front passes through, pressure increases.
- Considering the warm front:



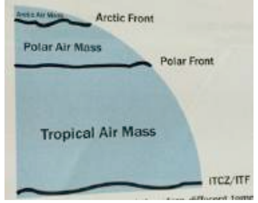
STRENGTHENING / WEAKENING

- **Frontogenesis** – Strengthening
- **Frontolysis** – Weakening
    - Marked by crosses on the chart

MET 19 – FRONTS AND POLAR FRONT DEPRESSIONS

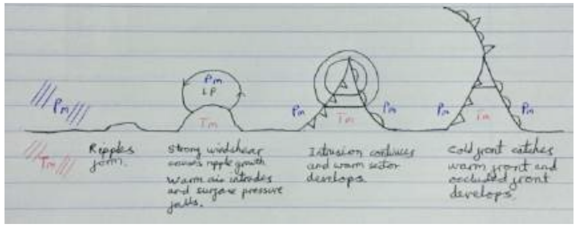
POLAR FRONT

- Where the **tropical air mass and polar air mass meet.**
- Located **further north in summer.**

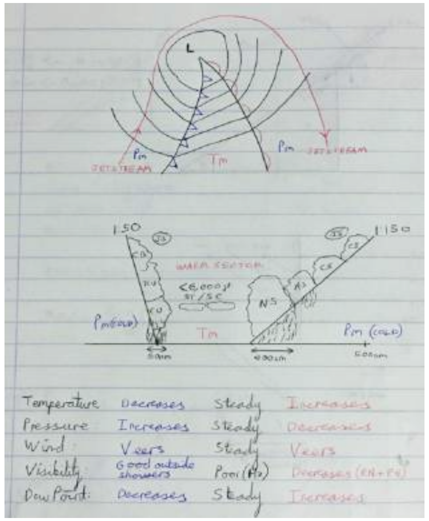


POLAR FRONT DEPRESSIONS (PFD)

- Forms along the polar front.
- Develops due to **ripples and intrusion of tropical warm air** which lowers the surface pressure.
- Takes **4 days** to reach the point of lowest pressure.
- Takes **10 days** or more to fill and dissipate.



POLAR FRONT DEPRESSIONS (PFD)



- Note the jet stream is closer to the surface front of the cold front than the warm front due to the steeper gradient.

PRESSURE AND FRONTS

- As a warm front approaches, pressure falls and then remains constant after it passes.
- As a cold front approached, pressure falls (due to lifting) then increases after it passes.

POLAR FRONT SFC PROJECTION

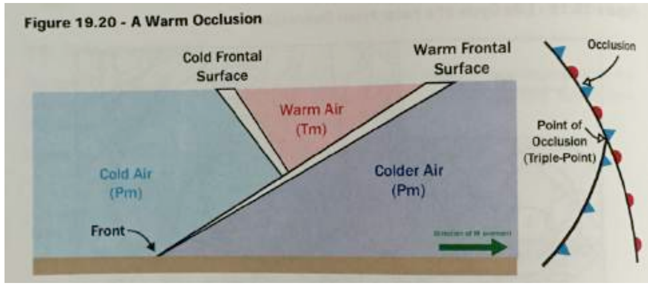
- The jet stream is closer to the surface front of the cold front than the warm front due to the steeper gradient.
- 50 – 200 nm behind cold front
- 300 -450 nm ahead of warm front

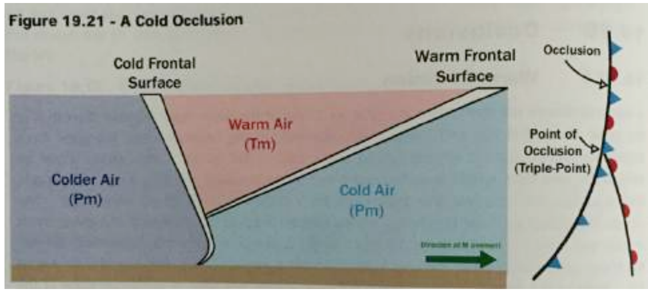
WARM SECTOR CLOUDS

- Kata Front = Stable = Stratiform
- Ana Front = Unstable = Cumuliform (can contain EMBED CB within NS)

OCCLUDED FRONT

- When the cold front catches the warm front.
- **Warm occlusion (Winter)**
  - Land is colder in winter so the cold air holds it's position and the warm front rides up above it.
- **Cold occlusion (Summer)**
  - Land is warmer in winter (less dense) so the cold air behind the cold front cuts into the polar air ahead of the warm front.

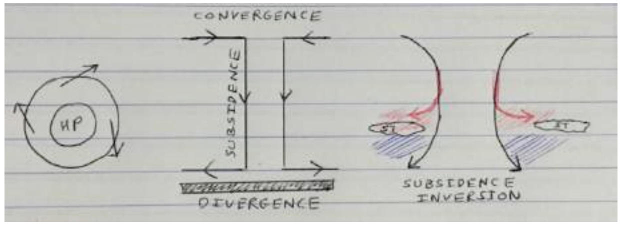




MET 20 – ANTI CYLONES

CHARACTERISTICS

- An **anticyclone is a high pressure system**.
- There is **divergence at the surface, convergence at altitude** and **subsidence in the centre**.
- Subsidence **limits the formation of clouds and precipitation.**
- A **subsidence inversion** often forms as subsiding air is warmed adiabatically and spreads out over cooler air near the surface.
- Anticylones are categorized as warm or cold depending on how they are formed.



CHANGES OF STRENGTH

- **Intensifying** – Pressure is increasing as convergence exceeds divergence.
- **Weakening** – Pressure is decreasing as divergence exceeds convergence.

WARM ANTICYCLONES (PERMANENT)

- Lie in the **tropical air south of the polar front.**
- Warm air near surface is overlaid by cold dense air from above.
- Characterised by a **pressure bulge upwards through a great depth.**
- **EG/ Azores High**

WARM ANTICYCLONES (BLOCKING)

- **Break-off** from a permanent warm anticyclone.
- **Temporary** - Establishes itself in the higher latitude for several days.
- **Last longer over land** than at sea.
- Can **deflect PFDs** north of the UK.

COLD ANTICYCLONES (SEMI-PERMANENT)

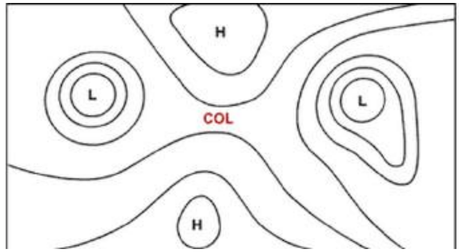
- Lie in the **polar air north of the polar front.**
- **Conduction** from cold surface subjects air to **intense cooling.**
- Since pressure decreases quicker in cold air, a shallow layer of subsidence is created.
- Typically does not show higher than 500 hPa
- **EG/ Siberian High**

COLD ANTICYCLONES (INTERMEDIATE HIGH)

- **Temporary**
- Formed by a **ridge**
- **Southward migration** can result in warming and formation of a **blocking high.**

COL

- Slack pressure between two highs and two lows.
- Clear skies and light wind result in max DV of temperature.
- Max heating during **summer results in thunderstorms.**
- Max cooling during **winter results in low cloud and fog.**

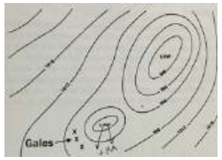


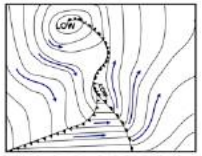
MET 20 – OTHER DEPRESSIONS (CYLONES)

SECONDARY DEPRESSIONS

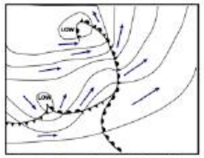
- Can form in 3 cases:
- **Within the circulation of a larger primary depression**
- **At the triple point of a PFD occlusion.**
- At the **trailing edge of a cold front**

- **Gales** form on the side furthest from the primary centre.
- **Heavy rainfall** moves outwards from the centre of the secondary low.





A Secondary Front Formed at the Tip of a Warm Sector Where Fronts Have Occluded



A Secondary Depression on the End of a Cold Front

THERMAL DEPRESSIONS (SUMMER)

- Over land
- Unstable air mass
- Slack pressure gradient

- Sun heats surface during the day and convection results.
- **Rising air creates a low pressure at the surface and a depression is formed.**
- Dry air = Cloudless
- Moist air = CU / CB / TS which die out in the evening once the isolation stops.

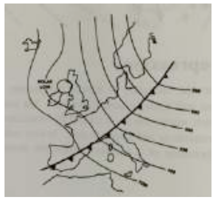
THERMAL DEPRESSIONS (WINTER)

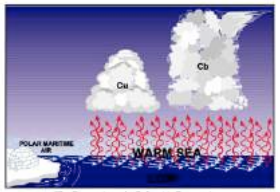
- Over water

- Land is cold but water (which has little DV) is relatively warmer than the land.
- When a cold front passes, the **cold air overlies the warmer air** and **instability results.**
- Convection causes CU / CB / TS to form.
- Normally expect good vis etc with the pass of the cold front but TS can persist.

POLAR LOW

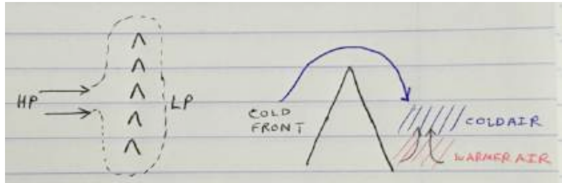
- A type of termal depression that is **non-frontal.**
- Cold polar maritime air **behind** a cold front moves **south-east (due to north-westerly winds) over a progressivly warmer sea.**
- **Instability and convection** results in CB and showers.





OROGRAPHIC DEPRESSIONS

- **Low pressure forms on the lee side** of a mountain range as the passage over the top is blocked and it flows round the sides instead.
- With the passage of a cold front, the **cold air at upper levels spills onto the lee side** where there is relatively warmer air at the surface.
- **Instability and convection results.**



TROUGHS

- **Strong convergence** at the surface results in lifting of air and vertical development clouds.

DUST DEVIL

- On a **hot day with clear skies,** convergence and rising air occurs at the surface.
- If windshear is present, small cylonic motion can result which will lift dust etc.

MET 21 – GLOBAL CLIMATOLOGY

CAUSE OF GLOBAL CLIMATOLOGY

- The **obliquity of the ecliptic** results in temperature variations which leads to pressure gradients etc.
- As a result of natures attempt to stabilize everything, global circulation patterns arise.

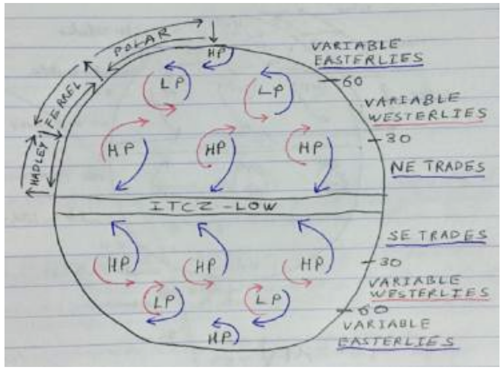
- The NH summer solstice occurs in June. There is max heating of the northern hemisphere during this period and the maximum temperature is reached in July (due to heating lag).

- The NH winter solstice occurs in December. There is minimum heating of the NH during this period at the minimum temperature occurs in January.

TROPOSPHERIC CIRCULATION

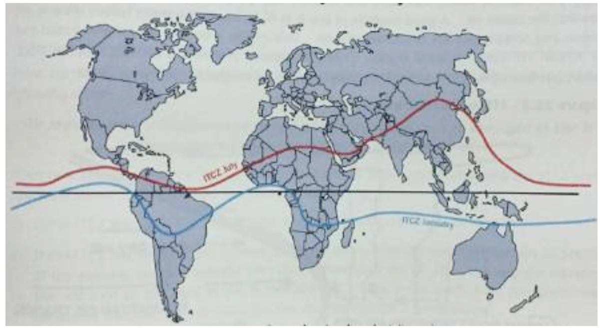
- Maximum heating at the equator results in air rising and convergence at the surface.
- This results in low pressure at the equator.
- Rising air diverges at the tropopause and heads north where it cools and descends at 30 N creating high pressure.
- Cold polar air descends and diverges at the surface resulting in high pressure.
- This flows south and heats up before converging at 60N and creating low pressure at the surface.

- Wind flows from high to low and the geostrophic force acts.
- This creates easterlies, westerlies and the trade winds.



MOVEMENT OF THE ITCZ

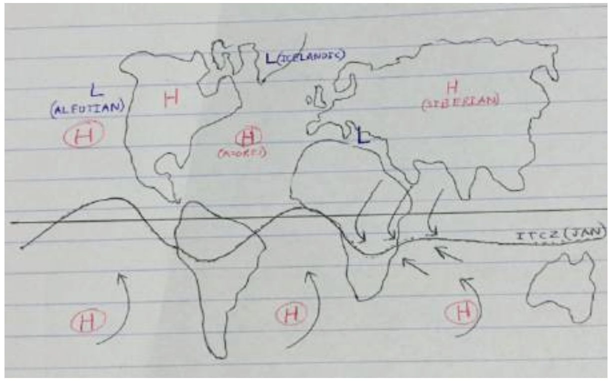
- The ITCZ is essentially the earth's heat equator.
- In **January**, the southern hemisphere receives the most heat and **the ITCZ is displaced south of the equator.**
  - Parts of the ITCZ remain north of the equator due to the high pressure south of the equator around the cold coasts.
  - This brings cold sea air north and prevents the ITCZ from dropping south.
- In **July**, the northern hemisphere receives the most heating and the **ITCZ is displaced north of the equator.**



MET 21 – GLOBAL CLIMATOLOGY

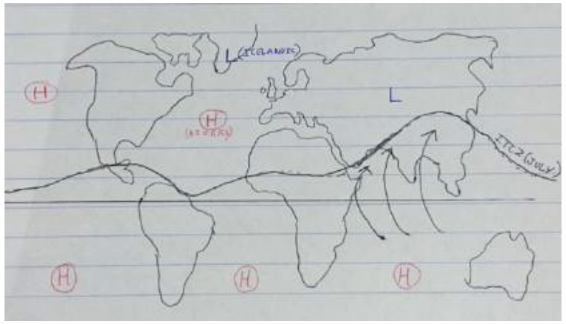
JANUARY PRESSURE SYSTEMS

- In January, the northern hemisphere is in winter.
- 3 HP STJs in the SH present as always, along with the Azores high and high off the west coast of America.
- Icelandic Low present.
- Cooling of N America and Russian land mass results in high pressure over these regions.
    - N American High
    - Siberian High
- A thermal low occurs in the Mediterranean where cold air from land blows over the relatively warmer sea mass.
- Note the NW and SE trade winds.



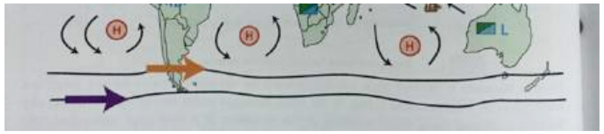
JULY PRESSURE SYSTEMS

- In July, the northern hemisphere is in summer.
- 3 HP STJs in the SH present as always, along with the Azores high and high off the west coast of America.
- Icelandic Low present but reduced in strength.
- Heating of Russian land mass results in low pressure over this region.

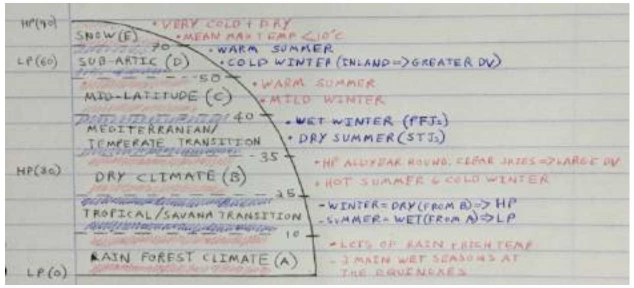


ROARING 40'S & HOWLING 50'S

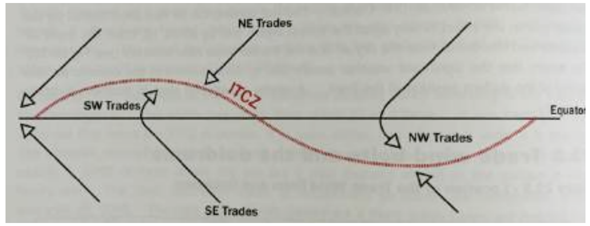
- Westerlies in the SH have very little land to impede their progress.



CLIMATIC ZONES (KOEPPEN CLASSIFICATION)



TRADE WIND VARIATIONS WITH ITCZ



MET 22 – TROPICAL CLIMATOLOGY

ITCZ

- Trade winds **converge** on the ITCZ
- Weak winds give rise to weak convergence

- There is more movement of the ITCZ over land than at sea.

- Instability is created where two air masses meet.
- High temperature, instability, convergence and heat give rise to **possible** TS up to the troposphere and beyond.

ITCZ CHARACTERISTICS

- Thermal low
- In vicinity of heat equator
- No circulation due to weak GF
- Weak convergence
- TS / Clear skies possible
- Unstable

MESOSCALE CONVECTIVE COMPLEXES

- **Oval / circular collection of thunderstorms**
- Occurs over a **very large scale**
- May persist for **12 hours or more**
- **Slow moving**

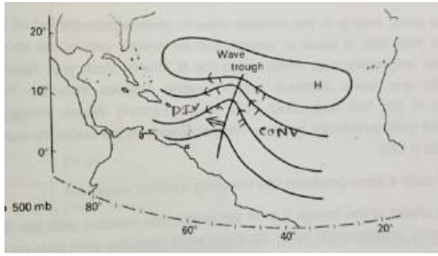
- Occurs within the warm sector at the **dryline**
  - Where cTw and cTm air masses meet

EASTERLY WAVES

- Troughs orientated N/S moving slowly in a westerly direction.
- Form over Africa and cross the North Atlantic on their way to America.

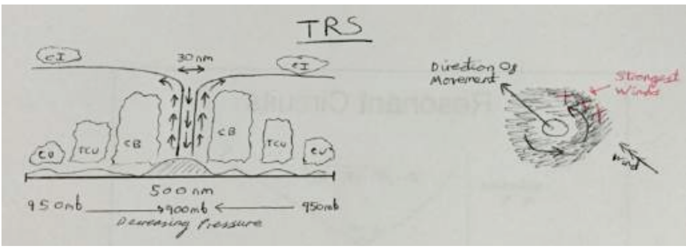
- On the east side, wx is poor due to convergence.
- On the west side, wx is fine due to divergence.

- **10%** of these become a **tropical disturbance**



TROPICAL DISTURBANCE

- Disorganised array of cloud and thunderstorms.
- Formed by:
  - Convergence at ITCZ
  - Intrusion of trough from higher lats
  - Easterly waves



TROPICAL STORMS & TRS

- Heating of a tropical disturbance and addition of moisture due to sea track results in further convection and lower pressure.
- Lower pressure increases the wind speed.
- Wind > 34 kts = Tropical Storm
- Wind > 64 kts = Tropical Revolving Storm (TRS)
- Tropical storms do not exist in the high pressure areas south of the equator.

TROPICAL REVOLVING STORMS

- Named depending on their geographic location.
- **Hurricanes (America) / Cyclones (Africa) or Typhoon (Asia)**

- **TRS Formation Requirements:**
  - Sea temperature of +27^{0}C
  - Between 5^0 – 25^0 with a trigger action (usually convergence at the ITCZ)
  - Light wind with little shear at height

- **Typical Diameter –** 500 m
- **Typical Pressure** – 900 to 960 mBar
- **Wind Speeds** - > 64 kts
- **Normally Summer – Autumn in NH**
- **Normally Winter – Spring in SH**

- **Descending air in the eye clears the cloud.** It does not cause high pressure however as it is pulled back up by low pressure near surface.
- TRS dies out over land as the moisture supply is cut off.
- Low pressure causes **swelling of the sea.**
- **Cirrus canopy rotates clockwise** due to divergence at altitude.

MET 22 – TROPICAL CLIMATOLOGY

MONSOON DIRECTIONS

January Monsoons

Darwin

Asia
Dakar

July Monsoons

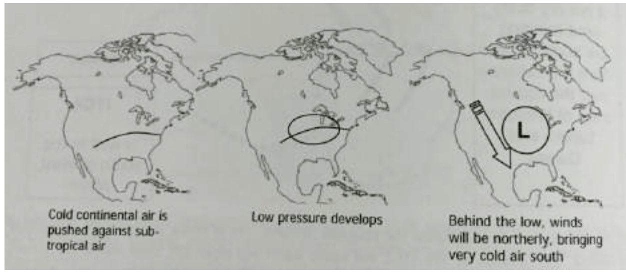
Asia
Dakar

Darwin

COLD AIR OUTBREAKS

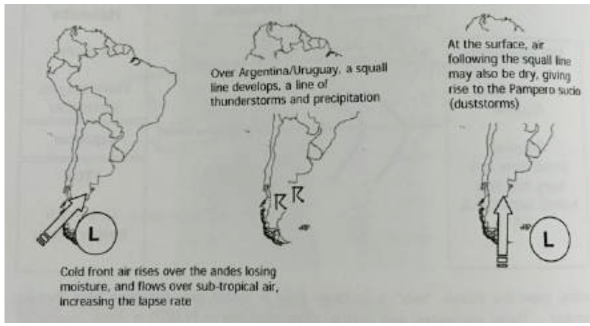
USA

- Winter / Early Spring or Summer
- Results in a blizzard



PAMPERO

- Winter / Early Spring or Summer



DUST STORMS

DUST STORMS

- Results from the **lifting of dust / sand** due to:
  - Increasing wind speeds
  - Cold Fronts
  - Local surface heating

- **Sand is heavier than dust** so is not blown very high and settles quickly once the storm dissipates.
- **Dust lingers in the air for longer** as it is lighter.

MET 22 – TROPICAL CLIMATOLOGY

MONSOON WEATHER

MONSOON DEFINITION

- Defines seasonal changes in weather when the wind changes direction by more than 120^0
- Such a change occurs due to movement of the ITCZ between seasons and the associated change in trade winds.

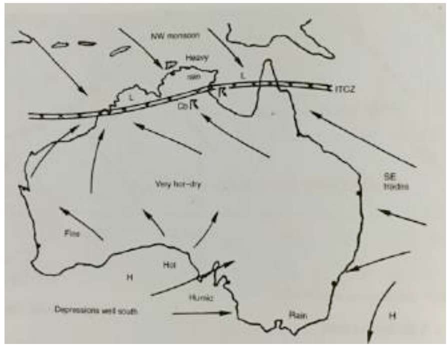
ASIA

- **January = NE Monsoon**
  - Normally clear and dry as the wind blows from the Siberian high.

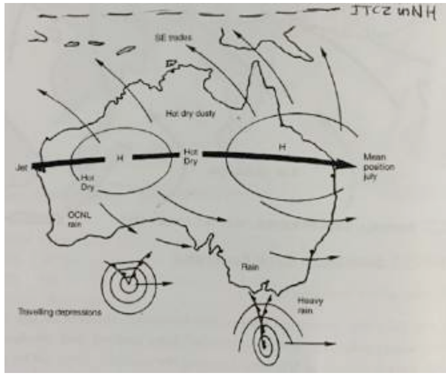
- **July = SW Monsoon**
  - Normally unstable with TS

AUSTRALIA (DARWIN)

- **January = NW Monsoon (CB / TS)**

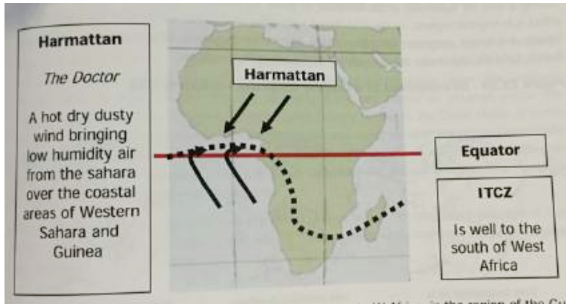


- **July = SE Monsoon (Hot, dry and dusty)**
  - ITCZ in NH and STJs over central Australia

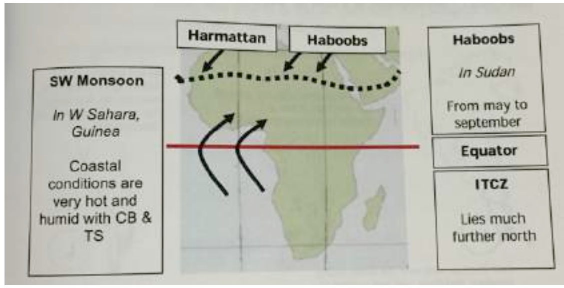


AFRICA (DAKAR)

- **January = NE Harmattan (Hot, dry & dusty)**
  - Harmattan = "The Doctor" giving a break from the normally humid conditions



- **July = SW Monsoon (CB / TS)**
  - Sudan experiences the Haboob's (NE dust storm)



MET 24 – MID LATITUDE CLIMATOLOGY

LOW PRESSURE

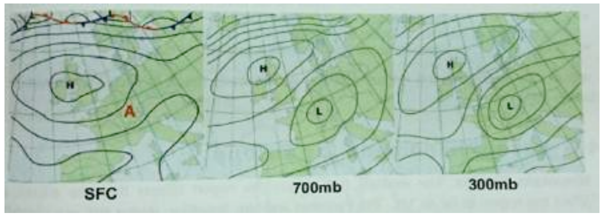
- PFDs hit Spain and the Mediterranean by winter but can route north of the UK in summer.

HIGH PRESSURE

- Siberian High in winters brings very cold winds and possible snow showers if the air travels any distance over the north sea.
- In summer, Azores high dominates.
- Blocking anticyclones can form from the Azores high.

COLD AIR POOLS

- Formed when cold air from an **old depression** is undercut by warmer air.
- They are **not visible on the surface chart.**
- **Difficult to forecast** due to their **unpredictable movement.**



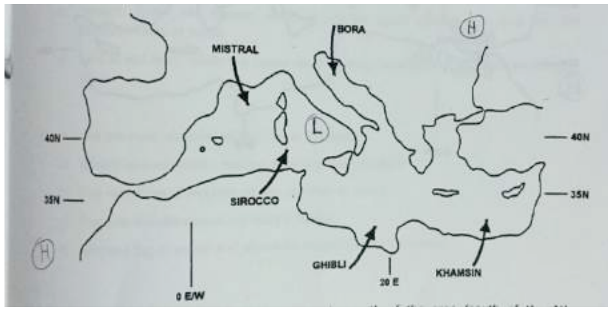
FLAT PRESSURE

- Area of **slack pressure gradient** at the SFC.
- Winter = Fog
- Summer = TS
  - 1200 = CU Humilus
  - 1400 = CU Mediocris
  - 1600 = CU Congestus
  - 1800 = CB / TS
  - 2100 = SC / AC

LOCAL SURFACE WINDS (WINTER)

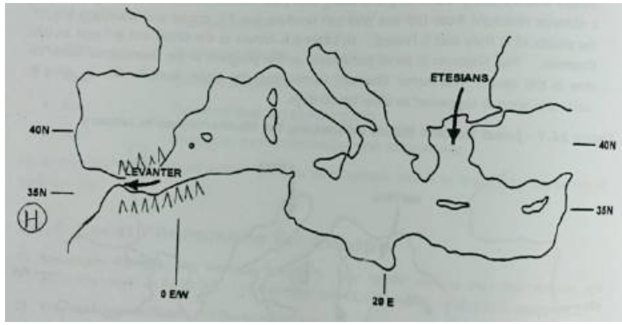
- Mix of very cold unstable outflow from Siberian high and warm, dry and stable inflow from the Sahara.

- **Mistral –** Ravine Wind | Becomes Unstable
- **Bora –** Ravine Wind | Becomes Unstable
- **Sirocco / Ghibli / Khamsin** – Blows from North Africa | Dry, hot and stable



LOCAL SURFACE WINDS (SUMMER)

- **Etesians –** Relatively Cool
- **The Levanter –** Very Humid

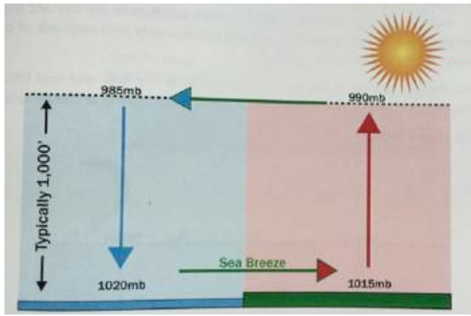


MET 24 – LOCAL WINDS

SEA BREEZE

- Requires a **slack pressure gradient**
- Occurs **during the day**

- Surface heating results in land being warmer than sea.
- Pressure decreases at a lower rate within warm air compared with cold air.
- The pressure at approx. 1,000 ft is high over land and low over the sea in comparison.
- The **first horizontal movement of air from land to sea occurs at 1,000 ft**
- The resulting circulation pattern creates high pressure over the sea and low pressure over the land at the surface.
- **Once the surface pressure differential exceeds the surface friction, a sea breeze from sea to land now results** at the surface.
- If persisting into the afternoon, the geostrophic force can cause the wind to blow parallel to the coast.



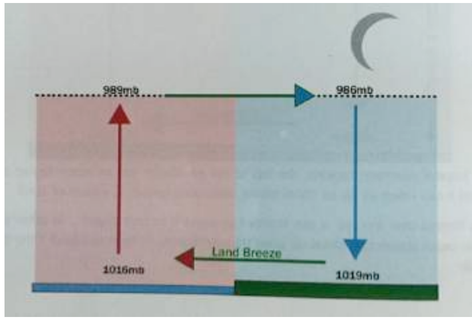
- **10 – 15 kts**
- **Extends 10 – 15 nm** either side of coast

LAND BREEZE

- Requires a **slack pressure gradient**
- Occurs **during the night**

- Surface cooling results in land being colder than sea.
- The **first horizontal movement of air from sea to land occurs at 1,000 ft**
- The resulting circulation pattern creates low pressure over the sea and high pressure over the land at the surface.
- **Once the surface pressure differential exceeds the surface friction, a land breeze from land to sea now results** at the surface.

- **5 kts (**Pressure gradient less at night)
- **5 nm** either side of coast



KATABATIC WIND

- Night / Early Morning (Bare Slopes)
- Day / Night (Ice covered)
- Most common on north facing slope (NH)

- Slopes cool at night via **radiation**
- Air in contact cools by **conduction**, becomes more dense and **flows down the slope**.
- Rivers at the bottom of the valley add moisture resulting in **valley (mixing) fog.**

- Ice covered slopes are colder than surrounding air even during the day,

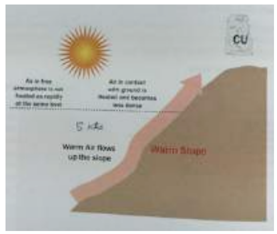
- Typically falls down at 10 kts

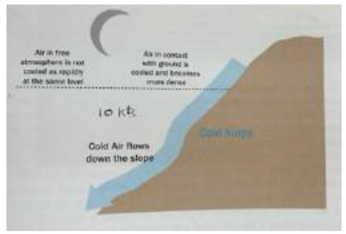
ANABATIC WIND

- During Day
- South Facing Slopes (NH)

- Slope is heated by insolation and air in contact with slope is heated by conduction.
- Air becomes less dense than surrounding air and **flows up the slope**.
- Lifting can result in Fair Wx CU at top of slope.

- Typically falls down at 5 kts (gravity slows it)





MET 24 – LOCAL WINDS

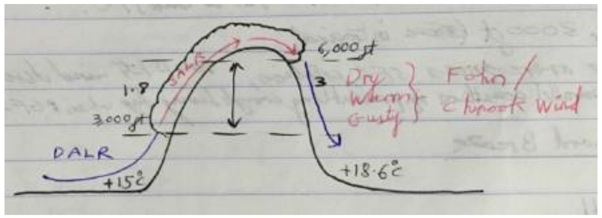
FOEHN WIND

- **Base higher on the lee side** due to loss of moisture from contact with surface on the winward side.

- In the ‘gap’ between the bases, the air on the windward side cools at the SALR whilst on the leeward side it warms at the DALR.
- The net effect is **warming on the lee side at 1.2^{0}C / 1,000 (DALR – SALR)**

- The wind blowing down the leeside is **warm, dry and gusty**. Known as the **Foehn / Chinook Wind**

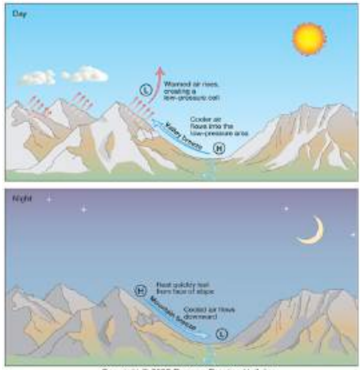
- In the example below, the temperature on the lee side is: 15 + (3 x 1.2) = + 18.6^{0}C



VALLEY & MOUNTAINS WINDS

- **Valley Wind**
  - During day
  - Similar to a sea breeze
  - Heating results in a anabatic breeze

- **Mountain Wind**
  - During night
  - Similar to a land breeze
  - Cooling results in a katabatic breeze



VENTURI / RAVINE WIND

- **Air accelerates and pressure drops** when blowing through a mountain valley.
- **Sudden reversals of wind direction** can occur within the valley.

HEADLAND EFFECT

- Similar venturi effect created as wind flows round a headland.

MET 26 – SATELLIITE AND GROUND RADAR

PURPOSE

- Enable predictions to be made in areas where **ground stations are not available.**

GEOSTATIONARY SATELLITES

- **Fixed position relative to the earth**
- Orbit at altitude of **36,000 km**
- **5 satellites are placed 70^{0} of lat apart**
- Distorted image above 55 N / S
- Provide **continuous coverage** of a fixed area

POLAR-ORBITING SATELLITES

- **Sun synchronous -** Fixed position relative to the sun
- Orbit at altitude of **800 km** = **higher resolution**
- Provide coverage of the high lats and polar regions
- **14 orbits occur each day**
- Full global coverage obtained **every 12 hours**
- Do not provide continuous coverage so **harder to observe trends**

VISUAL IMAGERY

- **Only available by day**
- Good for spotting **low cloud and fog** (except against white background in polar regions)
- Shows the **albedo effect** (reflections)

INFRARED

- Can be used during **day and night**
- Cloud levels are indicated via temperature changes
- Hotter (=> lower) clouds show as deeper tones of black.
- **Struggles with showing low cloud / fog** as the temperature is very similar to earth surface.

MSG – METEOSTAT SECOND GENERATION

- Higher resolution
- Colour imagery

GROUND RADAR

- **Higher transmitter power** available allows a **shorter wavelength** to be used.
- **Drizzle can also be picked up**
- Can be sent via **datalink** to aircraft

- **Beam Overshoot**
  - Radar is tilted up to prevent reflection
  - Low cloud further away from transmitter may not be picked up due to 'blind spot'

- **Beam Blocking**
  - High ground blocking line of sight

- **Beam Attenuation**
  - Similar to 'blind alley' with AWR

- **Virga**
  - Shows on radar but will not actually reach surface

- **Duct Propagation**
  - Inversion bends the radio beam and it paints the ground rather than the sky.

MET 27 – METARS AND TAFS

RVR

- Measured from a height of **2.5m AGL**
- Reported when prevailing vis < 1500 m
- Reports discontinued when vis > 2000 m

- P1500 = > 1500 m
- M0100 = < 100 m

- Trend based on 10 mins prior to issue
- D = Decreasing
- N = Constant
- U = Increasing

WIND REPORTING

- **Gusts** when **+ 10 kts** from the mean speed
- **Varying** when ± 60 kts
- **Windshear** when below 1600 ft

VIS REPORTING

- **< 800 m** = Rounded down to nearest 50 m
- **800 – 5 km =** Rounded down to nearest 100 m
- **5 km +** = Rounded down to nearest 1 km

- **Directional vis** reported when less than 1500 m or 50% of the prevailing visibility

CLOUD BASE REPORTING (ROUNDING)

- Up to 10,000 ft = 100 ft increments
- 10,000 ft + = 1,000 ft increments

TREND INFORMATION

- Based on forecast trend **+ 2 Hrs** ahead
- **NOSIG** = No significant changes expected

CAVOK

- No cloud below 5,000 ft or the highest MSA
- Vis 10 km +
- No CBs

- If there is no cloud below 5,000 ft / highest MSA but vis is less than 10 km, **NSW** is used and the vis is reported.

- No cloud at any level = **SKC (Sky Clear)**

"ODD" WX CODES

- PR – Partial
- MI – Shallow
- BC – Patches
- BL – Blowing
- DR – Drifting
- BR – Mist
- PO – Dust Devils

TURBULENCE & ICING

- 5 = Turbulence
- 6 = Icing

CONTAMINATION CODES

- First two numbers **indicate RWY**
  - 23 = RWY 23 L
  - 73 = RWY 23 R (+ 50)
  - 88 = All RWYs
  - 99 = Repetition

- Last two numbers indicate **braking action**
  - 91 = Poor
  - 92 = Poor / Medium
  - 93 = Medium
  - 94 = Medium / Good
  - 95 = Good
  - 99 = Unreliable
  - xx = Friction coefficient
  - // = Not reported

TEMPO

- Less than 1 Hr in each instance
- No more than 50% of forecast period in total

TAF VALIDITY

- 9 Hrs (Issued every 3 Hrs)
- 12 – 30 Hrs (Issued every 6 Hrs)

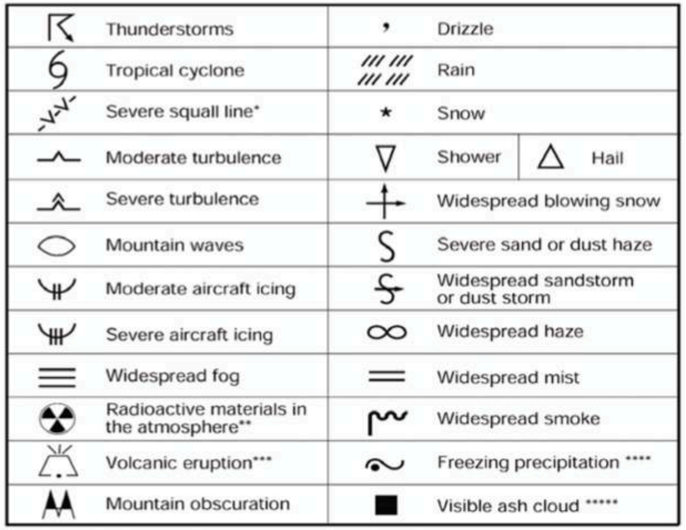
MET 28 - CHARTS

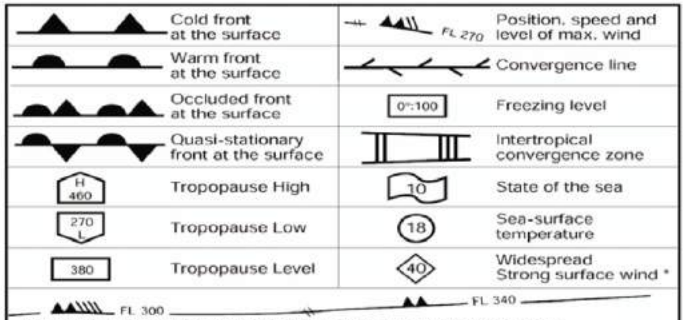
CHART TYPES

- **Significant Weather**
- **Upper Wind & Temperature**

FREQUENCY OF ISSUE

- Produced in **6 hourly** intervals (4 per day)
- Valid **3 Hrs eitherside** of the forecast time





Wind arrows indicate the maximum wind in jet and the flight level at which it occurs. Significant changes (speed of 20 knots or more, 3 000 ft (less if practicable) in flight level) are marked by the double bar. In the example, at the double bar the wind speed is 225 km/h (120 kt).

The heavy line delineating the jet axis begins/ends at the points where a wind speed of 150 km/h (80 kt) is forecast.

* This symbol refers to widespread surface wind speeds exceeding 60 km/h (30 kt).