

MET 1 - THE ATMOSPHERE

CONVERSION FACTORS

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

COMPOSITION

- Atmosphere has no specific upper limit.
- Nitrogen (N₂) 78%
- Oxygen (O₂) 21%
- Argon (A) 0.93%
- Carbon Dioxide (CO₂) 0.03%
- Hydrogen (H) Trace
- Ozone (O₃) Filters and absorbs UV
- Water Vap (H₂O) Gas state of water
- Solid particles Pollution*
- Concentration % of gases remains constant with the exception of water vapour which decreases with altitude.

VARIATIONS WITH HEIGHT

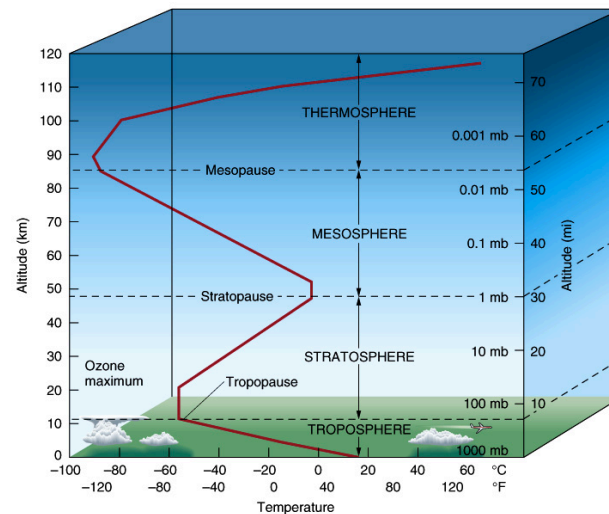
- Pressure decreases with height.
- Density decreases with height.
- Temperature varies with height.

ATMOSPHERIC PROPERTIES

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

LAPSE RATES

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



TRPOPOSPHERE

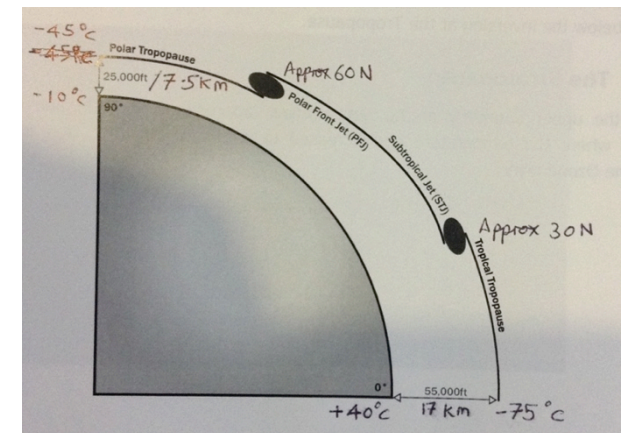
- Almost all water vapour within the atmosphere is contained here and hence this is where most of the weather occurs.
- +ve lapse rate

TROPOPAUSE

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

STRATOSPHERE

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



MET 3 – HEAT & TEMPERATURE

TEMPERATURE SCALES

- Celsius : Freeze 0 °C / Boil 100 °C
- Farenheight: Freeze 32 °F / Boil 212 °F
- Kelvin: Freeze 273 K / Boil 373 K
- $C \rightarrow F: \left(C \times \frac{9}{5}\right) + 32$
- $C \rightarrow K: +273$ (Approx double, add 30)
- Celsius is used for meteorological purposes

REPORTING TEMPERATURE

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

MEASURING TEMPERATURE

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

NOCTURNAL / TERRESTRIAL RADIATION INVERSION

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

SOLAR RADIATION

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

INSOLATION

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

RADIATION FROM EARTH

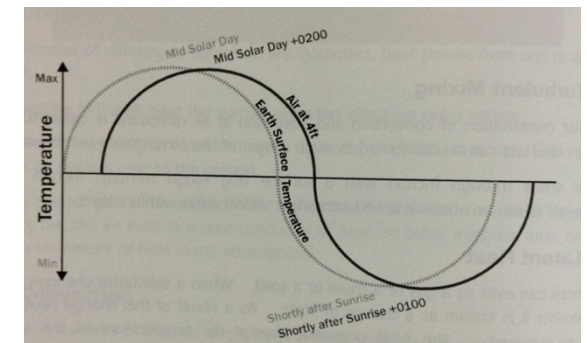
- **Long wave** radiation
- Occurs **24 Hrs**
- Negligible during day due to solar radiation.
- **Net outflow** of heat at night = **surface cools**
- Too high concentrations of carbon dioxide and water vapour (**greenhouse gases**) act like a blanket and can leading to warming.
- A calm and clear night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

HEAT TRANSFER

- **Conduction**
- **Convection** (due density changes)
- **Advection** (horizontal movement of air)
- **Latent heat** (absorbed if melt / evaporate)
- Irregular mixing of convection and advection gives rise to **turbulence**.

DIURNAL VARIATION

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



MET 2 – INTERNATIONAL STANDARD ATMOSPHERE

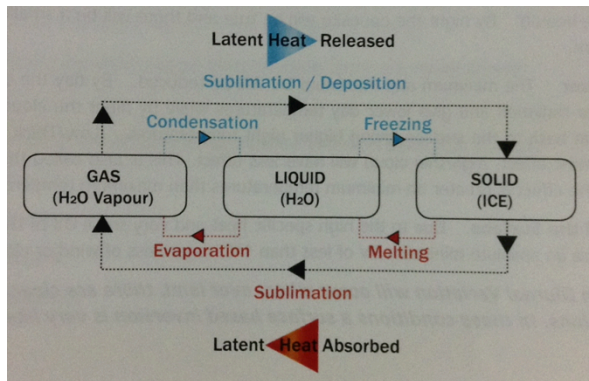
LATENT HEAT

Water Vapour

Liquid

Solid

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

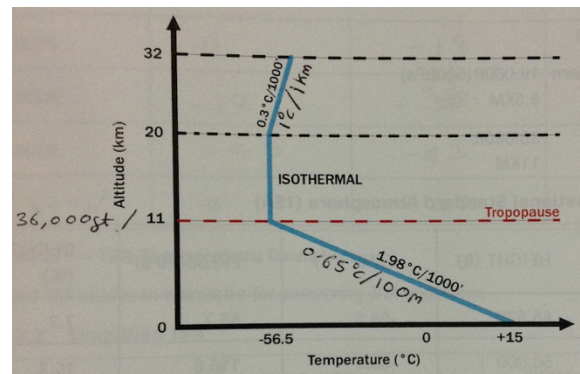


WHY ISA?

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

ISA TEMPERATURE

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



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

ISA

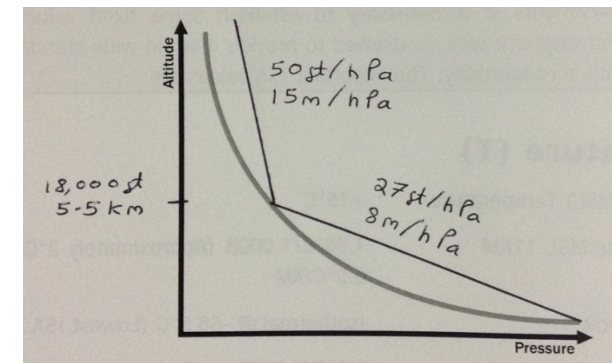
- Jet Standard Atmosphere
- Constant 2°C / 1000 ft for planning

ISA DENSITY

- MSL Density = 1.225 kg / m³
- Half Density = 20,000 ft

ISA PRESSURE

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



ISA PRESSURE VALUES

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

ISA DEVIATION

- ISA Deviation = Ambient (OAT) - ISA

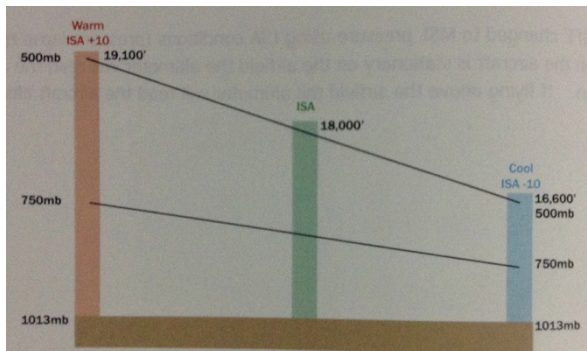
MET 4 – ATMOSPHERIC PRESSURE

VARIATION OF PRESSURE WITH HEIGHT

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

PRESSURE VARIATION WITH TEMPERATURE

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

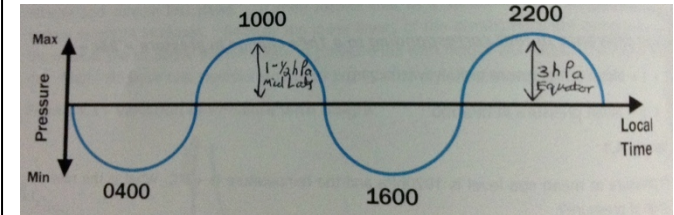


APLR

- **Ambient Pressure Lapse Rate**
- $APLR = \frac{96K}{P}$
- K = Mean temperature in Kelvin
- P = Mean pressure
- Pressure at MSL is 1000 hPa and temperature is +20 °C. An aircraft is flying at the 910 hPa level where temperature is -6 °C. What height is it flying at?
- Mean pressure = $(1000 - 910) / 2 = 955$ hPa
- Mean temperature = $[(20) + (-6)] / 2 = +7 = 280$ K
- $APLR = [(96 \times 280) / 955] = 28.15$ ft / hPa
- Pressure difference is $(1000 - 910) = 90$ hPa
- $90 \times 28.15 = 2533.5$ ft AMSL
- An $APLR < 27' / \text{hPa}$ = **Cold Air**
- An $APLR > 27' / \text{hPa}$ = **Warm Air**
- Shortest distance between two pressure levels occurs when pressure increases and temperature decreases.

DIURNAL VARIATION

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



PRESSURE MEASUREMENTS

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

MET 4 – ATMOSPHERIC PRESSURE

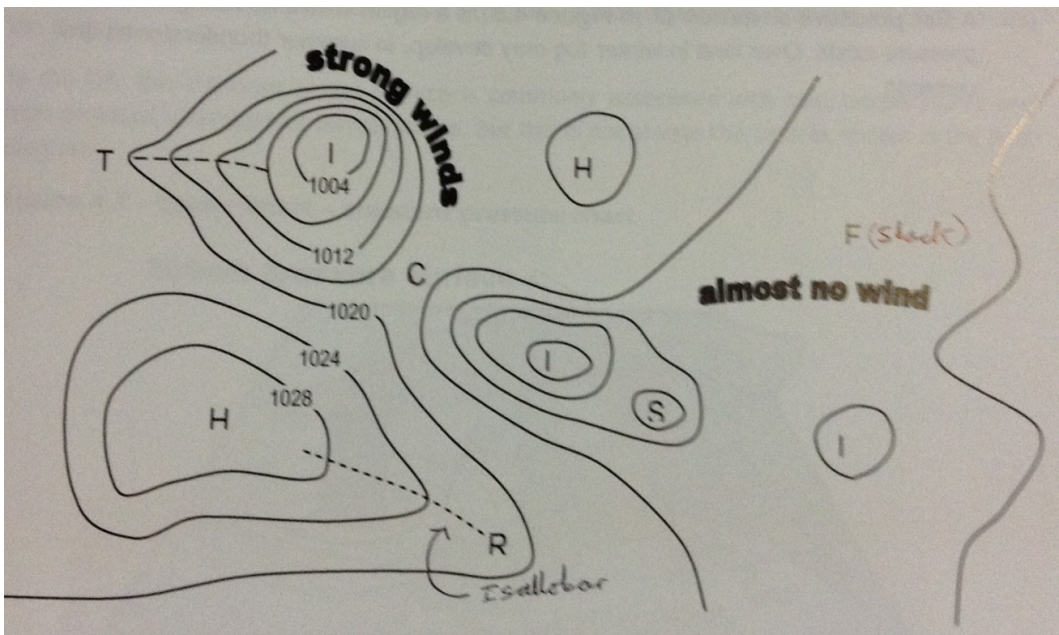
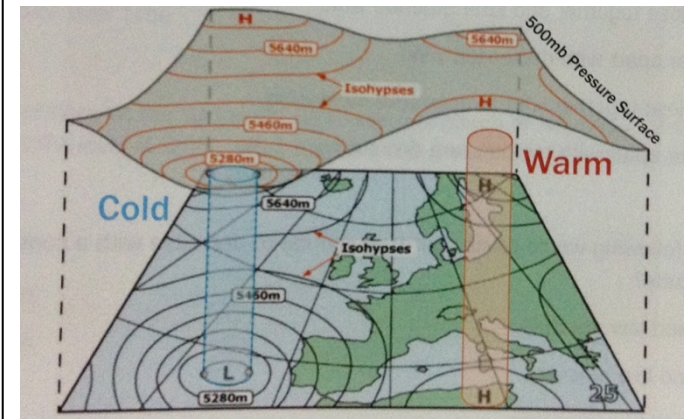
SURFACE PRESSURE CHART

- QFE's measured at each airfield.
- Converted to QFF's.
- **Isobars** join points of equal pressure.
- A high / low pressure area is determined by comparing the pressure of an area to that of the horizontal environments (surroundings)
- **Barometric Tendency** is the way and rate at which pressure is changing.
- **Isallobars** are lines showing equal change over a three hour period.
- **L = Low** (Depression / Cyclone)
- **S = Secondary Depression**
- **T = Trough**

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

CONSTANT PRESSURE CHART

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



MET 5 – DENSITY

DEFINITION

- **Density = Mass / Volume**

DENSITY RELATIONSHIPS

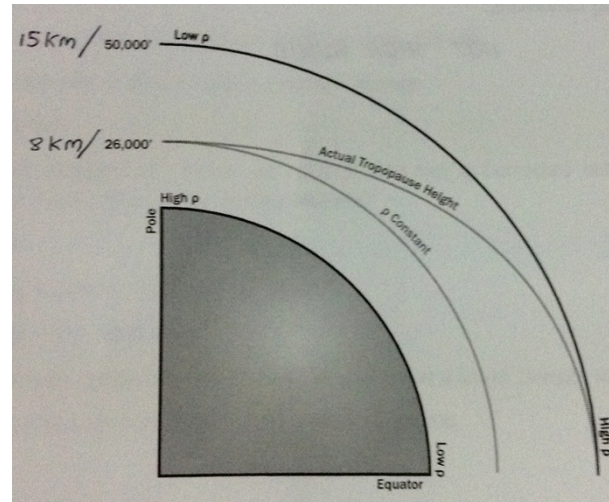
- **Density $\propto$ Pressure**
 - Higher Pressure = Higher Density
- **Density $\propto 1 / \text{Temperature}$**
 - Lower Temperature = Higher Density
- **Density $\propto 1 / \text{Humidity}$**
 - Humid air = Less Dense

WITH INCREASING HEIGHT...

- Pressure Decrease = Density Decreases
- Temperature Decrease = Density Increase
- Proportional effects: P_{TH}
- To change density by 1%
 - 10 hPa Change = 270 ft
 - 3 °C Change = 1500 ft
- Pressure therefore has the biggest effect and **density decreases with altitude.**

VARIATION WITH LATITUDE

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



DIURNAL VARIATION

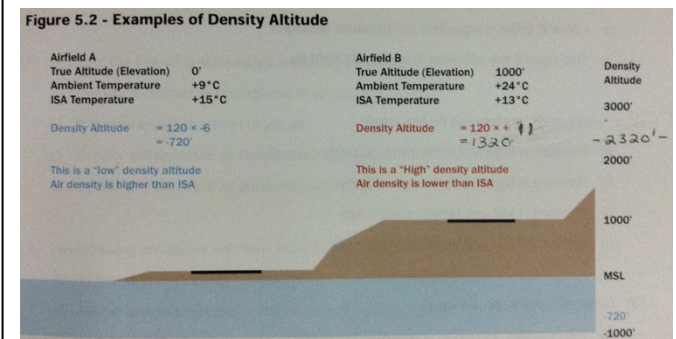
- **Opposite of temperature variation.**
- Best (highest) density = Sunrise + 30 mins
- Worst (lowest) density = Noon + 2 Hrs

DENSITY AND PERFORMANCE

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

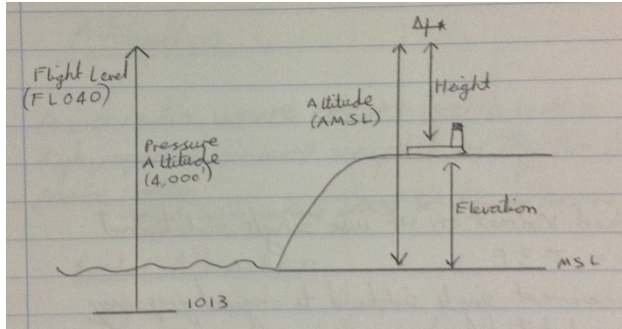
DENSITY ALTITUDE

- “Height in ISA which has a density corresponding to the actual ambient density.”
- Relative Density = Density Alt – Pressure Alt
- A high density altitude = lower density
- **Density Alt = Pressure Alt + (120 x ISA Deviation)**



MET 6 – ALTIMETRY

TERMINOLOGY



QNE

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

SPS

- Standard Pressure Setting
- 1013 hPa Datum
- "Flight Level"

RQNH

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

WHY QNH VS QFF

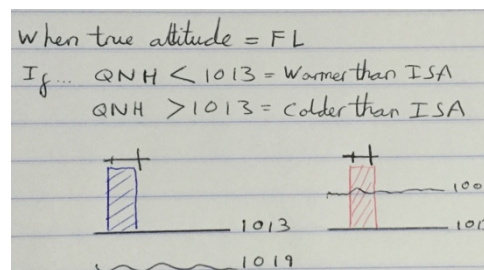
- QFF only used in the creation of synoptic charts.
- QNH used as the **altimeter is calibrated to 27" / hPa**.
- Using the QFF would display incorrect readings at touchdown.

QFE / QNH / QFF SIMILARITIES

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

TRUE ALTITUDE VS ALTIMETER

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

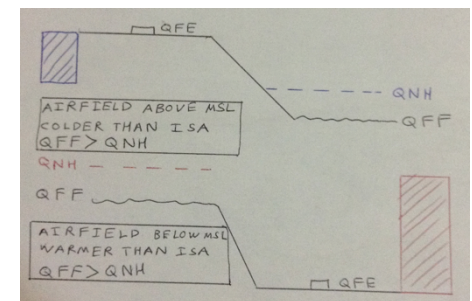


OVER / UNDER READ

- Over reads in cold air.
- Under reads in warm air.
- Can result in aircraft being at correct true altitude on ILS whilst the altimeter reads something else.

CALCULATING QNH LEVEL VS QFF

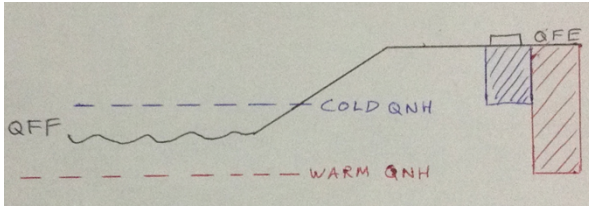
- The QNH level compared to the QFF level will depend on temperature.
- Draw either a small column of air (cold air) or large one (warm air) extending from the airfield to decide the QNH level.
- Remember, lower on the diagram is a **higher pressure** as you descend!!



MET 6 – ALTIMETRY

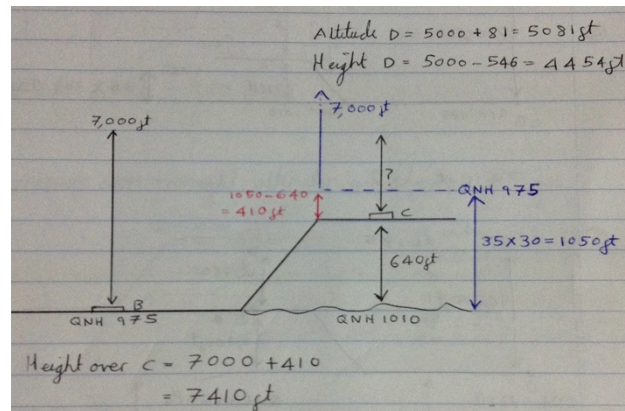
DITCHING

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



PRESSURE QUESTIONS

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



OVERNIGHT PRESSURE DROP

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

TRANSITION ALT / LEVEL

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

TEMPERATURE ERROR CORRECTION

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

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

MET 7 – LOW LEVEL WINDS

WHAT IS WIND?

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

WIND DIRECTION

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

WIND SPEED

- 1 KT = 1.85 KM/H = 0.52 MPS

WIND SYMBOLS

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

Symbol	Speed (kt)
Half Feather	5kt
Full Feather	10kt
1/2 & Full Feather	15kt
2 Full Feathers	20kt
Solid Pennant	50kt
Combination	65kt

WIND MEASUREMENT

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

GUST / LULL

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

SQUALL

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

VEER / BACK

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

PRESSURE GRADIENT FORCE (PGF)

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

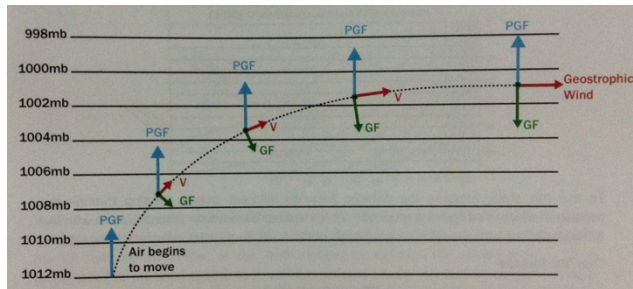
GEOSTROPHIC FORCE (GF)

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

MET 7 – LOW LEVEL WINDS

GEOSTROPHIC WIND

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



GEOSTROPHIC WIND (LATITUDE VARIATION)

- $PGF = GF = 2 \Omega \rho GW \sin \phi$
- $GW \propto 1 / \sin \phi$
- For the same pressure gradient, GW increases towards the equator.

BUY BALLOTS LAW

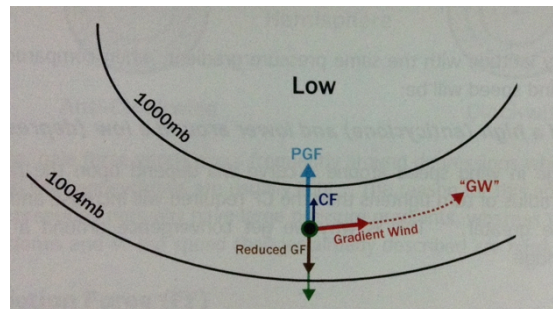
- Back to the wind, low pressure on the left**
- Opposite in the southern hemisphere

GRADIENT WIND

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

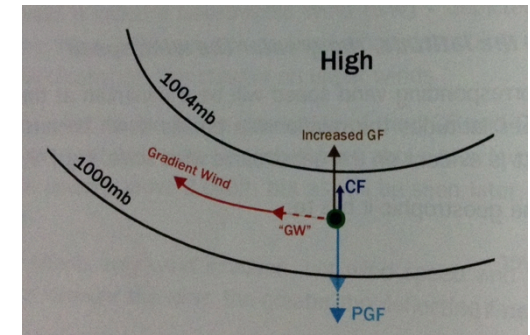
GRADIENT WIND – AROUND LP (NH)

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



GRADIENT WIND – AROUND HP (NH)

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



GRADIENT WIND – LATITUDE VARIATION

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

MET 7 – LOW LEVEL WINDS

AIRFLOW AROUND PRESSURE SYSTEMS

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

FRICTION LAYER

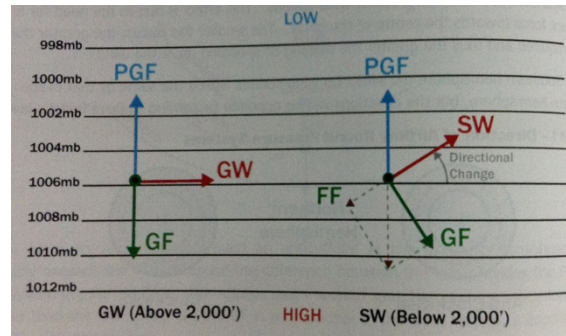
- Between 1,500 ft – 3,000 ft AGL (AVG 2K)
- Exceptionally can be up to 6,000 ft AGL
- Within this layer there is a **friction force** that causes wind to change speed and direction near the surface.
- A **thinner** layer is more effective.

CAUSES

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

FRICTION FORCE

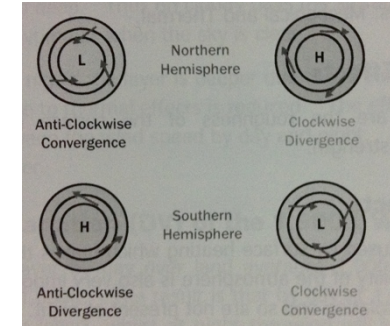
- The friction force acts **opposite to the wind**
- It causes the wind to **slow down** initially.
- **Geostrophic Force reduces** as a result.
- Unbalance of force now created and surface wind (SW) **turns towards low pressure**.
 - Backs in northern hemisphere
 - Veers in southern hemisphere



VALUES OF CHANGE

- **Over Land**
 - Backs 30°
 - Speed Decreases 50%
- **Over Sea**
 - Backs 10°
 - Speed Decreases 30%
- **Veers in SH rather than backs.**

SURFACE WIND AROUND HP / LP



COVERGENCE / DIVERGENCE

- Caused by frictional force at the surface.

ISOHYPSSES

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

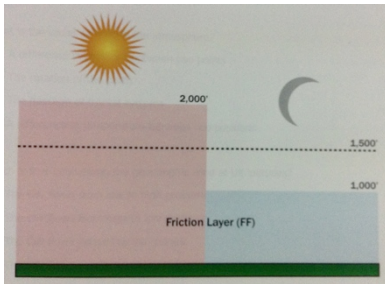
EYE OF PRESSURE SYSTEM

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

MET 7 – LOW LEVEL WINDS

DIURNAL VARIATION

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



FACTORS AFFECTING DV

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

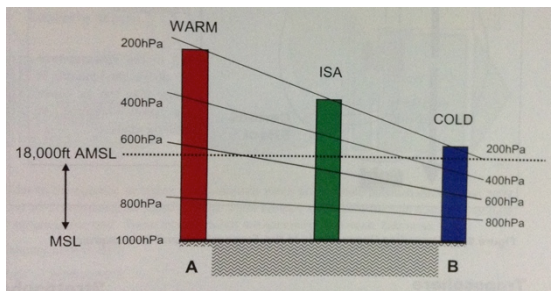
1,500 FT WIND

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

MET 8 - UPPER WINDS

CAUSE OF PRESSURE DIFFERENTIAL

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

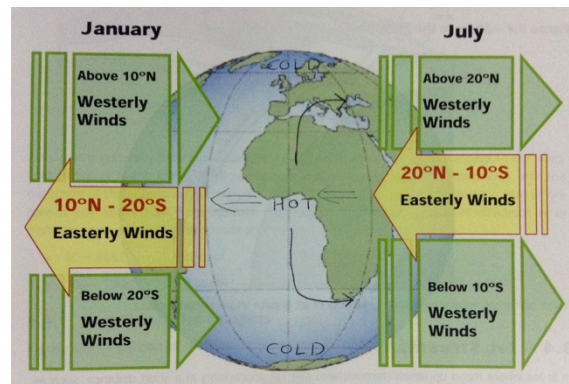


STRONGEST WINDS

- Located just below the tropopause

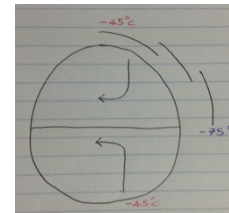
TROPOSPHERE UPPER WINDS

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



STRATOSPHERE UPPER WINDS

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



WINDS EXPERIENCED DURING FLIGHT

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

EFFECTS DURING WINTER

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

JET STREAMS

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

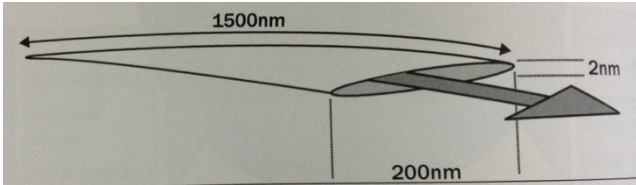
JET STREAM DEFINITION

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

MET 8 - UPPER WINDS	
--	--

JET STREAM DIMENSIONS

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



The diagram illustrates the cross-section of a jet stream. It shows a horizontal distance of 1500nm and a vertical distance of 200nm. A small, shaded, triangular region represents the jet stream core, with a width of 2nm. The diagram is labeled with '1500nm', '200nm', and '2nm'.

-
- A schematic diagram of a tapered optical fiber. The total length of the fiber is indicated as 1500 nm. The core diameter at the output end is 200 nm, and the cladding thickness is 2 nm. The fiber is shown tapering from left to right, with a shaded gray region representing the core and a white region representing the cladding.

JET STREAM SPEEDS

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

- [illegible]

- ~~~~~

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

- ## LOCATIONS OF JET STREAMS
- Polar jet front **moves more** than subtropical jet front. (More land mass)
-
- The diagram illustrates the seasonal shift of jet streams. In January, the Polar Jet Front (PFJ) is located between 35° and 55°N, and the Subtropical Jet Front (STJ) is between 25° and 40°N. By July, the PFJ has moved south to 45°-65°N, and the STJ has moved south to 40°-45°N. The Equatorial Easterly Jet (EEJ) is shown between 20°N and 10°S. Wind patterns are indicated by colored boxes: green for Westerly Winds (above 10°N and below 20°S) and yellow for Easterly Winds (between 10°N and 20°S).

The diagram illustrates the seasonal shift of wind systems across the globe. A central globe shows the continents of North and South America, Africa, Europe, and Asia. Arrows indicate the direction and latitude of major wind belts. To the left of the globe, a vertical column of boxes lists wind systems for January. To the right, a similar column lists them for July. The boxes are color-coded: green for northern and southern high latitudes, yellow for the tropics, and light blue for the southern mid-latitudes.

January	July
Above 10°N Westerly Winds	Above 20°N Westerly Winds
10°N- 20°S Easterly Winds	20°N- 10°S Easterly Winds
Below 20°S Westerly Winds	Below 10°S Westerly Winds

Specific wind systems and their latitudes shown on the globe:

- January:**
 - PFJ 35°-65° (Polar Front Jet)
 - STJ 25°-40° (Subtropical Jet)
 - STJ 40° (Subtropical Jet)
 - PFJ 45°-55° (Polar Front Jet)
- July:**
 - PFJ 45°-65° (Polar Front Jet)
 - STJ 40°-45° (Subtropical Jet)
 - EEJ (Equatorial Easterly Jet)
 - STJ 30° (Subtropical Jet)
 - PFJ 45°-55° (Polar Front Jet)

JET STREAM HEIGHTS

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

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

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

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

- Jetstreams normally cross occluded fronts.
- Surface projection of jet stream 300 – 450 nm ahead of the warm front and 50 – 200 nm behind the cold front.
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- Wind speed greatest in an area between a trough and a ridge.

MET 9 - TURBULENCE & WINDSHEAR

DEFINITIONS

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

TURBULENCE VS WINDSHEAR

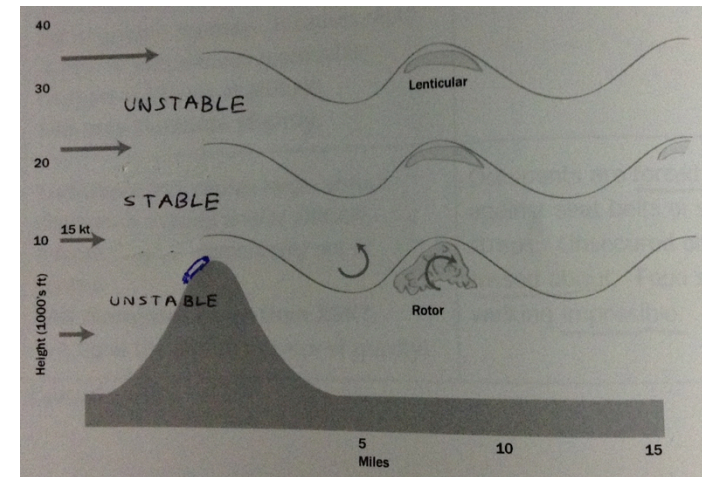
- **Wind Shear** – Abrupt displacement from flight path requiring substantial control action.
- **Turbulence** – Disruption to aircraft attitude but no significant effect on flight path.

MOUNTAIN (STANDING) WAVES

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

AVOIDING MOUNTAIN WAVES

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



MOUNTAIN WAVES CAUTIONS

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

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

INCIDENCE

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

MET 9 - TURBULENCE & WINDSHEAR

FRONTS

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

CLEAR AIR TURBULENCE (CAT)

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

CAT (TROUGH AND RIDGES)

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

CAT (CONVERGENCE / DIVERGENCE)

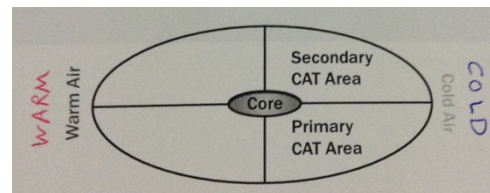
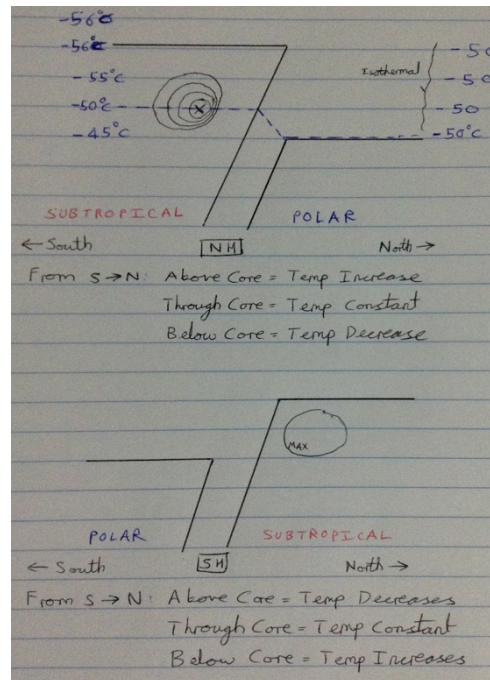
- When isohypses converge / diverge, CAT may form as a result of eddy formation.

STABILITY AND TURBULENCE

- More turbulence with an unstable atmosphere.

CAT (JETSREAMS)

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



CAT (JETSREAMS)

- Most frequent in the region 7000 ft below to 3000 ft above the tropopause.**
- Average depth of the layer is 2000 ft** (can be as shallow as 60 – 100 ft however)
- CI (Cirrus) cloud will move at high speed in a narrow band, **perpendicular** to the surface movement of the front.
- In the NH example (assuming front is moving north), it moves in direction of the wind which is coming out of the page.
 - “Back to wind, cold on the left”
- The core of a jet stream lies at a height where there is no horizontal temperature gradient and the slope of the pressure surfaces at the height of the core are at max.

MECHANICAL TURBULENCE

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

THERMAL TURBULENCE

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

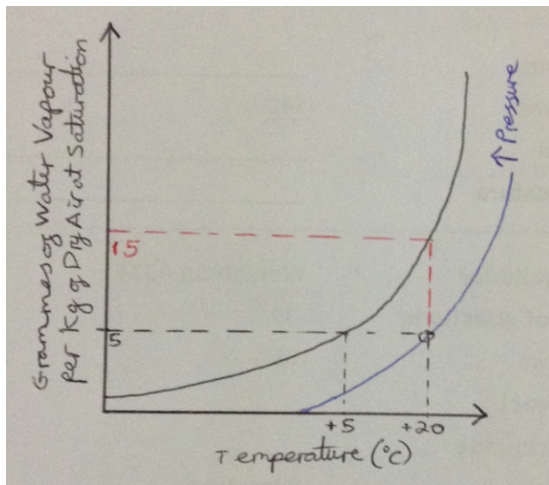
MET 10 - HUMIDITY

SATURATED AIR

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

HUMIDITY MIXING RATIO (HMR)

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



SATURATION OPTIONS

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

SATURATED MIXING RATIO (SMR)

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

DEW POINT

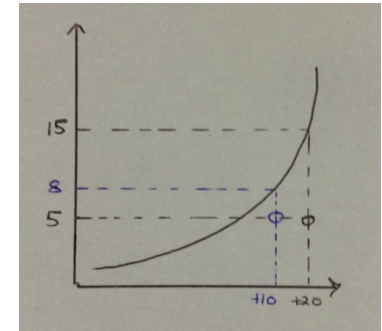
- **Temperature at which a volume of air must be cooled at constant pressure for saturation to occur.**
- If air is cooled to dew point it becomes **saturated**.
- Cooled **beyond dew point = condensation**
- Dew point can only be equal to, or lower, than the temperature of the air mass.
- Difference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

COOLING BEYOND SATURATION

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

RELATIVE HUMIDITY (RH)

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



EFFECT OF TEMPERATURE ON RELEASE OF LATENT HEAT

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

MET 10 - HUMIDITY

HMR

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

ABSOLUTE HUMIDITY

- Mass of water vapour contained in unit **volume** of dry air (gm/m³)

HYGROMETER

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

DV OF HUMIDITY

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

VAPOUR PRESSURE

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

MET 11 – ADIABTICS & STABILITY

RADIO SONDE BALLOON

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

WHY DOES AIR COOL WITH ALTITUDE?

- Consider a single parcel of air that's lifted.
 1. Pressure Decreases
 2. Volume Increases
 3. Molecules Slow Down
 4. **Adiabatic Cooling**
- The opposite process (on descent) results in **adiabatic warming**.
- This 'lifting' is done by **trigger factors**.

DRY ADIABATIC LAPSE RATE (DALR)

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

SATURATED ADIABATIC LAPSE RATE (SALR)

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

STABILITY

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

ABSOLUTE INSTABILITY

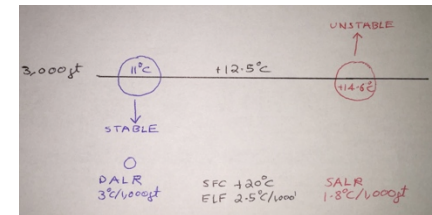
- **ELR > 3°C / 1,000 ft**
- Both an unsaturated and saturated parcel of air will be **unstable**.

ABSOLUTE STABILITY

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

CONDITIONAL INSTABILITY

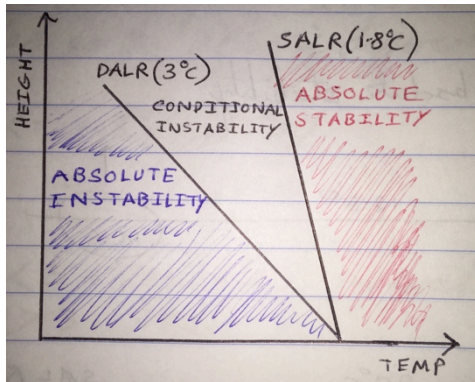
- **ELR 1.8°C --> 3°C / 1,000 ft**
- Unsaturated parcel is **unstable**
- Saturated parcel is **stable**



MET 11 – ADIABTICS & STABILITY

STABILITY GRAPH

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



DALR & SALR SPREAD

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

INVERSION STABILITY

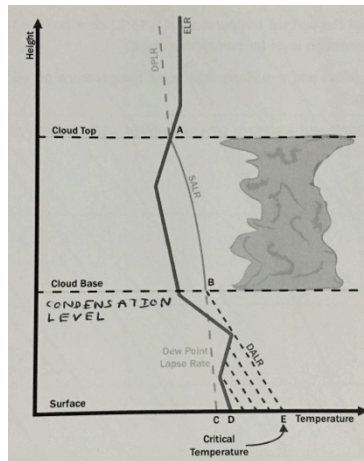
- With an inversion the ELR is +ve and to the right of the graph.
- An inversion is therefore **absolutely stable**

DEW POINT LAPSE RATE

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

TEPHI-GRAM: CRITICAL TEMP

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



ADIABATIC PROCESS

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

ISOTHERMAL LAYERS

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

ELR VARIATIONS

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

MET 12 – CLOUDS

STABLE STRATIFORM

Thin Layered | Cover Large Horizontal Area

LOW CLOUD

- Base: < 6,500 FT
- Water Droplets
- Grey From Below
- Stratus (ST)
- Stratocumulus (SC)

MEDIUM CLOUD

- Base: 6,500 – 23,000 FT
- Water Droplets + Ice Crystals
- Light Grey From Below
- Altostratus (AS)
- **Altostratus (AC) – Mackrell Sky**

HIGH CLOUD

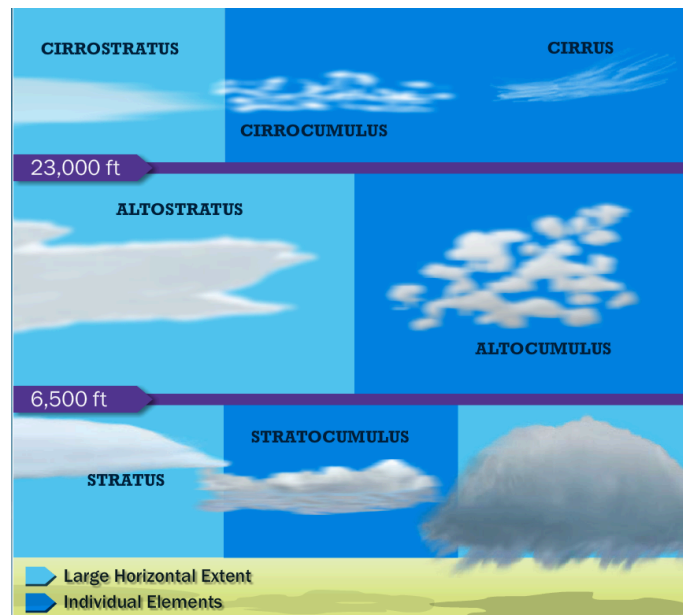
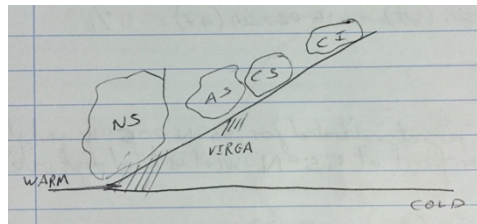
- Base: 23,000 FT +
- Ice Crystals
- White From Below
- **Cirrus (CI) – Mare's Tail**
- Cirrostratus (CS)
- Cirrocumulus (CC)

NIMBOSTRATUS (NS)

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

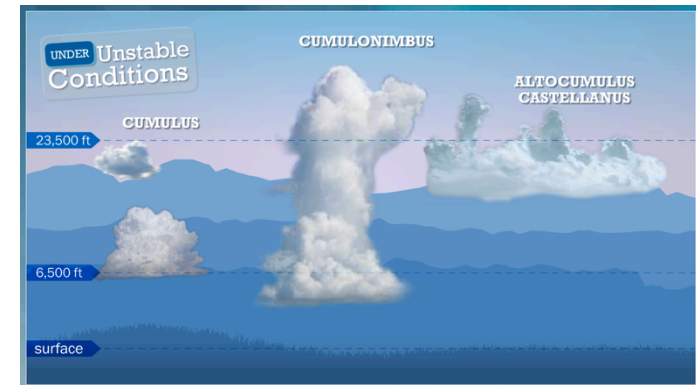
WARM FRONT

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



UNSTABLE CUMULIFORM

Large Vertical Development



CUMULUS (CU)

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



CB & AC CAST

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

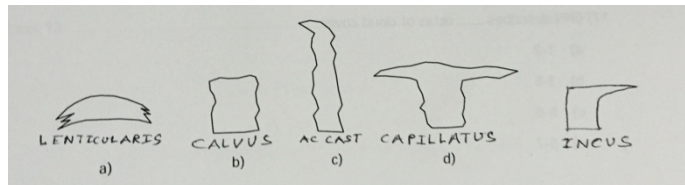
MET 12 – CLOUDS

SUPPLEMENTARY FEATURES

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



CB CLOUD SPECIES



CONTRAILS

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

WING TIP TRAILS

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

CLOUD REPORTING

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

CB REPORTING

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

DEFINITIONS

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

MET 13 – CLOUD TRIGGERS

6 TRIGGERS

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

- ## **6 TRIGGERS**
- Turbulence (Stable, Wind ≥ 8 kts, DP)
 - Convection (Unstable)
 - Orographic Lifting
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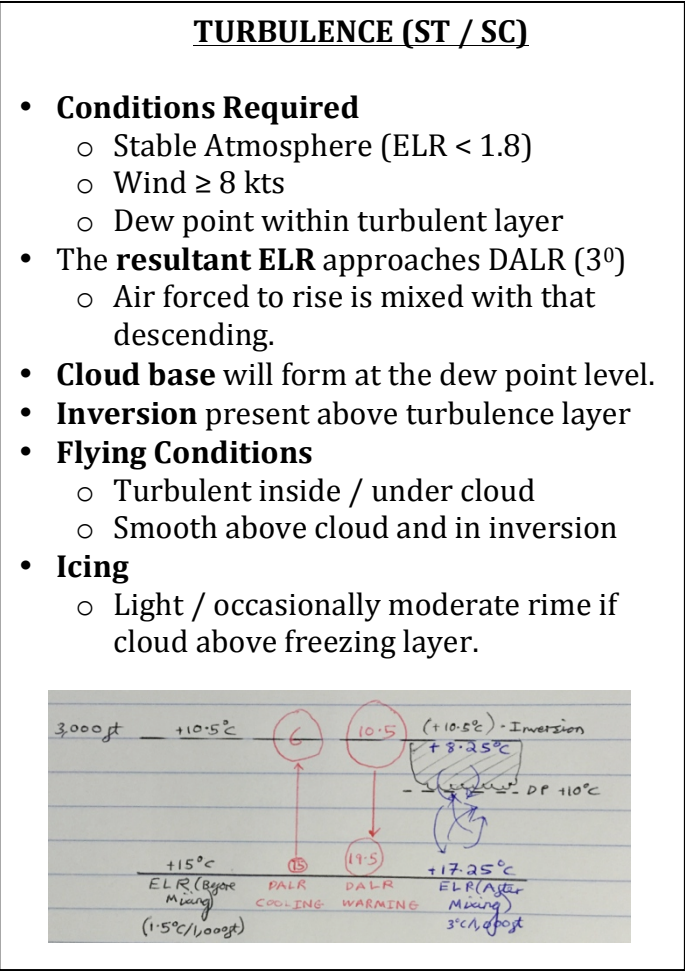
TURBULENCE (ST / SC)

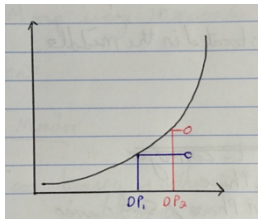
- **Conditions Required**
 - Stable Atmosphere ($\text{ELR} < 1.8$)
 - Wind ≥ 8 kts
 - Dew point within turbulent layer
- The **resultant ELR** approaches DALR (3°)
 - Air forced to rise is mixed with that descending.
- **Cloud base** will form at the dew point level.
- **Inversion** present above turbulence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

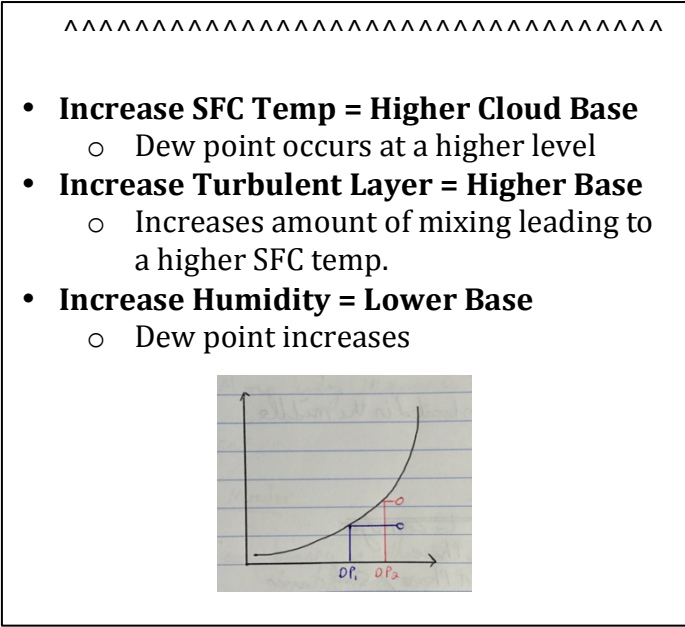
The diagram illustrates the relationship between Environmental Lapse Rate (ELR), Dry Adiabatic Lapse Rate (DALR), and cloud formation. It shows a temperature profile with an inversion layer and a mixing layer. Key values include 3000 ft, +10.5°C, +15°C, +17.25°C, and a dew point of +11.0°C. The diagram is divided into sections for 'ELR (Before Mixing)', 'DALR COOLING', 'DALR WARMING', and 'ELR (After Mixing)'.

Altitude / Feature	Temperature	Process / Note
3000 ft	+10.5°C	Top of inversion layer
Inversion Layer	+10.5°C to +8.25°C	Inversion (Temperature increases with altitude)
Dew Point Level	+11.0°C	Cloud base formation
Mixing Layer	+17.25°C to +15°C	ELR (After Mixing) = 3°C/1000ft
Below Mixing Layer	+15°C	ELR (Before Mixing) = 1.5°C/1000ft

- ## **TURBULENCE (ST / SC)**
- **Conditions Required**
 - Stable Atmosphere ($\text{ELR} < 1.8$)
 - Wind ≥ 8 kts
 - Dew point within turbulent layer
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- | Altitude / Feature | Temperature | Process / Note |
|--------------------|--------------------|---|
| 3000 ft | +10.5°C | Top of inversion layer |
| Inversion Layer | +10.5°C to +8.25°C | Inversion (Temperature increases with altitude) |
| Dew Point Level | +11.0°C | Cloud base formation |
| Mixing Layer | +17.25°C to +15°C | ELR (After Mixing) = 3°C/1000ft |
| Below Mixing Layer | +15°C | ELR (Before Mixing) = 1.5°C/1000ft |



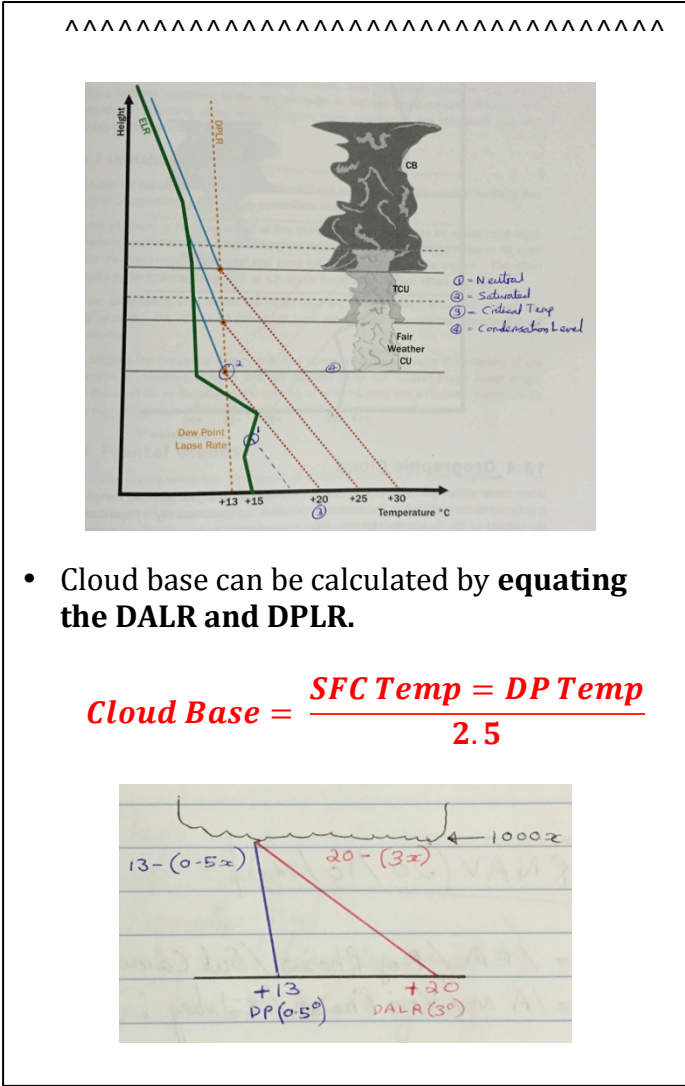
- **Increase SFC Temp = Higher Cloud Base**
 - Dew point occurs at a higher level
 - **Increase Turbulent Layer = Higher Base**
 - Increases amount of mixing leading to a higher SFC temp.
 - **Increase Humidity = Lower Base**
 - Dew point increases
- 



CONVECTION (CU / CB)

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

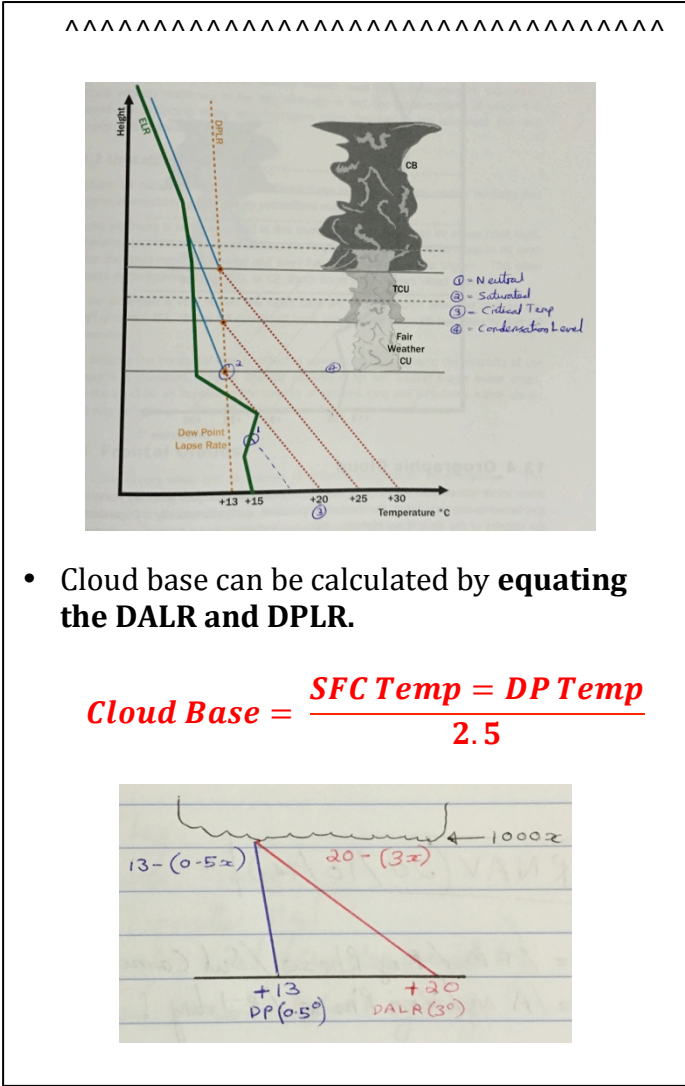
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-
- Cloud base can be calculated by **equating the DALR and DPLR.**
- $$\text{Cloud Base} = \frac{\text{SFC Temp} - \text{DP Temp}}{2.5}$$
-

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

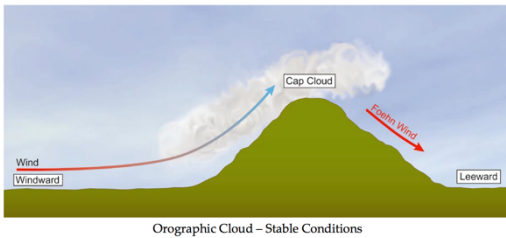
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MET 13 – CLOUD TRIGGERS

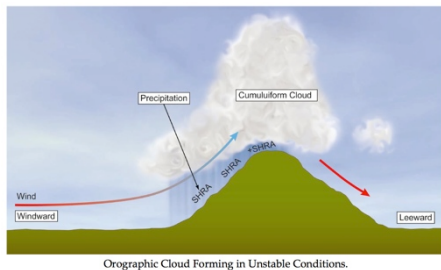
OROGRAHIC LIFTING - UNSTABLE

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



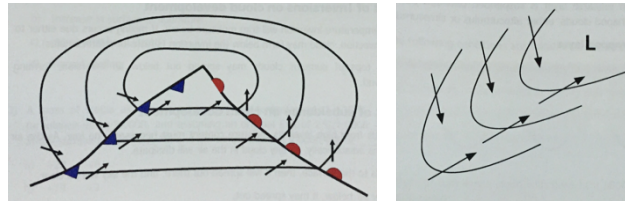
OROGRAHIC LIFTING - UNSTABLE

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



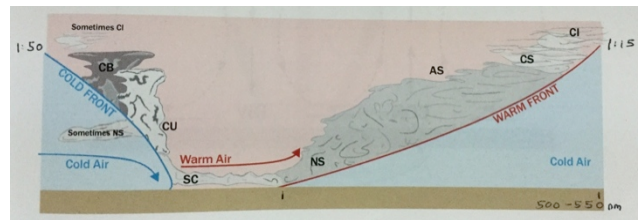
CONVERGENCE

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



FRONTAL CLOUDS

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



THIN LAYER LIFTING

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

MET 14 – VISIBILITY AND FOG

VISIBILITY MEASURING

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

OBSCURITY (VIS REDUCTION)

- **Less than 1000 m = Fog (FG)**
- **1000 m – 5 Km = Mist (BR)**
- **1000 m – 5 Km = Haze (HZ)**
 - Formed from solid particles
- **In order of decreasing vis:**
 - Hail
 - Rain
 - Drizzle
 - Sleet
 - Snow
- **Driving Snow** - Blown by wind when falling.
- **Drifting Snow** – Lifted less than 2m above surface after falling.
- **Blowing Snow** – Lifted more than 2m above surface after falling.
- **Shallow Fog** – Lifted less than 2m above surface.

TYPES OF FOG

RADIATION FOG

- **Conditions Required**
 - Over Land
 - Clear Sky (1 – 2 Oktas)
 - High Relative Humidity
 - Wind (5 kts)
- Radiation of the earth's heat at night causes cooling of the air in contact with the ground.
- Once cooled below the dew point and condensation occurs, a small amount of wind is required to lift it off the ground.
- Note that factors to produce max DV are required.
- **Average height of 500 ft**
- Can occur at anytime although **most likely in early morning (sunrise + 30).**
- **Cloud cover** will reduce heating and **rain** will keep air saturated, both causing radiation fog to persist.
- **More likely with a high pressure system.**
- **Dissipation Factors**
 - Sun (insolation)
 - Wind > 10 kts to lift it into ST / SC

ADVECTION FOG

- Movement of **warmer air over a colder surface.**
- **Conditions Required**
 - Land or sea
 - High RH
 - Surface with temperature < DP
 - Wind (up to 15 kts / 20 kts over sea)
- Colder surface cools warmer air (at a high RH) below the dew point.
- Forms **over land in winter** (land cooler)
- Form **over sea in summer** (land warmer)
- Will often form slightly off shore as it takes a while to pick up moisture from sea.
- **Can also occur between two seas at different temperatures.**
- **Can appear suddenly by day and night.**



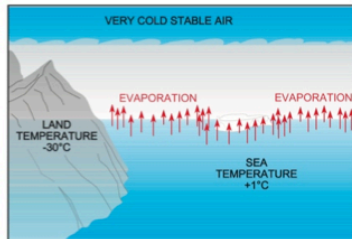
MET 14 – VISIBILITY AND FOG

HILL FOG

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

STEAMING FOG

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



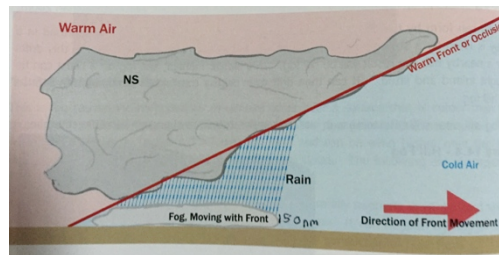
- Steaming fog occurs in air with cold mass properties.

VALLEY FOG

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

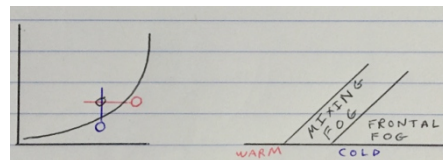
FRONTAL FOG

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



MIXING FOG

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



FREEZING FOG

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

ICE FOG

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

SOLID PARTICLES

SOLID PARTICLES

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

MET 14 – VISIBILITY AND FOG

FLIGHT VISIBILITY

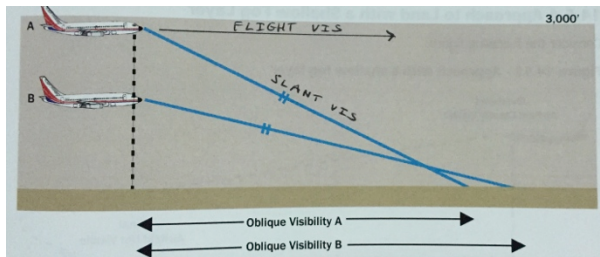
- The only measurable visibility is **oblique visibility** which is the distance along the ground between a point directly beneath the aircraft and the furthest point on the ground a pilot can see.
- Into Sun / Up-Sun / Down-Moon = Worst
- Into Moon / Up-Moon / Down-Sun = Best

SHALLOW FOG LAYER

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

VIS WITHIN HAZE LAYER

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



MET 15 – PRECIPITATION

BERGERON (ICE CRYSTAL) THEORY

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

COALESCENCE THEORY

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

PRECIPITATION TYPES

DRIZZLE (DZ) (Comma)

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

RAIN (RN) (Full Stop)

- Splashes when hits the ground

SNOW (SN) *

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

SLEET (SN) *

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

HAIL Δ

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

ICE PELLETS

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

FREEZING PRECIPITATION

- Freezing Rain
- Freezing Drizzle

REPORTING PRECIPITATION

DURATION

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

INTENSITY

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

MEASURING PRECIPITATION

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

PRECIPITATION EFFECTS

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

MET 16 - ICING

FROST POINT TEMPERATURE

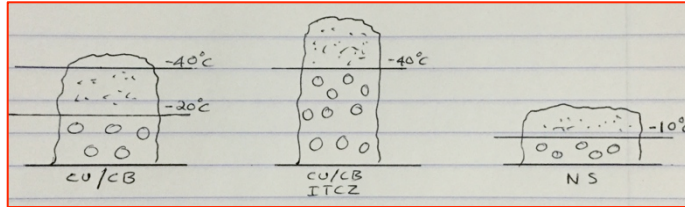
- When cooled below the frost point temperature, water vapour sublimates directly to ice.
- Frost will form on a solid surface of the same temperature when cooled below the frost point temperature.

ICING INTENSITY

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

SCWD

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



SCWD PROPORTIONS

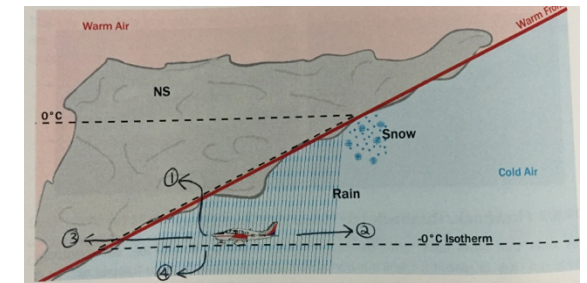
- For every degree below 0°C, 1/80th of the drop will freeze instantly on impact.
- The rest will flow back over the wing.

AIRFRAME ICING

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

FREEZING RAIN / RAIN ICE

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



HOAR FROST

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

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

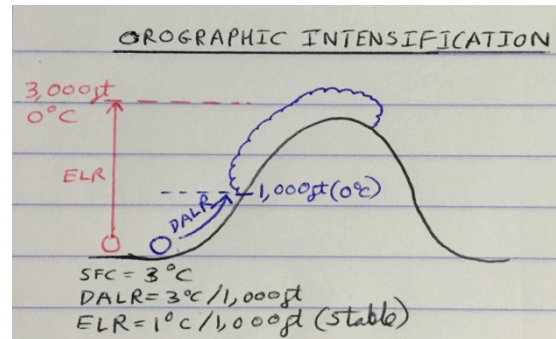
MET 16 - ICING

GROUND ICING

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

FACTORS AFFECTING ICING SEVERITY

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



ICING EFFECTS / HAZARDS

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

ICE PROTECTION & REMOVAL

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

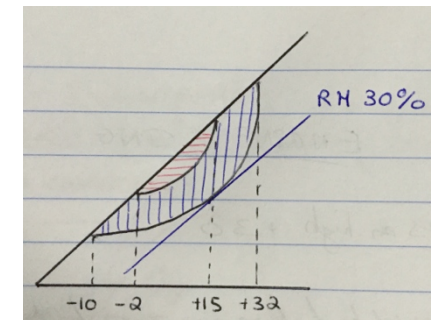
ENGINE ICING

PISTON ENGINES

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

CARBURETTOR ICING SEVERITY

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



TURBINE ENGINES

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

MET 17 – THUNDERSTORMS

CB'S VS THUNDERSTORMS

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

REQUIREMENTS FOR TS FORMATION

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

TRIGGERS

FRONTAL LIFTING TRIGGER

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

AIR MASS TRIGGERS

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

CLASSIFICATIONS

TS CLASSIFICATIONS

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

STAGES OF DEVELOPMENT

1. DEVELOPMENT STAGE

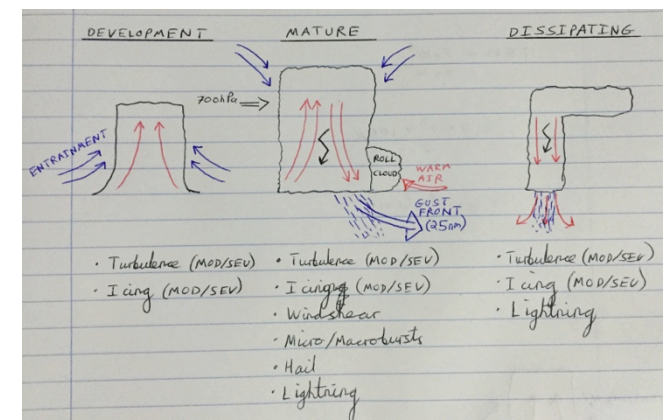
- Takes approx. 15-20 mins**
- CU Humilis develops into CU Mediocris then CU Congestus.
- It is driven by **latent heat due to condensation**
- Characterised by **updrafts**
- Entrainment** is the influx of dry air being drawn into the cloud.
 - Results in evaporation that could stop development if latent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

2. MATURE STAGE

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

3. DISSIPATING STAGE

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

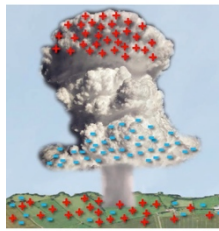


MET 17 – THUNDERSTORMS

LIGHTNING

LIGHTNING

- Ice crystals (top of cloud) tend to be positive
- Water droplets (bottom) tend to be negative
- **Leaders** extend from both ground and cloud. When they meet there is a flow of current and lighting strike occurs.
- Most likely to experience lightning **5,000 ft either side of the freezing level => With temperatures between -10°C and +10°C**



TYPICAL CHARACTERISTICS

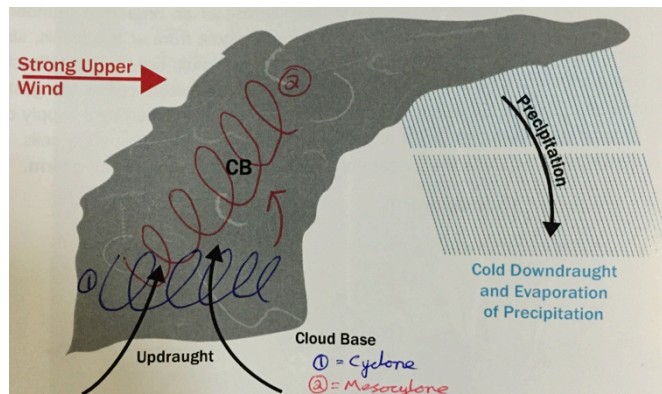
- Mainly occurs in **mid-west USA**
- Occur in **spring / early summer**
- **Hail can exceed 0.75 inches**
- **Gusts can exceed 50 kts**

1. INITIAL STAGE

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

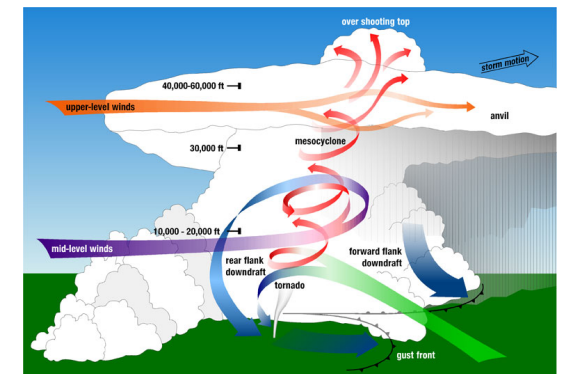
2. SUPER CELL

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



3. TORNADO

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



SUPER-CELL THUNDERSTORMS

DIFFERENCES

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

4. DISSIPATION

- Tornado dies out and thunderstorm follows.

MET 17 – THUNDERSTORMS

WATERSPOUTS

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

MICRO / MACRO BURSTS

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

PRESSURE VARIATIONS

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

TS AVOIDANCE

- An airborne weather radar (AWR) will sense the concentration of water droplets.
- **If avoiding TS using the AWR:**
 - Avoid by 10 nm when below 20,000 ft
 - Avoid by 20 nm when above 20,000 ft
- **If avoiding TS visually, avoid by 10 nm at any altitude.**
- If you must overfly a TS then **overfly by at least 5,000 ft.**

PEARSON TORNADO SCALE

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

TS CLASSIFICATION

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

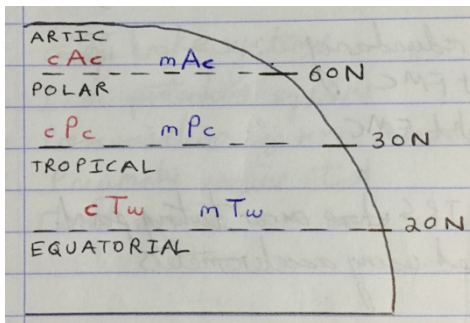
MET 18 – AIR MASSES

SOURCE CHARACTERISTICS

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

SOURCE NAMING

- Air masses are named according to the **temperature and humidity (in the horizontal plane) at source.**
- Named either **Continental (Land) / Maritime**
- Named **Equatorial, Tropical, Polar or Artic** depending on its latitude.
- Equatorial & Tropical will be a **warm air mass** and Polar & Artic will be **cold air masses.**
- Tropical Continental (cTw) Sahara
- Tropical Maritime (mTw) “Azore’s High”
- Polar Continental (cPc) “Siberian High”
- Polar Maritime (mPc)
- Artic Continental (cAc)
- Artic Maritime (mAc)



AIR MASS MODIFICATIONS

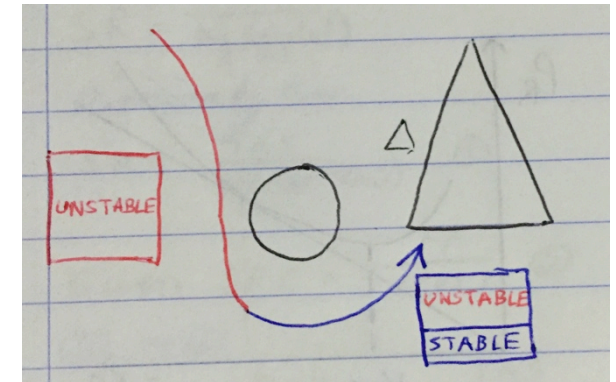
- As the air mass moves away from source, it's characteristics will change.
- A change in **latitude will affect temperature, stability and relative humidity.**
 - Move South = Warming from below = Stability Decreases & RH Decreases
 - Move North = Cooling from below = Stability increases & RH Increases
- The **surface it moves over will affect the absolute humidity.**
 - Over land = AH Decreases
 - Over Sea = AH Increases

CLOUD & PRECIP TYPES

- **If stability has decreased => Unstable**
 - CU / CB / TS with showers
 - Vis good outside showers
 - Inland, the moisture dries out leaving clear skies.
- **If stability has increased => Stable**
 - ST / SC with drizzle
 - Viz poor in haze
- **If continental air mass, it will be dry so no cloud forms and haze will be present.**
 - The exception is cPc with a sea track.
 - Added moisture gives ST / SC / CU with RA and SN.

RETURNING POLAR MARITIME

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

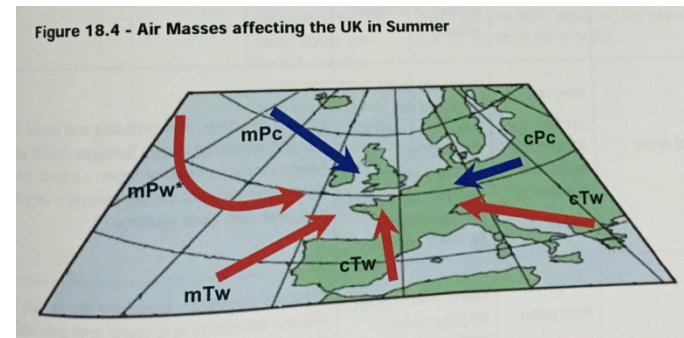
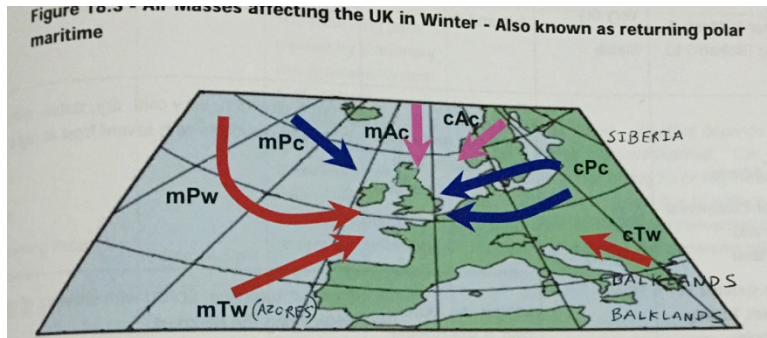


MET 18 – AIR MASSES

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

SEASONAL VARIATIONS

- Artic & mPw (Returning) – Winter Only



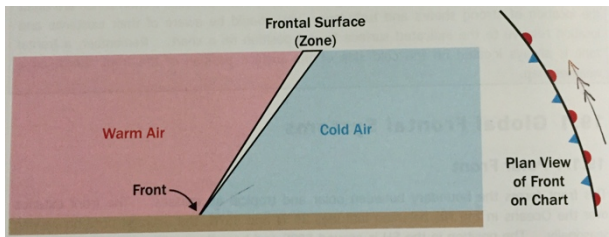
MET 19 – FRONTS AND POLAR FRONT DEPRESSIONS

WHAT IS A FRONT

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

QUASI-STATIONARY FRONT

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

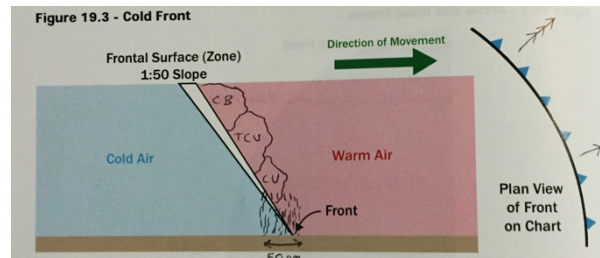


FRONTAL SPEEDS

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

COLD FRONT

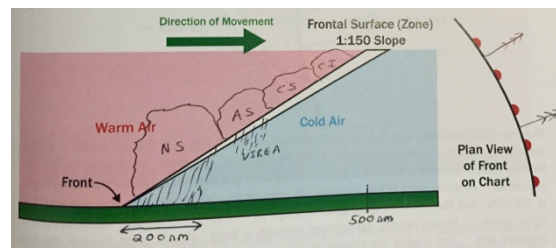
- Cold air replaces warm air at the surface.
- Unstable CB / TCU / CU
- **Precipitation 50nm wide both ahead and behind the front.**



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

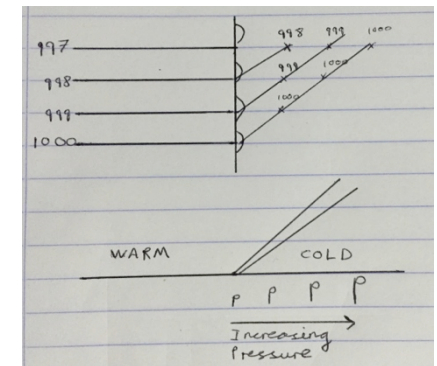
WARM FRONT

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



ISOBARS

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



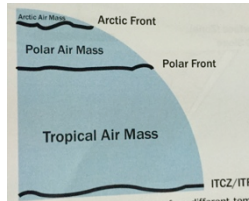
STRENGTHENING / WEAKENING

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

MET 19 – FRONTS AND POLAR FRONT DEPRESSIONS

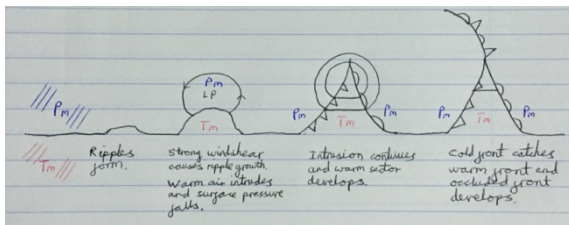
POLAR FRONT

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

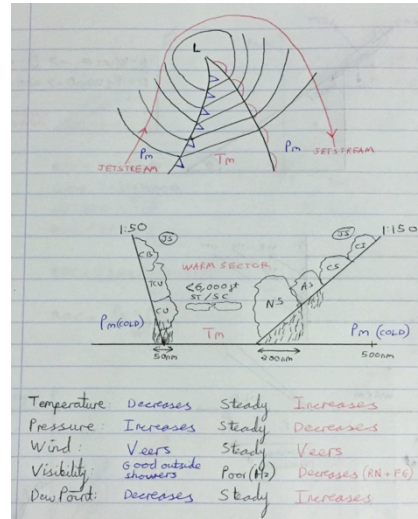


POLAR FRONT DEPRESSIONS (PFD)

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



POLAR FRONT DEPRESSIONS (PFD)



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

PRESSURE AND FRONTS

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

POLAR FRONT SFC PROJECTION

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

WARM SECTOR CLOUDS

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

OCCLUDED FRONT

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

Figure 19.20 - A Warm Occlusion

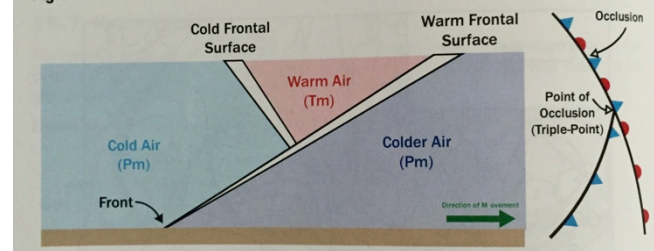
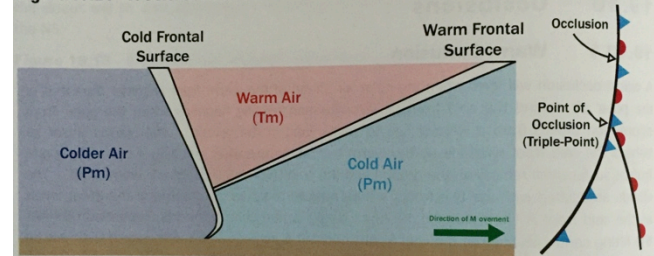


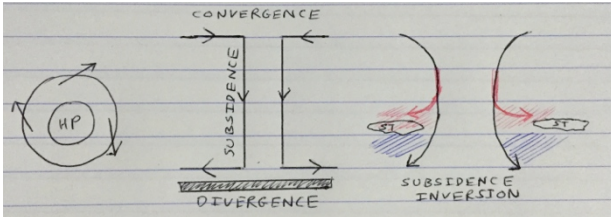
Figure 19.21 - A Cold Occlusion



MET 20 – ANTI CYLONES

CHARACTERISTICS

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



CHANGES OF STRENGTH

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

WARM ANTICYCLONES (PERMANENT)

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

WARM ANTICYCLONES (BLOCKING)

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

COLD ANTICYCLONES (SEMI-PERMANENT)

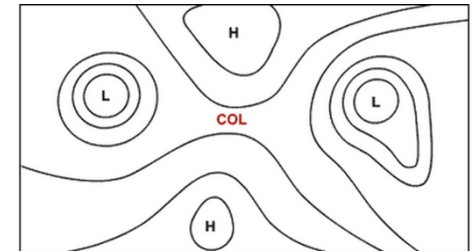
- Lie in the **polar air north of the polar front**.
- **Conduction** from cold surface subjects air to **intense cooling**.
- Since pressure decreases quicker in cold air, a shallow layer of subsidence is created.
- Typically does not show higher than 500 hPa
- **EG/ Siberian High**

COLD ANTICYCLONES (INTERMEDIATE HIGH)

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

COL

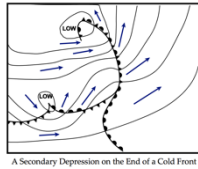
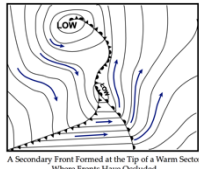
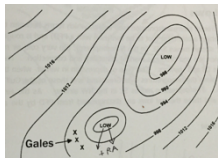
- Slack pressure between two highs and two lows.
- Clear skies and light wind result in max DV of temperature.
- Max heating during **summer results in thunderstorms**.
- Max cooling during **winter results in low cloud and fog**.



MET 20 – OTHER DEPRESSIONS (CYLONES)

SECONDARY DEPRESSIONS

- Can form in 3 cases:
- **Within the circulation of a larger primary depression**
- **At the triple point of a PFD occlusion.**
- At the **trailing edge of a cold front**
- **Gales** form on the side furthest from the primary centre.
- **Heavy rainfall** moves outwards from the centre of the secondary low.

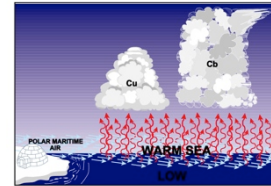
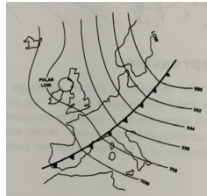


THERMAL DEPRESSIONS (WINTER)

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

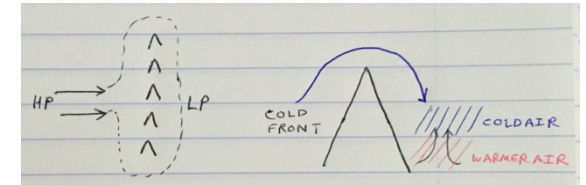
POLAR LOW

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



OROGRAPHIC DEPRESSIONS

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



TROUGHS

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

DUST DEVIL

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

THERMAL DEPRESSIONS (SUMMER)

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

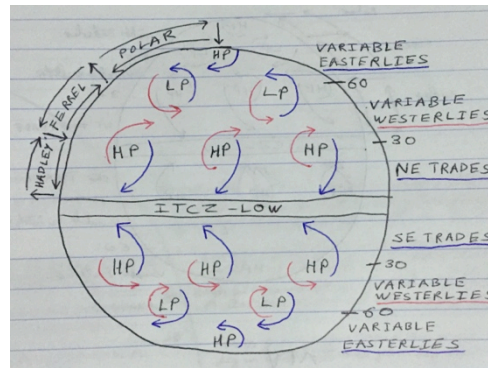
MET 21 – GLOBAL CLIMATOLOGY

CAUSE OF GLOBAL CLIMATOLOGY

- The **obliquity of the ecliptic** results in temperature variations which leads to pressure gradients etc.
- As a result of nature's attempt to stabilize everything, global circulation patterns arise.
- The NH summer solstice occurs in June. There is max heating of the northern hemisphere during this period and the maximum temperature is reached in July (due to heating lag).
- The NH winter solstice occurs in December. There is minimum heating of the NH during this period and the minimum temperature occurs in January.

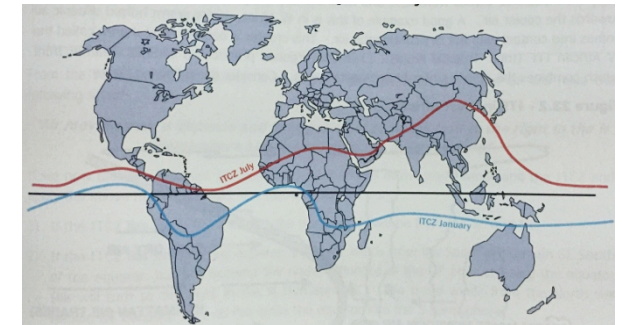
TROPOSPHERIC CIRCULATION

- Maximum heating at the equator results in air rising and convergence at the surface.
- This results in low pressure at the equator.
- Rising air diverges at the tropopause and heads north where it cools and descends at 30° N creating high pressure.
- Cold polar air descends and diverges at the surface resulting in high pressure.
- This flows south and heats up before converging at 60° N and creating low pressure at the surface.
- Wind flows from high to low and the geostrophic force acts.
- This creates easterlies, westerlies and the trade winds.



MOVEMENT OF THE ITCZ

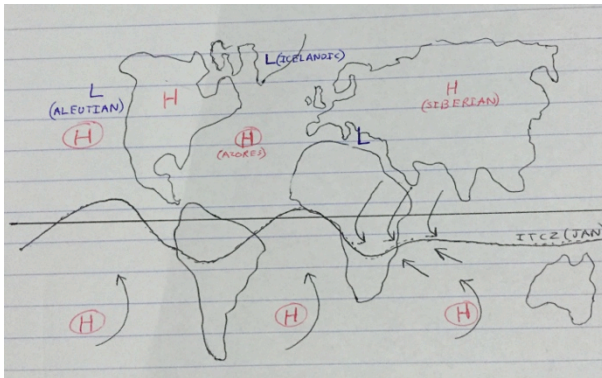
- The ITCZ is essentially the earth's heat equator.
- In **January**, the southern hemisphere receives the most heat and **the ITCZ is displaced south of the equator**.
 - Parts of the ITCZ remain north of the equator due to the high pressure south of the equator around the cold coasts.
 - This brings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



MET 21 - GLOBAL CLIMATOLOGY

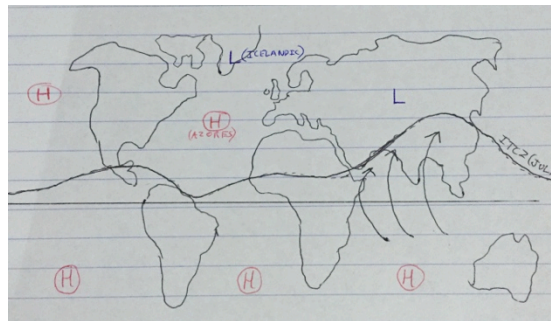
JANUARY PRESSURE SYSTEMS

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



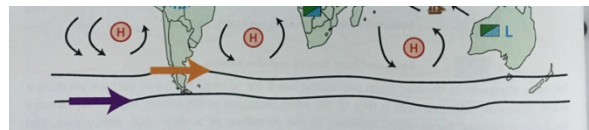
JULY PRESSURE SYSTEMS

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

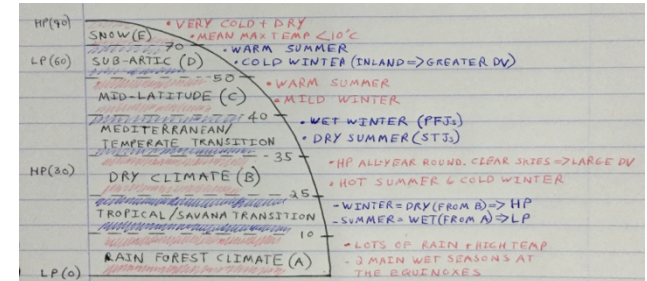


ROARING 40'S & HOWLING 50'S

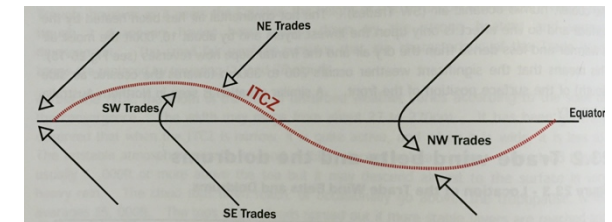
- Westerlies in the SH have very little land to impede their progress.



CLIMATIC ZONES (KOEPPEN CLASSIFICATION)



TRADE WIND VARIATIONS WITH ITCZ



MET 22 – TROPICAL CLIMATOLOGY

ITCZ

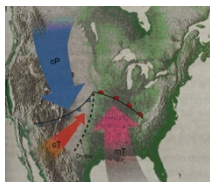
- Trade winds **converge** on the ITCZ
- Weak winds give rise to weak convergence
- There is more movement of the ITCZ over land than at sea.
- Instability is created where two air masses meet.
- High temperature, instability, convergence and heat give rise to **possible** TS up to the troposphere and beyond.

ITCZ CHARACTERISTICS

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

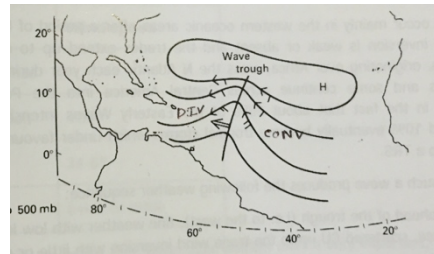
MESOSCALE CONVECTIVE COMPLEXES

- **Oval / circular collection of thunderstorms**
- Occurs over a **very large scale**
- May persist for **12 hours or more**
- **Slow moving**
- Occurs within the warm sector at the **dryline**
 - Where cTw and cTm air masses meet



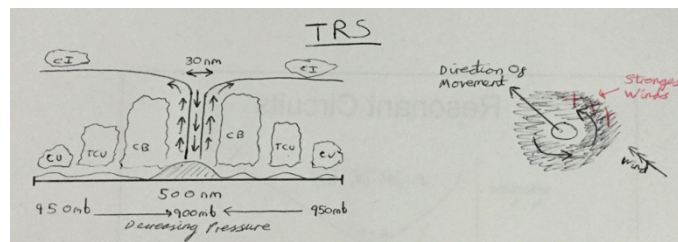
EASTERLY WAVES

- Troughs orientated N/S moving slowly in a westerly direction.
- Form over Africa and cross the North Atlantic on their way to America.
- On the east side, wx is poor due to convergence.
- On the west side, wx is fine due to divergence.
- **10% of these become a tropical disturbance**



TROPICAL DISTURBANCE

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



TROPICAL STORMS & TRS

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

TROPICAL REVOLVING STORMS

- Named depending on their geographic location.
- **Hurricanes (America) / Cyclones (Africa) or Typhoon (Asia)**
- **TRS Formation Requirements:**
 - Sea temperature of +27°C
 - Between 5° – 25° with a trigger action (usually convergence at the ITCZ)
 - Light wind with little shear at height
- **Typical Diameter – 500 m**
- **Typical Pressure – 900 to 960 mBar**
- **Wind Speeds - > 64 kts**
- **Normally Summer – Autumn in NH**
- **Normally Winter – Spring in SH**
- **Descending air in the eye clears the cloud.** It does not cause high pressure however as it is pulled back up by low pressure near surface.
- TRS dies out over land as the moisture supply is cut off.
- Low pressure causes **swelling of the sea.**
- **Cirrus canopy rotates clockwise** due to divergence at altitude.

MET 22 – TROPICAL CLIMATOLOGY

MONSOON DIRECTIONS

January Monsoons

Darwin

Asia
Dakar

July Monsoons

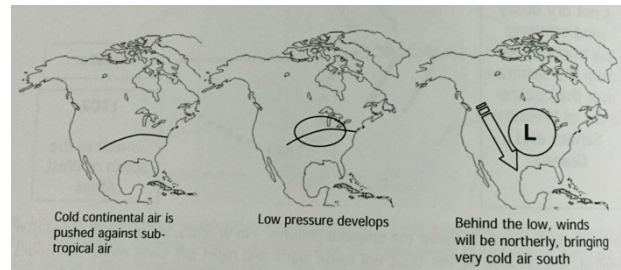
Asia
Dakar

Darwin

COLD AIR OUTBREAKS

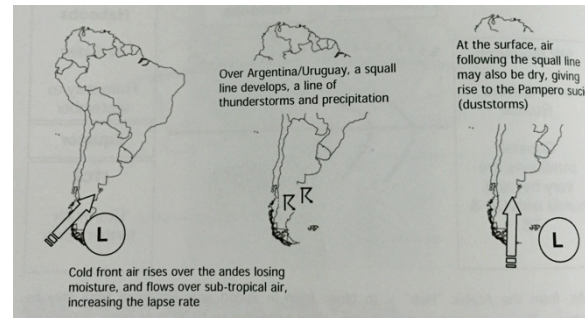
USA

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



PAMPERO

- Winter / Early Spring or Summer



DUST STORMS

DUST STORMS

- Results from the **lifting of dust / sand** due to:
 - Increasing wind speeds
 - Cold Fronts
 - Local surface heating
- **Sand is heavier than dust** so is not blown very high and settles quickly once the storm dissipates.
- **Dust lingers in the air for longer** as it is lighter.

MET 22 – TROPICAL CLIMATOLOGY

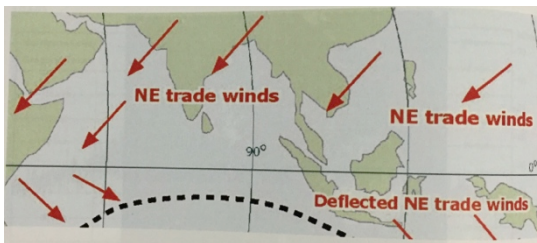
MONSOON WEATHER

MONSOON DEFINITION

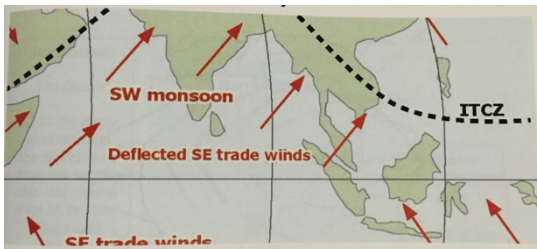
- Defines seasonal changes in weather when the wind changes direction by more than 120°
- Such a change occurs due to movement of the ITCZ between seasons and the associated change in trade winds.

ASIA

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

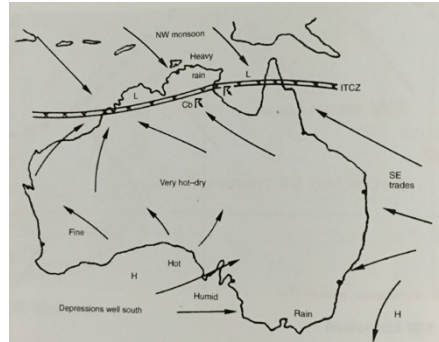


- **July = SW Monsoon**
 - Normally unstable with TS

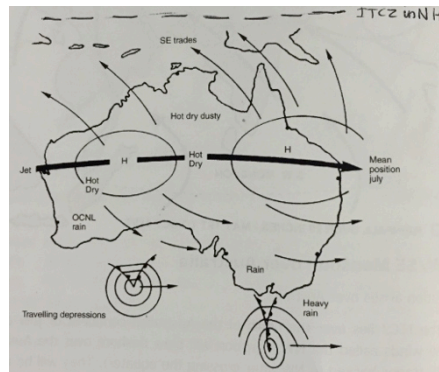


AUSTRALIA (DARWIN)

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

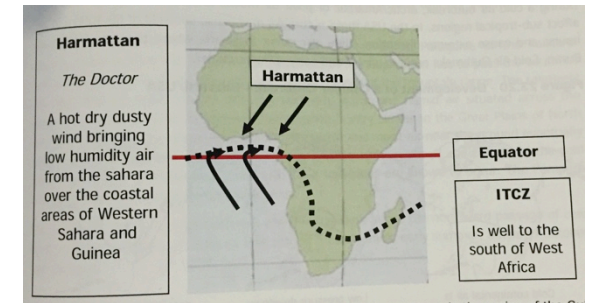


- **July = SE Monsoon (Hot, dry and dusty)**
 - ITCZ in NH and STJs over central Australia

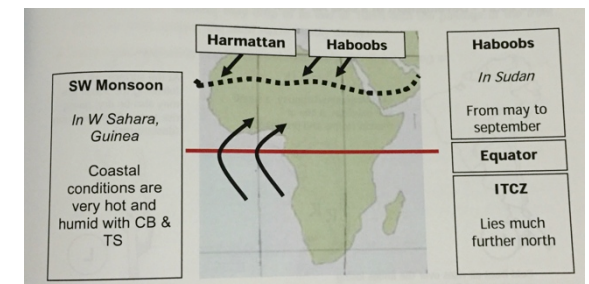


AFRICA (DAKAR)

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



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



MET 24 – MID LATITUDE CLIMATOLOGY

LOW PRESSURE

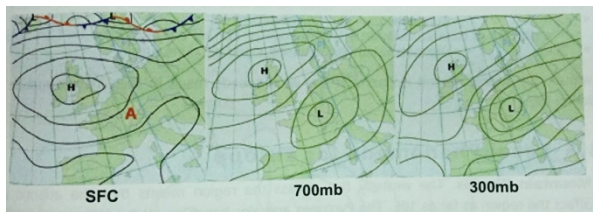
- PFDs hit Spain and the Mediterranean by winter but can route north of the UK in summer.

HIGH PRESSURE

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

COLD AIR POOLS

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

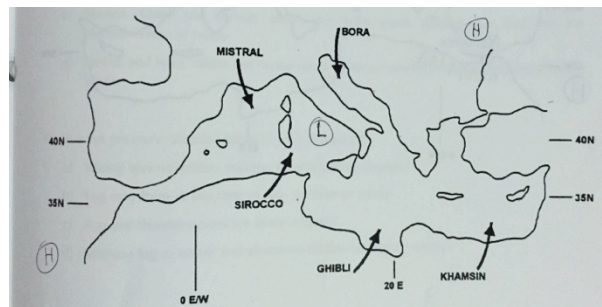


FLAT PRESSURE

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

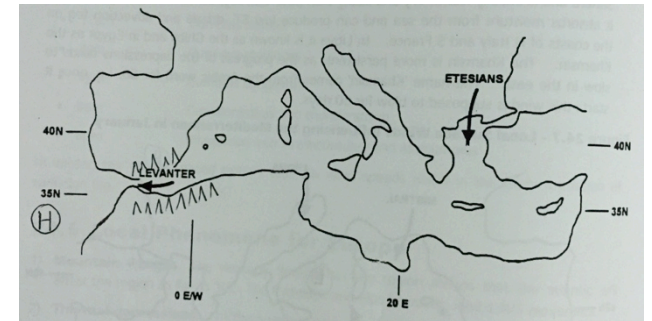
LOCAL SURFACE WINDS (WINTER)

- Mix of very cold unstable outflow from Siberian high and warm, dry and stable inflow from the Sahara.
- **Mistral** – Ravine Wind | Becomes Unstable
- **Bora** – Ravine Wind | Becomes Unstable
- **Sirocco / Ghibli / Khamsin** – Blows from North Africa | Dry, hot and stable



LOCAL SURFACE WINDS (SUMMER)

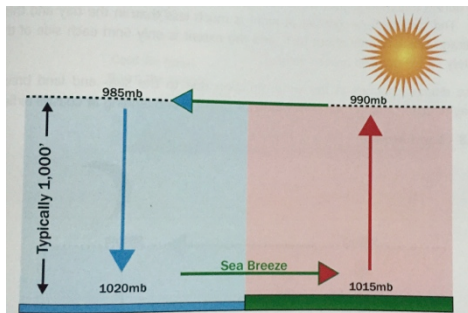
- **Etesians** – Relatively Cool
- **The Levanter** – Very Humid



MET 24 - LOCAL WINDS

SEA BREEZE

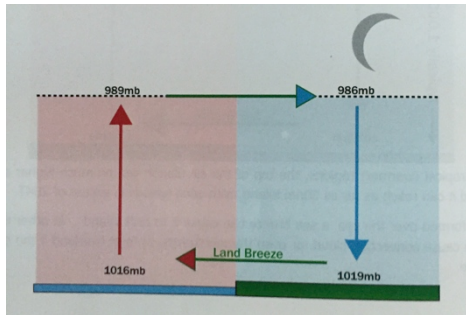
- Requires a **slack pressure gradient**
- Occurs **during the day**
- Surface heating results in land being warmer than sea.
- Pressure decreases at a lower rate within warm air compared with cold air.
- The pressure at approx. 1,000 ft is high over land and low over the sea in comparison.
- The **first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



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

LAND BREEZE

- Requires a **slack pressure gradient**
- Occurs **during the night**
- Surface cooling results in land being colder than sea.
- The **first horizontal movement of air from sea to land occurs at 1,000 ft**
- The resulting circulation pattern creates low pressure over the sea and high pressure over the land at the surface.
- Once the surface pressure differential exceeds the surface friction, a land breeze from land to sea now results at the surface.
- 5 kts** (Pressure gradient less at night)
- 5 nm** either side of coast

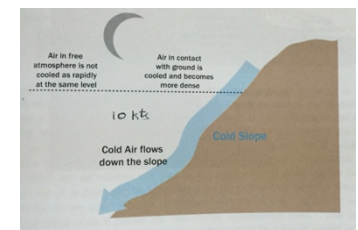
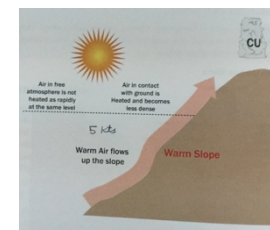


KATABATIC WIND

- Night / Early Morning (Bare Slopes)**
- Day / Night (Ice covered)**
- Most common on north facing slope (NH)**
- Slopes cool at night via **radiation**
- Air in contact cools by **conduction**, becomes more dense and **flows down the slope**.
- Rivers at the bottom of the valley add moisture resulting in **valley (mixing) fog**.
- Ice covered slopes are colder than surrounding air even during the day,
- Typically falls down at 10 kts**

ANABATIC WIND

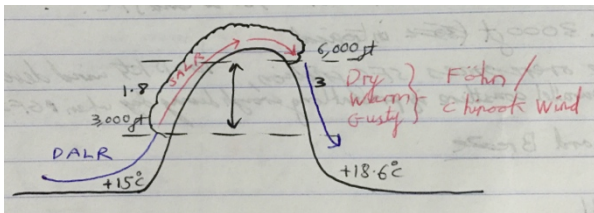
- During Day**
- South Facing Slopes (NH)**
- Slope is heated by insolation and air in contact with slope is heated by conduction.
- Air becomes less dense than surrounding air and **flows up the slope**.
- Lifting can result in Fair Wx CU at top of slope.
- Typically falls down at 5 kts** (gravity slows it)



MET 24 – LOCAL WINDS

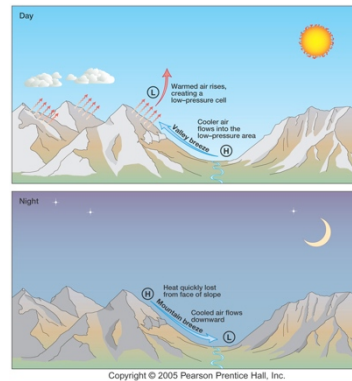
FOEHN WIND

- **Base higher on the lee side** due to loss of moisture from contact with surface on the windward side.
- In the 'gap' between the bases, the air on the windward side cools at the SALR whilst on the leeward side it warms at the DALR.
- The net effect is **warming on the lee side at 1.2°C / 1,000 (DALR – SALR)**
- The wind blowing down the leeside is **warm, dry and gusty**. Known as the **Foehn / Chinook Wind**
- In the example below, the temperature on the lee side is: $15 + (3 \times 1.2) = +18.6^{\circ}\text{C}$



VALLEY & MOUNTAINS WINDS

- **Valley Wind**
 - During day
 - Similar to a sea breeze
 - Heating results in an anabatic breeze
- **Mountain Wind**
 - During night
 - Similar to a land breeze
 - Cooling results in a katabatic breeze



VENTURI / RAVINE WIND

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

HEADLAND EFFECT

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

MET 26 – SATELLITE AND GROUND RADAR

PURPOSE

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

GEOSTATIONARY SATELLITES

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

POLAR-ORBITING SATELLITES

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

VISUAL IMAGERY

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

INFRARED

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

MSG – METEOSTAT SECOND GENERATION

- Higher resolution
- Colour imagery

GROUND RADAR

- **Higher transmitter power** available allows a **shorter wavelength** to be used.
- **Drizzle can also be picked up**
- Can be sent via **datalink** to aircraft
- **Beam Overshoot**
 - Radar is tilted up to prevent reflection
 - Low cloud further away from transmitter may not be picked up due to 'blind spot'
- **Beam Blocking**
 - High ground blocking line of sight
- **Beam Attenuation**
 - Similar to 'blind alley' with AWR
- **Virga**
 - Shows on radar but will not actually reach surface
- **Duct Propagation**
 - Inversion bends the radio beam and it paints the ground rather than the sky.

MET 27 – METARS AND TAFS

RVR

- Measured from a height of **2.5m AGL**
- Reported when prevailing vis < 1500 m
- Reports discontinued when vis > 2000 m
- P1500 = > 1500 m
- M0100 = < 100 m
- Trend based on 10 mins prior to issue
- D = Decreasing
- N = Constant
- U = Increasing

WIND REPORTING

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

VIS REPORTING

- **< 800 m** = Rounded down to nearest 50 m
- **800 – 5 km** = Rounded down to nearest 100 m
- **5 km +** = Rounded down to nearest 1 km
- **Directional vis** reported when less than 1500 m or 50% of the prevailing visibility

CLOUD BASE REPORTING (ROUNDING)

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

TREND INFORMATION

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

CAVOK

- No cloud below 5,000 ft or the highest MSA
- Vis 10 km +
- No CBs
- If there is no cloud below 5,000 ft / highest MSA but vis is less than 10 km, **NSW** is used and the vis is reported.
- No cloud at any level = **SKC (Sky Clear)**

“ODD” WX CODES

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

TURBULENCE & ICING

- 5 = Turbulence
- 6 = Icing

CONTAMINATION CODES

- First two numbers **indicate RWY**
 - 23 = RWY 23 L
 - 73 = RWY 23 R (+ 50)
 - 88 = All RWYs
 - 99 = Repetition
- Last two numbers indicate **braking action**
 - 91 = Poor
 - 92 = Poor / Medium
 - 93 = Medium
 - 94 = Medium / Good
 - 95 = Good
 - 99 = Unreliable
 - xx = Friction coefficient
 - // = Not reported

TEMPO

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

TAF VALIDITY

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

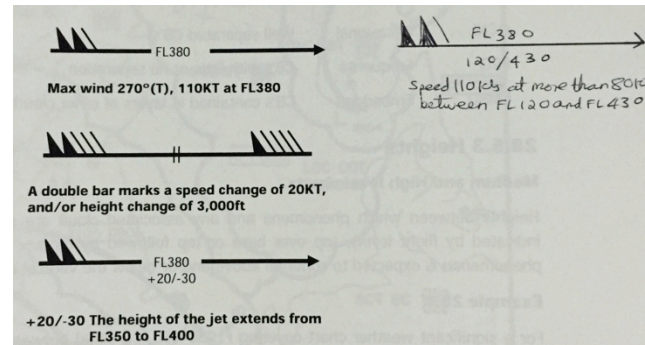
MET 28 - CHARTS

CHART TYPES

- Significant Weather
- Upper Wind & Temperature

FREQUENCY OF ISSUE

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



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

	Cold front at the surface		Position, speed and level of max. wind
	Warm front at the surface		Convergence line
	Occluded front at the surface		Freezing level
	Quasi-stationary front at the surface		Intertropical convergence zone
	Tropopause High		State of the sea
	Tropopause Low		Sea-surface temperature
	Tropopause Level		Widespread Strong surface wind *
Wind arrows indicate the maximum wind in jet and the flight level at which it occurs. Significant changes (speed of 20 knots or more, 3 000 ft less if practicable) in flight level are marked by the double bar. In the example, at the double bar the wind speed is 225 km/h (120 kt). The heavy line delineating the jet axis begins/ends at the points where a wind speed of 150 km/h (80 kt) is forecast. * This symbol refers to widespread surface wind speeds exceeding 60 km/h (30 kt).			