The Atmosphere

Composition

N2 = 78%
O2 = 21%
Ar = 0.9%, trace co2 and other.

Ozone = Allotrope (3 oxygen atoms) (15km-30km)

Pressure Temp and Density

PV = RT
Density = Pressure / Temp
Pressure = Force/Area
STD Pressure = 29.923 InchMerc , 1013.25 Millibar
STD Temp = 15°C = 288K
Ozone = 50k Ft – 100k Ft, Max heat at 50k Ft.

Measurement

Barometer = Vacuumed tube (reads inch of merc)
Aneroid = Capsule that expands and contracts (Altimeter).

Temperature Effects

Rate of evaporation
Relative Humidity
Wind Speed and direction
Precipitation patterns and types (rain, snow, sleet).

T(°F) = T(°C) x 1.8 + 32

	Pressure	Temp	Density
Dry air	1013.25hPA	15	1225g/m3
Water vapour	1013.25hPA	15	760g/m3

Moist air is less dense than dry air at the same temp and pressure.
Pressure and Density **ALWAYS** reduce with height.

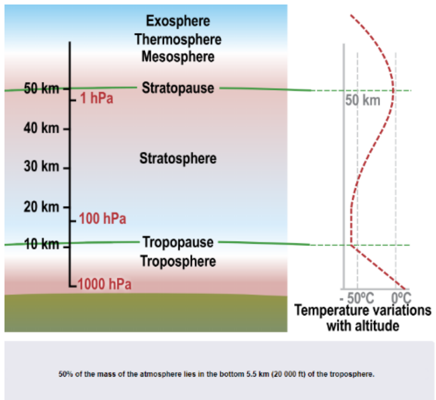
Vertical Structure of the atmosphere

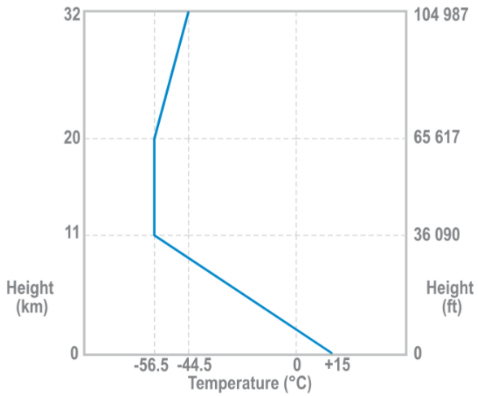
Feet per mb = 96T(K)/P(mb)
If no figure given use: 1mb = 27ft(8m)
700 500 300 hPa = 10kft 18kft 30kft
Under ISA pressure = 50% of MSL at 18k ft,
Density = 50% of MSL at 22k ft and 25% of msl at 40ft
Warm air mass = High pressure aloft.
Cool air mass = Low pressure aloft.

Layers of atmosphere

Troposphere: All weather occurs. SFC – 8-16km (varies from equator to poles)
Equator = 16km Poles = 8km
Stratosphere: from 8-16km to 50km (little water vapour), initially constant temp, increases with height after (in the ozone).
Ozone made by photochemical reactions with O2. UV breaks O_2, which makes 2O that combines with O_2. IE. $O + O_2 \rightarrow O_3$. (exothermic). Ozone is harmful.
Airlines Cruise (9-12km 30-39k ft).
Mesosphere: 50km – 85km
Termosphere: 85km – 600km (upper atmosphere)
Exosphere: Extends 10,000km above earth. (Orbit)

Tropopause heights vary in the mid latitudes, higher in summer, lower in winter.





The standard atmosphere

Troposphere
1.98 °C per 1000 ft.
(6.5°C per 1000m)

Stratosphere
Constant (-56.5) – 65k ft

0.3 °C per 1000 ft.
(1°C per 1000m)

Temperature

Temperature is a measure of molecular activity.

Water = 1 degree rise, 1 gram, 1 cal.

Insolation

Measure of solar radiation energy received on a given surface in a given time.

Absorption

The percentage of the suns energy that is absorbed by the earth depends on the type of surface and the angle of arrival of the radiation.

Lands heat and cool, but the temp of oceans remains constant throughout the year.

The sun heats the earth by **radiation**. The earth heats the atmosphere by **radiation, conduction**

Advection

Horizontal movement of heat by wind, air.

Thermal advection →

WAA (Warm air advection), common behind warm fronts and ahead of cold fronts.

CAA (Cold air advection), common behind cold fronts, contributes to sinking air.

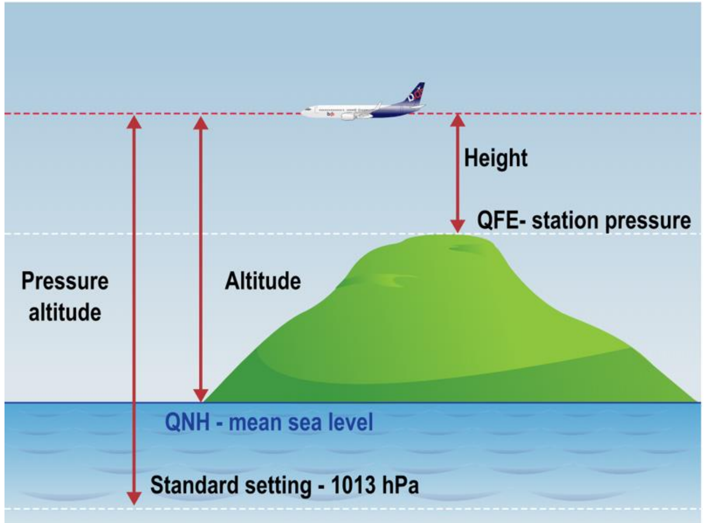
Altimetry

Q Codes

QFE – 0 at Ground level **(Field Elevation)**

QNH – Reads Station elevation (above sea level) (**Nautical Height)**

Standard Pressure = 1013.2hPa (pressure alt) (FL…)



For stations above sea level:

If it is warmer than ISA, QNH is greater than QFF

If it is cloder than ISA, QNH is less than QFF

For stations below sea level:

If it is warmer than ISA, QNH is less than QFF

Barometric Errors

Dangerous flying from high to low pressure as it will over read. (**High to low, careful go)**

Temperature Error

700hPa = 10,000ft at ISA

Colder = Lower alt.

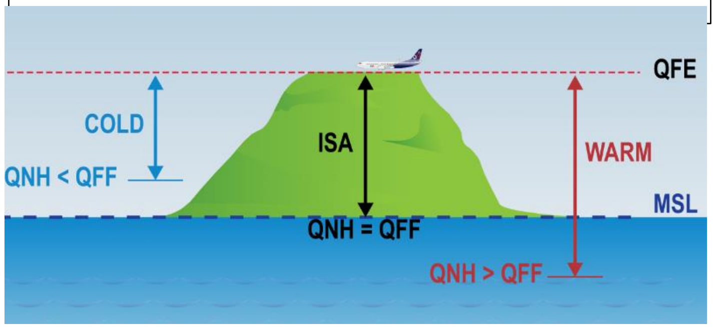
Rule of thumb:

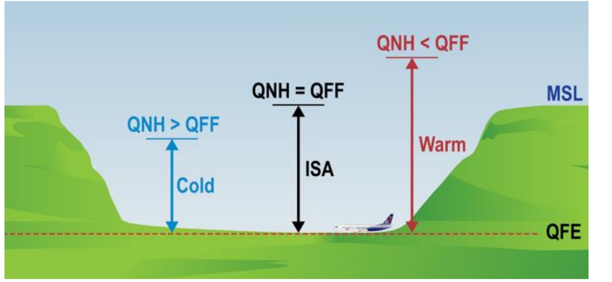
Barometric Error calculated separately and first.

ISA deviation can be assumed to be the same at all heights.

Pressures are whole millibars rounded **DOWN**.

4% height diff, for every 10degrees ISA deviation.





Temperature Error

When the temp is LOW aircraft will be LOWER.

Density Alt

120ft per temp deviation from ISA.

Moisture and convection

Saturation Vapour Pressure (SVP)

At equilibrium when the pressure of evaporated vapour matches that of the fluid evaporating. Depends ONLY on Temp and evaporating surface.

Air at low temps reaches saturation at low concentration of water vapour.

At 15degrees air saturates at 2%

At 30degrees air saturates at 4%

Atmospheric Humidity

Humid = Marked by relatively high level of water vapour in the atmosphere.

Vapour Pressure

The partial pressure of air that is exerted by water vapour(hPa or mb)

Absolute humidity

Mass of water vapour present per unit volume of space, (gram/m3). Thought of as density of the water vapour.

Specific humidity

Mass of water vapour divided by the mass of air ($g.kg^{-1}$).

Mixing ratio

Mass of water vapour divided by the mass of dry air ($g.kg^{-1}$).

Dew point temp

Temp of which air must be cooled (at constant pressure and vapour content) for saturation to occur.

Relative humidity RH:

Ratio of specific humidity to saturation humidity.

Saturation or equilibrium:

Condition of the atmosphere when the evaporation rate is equal to the condensation

Moisture in the air measured by the mixing ratio (ratio in grams of water vapour to kg of dry air)

More water vapour means more latent heat energy, if the air can't hold any more water, it is saturated.

Effect of altitude

As altitude increases, density decrease, as air becomes more saturated with water vapour, density decreases.

Relative density

How much water vapour air is holding compared to what it could hold.

Dew Point temp

Temp at which cloud or dew forms, dew point spread tells you how moist the air is, and indicates RH

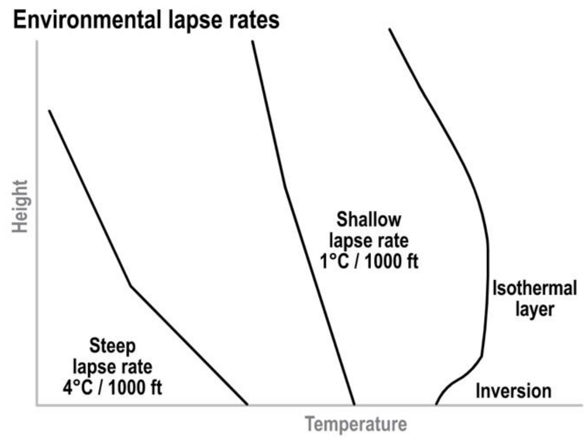
Measurement of humidity

The wet bulb / dry bulb spread tells you roughly how dry the air is, the wet bulb temp lies between the dew point and the OAT.

Measured with hygrometer

Or Hair hygrometer

RH% = 100 – 5x(temp -dewpoint)



The average ELR is 6.5º per 1000 m (about 2º per 1000 ft) The actual ELR is sensed by a radio sonde.
In an inversion temperature increases with height, in an isothermal layer it stays constant

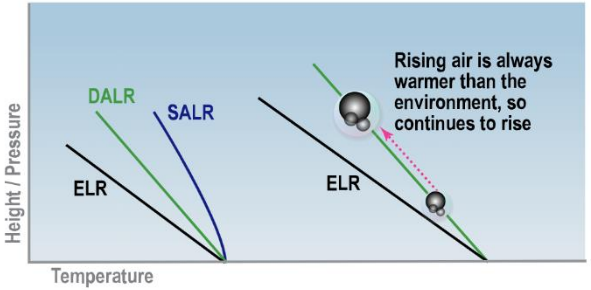
The DRY ADIABATIC LAPSE RATE (DALR) is a constant 3degrees per 1000ft.

The SATURATED ADIABATIC LAPSE RATE(SALR) at mid alts is 1.8 degrees for 1000ft at sea level

Moisture and convection 2

Unstable Air:

If the ELR > DALR then airmass is unstable

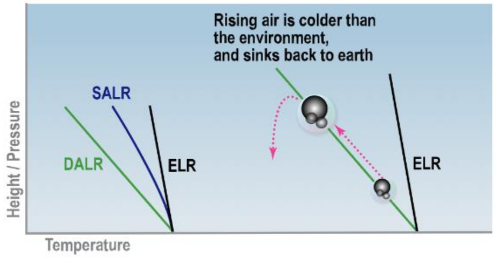


Stable air:

If the ELR is low – a temp inversion – then air in environment relatively warm.

Indifferent (neutral) stability:

Is an atmospheric condition that occurs when the environment lapse rate is equal to the dry adiabatic rate.



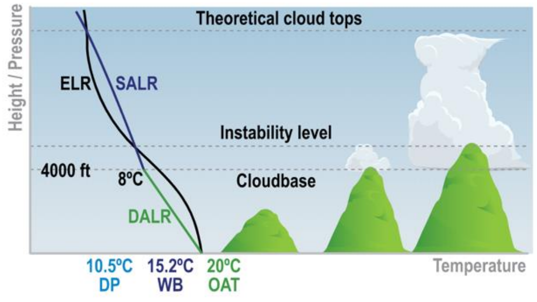
Conditionally unstable air:

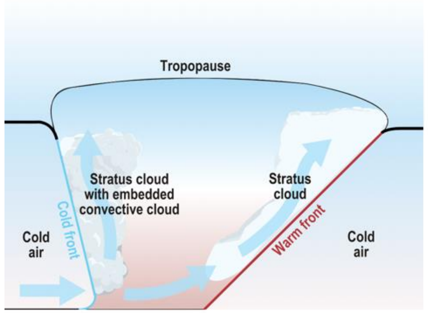
Conditions that enhance atmospheric instability:
Warming of the surface air by:
Solar heating of the ground
Warm 'advection' near the surface.
Air moving over a warm surface (eg warm water)
Cooling of air aloft by:
Cold 'advection' aloft.
Radiative cooling of air/clouds aloft.
Conditions that contribute to a stable atmosphere:
Radiative cooling of surface at night.
Advection of cold air near the surface.
Air moving over a cold surface (e.g snow)
Adiabatic warming due to compression from subsidence (sinking).

Cloud Formation:

Triggers and inversions

Triggers
Gets convection going.
Main triggers are:
Orographic triggering – when air mass is forced up over hills or mountains. Orographic means to do with mountains.
Thermal trigger occurs when air is heated in lower layers, (seasonal or day time heat, or factories and power stations).
Frontal convergence - Where two airmasses meet at a frontal surface the warmer air will rise.
Converging surface air only way is up (Non frontal convergence).
Turbulence – at low level.





Orographic triggering
If air mass abs unstable, any rising ground causes convection.
If clouds don't form from dry air, convections will still occur (blue thermals).
If air is stable, it will sink back down no matter how high the mountain, therefor no convection.

BIG HILLS = MORE CHANCE OF INSTABILITY.

More moisture:
Higher likelihood of instability
Lower the cloud base
Higher the cloud tops.

Thermal Triggers:
As a Paracel of air is heated above ISA, it will rise at DALR until it reaches ELR where the convection will stop.
-The first effect of thermal heating is LOW LEVEL TURBULANCE.
-Second effect is CONVECTIVE CLOUDS.
-Starting from a high temp, air must rise further to cool to dew point.
-Heating during the day leads to higher cloud bases and higher tops.
-Heating from below is a powerful trigger.

Frontal convergence:
When two airmasses with diff properties come together the warmer (less dense) air will rise over. If the front is moving rapid, the uplift will be more intense.
Frontal ascent occurs when two air masses meet.

Turbulence:
Doesn't change the total heat energy in the layer but has redistributed it.
Turbulence cloud layers will get deeper at night and the cloud will be denser.

Adiabatic Cooling:
Convection due to heating of the ground
Convection due to cold air passing over warm surfaces.
Convection due to convergence
Convection due to convective instability aloft.
Forced lifting by orographic ascent.
Forced lifting by frontal ascent.
Rotational pressure reduction
Diabatic Cooling:
Mixing of air of diff temps.
Fog
Turbulent mixing in the boundary layer.

Triggers Continued

Dissipation

3 Main ways clouds are dissipated (fall apart)

1) By the temp increasing
2) Clouds mixing with drier air (**Entrainment)**
3) Air sinking within the cloud.

Inversions:

4 Ways inversions form:

1) At fronts (1:50 Cold front) (1:150 hot)
2) Surface cooling
3) Subsidence in stable air masses
4) Above turbulence.

Valley Inversions

In mountain valleys on a clear night radiation cooling on valley sides produces cold air that slides down into the valley bottom.

Summary Table of Types of Inversion	
Type	**Reason For Formation**
Ground	(Nocturnal Radiation Inversion or Advection Inversion). The most common inversion is the radiation inversion. The earth is cooled at night by longwave radiation emission to space. This is maximized on clear nights with light wind and dry air. Air in the lower levels of the Planetary Boundary Layer (PBL) will cool much more rapidly than air in the upper levels of the PBL at night. These inversions generally erode rapidly once daytime heating warms the lower PBL. Ground inversions can also form when a warm air mass passes over (advects) a colder earth surface.
Subsidence	In an area of high pressure the air will sink with a speed of a few cm/sec. This subsiding air is warmed by compression (adiabatic warming).. Inversion produced at an altitude of 2000 to 6000 ft.
Frontal	At the borders of differing air masses the warmer, lighter air lies over the colder. In the transition zone between the two air masses there will be an inversion.
Turbulence/ Friction Layer	Through turbulent mixing the friction layer close to the surface adopts a DALR temperature gradient. At the upper level of the friction layer an inversion can occur.
Valley	At night the air on the valley sides cools, becomes heavier and sinks katabaticly. It collects on the valley floor producing a pool of cold air above which an inversion forms.
Tropopause	An inversion in the tropopause is created by the absorption of shortwave radiation by ozone. This inversion occurs near the 150 hPa level, but can be a little higher or lower depending on season and weather. The tropopause inversion and the extreme stability associated with it inhibit upward vertical velocities into the stratosphere.

Geostrophic and Gradient Winds

Wind measured with an anemometer.

Geostrophic Winds:

Free Stream wind is clear of surface friction

Iso Bar – Iso = Equal, Bar = Pressure.

Pressure Gradient Force (PGF): Moves air from high pressure to low pressure.

Acts at **right angle** to ISOBARS and is stronger when isobars are closer together.

Coriolis Force:

As soon as PGF acts on air, it is subjected to the Coriolis force.

NORTH HEMISPHERE Turns it to the right.

STRONGER CLOSE TO POLES

Buys Ballots Law

'If you stand with your back to the wind in the northern hemisphere low pressure is on the left.

Winds go **ANTI-Clockwise** in the **NORTHEN** hemisphere.

Wind speed can be found from isobar spacing.

Geostrophic Wind Scale:

Geostrophic winds rarely form at the equator due to no Coriolis force.

Tropical winds are called cyclostrophic winds and are forecasted by calculation.

Same issue when isobars are VERY Close, as the PGF is so high the Coriolis becomes insignificant.

Between 15degrees north and south the geostrophic wind scale does not work.

Geostrophic winds are higher at altitude.

For a given pressure gradient force as latitude

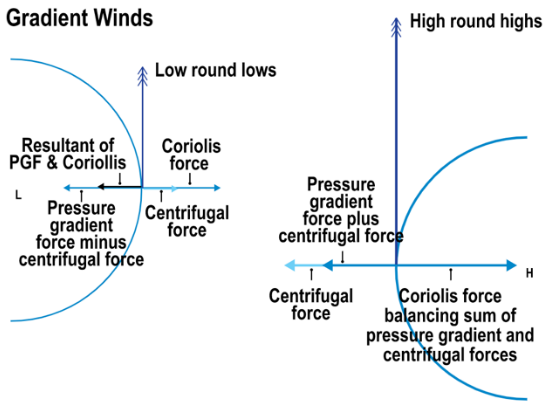
Gradient Winds:

Coriolis = 2wpvsin(lat)

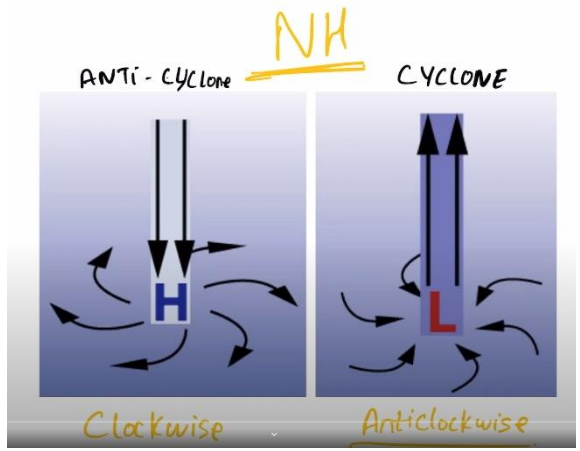
-The gradient wind is the geostrophic wind modified by centrifugal force.

-The gradient wind is 'high round a high' because centrifugal force acts in the same direction as pressure gradient force (Straightens it up).

-The gradient wind is 'low round a low' because centrifugal force opposes PGF (weakens it).



Low round a Low, high round a High



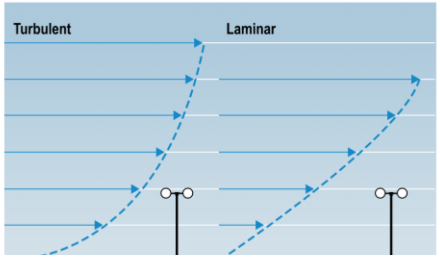
Opposite in the southern hemisphere.

Surface Winds:

Changes at a gradient.

How much the air slows depends on:
Wind speed, Drag of surface, Boundary conditions.

Turbulent – Free stream mixing.



Laminar is usually 1000-1500ft thick

Turbulent usually 2000ft thick

Surface winds MEASURED 10m above Taken over 2 MINS

Boundary Layers:

Laminar / turbulent depends on: Mechanical mixing over hills AND Thermal convection from the surface.

Laminar over smooth cold surface

Topographic Effects and Sea Breeze

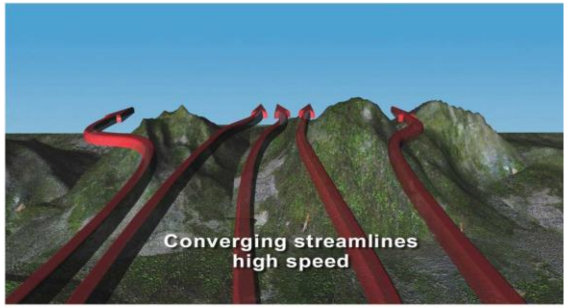
	By day		By night	
	°Backed	% Freestream	°Backed	% Freestream
Over land	30°	50%	40°	30%
Over sea	10°	70%	10°	70%

If a wind changes direction, e.g. from 250° to 240°, it is said to be backing
If a wind changes direction, e.g. from 010° to 020°, it is said to be veering

Slack and back for the Northern Hemisphere

Local Topographic Effects:

Valley Winds:



At night, high mountain slopes cool very quickly. This cold, dense air forms a local high-pressure area. The pressure gradient drives a gentle breeze down the slope into the valley that is strongest just before sunrise. This is a mountain breeze.

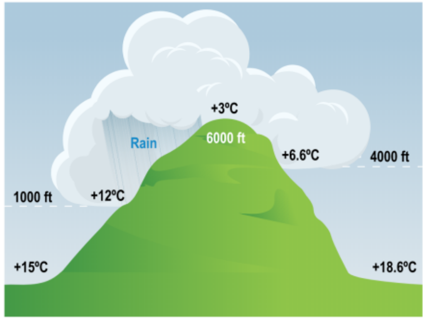
Caused by Venturi.

Mountain and Valley Breezes:

Föhn winds:

If moist stable air mass blows slowly over a range of hills, the air will rise over the hills, it will cool and form cloud then, being stable slide down the other side, where the cloud will end as the air warms up in the decent.

Föhn winds:



The Föhn effect produces warm, dry winds in the lee of mountains

Calculating temp rise:

TempRise = (lee cloudbase – windward cloudbase) x

Katabatic Winds:

'To go down', Cold air is cooled by conduction and becomes more dense sliding it down the mountains. **DOWN AT NIGHT**

Anabatic Winds:

'To go up' Flows up the side of mountains when the surface is hot, during the day. Heated by conduction **UP IN DAY**

Hazards:

-Icing and turbulence on windward side.

-Airflow over hill summit may induce low pressure and make altimeter over read.

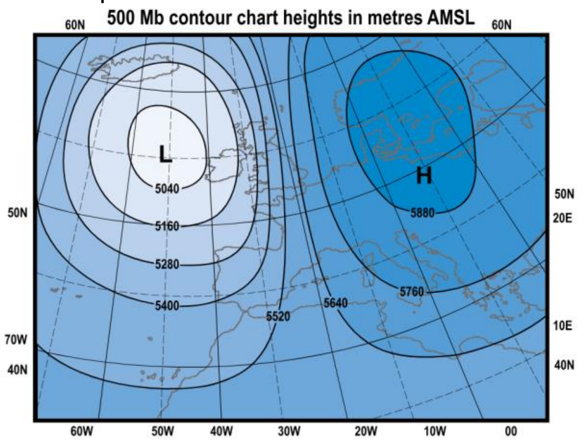
-On lee side of the hills warm Föhn wind may generate temp inversions over cold pools of air.

High Level Winds

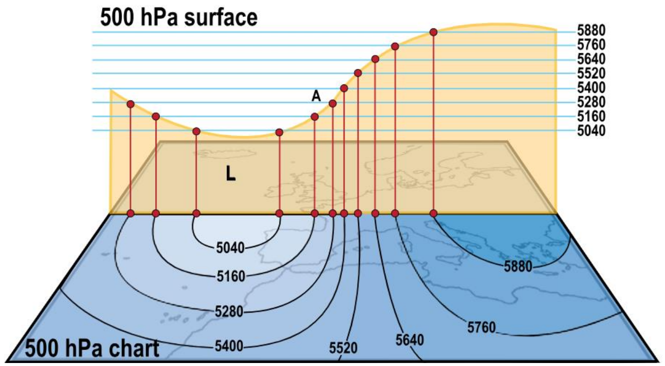
High Level Winds:
Higher Air mass temp – Higher pressure aloft
Low air mass temp – Low pressure aloft.

-The low-level wind blows parallel to isobars with low pressure on the left in the northern hemisphere
-The thermal wind component blows parallel to isotherms with low temperature on the left in the northern hemisphere.
-The upper wind blows parallel to contours with low contour height on the left in the northern hemisphere.

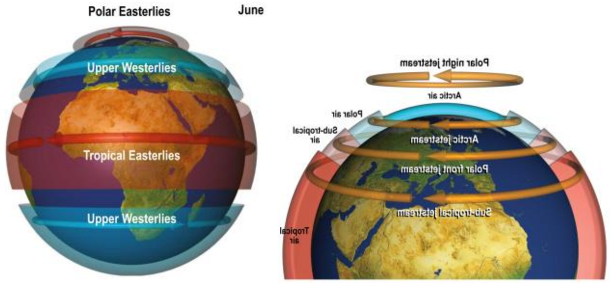
Contour Charts
Upper winds indicated on contour charts; Lines called isohypses.
'ISO' – Equal.



Upper winds blow along contour lines.
Upper winds are strongest where the contours are closest together.



Global Distribution of Upper winds:
Upper wind depends on temp.
Inter-Tropical Convergence Zone (ITCZ) 'Heat Equator'.



Jet Streams:
Troposphere divided into 4 main blocks:
Hot Tropical air at the equator,
Warm subtropical air from lat 30 to lat 50.
Cold polar air.
Very cold artic air (winter only).

Temp diff creates pressure diff at height, = maximum pressure gradient, which create very localised strong winds 'Jet Streams'.

Jets are found at air mass boundaries.
Jet stream : 'A strong narrow current of air on a nearly horizontal axis in the upper troposphere or low stratosphere, characterised by strong lateral and vertical wind shears. Wind speed >>60kts.

Usually Faster in winters and closer to the equator.
Polar Front – 30k ft – 200Kts
Sub-tropical Front – 40k ft – 100Kts

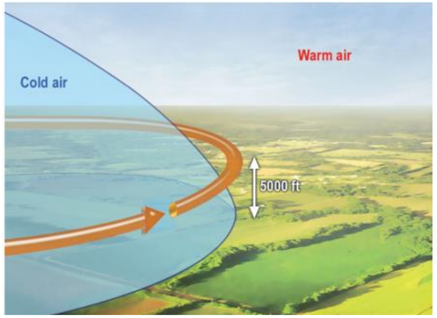
The Equatorial Jetstream
The ONLY easterly Jet.

45k – 50k ft at 100kts.

High Level Winds:

Low Level Jet Streams:

Occasionally can form at 5000ft , 70Kts.



Anatomy of a Jetstream:

Jet streams Typically:

1000NM long, 150NM wide, 10, 000 ft Deep.

Depth : Width = 1:100

Maximum CAT (Clear air turbulence) in the warmer air, on the cold air side of the core, level with and slightly below the core.

Jet Core Lies at **Maximum** pressure grad.

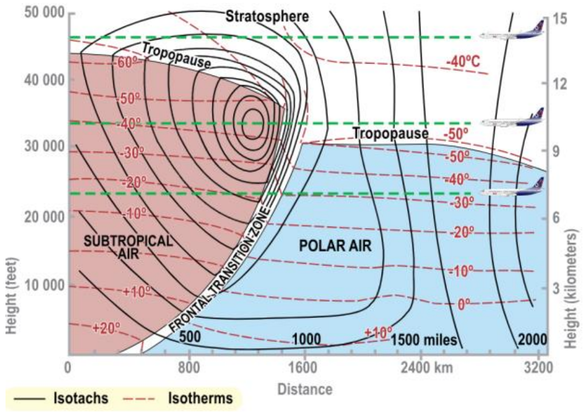
This occurs in the warm sector just below the tropopause.

Isotachs = Connecting equal wind Speed

Detecting Jet Streams:

Can be detected by wind readings,

Or **Outside Air Temp (OAT)**



Flying above the Jet core:

Not Big change, from cold sector to warm sector. Warm front will be 'colder' after passing.

Level with the jet core:

Not much change in OAT. Higher CAT as you approach the core. With no turbulence in the core.

Below Jet core:

Slight but steady increase in temp in the cold sector. Highest wind just after temp jump in the frontal layer.

JET STREAM levels:

Arctic 20kft

Polar Front 30kft

Sub-tropic 40kft

Equatorial 50kft

Clouds I

Classification:
Stable Air: Stratus
Unstable Air: Cumulus

Low: 6500ft AGL. (**No prefix)**
Medium: Above 6500ft (**Alto**)
High: Above 16,500ft (**Cirro**)

Nimbo: 'Rain bearing'

Most clouds confined to their level with exception:

a) Altostratus is usually found in the mid-level, but can go higher.
b) Nimbostratus is almost always found in the mid-level, but can go to other two levels.
c) Cumulus and Cumulonimbus usually have bases in low level but can extend to mid / high levels.

Level	Genera	Polar region	Temperate region	Tropical region
High	Cirrus Cirrocumulus Cirrocstratus	3 – 8 km (10 000 – 25 000 ft)	5 – 13 km (16 500 – 45 000 ft)	6 –18 km (20 000 – 60 000 ft)
Middle	Altocumulus Altostratus Nimbostratus	2 – 4km (6500 – 13 000 ft)	2 – 7 km (6500 – 23 000 ft)	2 – 8 km (6500 – 25 000 ft)
Low	Stratus Stratocumulus Cumulus Cumulonimbus	From the Earth's surface to 2 km (0 – 6500ft)		

High Clouds

All Cirrus family
Contain **ICE crystals** rather than water.
Flight conditions: GOOD, no icing, good vis >1000.

Cirrus (Ci)
Dethatched clouds of white, feathery appearance, move without change in form.

Cirrostratus (Cs)
Transparent white veil, not thick enough to block sun. Ice crystals refract light making haloes around the sun/moon.

Cirrocumulus (Cc)
Regular, thin patches of high cloud, without shadows, with ripples/lumps.

Medium Level Clouds

Clouds of **water** or of a mix of water and ice.

Altocumulus (Ac)
One or more layer of cloud with lumps or rolls which are merged.

Altostratus (As)
Greyish/Blueish Cloud sheet, Total/partial cover of sky. Thin enough to show sun. Possible light rain.

Low Level Clouds

Stratocumulus (Sc)
Grey / white, can cover sky/patchy.
Rounded masses / rolls, don't have to merge.
Called: 'Aligned in waves'
Mainly formed by turbulence, but can come from dying cumulus as it spreads.
Moderate to SEVERE icing if temp below 0.

Stratus (St)
Grey layer of cloud, uniform base.
Thick stratus may drizzle / snow.
Forms in moist air because turbulence with orographic lifting / surface cooling. Patches of fracto-stratus may form in rain or snow falling from altostratus or nimbostratus

Nimbostratus (Ns)
Thick, Grey layer of cloud, darker than stratus or altostratus. **Rain or snow**.
Blocks out the sun.
Associated with frontal lifting and can be found with bases in the band for low or mid clouds.
SFC-25000ft.

Cumulus (Cu)
Sunlit parts are VERY white.
Strength of vertical motion inside can be inferred by seeing the rising domes.
Strong updrafts
Warmer inside than surrounding air.
Limited development shows small clouds.
But can develop leading to turbulence and icing.

Cumulonimbus (CB)
Tops can reach 30,000ft in EU and over 55,000ft in tropics. (Lower stratosphere)

Show **Vigour**, tops fibrous as ice particles predominate over water drops.
Bring: Showers, hail and thunderstorms, severe turbulence and icing.

Cloud Shapes:

Cloud types can be further described by shape.

Fractus
Irregular or ragged shreds 'torn'.

Lenticularis
Convex lens shape

Castellanus
Usually applied to altocumulus, describes cloud tops developing vertical, like castles.

Capillatus
Only to Cumulonimbus clouds,
Suffix implies cirrus elements in a layered or disorderly pattern, anvil shaped.
Translates to 'Having hair'.

Mammatus

Brest Shaped. Cloudbase of cumulus and cumulonimbus clouds associated with imminent precipitation.

Types of Cumulus Clouds

Humilis

Cumulus clouds of only small vertical extent.

Mediocris

Cumulus clouds of moderate vertical extent.

Congestus

Cumulus clouds with marked "sprouting" normally with fairly extensive vertical extent, resembles a cauliflower. Otherwise known as Towering Cumulus.

Calvus

A Cumulonimbus that is losing some of its cumuliform shape in the upper parts. The top appears as a whitish mass with some vertical striations. It translates from Latin as "bald".

Other Cloud Types

Nebulosus

Like a layer or veil with no distinct details, applies to Sratocumulus, Altocumulus and sometimes Cirrocumulus.

Floccus

Cirrus, Cirrocumulus and Altocumulus with a tuft of cumuliform cloud that is ragged at the bottom. Often with virga which is an observable streak or shaft of precipitation that falls from a cloud but evaporates or sublimes before reaching the ground.

Fibratus

Cirrus and Cirrostratus that are very thin and detached streaks of cloud with no "hooks" at the ends or tufts.

Spissatus

Cirrus clouds with sufficient thickness to appear grey.

Uncinus

Cirrus clouds that are shaped like a comma, with a "hook" or tuft and a streak. Sometimes called mares' tail cirrus.

Clouds II

Classification by formation mechanism
Stratus cloud formed in **STABLE air**

Cumulus formed by **Convection** in **UNSTABLE air**. Needs only a small trigger to start it off. Stratocumulus is formed when convection is capped by a stable layer or inversion aloft. Altocumulus and cirrocumulus occur mainly when there is a distinct layer of unstable air aloft, in a generally stable air mass.

Large cumulonimbus, which become re-classified as thunderstorms when lightning and thunder start.

Nacreous Clouds
'Mother of pearl' clouds,
Lower Stratosphere 20-30km above earth.
Shiny bright from reflected sunlight

Noctilucent Clouds
Made of ICE crystals in the mesosphere
70-95km above.
Light from reflected sun.

Contrails
Formed by extra moisture that is being added to the atmosphere behind a jet engine. If air is cold enough to overcome the heating effect of the exhaust, then a contrail will form.

Polar Lights.
Aurora borealis (northern lights)
Aurora Australis (southern lights)
Hydrogen atoms and free electrons that are channelled by earths mag field towards the poles. Glowing when they strike the atmosphere.

Precipitation, Thunderstorms and Tornadoes

Precipitation

Anything that falls out of a cloud.

Type of precipitation depends on the cloud.

Drizzle (DZ)
Uniform precipitation of dine drops of water close to each other.
Diameter = 0.5mm
No impact of water surface.
Falls from layer of stratus, low, sometimes touching the ground (fog).

Supercooled drizzle, freezing drizzle (FZDZ)

Drizzle were temp drops below 0degrees.

Drops may freeze on impact.

Rain (RA)

'Precipitation drops that fall from clouds'

Water drops – 0.5 – 5.8mm diameter.

Supercooled Rain (Freezing Rain) (FZRA)

Rain where temp drops below 0degrees.

Freeze on impact

Snow (SN)
Ice crystals, singly or stuck together.
Size and concentration differ depending on temp and supersaturation.
Small drops of frozen water often attached to snow crystals.
At temps warmer than -5degrees crystals stick together to make snowflakes.

Snow Grains (SG)

Precipitation of very small opaque white particles of ice.

Flat or elongated.

Diameter usually less than 1mm.

Temps = **0 to -10 degrees.**

DO NOT bounce.

Fall from Stratus or fog.

Snow Pallets (GS)

White opaque ice particles that fall from a cloud. Conical or rounded.

Diameter up to 5mm

Comprised of central nucleus covered with frozen cloud droplet.

Hail (GR)
Particles of Ice.
Transparent or partially opaque.
5 – 50mm diameter.
Always occur as showers.
In heavy thunderstorms.
Can damage aircrafts.
Form around a nucleus, may not be around the geometric centre. Nucleus can be a few millimetre to cm in diam.
Density = 0.85 g/cm3 to 0.92 g/cm3.
Can stick together and produce large clumps.

Small Hail (GS)

Precipitation of translucent ice particles.

Almost always spherical and have sometimes have conical tips.

Never exceeds 5mm diameter.

Always occurs in showers from CB's.

0.8 g/cm3 to 0.99g/cm3 (rare)

Bounces with sound.

Small hail is an intermediate stage between snow pellet and hailstone.

Ice Pellets (PL)
Spheroidal or irregular and rarely conical.
Diameter less than 5mm
Originate as raindrops or snowflakes (less common).
Fall from Altostratus or Nimbostratus.
Not easily crushable
Bounce with sound.
Close to density of ice >= 0.92 g/cm3

Ice crystals (Diamond dust) (IC)
Precipitation that falls from a clear sky in very small ice crystals, often appear to be suspended in air.

Diamond dust can be observed in polar and alpine regions. Clear calm and cold weather.
Temps less than -10 degrees
Diameter of 100micrometers.

Condensation Nuclei
Water vapour needs something to condense to, called condensation nuclei,
Typically smoke, dust, ice, or salt crystals.
In extreme clean air, without condensation nuclei it is possible for vapour saturation to go beyond 100% (super saturated).

Drizzle and rain.
Theory A:
Ice Crystal theory:
Growing crystals, cannot be supported by updraft, therefor fall, when they fall, they collide with other crystals. Depending on collision, will result in different outcomes.

Theory B:
The Coalescence theory of precipitation:
Liquid drops frow in size because they collide and coalesce with other drops.
If an updraft is supporting drops of diff sizes the smaller ones will move up faster and they will collide. When the size is too large it will drop, bumping into other drops on the way down, becoming larger.
Explaining rain and drizzle.

Snow grains
Precipitation in the form of ice crystals.
As they fall from cloud, they are warmed by higher air temps below.
Fall from stratus or supercooled fog.
Slush:
Water saturated snow.

Snow (on the ground)
Dry Snow:
Snow which can be blown if loose, if compacted by hand will fall apart again.
Specific gravity up to but not including 0.35

Wet Snow
Snow which if compacted by hand will stick together (Snowball)
Specific gravity: 0.5 and over.

Compacted snow:
Snow which has been compressed into a solid mass that resists further compression and will hold together or break into lumps
Specific gravity 0.5 and over.

Hail
ONLY associated with CB clouds.
Because of the strong updrafts.
Cross section of hail shows rings, each corresponding to falling and a rising cycle.
Falls to the ground when it gets too heavy to be uplifted.
Largest hail found in CB's over continental interiors rather than over the sea because the convective and orographic triggers will be stronger over land than sea.

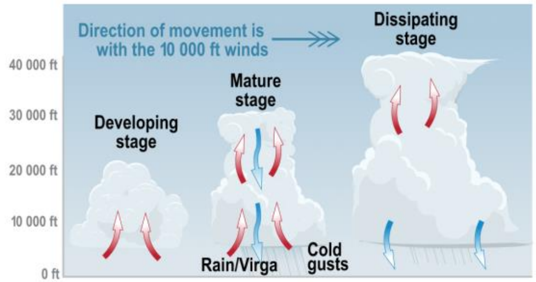
Hail and aircraft
Hail big enough to damage aircraft has been encountered as high as 45 000ft.
Hail of 100mm diameter encountered at 10000ft.

Air Mass thunderstorms:
Extreme forms of CB's.
To form **ELR >> SALR for over 10000ft.**
Moisture required.
Adequate trigger, day or night.

Single cell thunderstorms:
Thunderstorms have 3 forms:
Single-Cell, Multi-Cell, Super-Cell

Single cell is a cumulus cloud that becomes a cumulonimbus then a thunderstorm before dying away.
Short life, not as intense as the others.
NO CORRELATION BETWEEN EXTERNAL APPEARNACE AND SEVERITY OF ICING/TURBULENCE INSIDE A CLOUD.

Life cycle



The life cycle of a single-cell thunderstorm

Developing stage:

General updrafts (3000fpm – 4000fpm, max 5000fpm)

Moderate to severe turbulence.

No precipitation

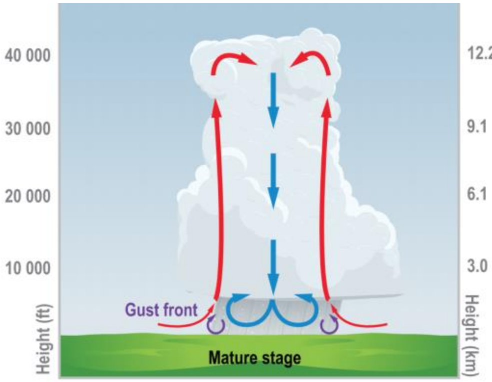
The Mature Stage:

Water droplets fall.

If no windshear aloft, and CB is vertical, downdraft will be in the middle, surrounded by updrafts.

Downdrafts – (3000fpm – 4000fpm can reach 6000fpm)

Updrafts – (5000fpm – 6000fpm can reach 10,000fpm).



Microbursts – 5km across, last up to 5 mins and will have vertical downward speed of 6000ft/min.

As air reaches surface creates dangerous low level wind shear

Dissipating Stage:
Lasts until the storm is spent. (Typically, two hours)
Vertical currents weaken, air within cloud subsides more than ascends, collapsing the cloud.
Higher levels make anvils as upper wind spread the ice crystals

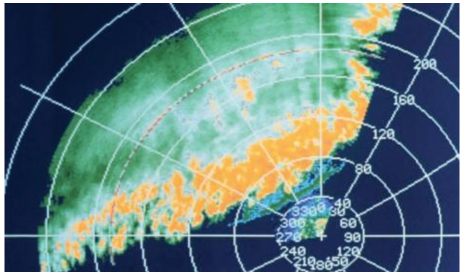
Hazards:
Severe Icing
Turbulence,
radio static interference with nav aids,
pitot blockage ….

Lightening can appear in the mature phase of a storm.
Caused by build-up of electrical potential.
Upper cloud has a positive charge, lower has negative.
Lightening found inside the cloud from **5000ft below to 5000ft above** the freezing level.
St Elmo's Fire: Blue glow around windscreen and external parts of aircraft, weather phenomenon, luminous plasma is created by a coronal discharge from a sharp or pointed object.
Electrical charges don't usually cause heavy damage, just burns and small puncture holes.

Induced voltages can magnetise structures making magnetic compasses useless and damage un-shielded electrical equipment.
Flashes can blind crew for short time.

Orographic Thunderstorms:
In dry stable/moist unstable conditions air can be forced over obstacles (hills etc) until the condensation level is reached, after the moist unstable air will continue to rise on its own and thunderstorms can happen.
Medium altitude thunderstorms:
Can form when air in this layer is unstable and the above lying layers are cooling (e.g. advection).
Base high about 10,000ft. Not caused by warm air rising, can occur any time.
Altocumulus castellanos clouds form an unstable layer of air at medium alts.

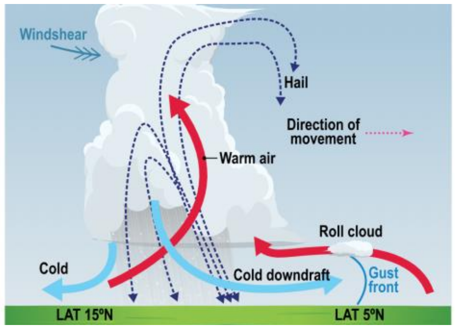
Multi-Cell Thunderstorms:
Single-cell thunderstorms are rare (triggered by thermal heating).
More common for clusters to form over several km in lines called 'Squall'.



Multi cell storms are active for several hours until individual single-cells die.
Squall line thunderstorms = severe flying conditions, heavy hail, destructive winds etc.

Super-cell thunderstorms:
Formation:
Requires different start conditions.
Requires **good supply of warm moist air at low level**. Held down by a thin stable layer above so the energy supply is not dissipated by turbulence.
A change of direction and strengthening of winds aloft which tilt the CB tower.

Development:



Development:
Updrafts no longer on same axis as downdrafts, two are side by side allowing convection without restriction.
Carries hail aloft and takes top through tropopause.

Conditions needed:
Warm air below,
Cold dry air above, with strong upper winds.
Occur most frequently at boundary between sub-tropical and polar air.
Main areas: Midwest America, have been seen in EU from Spain to UK.

Last several hours
Severe Icing,
Severe Turbulence
CAT outside and above the storm,
Lightning and heavy rain and hail.

Frontal Thunderstorms:
Cold front, warm air is pushed upwards by the undercutting cold air.
When air is moist and unstable thunder clouds can form.
Mainly happen in summer.

Tropical Thunderstorms:
Like standard storm.
Organised in line squalls.
Higher energy,
Reach **40,000ft – 60,000ft (max 75,000ft)**

Thunderstorm avoidance:
DO NOT FLY under the anvil as turbulence and hail expected
Recommended turbulence avoidance limits are:

- In visual flight avoid by 10NM
- With weather radar avoid the echoes by
- **- Between 0 – FL250: by 10Nm**
- **- Between FL 250 – FL 300: by 15NM**
- **- Over FL 300: by 20NM**

In both cases clear the tops by 5000ft at least.

Tornadoes:
Wind > 200Kts
Move with a thunderstorm with avrg speed of 35mph.
Diameter varies from 90m to 1.6km. usually less than 150m.
Come in many shapes and sizes.
Usually dark, due to soil and other debris picked up.
The core size is no greater than a few hundred meters.

Super-cell storms in USA are often accompanied by tornadoes.
Can exist in a cloud and can be fatal to aircraft.
Tornado strength measured by '**The Enhanced Fujita Tornado Scale.' From 0-5.**

Dust devils
Well-formed long-lived whirlwind, from half a meter wide and a few meters tall to >10m wide and >1000m tall.
Usually harmless but can grow to a large size.

Unlike tornadoes they don't need a parent circulation (supercell).
Form as swirling updrafts.
Sunny conditions,
Fair weather.

Waterspouts: similar to a tornado but over sea and less intense

Turbulence

Windshear:
Sharp change in speed or direction over a short distance, vertically or horizontally and can cause turbulence. Low-level windshear is described as significant wind shear in the atmosphere below a height of 1600ft agl. Preventative measure required.

Horizontal Windshear:
Encountered when flying level, including vertical gusts.

Vertical Windshear:
Encountered when climbing or descending (Kts/100ft)

Windshear Categories

ICAO characterises wind shear as:

Light	0 to 4 KT inclusive per 30 m (100 ft)
Moderate	5 to 8 KT inclusive per 30 m (100 ft)
Strong	9 to 12 KT inclusive per 30 m (100 ft)
Severe	above 12 KT per 30 m (100 ft)

Gustiness and turbulence:
Synonyms.
Gustiness: Irregularity in wind speed.
Turbulence: used with ref to levels above surface.

Effects of wind shear:

- Increase headwind/tailwind ∴ climb.
- Decreasing a headwind/tailwind = Decrease in airspeed = aircraft sink
- Up/downdrafts result in

Temperature inversions:
In addition to wind shear, when passing transition area from cold to higher warmer air, that engines produce less power which combined with reduced lift in less dense warm air will have bad effects on pref.

Windshear warnings:
A Low-Level Wind Shear Alert System **(LLWAS).** Used to detect windshear on ground.

Turbulence:
Both in and out of clouds.
'Variation in the wind along the aircrafts flight path of a pattern, intensity and duration that disturbs the aircraft attitude about its major axes but does not significantly alter flight path.

Types of turbulence:

- Clear air turbulence (CAT).
- Convective turbulence.
- Mechanical turbulence.
- Orographic turbulence.
- Frontal turbulence.

Normally found over rough ground, near mountain waves etc, inversion layers, in and around CBs, in TS zones, in unstable layers, jetstreams. Troughs and ridges.

Type	Formation	Where Usually Found
Clear Air	Clear Air Turbulence (CAT) is the turbulent movement of air masses in the absence of any visual cues such as clouds, and is caused when bodies of air moving at widely different speeds meet.	The atmospheric region most susceptible to CAT is the high troposphere at altitudes of around 23 000-39 000 ft near the tropopause. Here CAT is most frequently encountered in the regions of jet streams. At lower altitudes it may also occur near mountain ranges. Towering Cumulus and CBs give warning of violent convective turbulence but if the air is too dry for cloud convective turbulence can still occur.
Convective (Thermal)	Caused by convection currents resulting from insolation. Different surfaces have differing abilities in absorbing or reflecting heat called the 'Albedo Effect'. Barren surfaces such as sandy and rocky wastelands and ploughed fields become hotter than ground covered by vegetation.	Thermal turbulence is greatest around 1500 hrs on clear sunny days (max temp!) Localised vertical air movements both ascending and descending. There is no thermal turbulence over the sea.
Mechanical	Caused by physical obstructions to the normal flow of air such as hills, mountains, trees and buildings. The degree of mechanical turbulence depends on wind speed and roughness of the obstructions. The higher the speed and/ or the rougher the surface, the greater is the turbulence.	Obstructions, such as buildings, trees, and rough terrain, disrupt smooth wind flow and eddies are developed. An aircraft flying through these eddies experiences turbulence. This turbulence we classify as 'mechanical' since it results from mechanical disruption of the ambient wind flow.
Orographic	Mountain waves (standing waves or lee waves) occur when: ▪ the wind direction is perpendicular to the mountain range (+/-30°); ▪ the wind speed at the summit at least 15 KT (speed increasing as altitude increases); and ▪ there is a marked layer of stability around the altitude of the summit, which prevents air continuously rising. Under each wave crest is a rotary circulation. The 'rotor' forms below the elevation of the mountain peaks.	May extend 100 miles or more downwind from the barrier. Wave crests extend well above the highest mountains, sometimes into the lower stratosphere. Turbulence can be violent in the overturning rotor. Updrafts and downdrafts in the waves can also create violent turbulence. When moisture is sufficient to produce clouds, then the crest of the waves may be marked by lens-shaped clouds. In this case the rotor may also be marked by a rotor cloud.
Frontal	There is a change in wind direction of 20° or so at the frontal surface; a sudden change in wind direction will lead to turbulence.	On passing through a frontal surface. The turbulence is often accompanied by wind shear.

Clear air turbulence CAT:
Turbulence **NOT** in clouds.
Associated with jet streams.

Action in Turbulence:
In cruise you will have a speed range.
In turbulence speed will fluctuate.
Aircraft speed should be reduced to the middle band of the speed range to avoid going above or below max.

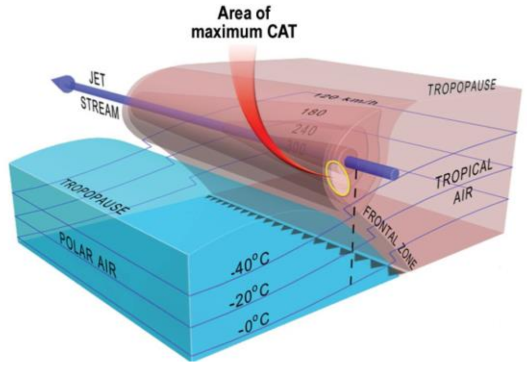
Convective current turbulence = **Climb**

Light Turbulence:
Conditions less than moderate turbulence.
Changes in accelerometer readings less than 0.5g at CoG.

Moderate Turbulence:
Moderate changes in AC attitude / altitude,
Still have positive control.
Small variations in speed.
0.5 – 1g changes at CoG.
Hard to walk. Strain on seat belts.

Severe Turbulence:
Abrupt changes in AC attitude/altitude.
AC out of control for short periods.
Large variations in speed.
Greater than 1g variation at CoG.
Forced violently on seatbelt.
Loose objects tossed.

Jet Stream CAT

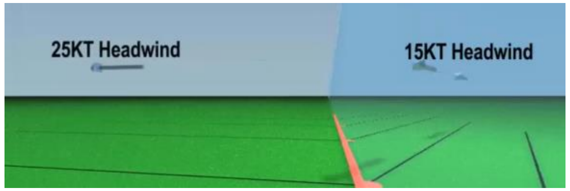


Windshear around Jetstream will cause turbulence.
Maximum CAT occurs at max windshear.
Level with or just below height of jet core.

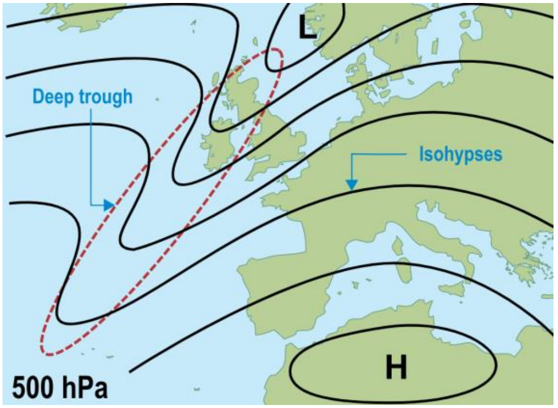
CAT associated with jet stream core normally about 6000ft thick vertically.
Avoid CAT by **going over or under it.**

Turbulence at fronts
Fronts create Jetstreams and CAT at high levels.
Wind direction changes at a front.

Frontal Windshear:
Hazard at low level, Issues with wind vector changing on landing / take off.
Critical at cold fronts

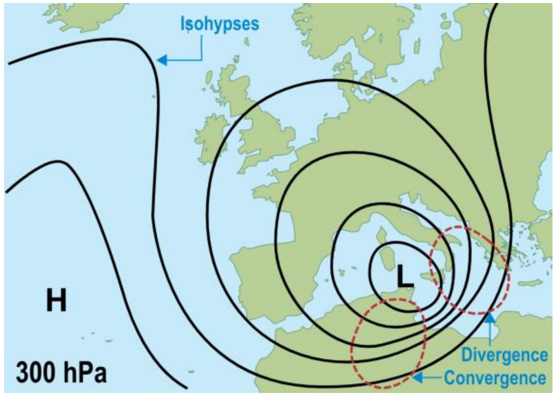


Troughs:
'Line of low pressure created by the circulation of air'.
Where the lines of the isohypses bend, the wind direction changes rapidly. ∴ expect turbulence.



Troughs produce convective cloud, showers, and thunderstorms due to low pressure.

Convergence and Divergence:



Upper air turbulence expected in both convergence and divergence.
Surface convergence generated convective clouds.
Divergence does not.

Convective Turbulence:
During mornings, wind speed and turbulence will increase.
Calmest flying conditions will be in the early morning.
Convective turbulence will reach its strongest by mid-afternoon.

CAT Near Thunderstorms:
Severe turbulence inside CB's and thunderstorms.
High risk of CAT outside the CB, and above/below.

In VISUAL flight : avoid by 10NM

When weather radar is in use the echoes show the core of the cloud not the edge, so the avoidance limits are greater. AVOID ECHOES BY:

0 – FL250 : 10NM
FL250 – 300: 15NM
Over FL 300: 20NM

Hazards near thunderstorms:
Do not overfly CBs by less than 5000ft.
Nor under the anvil (due to Hail not CAT).

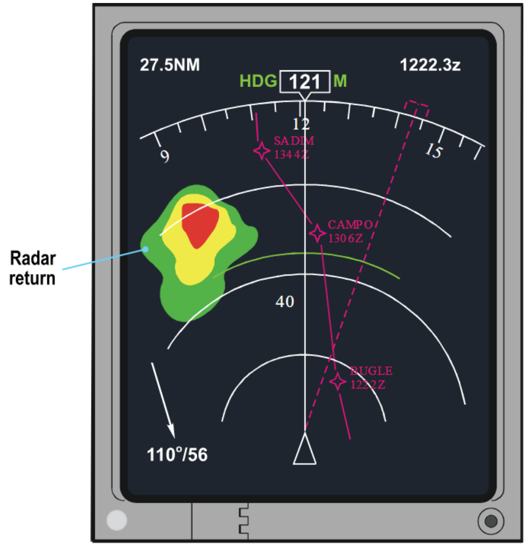
CAT beneath a CB caused by updrafts and downdrafts, can be severe.

Gust front: Cold air descending from thunderstorm, running ahead of the storm producing mini cold front with windshear, turbulence.
Can extend 25-30km ahead of storm
Up 6000ft.
Windshear around gusts, up to 80Kts with 90-degree direction changes.

Turbulence inside a thunderstorm:
Due to updrafts (60Kts) and downdrafts (40kts), Turbulence will be moderate to severe.

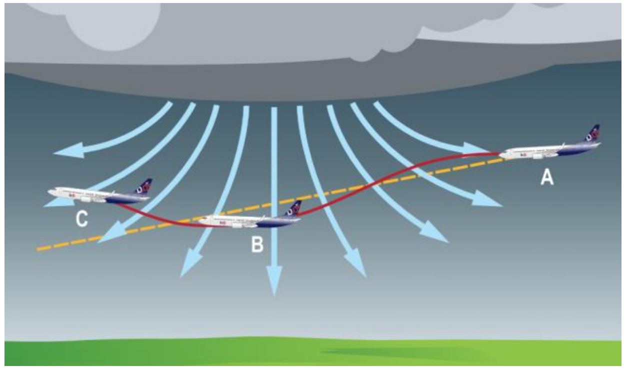
Micro-bursts caused by downdrafts of a thunderstorm bursting out the cloud.

Weather radar on an AC detects raindrop size and concentration.
Doppler radar record movement of raindrops and show turbulence in a cloud.
Maximum signal is red, Turbulence is magenta or sometimes white.
Wind shear alert system (on ground).



Microbursts and Standing Waves

Microbursts:
Extreme form of windshear, made by descending air, from thunderstorm cell.
3000-4000fpm downdraft (up to 6000fpm)
60kts vertical speed.
When it hits the ground, they can flow **50kts** one way and **50kts** the other way.
Last a few mins. Can be Fatal.

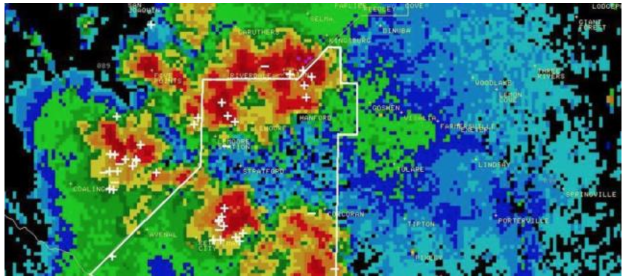


A = Headwind B = Downwind C =Tail wind.

Initiated by **precipitation,** marked by a column of rain.
If air below cloud is dry, rain will evaporate, making ‘dry’ microburst.
Dry microbursts more intense than wet ones.

Downbursts can occur at medium altitudes without reaching the surface.

Microburst Detection:


Ground radar showing storms with microburst

Downbursts can be **1-4km across.**
Most dangerous is in first few mins.
Can continue with less intensity for 15mins.

Downbursts spanning greater than 4km are called **Macrobursts.**
Macro bursts can last **30mins speeds >120kts.**

Detection: with:

1. **LLWAS (low level windshear alert system).**
2. **Low frequency doppler radar.**

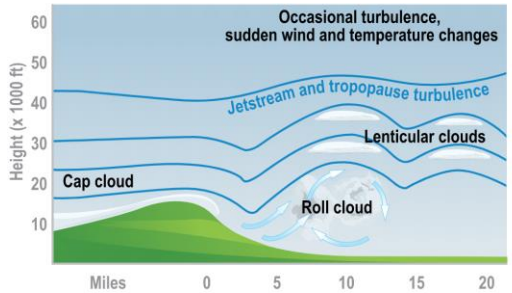
Tornadoes:
‘Narrow vertical funnels of air rotating at high speed.’ **200kts wind speed common.**
Pressure at centre of tornado low enough to explode an aircraft.
Life span: **Few mins to 30 mins,**
Move speed: **20 – 40kts.**

Windshear at inversions and in the boundary layer:
Critical conditions:

- Freestream wind >40kt, implies turbulence in the boundary.
- Vector diff between surface and free stream wind of 40kts or more. (Same as above.)
- A temp inversion of 10degrees or more in the first 1000ft agl.
- Presence of turbulence inversion.

Standing waves:
‘Occur in the troposphere when a stable air mass blows at moderate speed over a range of hills or mountains.’
Conditions for standing waves/lee waves:

- Wind of 15kt or more over small mountains, to >30kts over large mountains.
- Wind speed increasing steadily with height
- Wind direction roughly constant
- Wind direction within 30 degrees of the perpendicular ridge line
- A stable air mass.



Max turbulence at height of ridge.

Rotor Streaming:
First peak of wave formation maybe strong enough to start a **horizontal rotor.**
Severe turbulence in rotors.
Turbulence behind hills, rotors and rotor streaming are not confined only to standing wave conditions. They CAN occur in any strong wind conditions.

Other visual clues for standing waves:
Lenticular clouds.
Turbulence from standing waves can be felt right up to **low stratosphere.**

Wake Turbulence:
Large AC, High Angle of attack make severe **wake.**
In the form of **Wing tip rotors.**

Starts on take-off as the AC rotates. Till landing and the AC nose touches down.
Rotors move back at 5kts.
Strong Cross wind can destroy the wake.

2mins or 4NM for HEAVY BEHIND A HEAVY on approach / departure.

Turbulence – Hazards and avoidance:
Hazards:

- **Severe jolts**
- **AC structural damage**
- **Airspeed fluctuations**
- **G-Loading**
- **Injury.**

Avoidance:
<u>Pre-flight</u>

- **Access weather info for planning.**
- **Turbulence forecast not very reliable.**
- **Pilot reports**

<u>In flight</u>

- Weather radar cannot detect turbulence directly. They detect solids and liquids.
- **Most turbulent areas of a thunderstorm contain most water and ice.**
- **Downwind of thunderstorm core is turbulent.**
- **CAT not visible in radar.**
- **CAT detected by LIDAR.**
-

Icing

Airframe Icing:
Ice does not stick to AC as a sold.
It **MUST form on the AC.**
By: **Direct Sublimation, Hoar frost, liquid striking airframe.**

Happens when rain falls on cold airframe or when supercooled water hits the airframe.

Clouds contain **supercooled** liquid as low as **-45 degrees.** Which are **UNSTABLE,** when shocked, they revert to **ICE (more stable).**

Liquid to ice – Exothermic.

Rime ice and Clear Ice:

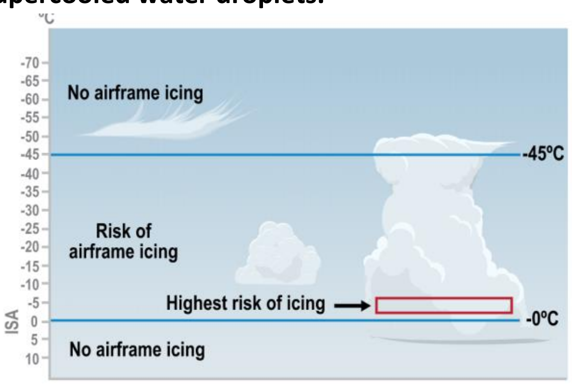
Clear ice: **Ice sticks** to the **leading edge**, remaining water runs back over the airframe.
Freezing water forms clear, hard, durable ice.
Covers static vents, Jams control hinges etc…
Hard to remove clear ice.

Rime Ice:
'The ice that is formed when droplets freeze on impact with the airframe instantly.'
Very low temp.
Traps tiny pockets of air.
Will form white, crunchy easy broken rime.

FOR EVERY DEGREE OF SUPERCOOLING, 1/8 OF THE DROP FREEZES ON IMPACT.

Mixed Ice:
Forms at temp: **-10C to -15C.**
'Impacting water droplets freeze quick and any ice crystals in the cloud freeze to AC.'
Looks:
White, Porous, Opaque (Mix of clear and rime).
No airframe icing will occur below -45C.

In stratus, clear ice: 0 to -7C
In cumulus: up to -23C because of larger supercooled water droplets.



Most hazardous conditions:
'Worst ice occurs just below 0C'
Faster build-up of ice at higher speeds.
But at VERY high speeds less build up.

Most build-up of ice occurs with highest concentration of largest super cooled water drops.
MUST BE ACTIVE CONVECTIVE CLOUD. Cu CB and thunderstorms.

Icing in clouds:
The -45C isotherm varies from 18,000ft (arctic) – 37,000ft (equator), 40,000ft India.

Cloud type	Severity	Icing type
Ci	nil	-
Cs	trace	rime
As	light	rime
Ac	light	clear/rime
Ns	moderate	clear/rime
St	light/moderate	clear/rime
Sc	moderate	clear/rime
Cu	moderate	clear
CB	moderate/severe	clear
Thunderstorms	moderate/severe	clear

Note: **Orographic lifting** increases icing!

Summary of icing:
3 most common temp zones:

0 to -15C: Clear ice.
-10 to -15: Mixed clear and time ice.
-10 to -20: Rime.

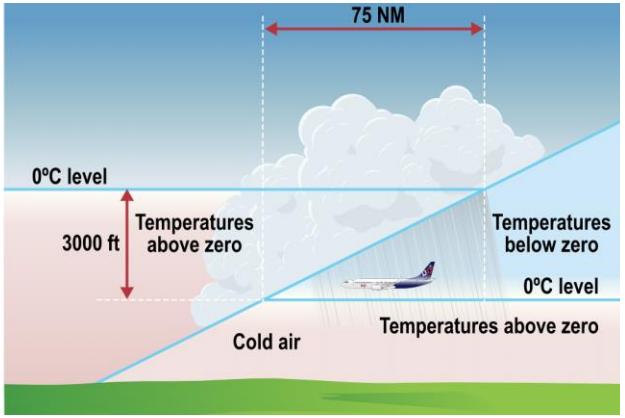
Icing not a big threat if air temp is <-20C EXCEPT in large CBs, as uplifts transport droplets.

Factors affecting icing threat:

- Particle size
- Particle concentration
- Shape of AC surface
- AC speed
- Environmental temp
- AC surface temp <0C

- **Large particle hit the surface, small don't.**
- **As airspeed increases so does number of strikes of droplets.**
- **Thin wings catch more.**
- **Catch greatest for thin wing AC flying high speed through clouds.**

Icing fronts:
Airframe icing associated with warm fronts: **Rain ice.**
'Rain ice = Heavy clear ice, AC flying above 0C in cold air, below the frontal surface and below the 0C level of warm air. 'RAIN ICE TRIANGLE'



Rain ice comes below the warm front surface, in rain but clear of the frontal cloud.

Frontal slope is 1:150, rain ice triangle, very thin and flat.

Exit strategy: climb or descend.

Hoar Frost:
'Formed when airframe VERY cold, and AC is in warm moist air, moist air will sublimate.'
Aircraft flying in warm air soon warms, so effect is transient.
Most common on ground.
Can be very dangerous.

Active frost and cold soaked fuel frost:
Hoar needs to be removed before flight: **will not reform.**
Active frost like hoar. BUT CONTINUOUSLY REFORMS. Can ONLY be removed with DEICING FLUID.
Conditions:

- AC skin below freezing
- Air temp is close to dew point (within 3C)
- Dew point is below freezing and:
- A cloudless sky with calm winds
- A warm front bringing warm, moist air.

Cold soak fuel frost:
'Moisture in the form of precipitation of high humidity can deposit frost or ice on a cold wing, even in warm weather.'

Occurs when fuels is **Cold soaked,** and in **contact with aircraft skin.**

Packed Snow:
'ice crystals at temps below 0C will melt if compressed, and freeze when pressure is removed. (snow balls).
In snow shower small risk snow will stick.
Low chance.

ICAO Classification of icing:

Light: less than moderate icing
Moderate: Conditions in which a change of heading and/or altitude may be considered desirable.
Severe: Conditions in which an immediate change of heading and/or altitude is considered essential.

High altitude ice crystal icing:
'ice crystal icing' – forms by convective weather lifting small ice crystals. High level!

They do not stick to airframes because it's too cold.
They stick to engine surfaces as its warmer.
Can also occur in small storms (infrequently).

High altitude ice crystal icing ICI:
'ice crystal icing' – forms by convective weather lifting small ice crystals. High level!

They do not stick to airframes because it's too cold.
They stick to engine surfaces as its warmer.
Can also occur in small storms (infrequently).

Jet engine intake icing:
'Most subsonic jet intakes have some degree of convergence, which increases air velocity therefore dropping in pressure and temp.
If temp drop to icing range and humidity is high, ice may form.'
Most jet engine intakes are heated to avoid this.

Indications:

- Un-commanded thrust reduction.
- ICI disrupted intake airflow has created abnormal pressure gradient in engine core, leading to airflow reversal!

Ice water content (IWC). 'Ice mass in unit volume of atmospheric air. It can vary largely from 0.0001 g/m3 in thin cirrus to 1g/m3 in convective core.

Avoidance
Clues include:

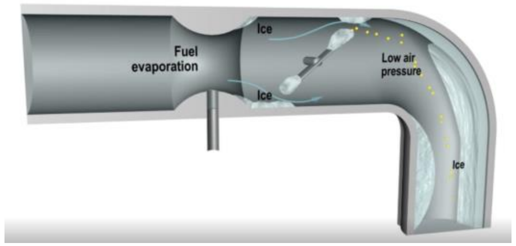
- An air temp way above corresponding ISA.
- Presence of turbulence (light to mod)
- Heavy rain below freezing
- St Elmos fire on flight deck.
- Appearance of small droplets of moisture on flight deck windscreen.

Best way to avoid with weather radar staying clear of convective activity at altitude.

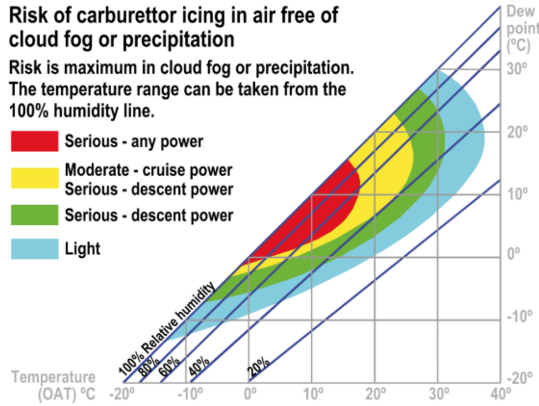
Deviate by 20NM from areas with large convective cells. If engine at risk 50NM.

Piston engine intake icing:
'Carburettor icing, only effects engines with carbs, not modern fuel injected.'
Hazard on warm good-weather days!

There is a **Venturi in the engine** that speeds up flow, when ide, throttle is nearly closed, making the constriction heavy, therefore larger temp drop. In addition, evaporating fuel adds latent head of vaporisation dropping temps more.
Piston engine intake icing caused by venturi effect and the evaporation of fuel.



Forecasting carb icing:



KEY FACTOR IS HIGH HUMIDTY.
In fog / cloud assume RH = 100%

Ice avoidance techniques.
During pre-flight planning (BEST option):

- **Use resources:** TV, websites, pilot reports etc.
- **<u>Ask questions:</u>**
- **Where are the fronts?** Most ice in fronts and low-pressure centres.
- **Where are the fronts moving?** Check 'upstream' weather reports.
- **Where are the cloud tops?** Expect much higher clouds over mountains.
- **Where are the cloud bases?** Below clouds where freezing rain or drizzle is not present, there will be no structural icing.
- **Where is the warm air?**

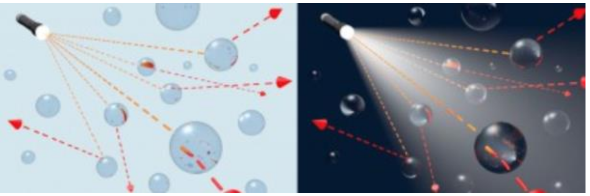
- **Air mass clouds or frontal clouds?** Know the diff between.
- **Alternative routes?**
- **Escape routes?**

In-flight:

- Talk to ATC about weather developments
- Airspeed key to measure icing, if airspeed drops exit immediately.
- Stall speed margins decrease with speed loss.
- First sign of ice advice ATC.
- Use anti icing
- Modify route
- Extra caution around mountains.

Visibility

Poor visibility
'Either by day or night, vis reduced when small particles obstruct, ice crystals, or solids like dust, sand and smoke.'



Hazards:
Diffraction though water drops in rain, mist or fog can give **false indication of angle of approach**. Makes you think you are **closer** to touchdown than you are.

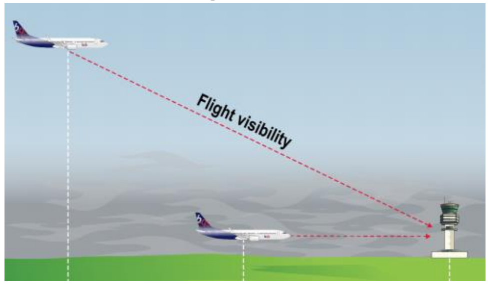
Define visibility:
Flight vis and aerodrome vis are **different.**

Aerodrome vis reported as 'Prevailing visibility' or 'Runway Visual Range'.

ICAO Annex 3 Definition of Visibility:

2. The greatest safe distance at which a black object of suitable dimensions, situated near the ground, can be seen and recognised when observed against a bright background

1. The greatest distance at which lights in the vicinity of 1000 candelas can be seen and identified against an unlit black background.



Prevailing Visibility:
'Aerodrome visibility'
Definition: 'The visibility value that is reached or exceeded within at least half the horizon circle or within at least half the surface of the aerodrome. These areas could comprise contiguous or non-contiguous sectors'

Runway Visual Range (RVR).
'Maximum distance in the direction of take-off or landing at which the runways, or specified lights delineating the runway, can be seen from a position on the centreline corresponding to the average eye level of a pilot at touchdown.
Measured by infra-red laser at edge of runway.

RVR Reporting:
RVR reported:
in steps of 25m, up to 200m,
in steps of 50m up to 800m,
then in steps of 100m.
Not normally reported at all if it 1500m or more.

Touch down	Mid point	Stop end	Reported as
1600	1700	1900	not reported
1200	900	1000	RVR 1200
800	900	1100	RVR 800
1000	700	900	RVR 1000 mid-point 700
600	500	550	RVR 600 500 550
600	500	750	RVR 600 mid-point 500
400	450	350	RVR 400 stop end 350
300	350	350	RVR 300 350 350

Fog or mist:
Definitions of low vis conditions as follows:

- **Fog** caused by water droplets or ice crystals, **Vis less than 1000m. RH = 100%**
- **Mist** caused by water droplets or ice crystals, defined as vis **at least 1000m but not more than 5000m**. **RH = 95%**
- **Freezing fog** is fog below 0C, **supercooled water drops.**
- **Ice fog** consists of **Ice crystals** rather than water drop. **Very Rare, found in polar. Temps below -20C.**
- **Haze = solid particles if vis <1000m.**
- **Sandstorm = gradient wind Harmattan or convective (Haboob)**
- **Blowing Snow: snow below 0 blown by wind.**

Radiation fog:
'Forms when surface cools at night, from loss of heat through long wave radiation, the surface cools air in contact by conduction, brining it below dewpoint.'
Only over land.

Radiation fog 2:
If air is very still conduction will be limited to a thin layer near surface.
Conditions favouring radiation fog:

- **Overland**
- **At night**
- **Clear skies**
- **Light winds – 2kts to 8kts**
- **High relative humidity.**

Dawn is a likely time for radiation fog to form.

Radiation fog 3:
If the dewpoint temp is below 0C the air will meet the frost point first, and moisture will sublimate to ice. Forming heavy frost on the surface.
Radiation fog cleared by surface heating during the day.

Advection Fog:
'Occurs when warm air mass moves over a cold surface.'
About 15Kts wind speed is needed to move airmass.
Comes from subtropical high-pressure regions.
Can happen to land and sea, day or night.

Arctic smoke:
'Arctic smoke or Sea smoke or Steaming Fog has the reverse mechanism from advection fog and is formed when cold air passes over warm air.
Very cold air flows from ice caps to warm land.
SFC to 500ft.

Frontal and other types of fog:
Fog associated with the passage of a warm front.

<u>Fog Characteristics Summary:</u>
Fog is a cloud (Usually stratus) in contact with ground, with VIS <1000m.

Formation:
Increasing moisture and/or cooling air.
Moisture increased by:

- **precipitation,**
- **evaporation from wet surface, moisture advection.**

Cooling of air results from the following:

- **Radiation cooling**
- **Advection over a cold surface**
- **Upslope flow**
- **Evaporation.**

Dissipation:
Removing moisture and/or heating the air dissipates fog and stratus. Decreased by the following:

- Turbulent transfer of moisture downward to the surface.
- Turbulent mixing of the fog layer
- Advection of drier air
- Condensation of water vapour to clouds.

Heating of the air results from:

- Turbulent transport of heat upward from air in contact with warm ground.
- Advection of warmer air
- Transport of the air over a warmer land surface
- Adiabatic warming of the air through subsidence or downslope motion.
- Turbulent mixing of the fog layer with adjacent warmer air aloft.
- Release of latent heat associated with the formation of clouds.

Fog Types Table:

Fog Type	Formation	Conditions Required	Significant Characteristics	Conditions for Dissipation
Radiation	Cooling	Night cooling of ground by radiation. Air in contact is cooled. Clear skies,moist air, light winds (2-5 knots). Stable atmosphere.	Over land only. Can be a very thin layer in the calmest winds. Depth of layer increases as more of the layer in contact with the surface cools.	Warming of surface by solar heating. Convective thermals mixing out surface air with drier air aloft.
Advection	Cooling	Warm moist air moving over a colder land or sea surface. Wind>15 knots.	Over land and sea. Frequent in coastal regions.	Change one or more of formation factors. Either less moist air, a change of wind direction or heating of the cool surface.
Steam (Evaporation Fog, Frost Smoke or Arctic Sea Smoke)	Add Moisture	Cold air passes over warm water surface. Evaporation of water into air until saturated. A marked surface temperature inversion in the air before it moves over the sea or inland water body. A low air temperature, typically 0°C or below, so that a comparatively small amount of moisture can produce supersaturation.	It is commonly seen as wisps of vapour emanating from the surface of water. This fog is most common in middle latitudes near lakes and rivers during autumn and early winter, when waters are still warm and colder air masses prevail. A strong inversion confines the upward mixing to a relatively shallow layer.	Re-evaporation of the water in the fog by solar heating. Strong winds.

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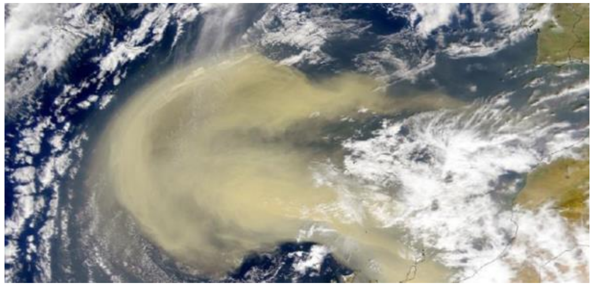
Dust and sandstorms:
Occurs in desert areas, hazard to AC.
Low level wind lifting sand into the boundary layer.

Poor vis in dust and sand with all areas around the Sahara in the winter. And with Arabian gulf in in the summer.



Blowing Snow:
For snow to lift in strong winds it must have remained at a temp from -5 to -20C, **Moderate winds** will lift the snow to low level.
Not usually a hazard but **removes ground details.**
Strong winds will lift snow into the boundary layer where it becomes a vis hazard, where all reference can be lost in 'white-out'.

Rain and Drizzle.

Visibility in Rain > Visibility in drizzle.

Small water drops indicate little lifting and stable air.

Larger drops indicate greater lifting and unstable air

Unstable air clears pollution vertically and visibility is better than in stable air.

Visibility in winter precipitation.
Liquid equivalent snowfall rate is defined as the amount of melted snowfall per unit time, measured by a snow gauge in mm per hour.

Rimed snow refers to snowflakes that are partially or completely coated in tiny frozen water droplets called 'rime'.
Rime forms when passed though super-cooled cloud.

Wetness of snow is amount of liquid content within the falling snow.

Relationship between liquid equivalent snowfall rate and visibility depends on **crystal type,**
degree of riming,
degree of aggregation
degree of wetness of the crystals

Factor of 4 increase in vis for wet or rimed snow vs dry snow for same snowfall rate.

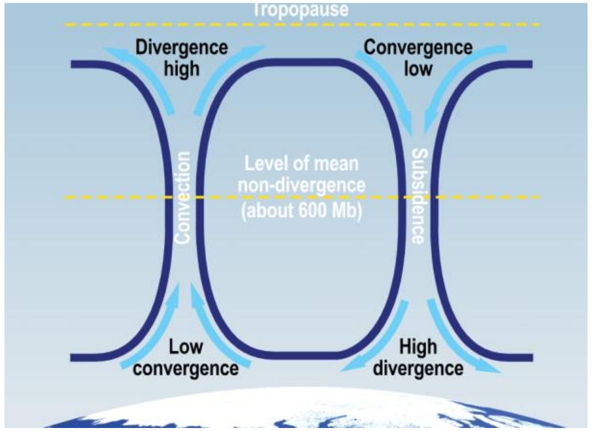
Vis increased by factor of 2 due to higher terminal velocity of wet or rimed snow vs dry snow.

Wet or rimed snow 8 times increased vis compared to dry.

Pressure systems

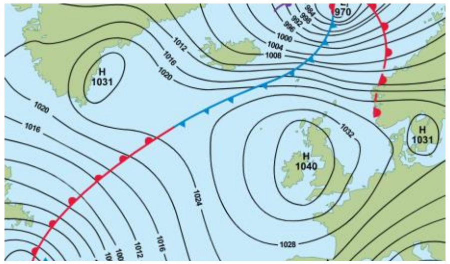
Convergence and Divergence:

Surface low leads to rising air (convection) which diverges in the upper high.
Air flows from High – Low

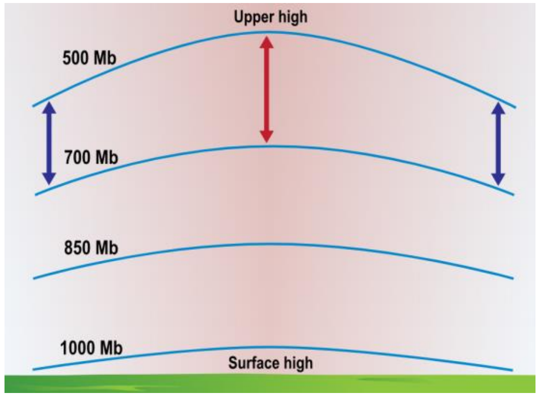


600 hPa = 14,000ft 'Barostatic level'
Over poles Barostatic = 700hPa (10,000ft.)

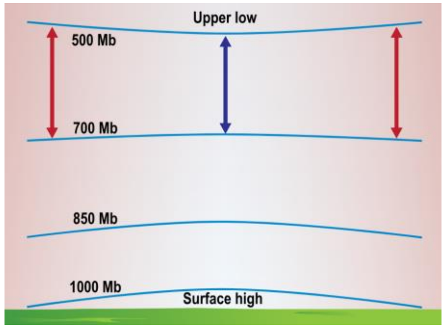
<u>Anticyclones</u> or Highs:
High pressure = ANTICYCLONE.
Clockwise in the northern.
Anti in the southern.
'Warm or cold highs according to whether the core at a particular level is warmer or colder than the surrounding.'



Warm Anticyclones:
Warm Anticyclones are formed when an excess of air in the high troposphere leads to subsidence and then divergence at the surface. Vertical spacing of isobars must be greater than the surrounding air as long as the core is warm.



Cold Anticyclones:
Formed when cold surface temps make the lower troposphere cold and dense.



Phenomenon is known as cold air pool. Greatest activity (Instability) occurs when there is the greatest temp contrast between the cold air at mid and upper levels and the air at the surface.

Cold air pool indicated by low contour (isohypses) height on the 500hPa chart and higher. Also on the upper wind and temp charts.

Temporary cold anticyclones:
Cold air, Poleward side, northern and southern polar fronts.
Last only few days.

General Properties of Anticyclones:
Large (1500NM)
Slow to form / dissipate
Stationary / slow moving.
Surface pressure gradient at centre = slack, winds light.

Warm Anticyclone = STABLE fine and calm weather.
If over sea or moisture = fog forms.

Solar heating = mild instability at low level.
This leads to small fair-weather Cu's.

Cold Anticyclones = CAN BE UNSTABLE.
If convective lifting and moisture present = Large CB's.
Most cold CBs in dry areas.

Cyclones, Lows or Depressions:

Cyclone = **LOW PRESSURE system.**
anticlockwise in the northern hemisphere.
Often called 'Lows' or 'Depressions'.

General Properties of Depressions:

Small – **300Nm Across**

- **Active, form rapidly Move at fair speeds and fill rapidly when dying.**

Take energy in at low levels, as Latent heat, or warm air and carrying it aloft.
This energy translate to **Kinetic energy (winds)**

Strong Winds.
Surface convergence
Upper divergence
Convection
Precipitation.

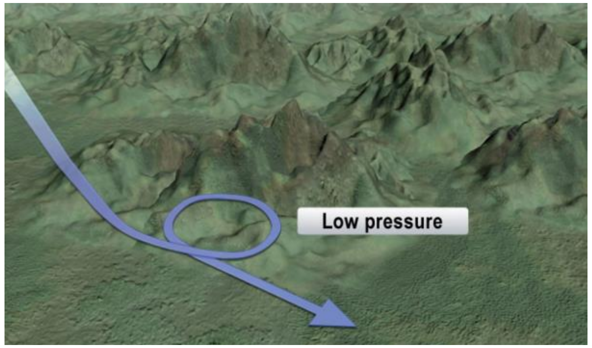
Depression classified by the way they form:

- Frontal depressions, formed along the line of the polar front
- Orographic depressions, sometimes called **lee** depressions, **formed by swirling of the airflow behind hills and mountains.**
- Thermal depressions, **caused by surface heating.**
- Cold air lows, 'polar lows', associated with small-scale instability developing in polar airflow.

In Europe thermal lows form near Cyprus in winter when cold continental air comes from the north.

Orographic Depressions:

Aka 'Lee' depressions.
Lee low is a low-pressure forms preferentially to the lee of a mountain when air is **right angle** with barrier. Air column squashed by vertical contraction as it crosses the barrier. Developing a strong spin.
Spin manifested as a low-pressure centre.

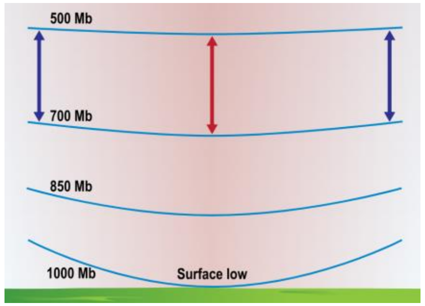


Thermal Lows:

Form when surface is **Hot.**
Low level air heated and rise.

High temps don't always lead to lows
Continued surface heating can make airmass **unstable** and convective activity starts and results in depressions.

Thermal lows form **over water in winter**. As the water levels are higher than land.

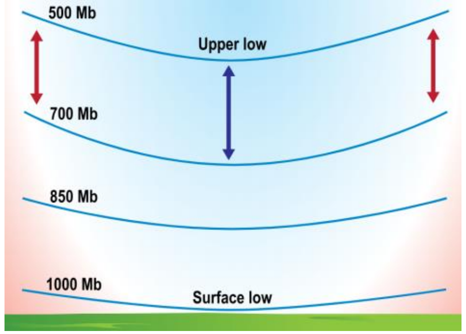


CSA of thermal lows

Cold Lows:

Cyclones can also be classed as warm or cold lows depending on whether the core at a particular level is warmer or colder than the surrounding environment.

Frontal depressions are typical cold surface low.

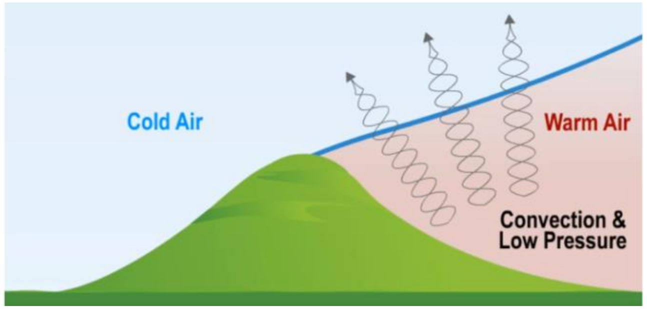


Polar-Lows:

Polar-air depression is small-scale non-frontal low, or pressure system categorise the highest latitudes.
Secondary depression forms over **oceans**.
These lows are **Small. May not show on pressure chart.**
Bring convective activity and heavy snow shower in Scotland and England etc.

High level cloud lows:

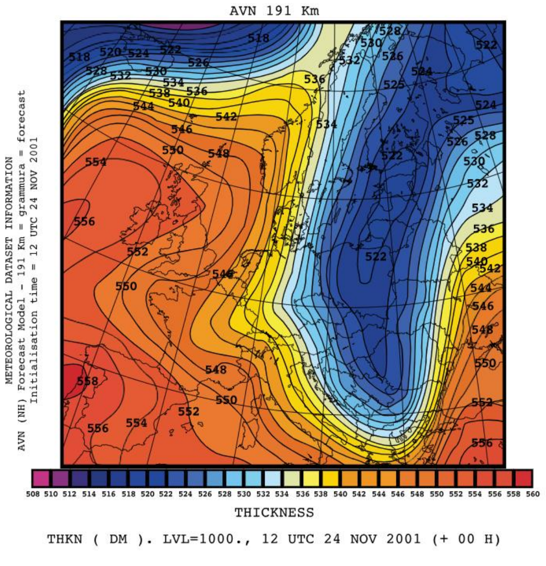
Cold lows also exist at height when high level polar air extends into temp regions, sliding over warmer air under.



Cold air outbreak:
Cold Lows such as this can also be described as cold air outbreak or, where cold air cut off from source = 'Cold pool'

Cold air outbreak at height = unstable.
Warm below, high above = high lapse rate.
Cold air outbreak in low layers is stable but can destabilise by surface heating.

Thickness chart: shows the thickness of the air between 1000hPa (near surface) and 500 hPa (18,000ft).

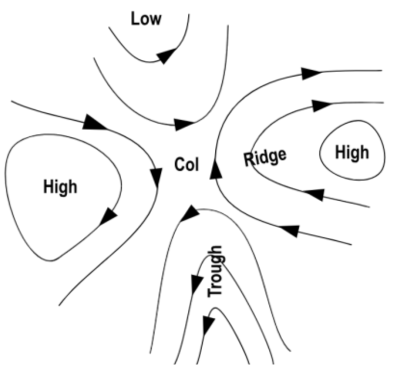


Ridges, Troughs and Cols:
A ridge (or wedge) is an elongated area of high pressure, characterized by a generally anticyclonic type of weather (settled fair weather), maybe an extension of an anticyclone or high-pressure region.

Troughs are a normally elongated feature of low atmospheric pressure on a pressure chart, 'Kink' in the axis of V-shaped isobars.

Troughs coincide with fronts.
Sometimes: Unsettled weather, cloudy conditions, and precipitation.

Cols:
Between 2 highs and 2 lows, have a pressure pattern that produces virtually no low-level wind.
Over land in winter = deteriorating vis due to radiation fog.
Over land in summer = surface heating = rise low level temp = convections = airmass thunder storms = CBs.



Cold air pools (Cold air drops):

Cold air pools are also called cold drops or cold-air drops.

'Region or pool of relatively cold air surrounded by warm air.'

If, in summer, a cold air pool lies over a land area, then cold air will become unstable due to heating of air in lower layers near the surface = convection clouds = showers and precipitation.

The dependence on solar radiation means convective activity follows a daily rhythm, **greatest activity during the afternoon.**
Weather active for several days to a week.
Hard to predict movement.

Large portion of weather is **Air Mass weather.** Determined by the characterisation of **air passing overhead, its stability (lapse rate), temperature and moister.** And the interaction with the surface conditions: **Surface Temp, heating by sun, and physical features.**

What is an air mass?
Must be **homogeneous.**
In order to be homogeneous must be **stationary** for longer time.
Low pressure (cyclones) = DYNAMIC moving.
High pressure (Anticyclone) = Stable, Stationary.

Airmass = BIG STABLE HIGH.

Definition of airmass:
Characteristics:

- **All start stable, maybe temp inversion.**
- **If source region cold, airmass cold.**
- **If source region warm, airmass warm.**
- **If over land/ice = dry**
- **If over sea = moist**

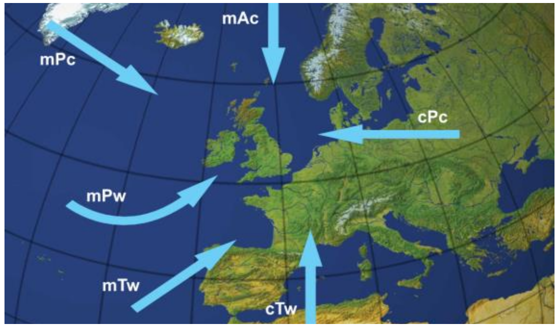
The surface will modify air mass when it moves.

- **Air mass traveling on land remain dry**
- **Moving over sea = more moisture = +RH in low layers, more prone to convection.**
- **Over warmer surfaces = heating = increasing ELR = Less stable air.**
- **Over colder = cooling = decreasing ELR = More stable.**

Air Mass Weather:

Classification:
Maritime = Oceanic air
Continental = Land air.
3 letter code:

Track	Continental	c
	Maritime	m
Source region	Polar	P
	Artic	A
	Tropical	T
Temperature	Warm	w
	Cold	c



Maritime Polar Cold Air (mPc):
Starts over polar caps as cold dry stable air.
As it moves south, over Atlantic, picks moisture, warm sea heats low level, temp rise, air less stable, convective currents. Therefore **Moist unstable air arrives. Convective cloud, showers, good vis.**

Orographic triggers = Cu over mountains.
Winter = cool land = Small/medium Cu (disperse in the night)
Summer = Hot land = Thermal trigger = Cu / CB (stay at night)

Maritime Arctic Cold Air (mAc):
Ice cap moves over sea:

Cu and CB form over sea, bring heavy snowfall, Small thermal depressions (poler lows) also form.

Continental polar cold air (cPc):
Comes from Siberian high's, a cold, dry, stable airmass over Europe and Russia.
Temp inversion = Traps industrial contamination = poor vis, but no clouds.
Windshear / Turb at inversion layer.
Makes central Europe very cold.

cPc going through Baltic North Sea, warms from sea = less stable = can produce snow.
ONLY PRESENT IN WINTER.
In summer surface temps rise (20-25C) becomes low pressure.

Continental Tropical Warm Air (cTw):
Comes from North Africa in summer where it is stable and hot.
-As it moves north = cools = more stable.
-Crosses Mediterranean = moisture = crosses alps = moisture lost.
-once north of alps, no cloud and poor vis because of subsidence and temp inversions. = blue skies and hot weather. Eventually daytime heating = convective weather (Cu)

-cTw is a summer airmass, but 'Summer' extends into the autumn in practice.

Continental Tropical Warm Air Cont. (cTw):
If path = northsea, Moisture in lower layers will be trapped underneath the inversion and thin layer of advection fog will blow onto shore.

Maritime Tropical Warm Air (mTw):

As air tracks northeast to northwest europe, lower levels cool = + RH = + Stability.
Vis is moderate – poor.
Stable at all levels.

Maritime Polar Warm Air (mPw):

Same source as mPc.
Differs because of longer sea passage. Travels further south.
As it travels south, picks up moisture = + ELR = - Stability at all levels.
When it returns north, the effect reverses. Low levels cool = more stable, but mid and high stay unstable.

Moist stable air conditions = Low stratus, poor vis, drizzle, advection fog, convections.

Fog and stratus lift in turbulence overland to Sc (when wind is + 15kts.

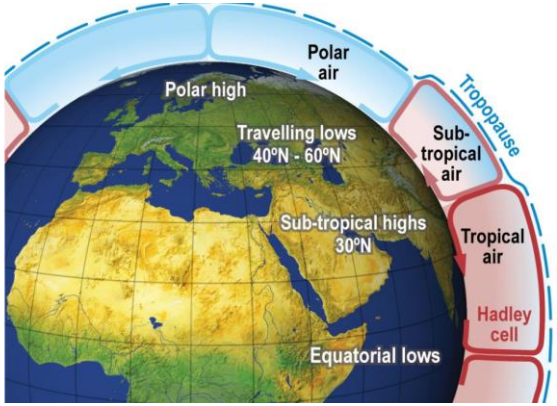
Equatorial Air Mass:
There is no one airmass.
Develops at latitudes from 25N to 10S.
Temps are high, not much land therefore masses are maritime. Very moist because water evaporates into the hot air at the equator.

Warm air rise = low pressure, trade winds blow into area of low pressure, push warm air into cooler upper atmosphere = condenses into ice crystals = rain.
Thunderstorms frequent in regions dominated by equatorial air masses.

Cold air outbreaks and cold pools:

Intrusions of cold air either at surface or at height, into warmer temp regions. A cold air mass over warm surface and cold air pool at altitude can both result in extensive instability and if moisture present extensive convective clouds.

Global Circulation:
Vertical circulations takes place on global scale:
3 main band: **Tropical, Sub-Tropical, Polar air.**



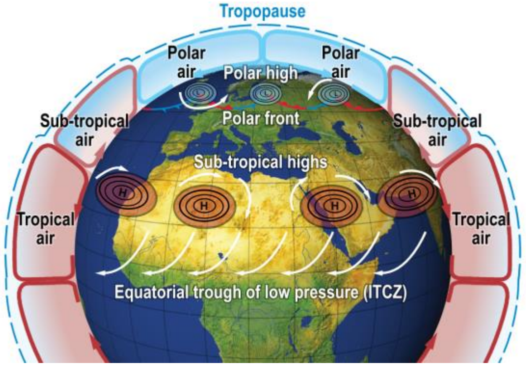
Air at equator = heated = rising to the tropopause = diverges outwards.
At about 30Degree latitude it splits.

Polar air separated from the sub-tropical air by a thin shard boundary called the polar front.
Tropical -to Sub-tropical is more diffused.

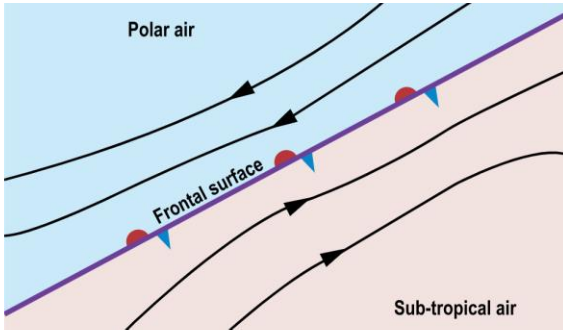
Tropical circulation cell is called **'Hadley Cell'**
Sub-Tropical circulation cell between the Hadley and Polar cells is called **'Ferrell Cell'**

Polar Front Depressions

Rotation of the earth:
Remember: Coriolis effect opposite in south hem.



North Atlantic Polar Front:
Influences most of the weather over northwest EU.



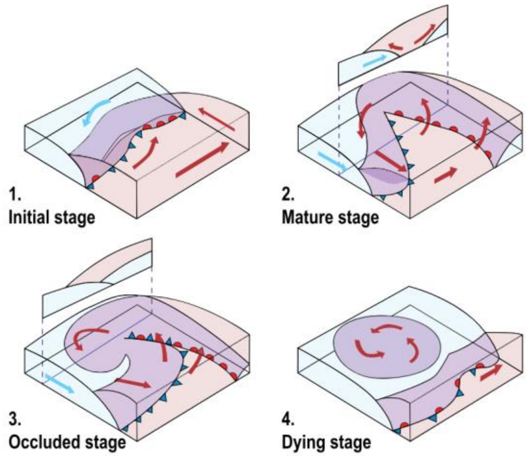
Without movement its known as stationary or quasi-stationary front.

Formation of Depressions:
At regular intervals the front wobbles and forms a wave. If the length of these waves between **500km and 1600km** a **Depression will form.**
Convergence towards to low will be deflected by the Coriolis effect, Circulation will begin at low level, and the characteristic isobar pattern of a frontal depression will appear.
Depression now self-sustained, until the energy supply runs out, and depression slows down and fills.

The Westerly wave:
Wave and depression as it front move along the front at speed: **2000ft wind.**
Atmospheric pressure of polar from depression normally lower in winter because temp contrasts between arctic and equatorial areas much higher in winter.

Formation of Occlusions:
Circulation pulls warm air down to warm side, forming cold fronts. Pushing warm air up over cold air, forming a warm front. Cold front moves faster than warm front, which is held back by more surface friction, so cold air will gradually catch up with warm front, and then overtake it, forming and occlusion or occluded front.

Summary of stages:



Movement of the Depression:

Moves as driven by free wind flow,
Movement of depressions is complex, basic guidelines :

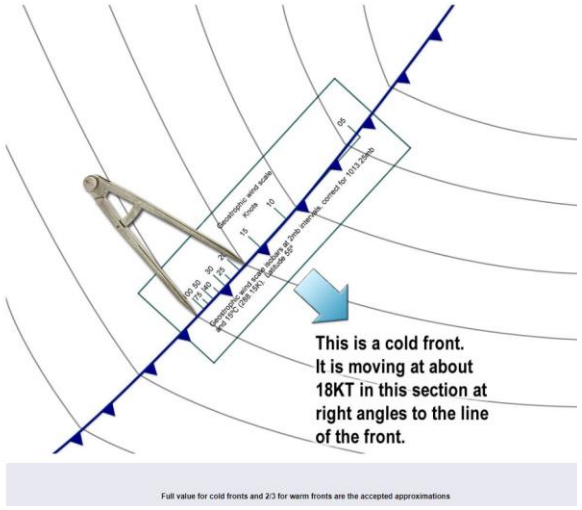
- **An open warm sector depression system as a whole moves in the direction of the nearest isobars to the centre in the warm sector. Speed = 80% of the full geostrophic value.**
- **If there are no fronts left on the depression, find where the isobars are closest. The depression is prob moving in the direction of the wind at that point.**
- **As the depression occludes it slows and curves towards the pole.**

- **Secondary lows in the maritime polar cold (mPc) air or on the cold front move around the main depression with a cyclonic rotation (anticlock in north hem)**
- **Secondary lows on the warm front move more or less radially out and away from the centre of the main depression.**
- **The mean time interval between polar front al wave in west Europe is 1-2 days.**

Effect of blocking anticyclones:
Warm quasi-stationary anticyclones that have broken away from the Azores high can disrupt passage of the travelling lows over the north Atlantic and their associated fronts.
Blocking anticyclones can lead to heat waves in summer and long periods of cold weather

Movement of the Front:
Fronts move independently of the depression centre.
Each section of the front moves at right angles to the frontal surface. (On curved fronts, diff bits are moving off in diff directions).
Speed of any section can be measured by comparing the gap between the isobars along the front to the geostrophic wind scale.
Cold fronts and cold occlusions move at roughly the speed taken directly from the scale, but warm fronts and warm occlusions are slower, and they move at 2/3 of measured geostrophic component.

Measuring the speed of a front:
See diagram:

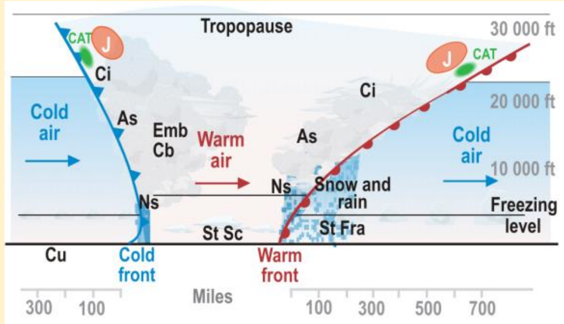


Polar Frontal Depressions 2

The Structure of a Warm sector in a polar front depression:

Cloud and precipitation:
At Leading edge of warm sector the warm air is sliding over cold to produce warm front.
At trailing: cold air forcing under warm air.

- Warm front slope = 1:150
- Cold air front slope = 1:80



Pressure, Temp, and low-level winds:
In southern hem, warm sector will be on the north side of the depression, wind circulation will be in the opposite sense, surface wind will back as the fronts pass.
Front = Area of low pressure, isobars bend towards low pressure end of the front.
If you cross a front moving at right angles to the front line, there will be a small drop in pressure followed by a small rise.

	Position	Wind	Pressure	Temperature
A	Approaching the warm front	Steady, SW	Falling	Steady, cool
B	At the warm front	Veers	-	Increases
C	In the warm sector	Steady, W	Steady	Steady, warm
D	At the cold front	Veers	Falls	Falls
E	Behind the cold front	Steady, NW	Rising	Steady, cool

Warm Fronts:
'Warm air moving towards cold air'.
Warm air lighter than dense cold air = slides over it.
Transition zone: red half circles
Warm fronts move at: 10Kts
Movement complex as it speeds up during day due to heating **slows down at night** (cooling).
In day mixing occurs both sides of the front causing front to move forward. At night radiational cooling creates cool dense surface air behind front, which inhibits lifting and forward progress.
At altitude warm air precedes surface warm front and first signs of warm air can be seen about 750 miles ahead of warm front.
In stable warm air first signs of approaching warm air: **cirrus clouds. These get thicker until they become Cirrostratus.**
Cloud base lowers and cloud becomes Altostratus = light rain. Then heavy rain as it becomes a nimbostratus.
Avrg Width of precipitation zone = 185 miles. (300km). In precip zone low stratus likely making VFR impossible.

If warm air sliding over the cold is unstable it is possible embedded thunderstorms could form. Turbulence usually weak, apart from at the frontal layer = strong.
Severe icing in nimbostratus if temp = -7 to -10C.
Vis impairment due to humidity increase by evaporating rain drops leading to stratus fractus or frontal fog.

Cold Fronts:
At cold front: polar air moving towards warmer sub-tropical air. **Cold air undercuts warm air pushing it upwards.**
Transition zone: line with blue triangles.
Active cold fronts are slow moving = 15Kts.
Inactive cold fronts are fast moving = 25kts.
In general cold front is 50% faster than warm.

If warm air is stable (in winter), Clouds of more stable layered type (Nimbostratus and Altostratus) occur. During the summer the warm air is usually unstable, and passage of cold front can bring thunderstorms and high wind.

Thunderstorms = Turbulence, icing, wind shear, lightning, hail etc…) expected especially in summer. Low fractured clouds and poor vis in

Warm Sector:

Area behind warm front and ahead of cold front known as 'Warm sector' consists of **Tropical Maritime air.**

Warm sectors bring = Mild and wet weather **in winter**, thick clouds of **stratus** = hill and coastal fog + poor vis.

Temps in warm sector are warm in summer (not too hot). Lower air is stable but if forced on hills upper layers become conditionally unstable = thundery showers. Moderate winds. Vis moderate.

Behind a cold front:

Area behind a cold front can be changeable and seasonally dependent.

In spring and summer convection clouds form in fresh, cold polar air.

Cumulus clouds grow during the day = showers and thunderstorms. Most active period after midday. in evenings cumulus becomes stratocumulus which then dissipate as the day goes on.

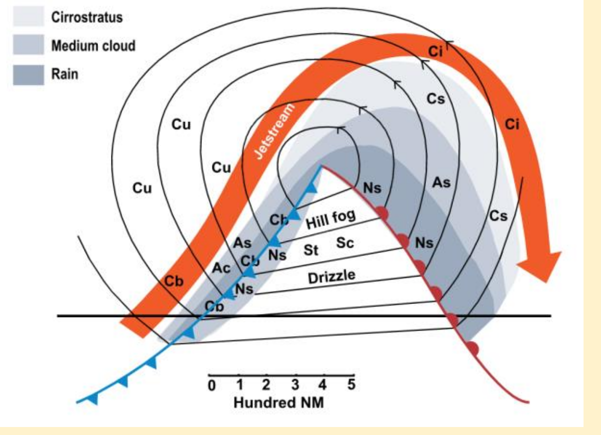
Outside showers, vis = good.

In showers, vis = bad.

During autumn the weather behind the front is less active as the polar air is warmer than in spring and the solar radiation less intense.

High Level Winds:

The cloud and upper wind structure of a typical warm sector depression show:



Jet stream running parallel to the frontal lines.

Influence of a mountainous area on frontal passage:

When warm front crosses mountain range, some cold air may be trapped upstream of the mountain. **Causes warm air to be directed upwards and is possible long-term precipitation occurs on the upstream side.**

Due to sinking air frontal activity is less on the lee (downstream) side.

Hazards at fronts:

Icing:

No icing in the Ci of approaching warm front, trace and light rime ice will appear in the As. Moderate mixed rime and clear possible in Ns,

Worst hazard is RAIN ICE.

Leave rain ice triangle by climbing.

In warm sector carb icing maybe a hazard. At cold front, with its embedded CB always assume severe icing.

Turbulence:

Light/moderate turbulence in warm front zone.

Windshear at frontal surface.

At Cold front = moderate/severe turbulence.

CAT around Jetstream.

Occluded fronts:

As cold front overtakes warm front and occludes the characteristic weather of the two will combine.

Warm Occlusions:

Will have the shape at the surface of a warm front. Uplift moderate, weather will be a mix of warm and cold front.

In warm occlusions precipitation falls ahead of surface position of occlusion.

Cold occlusions:

Shaped like a cold front.

Precipitation falls near the surface position.

Quasi-Stationary Fronts:

'A front along which one air mass is not appreciably replacing another air mass.' **A stationary front may develop from the slowing down or stopping of warm/cold fronts.**

When this front forms, slope of warm/cold front is very shallow. The cold air stays on the ground, and warmer air is displaced upwards. Front stops moving because winds behind and ahead become parallel to the stationary front.

Fronts moving less than 5kts = Stationary fronts.

Characteristics of stationary fronts:

When front is stationary, the cold air mass does not move toward or away from the front. Wind above the friction layer blows parallel to it!
Wind shift across the front usually near 180degrees.
Follows that the isobars, too, are nearly parallel to a stationary front.
Makes easy to recognize on a weather map.

Stable stationary fronts:
'There is frictional inflow of warm air toward a stationary front causing a slow upglide of air on the frontal surface.'
As air is lifted beyond saturation, clouds form in warm air above the front.
If warm air in a stationary front is **stable** and slope is **shallow**, **stratiform clouds form. Drizzle may fall, as air lifted beyond freezing, icing conditions arise.**
At very high levels above the front ice clouds are present. If slope is steep warm air is being advected up the frontal slope, stratiform clouds with embedded showers result.

Unstable stationary fronts:
If warm air is conditionally unstable, slope is shallow and sufficient lifting occurs, clouds are then cumuliform or stratiform with embedded towering cumulus.
If energy release is great (warm, moist, unstable air) thunderstorms result.
Within cold air mass, fog and low ceiling may result if the cold air is saturated by warm rain or drizzle falling through it from the warm air mass above.
If temp <0C, icing may occur but is light.
If slope is steep and sufficient, warm air is advected up the slope or the front moves slowly toward the warm air mass, violent weather can result. Heavy rain, severe thunderstorms, strong wind, and tornadoes.

Global Weather Patterns and temperatures:

Surface air temperature and the ITCZ:

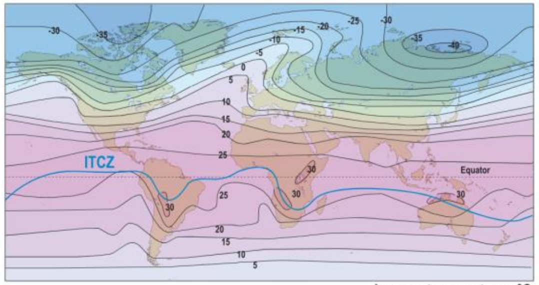
Surface air temps affected by 2 major factors:

- Isolation
- Sea temperature (in coastal regions).

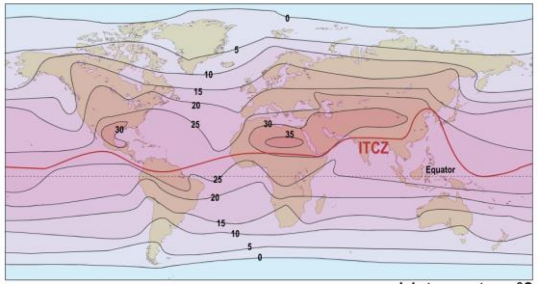
Global temp varies with latitude (colder at poles).

Land heats up in summer, sea remains similar temp.

The Inter Tropical Convergence Zone (ITCZ): follows the thermal equator, goes where the surface temp rises – over big land masses.

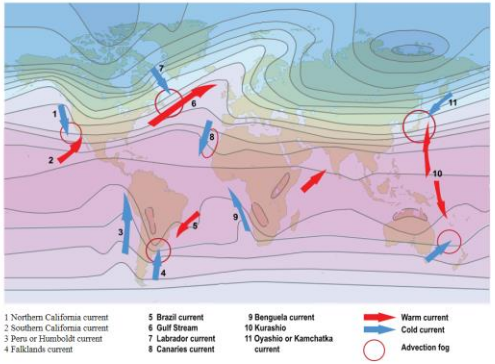


January temperatures °C



July temperatures °C

Sea temperatures:



On the other hand, the absence of cold currents in the Indian Ocean and the East Indies allows a wide variation in the ITCZ position.

Surface temps near the coast influenced by **larger ocean currents.** Most important are: **Warm and Cold as shown above.**

Converging cold currents tend to stabilise the ITCZ position.

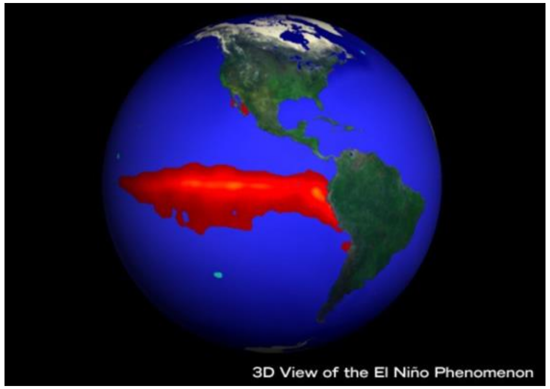
Absence of cold currents in the Indian ocean and east indies allows a wide variation in the ITCZ position.

Advection fog:

Shown in diagram above: Areas known for sea based advection fog, where warm moist air passes over cold sea surface.

They all occur at the junction of cold and warm sea currents, except for one location off west Africa.

El Nino:



A weather phenomenon directly connected to pacific sea temps.

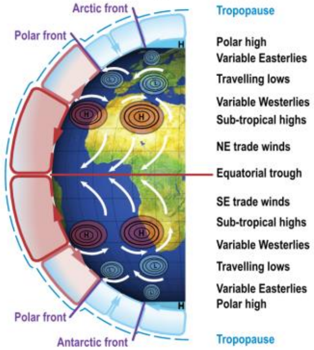
Every 3 to 7 years (for unknown reasons) the cold water sinks below the surface and warm water flows back from the far east. Making the far east cooler and pacific warmer than normal and heavily distorts normal weather patterns.

Colder than normal pacific = La Nina.

Global Weather – Low Level Winds, Fronts and the ITCZ

Surface pressure:

Diagram shows theoretical global circulation:



Atmospheric circulation = **Large scale movement** (one of the ways thermal energy is redistributed on the surface of the earth)

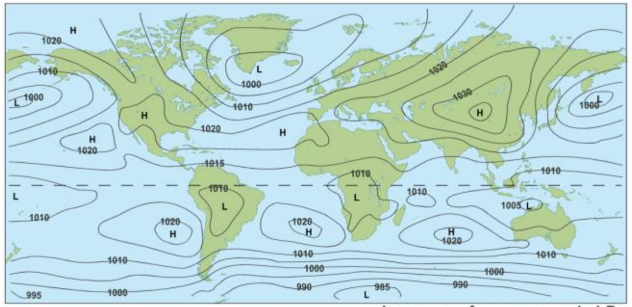
Smaller scale weather systems – Mid-latitude depressions, or tropical convective cells occur 'randomly', predictions are hard.

Wind belts organised into 3 cells in each hemisphere:

- **Hardley cell**
- **Ferrel Cell**
- **Polar cell**

Vast bulk of atmospheric motion occurs in the **Hadley Cell.**

Surface Pressure – January:

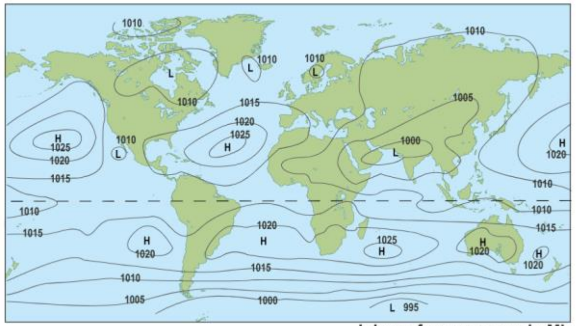


January surface pressure in hPa

Surface Pressure – January:

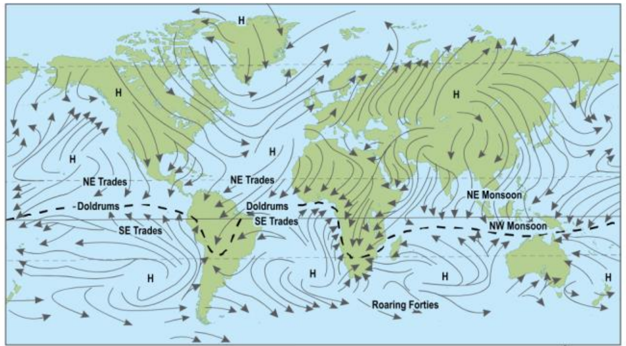
Actual sea level pressure distribution in january. High and low pressure changes caused by suns heating and ocean currents.

Surface Pressure – July:



July surface pressure in Mb

Low Level Winds:



January

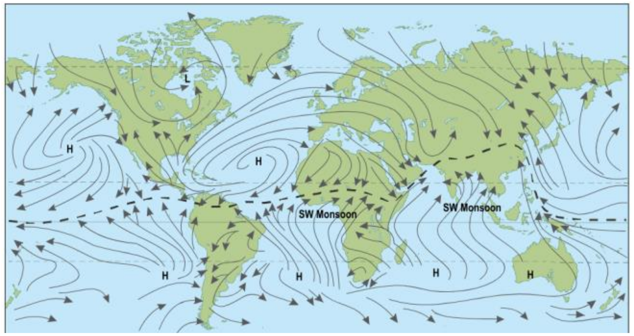
Shows how the ITCZ is low pressure.

Trade winds: East → west. Small Cu, tops limited to 8000ft, 15kts wind and fine weather with occasional CB and showers. Air moist in lower part and dry in upper part.

The Harmattan:

In about august ITCZ begins to retreat following the sun south. Airflow over north Africa now dry, dusty NE wind from the Sahara. **'The Harmattan'**. – Brings:

- Dry weather
- Poor visibility
- Picks moisture from jungle and forms sea fog



The Doldrums:

At the convergence line when it is near the geographic equator there is a band of light and variable winds called the **Doldrums**. Where converging winds will have to cross the equator to reach the ITCZ.

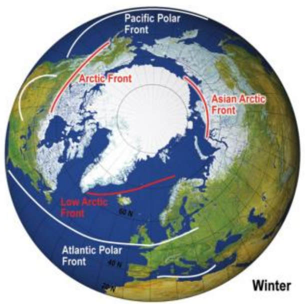
They will turn as the Coriolis force reverse, and the long track and heating from below will produce a lot of convective activity = CB = Thunderstorms = Rain.

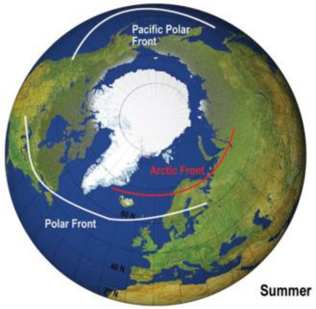
The Doldrums only exist when the ITCZ is near the geographic equator.

The Far East:
More complex.
Subtropical highs are replaced by cold Siberian highs as the source of converging winds in the north.
These start very cold, dry, and stable. By the time winds have reached warmer seas about lat20 they become more unstable.

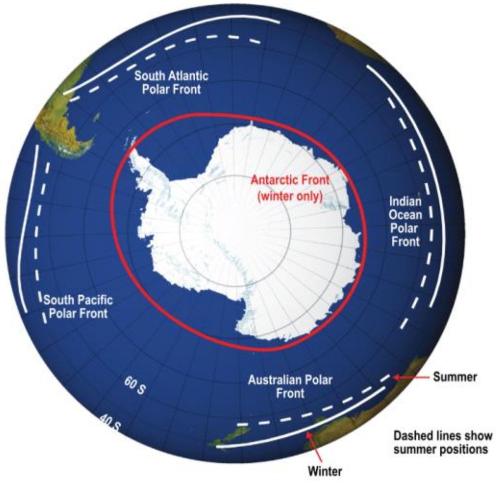
The Roaring Forties:
On the polar side of the sea-based sub-tropical highs the winds will be warm, damp, and stable – Tropical maritime, this brings fine warm weather.
Similar but stronger wind conditions prevalent closer to the south pole are referred to as the **'Furious fifties' and the 'Screaming sixties'.**
Local winds:
Mistral, Bora, Sirocco, Ghibli and Khamsin.

Northern Hemisphere:



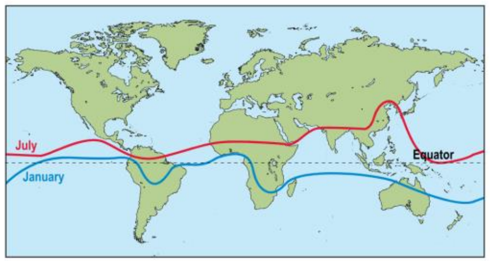


Southern Hemisphere:



Polar front depressions:
The dominant weather on the polar front is a series of depressions that form, intensity and move eastward and fill, fuelled by cold unstable polar air and warm moist air stable air from the sub-tropical highs on the equator side.

Polar front depressions:
The dominant weather on the polar front is a series of depressions that form, intensity and move eastward and fill, fuelled by cold unstable polar air and warm moist air stable air from the sub-tropical highs on the equator side.



The ITCZ:
A zone where converging surface air meets up near the thermal equator, at a low-level trough. Associated with unstable convective cloud and a lot of precipitation. Weather pattern not uniform.

Converging air starts from the stable high-pressure region and is dry if source is over land and moist if over sea. Even if it starts dry it picks up moisture on any sea track and becomes moist and unstable. Activity depends on whether it's a sea track or a land track.
Sea track = more unstable = more Cu and CB = +rain
On track any triggering from mountains or hot surfaces will produce instability and CB hundreds of miles before the wind reaches the actual convergence line.

As the ITCZ passes over head = **Heavy precipitation, very poor vis at the surface**

Mesoscale Convective system:
Thunderstorm regions can be round or linear in shape. 100km or more across in one direction but smaller than extratropical cyclones and include systems such as: tropical cyclones, squall lines, and mesoscale convective complexes (MCCs).

MCCs are a unique kind of mesoscale convective system which is defined by characteristics observed in infrared satellite imagery.

Area of cold cloud tops >100,000 sq km.
Temp <= -32C and an area of cloud top of 50,000sq km. with temps <= -52C

Cloud Clusters:
Tropical Cloud Clusters TCC's defined as synoptic-scale areas of deep convection and associated cirrus outflow.
Critical role in energy balance of the tropics, releasing large amounts of latent heat high in troposphere.

Tropical Squall Lines:
Common phenomenon in the rain areas of the tropics.
Form over land areas and even continue over the ocean for days.
Scale = 20-200km.
Carry long anvil clouds that can extend several 100 km carrying both stratiform and convective rains.
Tropical squall lines propagate westward.
Midlatitude squall lines propagate eastward.

Cold air outbreaks:
During winter seasons, disturbances of mid-lat origin may penetrate deep into the tropics.

Two examples: Blizzards and the Pampero.

Blizzards develop in the USA when warm, moist air from Mexico meets cold air mass from Canada during winter. Powerful low-pressure areas form cold air pushes from the back of this depression southwards.
Within 24 hours 50-100cm of snow can fall.
The bigger the temp diff the bigger the snow storm will be.
During June to Oct – Pampero occurs in Argentina and Uruguay. Similar to a blizzard.

The ITCZ continued:

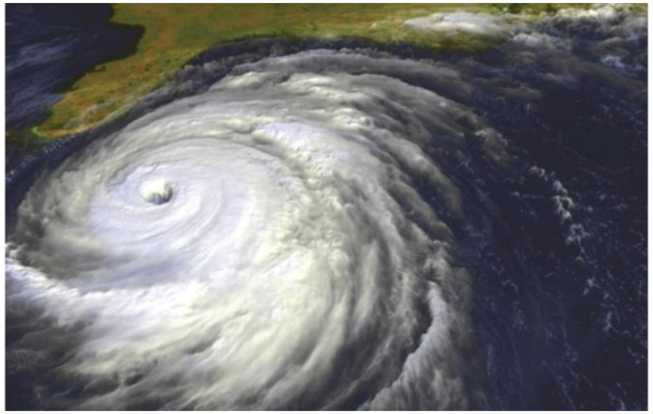
Worst areas of moisture, uplift and high temps produce Cu and CB's reaching over 50,000ft. May be Ns and As clouds as well, with embedded convective cells = heavy rain, violent turbulence, and severe icing even at higher levels. These conditions are 'patchy'

The ITCZ is between 30Nm and 300Nm wide. The worst weather is on the trailing edge.
French charts show the ITCZ as the FIT (Front inter-Tropicale)

The Equatorial Double Rains:
In central Africa, ITCZ passes twice over the geographic equator and brings rain in two phases called the equatorial double rains. Here 75% of the annual rain falls in two periods, roughly in April and October.

Tropical Revolving Storms:

Tropical Revolving Storms:
TRSs are **Enormous** thermal **LOWS**, start at time and place of max heating.
TRSs take their energy from **Water vapour** from a **warm sea, condensed aloft, releasing latent heat.**
Low Pressure
Surface Convergence
Instability
Sea temps of >26C needed
Do not form over cold sea
Die when they move over land/cold seas.
Become depressions.

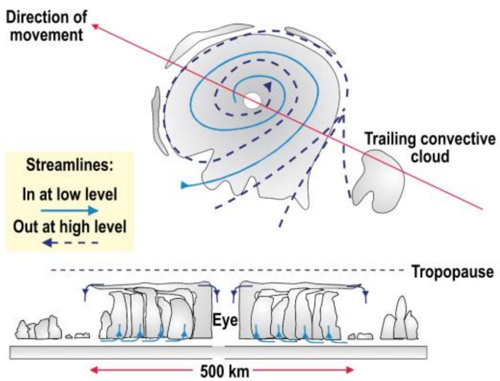


Conditions required:

- **Water >26C (60m deep)**
- **Wind needs to be converging near surface.**
- **Air unstable so it will rise.**
- **Air up to 18,000ft needs to be humid** (Condensation supplies extra latent heat)
- **Existing wind needs to come from same direction** (So doesn't rip it apart)
- **Upper atmosphere high pressure needed.**

Coriolis force = 0 at the equator: do not form less that 5degree lat.
Normally form at 10-20degrees lat.
Wind speeds = 80-180Kts
Big CBs
To qualify as full scale TRS = Wind 64kts sustained. 'Hurricane force'. (Beaufort scale)

Cross sections:
Diameter varies from **300km -1500km**



Circulation – anti-clockwise around centre of low pressure. (Northern hem)
Low-level convergence and convection inside storm lead to outflow at height.
Extensive CB formation (bands concentric to the eye)
Subsidence takes place between these cloud bands in the outer part of the storm, as well as the eye.

Eye of the storm:
Central subsidence produces clear area of light winds (eye of the storm). Can be 100km in diameter.
Flying conditions very hazardous apart from the eye.
Severe turbulence everywhere
Severe icing at medium level
Low winds strong
Sea waves huge
Cloud base 1000ft
Vis below cloud poor (rain)
Fastest wind just around the eye, 'eye wall'

Warning of approaching storms:
Satellite photography,
High Cirrus
Heavy sea swell
Falling pressure

Development stages:
4 phases before 5th mature phase.

1 First phase: Tropical Disturbance
Area of low-pressure forms, rising air at the centre.
Water vapour condenses = clouds = releases latent heat, into mid and upper atmosphere. Build-up of CB.
Light winds.

2 Second Phase: Tropical depression:
Near surface air converging towards the centre of depression strengthens the cyclonic circulation.
As air deflected outwards by the tropopause (divergence) surface pressure falls, CBs near centre of system.
Surface winds up to 33kts.

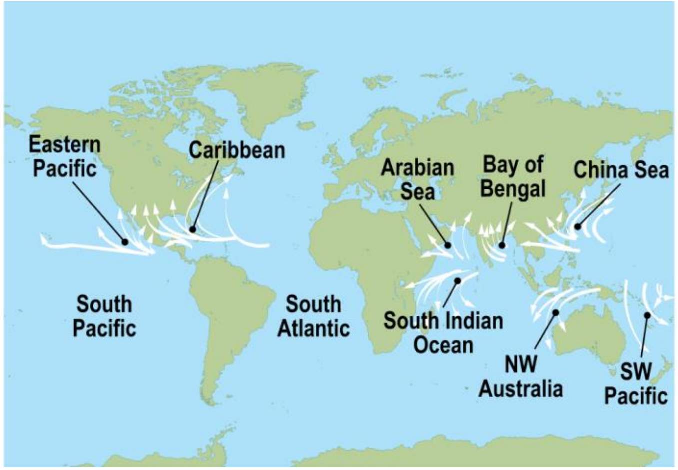
3 Third Phase: Tropical storm:
Centre surrounded by large CBs.
Rising air within CBs diverging just below the tropopause.
Most the diverging air moves away from the centre of the system creating the eye.
Air towards eye sinks.
Surface pressure continues to fall
Surface winds = 34-63Kts

4 Fourth Phase: Severe Tropical Storm:
Surface pressure **VERY LOW.**
Eye of storm cloud free/light wind (because of sinking air).
Rest will have strong cyclonic winds and huge CBs
Surface winds = 63Kts.

5 Fifth Phase: Mature Tropical Revolving Storm:
During development storm moves **East to west.**
ONCE DEVELOPED TRACKS AWAY FROM EQUATOR.
Winds >70Kts.
Heavy rain
Extensive CBs
As system moves from equator, surface pressure will increase, and intensity will decrease.
Movement RARELY forecast exact.

Source Regions and tracks:
Diagram shows tracks from recorded data:
Line thickness = Frequency.

No TRS in south Atlantic or Eastern pacific near south America, (cool ocean currents = sea temp low).



Late triggered TRSs bring heavy rain to the northern Bay of Bengal after the SW monsoon has left the region.

Source Regions and tracks:
TRS are known as cyclones.
Storms in north Caribbean named Hurricanes.
South China sea = Typhoon (Most don't reach land).

Naming Conventions:
Alphabetically names as the seasons progresses.
Hurricane area alternates between male and female each year.

TRS Seasons:
When local sea temp at highest (late summer, early autumn).
Often just after the passing of the ITCZ.
Normally June-Nov in Northern Hem.
Dec-April in Southern Hem.

Where?	Named?	When?	Average Annual Frequency >34 KT Storm	Average Annual Frequency >64 KT Hurricane / Typhoon / Cyclone
North Atlantic Ocean	Hurricanes	Jun - Nov	11	6
Northeast Pacific	Hurricanes	May - Nov	17	9
Northwest Pacific	Typhoons	Year-round (min Feb / Mar)	26	16
North Indian Ocean	Cyclones	Apr / May Oct / Nov	5	2
Southwest Indian Ocean	Cyclones	Dec - Apr	10	4
Southeast Indian Ocean	Cyclones	Dec - Apr	7	3
Southwest Pacific	Cyclones	Dec - Apr	9	4

TRS Basins:
Areas of tropical cyclone formation divided into 7 basins:
<u>Northern Hemisphere</u>
North Atlantic Ocean
Eastern Pacific
North-western Pacific Ocean
North Indian Ocean
<u>Southern Hemisphere</u>
Southwest Indian Ocean
Australian Region
Southwest Pacific Ocean

Easterly Waves:

ITCZ Line of low surface pressure following 'Heat equator'.
Isobars run parallel to the ITCZ with pressure values increasing away from the ITCZ.
Disturbance moves from East to West (Easterly Wave) in contrast to the **Polar Front Westerly Waves, the series of depressions that form on the polar front.**
Easterly waves form close to the ITCZ between Lat 5degrees and 20degrees N/S.

Easterly Waves appear on surface chart as a trough of low pressure.

Easterly waves form in the trade wind zone, between the ITCZ and sub-tropical highs.

Easterly Wave Weather:

Weather associated with easterly waves = SEVERE.

A **Line** of CBs and Thunderstorms aligned north/south forms along trailing easterly edge of an easterly wave.
Line of active CB Aligned North/South and moving east to west know as TROPICAL TORNADO.

1 in 10 easterly waves will develop into tropical revolving storms.

At some point along the squall line surface pressure will drop rapidly and a TRS will form which will develop.
The west African Tornado is the source of hurricanes in the Caribbean.

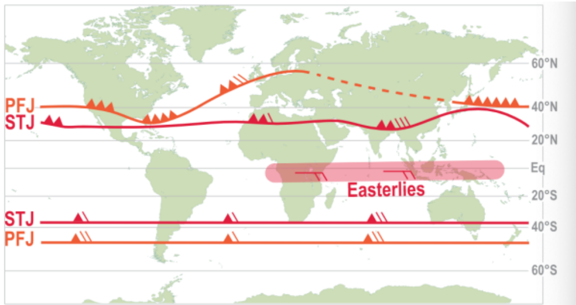
Thunderstorms are most likely to form on the east side of an easterly wave.

Upper winds, Monsoons and Climate Classification

Upper winds:
Easterlies at the equator and the poles during summer
Westerlies in the mid-latitudes and over the poles during winter.

Jet streams tend to be faster and closer to equator in winter.

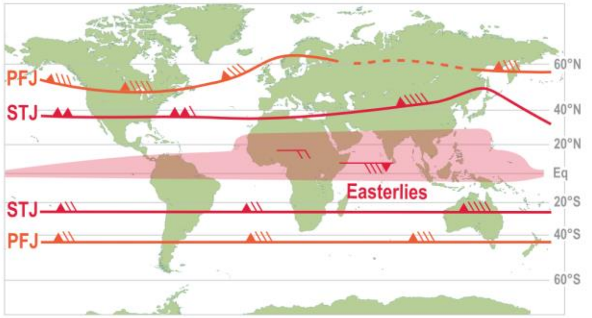
<u>January:</u>
In winter the polar front jet PFJ runs 'from Florida to Folkestone' and is stronger than in summer.



Upper Winds January

In southern hemisphere, in January, sub-tropical Jetstream crosses the south pacific and south Atlantic at around 35S-40S.
Southern Polar front Jetstream Parallel to the STJ between 50S and 55S. Speed = **60-70Kts.**

July:



Upper winds July

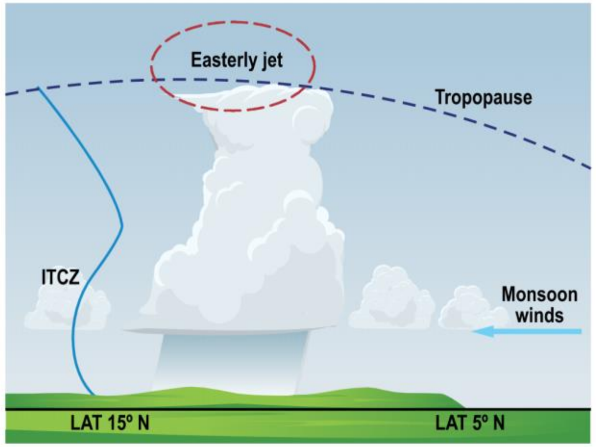
In July whole system of westerly jet streams moved north with the sun.
Summer jet stream not as high as winter
Jetstream typically 80-120Kts.
Summer polar front jet runs 'from newfoundland to Norway' and is weaker than in the winter.

The arctic and Antarctic jet streams are only present in winter at about 20,000ft and 80kts.

Southern jet streams are faster in JULY.

Jetstream	Mean Core Altitude	Season	Geophical Latitude	Wind Speed
Artic/Antarctic Jetstream	20 000 ft	only in winter	60° - 80°	About 80 kt
Polar Front Jetstream	30 000 ft	all year	Winter 40° - 70° Summer 50° - 80°	Up to 300 kt
Subtropical Jetstream	40 000 ft	all year	Winter 20° - 35° Summer 35° - 45°	About 100 kt
Equatorial Jetstream	50 000 ft	June - August	5°N	60 - 100 kt

Monsoons and Local Seasonal Winds:
Much of significant weather occurs in the 'Monsoons'.
West African Monsoon:



SW monsoon starts with arrival of ITCZ, associated belt of convective activity from the south. Winds come from south Atlantic high, were the SE trades approaching the equator, but change direction to SW in the northern hemisphere.
LOW-LEVEL WINDS, 5,000ft – 8,000ft.
Wet, warm, unstable, Cu and CBs behind advancing ITCZ.
Northern ITCZ is receiving dry in-flowing winds from Sahara, little convective activity.

As ITCZ reaches furthest North (15N overhead Dakar) main rain belt clears the southern coast.

In Aug ITCZ retreats following sun south.
Harmattan picks up moisture by transpiration from the jungle and forms sea fog.

India and the far East:
Thermal Effects huge Asia land mass dominate over India and far east.
As ITCZ goes north, following is warm, wet, unstable, convective clouds and rain.

TRS's are features of this period (Typhoons).
Typhoons can start from **June and continue to November.**
TRS's can be triggered by the ITCZ

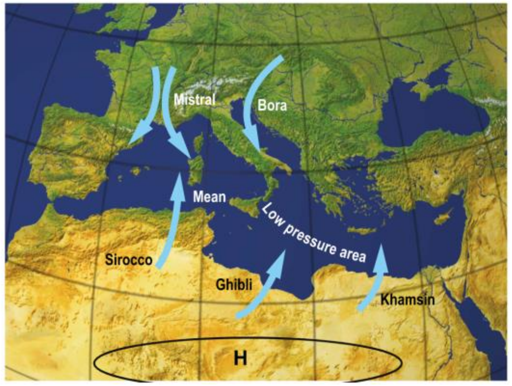
Heavy rain in the northern Bay of Bengal in October will be from a TRS and not from the SW Monsoon, which will be over.

India and the far East:
As ITCZ retreats, converging winds follow.
Coming from Siberian high.
Winds originally Cold, Dry, and stable brining stable conditions to India and Burma.
With long sea passages airmass becomes Unstable, convections will start…

The ITCZ will reach northern Australia at its Furthest south, and winds, changing direction in the southern hemisphere, will become the NW monsoon, bringing BAD weather to PNG and Darwin.

Monsoon hazards include:
Heavy rainfall, En-route icing, fastmoving cloud, severe turbulence, Gusty wind, lightning inside and outside clouds.

Local Mediterranean Winds:
5 significant local Mediterranean winds:
Mistral
Bora blowing from alps
(North African winds) Sirocco, Ghibli, Khamsin.



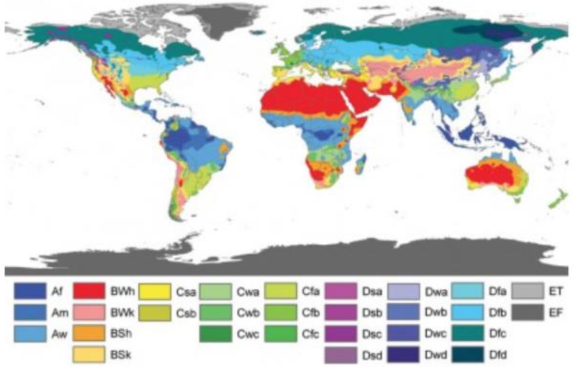
Mistral = Begins as northerly gradient wind blowing over France – **Wind >50kts.**

Bora = Pure Katabatic wind – Wind >=70Kts.

Sirocco, Ghibli, Khamsin = all blow out of the winter high pressure in Sahara, all dry stable dusty winds.

Name	Description
Bora	The Bora is a northern to north-eastern katabatic wind in the Adriatic Sea.
Mistral	The Mistral is a strong, cold, northwesterly wind that blows from southern France into the Gulf of Lyon in the northern Mediterranean
Sirocco	The Sirocco is a Mediterranean wind that comes from the Sahara and can reach hurricane speeds in North Africa and Southern Europe, especially during the summer season.
Ghibli	Ghibli- Libyan name for the Sirocco
Khamsin	The Khamsin is a dry, hot, sandy local wind, blowing from the south, in North Africa and the Arabian Peninsula. From the Arabic word for "fifty", these dry, sand-filled windstorms often blow sporadically over fifty days
Harmattan	The Harmattan is a dry and dusty northeasterly trade wind which blows from the Sahara Desert over the West African subcontinent into the Gulf of Guinea between the end of November and the middle of March. In some countries in West Africa, the heavy amount of dust in the air can severely limit visibility and block the sun for several days, comparable to a heavy fog. This effect is known as the Harmattan haze. It costs airlines millions of dollars in cancelled and diverted flights each year. In some countries in West Africa, the heavy amount of dust in the air can severely limit visibility and block the sun for several days, comparable to a heavy fog. This effect is known as the Harmattan haze. It costs airlines millions of dollars in cancelled and diverted flights each year
Chinook	The Chinooks are föhn winds in the interior West of North America, where the Canadian Prairies and Great Plains meet various mountain ranges. A strong föhn wind can make snow one ft (30 cm) deep almost vanish in one day. The snow partly melts and partly sublimates
Pampero	The Pampero is a burst of cold polar air from the west, southwest or south on the pampas in the south of Brazil, Argentina and Uruguay. The Pampero is most common in winter in the southern hemisphere (principally between May and August).

Köppens Climate Classification:
5 major climate zones and their subcategories by a 3-letter code.



Zone A:
Equatorial or tropical climates have a constant high temp all year round with avrg of 20c or higher. Subdivided as follows:

Tropical Rain Forest Climate (Af)
All 12 months have avrg rainfall of >60mm:
Eg. Singapore, Borneo, and amazon basin.
Tropical Monsson Climate (Am)
Monsoon (seasonal) winds create dry season and wet season:
Eg. Bangladesh Mumbai, Miami
Tropical Savannah Climate (Aw)
Dry seasons and wet seasons, overall, less rain than monsoons.:
Eg: North Australia, South Brazil, East Africa.

Tropical forest climate found 10N and 10S. Savannah climate has yearly variations in rainfall with a wet and dry season. Known as the tropical transitional climate and is influenced by seasonal movement.

Zone B:
Dry and semi-arid climate
Annual rainfall less than that potentially lost by evaporation and foliage.
If much less its classed as a desert, BW, if a bit less it is steppe, BS. Deserts and steppes can be further classed as mid-latitude, with avrg annual temp <20C or sub-tropical avrg temp >20C.

Sub-tropical Steppe (BSh)
Sub-tropical Desert (BWh)
Mid-Latitude Steppe (BSk)
Mid-Latitude Desert (BWk)

Zone C
Temperate, warm temp, climates have temp in coldest month, avrg between 18C and -3C.
2nd letter indicated dry season,
s for summer.
w for winter.
F stands for German 'Feucht' means 'moist'.

3rd letter indicated degree of summer heat,
a = hottest
c = coldest.

Humid Sub-Tropical Climates (Cfa, Cwa)
Mediterranean Climates (Csa, Csb)
Maritime Temperate Climates (Cfb, Cwb)
Temperate Climate with Dry Winters (Cwb)
Maritime Sub-Arctic Climates (Cfc)

Mediterranean climate is anti-cyclonic and hot in summer, influenced by frontal depressions in winter. This is known as the temp transitional climate and is influenced by seasonal movement of the sun, annual rainfall is <700mm

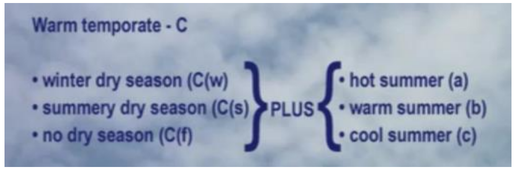
Zone D:
Climates are characterised by having high temps in summer and low temps in winter.
Usually occur in continental interiors north of about 40N.
Zone D climates extremely rare south of the equator. Only in isolated areas of New Zealand.
Zone D uses same 2nd and 3rd as zone c.
Additional to d = Extremely cold.

Hot summer continental climates (Dfa, Dsa, Dwa).
Warm summer continental climates (Dfb, Dsb, Dwb)
Continental sub-arctic climates (Dfc, Dwc)
Continental sub-arctic climates with very cold winters (Dfd, Dwd).

Zone E:
Polar climates. Include areas of Andes, Rockies, and Himalayas. Avrg temp <10C all year.
Codes are two letters, 2nd letter =
T = Tundra.
F = Ice cap.

Tundra climate (ET)
Warmest month temp 0-10C allowing some veg to grow.
Ice cap Climate (EF)
Below zero all year, low precipitation.

Zone C again:



Met Practical 1: Sources of information, SIGMETs and AIRMETs.

<u>The meteorological service:</u>
Annex 3 to the ICAO sets standards for weather reporting and forecasting.
The WMO (World meteorological organization) ensures that these standards are implemented for aviation.

<u>World area forecast system and world area forecast centres (WAFC):</u>
The WAFS is defined in ICAO Annex 3, Meteorological service for international air navigation, as "… a worldwide system by which world area forecast centres provide aeronautical meteorological enroute forecasts in uniform standardized formats."

A WAFC is "… a meteorological centre designated to prepare and issue significant weather forecasts and upper-air forecasts in digital form on a global basis."

Two ICAO-Sponsored WAFCs are provided by USA and UK and are referred to as the Washington WAFC (In Kansas) and the London WAFC (in Exeter).

WAFCs also produce Gridded forecast products using Numerical Weather Prediction (NWP).

<u>Weather Domains:</u>
ICAO recognises 3 weather domains:

- Low level (SFC – FL100)
- Medium Level (FL100-FL250)
- High Level (FL250-FL630)

Met information normally available for commercial air transport flights include charts showing:

- **Upper air winds and temps**
- **Upper air humidity**
- **Contour and thickness charts**
- **Flight level and temp of tropopause.**
- **Direction, speed, and FL of max wind.**
- **Significant weather (SIG WX) phenomena**

And text-based information showing:

- **METARs** – Aerodrome actuals, which may include a TREND, short term forecast.
- **TAFs** – Aerodrome Forecasts
- **SIGMETs** – Warnings of significant weather
- **SPECIs** – Special reports
- **GAMET and AIRMET** – Information for low level flights.

<u>Sources of Pre-Flight Weather Information:</u>
Meteorological (MET) offices situated in aerodromes provide forecasts and briefings.

- Most countries provide recorded telephone message service for GA
- More detail found in text or fax from Aeronautical Fixed Telecommunications Network (AFTN) fax and telex.
- Text based Met information in Europe is distributed on AFTN by meteorological Operational Telecommunications Network Europe (MOTNE).
- Access to FULL met service for nation and international found on-line through Meteorological information standard terminal (MIST) in most Airports.

Special Route Forecasts:
Meteorological authority provide special route forecasts if required.
ICAO rules require this info to be supplied as soon as its available, but not later than 3 hours before

In flight Weather information:

Routine Weather information is available in flight through the VOLMET service, ACARS and ATIS and ATS units.

VOLMET based on HF and VHF reports current METARs and SPECIs in plain language.

ACARS is a ground/air link that passes info of all kinds, for met, can be used to pass warnings, SIGMETs and ATIS info.

ATIS = Automatic Terminal Information System

Broadcasts: Weather actual, Traffic information, Runway conditions, General Warnings.

Example:

"Bristol, information foxtrot, 0850Z. Runway in use 09, left hand. Surface wind 100 magnetic, 05 knots. Prevailing visibility 2000 metres, light rain. Scattered at 200 ft, overcast at 400 ft. Temperature 15°C, dew point 14°C, QNH 1007 mb. Touchdown QFE, runway 09, 984 mb. Regional QNH, Portland 1003 until 1000Z. Runway, wet, wet, wet. Fog warning current. Acknowledge receipt of information foxtrot on first contact with Bristol."

Reissued every 30 mins or as METARS issued or any other change warrants.

- Wind magnetic to align with runway.
- Wet, Wet, Wet = Runway beginning, middle, end all wet.
- Fog warnings usually issued if vis <600m.

In flight Briefings:

In **exceptional** circumstances you can get a special in-flight enroute weather service. Prior notification to the Authority is required giving Sector, FL, time in sector. ATS unit will work with you.

Diversion Briefings:

If you must divert enroute, a diversion briefing will be given.

In addition ATS unit will pass any relevant SIGMET and AIRMET warnings.

SIGMETs and AIRMETs

Meteorological watch office (MWO)

Provide SIGMET and AIRMET for designated routes/portions.

SIGMET warnings routinely issued by each FIR(MWO) and relate to cruising levels above FL100.

SIGMETs:

Thunderstorm	Obscured Embedded Frequent Squall line Obscured with hail Embedded with hail Frequent with hail Squall line with hail	OBSC TS EMBD TS FRQ TS SQL TS OBSC TSGR EMBD TSGR FRQ TSGR SQL TSGR
Tropical cyclone	Tropical cyclone with 10 minute mean surface wind speed of 63 km/hr (34 KT) or more	TC (+cyclone name)
Turbulence	Severe turbulence (except CU/CB)	SEV TURB
Icing	Severe icing Severe icing due to freezing rain (except CU/CB)	SEV ICE SEV ICE (FZRA)
Mountain wave	Severe mountain wave	SEV MTW
Duststorm	Heavy duststorm	HVY DS
Sandstorm	Heavy sandstorm	HVY SS
Volcanic ash		VA (+ volcano name if known)
Radioactive cloud		RDOACT CLD

AIRMETs

Used for traffic in lower levels FL100-FL150 or higher in mountains.

Surface wind speed	Widespread mean surface wind speed above 60 km/hr (30 KT)	SFC WSPD (+ wind speed and units)
Surface visibility	Widespread areas affected by reduction of visibility to less than 5000 m including the weather phenomena causing the reduction of visibility	SFC VIS (+ visibility) (+ one or more of the following weather phenomena: BR, DS, DU, DZ, FC,FG, FU, GR, GS, HZ, IC, PL, PO, RA, SA,SG, SN, SQ, SS or VA
Thunderstorms	Isolated without hail: Occasional without hail Isolated with hail Occasional with hail	ISOL TS OCNL TS ISOL TSGR OCNL TSGR
Mountain obscuration		MT OBSC
Icing	Moderate (except CU/CB)	MOD ICE
Turbulence	Moderate (except CU/CB)	MOD TURB
Cloud	Widespread areas of broken or overcast cloud with height of less than 300 m (1000 ft) agl Broken Overcast	 BKN CLD (+base/top) OVC CLD (+base/top)

Cumulonimbus	Isolated Occasional Frequent	ISOL CB OCNL CB FRQ CB
Towering cumulus	Isolated Occasional Frequent	ISOL TCU OCNL TCU FRQ TCU
Mountain wave	Moderate	MOD MTW

SIGMETs and AIRMETs Examples:

SIGMET:

SIGMET	Cancellation of SIGMET
EISN SIGMET 2 VALID 101200/101600 EINN- SHANNON FIR/UIR OBSC TS FCST S OF N54 TOP FL390 MOV E WKN	EISN SIGMET 3 VALID 101345/101600 EINN- SHANNON FIR/UIR CNL SIGMET 2 101200/101600

Decoded:

SIGMET Number 2, since 0001 UTC Issued for the Shannon FIR/UIR (EISN) By Shannon international meteorological watch office (EINN), Valid on the 10^{th} between 1200UTC and 1600UTC.

In the Shannon FIR and UIR obscured thunderstorms are forecast south of 54N with tops up to FL390, moving east and weaking.

SIGMETs and AIRMETs Examples:

AIRMET:

AIRMET	Cancellation of AIRMET
EISN AIRMET 1 VALID 151520/151800 EINN- SHANNON FIR ISOL TS OBS N OF N50 TOP ABV FL100 STNR WKN	EISN AIRMET 2 VALID 151650/151800 EINN- SHANNON FIR CNL AIRMET 1 151520/

Decoded:

AIRMET number 1 since 0001 UTC issued for the Shannon FIR (flight information region) (EISN) Valid on the 15^{th} between 1520UTC and 1800UTC. In the Shannon FIR, Isolated Thunderstorms have been observed, north of 50N tops above FL100 stationary and weakening.

Aerodrome weather warnings:

Specific weather conditions at aerodromes are broadcast on the ATIS, given by radio to arriving or departing AC, these are:

General Warning:

- Tropical Cyclone (Mean surface wind >63km/hr (34kts)
- Thunderstorms
- Hail
- Snow (including expected or observed accumulation)
- Freezing precipitation
- Hoar frost or rime
- Sandstorm
- Dust storm
- Rising sand or dust
- Strong surface wind and gusts
- Squall
- Tsunami
- Other phenomena as agreed locally

Windshear warnings:

- Information from Doppler radar systems or surface wind and pressure sensors
- Aircraft observations

Windshear associated with:

- Thunderstorms
- Microbursts
- Funnel cloud
- Frontal Surfaces
- Strong surface winds coupled with local topography
- Sea Breeze fronts
- Mountain waves including low level rotors in terminal area
- Low level temperature inversions.

Aircraft Observations:
Aircraft required to report on observed weather.
When called for AIREPs are reports of:

- Position
- Time
- Flight level
- Temperature
- Computed wind
- Cloud descriptions and any icing/turbulence.

Maybe handed in at the end of a flight.

Special aircraft observations **AIREP SPECIALs** (message type designator **ARS**) are reported immediately and are **required** in any European FIR/UIR/OCA whenever:

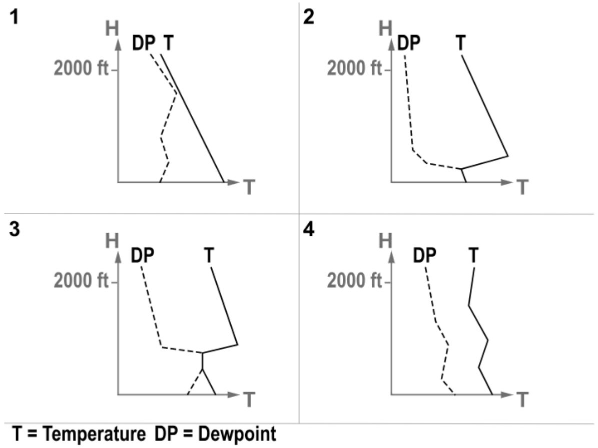
- Severe icing/turbulence is encountered
- Moderate turbulence, hail or CB clouds are encountered.
- Other met conditions that might affect safety or affect aircraft operations. E.g. in the list of SIGMET phenomena
- Volcanic ash
- Pre-eruption activity
- Exceptionally, when requested by the meteorological authority.

These reports are subjective assessments of the effects on one particular aircraft the report **must** contain AC type.

Radiosonde Observations:
Upper air data collected by balloon.
Records:

- Pressure
- Humidity

And radios it back to ground.
Radar tracking can also give upper wind data.



Example of radiosonde. 2 indicates fog on ground
3 indicated stratus clouds.

AMDAR and ACARS:
Software fitted to aircraft to record nav system, temp and pressure probes and transmit it during flight either through satellite link (AMDAR, aircraft meteorological data relay), or through VHR datalink (ACARS or ADS-B) for onward transmission to WAFCs at Washington or Exeter.
Reports available through climb cruise and decent with accurate weather.

Met Practical 2: METARs, TAFs, SPECIs and SNOWTAMs

METARs TAFs and SPECIs
These are coded written reports and forecasts that arrive by: fax, internet, teleprinter or the AFTN. METARS can be spoken on the VOLMET service.

METARs and SPECIs
METARs are aviation routine weather reports. Compiled **Hourly or HALF hourly, often at H+20 and H+50.**
Maybe supplemented by a **TREND** (2hr short forecast)
SPECIs = Critical weather conditions.
e.g.:

```
METAR EGGW 301020Z 31015 g27 KT 280V350 4000 0900NE
R23/P1500 SHRA FEW005 SCT010CB BKN025 10/03 Q0995 RETS WS
TKOF RWY23 NOSIG
```

Decode:

Report Type	Location identifier	Date / time	Wind	Horizontal visibility	RVR
METAR	EGGW	301020Z	31015G27KT 280V350	4000 0900NE	R23 / P1500

Weather	Cloud	Temp / dew point	QNH	Recent weather	Wind shear	Trend
SHRA	FEW005 SCT010CB BKN024	10 / 03	Q0995	RETS	WS TKOF RWY23	NOSIG

Report Type:
METAR, or it could be SPECI if it has been raised to report on critical weather changes.
Location indicator:
EGGW – ICAO 4letter code.
Date and Time:
Date and time observations in hours and minutes UTC followed by Z.

If in bulletin,
SA = METAR
SP = SPECIs

Wind:
Wind direction in degrees true to the nearest 10 degrees. **Speed recorded is the MEAN wind speed over the 10 mins PRIOR to observation.**
Calm = 00000
Variable wind direction = VRB
Wind always recorded clockwise, whether the wind has veered or backed.

Prevailing Visibility:
4000 09000NE = 4000m.
The prevailing visibility is the visibility that is reached or exceeded within at least half the horizon circle. When the lowest visibility is different from the prevailing visibility and:

1- Less than 1500m or
2- Less than 50% of the prevailing visibility and less than 50000m

Lowest vis observed always be reported in relation to the aerodrome indicated by regerence to one of the eight points of the compass.
In this case example: lowest vis was 900m in the NE direction = **0900NE.**

USA use statute miles, SM.

Runways Visual Range:
R23/P1500 = Runway 23, touchdown RVR is plus 1500m.
Measurement is the minimum touch down RVR In the **Last 10 mins before time of observation, in meters.**
If maximum that the equipment is calibrated, then max is given preceded by a P(uls).
If less than minimum, preceded by M(inus).
If has been steady can be followed by **N(o change).**
If changing rapidly = **U for up and D for down.**
If variable over the 10 min observation = **V**

RVR not normally reported if vis is 1500m.
ONLY TOUCHDOWN RVR.

Weather:
SHRA = moderate showers of rain.
CODES:

Intensity or Proximity		Descriptor		Precipitation		Obscuration		Other	
–	Light	MI	Shallow (less than 2m above ground)	DZ	Drizzle	FG	Fog	PO	Dust Devils
No qualifier	Moderate	BC	Patches	RA	Rain	FU	Smoke	SQ	Squalls (a marked increase in wind which lasts for some minutes - a gust lasts for a matter of seconds)
+	Heavy or "well developed" for FC and PO	DR	Drifting	SN	Snow	VA	Volcanic ash		
		BL	Blowing	SG	Snow Grains	BR	Mist		
VC	Within 8km but not at the station	SH	Showers	IC	Ice crystals (diamond dust)	DU	Dust	FC	Funnel clouds
		TS	Thunderstorms	PE	Ice pellets	SA	Sand	SS	Sandstorm
		FZ	Freezing (super cooled)	GR	Hail	HZ	Haze	DS	Dust Storm
		PR	Covering part of the airfield (if used with fog it means 'banks')	GS	Small hail, less than 5mm diameter, and/or snow pellets				

Cloud:
FEW005 SCT010CB BKN025.

Okta is a unit of measurement used to describe the amount of cloud cover at any given location such as weather station.
Sky conditions measured in 1/8th
0 = Clear, 8= Complete overcast.

Base = lowest height of visible portion of a cloud.

Cloud base measured using Ceilometer. Reflects a beam of light off the cloud base and then calculates its distance using triangulation.

Alternatively, can be estimated using surface measurements of temp and humidity.

1) Find the diff between surface temp and dew point, aka 'spread'.
2) Divide spread by 2.5 (if temp in C), multiply by 1000. This gives cloud base feet above ground.
3) Add field elevation to obtain altitude of cloud base above mean sea.

Ceiling = height above ground or water of the base of the lowest layer of cloud below 20,000ft covering more than half the sky.

Sky obscured = VV (vertical visibility, followed by 3 number for vertical vis in hundreds of feet.)

CAVOK:

- Visibility >10km
- No cloud of significance, (No cloud below 5,000ft, or below the highest minimum sector altitude (MSA), whichever is the greater, no CBs or TCUs at or near the station.
- No weather phenomena at or near (Precipitation, Thunderstorms, Shallow fog, Low snow)

Under this no RVR or weather groups.

Air temperature and Dewpoint:
10/03 = Air temp 10C and Dew 3C.
M used for minus.
If no dew point = 10///.

QNH
Q0995 = QNH 995mb. **ROUNDED DOWN.**

Recent Weather:
RETS. There have been thunderstorms since last report but there are none now. Records significant weather, which includes moderate or heavy drizzle, since last report. **Used prefix RE.**

Windshear:
WS TKOF RWY23 = There is windshear reported on take-off of Rwy23 below 1600ft. LDG for landing.

Trend:
NOSIG = no significant change of weather is forecasted in the two hours after.
Elements **not covered = Temp/dew, pressure, RVR.**
Apart from NOSIG Change indicators can be:

- BECMG (becoming) – Permanent change
- TEMPO (Temporarily) – Temporarily change

Maybe time qualified by 4 figures (hours / mins).

Preceded by
FM (from)
TL (until)
AT (at time given)
NSC (No significant clouds)
NSW (No significant weather)

Runway Condition:
8 figure group added to METAR / SPECI if snow or another runway contamination is present.

	Runway Designator - first and second digits
27	(Runway 27) - magnetic heading designator for single runways or left runways
77	(Runway 27 right) - add 50 to designator for right runways
88	all runways
99	repeat of last message, no new information

Runway Contamination Type - third digit			
0	clear and dry	6	Slush
1	damp	7	Ice
2	wet, or water patches	8	Compact snow
3	rime or frost covered	9	Frozen ruts or ridges
4	dry snow	/	Type of contamination not reported
5	wet snow		

Extent of Contamination - fourth digit			
1	10% contaminated	9	51% to 100% contaminated
2	11% to 25% contaminated	/	extent of runways contamination not reported (e.g.runway clearance in progress)
5	26% to 50% contaminated		

Depth of Contamination - fifth and sixth digits			
00	less than 1 mm	95	25 cm
01 to 90	whole mm depth (e.g. 08 = 8 mm depth)	96	30 cm
		97	35 cm
		98	40 cm or more
91	not used	99	runway(s) non operational but depth not reported
92	10 cm	//	depth not significant or not reported
93	15 cm		
94	20 cm		

Runway Condition continued:

Friction coefficient, if available, is also reported as a two-digit decimal fraction as the 7th and 8th digit.

91	braking action poor	95	braking action good
92	medium to poor	99	figures unreliable, but braking action suspect
93	medium		
94	medium to good	//	not reported; runway closed

TAF DECODE:
Forecasts are called TAFs
Usually cover a period of 9-24 hours.
9-hour TAFs are updated and reissued every 3hours, and 12- and 24-hour TAFs every 6 hours, amended if forecast changes.
E.g.:

```
TAF EGGW 130600Z 1307/1316 31015 KT 8000 SHRA FEW005
SCT010 SCT018CB BKN025 TEMPO 1311/1316 4000 +SHRA PROB30
1314/1316 TSRA BKN010CB
```

Decoded:
Validity Time:
EG: 1307/1316 = 13th from 0700Z to 1600Z

If TAF issued in bulletin:
FC (Up to 12hr TAF)
FT (12-24hr TAF)

EG.
Bulletin heading: FCUK33 EGYY 130600Z
TAF starts: EGGW 1307/1316…

Amendments:
if the TAF is a re-issue which amends a previously issued TAF the abbreviation **AMD** will appear between the location ID and date/time of origin.

Report Type	Location Identifier	Date/Time Origin	Validity Date/Time	Wind	Visibility
TAF	EGGW	130600Z	1307 / 1316	31015 KT	8000
Weather	Cloud		Variant	Validity Time	Visibility
SHRA	FEW005 SCT010 SCT018CB BKN025		TEMPO	1311 / 1316	4000
Weather	Probability		Validity Time	Weather	Cloud
+SHRA	PROB30		1314/1316	TSRA	BKN010CB

Surface wind:
Same as METAR

Prevailing Visibility:
Same as METAR

Weather:
If no sig weather is forecast, group is omitted. If after a variant the weather ceases to be sig, **NSW** is used.

Cloud:
When there is no CB or TCU, or cloud below 5000ft or the highest MSA, and CAVOK is not appropriate, then NSC, **no sig cloud is used.**

Variant:
3 Types of variants:
FM (From)
BCMG (Becoming)
TEMPO (Temporarily).
Followed by 6 figures (Date, Hours, Mins)

E.g.
FM101230 1500 SHRASN.

= From 1230Z on the 10th of the month visibility will be 1500m in moderate rain and snow showers.

BCMG
E.g.
BECMG 2209/2211 27012KT 4000 BKN010

= Between 0900Z and 1100Z on the 22nd of the month the wind will change to 270,12Kts the vis to 4000m and cloud cover to 5-7 oktas at 1000ft AGL.

TEMPO
E.g.
TEMPO 1308/1309 0400 MIFG

= Between 0800Z and 0900Z on the 13th Vis will be 400m in shallow fog.

Probability:
Only PROB30 and PROB40 used.
E.g.: PROB40 TEMPO 2614/2616 TSRA BKN010CB

= 40% chance temporarily between 1400Z and 1600Z on the 26th moderate thunderstorms rain with 5-7 okdats CB at 100ft AGL.

PROB30 and PROB40 Means variant weather is less likely than basic weather.
TEMPO is limited to 50% probability.
TEMPO also introduces weather less likely than base.

FM and BECMG = no probability.

Amendments:
Amended TAG is identified by AMD after TAF identifier.
In TAF bulletins,

- **AMD**
- **AAA**
- **AAB**

Etc…
Not in TAFs.
Amended TAF covers remaining part of original period of validity.

Other Groups:

Temperature

Group Indicator	Forecast Temperature	Validity Time
T	M05 (minus 5°C)	22 (2200Z)

Airframe Icing

Group Indicator	Severity and Type of Icing	Height agl of Lowest Icing	Thickness of Icing Layer
	0 None 1 Light 2 Light in cloud 3 Light in precipitation 4 Moderate 5 Moderate in cloud 6 Moderate in precipitation 7 Severe 8 Severe in cloud 9 Severe in precipitation	3 digits - hundreds of feet	0 - up to cloud tops 1 to 9 - thickness in thousands of feet

Other Groups:

Turbulence

Group Indicator	Turbulence	Height agl of lowest turbulence	Thickness of turbulence
5	0 None 1 Light 2 Moderate in clear air, infrequent 3 Moderate in clear air, frequent 4 Moderate in cloud, infrequent 5 Moderate in cloud, frequent 6 Severe in clear air, infrequent 7 Severe in clear air, frequent 8 Severe in cloud air, infrequent 9 Severe in cloud air, frequent	3 digits - hundreds of feet	0 - up to cloud tops 1 to 9 - thickness in thoudands of feet

GAFOR and GAMET:
GAFOR: ('General Aviation Forecast')
GAMET: ('Area forecast is an are forecast for low level flights for a flight information region or sub-area.')

SNOWTAM:
A NOTAM system, a detailed statements of snow conditions at an airfield, including aprons, taxiways, snowbanks, times of clearance, runway breaking action etc.

Most essential part of a SNOWTAM = runway breaking action, disseminated by MOTNE and are given as a sequence of numbers identical to the runway condition group appended to the METAR.
Max validity of SNOWTAM is 24hr.

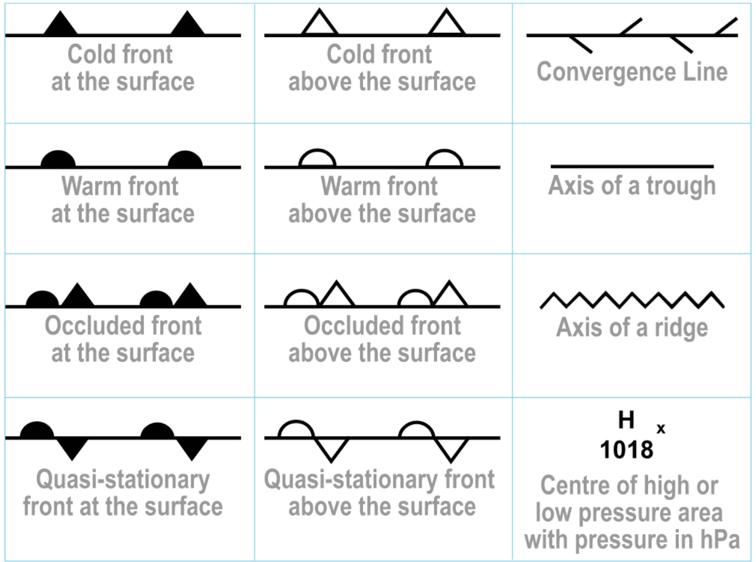
Met Practical 3: Charts

MSL Pressure Charts:
Plots on Synoptic Charts:
One element is QFF = Mean Sea level pressure.
Charts of MSL pressure are then plotted from the pressure data and these show surface ISOBARs, Fronts, Pressure system and winds.

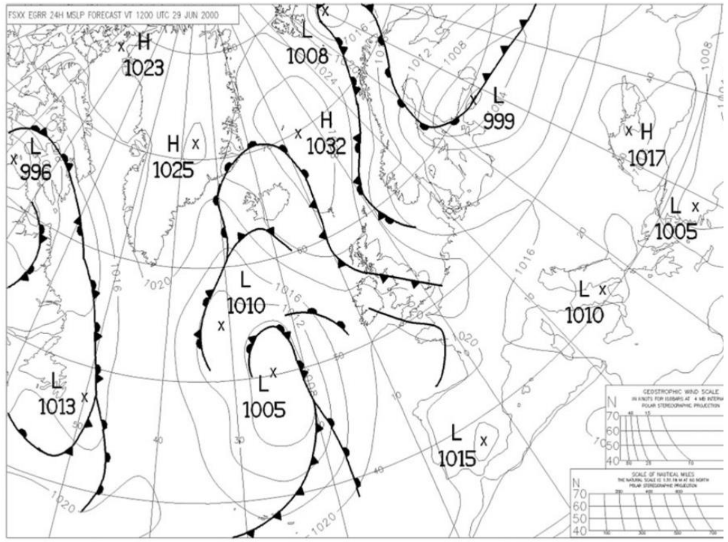
Data for MSLP taken every <u>6 hours</u>:

- **0000Z**
- **0600Z**
- **1200Z**
- **1800Z**

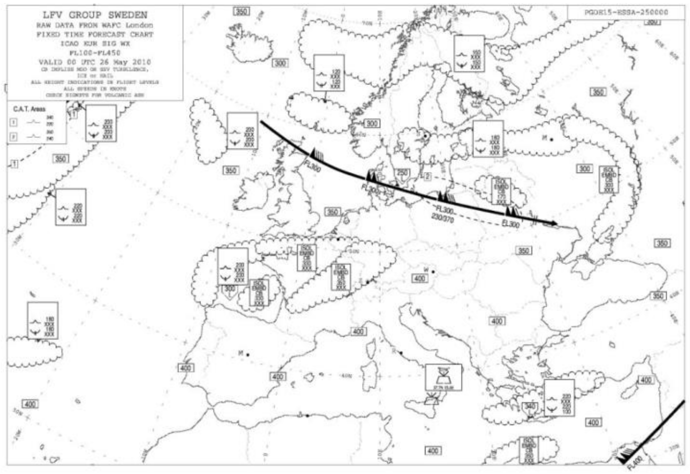
Charts published 4hrs later.



MSL Pressure Charts Example:



Valid for 1200UTC on 29 Jun 2000.



Significant weather chats prepared in advance (**24hr in advanced**).

Items included in forecasts:

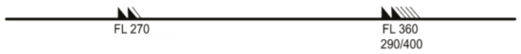
a) Tropical Cyclones >34kts.
b) Severe squall lines
c) Moderate or severe turbulence (cold or clear air)
d) Moderate or severe icing
e) Widespread sand/dust storm
f) Cumulonimbus cloud associated with thunderstorms
g) Flight level of tropopause, Highs/Lows point of tropopause
h) Jet streams
i) Info on volcanic eruptions
j) Radioactive release into atmosphere.

Notes:

1. a-f only included if expected to occur between lower and upper levels.
2. Abbreviation CB only refers to expected Cumulonimbus.
3. CB includes all that is associated.

Symbology:

	Tropopause High		Freezing Level
	Tropopause Low		Convergence Line
	Tropopause Level		Axis of a ridge
	ITCZ / FIT		Axis of a trough



Wind arrows indicate the maximum wind speed in a jet and the level at which it occurs. A solid triangle indicates 50KT, a line indicates 10KT. In this example winds of 110KT and 140KT are shown. Where the max speed exceeds 120KT the vertical extent of the jet core is also shown.

	Tropical cyclone		Drizzle
	Severe squall line		Rain
	Moderate turbulence		Snow
	Shower		Hail
	Severe turbulence		Thunderstorm
	Mountain waves		Widespread blowing snow
	Light aircraft icing		Severe sand or dust haze
	Moderate aircraft icing		Widespread sandstorm or dust storm
	Severe aircraft icing		Widespread haze
	Widespread fog		Widespread mist
	Radioactive materials in the atmosphere		Freezing fog
	Volcanic eruption		Widespread smoke
	Mountain Obscuration		Freezing precipitation

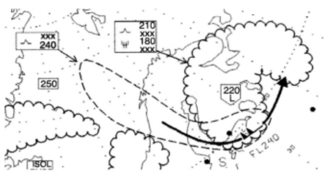
Medium and High Level Significant Weather Charts

In this image, which was taken from the medium level significant weather chart, there is an area of significant weather to the right which is outlined by the scalloped edge boundary. Within that area aircraft will encounter moderate icing from below FL100 up to FL180 and moderate turbulence from below FL100 up to FL210.

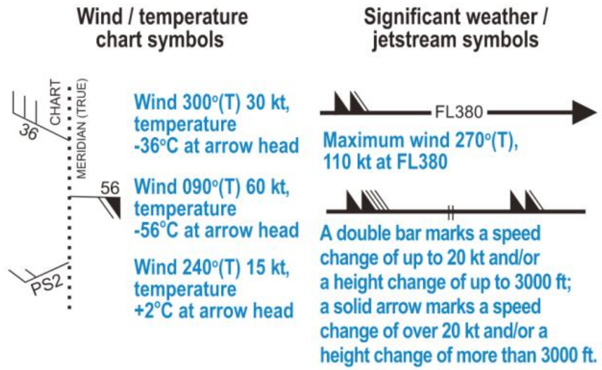
In the CAT area shown there is moderate turbulence from FL240 up to above the coverage of the chart (XXX) i.e. above FL250.

The jet stream shown has its core at FL240 where its speed is 100 KT. Just above the jet stream the tropopause is at a low point at FL220 it goes up in all directions from that point. To the left a spot height for the tropopause is shown at FL250. In order to estimate tropopause heights where no spot height is given you should interpolate. Don't forget that, above the tropopause in the lower stratosphere, OAT remains constant.

Where CBs are shown there is an assumption that thunderstorms, hail, moderate or severe turbulence and icing are also present. There is a note to that effect on each chart.

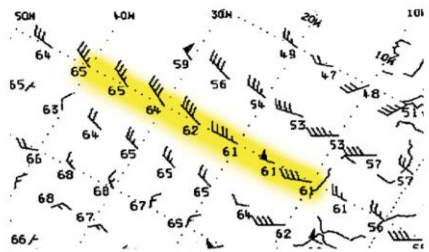


Upper wind and temperature Charts:



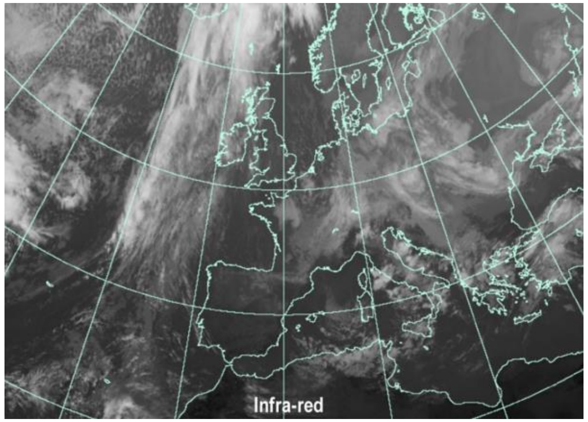
Temps are always negative unless prefixed with a +.

Calculating Mean winds:



Along the 40°N parallel there are seven spot winds between 040°W and 010°W.
The wind direction varies at a fairly steady rate from 290°T to 250°T (these directions can be measured on the chart using a protractor if necessary) giving a rough mean of 270°T.
The wind speeds are 35 KT, 35 KT, 40 KT, 40 KT, 45 KT, 50 KT and 40 KT giving a calculated mean of 40 KT.
The temperatures are shown as -65°C, -65°C, -64°C, -62°C, -61°C, -61°C, -61°C and -61°C giving a calculated mean of -63°C.

Satellite Images:



Types of satellite:

36,000km altitude revolves around the earth once every 24hr.
If placed at launch over the equator, orbaiting in the same direction of the earth itll apear stationary.
AKA: **Geostationary orbit.**

Infra-Red Images:

Shown above

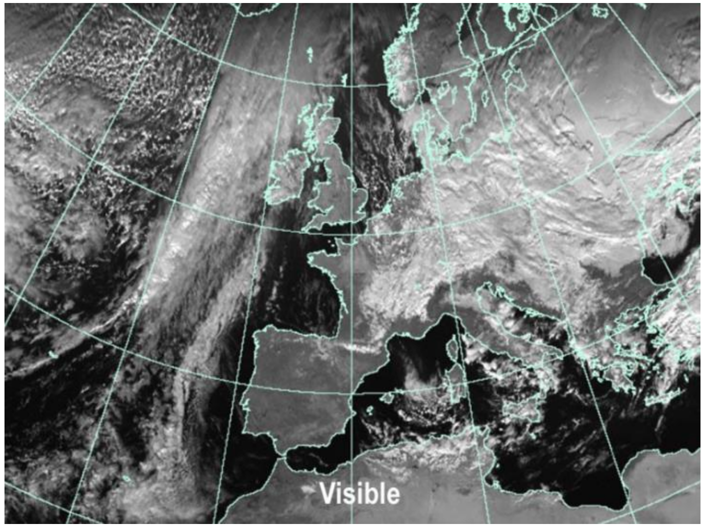
Temps displayed as grey level:

White = Cold

Black = Hot

Black areas are normaly cloud free, Although there may be low cloud or fog at surface temps that does not show.
Very cold land may show up grey, before dawn. This can normally be distinguished from cloud by the fact that it is a unifrom grey and ends shprply at coastlines.

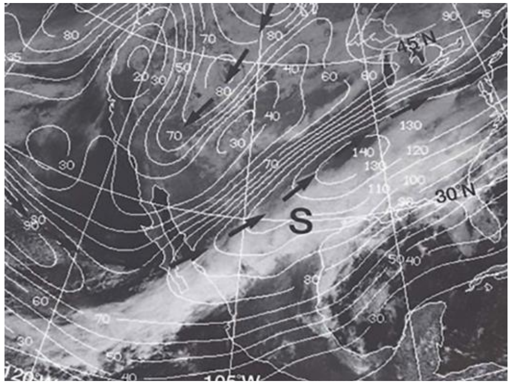
Visible Images:



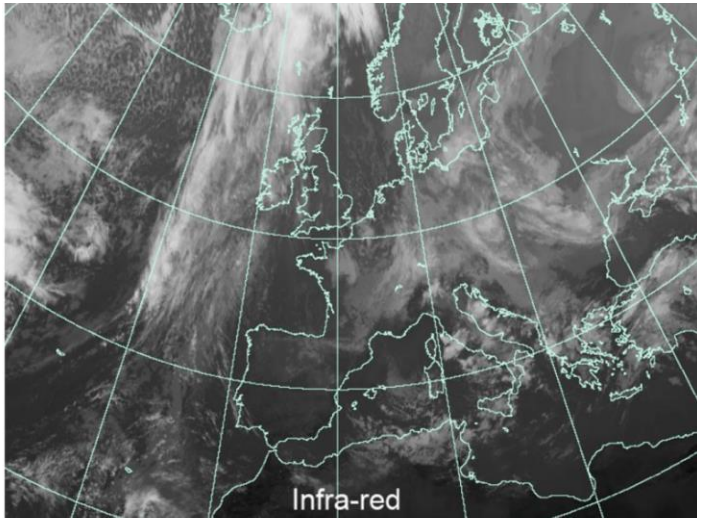
Black and white: showing reflective surfaces like cloud, snow, and ice as white or grey areas, while land and sea are darker.
Visible ONLY AVAILABLE IN DAY LIGHT.
Otherwise use Infra-Red.

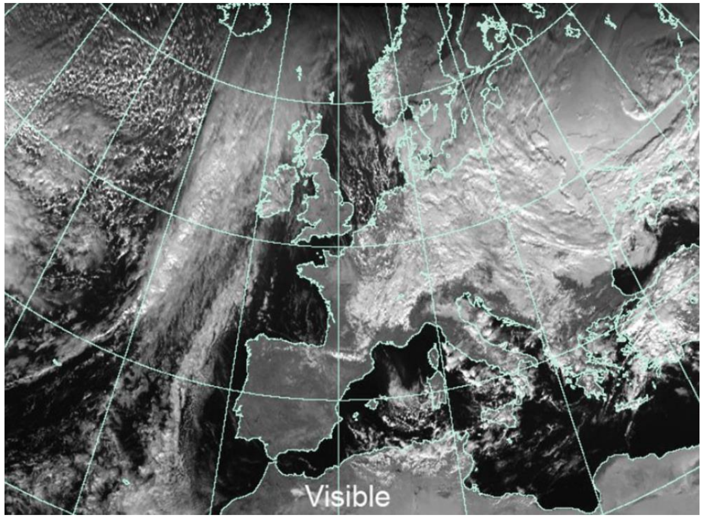
Locating a Jetstream:
Satellite imagery useful to locate jets.
Using atmospheric motions vectors (AMVs)

AMVs are derived by tracking either cloud or water vapour (WV) features in sequential images of multispectral stellate imagery.



Interpreting the images:

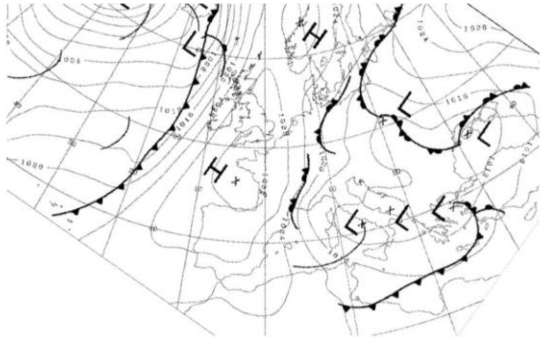




Both taken at same time, one IR one visible:

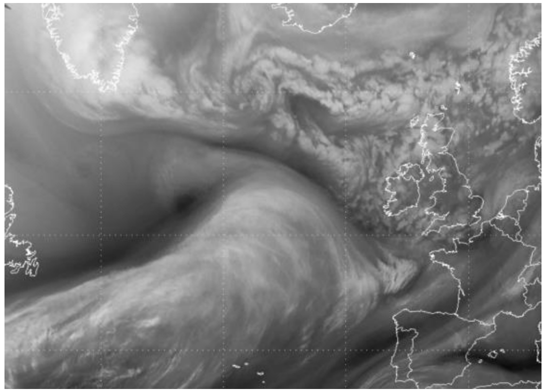
- If both images are bright in same are likely to be thick, high cloud. Can be seen in frontal cloud approaching Ireland.
- If visible images show cloud returns, but the infrared image is dark it means that the cloud is low level, possibly stratus or fog.
- The visible image shows the full extent of cloud cover, on the IR, warm low level cloud is indistinguishable from land or sea.

Interpreting the images:
Satellite best used in conjunction with low level charts showing frontal systems.



Same as prev images:

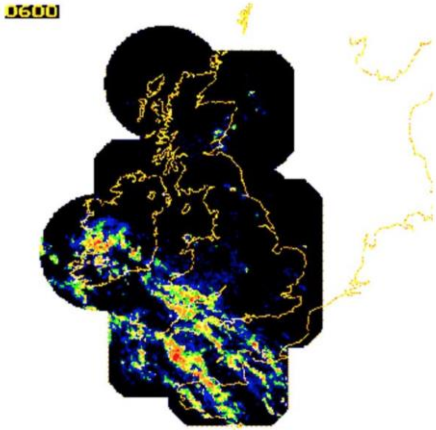
Water vapour images:



Highlights the presence of water vapour in upper atmosphere, usually above 20,000ft AMSL.
Used by forecasters to analyse moisture trajectories and the upper-level field of motion.
Allows us to identify jet streams, headwinds aloft and possible mountain wave turbulence even under clear skies.

Weather Radar:

Ground weather Radar:



Gives warnings of severe turbulence associated with TS and CBs

Pulse of energy transmitted and bounces of target causing some energy to be reflected to the receiver. (Targets weather droplets). Uses time to map position.

Turbulence difficult to detect:

Areas of highest concentration of raindrops, a reasonable but not fully accurate indication of where the worst turbulence will be.

Order of reflectivity, radar detects:

- **Wet Hail**
- **Rain**
- **Wet Snow**
- **Dry Hail**
- **Dry snow**
- **Drizzle**

Radar does not detect clouds fog or wind, windshear (except when associated with a microburst), CAT, Sandstorms, or lighting.

Airborne Radar:

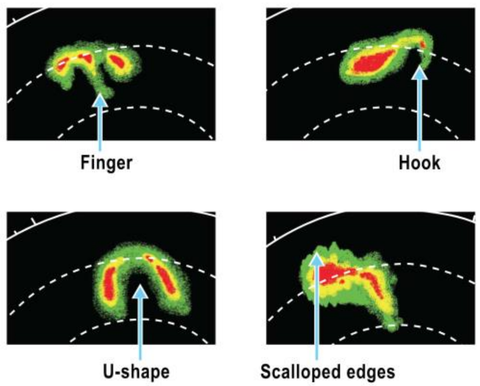
Purpose of airborne is to avoid thunderstorms and their associated hazards (turbulence and hail).

Works same as ground radar.

Super imposed on the Electronic Navigation Display (ND).

Shows increasing intensity with colour, with green indicating weakest returns, then amber then red.

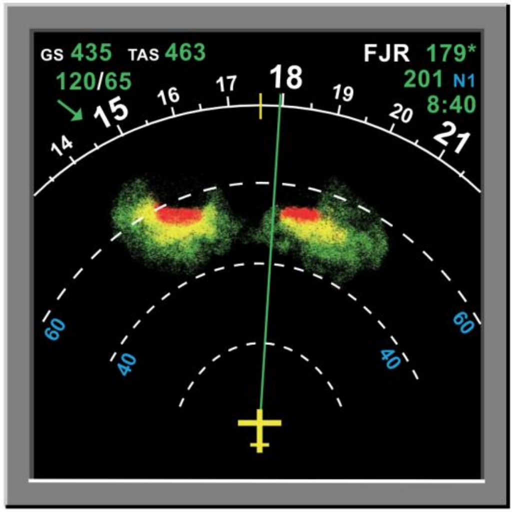
Interpreting airborne weather radar displays.



Cloud shapes indicate turbulence

The above indicates severe TS activity.

Radar Shadowing:



It is possible for intense returns to mask the clouds behind them and falsely indicate a clear area. This is caused by attenuation of a signal.

Scales:

Pilots need to be aware of scales selected, a short-range scale may seem to indicate a passage but when zoomed out will show otherwise.

Stormoscopes:

Another device used in conjunction with airborne radar is called stormoscope.

Detects electrical discharge (ie Lightening), and direction relative to AC.

Tropical Cyclone Advisory Service:

In areas where tropical cyclones occur, TCACs (Tropical Cyclone Advisory Centres) will be established to monitor and advice of tropical cyclones.

Msgs have standard format:

19 elements, an = sign indicated the end of an element.

TC ADVISORY:	Identification of type of message
DTG:	Year, month, day and time (UTC) of issue
TCAC:	Name of TCAC
TC:	Name of tropical cyclone
NR:	Advisory issue number (each cyclone starts "01")
PSN:	Position of centre of cyclone
MOV:	Direction and speed of movement using 16 compass points and km/h or kts.
C:	Central pressure (hPa)
MAX WIND:	Max surface wind near centre

FCST PSN + 6HR:	Day and time (UTC), forecast position of centre of tropical cyclone
FCST MAX WIND + 6HR:	Forecast maximum wind in 6 hours from advisory
FCST PSN + 12HR:	Day and time (UTC), forecast position of centre of tropical cyclone
FCST MAX WIND + 12HR:	Forecast maximum wind in 12 hours from advisory
FCST PSN + 18HR:	Day and time (UTC), forecast position of centre of tropical cyclone
FCST MAX WIND + 18HR:	Forecast maximum wind in 18 hours from advisory
FCST PSN + 24HR:	Day and time (UTC), forecast position of centre of tropical cyclone
FCST MAX WIND + 24HR	Forecast maximum wind in 24 hours from advisory
RMK:	Remarks
NXT MSG:	Expected year, month, day and time (UTC) of next advisory message.

TCACs Message Example

Example:

```
TC ADVISORY=
DTG: 20080925/1600Z=
TCAC: YUFO=
TC: GLORIA=
NR: 01=
PSN: N2706 W07306=
MOV: NW 20 kmH=
MAX WIND: 90 kmH=
FCST PSN +6HR: 25/2200Z N2748 W07350=
FCST MAX WIND +6HR: 90 kmH=
FCST PSN +12HR: 26/0400Z N2830 W07430=
FCST MAX WIND +12HR: 90 kmH=
FCST PSN +18HR: 26/1000Z N2852 W07500=

FCST MAX WIND +18HR: 85 kmH=
FCST PSN +24HR: 26/1600Z N2912 W07530=
FCST MAX WIND +24HR: 80 kmH=
RMK: NIL=
NXT MSG: 20080925/2000Z
```

The volcanic ash advisory service:

VAACs (Volcanic Ash Advisory Centres) Established to monitor and advise of the progress of volcanic ash clouds. The advisory messages have a standard plain language format Similar to TC advisory.

VA ADVISORY:	Identification type of message
DTG:	Year, month, day & time (UTC) of issue
VAAC:	Name of VAAC
VOLCANO:	Name of volcano & IAVCEI number
PSN:	Location of volcano
AREA:	State or region affected
SUMMIT ELEV:	Summit elevation (m)
ADVISORY NR:	Year and advisory issue No
INFO SOURCE:	Information source
AVIATION COLOUR CODE:	Red, orange, yellow, green unknown or nil (optional)

"IAVCEI = International Association of Volcanology and Chemistry of the Earth's Interior."

ERUPTION DETAILS:	Day/time of eruption(s)
OBS VA DTG:	Day and time (UTC), of observation of volcanic ash
OBS VA CLD: or EST VA CLD:	Observed or estimated horizontal and vertical extent of ash cloud and its movement
FCST VA CLD + 6HR	Day and time (UTC) with forecast altitude and position for cloud mass
FCST VA CLD + 12HR	Day and time (UTC) with forecast altitude and position for cloud mass
FCST VA CLD + 18HR:	Day and time (UTC) with forecast altitude and position for cloud mass
RMK:	Remarks
NXT ADVISORY:	Expected year, month, day and time (UTC) of next advisory message.

The Volcanic Ash Advisory Service Example Message

Example:

```
VA ADVISORY=
DTG: 20080802/0700Z=
VAAC: TOKYO=
VOLCANO: USUZAN 805-03=
PSN: N4230 E14048=
AREA: JAPAN=
SUMMIT ELEV: 732 m=
ADVISORY NR: 2008/432=
INFO SOURCE: GMS JMA=
AVIATION COLOUR CODE: RED=
ERUPTION DETAILS: ERUPTED 20080402/0614Z ERUPTION OBS VA TO
ABV FL300=
OBS VA DTG: 02/0645Z=
OBS VA CLD FL150/350 N4230 E14048 - N4300 E14130 - N4246
E14230 - N4232 E14150 - N4230 E14048 SFC/FL150 MOV NE 25 KT
FL150/350 MOV E 30 KT=
FCST VA CLD +6HR: 02/1245Z SFC/FL200/350 N4230 E14048 -
N4232 E14150 - N4238 E14300 - N4246    E14230 FL350/600 NO
VA EXP=
FCST VA CLD+12HR: 02/1845Z SFC/FL300 N4230 E14048 - N4232
E14150 - N4238 E14300 - N4246 E14230 FL300/600 NO VA EXP=
FCST VA CLD +18HR: 03/0045Z SFC/FL600 NO VA EXP=
RMK: VA CLD CAN NO LONGER BE DETECTED ON SATELLITE IMAGE=
NXT ADVISORY 20080402/1300Z
```