Student Study Notes – Canadian PPL
Aviation Ground School: Weather & Meteorology

This version of my "Weather & Meteorology" study notes is from January 1st, 2017. I'll update this document any time I find the need to make any changes, and as I continue to progress through additional training.

I am sharing these study notes for anyone else who is taking their PPL in Canada. These aren't intended as a replacement for proper training. I'm only sharing these notes as a supplement covering many of the key points that I decided that I really needed to memorize while going through my own PPL studies. The info in these notes comes from a large number of different sources: The Transport Canada Flight Training Manual, Transport Canada's Aeronautical Information Manual (AIM), various flight schools and instructors (in multiple provinces), and numerous other books and online sources. These notes are not always in any particular order, although I tried to keep similar topics together in many cases.

Please note that while I have made every effort to ensure that all of the information in these notes is accurate, based on the sources from which I learned, you should verify everything here against what you've learned in your own study programs. I (Jonathan Clark) shall not assume any liability for errors or omissions in these notes, and your official pilot training should always supersede any information presented herein. As the Canadian PPL curriculum is updated occasionally, I recommend that if you want to be 100% certain that everything in this set of study notes is correct, you should print a copy and ask your instructor to review these notes with you.

If the aircraft type is not specified in the notes below, you should always assume that they refer specifically to characteristics of a Cessna 172M, which is a common training aircraft, and the type that I have used most frequently. Know the characteristics of your own specific training/examination aircraft by memory!

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Let's Get Started – Ground School: Weather & Meteorology

Solar radiation is short wave. It hits the earth and is reflected back as long wave radiation. Long wave is then absorbed by water vapor as latent heat.

Rising warm air at the equator creates a low. It then travels to the poles where it cools and sinks, creating highs.

The atmosphere is thicker at the equator than at the poles.

Air flows from areas of high pressure to low pressure (wind). The strength of the wind depends mostly on the pressure differential between the two areas, and partly on the temperature differential.

The atmosphere consists of 78% nitrogen (N_2), 21% oxygen (O_2), and 1% trace gases.

Permanent trace gases include Argon (A_R), Neon (N_E), Helium (H_E), Hydrogen (H_2), Krypton (K_R), and Xenon (X_E).

Variable trace gases include carbon dioxide (CO_2), ozone (O_3), methane (CH_4), sulphur dioxide (SO_2), and water vapor (H_2O).

Atmospheric layers:

1. Troposphere: Up to 20,000 feet, although this height often varies significantly. Temperature decreases with height, +20 °C to -70 °C.
2. Stratosphere: 20,000 to 160,000 feet. Temperature increases with height, -70 °C to zero.
3. Mesosphere: 160,000 to 280,000 feet. Temperature decreases with height, zero to -100 °C.
4. Thermosphere: 280,000 feet (50 miles) up to 350 miles or 500 km. Temperature increases with height, -100 °C to over 1000°C.
5. Exosphere.

The **transition zones** found between the strata are where there is a change in the **lapse rate**.

"Space" starts about 50 miles or 80 kilometers above the Earth's surface (at the beginning of the thermosphere). This is a slightly vague definition.

About 99% of the atmosphere is found within the first forty kilometers above the surface. Half of this is located within the first 5km, in other words, more than half of the total volume of the atmosphere is found within the troposphere.

Lapse Rate – The temperature change with height. The defined Standard Lapse Rate is 1.98°C per 1000' (in the troposphere).

Most "weather" takes place in the troposphere. About 99% of the water vapor in the atmosphere is found within the troposphere.

Troposphere:

- Means "region of mixing," has vigorous air currents.
- Temperature and water vapor decrease rapidly with altitude.
- Average temperature is -56°C.
- Although we defined the upper boundary of the troposphere to be around 20,000 feet, it can actually be quite a bit higher, depending on the season and the location on earth. The height varies seasonally, and it is higher in the summer than in the winter.
- The tropopause is the boundary layer between the troposphere and the stratosphere above it.

Stratosphere:

- Temperatures increase as altitude increases, up to zero.
- Because the air temperature increases, it does not permit convection, so weather that transits through the tropopause cannot rise any further.
- This lack of convection has a stabilizing effect on thunderstorms.
- The stratopause (formerly mesopeak) is the boundary layer between the stratosphere and the mesosphere above it.

Mesosphere:

- Temperature decreases as altitude increases.
- Concentrations of ozone and water vapor are negligible.
- The chemical composition of gases at any given altitude depends strongly on altitude. Gases start to form into layers according to their molecular mass, so lighter gases settle at higher layers than heavier gases.
- The mesopause is the boundary layer between the mesosphere and the thermosphere above it.

Thermosphere:

- The temperature increases significantly with the altitude, very rapidly.
- Temperatures can get well over 1000°C. These temperatures are caused by intense solar radiation.
- This is the layer which hosts the northern lights.
- The thermopause is the boundary layer between the thermosphere and the exosphere above it.

Exosphere:
- Starts at about 500km.
- The upper boundary is undefined. Perhaps between 1,000 and 10,000km, depending on whom you ask.
- Pressure is little more than a vacuum.

At altitude of approximately 150km, you start to enter the altitude for satellites, and aerodynamic lift can no longer be used for maintaining height.

Definition of **Standard Atmosphere**:
- At sea level.
- +15°C.
- Change of 1.98°C per 1000’ (the standard lapse rate).
- 29.92” Hg or 1013.25 millibars/hectopascals.
- 1” drop in mercury per 1000’ increase.
- Dry air, no humidity.

Pressure measurements:
- Aviators use pressure of mercury (Hg) in inches.
- Meteorologists use millibars.

29.92” Hg = 1.0 atm = 101.325 kPa = 1013.25 mb

Station Pressure – The weight of air pushing down on a station, then the station “adds” an imaginary column of air between the station and sea level, which translates the physical reading to a theoretical reading that estimates sea level pressure at the station.

With respect to temperature, the average surface temperature of the station over the past twelve hours is what is used.

Isobars – Lines on a weather chart that connect areas of equal pressure. Isobars are correct for sea level pressure. The standard is to have them 4 millibars apart. Widely spaced isobars mean a shallower pressure gradient and relatively light winds.

The **standard airflow** *tends* to be counterclockwise/upwards/inward around a low pressure system, and clockwise/down/outwards around a high pressure system.

Pressure Gradient – The change in pressure over a given distance.

Although warm air usually creates a low, and cool air usually creates a high, remember that you always have to think in relative rather than absolute terms, in comparison to nearby air. Also, other factors can come into play.

Pressure Systems include **highs, lows, troughs, ridges, and cols**.

High Pressure Center:
- Air is sinking.
- In the northern hemisphere, air rotates clockwise and gently flows outward and downward.

- Also known as an anti-cyclone.
- Large blue “H” on a weather map.
- In general, is a region of subsiding air.
- Suppresses the upward motion that is needed to support the development of clouds and precipitation.
- Commonly associated with fair weather and light winds.
- Can remain stationary for days at a time.

Low Pressure Center:
- Rising air rotating counterclockwise. This flow tends to increase as you move toward the center of a low. Strong inward and upward flow.
- Also known as a cyclone.
- On a weather map, it is a red “L”.
- Air rises and becomes less dense as it rises.
- Rising motions favor the development of clouds and precipitation.
- Lows usually tend to move quickly, perhaps 500 miles/day in summer and 700 miles/day in winter.

Trough:
- Elongated area of low pressure.
- Symbol is a long purple line.
- Likely to bring about a wind shift at the surface.
- A trough can act like a weak front.

Ridge:
- Sawtooth pattern on a weather map, although it is quite rare.
- Area of elongated high pressure.

Col:
- A neutral region between two highs and two lows.
- Weather at a col tends to be unsettled.
- In the winter, expect fog.
- In the summer, expect showers and thunderstorms.

Boyle’s Law – At a given pressure, warm air will take up a greater volume than cold air. This greater volume will typically exert itself by moving vertically upwards.

On cold winter days, when flying IFR, we need to factor cold weather corrections into altitude calculations.

At a given altimeter setting, an airplane will be much closer to a ground obstacle in the winter than it would be in the summer.

Turning the altimeter sub-scale down results in a lower altitude.

If you set the altimeter (on the ground) in the **Kollsman window** and it shows a difference of more than 75 feet from aerodrome elevation, you need to re-calibrate it.

As you progress on a cross-country and keep adjusting your altimeter, try to always use a setting from a station within 100 miles of your position.

When flying towards a low, if maintaining what appears to be a constant altitude on the altimeter, the aircraft will gradually descend unless an altimeter correction is made. From high to low, look out below!

The altimeter does not compensate for non-standard temperatures! If terrain or obstacle clearance is a factor, a conservative higher altitude should be flown to ensure adequate clearance. "From hot to cold, don't be bold, or you won't grow old."

When the air temperature is above standard, density altitude will be higher than pressure altitude. Remember that higher density altitude means "air is less dense," so the aircraft will not perform as well at that higher temperature.

True altitude is our exact height above sea level. Cold temperatures cause the pressure level to compress. Our indicated altitude must be corrected for temperatures, especially for IFR or obstacle clearance! Use the left window in the E6B for calculations of true altitude.

Rule of thumb for **True Altitude calculations**:
Multiply temperature variation from ISA (15°C) by 4 feet per 1000.'

The two main ways that the atmosphere is heated are radiation (terrestrial, not solar) and convection.

The atmosphere is heated from the bottom up!

Variations in Heating:

- **Diurnal** variation: Day and night.
- **Seasonal** variation: Due to the axial tilt of the Earth. A shallow lighting angle in winter results in less heating, but there is a steeper lighting angle in summer. Also, there are more hours of daylight in summer.
- **Latitude**: Closely related to seasonal variation, although of course this is a constant factor rather than a cyclical one.
- **Topography**: Land absorbs radiation faster than water, and also releases heat more quickly at night. Items such as vegetation, soil type, slope, and aspect can significantly affect the amount of heating.

Methods of Heat Transfer:

1. **Convection**: Air near a warm surface is heated, and rises due to its buoyancy. Different surfaces (water, trees, and buildings) convect heat differently. Convection transports heat in the vertical sense quite efficiently.
2. **Advection**: Air is carried from one region to another by wind. Air is then warmed by the surface below. This moves heat laterally.
3. **Conduction**: Heats layers of air that are in immediate contact with the Earth's surface.
4. **Latent Heat**: Heat energy that is stored in water vapor. When water vapor rises and condenses, the heat in the water vapor is released during condensation.
5. **Compression**: When a large parcel of air sinks, it is compressed. Pressure increases, and the temperature increases.
6. **Turbulent Mixing**: Turbulence that is caused by friction between the air and ground will create eddies with vertical components. This will allow warm air near the surface to be lofted into the atmosphere.

Atmospheric cooling causes things like clouds, fog, and precipitation. This can happen through radiation, advection, and adiabatic cooling.

Radiation Cooling:

- After the sun sets, the surface continues to radiate heat.
- This causes the ground to cool, then air in contact with the ground is cooled through conduction (heat passing from the air to the colder ground surface).
- Radiation cooling rarely has an effect beyond the first few thousand feet above the Earth's surface.

Advection Cooling:

- Air is carried from a warm area to a cooler area.

Adiabatic Cooling:

- Rising air starts to expand, and this leads to cooling.
- This can happen near mountains, near fronts, and in areas with a lot of convection.
- This cooling occurs at different rates depending on whether the air is saturated (with humidity) or not.
- Unsaturated air will cool at the dry adiabatic rate of 3^{o}C per 1000'.
- Once saturated, it cools at 1.5^{o}C per 1000'.
- Air with some humidity, if not yet saturated, is still subject to the "dry" adiabatic rate.

Environmental Lapse Rate – This is the observed actual change in temperature with a change in altitude. This changes over time and is not a constant value. It changes from day to day, and even throughout the day.

Inversion:

- Occurs when temperature increases as altitude increases.
- Air is very stable.
- Acts as a barrier to vertical movement of air.
- A common cause of surface based inversion is radiation cooling from the surface on cool nights.
- During a low level inversion, if the relative humidity is high, expect smooth air and poor visibility due to haze, fog, and stratus cloud.

Isotherm – A line on a chart connecting areas of equal temperature. Usually dashed. May be darker for an important isotherm such as 0^{o}C.

Isothermal Layers – When the temperature remains the same at different altitudes. Like an inversion, it gives rise to very stable air.

Transpiration – Moisture (water vapor) that is released by plants.

Sublimation – When a substance changes directly from a solid to a gas. This is how dry ice and snow forms.

Deposition – When a substance changes directly from a gas to a solid. This is how hoar frost is formed.

Dew Point – The temperature that air must be cooled to in order to reach 100% saturation. Knowing the dew point also gives us a measure of how much water the atmosphere is currently holding. When the temperature is close to the dew point, humidity is high. Also, the higher the dew point, the greater the amount of moisture present.

As air warms up, it can hold more water vapor.

Relative Humidity – The percentage of saturation of a parcel of air at that given temperature.

Adding moisture to the air (by evaporation or sublimation) increases the relative humidity *and* the dew point.

An **adiabatic parcel** will not add or remove heat from the surrounding atmosphere. When such a parcel rises, it expands and cools. When it sinks, it will be compressed and warm.

Adiabatic Lapse Rate – Theoretical, can be calculated.

If a dry parcel of air does not mix with the surrounding air, then it can be considered adiabatic.

Dry Adiabatic Lapse Rate (DALR) – 3^{o}C per 1000'.

The change in dew point temperature:

- The dew point also falls as the column of unsaturated air rises.
- The decrease in dew point temperature is 0.5^{o}C per 1000'.
- Therefore, in a rising parcel of unsaturated air, the temperature and dew point converge at a rate of 2.5^{o}C per 1000'.
- Use this for calculations of cloud base.

Saturated Adiabatic Lapse Rate (SALR):

- Accounts for latent heat released as water condenses.
- Once air has cooled to the dew point and starts condensing, the air parcel cools more slowly because condensation releases energy.
- 1.5^{o}C per 1000'.

Freezing level in feet above cloud base:

Freezing Level = (1000 x Dew point) / 1.5

Note that the dew point changes with altitude. A new dew point must be calculated at the freezing level by decreasing the surface dew point by 0.5^{o}C per 1000' AGL.

Steep lapse rates lead to instability.

Precipitation - Occurs when condensing water droplets become large and heavy enough to overcome lifting agents such as fronts & updrafts.

Icing is worse near the top of a cumulus cloud.

Three **types of rainfall**:

1. Frontal.
2. Relief.
3. Convectional.

Frontal Rainfall:

- Also known as convergent or cyclonic rainfall.
- Caused by the convergence of two air masses (fronts).
- Warm front rainfall tends to be steady.
- Cold front rainfall tends to be showery.

Relief Rainfall:

- Also known as orographic rainfall.
- Warm moist air is forced to rise over an obstacle such as a mountain range.
- This cooling causes condensation, forming clouds and rain.
- Most of the rain is on the windward side of the mountain.
- Mountains will also cause air streams to converge and funnel through valleys.
- Rainfall totals will increase when mountains are parallel to the coast.

Convectional Rainfall:

- The ground surface is locally heated, adjacent air expands and rises, convection rainfall occurs.
- This heating occurs daily in summer.
- Large cumulonimbus clouds are likely to form.
- Rain cools the air as it falls, because some of it evaporates as it falls.

- The unstable conditions, possibly helped by frontal or orographic uplift, force the air to rise in a strong vertical updraft or chimney.
- The updraft is maintained by energy released through latent heat as water vapor condenses then freezes.
- The top of the cloud is characterized by ice crystals in an anvil shape.
- The top of the cloud is flattened by reaching the temperature at the troposphere.
- When the ice crystals and frozen water droplets (hail) become large enough they fall in a downdraft.
- This downdraft reduces the warm air supply to the "chimney" and will limit the lifetime of the storm.
- These storms are usually accompanied by thunder and lightning.
- Ice crystals have a positive charge.

Snow forms under the same conditions as rain except that the dew point temperatures are below freezing so the vapor condenses straight to a solid (deposition).

Snow:
- Ice crystals will form if there are small particles present for them to form onto. These may aggregate to form snowflakes.
- Since warm air holds more moisture than cold air, snowfalls are heaviest when the air temperature is just below freezing.

Sleet:
- Starts off as ice/snow when upper air is below freezing.
- A lower air temperature as it is falling allows it to partially melt.
- Then it goes through another cold layer and refreezes before it hits the ground.

Freezing Rain:
- Droplets stay in liquid form as they fall but are very close to freezing.
- They then hit frozen objects or ground, and freeze on contact.

Hail:
- Frozen raindrops that are more than 5mm in diameter.
- Hail keeps circulating up and down through a frozen layer until it is heavy enough to punch downwards, form a downdraft, and fall to the ground.
- Can occur anytime, but is most likely to occur during summer and in cold fronts.

Stable Air – A small change will be resisted and the system returns to its previous state.

Unstable Air – A small change initiates a bigger change, and so on. Lifting actions in the atmosphere decrease stability.

A rising (isolated) adiabatic parcel of air can only cool at one of two rates:
- Dry (unsaturated) adiabatic rate: 3^{o}C per 1000'
- Saturated (wet) adiabatic rate: 1.5^{o}C per 1000'.

Stable Air:
- Smooth flying.
- Poor visibility.
- Steady precipitation.
- Layer cloud (stratus).
- Ultimately ends in fog.

Unstable Air:
- Bumpy flying.

- Good visibility.
- Showery precipitation.
- Cumulus cloud.
- Ultimately ends in thunderstorm.

If the layers of air closest to the surface are cooled, we increase the stability of the atmosphere. This can happen by radiation at night, or by influx of cold air (cold advection).

Stability can also be increased by warming air at higher altitudes:
- Radiation cooling.
- Warm advection aloft.
- Large scale sinking of air.

Subsidence Inversion:
- Air mass sinks and compresses.
- Upper part of layer sinks/compresses more (relatively) than the bottom.
- Upper part therefore increases in temperature more than the air at the bottom.
- Common in winter.

Things that **enhance unstable conditions**:
- Daytime radiation.
- Warm air moving into a region (surface warm advection).
- Surface cold advection also. If cold air is warmed by a warm surface, then it emulates the same behavior as if it had been warm air advecting.
- Effects are enhanced if there is moist air near the ground, and dry air aloft.

Dark earth absorbs more heat (solar radiation) than lightly colored earth.

Cooling of the upper atmosphere:
- Also causes instability.
- If cold air moves into higher altitudes and causes temperatures to cool faster than at the surface.

Different lapse rates:
- **Steep**: Temperature decreases rapidly with altitude (leads to instability).
- **Shallow**: Temperature decreases slowly with altitude, fairly stable.
- **Inversion**: Temperature increases with altitude, stable.
- **Isothermal layer**: Temperature stays constant, stable.

If the environmental lapse rate is less than the DALR or the SALR, stability is favored. In this case, a parcel of air that attempts to rise will end up cooler than the air around it.

Ways to cause **heating of air near surface**:
- Radiation: Long wave from ground.
- Conduction: Warm air contacting cold.
- Advection: Horizontal movement of air.
- Convection: Unequal surface heating.

Lifting processes that can cause instability:
- Convection: This happens due to unequal surface heating.
- Convergence: Excess air rises as pressure systems meet.
- Mechanical Turbulence: Surface friction.
- Orographic Lift: Air moving up hills/mountains (anabatic/katabatic).
- Frontal Lift: Advancing air being pushed up by cold air on the bottom.

Four types of stability:

- **Absolute** Stability: DALR and SALR are steeper than ELR.
- **Conditional** Stability: ELR is between DALR and SALR.
- **Absolute** Instability: ELR is steeper than both the DALR and SALR.
- **Potential** Instability: Instability would depend on some sort of a trigger mechanism, such as lift. An example would be when the air is initially stable and unsaturated, but after becoming saturated, the lapse rate changes and "adds" heat. This situation somewhat resembles conditional instability. Another scenario would be an ELR that becomes steeper with altitude.

Layers of the sun:

- Photosphere (main mass).
- Chromosphere (similar to Earth's atmosphere).
- Corona (all the stuff well above the surface).

Solar Wind – Charged atomic particles coming from the corona, moving quickly enough to escape the sun's gravity. These solar particles interact with the Earth's magnetic field and with other particles in the upper atmosphere (aurora borealis or aurora australis).

Sunspots:

- Operate on an eleven year cycle (but varies from nine to fourteen years).
- Tied to the sun's periodic/variable energy output.

Solar Flare:

- Occurs when the area above a sunspot brightens and releases huge amounts of energy in the forms of ultraviolet, x-ray, and radio electromagnetic radiation, and high speed solar particles.
- Can yield spectacular aurora, interfere with radio and television reception, and knock out satellites and power grids.

Earth's axis is tilted at 23.5^{o} with respect to Earth's orbital motion.

The equator is equidistant from each pole at every point along the equator.

Summer Solstice – Has the most hours of daylight of any day of the year, usually around June 21st.

Winter Solstice – Has the least hours of daylight, usually around December 21st.

Equinox – There are two of them, usually around March 21st and September 21st. On these two days, the sun is directly "over" the equator. Spring is the vernal equinox, and fall is the autumnal equinox.

At the two solstices, the sun is above 23.5^{o} latitude. One of the poles will experience 24 hour daylight, and the opposite will experience 24 hour darkness (this 24 hour darkness/light actually lasts for several days).

Atmospheric Scattering – As sunlight and radiation passes through the atmosphere, particles of gas and dust are able to scatter it. At the equator, there is not much scattering, as light and radiation passes straight through the atmosphere's normal depth. However, light and radiation reaching the poles does so obliquely, passing through the equivalent depth of many atmospheres.

Cloud – A visible aggregate of tiny water droplets and/or ice crystals. Air must be saturated for clouds to form.

Air can be saturated in three ways:

1. By lowering the air temperature to the dew point temperature.

2. By adding water vapor into the air.
3. By mixing warm moist air to cold air.

Steam Fog – When you have a parcel of air that has some water vapor, and you evaporate more water into it, that becomes a cloud.

Okta – One eighth of the celestial dome.
SKC: Clear sky.
FEW: 1/8th or 2/8th.
SCT: 3/8th or 4/8th, scattered.
BKN: 5/8th to 7/8th, broken.
OVC: Overcast, 8/8th, completely covered.

Ceiling:
- Occurs with BKN or OVC, ie. more than half.
- VFR pilots are not allowed to fly over BKN or OVC, unless you have a VFR OTT rating.
- Ceiling is VV, vertical visibility, on the TAF or METAR.
- Example: VV003 = 300 feet.
- Has a scalloped border on the GFA.

Clouds are classified into four families based on altitude and vertical development/appearance:
- High: Above 20,000 feet, with a top usually around FL400 in Canada but it can be higher in other parts of the world. Includes cirrus, cirrocumulus, cirrostratus.
- Middle: From 6,500' to 20,000', includes altostratus, altocumulus.
- Low: Below 6,500', includes stratus, cumulus, stratocumulus, nimbostratus, stratus fractus, and cumulus fractus.
- Vertical Development: Pass through two or all three of the above categories, includes cumulus, altocumulus, towering cumulus, and cumulonimbus.

Cumulus clouds are always puffy or pillowy, and often feature showery/inconstant precipitation. Cumulus clouds frequently have roughly the same diameter, no matter what their altitude.

Stratus clouds are flat clouds that feature constant precipitation.

Nimbo clouds generate rain.

Cirrus (CI):
- High and wispy.
- Generally above 20,000'.
- Sometimes called mares' tails.
- Made of ice crystals.
- Generally appear in high pressure systems, warm weather, and ahead of warm fronts.
- Point in the direction of air movement at their elevation.

Cirrostratus (CS):
- Really good at producing halos.
- Sheet-like, high level, composed of ice crystals.
- Tend to thicken as a warm front approaches, signifying an increased production of ice crystals.

Cirrocumulus (CC):
- Appear as a white sheet with a pebbly pattern.
- Somewhat rare.

Altocumulus (AC):
- Puffy, cotton ball.
- On a warm, humid summer morning, they may be followed by thunderstorms as the day progresses.

Altostratus (AS):
- Layer cloud with no definite pattern.
- Steely or bluish in colour.
- Sometimes the sun or moon can be seen dimly throughout.
- Seem to make the sun look like it is behind heavily frosted glass.

Stratus (ST):
- Low layer cloud.
- Resembles fog but does not rest on the ground.
- No waves or patterns, gray.

Alto Cumulus Castellanus (ACC):
- Created from instability associated with air flows having marked vertical shear and weak thermal stratification.
- Can produce heavy precipitation.

Nimbostratus (NS):
- Dark, low level clouds accompanied by light to moderate precipitation.
- Mostly water droplets, not ice crystals.

Stratocumulus (SC):
- Low, lumpy layer of clouds.
- Sometimes accompanied by weak intensity precipitation.
- Stratocumulus on the windward side of a mountain range may be super-cooled and may lead to icing.

Stratus Fractus (SF):
- Stratus cloud that has been torn by wind into fragments.
- May release drizzle.

Cumulus Fractus (CF):
- Stratocumulus torn by wind.
- Can be differentiated from stratus fractus by their more rounded tops.

Cumulus (CU):
- Fair weather.
- Appearance of floating cotton.
- Have a lifetime of 5-40 minutes.
- Given suitable conditions, can develop into towering cumulus and then cumulonimbus.

Towering Cumulus (TCU):
- Growing cumulus cloud.
- On the way to becoming a cumulonimbus.
- Like a giant cauliflower in the sky.

Cumulonimbus (CB):
- Much larger and more vertically developed than fair weather cumulus.
- Fuelled by vigorous convective updrafts that are at times in excess of fifty knots.

- Depending on the height of the troposphere and the buoyancy of the updraft, the tops of cumulonimbus clouds can reach up to 60,000'.

Mammatus:

- Powerful cumulonimbus clouds that may have appendages protruding from the base.
- Indicate that the atmosphere is extremely unstable.
- Severe weather possibly imminent.

Mountain Wave Clouds:

- Top: Moist layer of air, lenticular clouds.
- Middle: Dry layer of air.
- Bottom: Cap cloud, rotor clouds.

Orographic Clouds - Associated with mountains, develop when air is forced to rise by the Earth's topography. This can happen either prior to encountering a ridge, or after.

Lenticular Clouds – Form in the wave crest, very high and hundreds of miles long. Can look like a tortoise shell or like a stack of pancakes.

Rotor Clouds (roll clouds) – Form downward and below each wave crest. They are dissipating and forming at the same time due to the rotation of air.

Cap Cloud – Lie over the top of the mountain and extend partially down the leeward slopes, indicating an extremely strong downdraft.

Contrails:

- Cloud formed by the water vapour contained in the exhaust of jet engines.
- At high enough altitudes, the vapour turns immediately to ice crystals.
- Resemble a long thin line of cirrus.

Mountain Waves:

- Oscillations on the lee (downward) side of a mountain caused by disturbances in the horizontal air flow due to the impeding terrain.
- Can have speeds in excess of 5000 feet/second.
- About 150 NM in length is common, and can be much longer.
- Most severe near the mountain or mountain ridges, and at about the same height as the top of the summit.
- Significant horizontal and vertical shear may exist.
- Average wave length is 8 NM.
- A standing mountain wave is fairly stationary as it propagates horizontally.

Conditions conducive to forming a mountain wave:

- Wind direction must be within 30° perpendicular to the mountains.
- Wind velocity on leeward side must be 25 knots or more.
- Winds aloft increase with height.
- Stable air mass layer aloft or an isothermal layer or inversion near the mountain top.

Factors affecting wavelength:

- Stability: Higher stability makes shorter wavelengths.
- Wind Speed: Higher wind speed equals longer wavelengths.
- Lateral Positioning of Ridges: Ridge spacing can also change the wavelength.
- Ridges will need to be 5km apart.

Amplitude:
- Half the vertical distance from the wave trough to crest.
- Varies with height above the ground.
- Smaller amplitudes near the surface and near the tropopause.
- Larger amplitudes between 3000’ to 6000’ above the ridge.
- Generally, the greater the amplitude, the shorter the wavelength.

Factors affecting amplitude:
- Lower stability produces lower amplitudes.
- Larger mountains produce greater amplitudes.
- Ridges with widths similar to typically formed wavelengths will produce greater amplitudes.
- A sharp lee slope will produce greater amplitudes.
- Drops of greater than 3,000’ tend to produce the largest amplitudes.

There must be sufficient moisture for clouds to form, so lack of clouds does not always mean that it will not be turbulent.

Clouds that might indicate the formation of mountain waves include lenticular, rotor, cap, and banner.

Lenticular clouds:
- Typically from 20,000’ to 40,000’.
- As the air in a mountain wave rises, it cools by expansion and condenses out moisture to form the leading edge of the lenticular cloud.
- After air flows over the crest, it continues downward. Due to compression, the moisture evaporates and is absorbed.
- The associated winds extend to the troposphere, making it difficult to avoid by simply flying over it.
- Lenticulars form in the crests of waves, and can be hundreds of miles long.
- In a PIREP or METAR, it will be reported as either Alto Cumulus Standing Lenticular (ACSL) or Cirrocumulus Standing Lenticular (CCSL).

Cirro means ice crystals.

Rotor Clouds:
- Indicate the presence of mountain waves.
- Possess the greatest amounts of turbulence.
- Avoid flying through, between, or below rotors!
- Will form downward from each wave crest, land within the lower turbulent zone.
- Can be dissipating and forming at the same time due to the rotation of the air.
- Diameter between 600’ and two miles.
- Center of rotation typically near the ridgeline.
- The first rotor will be the most intense.

If you *must* pass through an area with rotors, the best choice is above them, and the second best option is around them. Never fly under them if there is any alternative at all.

When flying downward into mountain wave turbulence, your aircraft will hit the turbulence faster and more violently. Configure the aircraft for turbulence penetration.

Altimeter effects from a mountain wave:
- The drop in pressure associated with an increase in wind speeds will cause the altimeter to read incorrectly.
- This, coupled with non-standard temperatures, may result in an altimeter over-reading by as much as 3,000’ feet.

Four types of **winds in mountain terrain** include **anabatic, katabatic, glacier winds**, and **funneling**.

Anabatic:
- Formed as the sunward side of a mountain slope heats up.
- Warm air starts to rise up the slope, creating an upwards flow on the mountain.
- Pockets of turbulence are possible as the mountain slope heats up at different rates.

Katabatic:
- Flows downslope.
- Can happen in areas that are shaded, although they are typically more powerful at night when radiation cooling starts to happen.
- Wind will then flow down mountain valleys.

Glacier Wind:
- Extreme type of katabatic wind.
- Cools over glacier, starts to rush downhill, sometimes faster than 80 knots.

Funneling:
- Flows perhaps between two ridges, or around a single peak.
- Speeds up, pressure drops abnormally.
- Very dangerous.

To limit exposure to mountain winds:
- When crossing ridges from downwind, do it at a 45^{o} angle and with a minimum clearance of 3000' when strong winds are present.
- If caught in a downdraft, speed up to get out of it rather than pitching for V_Y to attempt to outperform it.
- Check AIRMETs and PIREPs.

Types of Turbulence:
- Convective.
- Mechanical.
- Frontal.
- Orographic.
- Mountain wave.
- Shear (wind shear).

Convective Turbulence:
- Caused by uneven heating of the earth's surface.
- Darker areas such as soil, rocks, or sand heat up faster than lighter areas such as grass or water.
- Warm air will rise and be replaced by cooler sinking air.
- Indications include fair weather cumulus, TCU's, ACC's, and CB's.
- If possible, fly above clouds to avoid convective turbulence.

Mechanical Turbulence:
- Caused by friction between air and ground.
- Created when wind encounters terrain like trees, or man-made objects/buildings.
- The GFA shows heights that MECH will be based at, along with maximum height.
- From the surface, usually extends to between 2000' and 5000' AGL.
- Only shown on forecast if expected to be moderate or worse.

Frontal Turbulence:

- Caused by friction between two opposing air masses.
- More commonly associated with cold fronts than with warm fronts, although it can be either.

Orographic Turbulence:

- Caused by friction in air currents through mountainous regions.
- Airplanes approaching hills or mountains from the windward side are helped by rising currents.
- Aircraft approaching from the leeward side encounter descending currents.

Mountain Wave Turbulence:

- The fact that mountain waves are stationary means that the effects of turbulence on an aircraft are different when flying downwind than when flying upwind.

Shear Turbulence:

- Also known as wind shear.
- A change in wind speed and/or wind direction in a short distance.
- Can exist in a horizontal or vertical direction.
- The greater the speed/direction change, the greater the severity.
- Some forms include microbursts and virga.

Low Level Wind Shear:

- There are **six different types**: Microbursts, virga, rotor winds, low level nocturnal inversions, low level jets, and funnel winds.
- Can present a significant hazard to aircraft during takeoff/landing/climbing/descent.
- Defined as a significant, non-convective wind shear that could adversely affect aircraft operation within 1500' over an aerodrome.
- On the TAF/METAR, the height of the top is given first, followed by wind speed and direction at that height.
- To a large extent, wind shear is an element that cannot be satisfactorily observed from the ground. Aircraft reports and radiosonde reports are often the only ways that we can determine its possible presence.
- The main effect is rapid gain/loss of airspeed.
- On a chart, seeing WS indicates strong non-convective low-level wind shear expected within 1500' AGL.

Wind shear reporting guidelines:

- Change in wind speed of greater than 25 knots within 500' AGL.
- Change in wind speed of greater than 40 knots within 1000' AGL.
- Change in wind speed of greater than 50 knots within 1500' AGL.
- Pilot reporting gain or loss of indicated airspeed of greater than 20 knots within 1500' AGL.

Radiosonde – A battery-powered telemetry instrument package/probe carried into the atmosphere (usually by a weather balloon), which measures various atmospheric parameters and transmits them by radio to a ground receiver.

Low Level Jets:

- Often associated with a frontal system.
- A powerful jet of air following a front can produce significant turbulence.
- Represented by a double-line black arrow on the charts.

Nocturnal Inversion:

- As night falls, winds aloft become decoupled with surface winds.

Microbursts:

- Formed by cold dense air and rain shafts as they rapidly descend.

Virga:
- Similar to a microburst. Rain that falls, dragging cold dense air along with it.
- Should this rain fall into a layer of drier air below, it will evaporate.
- The cold air that was falling with it will continue downwards, but without any rain that would be a visual indicator of a strong downdraft.

Funnel Winds:
- Gently blowing winds can be forced into valleys, where they will speed up and create an area of shear.

Clear Air turbulence (CAT):
- Frequently associated with a jet stream aloft. Can also be caused by a sharp temperature gradient, mountain waves, or wind profiles that vary significantly.

Turbulence Reporting:
- Light: Slight changes in attitude/altitude.
- Moderate: Greater intensity, aircraft under control.
- Severe: Large abrupt changes, temporarily out of control.
- Extreme: Airplane is violently tossed, control is impossible.
- Chop: Intermittent turbulence.

The Coriolis force always makes things appear (to an observer in the northern hemisphere) to curve to the right.

In the upper troposphere, the air is unaffected by friction and we can see that there is a balance between the Pressure Gradient Force and the Coriolis force.

Resultant Wind – Thanks to the balance between the pressure gradient wind and the Coriolis force, the geostrophic wind blows parallel to the isobars. However, it is also slightly modified by friction from the surface which reduces the Coriolis force and causes the wind to blow at a slight angle to the isobars.

Buys Ballot's Law:
- If you stand with your back to the wind (in the northern hemisphere), the low is always on the left and the high is always on the right.
- Determining the highs and lows tells you the direction that the pressure gradient wind is blowing.
- Coriolis force is always in the opposite direction to the pressure gradient force.

Tri-Cellular Model:
- Warm air rising at the equator, then moving to the poles and sinking, is just one aspect to consider.
- The earth's rotation, uneven distribution of its land masses, and the oceans all play a part in air circulation.
- This all means that there is more than one cell responsible for recirculating the air through the atmosphere.

Latitude Regions:
- **Polar**: From 60^{o} latitude to the poles, known as the polar cell, easterly winds.
- **Mid Latitude**: From 30^{o} to 60^{o} latitude, known as the Ferrel cell, warm southwesterlies.
- **Tropical**: From the equator to 30^{o}, known as the Hadley cell, northeast trade winds.

There is generally HIGH pressure at the Poles and at 30^{o} latitudes.
There is generally LOW pressure at the Equator and at 60^{o} latitudes.

Doldrums – Low pressure, light wind area near the equator.

The equator is also known as the Inter Tropical Convergence Zone (ITCZ).

The areas at 30^o latitude (which are generally high pressure areas) usually have clear skies and stable conditions.

The areas at 60^o latitude (called the polar front) usually have low pressure, unstable conditions, and cyclonic rainfall.

Veering: Wind direction changing clockwise.

Backing: Wind direction changing counter-clockwise.

A calm ocean surface is smooth and has little effect on the wind. A city has a great effect on the wind speed and direction.

Winds usually veer and increase during a climb out, and usually back and decrease during an approach. This is just the way things generally work when you're changing altitude. Non-standard winds frequently indicate warm fronts.

Gust – A brief rapid change of wind direction and/or speed.

Squall – A prolonged change of wind direction and/or speed. Be careful, as another separate definition of a squall is a long line of thunderstorms.

Diurnal Effects:
- During the day, vertical currents are formed that link the upper and lower winds, making them similar.
- At night, a nocturnal inversion develops and there is no link between upper and lower surface winds; they back and decrease.
- There can be a large difference between upper and lower winds.
- Winds at surface can be stronger and gustier during the day.

Sea Breezes:
- A high develops over water (in the day) and a low over land.
- Air flows from highs to lows, ie. a cool breeze will be coming off the ocean towards the land (during the day).
- The reverse (a land breeze) happens at night, with winds blowing out to the ocean.

Types of Wind Shear:
1. **Speed**: Wind is blowing at different speeds at different altitudes.
2. **Directional**: Wind is blowing in different directions at different altitudes.
3. **Increased Performance**: An increasing headwind or decreasing tailwind.
4. **Decreased Performance**: A decreasing headwind or increasing tailwind.

Rossby Waves – Very strong winds in the upper troposphere, organized into wave patterns. They are the result of temperature variations and the rotation of the earth. Depending on the season and circulation, there can be anywhere from three to seven existing at any given time.

Jet Streams:
- Blow in excess of 230 km/hr.

- Rapid transfer of energy around the globe.
- Can distribute debris from eruptions around the world within a week.
- Usually at least 60 knots.

Main Jet Streams:
- **Polar Front** (PFJS): From about 40° to about 60° latitude.
- **Subtropical** (STJS): At around 25° to 30° latitude.
- **Easterly Equatorial** (EEJS): At the equator.

Polar Front jet stream (PFTS):
- When it moves south, it brings cold air, which gives us dry and stable conditions with high pressures.
- When warmed, it moves northward, giving strong winds and heavy rainfall.
- As winter approaches, it becomes stronger and plunges far to the south.
- The wind speed is greater in winter, due to large temperature differences between the Polar and Ferrel cells.
- During summer, it moves northward and wind speeds usually decrease.

Sub-Tropical (STJS):
- Found on the boundary between the Ferrel and Hadley cells.
- Weaker than the polar front jet stream due to lower temperature variations between cells.

Easterly Equatorial jet stream (EEJS):
- Tends to form aloft along the ITCZ (equator).
- Fairly seasonal, associated with summer monsoons in India.
- Gentle jet stream.

Air Mass:
- A large body of air (usually at least 1000 miles across) that has similar properties of temperature and moisture throughout.
- The most likely source region is a large flat area where air can be stagnant long enough to take on the characteristics of the surface below.
- The source region is always an area of high pressure. Slowly moving highs are the best. Wind varies little with height.
- Usually named based on temperature and humidity, which of course is determined by the source region. The name will be two parts, with the first part identifying the moisture region and the second part identifying the temperature region.
- Moisture Regions: Continental (dry) or maritime (moist).
- Temperature Regions: Arctic (coldest), polar (mid-temp), or tropical (warmest).

Canada doesn't have many continental-polar air masses because we're actually a source for them. We don't have many continental-tropical air masses either. That leaves CA, MA, MP, MT: Continental Arctic, Maritime Arctic, Maritime Polar, and Maritime Tropical.

Air masses are generally **modified** by either warming or cooling from below:
- An air mass being warmed from below results in instability and convection.
- An air mass being cooled from below results in an inversion and stability.

Fronts cause abrupt changes in temperature, wind, and stability.

Frontal weather is determined by:
- Stability and moisture content of warm air.
- Speed of cold air.
- The slope.

A front is named after the advancing air mass.

Symbols for fronts on maps: Warm fronts are red semi-circles, cold fronts are blue triangles, and occluded fronts are a mix of each.

Types of fronts:

1. Cold.
2. Warm.
3. Occluded.
4. Stationary.
5. Trowal.
6. Upper fronts.

Cold Front:

- Transition zone where cold air is replacing warm.
- Tends to move more quickly than warm front.
- Tends to undercut a warm air mass.
- Tends to produce CU, CB, and TCU clouds.
- Isobars make a V-shape in the vicinity of the front.
- Maybe 500 miles wide.

Before passage of a cold front:
Winds: South or southwest.
Temperature: Warm.
Pressure: Falling steadily.
Clouds: Increasing; CU, TCU, CB.
Precipitation: Short period of showers.
Visibility: Fair to poor, haze.
Dew Point: High, remains steady.

As the cold front passes:
Winds: Gusty and veering.
Temperature: Sudden drop.
Pressure: Slight rise.
Clouds: CB.
Precipitation: Heavy rain, thunder and lightning, may hail.
Visibility: Poor but improving.
Dew Point: Sharp drop.

After the cold front has passed:
Winds: West to northwest.
Temperature: Steadily dropping.
Pressure: Rising steadily.
Clouds: CU.
Precipitation: Showers, then clearing.
Visibility: Good, except in showers.
Dew Point: Lowering.

Warm Front:

- Warm air mass replacing cold.
- Slower than a cold front, overrides cold air.
- Slope very shallow, typically one half of one degree.

- Maybe 200-250 miles wide.

Before passage of a warm front:
Winds: South to southwest.
Temperature: Cool to cold, slowly warming.
Pressure: Falling gradually.
Clouds: In order, CI, CS, AS, NS, ST, and sometimes fog, CB in summer when fast moving warm air.
Precipitation: Light to moderate, rain, snow, sleet, and drizzle.
Visibility: Poor.
Dew Point: Steady rise.

As the warm front passes:
Winds: Variable veering.
Temperature: Steady rise.
Pressure: Leveling off.
Clouds: Stratus type, NS.
Precipitation: Drizzle or none.
Visibility: Poor but improving.
Dew Point: Steady.

After the warm front has passed:
Winds: South southeast.
Temperatures: Warmer then steady.
Pressure: Slight rise, followed by a fall.
Clouds: Clearing with scattered SC, occasional CB in summer.
Precipitation: Commonly none, sometimes light rain or showers.
Visibility: Fair in haze.
Dew Point: Rises, then steady.

Occluded Front:
- When a cold front associated with a low "catches up" to the warm front, overtaking and undercutting it. Does a wrap-around, disconnecting the warm air from the surface.
- Usually shows on a weather chart as alternating purple half circles and triangles.

Trowal:
- Used in Canada as another name for an occlusion. Stands for "trough of warm air aloft."
- Usually a blue line with red quadrilaterals on a weather chart.
- Can vary significantly depending on moisture content of warm air, ie. anything from dry to heavy precipitation.
- Generally resembles a warm front ahead of the trowal, and a cold front trailing.
- In relation to the associated low, maximum precipitation, icing, and convective activity will typically be in the northeast sector.

At a trowal/occlusion, remember that there are three air masses present: cold air, cool partially mixed air, and warm air.

Stationary Front:
- Not moving, neither air mass is replacing the other.
- Noticeable temperature change and/or change in wind direction is common when crossing from one side to the other.
- Winds will be blowing parallel to the front.

Frontogenesis – Occurs when the temperature gradient becomes sharper.

Frontolysis – A dissipating front.

Upper Fronts:

- Can happen when air is trapped on the surface and the frontal weather is pushed aloft.
- There will be few indications of the frontal passage to a ground observer. No wind shift and no temperature change. However, precipitation is still likely to fall.
- Upper fronts have empty symbols on a weather chart.

Frontal Fog – Associated with weather fronts, particularly warm fronts. Caused when frontal precipitation falling into the colder air ahead of the warm front causes the air to become saturated through evaporation.

With the passage of a cold front, the surface wind usually veers and increases with speed.

Airframe Ice – Forms when super-cooled water droplets strike an airframe that is at a temperature of less than zero degrees. The three main types are rime, clear, and mixed.

Rime Ice:

- Likes to form in layered cloud, like stratus.
- Rough, milky, opaque.
- Lots of air pockets, like what you see when you open your freezer.
- Freezes instantly.

Clear Ice:

- Larger drops, may be cumuliform.
- Smooth and transparent.
- Hits the leading edges, does not freeze instantly. Flows a bit, filling in cracks and pockets, then freezes.
- Larger accumulations are characterized by upper and lower horns.
- Extremely dangerous.

Always do everything possible to stay out of freezing precipitation. It is one of the most dangerous things out there for pilots.

Factors having an effect on the rate of ice accumulation:

1. Shape: Thinnest surfaces collect the most ice.
2. Speed: Higher airspeeds result in greater rates of ice accumulation.
3. Droplet size: Large droplets are more likely to strike the wing than a smaller droplet.

Icing Intensity comes in four levels: trace, light, moderate, and severe.

Trace icing:

- Ice becomes perceptible.
- The rate of accumulation is slightly greater than the rate of sublimation.
- Generally not hazardous unless you're in it for a while (well over an hour).
- There is no symbol on the weather charts for trace icing.

Light icing:

- The rate of accumulation will create a problem if the flight is prolonged (over an hour).
- There is no symbol on the weather charts for light icing.

Moderate icing:

- Even short encounters are potentially hazardous.

- Has a symbol on the weather charts.
- De-icing or anti-icing equipment will be required to clear it, and a diversion may be necessary.

Severe icing:

- The rate of accumulation is fast enough to render de-icing or anti-icing equipment useless.
- An immediate diversion is necessary.

When icing is encountered:

1. Make an immediate decision.
2. Climb, descend, or go back.
3. Activate de-icing or anti-icing equipment, if available.
4. Turn on pitot heat and cabin heat.

Dangers of icing:

1. Poor aerodynamics.
2. Increased drag and weight.
3. Decreased lift and thrust.

Effects:

- Aircraft's performance will decrease.
- Increase in drag caused by rough surfaces.
- Decrease in power due to intake blockages.
- Engine failure due to carb icing or blocked air intake.
- Engine foreign object damage (FOD) is likely for turbine engines.
- Ice alters the wing shape, you become a test pilot.
- The angle of attack decreases, perhaps low enough to happen before the stall alarm sounds.
- Deteriorating trim effectiveness.
- Asymmetric shuddering and vibrations if one prop blade sheds ice.
- Control surfaces may freeze in place.
- Flaps can be damaged during extension/retraction.
- Landing gear may freeze in place or be damaged.
- Fuel vents may become blocked, which can lead to fuel starvation.
- Pitot tube blockages will lead to airspeed errors.
- Obscured cockpit visibility.
- Antenna problems, poor radio reception.
- Bank angles greater than 5^o can cause a stall.

How to deal with potential icing:

- Consider climbing through ice more quickly, if you're stuck in it.
- File a PIREP.
- On landing approach, use more power and higher airspeed.
- Clear ice tends to form in cumuliform clouds, try to avoid them whatever the season. The worst icing in these clouds is between -10^oC and 0^oC.
- Rime ice tends to form in stratiform clouds. Accumulation is greatest between -10^oC and -20^oC.

De-Icing and Anti-Icing equipment:

- Balloons.
- Heaters.
- Jets may use bleed air from engines.
- Weeping Wing systems (also known as TKS) may pump fluid through mesh screens on the leading edges of the wing and tail.

Frost forms on the aircraft when the surface temperature of the aircraft is below the dew point and below 0ºC.

Frost can reduce wing lift by 30% and increase drag by 40%.

Cold Soaking – Typical when an aircraft comes down from the flight levels (where it is cold) and into warmer air below. Warm moist air will then condense and freeze as it comes into contact with the cold portions of the wings.

If you start losing power, impact ice may be causing a problem. Select carb heat or alternate heat. Lean the mixture if carb heat is used continuously.

How to Avoid:

1. Stay out of clouds and visible moisture when the outside air temperature (OAT) is below freezing.
2. Fronts and low pressure systems are often associated with clouds.
3. If you must fly through a front, do it directly instead of at an angle.
4. A winter warm front is terribly dangerous.

Carry extra fuel, in case a diversion is needed!

Tail Stall:

- Tail can collect ice a lot faster than the wing.
- Horizontal stabilizer produces a down force that keeps the nose up.
- If the tail stalls due to excessive icing, we would have a sudden and violent pitching of the nose down.
- This would be preceded by oscillations in the control column, as opposed to the sensation of wing buffeting.

Recognition of a Tail Stall:

- Can lead to abnormal pitch forces when flaps are extended, so don't extend.
- A buffeting may be felt in the control column(s), instead of in the airframe.
- A pilot induced oscillation may be an early indication.

Recovery:

- Raise flaps to previous setting immediately.
- Pull back on the yoke, and reduce power if altitude permits.
- Do not increase airspeed unless necessary to avoid a wing stall.

If you suspect tail icing:

- Approach at the proper speed for your configuration.
- Keep the flaps retracted.
- Keep small bank angles for turning.
- Avoid abrupt pitch-down movements and thrust changes.

Hoar Frost:

- Caused by cooling on clear/calm nights.
- Dew point of surrounding air is below zero.
- Water vapor turns directly to ice (deposition).
- Frost colour is white and opaque.
- Melts quickly.

Thunderstorm Development **Requirements**:

- High moisture content.

- Steep lapse rate.
- A lifting agent.

Development Stages:
1. Cumulus/developing stage: Updraft dominated.
2. Mature stage: Updrafts and downdrafts.
3. Dissipating stage: Downdraft dominated.

Cumulus Stage:
- Warm moist unstable air is forced to rise.
- Moisture rapidly cools into liquid drops of water due to the cooler temperatures at high altitude, which appears as cumulus clouds.
- As this water vapor condenses into liquid, latent heat is released. This warms the air, causing it to become less dense than the surrounding dry air.
- Upward growth rate of 5 to 20 m/s, which is 10 to 45 mph.
- The updraft holds all the water droplets and ice crystals, so the rain is unable to fall.
- Usually, there is no precipitation in this stage.

Mature Stage: (Air Mass Storm)
- Warmed air continues to rise until it reaches existing air which is warmer, then the air can rise no further.
- This cap is often the tropopause.
- Air is forced to spread out, giving it an anvil shape.
- Water droplets coalesce into larger and heavier droplets and freeze into ice particles. As they fall, they melt into rain.
- The cloud may have already reached a height of 60,000' and the updraft may be travelling at more than 6,000 feet/minute.
- While updrafts are still present, falling rain also creates downdrafts.
- There will be strong downdrafts in areas of the heaviest precipitation.
- The heavy rain cools and drags down the air with it, at speeds of up to 2000' per minute.
- Precipitation/turbulence/thunder/lightning are at their most intense.
- Turbulence is high due to the opposite rushing air currents at the middle level.
- Updrafts continue to dominate the inner portions.
- Most of the downdrafts form on the outside edges.
- Typically lasts fifteen minutes, but can last for an hour.

Dissipative Stage:
- As heavy precipitation falls through the cloud, the cloud cools, and then downdrafts dominate the base of the cloud.
- If atmospheric conditions do not support "super cell" or "squall" development, this stage occurs rather quickly.
- The downdraft will push down out of the thunderstorm, hit the ground, and spread out, causing a microburst.
- This cooling causes the cloud to lose energy and the rainfall gradually ceases.
- Cool air carried to the ground by the downdrafts cuts off the inflow, so the updraft disappears and the thunderstorm will dissipate.

Methods of Lift that create thunderstorms:
1. **Orographic** (Air Mass thunderstorm) – Form in mountains, created as air moves up a steep slope.
2. **Convection** (Air Mass thunderstorm) – Rising hot air creates the energy source. Often seen on a summer afternoon. Can even be triggered by wildfires.
3. **Frontal** – Created by frontal lift. Fast moving cold fronts can create energetic storms (known as Steady State thunderstorms).

Squall Line:
- A line of thunderstorms moving in unison.
- Frequently found well ahead of a fast moving cold front.
- Exercise extreme caution when close.
- Leading edge will be where updrafts and downdrafts are most severe.
- If you have to pass through, penetrate the lightest areas.

Do not mistake a shelf cloud for a tornado. This happens commonly.

Lightning:
- Air has an electrical resistance.
- When the electric potential or difference is large enough to break down this resistance, the electrons flow to the positive charge, forming lightning.
- There can be lightning from clouds to the air, to the ground, or to other clouds.
- The greatest likelihood of lightning hitting an aircraft is between $-5^{o}C$ and $+5^{o}C$.
- Lightning can strike an aircraft flying in clear air in the vicinity of a thunderstorm.
- Lightning may or may not cause problems if it hits an aircraft.

There is no useful correlation between the external visual appearance of a thunderstorm and the severity or amount of turbulence or hail in it. The visible thunderstorm is just a portion of a violent system of updrafts and downdrafts that often extend far beyond. Severe turbulence may extend up to 20 NM from severe thunderstorms. No flight path through an area of strong or very strong radar echoes that is separated by less than 40 NM can be considered to be free of severe turbulence.

Engine Water Ingestion – The strength and velocity of updrafts in a thunderstorm are strong, and heavy concentrations of water collect in clouds. This moisture may exceed the amount that a turbine engine can ingest, and the engine can flame out, so turn on the igniters if you're in a turbine.

The pressure ahead of a thunderstorm falls rapidly, then rises abruptly after the rain starts.

Whenever possible, do not take off or land when a thunderstorm is approaching. They can have gusts exceeding 50 KTS, and wind direction can reverse in seconds.

If flying over a thunderstorm, clear the top by at least 1000' for each 10 knots of wind speed at cloud top.

Hurricane – A huge destructive cyclonic storm originating in tropical waters. Often 100 miles across.

Tornado:
- Rotating funnel shaped cloud linking the ground to a large thunderstorm.
- The funnel cloud does not become a tornado until it touches down.
- Diameter is often only around thirty feet, but can be up to half a mile.
- Usually happens in spring/summer.
- Average forward speed is 50 km/hr.
- Wind speeds within the tornado can range from 65 km/hr to 450 km/hr.
- The path of destruction is usually three to four kilometers long.

Waterspouts – Funnel clouds that touch water, usually slightly less powerful than tornadoes.

Put your airplane into a hanger before a storm, if you have one!

Fog is not associated with convection.

Dashed brown line on the weather chart is usually fog.

Fog formation requirements:
1. High humidity.
2. Condensation nuclei.
3. Very light surface winds.
4. A process to either cool or to add moisture, to get the condensation going.

A temperature to dew point spread of 3ºC or less and dropping will probably lead to fog.
Six fog types include radiation, advection, upslope, frontal, steam, and ice.

Radiation fog:
- Formed by radiation cooling on clear nights where relative humidity is high and light winds are present.
- Most likely to be present shortly after sunrise.

Advection fog:
- Formed by the horizontal movement of warm moist air over a cool surface.
- The thickest advection fog will usually form at night with low winds.
- Common during winter warm-ups and early spring thaws.
- Typically dense and can last for several days.

Upslope fog:
- Moist air moves up rising terrain.
- Easterly wind flowing across the plains can cause upslope fog.

Frontal fog:
- Precipitation from a warm front or cold front falls into colder air below it and ends up saturating it.
- More typical with a warm front.
- Also known as precipitation fog.

Steam fog:
- Also known as arctic sea smoke.
- Typical over a lake/river/pond at sunset or sunrise.
- The process begins when cold dry air blows over warm water.
- Water evaporates into the lower layers of the air saturating it.
- As the excess water vapor condenses, fog/mist forms.

Ice fog:
- Sometimes forms when temperatures are significantly below zero.
- Often created by exhaust from engines or factories on cold winter days.

Naming conventions: Called Mist (BR) if visibility meets or exceeds 5/8ths mile. Called Fog (FG) if visibility is less than 5/8ths of a mile.

Haze - Forms on days with high temperatures and high humidity.

Each region in Canada has a FIC, eight in total: Whitehorse, Kamloops, Edmonton, Winnipeg, North Bay, London, Quebec City, and Halifax. You usually contact a FIC by calling 1-866-WXBRIEF.

FSS's are sub-locations that coordinate with the FIC. We normally contact them by radio while en route. They are referred to as "Radio" and their service is Flight Information Services Enroute (**FISE**).

Sometimes, a FSS will be responsible for overseeing the control of a Class E control zone, and FISE will be done by the nearest FIC via VHF repeater. Usually 122.5 or 123.XXX MHz.

Direct User Access Terminal (**DUAT**) – Can legally be used as the sole source of pre-flight planning info.

Automatic Terminal Information Service (**ATIS**) – A short, pre-recorded audio summary of the current weather at an airport, which plays on constant repeat. Reduces radio congestion.

VOMET:

- Weather info via high frequency (shortwave).
- Used for North Atlantic crossings.
- Frequencies are found in the CFS.

PBS – Pilot Briefing Service
TWB – Transcribed Weather Broadcasts

CAVOK – Stands for Ceiling & Visibility OK. This means visibility is greater than or equal to 6 SM, ceiling is greater than or equal to 5000', and no cumulonimbus, precipitation, thunderstorms, fog, or drifting snow are present.

Understand the difference between **current reports** (METARs, AWOS, PIREPs) and **forecasts** (TAF's and GFA's). Current reports are measurements, and forecasts are estimates.

METAR:

- Winds are knots true.
- Cloud heights are AGL.
- Visibility is in SM.
- Times are in UTC/Zulu.

You *must* know how to decode a METAR, and know all of the abbreviations. Memorize them.

METAR includes: The type of report, airport identifier, date/time, wind direction and velocity, visibility, runway visual range, weather phenomena, sky coverage, temperature/dew point, altimeter setting, remarks.

SPECI – Special METAR report
RVR – Runway Visual Range

The RVR is always followed with either /D or /U or /N to represent downward, upward, or no change.

An Automated Weather Observation Station (AWOS) is noted by AUTO in the METAR. Use these observations with caution! Heavy rain or blowing snow can cause incorrect readings.

If filing a **PIREP**, go through these nine items in order:

1. Location and time.
2. Altitude.
3. Aircraft type.
4. Cloud (base, amount, top).
5. Temperature.
6. Wind direction and speed.
7. Turbulence.
8. Icing.
9. Remarks.

Mandatory PIREP codes:

UA: Normal PIREP.
UUA: Urgent PIREP.
/OV: Location of the PIREP, in relation to a NAVAID, an aerodrome, or geographical coordinates.
/TM: Time the PIREP was received from the pilot, in UTC.
/FL: Flight level, essential for turbulence and icing reports.
/TP: Aircraft type, essential for turbulence and icing reports.

Optional PIREP codes: (at least one is required)

/SK: Sky cover. Used to report the cloud layer amounts and the height of the cloud base.
/TA: Ambient temperature, important for icing reports.
/WV: Wind velocity referenced in terms of True north (magnetic north in US).
/TB: Turbulence intensity, whether it occurred in or near clouds, and duration.
/IC: Icing, reported by type and intensity or rate of accretion.
/RM: Remarks, any other weather conditions that are not covered already.
/WX: Flight visibility and weather.

Identifiers:

- 2 letter are NDB's.
- 3 letter are VOR's.
- 4 letter are airports.
- 5 letter are intersections.

You need to be able to completely decode all weather products for your written exam and flight test.

Notice To Airmen (**NOTAM**) – Contains info concerning "stuff that's happening" which might affect pilots or normal flight operations. Usually distributed at least five but no more than 48 hours in advance.

NOTAM's are tailored by locations and by who is affected. There are about 210 files (location indicators) for Canada.

NOTAM Categories:

- Aerodrome: Anything within 25 NM of an aerodrome.
- Flight Info Region: Of general interest throughout the FIR.
- National (CYHQ): Affects the entire country.

Criteria for Issuing a NOTAM:

1. Changes to navigation aids.
2. Changes in frequencies, etc.
3. Changes in airspace or air traffic procedures/services.
4. Changes to runways or approach systems.
5. Hazards.
6. Military ops or airspace reservations.
7. Changes in CYR/CYA.
8. Communication problems.
9. Safety issues.
10. Equipment/facilities deficiencies.

Types of NOTAMS's:

N – New.
C – Cancelling.
R – Replacing.

J – Runway Surface Condition Report.
Q – Query or Response NOTAM.

The reason why the RSC report is identified by a J is because it stands for the James Brake Index.

Always check the NOTAMS!

Graphical Area Forecast (**GFA**):

- Clouds and weather.
- Icing, freezing, and turbulence levels.
- Two sets of maps.
- Depicts the most probable meteorological conditions expected to occur below the 400 Mb or 24,000' level.
- Designed to meet en route weather forecasting and pre-flight planning requirements of general aviation and regional air carriers.
- Issued four times daily, about half an hour before the beginning of the forecast period. Valid for six-hour periods starting 0000, 0600, 1200, and 1800 UTC.
- Seven different coverage regions.

What is included in the GFA:

- Six charts total for each six hour issue.
- Three for clouds and weather (CLDS/WX).
- Three for turbulence and freezing level conditions (ICG/TURBC/FRLVL).
- For each of these sets of three, a near term forecast, a 6hr forecast, and a 12hr forecast are depicted individually.
- Note that the 12hr CLDS/WX chart also includes an IFR outlook for an additional 12-hour period, so it's good for 24 hours.
- Speeds are in knots, and heights are ASL.
- Horizontal visibility is in SM.
- Times are UTC/Zulu.
- You will be asked to interpret a GFA on your exam.
- The scale on the map is in NM.
- Memorize all of the standard abbreviations that are found in the AIM meteorology section.

Category Ceiling Visibility:

- IFR: Less than 1000' AGL, and less than 3 SM visibility.
- MVFR: 1000' to 3000' AGL, and 3 to 5 SM visibility.
- VFR: Greater than 3000' AGL, and greater than 5 SM visibility.

Synoptic Features – Weather features that are generally at least a thousand kilometers across, ie. very large. Planetary features are larger, and mesoscale features are smaller.

Mesoscale Levels:

1. Mesoscale Alpha: From 1000km across down to 200km.
2. Mesoscale Beta: From 200km across down to 20km.
3. Mesoscale Gamma: From 20km across down to 2km.

If a synoptic feature is forecast to be moving at five knots or faster, there will be an arrow and a speed value. For speeds of less than 5 KTS, use the letters QS for quasi-stationary.

Clouds on GFA's:

- Bases and tops between the surface and 24,000' are indicated.
- The tops of convective clouds (TCU, ACC, CB) are indicated even if they extend above 24,000' ASL.

- Cirrus clouds are not depicted.
- Cloud types will be indicated if considered significant.
- A scalloped border indicates a ceiling where the sky is BKN or OVC.
- If the visibility is greater than 6 SM, and the sky is SKC/FEW/SCT, then a scalloped border is not used.
- When multiple layers are forecast, the amount of cloud at each layer is based on the amount at that level, not overall. Bases and tops of each layer are indicated.
- CIG stands for Ceiling, and implies AGL.
- Visibility of greater than 6 SM is listed as P6SM.
- A dashed green boundary with an interior of solid slanted bars is used to enclose areas of intermittent or showery precipitation.
- A solid green line with a dotted interior is used to enclose areas of continuous precipitation.

Convective storm clouds:
ISOLD – Isolated – less than 25%.
SCT – Scattered – 25% to 50%.
NMRS – Numerous – Greater than 50%.

Surface Based Layer:
- Referred to as OBSCD.
- Fog or Mist.
- VV into surface based layers is AGL.

Obstructions to Vision (enclosed within a dashed orange line):
LCL – Local – Less than 25%.
PTCHY – Patchy – 25% to 50%.
XTNSV – Extensive – Greater than 50%.

Wind barbs:
- Used if the sustained speed is 20 KTS or more.
- Show speed and direction.
- The “feathers” on the barb correlate to the numerical wind speed.
- G stands for gusting.
- Uses true wind direction.

Icing on Charts:
- Icing is depicted in blue whenever moderate or severe icing is forecast.
- Areas of light icing are described in the comments box.

Turbulence on Charts:
- Depicted in red.
- Depicted whenever moderate or severe turbulence is forecast.
- The base and top of each layer are shown.
- If turbulence is due to any of the following five conditions, the cause will be identified with the appropriate abbreviation: MECH (mechanical), LLWS (low level wind shear), LEE WV (mountain wave), LLJ (low level jet), and CAT (clear air turbulence).

Freezing level:
- Contours are abbreviated by dashed lines.
- Height is measured ASL.
- Contour lines are at 2500’ ASL levels, starting at the surface.

GFA Amendments:
- Automatically amended by AIRMET’s.

- Happens if there are significant deviations from the forecast.
- The GFA is automatically amended by SIGMET bulletins, even though that is not explicitly stated in the SIGMET itself.
- A chart will be reissued with comments if necessary.

AIRMET – Airman's Meteorological Event.
SIGMET – Significant Meteorological Event.

Look at the GFA first, then the TAF, then the METAR. This lets you look at the big picture first, then a five-mile region, then a point analysis.

Terminal Area Forecast (TAF):
- Weather expected within 5 NM of the airport.
- Cloud heights are AGL.
- Wind degrees are true.
- Typically issued 4 times daily, for either 12, 24, or 30 hour periods.
- To add a forecast for low-level non-convective wind shear, an example is: WS018/34045KT, which means that the surface to 1800' AGL has shear, and at 1800' the wind is 340^{o} True at 45 knots.
- Wind shear below 1500' AGL, if expected to be significant, is always included in the TAF.

Sky Cover in a TAF:
- Cloud layers forecast as per METAR.
- Only CB will be specifically identified in the forecast.

For a TEMPO notation, in order to be legal, the forecast "temporary" conditions cannot be expected to last more than 50% of the total duration of the TEMPO, and none of the intermittent occurrences can last for more than one hour.

FM – From, permanent change.
BECM – Becoming, permanent but gradual change.
PROB XX – Probability of XX%. Must be less than 50%.

Remarks on TAF:
- RMK then details.
- Unique to Canadian TAF's.

Upper Winds and Temperatures:
- Referred to as the FD charts.
- Forecasts of wind direction and velocity, as well as expected air temperatures at specific heights.
- Forecasts are prepared every twelve hours.
- It is rare that these forecasts are completely accurate.
- In flight, be prepared to use your ten degree drift lines.
- Wind direction is True, the speeds are in KTS.
- Code of 9900 stands for light and variable winds, no wind corrections are required for the Nav Log.
- Unlike many other areas, a code of a minus sign *does* mean below zero degrees. If all temps are below 0^{o} at higher levels, then the minus sign will be omitted, so you have to look at other parts of the chart to verify.
- Field elevations above 1500' will not report a 3000' FD.
- Temps are not reported on a 3000' FD.
- Different format: ie. 1921+14 means wind direction 190^{o}, speed 21 knots, temperature +14^{o}C.
- If the wind direction is between 51 and 86, subtract 50 to get the wind track, and also add 100 knots to the wind speed. For example, 731960 means 230^{o}T because (73-50)=23, x10=230, and wind speed is 119 knots, and the temperature is minus sixty.

Airman's Meteorological Advisory (**AIRMET**) - Short term weather advisory, designed to highlight weather that is not described in the current GFA. Can be issued for:

- Instrument Meteorological Conditions (IMC).
- Freezing precipitation (unless it is in a SIGMET).
- Moderate icing.
- Moderate turbulence.
- Isolated thunderstorms.
- Wind varies by greater than 60º direction from forecast.

SIGMETS are more severe, and might be issued for severe thunderstorms, squall line, hail, volcanic ash, hurricanes, tornadoes, severe icing, marked mountain waves, widespread sand or dust storms, and low level wind shear.

In-flight SIGMETS will be broadcast on 126.7 MHz, and you can get more info on the FISE frequency.

Weather Charts: Surface charts and upper level charts (constant pressure charts).

Most charts have pressures reduced to sea level. The upper level charts do not. They are very different!

Surface Analysis Charts: Actual observed information.
Surface Prognostic Charts: Forecast info.

Surface Analysis Charts:

- Actual weather as observed from the surface to 3000' AGL.
- Information can be a few hours old since it can take up to three hours to create a map.
- Info is based on observations taken at 00Z, 06Z, 12Z, and 18Z.
- Allows you to see how the weather has been developing over time.
- Most symbols are the same as the ones used in the GFA.
- Black location dot is overcast.
- Barbs on a wind flag are 10 knots for each long barb, and less for shorter barbs.

Wind always veers at a front.

Surface Prognostic Chart:

- Looks similar to the SAC. Don't confuse them! Check the title.
- Issued 48 and 36 hours before the standard validity times of 00Z and 12Z.

Upper Level Charts:

- Issued by the weather office at 00Z and 12Z.
- Can give us a 3D view of the weather.
- Analysis, not prognostic!
- Levels used (standard) are 850 mB, 700 mB, 500 mB, and 250 mB.
- If you're doing commercial or ATPL, you might use a fifth chart, the 400 mB.
- There are also two prognostic charts: the Significant Weather Prognostic chart and the Significant Weather Prognostic High Level chart (there are actually more, but these are the two commonly used in Canada).

When we are looking at a constant pressure chart, we are actually looking at the height of the air for a given pressure at a given location.

Average altitudes for these pressure levels:
850 mB – 5,000' ASL – 150 dM (decameters)

700 mB – 10,000' ASL – 300 dM
500 mB – 18,000' ASL – 570 dM
250 mB – 34,000' ASL – 1050 dM

An airplane that is flying through different temperature columns of air up in the Flight Levels will have its True altitude constantly changing. This does not matter! All the other airplanes will have their altimeters set to 29.92, and they will also rise and fall with the changes.

Contour Lines – Lines connecting similar heights (of air pressure levels). Therefore, lines on a CPC are not isobars! The whole horizontal plane of the map is an isobar, except in two dimensions as a layer, not as a single line. It is still important to note that tightly packed contour lines are still indicators of high wind speeds.

Satellite imagery is a good complement to (not a replacement for) other information.

Geostationary Satellites:
- Placed in orbit above the equator at an altitude of about 36,000 kms.
- The satellite's motion through space matches the pace of the earth's rotation.
- An observer on the ground sees the satellite as motionless in relation to the stars and earth behind.
- The satellite still completes one rotation of the earth per day.

The National Oceanic & Atmospheric Administration (NOAA) uses three geostationary satellites for imagery: GOES West, East, and South. These normally each see one half of the earth, a disc which depends on their orbital parking spot. They produce a full image every thirty minutes, although they can be tasked to "rapid scan" smaller areas more quickly. However, because they are in orbit over the equator, they don't provide accurate information at latitudes over 60^{o}N.

Polar Orbiting Satellites:
- Orbit at an altitude of about 850km.
- They complete an orbit every 105 minutes, or 14 times/day.
- Because the earth rotates beneath them, they "appear" to move west by about two time zones per orbit.
- Over any given time zone, there are about two passes per day, which averages to about one pass per day during visual daylight hours.
- Currently, there are two NOAA satellites working, one on each side of the planet. Together, they provide images once every six hours.
- They can provide images at very high resolution since they're so low.

Image types can be visible or IR. Depending on the wavelengths used, IR can tell us surface temps, cloud top temps, or moisture content of the atmosphere.

For white temperature labels, the coldest temperatures are bright whites. On color temperature labels, green/purple are warm and down to orange/yellow/red are very cold. These are the Environment Canada standard colours.

For visible satellite images, they use a white albedo style. IR images use a temperature scale.

Infrared Images:
- Fog, which can be quite shallow, can be hard to pick out if it is the same temperature as the ground below it.
- In an inversion, where temperatures aloft can be even higher than the ground, clouds can even appear as dark objects.

- The typical resolution on IR images is about 4km at the equator and deteriorates further north, especially past 60° latitude.

Visible Images:
- Need to be taken during daylight hours.
- Appearance changes throughout the day as the angle of incident light changes.
- Clouds are generally defined better than on IR.
- Banks of fog and large cumuliform clouds are easy to see.
- Resolutions are around 2km at the equator and deteriorate further north, especially past 60° latitude.

Water Vapor Imagery:
- Starting to become more common.
- Does not tell us where clouds are, but does tell us where there is a lot of moisture in the air.
- Areas of high moisture content will be bright white, while areas that are relatively dry will be a dark shade, or black.

Conclusion

The topics included in a study of weather & meteorology have a far greater scope than I've covered here. It would also be wise to spend quite a bit of time studying the various publications that I've linked to on this page: http://www.djbolivia.ca/aviation.html

I have links there to several additional aviation-related publications.

Thanks for reading, I hope this was helpful to pilots in training. If you find any errors in the above information, feel free to contact me at jonathan.scooter.clark@gmail.com

- Jonathan Clark