Meteorology

Tropopause/Troposphere

- Troposphere
  - Concerns aviators
- Tropopause
  - Mid-latitudes ISA: 11km & -56.5°C
  - Equator: 16km & -75°C
  - Tropical (area around equator) tropopause 54000ft
  - Separates troposphere with stratosphere
  - Lower in summer, higher in winter
  - Temp higher at poles
  - Temp lapse rate changes abruptly
  - Breaks: Core of jetstreams found here
  - Area where temp change does not **exceed 2/3** of **1°C/1000ft in altitude range of 6000ft**
  - Higher temperature of airmass = higher pressure & higher tropopause
- Stratosphere
  - Ozone contained
  - Layer absolutely stable
  - Lower part temperature constant
- Stratopause
  - 50km
- Determining Tropopause height with formula: **16km** (winter) or **18km** (Summer) **x cos latitude**

Temperature

- Insolation(Downward):
  - **Earth heating** from heat energy from the **sun**, partly absorbed by atmosphere, partly reflected by clouds mostly reaches surface
  - **Insolation max** at **noon**
  - Amount of heat depends on sun's **elevation** & **duration** of insolation.
  - Most significant warming is through **convection**(upward currents of air bringing heat) & **condensation**(release of latent heat) of air
  - Variation of solar energy at earth's surface is the **primary cause** of weather
- Terrestrial radiation(Upward):
  - Heat energy **from the earth** radiates to space/atmosphere/troposphere
  - The clouds blocks radiation from **slipping to space**(from surface) i.e. clear nights = colder
  - The main methods of heat transfer are through **formation of clouds** & **outgoing long wave radiation**.
- Inversion:
  - **Subsidence** inversion is caused by an old pressure system.
  - A **valley** inversion happens when **cool dense** air descends down valley slopes into basin.
  - Main cause of **terrestrial radiation** is a **cloud-free** night in **winter** when the ground is **dry**. In winter, the ground is colder than in summer, conduction cools the air above.
  - Found commonly in **stratosphere**
- Diurnal variation:
  - **Highest** temperature **2 hours after noon, lowest** temperature **half hour after sunrise.**
  - Highest diurnal variations: **Deserts.** Hot during day, cold at night.
  - Lowest diurnal variations: **Tropical** areas.
  - **Variation is highest** when **sky clear** & winds are **weak**.
  - Variation bigger over **larger land masses** compared to the sea/other regions
  - Wind **increases difference** in temperature between surface and 4ft (Mixing)
- Specific heat capacity:
  - Amount of **heat per unit mass required** to raise the temperature by 1°C, i.e. higher specific heat = takes more time to heat up
  - Water has **higher** specific heat than land
  - Grass less SH than concrete
  - Rocks very low SH
- Isotherms: Tropical = 16000ft, Temperate = 6000ft, Polar = 0ft

Pressure

- Amount of pressure decreasing with height, **lessens with height/smaller at higher levels/larger at lower layers**. E.g. MSL 27ft/hPa, 18000ft/5.5km 50ft/hPa
- Rate of pressure decrease with height is greater in cold air (More compact vertical isobars)
- QFF: Current pressure at aerodrome converted to **MSL & actual** conditions, used in weather charts
- Isobars: Lines of **equal pressure** reduced to sea level, lines of **equal QFF**, same **air pressure at given level**
- Isohypse: **True altitude** of a **pressure level**
- Contour heights: True **heights AMSL**
- "LOW": Area of low pressure compared to horizontal environments and "high" Vice versa
- SEE positive & negatives
  If height is ABOVE MSL (+) and Temp is > ISA (+) then QNH > QFF
  If height is BELOW MSL (-) and Temp is < ISA (-) then QNH > QFF
  If height is ABOVE MSL (+) and Temp is < ISA (-) then QFF > QNH
  If height is BELOW MSL (-) and Temp is > ISA (+) then QFF > QNH
  AT MSL QFF is always = QNH = QFF
- 5 triple 1, 2 triple 3 & 4. 876543221
- Change in height H = 96 x T ÷ P, (Temp decrease, pressure increase to make isobars closer together)

Density

- Inversely proportional to temperature
  Directly proportional to pressure
- There is lesser pressure & density in upper levels (Logic)
- Density = Pressure/constant x temperature
- Affected by altitude, temp & amount of water vapour
- High **density altitude** = low performance
- Density altitude: Altitude in **standard** atmosphere to which **observed density corresponds**

ICAO ISA

- Tropopause height: 36000ft, 11km, -56.5°C
- 1m = 3.28ft
- 1°C /2000ft & 0.65°C/100m

Altimetry

- Q-codes
  - QFE: (Height) = **Atmospheric pressure at the official aerodrome elevation**
  - QFF: QFE reduced to **MSL** according to **actual** conditions
  - QNH:
    1. Atmospheric pressure/QFE reduced to **MSL** using the **values of the standard temperature/standard temperature gradient**
    2. QNH = QFE + AD elevation in hPa
    3. Difference between QNH & QFE is **always the same**
    4. When airport is below MSL, QFE is always more than QNH
- TA: Transition altitude, altitude at which we refer vertical position in terms of altitude based on QNH
- TL: Transition level, lowest usable flight level
- ISA deviation negative = air is colder = true altitude less than indicated
- Always do pressure correction before temp correction then, determine if flying to lower or higher pressure
- 4% for every 10°C deviation always applied to **true altitude OR height above the elevation**
- 1 inch – 1000ft
- Pressure altimeter: Indicates altitude corresponding to **difference** between **reference pressure & the pressure where the instrument is**. The distance between **two isobaric surfaces** in the standard atmosphere
- Best conditions for flight level to clear all obstacles: Temp >/= ISA, QNH > 1013
- To find lowest usable flight level from a MSA, Get lowest QNH and highest negative temperature
- To assume whether air mass is colder or warmer: Look at either given pressure or temperature
- Temperature correction must be done using the height from the station where the altimeter starts measuring from

Wind

- Winds are created due to **temperature** difference e.g. surface heating. Strongest winds are between **two air masses**
- Cup anemometer measures **wind speed** at **8-10m** AGL
- Km/h **= (knots x 2) - 10%**
- Knots = **[(km/h) ÷ 2] + 10%**
- Veers: clockwise, backs: anticlockwise

Cause of winds:

Primary – Difference in TEMPERATURE

Horizontal pressure difference:

- **Geostrophic wind**:
  Parallel to **straight** **isobars**, **perpendicular/right angles** to & **balanced** with **PGF & CF,** Winds >2000ft **no friction**
  - Only exists above 15**°N/S**
  - Proportional to PGF
  - Inverse to CF (Earth's rotation)
  - Inverse to latitude, higher latitude = more CF, wind speed less
  - Inverse to density
  - NO CENTRIFUGAL FORCE
- **Gradient wind**:
  Parallel to **curved isobars** due to **surface friction, PGF, CF & centrifugal force**
  - **Decreases** with **increase of latitude**
  - Gradient wind is higher than geostrophic wind around a high. Centrifugal force added to PGF
  - Gradient wind is lower than geostrophic wind around a low. Centrifugal force opposes PGF
- **PGF**:
  Force **perpendicular** across isobar towards LOW
  - Proportional to pressure gradient
  - Inverse to density
  - PGF always acts from H to L pressure
- **Coriolis force/earth's rotation**:
  - CF deflects wind to the right in N hemisphere, left in S hemisphere
  - Prevents wind from flowing directly H to L
  - Northern hemisphere: CCW HI, CW LO
  - Southern hemisphere: CW HI, CCW LO
  - Coriolis force decreases with latitude
  - Coriolis force decreases with decreasing wind speed
  - **0 - 10°** N & S CF negligible
- **Surface winds:**
  <2000ft (**Friction layer**) deflected **due to coriolis force**, blows **across** isobar, **convergence** and deflection caused by **friction which decreases wind speed** & causes **direction change**
  - **Backing** northern hemisphere
  - **Veering** southern hemisphere
  - Land **50% 30°**, sea **70% 10°**
  - Friction layer:
    1. Stability of air
    2. Time of day: Strongest at mid-afternoon, weakest at night
    3. Wind speed: Thicker when higher
    4. Type of surface
- **Cyclones(Low):**
  - Convergence caused by frictional forces & **cyclonic** curvature of the isobars
- **Anticyclones(High)**:
  - At **same distance** between isobars, any latitude: $\mathbf{V_{Low} < V_{straight} < V_{High}}$
  - **Blocking/warm anticyclone** has inversion layer near surface which is colder than upper air, thus increased performance
  - **Warm anticyclone** over land in summer has **fine weather,** it **increases intensity** with **altitude**
- Errors: Isallobaric effect, when pressure is changing rapidly

- Diagram: Feathers point to lower pressure value

Local winds

Land & sea breeze:

- Due to **diurnal variations**, slack pressure gradient, higher land temperatures due to clear skies, pressure **at higher levels increasing**, **land surface cools & heats faster** than sea:
  - Wind sea to land during the day, **1000 – 3000ft** 10kts
  - Land to sea during the night, **1000ft** 5kts (Weaker)

Mountain winds

- Downslope/Mountain wind: Katabatic at night, (Kata –cold, gets warmer and dryer as it descends)
- Upslope/Valley wind: Anabatic during day

- Due to **venturi effect** when passing through valley there is a low pressure, causing a drop in static pressure and an apparent increase of indicated altitude, **actual altitude is lower**

Mountain/standing/lee waves

- Conditions for formation:
  - Wind speed more than 20kts, turbulence downwind side of range
  - Wind blows at right angles to the mountain range or within 30°
  - Wind speed increases with altitude up to tropopause but **does not change direction**
  - Stable atmosphere, less stable above and below/inversion just above the crest
- Creates altocumulus lenticularis (Lens), rotor & cap clouds. **Does not form when air is too dry**

Turbulence

- Associated with **inversions at low levels**, more **instability**, more turbulence
- Mechanical:
  - Due to **friction** & irregular ground surfaces
  - Strong wind & steep lapse rate, increase with wind speed
- Thermal/convective:
  - Vertical movement of air due to insolation(sun's radiation)
  - Convection & unstable airmass, highest early afternoon
- CAT: Around **jetstreams** & vicinity of **CB**, **strongly curved closely packed isohypses**

Jetstreams

- Formed due to **horizontal** temperature gradients
- Jetstream **core:**
  - In the **warm air side/warm air aloft** below the tropopause
  - At height where there is **no horizontal temperature gradient, no temp change** when **crossing** the core
  - Slope of the pressure surface at height of core is maximum
- **CAT**/windshear: Most severe in the **cold air side of a jetstream**, **below tropopause**
- Properties:
  - Length: 1000NM
  - Width: 150NM
  - Thickness: 18000ft
  - Height to width ratio = 1:100
  - Wind speed: >60kts
    a) Speed higher in winter and further south
    b) Highest at Japan in JULY
    c) Strongest in the area between a trough & a ridge
- Polar frontal jets:
  - FL 300 winter 350 summer
  - Use buy ballots law to determine cold or warm front
  - 50 - 100NM behind cold
  - 300 - 450NM ahead of warm
  - Moves along fronts north of depression, not across it, but cuts across occluded fronts
- Sub-tropical jets:
  - FL400/200hPa
  - Max wind speeds found in tropical air below tropopause
- Easterly/equatorial/tropical jets:
  - Only in summer northern hemisphere (June – August)

- FL450 - 500
- Visual indication: Long streaks of **cirrus clouds** on **equatorial side** of the jetstream

Humidity

- Water vapour
  - Contained in 0-5% of air
  - Water vapour 0 at poles25g/m^3 at equator
  - Air's ability to hold water vapour increases as **temperature** (**main factor**) increases also increases as **altitude decreases**
  - Water vapour **is constant**, only air's ability to hold water vapour change
- Mixing ratio = **Grams** of water vapour/**kg** of **dry air**
- Relative humidity:
  - Ratio between **actual mixing ratio/water vapour**(FIXED) & **saturation mixing ratio/water vapour**(varies) x 100
  - When air is **saturated/reaches dewpoint** relative humidity & water vapour content is constant at 100%
  - Relative humidity **decreases** as:
    1. **Air's ability to hold water increases**
    2. **When temperature increases**
    3. **When parcel of air descends**
    4. **Amount of water vapour decreases**
  - Relative humidity **increases** as:
    1. **Air's ability to hold water vapour decreases**
    2. **As temperature decreases**
    3. **As parcel of air ascends**
    4. **Amount of water vapour increases**
  - **Lowest** in **desert** areas in **summer/July** at latitude **30°N - 40°N**
- Dew point:
  - Actual water vapour content (Ambient) decreases to remain equal to the **saturated water vapour content (Dewpoint)**
  - When air is saturated & **cooled** further i.e. **temperature decrease/altitude increase** amount of **water vapour decreases** (Due to condensation)
  - Dewpoint constant, but after saturation/condensation if **temperature falls further**, **dew point reduces** (At the same rate)
- Evaporation increase as **temp increase** and as **pressure decrease**

Change of state

- Latent heat: Heat emitted which increases temperature of the air
- When air reaches **vaporization pressure** air is warmer due to release of latent heat
- Melting, freezing, sublimation, vaporization, condensation

Adiabatic

- Convection: Upward motion of air; subsidence downward motion of air
- As **air descends** and **evaporates,** rate of **heating** of SALR is lower than DALR, as **air compresses**; **heat is absorbed** during change of state (Evaporation)
- As **air ascends** and **condenses**, rate of **cooling** of SALR is lower than DALR as **air expands; heat is released** during change of state (Condensation). Also **modifies lapse rate** of parcel from **DALR to SALR,** moving it **vertically**
  - Air parcel ascended will stay level when it is the same temperature as environment
  - Temp of air parcel lower than environment = Air sinks as it has higher density = Stable
  - Temp of air parcel higher than environment = Air continues to rise = Unstable
  - After turbulent mixing, unsaturated air remains at DALR
  - Even ascending at isothermal layers, unsaturated air cools at DALR
- ELR = **2°C/1000ft** or **0.65°C/100m**
  SALR = **1.8°C/1000ft** or **0.6°C/100m**
  DALR = **3°C/1000ft** or **1°C/100m**
- Absolute stability: ELR < SALR < DALR
  Absolute instability: SALR < DALR < ELR
  Conditionally instable: SALR < ELR < DALR

Neutral stability: **ELR = DALR** for **dry** air, **ELR = SALR** for **moist** air

- OAT at an altitude = Temperature +/- (DALR x altitude)
  Wet bulb temperature at an altitude = Temperature +/- (SALR x altitude)
  Cloud base/condensation level = (Temperature – dewpoint) x 400
  DALR used for temp above surface to bottom of cloud
  SALR used when above bottom of cloud
- Unstable atmosphere: Good visibility between showers
- Cirrus clouds are where SALR & DALR are closest

Clouds

- There are 10 basic cloud types
- Clouds:

1. Stratus:
- Uniform base and uniform appearance
- Give drizzle or snow grains
- The outline is clear

2. Stratocumulus
- Patches, pebbles or rollers
- Clear of ground

3. Nimbostratus:
- Continuous falling rain or snow
- Grey often dark
- Reach the ground
- Block out the sun

4. Altostratus:
- Sheet or layer of strated fibrous, uniform appearance
- Doesn't show halo appearance
- Cloud thinner than NS
- Light precipitation

5. Altocumulus lenticularis: Indicates mountain waves
- Pebble or cylindric form
- Never touches the ground

6. Cirrus:
- White or white delicate filament or white filament
- Narrow band
- Fibrous hair like or silky sheen

7. Towering cumulus congestus
- Sprouting vertical extent
- Bulging upper part like a cauliflower
- Temperature in the cloud higher than ambient

8. Capillatus cumulonimbus:
- Anvil, plume, vast, mass of hair
- Shower or thunderstorm &squalls
- Hail, Virgo

9. Castellanus cumulonimbus:
- Turrets
- Taller than they are wide
- Seem to be arranged in line

- Heights:
  Low: 0 – 6500ft
  Medium: 6500 – 23000ft
  High: 16500 – 45000ft
- Stratus: Stratified clouds indicate stability
  - Formed via radiation during the night from the earth surface in moderate wind
  - Formed via turbulence when in the friction layer mixing occurs due to turbulence & condensation level is above top of turbulent layer
  - Dissipated through insolation (As temperature increases due to sun’s heat), which lifts condensation levels\

- Temperature nearly **similar to surroundings**
- Cumulus:
  - Indicates up & downdraughts
  - Top of clouds are limited **due to inversion**
  - Large water drops, instability, turbulence, showers & **clear** ice
  - Fair weather cumulus: Heating of land surface by day in a stable atmosphere, indicates **turbulence at and below cloud level**
  - Temperature **higher than surroundings**, warm air rapidly rising to cooler air above
- Turbulence cloud is created as a result of mixing from turbulence
- Orographic clouds: Air forced up a mountain reaches dew point with height, creating clouds
- Polar maritime air **at night** moving over northwest Europe decreases cloud amount (No convection) and lowers cloud base (Cloud base formula)
- Cirrostratus gives HALO
- Advection can form fog (advection fog) & clouds (warm/cold fronts)

Fog
- Radiation fog: Vertical
  - **Only on land**, after sunrise
  - Clear sky for terrestrial radiation, heat loss from the ground on clear nights
  - High humidity, high pressure areas with calm very light winds **<u><5kts</u>**
  - Dissipates and forms stratus with increasing wind speed & insolation
  - Up to **500ft**
- Advection fog: Horizontal
  - Ground cooling due to radiation
  - Cold surface: Temp of surface lower than air moving over it
  - Wind speed up to 20kts sea & 15kts over land
  - Humid air, clears by changing air mass
  - Cold sea current e.g. Labrador, during **spring** in Newfoundland
  - Warm air moves over cold land, crating fog, winds get stronger and mixing of the air creates stratus, which are turbulence clouds
- Steam/artic fog
  - Cold air mass moving over warm water surface
  - No wind
- Orographic/hill fog:
  - Day/night fog
  - Air forced **upslope or downslope** katabatic wind flowing down a valley cools till dew point
  - High relative humidity air forced up a hill/mountain
  - Dissipates with a change of airflow direction
- Frontal fog:
  - Due to **evaporation** & **condensation** of warm falling precipitation into cold moist layer ahead of **warm front**
  - Very **humid warm air** meets very **humid cold air**
  - Condensation of air saturated by evaporation of precipitation
  - Forms at day/night in a narrow band where frontal surface meets the ground
  - Dissipates after passage
- Visibility
  - Fog: <1000m
  - Mist: ≥1000m but <5000m
  - Haze: Smoke/Dust/Sand ≤5000m
- Other fogs
  - Shallow fog depth: 2m land & 10m water
  - Freezing fog: Supercooled water droplets
- Dissipation of fog/lifting to low stratus:
  - Surface heating
  - Wind speed increasing

Development of precipitation

- Bergeron-Findeison(Ice crystal) process:
  - Saturation **vapour pressure** over **water** is **greater than on ice**
  - Takes place in clouds with only **ice crystals** & **supercooled water droplets** which warms and falls as rain
  - At high levels in a cloud some water droplets turn to ice & grow by sublimation
  - Happens in **mixed phased clouds**
- Coalescence
  - Merging of two or more water droplets, when droplets get to large they fall as rain
  - At **mid latitude** this process **only produces drizzle**
  - Upward currents increase growth rate of precipitation due to collision of water droplets
- Conditions for freezing rain:
  - Surface temperature <0°C
  - Temperature inversions with warm air aloft falling into air below 0°C
  - Ahead of warm fronts or occlusions with continuous precipitation

Precipitation types

- Light, moderate or heavy
- Drizzle:
  - 0.2 – 0.5mm small water droplets
  - Falls from clouds only containing water such as ST/SC
- CB clouds, convective clouds:
  - Hail/grail (GR): In continental regions in mid-latitudes, large hail associated with severe thunderstorms
  - Rain showers, hail showers
- Ice pellets: **Frozen precipitation**
  - Translucent/transparent freezing of raindrops bouncing of surfaces <5mm
  - Indicates freezing **rain at higher levels**
- Freezing rain/supercooled water droplets:
  - Liquid form, forms in clouds, fog precipitation
  - Small droplets: Rime ice, freeze immediately
  - Large droplets: Clear ice, Partially freeze on impact, remaining part flows back along surface & freeze
- Snow grains:
  - < 1mm white opaque
  - Falls from stratus or supercooled fog
- Snow: Biggest impact on visibility
- Virga: Streaks of precipitation, water or ice particles evaporating before reaching the ground
- After a rain shower passes an airfield, **air temperature drops and dew point rises**, as **cold air from above reaches ground & humidity content rises**

Air masses

- It is an extensive body of air within which the temperature
- Properties obtained from pressure system & characteristics of source
- Polar continental air has lowest temperatures
- Tropical continental air originates from Balkans, near east & Siberian landmass
- Europe:
  - Western: Polar & tropical maritime
  - Northern/Scandinavia: Polar maritime & polar continental
  - South/Mediterranean: Tropical maritime & tropical continental
- Cold air mass:
  - **Unstable** giving showers
  - Gusty winds & good visibility
- Warm air mass:
  - **Stable,** cooling from below
  - Continuous rain & poor visibility
- Warm sector:
  - Visibility 5 – 10km

Fronts:

- Basic facts:
  - Interval between frontal waves: 1 - 2 days
  - Summer: NE Canada Newfoundland to N Scotland
  - Winter: Florida to SW England
  - Upper winds blowing across fronts make it move faster
  - Direction of frontal depressions are in the direction of warm sector isobars
  - Surface winds veer & upper winds back
  - Transition zone between two air masses creates a frontal low pressure
  - **Generally** caused by temperature contrast between artic air & equatorial air
  - Wind directions: Behind cold: NW, In front of cold : W, in front of warm: South, North of centre of low: East
- Warm front:
  - Risk of fog greater ahead & behind compared to cold front
  - CI announce arrival, Halo effect
  - 1:100 – 150
  - TS forms when **warm air is unstable**
  - FZRA in just in front of surface position of warm front may cause clear ice accretion
  - Surface position may have windshear
  - Velocity: 2/3 speed of measured distance between isobars
  - Stratus/cumulus fractus clouds exists in warm or cold front
  - Reason for very low clouds ahead of warm front:
    1. Saturation of cold air by rain falling into it & evaporating
    2. Rain drags warm air into cold air and condenses it
  - Pressure
    1. Before: Decrease
    2. At passage: At lowest point
    3. After: Steady increase/slight rise then falls
- Cold front:
  - Mainly towering clouds
  - Wind **veers**(To the right with a headwind) & increase with height with in N hemisphere
  - 1:10 – 80
  - Surface position may have windshear
  - Behind cold front mostly scattered cloud cover & isolated showers
  - Strengthens when approaching upwind of a mountain
  - Pressure
    1. Before: Decrease (**Pressure decrease** indicates a **climb on altimeter**)
    2. At passage: Falls then **increase**
    3. After: Steady increase
- Occluded warm:
  - Warmer air behind front
  - On surface charts **extension of warm front**
  - Usually in **winter**
  - Ahead of warm occlusion: Low level ST clouds
- Occluded cold:
  - Colder air behind front
  - On surface charts **extension of cold front**
  - Usually in **summer**
- Stationary front:
  - **No** horizontal **motion perpendicular** to front
  - Surface wind **parallel** to front
- Warm sector:
  - Tropical air
  - Moderate to good visibility, haze & few or scattered cumulus, drizzle, **no high level clouds**
  - Poor visibility at lower levels possible advection fog, mist & drizzle
  - **Summer:** Fair weather CU
  - **Winter:** ST & SC broken to overcast, poor visibility in mist & drizzle
  - Generally stable VMC conditions above ST & SC clouds

Pressure systems:

Main lows:

- Winter: Iceland/Greenland
- Summer: North Canada

Main anticyclones:

- Winter: Azores, Siberia, Canada, South Pacific
- Summer: Azores, SE USA, SW Europe
- Sub-tropical highs exist on 30°N

Anticyclones:

- Principle of divergence(At surface) & subsidence(Sinking), as air sinks it is heated by compression, sinking dry air and producing inversions, fog and low ST
- Stable layer at an old high pressure system creates **dry air** and a **subsidence inversion**
- Cold high pressure:
    1. Decrease in intensity with increase of altitude
    2. May weaken at altitude & change to low pressure
- Calm winds & haze
- Blocking anti-cyclone: Quasi stationary, **warm anticyclone**, converts normal W –E movements to meridional
- **Cold temporary anti-cyclone**: Found between **two frontal depressions**

Thermal & dynamic depressions/lows:

- Low pressure areas:Convergence with lifting air mass
- Thermal warm low pressure areas:
    - Surface of the earth is warmer than the air over land in summer, **may occur on water** in winter
    - Temperature rise in an area in relation to the environment
    - Weakens with increase in height and may turn into a high
- Dynamic cold low pressure area:
    - Low strengthens when temperature difference increase in winter, increase with increase in height
    - Air centre of low pressure area colder than surroundings, example Icelandic low
- Polar/instability lows:
    - Cold polar/artic air moving SE over warmer seas, forming only at sea in winter
    - Low pressure receiving energy from released condensation heat
    - Short wave disturbances along the polar front
- Secondary depressions/lows:
    - Moves **anticlockwise/cyclonic** around the main in N hemisphere
    - Formed at **cold fronts**

Tropical revolving storms

- Caused via latent heat released from condensing water vapour, main source of energy
- Occurs in **<u>late summer</u>** or early autumn and decays upon reaching landmass
- Diameter of the eye: **10 – 20NM**, Diameter of whole TRS: **270NM, DENSE CI** indicates TRS
- Has the highest cloud tops among other weather phenomena
- Most dangerous zone in TRS: Wall of clouds around the eye, greatest wind speeds
- The eye: Extends from surface to top/troposphere, air is <63 knots & descending, **warmer** than surroundings
- Most dangerous TRS: South China Sea & Philippines
- Most frequent TRS are typhoons: North West Pacific, Japan, China & Taiwan
- Disturbance, depression, storm, severe storm, revolving storm
- TRS forms on western part of tropical oceans as **trade winds** bring humidity as it blows along sea passage
- Cyclones form at: Caribbean sea, Gulf of Bengal & Indian ocean east of Madagascar
- Cyclones do not form at the South Atlantic or South Pacific ocean because of low water temperature
- Hurricanes in North Atlantic:
    - Eye can be observed by satellites
    - Move parallel & away from equator
    - Speed >64 knots
    - Caribbean area, moves west and turns north east, towards US SE coast
    - To form: Surface temperature > 27°C, 5 - 15° away from the equator

- Locations:
  - East Darwin: 2
  - West Darwin: 5
  - Atlantic: 6
  - Philippines: 9
  - Bay of Bengal: 12
- Time of year
  - Hurricane: US=JUNO
  - Typhoon: SE-ASIA=JUNO
  - Cyclones:
    - ARABIAN SEA=MANOV
    - BAY OF BENGAL=JUNO
    - AFRICA(South of Indian ocean)=DECAP
    - PACIFIC=DECAP
    - DARWIN=DECAP

Climate zones:

- Zones Poles to equator:
  1) Polar high: Mean temperature of all months below +10°C, high pressure weather dominates with the sub-soil being frozen
  2) Disturbed temperate low (40° – 60°) for coastal areas: **Chilly summers** & **warm winters.** Weather systems mainly from travelling frontal depressions
  3) Sub-tropical high (20° - 40°)
  4) Tropical transitional (Trade winds)
  5) Equatorial convergence zone (ITCZ): Moves N in Summer (June/July/Aug), S in Winter (Dec/Jan/Feb)
- Seasons occur & exist due to the earth's spin axis inclined to the plane of its orbit around the sun
- Mid-latitude climate: Central Europe
- Mediterranean climate: Anti-cyclonic & hot in summer, frontal depressions in winter, annual rainfall <700mm
- Savannah climate: Variations in rainfall with a wet & dry period
- Tropical rain climate: 10°N - 10°S, humidity 80%, Isotherm 15000ft, average temp 28°C

Tropical climatology:

- Darwin: During July: Dry season, poor visibility of dust & haze
- Monsoons:
  - In summer of N hemisphere (July), S hemisphere experiences SE monsoon and after passing equator it becomes SW monsoon in N hemisphere
  - In winter of N hemisphere (January), N hemisphere experiences NE monsoon and after passing equator it becomes NW monsoon in S hemisphere
- Easterly wave:
  - Travelling east to west
  - It is a wave in the trade wind belt with severe convective weather rear of its trough
  - Originates from trade wind belt between sub-tropical high belt & ITCZ
  - Thunderstorms mostly develop on the east side of the wave
  - It is a **weak trough**
- Equatorial region: Rain, hail showers and thunderstorms occur all year, most frequent April – May & October – November (Spring/autumn)
- ITCZ:
  - Characterized by different wind directions on both sides of the zone
  - Moves more over land
  - In summer 10° - 25°N in west Africa & northern coasts of Arabian sea (Typical mean location: 20°N over west Africa), 40°N in China
  - In summer around 20°N over Asia & Northern Africa, light easterly upper winds occur
  - Does not move much over the oceans, thus, central Atlantic ocean only has NE trade winds
  - Freezing level isotherm: 15000ft(12000 -16000ft), **icing** occurs around 16000 – 28500ft
  - Areas on the geographical equator experience 2 wet seasons, Mar-May, Oct-Nov (Spring & autumn)
  - ITCZ position 0 - 7°N in January between Dakar & Rio, in vicinity of Dakar in July

- Trade winds:
  - Originates from sub-tropical high & moves towards ITCZ
  - Blows between horse latitude & doldrums
  - Occurs on **lower** part of troposphere & more pronounced over the oceans than the continents, upper limit up to <u>FL100</u>
  - Lower part is relatively moist & upper part is dry
  - Causes light easterlies in upper levels in the summer NH
- Doldrums: Weak ITCZ
- Horse latitudes: Sub tropical highs e.g. Azores, usually dry & clear
- Pamperos: Advance of cold air in South America

Mid-latitude climatology:

- Westerly waves/westerlies: Occur at 40 - 60°N mid-latitudes, weather conditions are very changeable
- Cold air pools:
  - Occurs anytime, found at upper levels 16000 – 30000ft
  - Can only be identified via isohypses on upper level air charts, not surface charts
  - Identified as a low pressure area aloft in a high level upper air chart
  - Air is colder & denser than surroundings
  - Direction & speed difficult to forecast
  - Weather activity most during afternoon

In winter
  - Stable atmosphere, low visibility,
  - Flying away from it **performance reduces**
  - Low visibility at the surface

In summer
  - Instability
  - Low pressure characteristics
  - Dominant precipitation **if not** showers & thunderstorms
- Omega situation is a high pressure between two low pressure area, looks like an omega & causes **long term** fine weather
- Flat pressure pattern in the summer: Generally fine weather with thunderstorms in the afternoon/evening
- Roaring forties 40 - 50°S: Faster than westerlies in the northern hemisphere

Local winds & associated weather:

- Foehn(Alps)/Chinook(Rocky Mountains):
  - If wind from the south, no precipitation on the north
  - Warm dry air descending at the leeward of the alps, **warm katabatic** wind
  - Moisture loss during precipitation when air forced up windward side, clouds on windward side
  - Air rising on windward side at SALR & descends on leeward side at DALR
  - Turbulence on leeward side, higher temperatures & good visibility
  - Occurs when there is a low in Mediterranean
- Bora: Cold katabatic wind blowing from the Balkans to the Adriatic, possibility of violent gusts
- Mistral: Northerly cold wind blowing from France to Mediterranean sea
- Pamperos: Cold wind from Antarctica flowing over South America
- Harmattan: Dust & sand from Sahara blows over North West Africa in winter up to 15000ft
- Sirocco: Southerly dust & sand blowing from Africa to Mediterranean sea reaching Europe, low pressures over Mediterranean

Icing:

- Icing causes stall speed to increase, stalling angle to lower
- Change of course/altitude **desirable** = Moderate, Change of course/altitude or divert **immediately** = Severe
- SCWD: Found any time of the year
- **Stratocumulus** clouds 0°C near the surface risks of **severe icing** in upper parts where there is accumulation
- **Alto**cumulus & **alto**stratus clouds create light to moderate icing when not subjected to orographic lifting

- Icing factors:
  - Water droplet size: Large or small SCWD
  - Aerofoil shape: Sharp & thin edges/profiles = more ice
  - Probability for **airframe icing** when airframe is below 0°C above freezing level
- Clear ice/glaze:
  - **Visible moisture**
  - Large SCWD (**FZRA/RAIN ICE**)
  - Heavy & difficult to remove
- Rime ice
  - Small SCWD (**FZDZ/FZFG**), fog droplets are supercooled
  - Milky, granular, white, rough & powdery
- Hoar frost
  - Thin white crystal like deposits that forms in clear air
  - Aircraft surface below 0°C descending to warm moist air
  - Negative effect on lift
  - Temp of the surface is lower than the dew point of the air, and this dew point is less than 0°C
  - Water vapour turning directly into ice crystals on aircraft surface
  - Forms on the ground after an **inversion** & clear sky
- Icing due to orographic lifting:
  - Ascent of air **releases more water** (SCWD), which is **retained** in the cloud by the increased **upward** effect
- Carburettor icing
  - In clear air, forms on the venturi: butterfly valve or throat
  - Especially at low power/**descent** settings when valve nearly closed creating significant pressure/temp drop
  - As carb heat is on, hot air is fed to the venturi & performance drops as hot air is less dense, ice melts & RPM drops. After melting it should increase again
  - At low OAT to dew point spread

Subject	Clear	Rime	Mixed	Others
CU/CB/Thunderstorms	0°C to - 23°C	-10°C to 30°C (Top)	-17°C to -23°C	-
NS	0°C to - 10°C	-7°C to -13°C	-7°C to -13°C	-
ST/SC/AS	-	0°C to -15°C	-	-
Hoar frost on airframe	-	-	-	-15°C
Carburettor	-	-	-	RH>30%, Min -5°C Max 30°C

Turbulence & wind shear:

- CAT:
  - Avoided by changing flight level, usually descend as reported jetstreams have a thick layer
  - When experienced: Maintain wings & control pitch smoothly, decrease speed/climb/descend above zone
- CAT Levels
  - Moderate: Moderate altitude/attitude changes, small variations in airspeed strain on seat belts, unsecured objects dislodged, walking difficult but aircraft **remains in positive control** at all times
  - Severe: Abrupt altitude/attitude changes, aircraft out of control short periods, accelerometer > 1g, loose objects **tossed** about, can cause damage, unpleasant
- Windshear:
  - Expressed in **kt/100ft**
  - A vertical/horizontal wind velocity/direction variation over a **short** distance & limited period of time
  - Is a type of CAT that is proportional to intensity of the windshear
  - Low level temperature **inversions**, is greatest at the top of a marked surface based inversion, associated with radiation inversions
  - **Vertical** windshear: Vertical variation in horizontal wind, change of horizontal wind direction/speed with height
- Effect of windshear/gust on aircraft:
  - Tailwind increase: Airspeed decreases, as a result low airspeed = lift decreases and rate of descent increases
  - Headwind increase: Airspeed increases, as a result high airspeed = lift increases and rate of descent decreases
- Intensity
  - Light = <4 kts/100ft
  - Moderate = 4 - 8 kts/100ft

- Strong = 8 - 12 kts/100ft
- Severe = >12 kts/100ft

Thunderstorms:

- Lasts typically 2 hours, max height of CB = 20km, hail from ground up to FL450
- AC Castellanus indicates upper level instability & possible thunderstorms, precedes thunderstorms
- Most probable severe thunderstorm occurs when cold maritime air advects over warm sea surface
- Conditions for formation:
  1) Unstable air/conditional instability: ELR higher than SALR through a great vertical extent
  2) Humidity: High relative humidity
  3) Lifting action(Trigger): Initial lifting process
     - Convection
     - Advection
     - Frontal uplift
     - Orographic uplift
     - Convergence of air associated with low pressures
     - Intense **insolation** of a COL or weak low
- Stages:
  1) Initial:
     - 15-20 mins
     - Only updraughts
  2) Mature:
     - Greatest intensity, updraughts & downdraughts, rotor clouds
     - 20 – 30 mins
     - Below -23°C icing still possible
     - Start of stage marked with start of precipitation
  3) Dissipating:
     - Well-developed anvil can be seen, only downdraughts
     - 30 mins – 3 hours
- Lightning:
  - When flying through electrically charged air the aircraft in itself may carry charge & trigger lightning discharge
  - When lightning strikes the aircraft is temporarily part of the trajectory
  - Stormscope: On board instrument to measure **electrical discharge**
  - Example: St Elmo's Fire
  - Leads to disorientation, temporary difficulty in determining attitude of flight
  - If aircraft was made of composites, severe damage occurs, crew may be blinded & temporarily lose hearing
- Radar reflection reflectivity:
  - Increases with severity & frequency of turbulence,
  - A function of number & size of water droplets in a given unit of volume
- Air mass & frontal thunderstorms:
  - Main thunderstorms, most frequent in tropical areas
- Air mass thunderstorms:
  - Isolated & develops in the afternoon over land in summer,
  - Due to convection/thermal triggering,
  - Most **difficult to forecast or detect**
- Frontal thunderstorms:
  - Most difficult to avoid
  - Most fastest moving
  - Formed due to **rising air in falling pressure** at air mass **boundaries**
  - Warm front thunderstorm: When **warm** air is moist & ELR > SALR
- Single cell thunderstorm:
  - Moves according to 700 hPa winds
- Squall line thunderstorms:
  - Most destructive
  - Band/line of thunderstorms ahead of cold front
- **Supercell** thunderstorms:
  - Requires **lots of moisture & wind vector change aloft**

- TS/CB avoidance criteria:
  - 5000ft vertical separation
  - 10NM without AWR, best to avoid but when necessary fly through the sides

  Thunderstorm cells:
  - 5NM GND – FL200
  - 10NM FL200 – 250
  - 15NM FL250 – 300
  - 20NM Above FL300
  - Avoid flying under "Anvil" due to hail, lightning & severe turbulence
- Microburst: Downdraught high speed **lower** temperature **4km in 5 mins**, Typical – 50 knots, max – 100 knots
  Macroburst: More than 4km, great change over a large area
- Gust front:
  - Descending **cold air** undercutting warmer inflowing air

Tornadoes

- Diameter: 100 to 150 metres
- Associated with CB clouds
- Wind speeds over 200 knots
- Movement speed 20 – 40 knots
- Most likely occurs in spring & summer
- West African Tornado (WAT): **Squall line** created by **atmospheric waves**
- Life span up to 30 mins

Inversions

- Low level temperature inversions formed due to radiation cooling on clear nights, promotes windshear
- Above inversion layer: Better visibility, reduced performance due to warmer air, stronger veering & wind speed increase
- Valley inversion: Radiation cooling + gravity

Mountain waves

- Best time to fly over alps in summer on a hot day: Morning
- Conditions:
  - Stable air, speed >25 kts blowing **across** ridge
- Indicates strong wind & turbulence, may be accompanied by rotor/roll clouds or **ragged altocumulus lenticularis**
- Rotors:
  - Upper part of wind flows in the same direction as wind, lower part in opposite direction
  - Exists on leeward side
  - A **low-level** phenomenon
  - Standing waves exist in vicinity of roll cloud or rotor zone beneath first wave
  - CAP clouds, seem harmless but brings downdraughts 5000ft/min
- Flight headwind towards high ground (Towards leeward side of mountain) is more hazardous than tailwind toward high ground (Approaching from windward side of mountain)
- Clouds pushed up a mountain contain moderate to severe **mixed ice**
- Out of phase with waves are nonsense

Visibility

- Depends on **type of precipitation** and **intensity**
- Rank:
  - Blowing snow: 1 – 50m
  - Tropical downpour: Tens of metres
  - Heavy snow showers: 100m
  - Heavy snowfall: 50 – 200m
  - Drizzle: 500 – 300m
  - Fog: < 1000m
  - Heavy rain: < 1000m
  - Moderate snow: 1000m

- Mist: >1000m but <5000m
- Moderate rain: 3000 – 5000m
- Haze: <5000m

- Visible moisture:
  - Cloud
  - Fog
  - Mist
  - Spray
  - Precipitation
- Solid particles:
  - Atmospheric pollution
  - Dust
  - Sand
  - Volcanic ash
- Haze: Formed due to solid particles, during sunset , sun is at a low position deteriorating conditions more
- Unstable air: Showers of rain or snow
- Low level inversions: Traps dust, smoke or other solid particles which makes moderate to poor visibility as there is no vertical exchange

Observations:

- AWR:
  - Shows on plan position indicator the areas of precipitation of rain snow/or and hail
  - Accurate assessment of weather ahead may be hampered by attenuation of the radar echoes by heavy rain
  - Best way in dealing with thunderstorms in a cold front: Avoiding embedded CBs using AWR
  - Clear areas indicates no echoes being received, however radar provides no assurance of being in VMC in this area
- Most significant clouds: CBs & TCU
- Atmospheric pressure: Mercury/aneroid barometer, recorded on a barograph
- Humidity:
  - Hygrometer
  - Psychrometer: Compares dry bulb temperature with lowest temperature to which air is cooled by evaporation of water
  - Dry & wet bulb thermometer
- Surface temperature: Height of **2m,** measures maximum, minimum, dry & wet bulb temperatures
- Temperature & humidity aloft: Radiosondes
- Radiosondes:
  - An instrument measuring meteorological variables provided with radio transmitter for sending to observation station
  - Measures direct or indirect parameters e.g. winds **indirect**, air temp, pressure & humidity direct
- Surface wind measurement: Mast **10m** above runway by cup anemometer connected to electrical anemograph
- Gust: When wind deviates more than 10 knots of mean value, occurs less than a minute over a **short distance**
- Squall: Sudden increase of wind speed at least 16 knots lasting for at least 1 minute
- Horizontal visibility:
  - Determined by observer by means of marks/lights at known distances
  - Meteorological visibility on ground, used for VFR flight planning by MET office
- Vertical visibility:
  - Used whenever the sky is obscured by fog or heavy precipitation & the height of the cloud base cannot be measured
- Flight visibility: Average visibility as seen from the cockpit
- Runway visual range (RVR):
  - Length of runway a pilot would see when on the threshold
  - Visibility of RVR is generally greater than MET visibility
  - Determined by the use of **forward scatter meters or transmissometers**
  - Used when visibility decreases below 1500m
  - P: Plenty – Greater than
  - M: Minor – Lower than

- D: Down – Decreasing
- U: Up - Increasing
- N: Neutral – No change
- V: Variable – Changing every minute
- RVR represented on METAR is value **representative of the touch down zone** (TDZ)

- Cloud coverage:
  - SKC: 0
  - FEW: 1 -2
  - SCT: 3 - 4
  - BKN: 5 - 7
  - OVC: 8
- Cloud ceiling: Lowest cloud layer that covers **half the sky** below **20000ft**
- Cloud base: Reported in steps of 100ft up to **10000ft** & 1000ft above 10000ft
- Routine air report (AIREP)
  - Routine automatic report on weather conditions in flight
  - Air reports should be reported as soon as practicable
- Special air report (PIREP)
  - Section 1: Position report: Aircraft ident, height, position & time
  - Section 3: Meteorological information
  - May trigger a SIGMET message
- Satellites:
  - Used to locate fronts in areas with few observation stations
  - Pictures from polar orbiting satellites have better resolutions
  - Polar orbiting satellites, used to detect fog & cloud are closer to earth than geostationary satellites
  - To locate areas of fog, VIS & IR settings with polar orbiting satellites are used
- Sources of meteorological information:
  - ATIS
  - VOLMET
  - All ATS units
- Aeronautical Meteorological stations:
  - Makes actual observations at aerodromes and offshore platforms
  - Provides METAR & MET reports
- World Meteorological Organization (WMO): Establish & implement together with ICAO a global regulatory framework for national meteorological services
- Meteorological watch office: Generates SIGMETs

Weather charts tips:

- Surface weather charts are weather **forecast** which is current, for time given on the chart, used to avoid areas with turbulence, CAT & jetstreams
- Line connecting places of the same temperature: **Isotherm**
- Line connecting positions with same height of constant pressure: **Isohypses,** a number on the isohypses represents topography height in **decameters**
- Line connecting points of equal wind speeds: **Isotachs**
- Lines on a contour chart joins points of equal height
- When they ask for temperature, check the tropopause level
- Tropopause in standard ISA is FL360 at 57°C
- Wind speeds can be found by interpolation of wind information from two charts while considering maximum wind information found on the significant weather chart
- Find average temperature>>>Find flight level temperature
- High pressure areas near maritime areas:
  - Summer low visibility, generally clear skies and possibility of afternoon thunderstorms due to heating
  - Mountainous area has orographic fog in relatively high pressures
  - Winter near hills/mountains near maritime area: Snow showers with gale force winds
- Weather after cold front passage:
  - Pressure slow rise
  - Broken clouds CU/CB with heavy precipitation & possible thunderstorms
- Stationary front: Red & blue

- Occluded front: Violet
- Warm sector:
  - Constant temperature
  - Overcast with stratus or stratocumulus & drizzle, moderate to strong winds
- CB clouds
  - Thunderstorm symbol implies moderate/severe turbulence/icing
  - ISOL: Individual CBs
  - OCNL: **Well separated**
  - FREQ: CBs with little or no separation
  - EMBD: Thunderstorm clouds contained in other clouds
- Wind directions: Buy Ballot's law, back to the wind, low pressure is on your left in Northern Hemisphere
- Frontal passage NH wind **veers**, but anywhere else on the **surface** wind **backs, speed** determined by distance between **isobars**

Information for flight planning

- METAR:
  - Every 30 mins, valid at time of observation
  - VC: Present weather within range of approx. 8 & 16km of the aerodrome reference point
  - BR = Mist, HZ = Haze, DU = Dust, DS = Dust storm, BL = Blowing, BC = Patchy, SQ = Squall, SG = Snow grains
  - PL = Pellets <5mm
  - RERA: There has been moderate/heavy rain since the last issue of METAR
  - MIFG: Shallow fog height 2m/6ft, above this layer good visibility is possible
  - TREND: **Landing forecast** valid 2 hrs in a METAR/SPECI, trend type METAR
  - SPECI: A **special aerodrome weather report**, issued when a significant change of the weather conditions have been observed
  - BECMG: Permanent change in 2 hours
  - TEMPO: Occur within the hour **or** half the period forecasted
  - MPS: Metres per second
  - Clouds are presented by: **Amount, type & height of base** above aerodrome level (AAL)
  - Visibility value transmitted in a METAR is the **greatest value, which is reached within at least half the horizon circle** of the aerodrome, prevailing visibility
  - VV/// = Vertical visibility not measurable
  - Gives **icing information on runway**
  - Wind in relation to true north, average wind speed within last 10 mins
  - Guts reported if there are winds above 10 knots above mean wind speed
- TAF:
  - Airport forecast
  - Clouds reported above aerodrome level
  - AMD: Amended revised TAF
  - **Unless stated in the TAF**, 9 hours validity
- Friction coefficient
  - 40+ = good
  - 36+ = medium-good
  - 30+ = medium
  - 26+ = poor-medium
- Volmet:
  - Issues METAR & SPECI
  - VHF Volmet: For regional coverage
  - HF Volmet: International coverage
- ATIS:
  - Broadcasts MET report & SPECI **not METAR**
  - QNH rounded **DOWN** to nearest hPa
  - Temperature & dewpoint rounded **UP**
  - Meteorological & operational information
- SIGMET issued when:
  - Severe icing (Also SWC)
  - Severe mountain wave

- Heavy dust storm
- Convective SIGMET: Thunderstorms obscured by massive layers
- Issued by **Meteorological watch office**

- GAMET & AIRMET:
  - Area forecast for low level flights
  - Meteorological visibility below 5000ft
- Windshear:
  - Reported every one min
  - MBST: Microburst, FNA: Final
  - Low level windshear occurs below 2000ft
- CAVOK:
  - No low drifting snow
  - 9999, no significant clouds (NSC) & no significant weather (NSW) below highest MSA
  - No clouds below 5000ft
  - No "CB"
- Aerodrome warning:
  - Message from MET concerning MET conditions that may adversely affect aircraft on ground including parked aircraft, aerodrome facilities & services
  - Should be **cancelled** when conditions are no longer occurring
- "Meteorological briefing": Oral commentary on existing & expected meteorological conditions
- "LLWAS": North American system for detection & warning provision of low level wind shear
- ACARS: Transmission of operational messages including METAR/TAF from ground to air