CPL Theory Meteorology (CMET)

CAE Oxford
Aviation Academy

CMET 4 – Atmospheric Stability

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Related Documents	Document Identification

CMET 4 – Atmospheric Stability

Amendments made to this document since the previous version are listed below. All amendments to this document have been made in accordance with CAE OAAM's document management procedure.

Slide	Changes

STATES OF WATER

States of Water

- Moisture in the air is important – without it, clouds and other weather phenomena could not exist

- Moisture exists in 3 states:

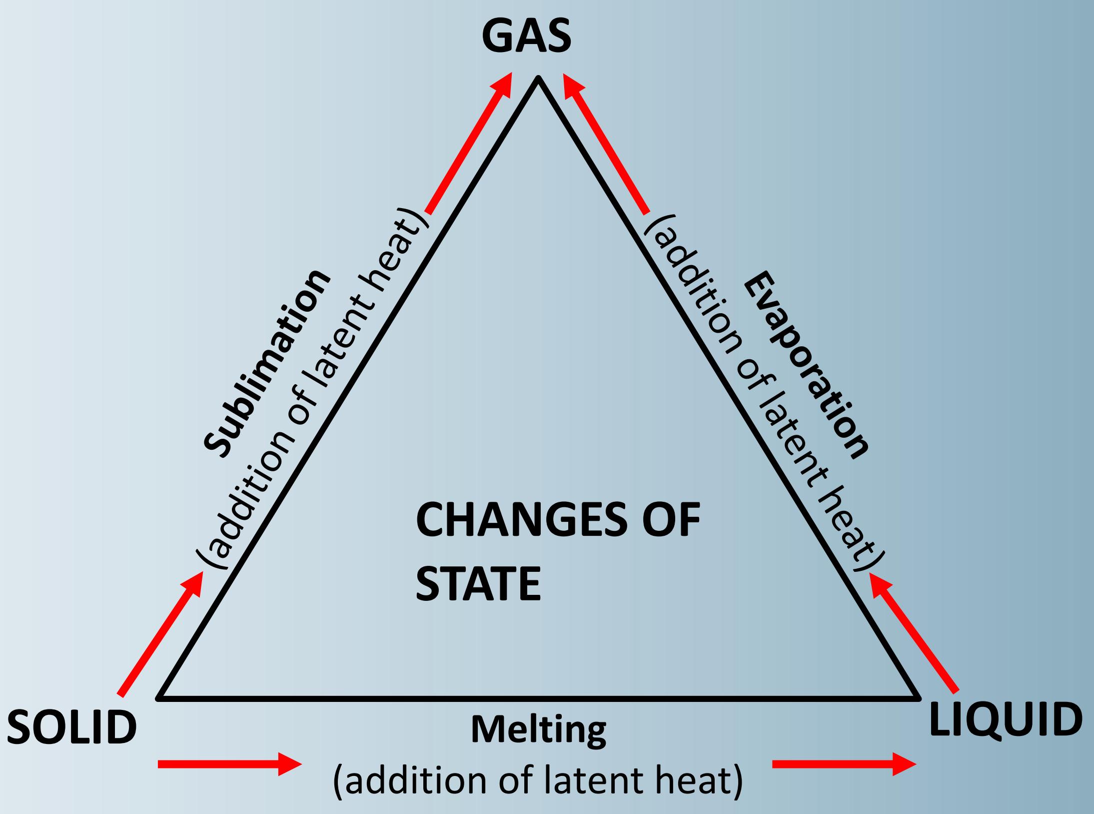
1. Liquid **e.g. rain**

2. Solid **e.g. ice**

3. Gas **e.g. water vapour – a colourless and odourless gas**

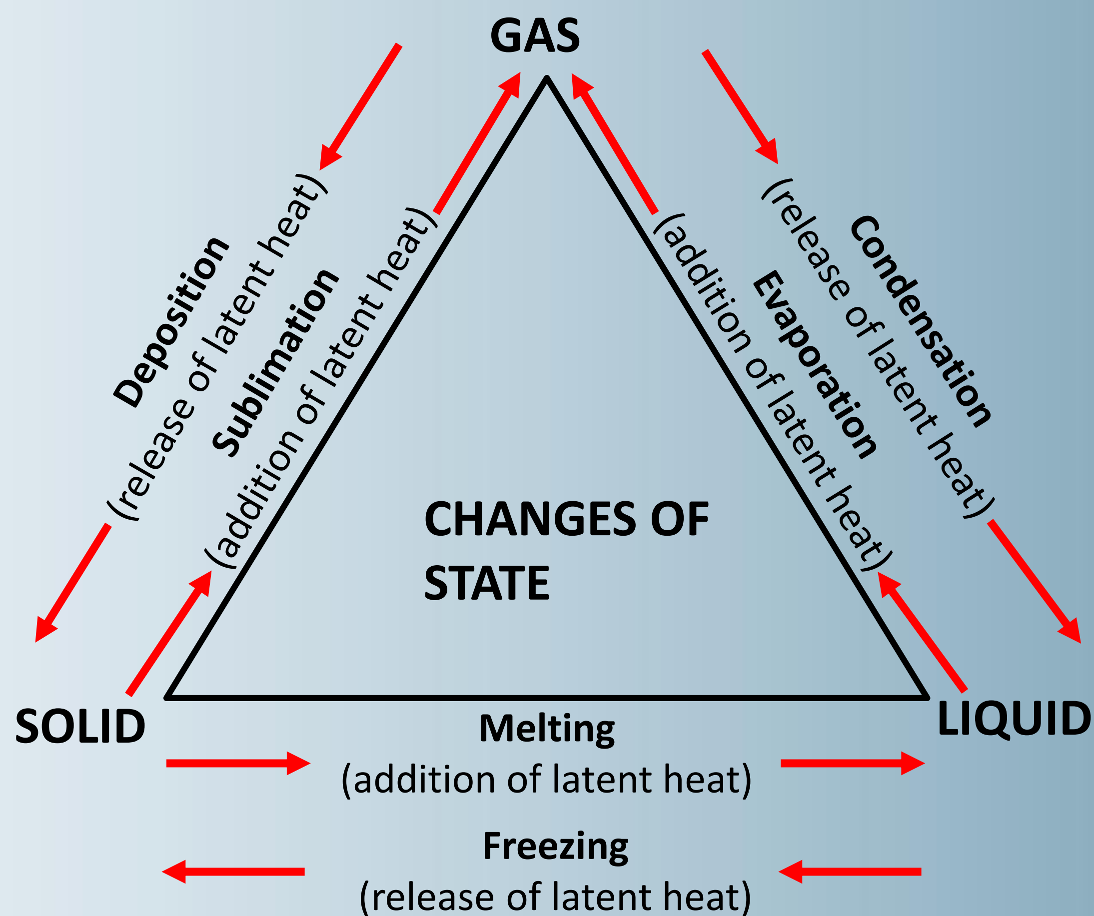
States of Water

- For moisture to change into a higher state (e.g. liquid water → water vapour), energy is required
- This energy comes in the form of heat energy – known as **latent heat**
- The liquid water will literally suck this heat from the surrounding air, meaning that the air will now be cooler
- Note that **the moisture itself will NOT change temperature** – all the heat energy has been used to change state



States of Water

- When a substance changes to a lower state (e.g. liquid water to ice), latent heat is released into the atmosphere
- This means the atmosphere becomes warmer
- But once again, the moisture itself has no change in temperature



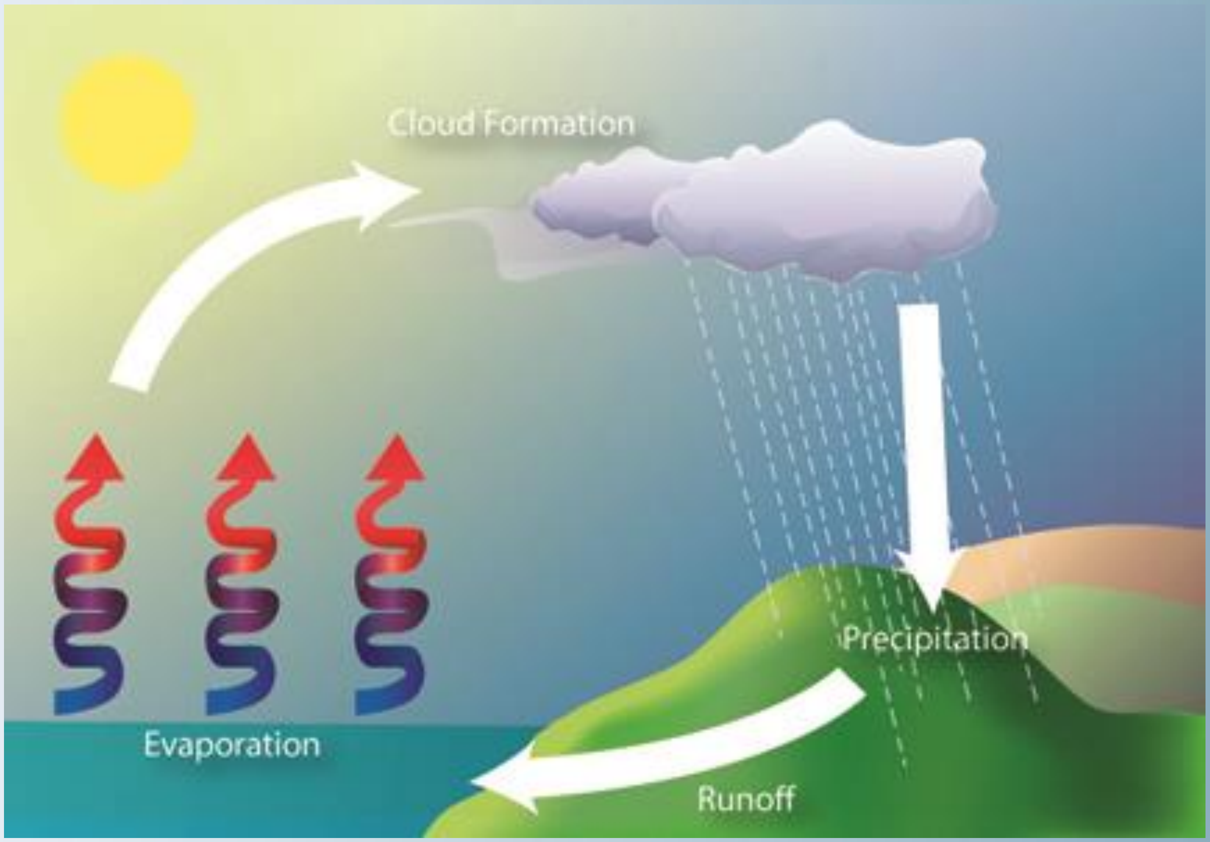
HUMIDITY &
RELATIVE HUMIDITY

Humidity & Relative Humidity

- Water vapour is present in the atmosphere via **evaporation**

- Places over wet surfaces such as oceans will have a greater level of humidity than desert or inland areas

- Humidity is also **more abundant at lower levels** and **decreases as altitude increases**



- The **actual amount of water vapour** in the air is known as **humidity** and is not important to us

- What we are concerned with is **relative humidity**

Humidity & Relative Humidity

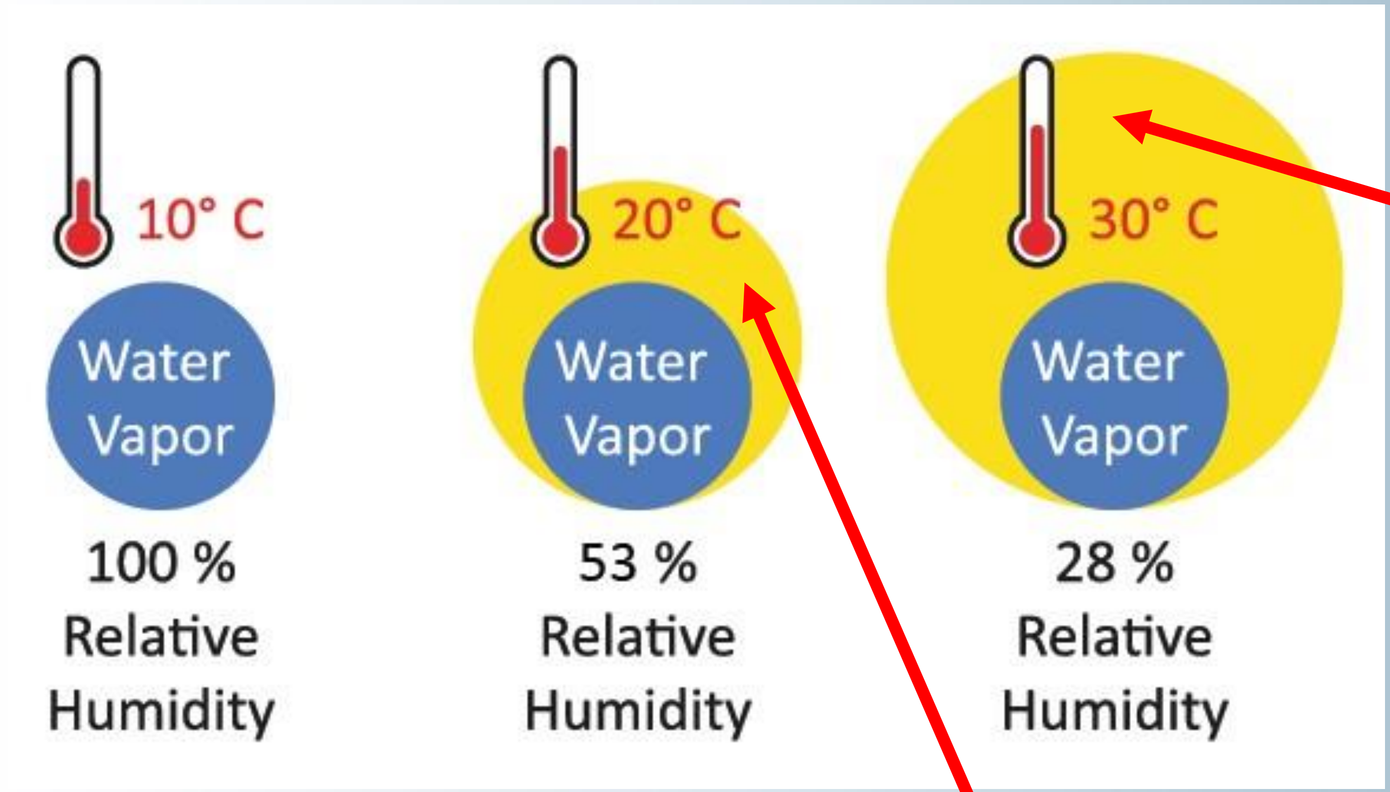
- Relative humidity can be defined as:

1. A ratio

"The amount of water vapour present in a sample of air compared to the maximum amount that could be contained at that temperature and pressure"

Actual Amount of Water Vapour : Maximum Possible Amount of Water Vapour

Humidity & Relative Humidity



Amount of water vapour air can hold at 30° C

Amount of water vapour air can hold at 20° C

Humidity & Relative Humidity

- Relative humidity can be defined as:

1. A ratio

"The amount of water vapour present in a sample of air compared to the maximum amount that could be contained at that temperature and pressure"

Actual Amount of Water Vapour : Maximum Possible Amount of Water Vapour

2. A percentage

(Actual Mass of Water Vapour x 100) ÷ mass of water vapour at saturation

- But what is saturation?
- Let's go over this slowly…

Humidity & Relative Humidity

- A sample of air is lying just above the surface of the earth

Parcel of Air / Air Sample

Humidity & Relative Humidity

- A sample of air is lying just above the surface of the earth

- During the day, this air is warmed by **terrestrial radiation** via **conduction**

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Humidity & Relative Humidity

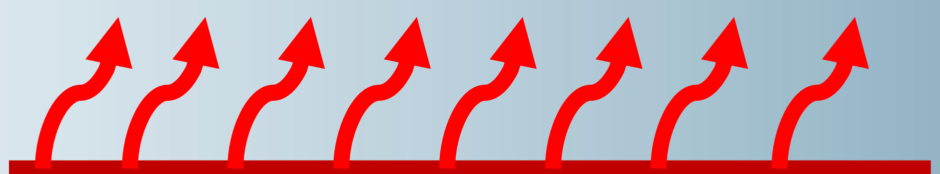
- A sample of air is lying just above the surface of the earth
- During the day, this air is warmed by **terrestrial radiation** via **conduction**
- This now **warm air** begins to **rise**

Humidity & Relative Humidity

- **As it rises**, the surrounding air pressure reduces

- As a result, **the volume of the sample increases** - in other words it is expanding (remember – warm air is less dense)

Parcel of Air / Air Sample



Humidity & Relative Humidity

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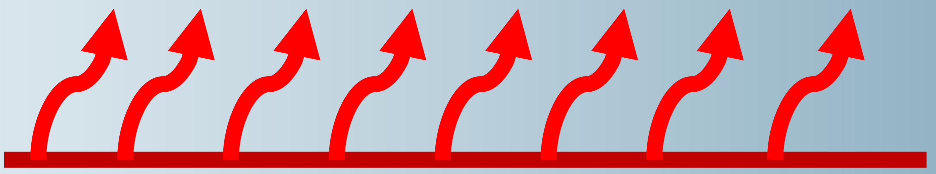
  the surrounding air pres
  reduces

Parcel of Air / Air Sample

- As a result, **the volume of the sample increases** - in other words it is expanding (remember – warm air is less dense)
- This **expansion causes the air to cool**



Humidity & Relative Humidity

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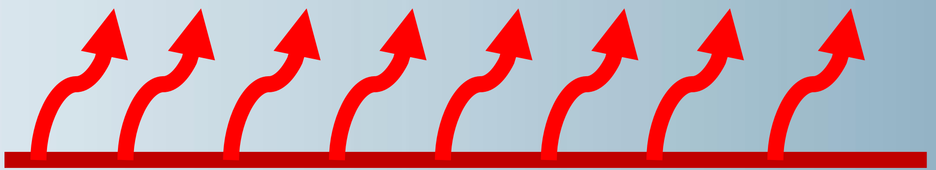
Parcel of Air / Air Sample

- As a result, **the volume of the sample increases** - in other words it is expanding (remember – warm air is less dense)

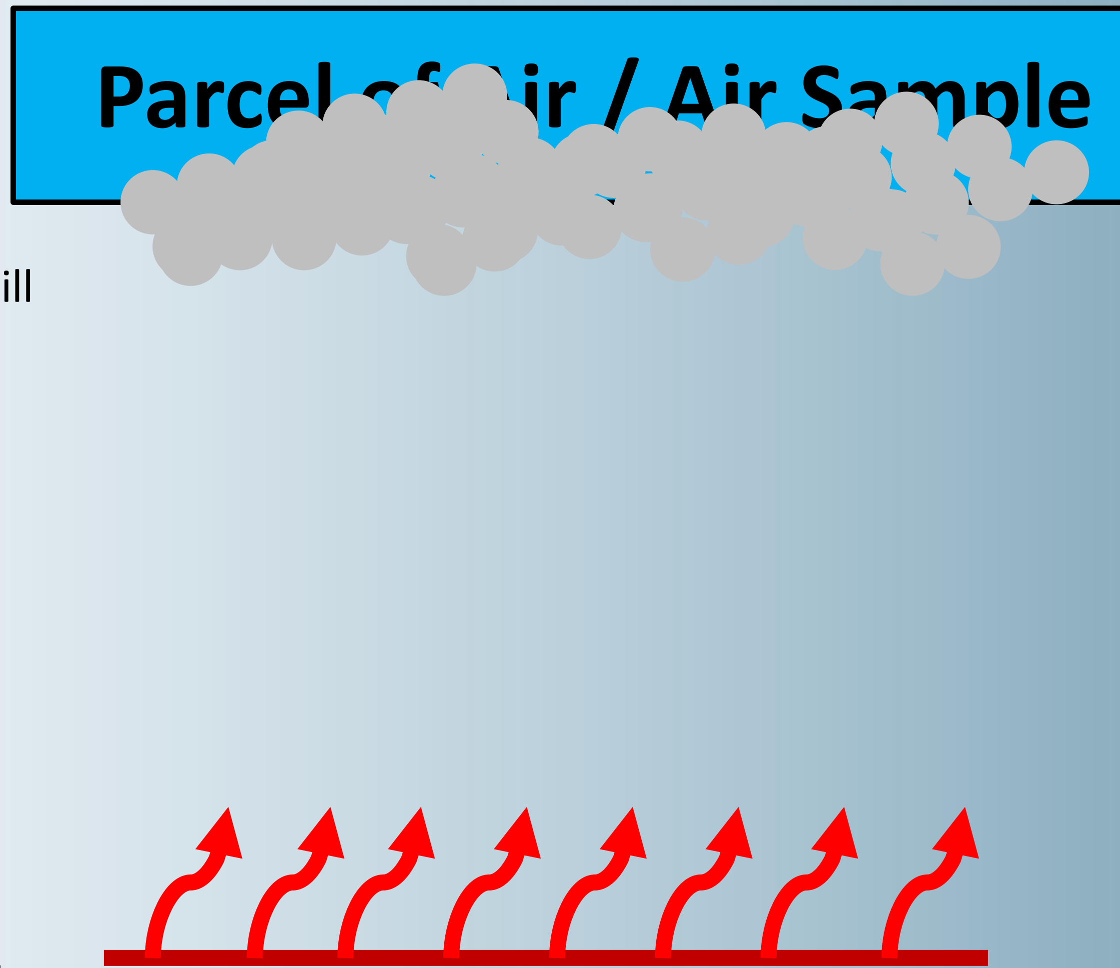
- This **expansion causes the air to cool**

- Even though no heat energy has been removed from the sample, the heat energy is simply more spread out, resulting in a lower overall temperature



Humidity & Relative Humidity

- **Cool air can hold less water vapour and therefore its relative humidity will rise**
- At a certain temperature – known as **dewpoint,** the air will reach **saturation – a relative humidity of 100%**
- Any excess water vapour will condense to form water droplets
- For water droplets to form, **hygroscopic nuclei** must be present
- A large collection of these water droplets will form a **cloud**.



Humidity & Relative Humidity

- Now that we have a better idea of what is really going on, the following can be said about a sample of air:

1. If a sample of air is holding as much water vapour as it can, it is said to be saturated

2. If a sample of air is saturated, it has a relative humidity of 100%

3. In cloud, the air is saturated and the relative humidity is 100% - as the air continued to cool, excess water vapour has condensed into water droplets to form cloud

4. Over a desert during the day, the air is unsaturated and the relative humidity could be as low as 10%

DEW POINT

Dew Point

- Note that clouds are **NOT** formed from water vapour - water vapour is a colourless and odourless gas – **it is invisible!**

- Clouds only form **once the water vapour has condensed** after the air reaches dew point

- The correct definition for dew point is:

"The temperature to which a sample of air must be cooled at constant pressure in order for it to become saturated."

- Any further drop in temperature below dew point will result in condensation and formation of cloud/fog etc.

- As moisture content depends on altitude, the dew point temperature will reduce with altitude

- This is known as the **Dew Point Lapse Rate** and is about **0.6°C/1000ft**

LAPSE RATES

Lapse Rates

- As you may have figured out, the **lapse rate is the rate at which an air sample cools as it rises**
- Remember, the **cooling occurs via expansion** – not via the removal of any heat energy
- This process is termed **adiabatic** – meaning a **change in temperature due to a change in pressure**, without any addition or subtraction of heat into or out of the air
- There are 4 lapse rates we are concerned with:

    1. **Dry Adiabatic Lapse Rate (DALR)**
    2. **Saturated Adiabatic Lapse Rate (SALR)**
    3. **Environmental Lapse Rate (ELR)**
    4. **Dew Point Lapse Rate (DPLR)**

Lapse Rates

Dry Adiabatic Lapse Rate (DALR)

- A dry/unsaturated sample of air will cool at the DALR as it rises and expands
- This is **3°C/1000ft**

Saturated Adiabatic Lapse Rate (SALR)

- If a sample of air cools to its dew point and becomes saturated, condensation occurs
- As water vapour has changed state into water, latent heat is released
- This causes the saturated air sample to cool more slowly – at **1.5°C/1000ft**

Lapse Rates

Environmental Lapse Rate (ELR)

- The ELR is not concerned with a sample of air – rather the air surrounding that sample
- In ISA conditions, the ELR is **2°C/1000ft**
- In reality, it may be lower or higher than this value

Dew Point Lapse Rate (DPLR)

- The DPLR is the decrease in the dew point temperature as altitude increases
- This is **0.6°C/1000ft**
- The DPLR and DALR can be used to calculate cloud base heights – you will learn this at ATPL Level

STABILITY vs. INSTABILITY

Stability vs. Instability

- The atmospheric stability is determined by the relationship between the lapse rates we have just discussed

- Remember:

DALR – the lapse rate for a parcel of dry air (3°C/1000ft)

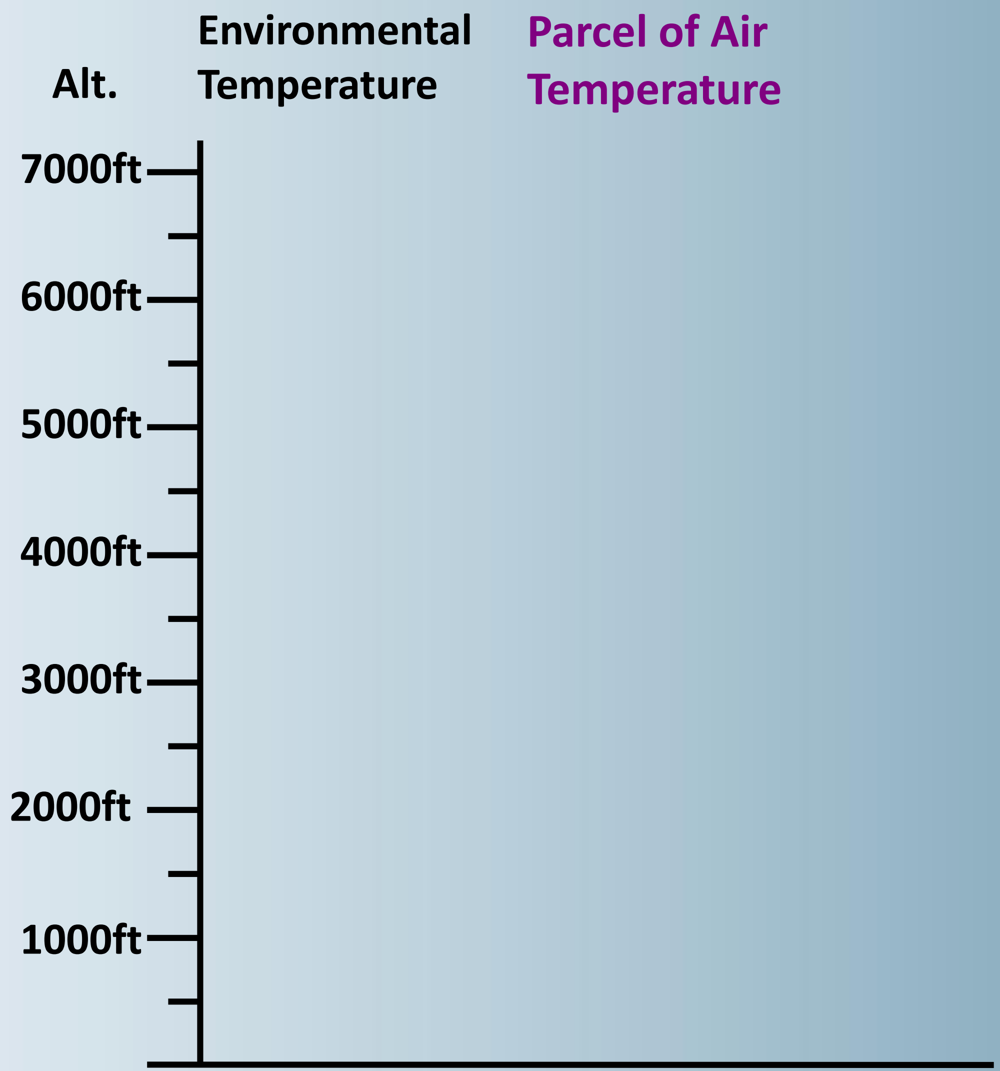
SALR – the lapse rate for a parcel of saturated air (1.5°C/1000ft)

ELR – the lapse rate of the surrounding air

Stability vs. Instability

Stable Atmosphere

- When a parcel of air rises it will expand and cool
- If it cools to the same temperature as the surrounding air, it will stop rising
- This is because its density is the same as that of its surroundings
- An atmosphere where air remains at one level is called stable



Stability vs. Instability

Stable Atmosphere

Example:

- ***ELR = 2° C/1000ft***
- ***DALR = 3° C/1000ft***
- ***SALR = 1.5° C/1000ft***
- ***Dew Point = +1° C***
- As altitude increased, the temperature difference between the parcel of air and the environment decreased
- The parcel of air never reached its dew point temperature and therefore cloud has not formed

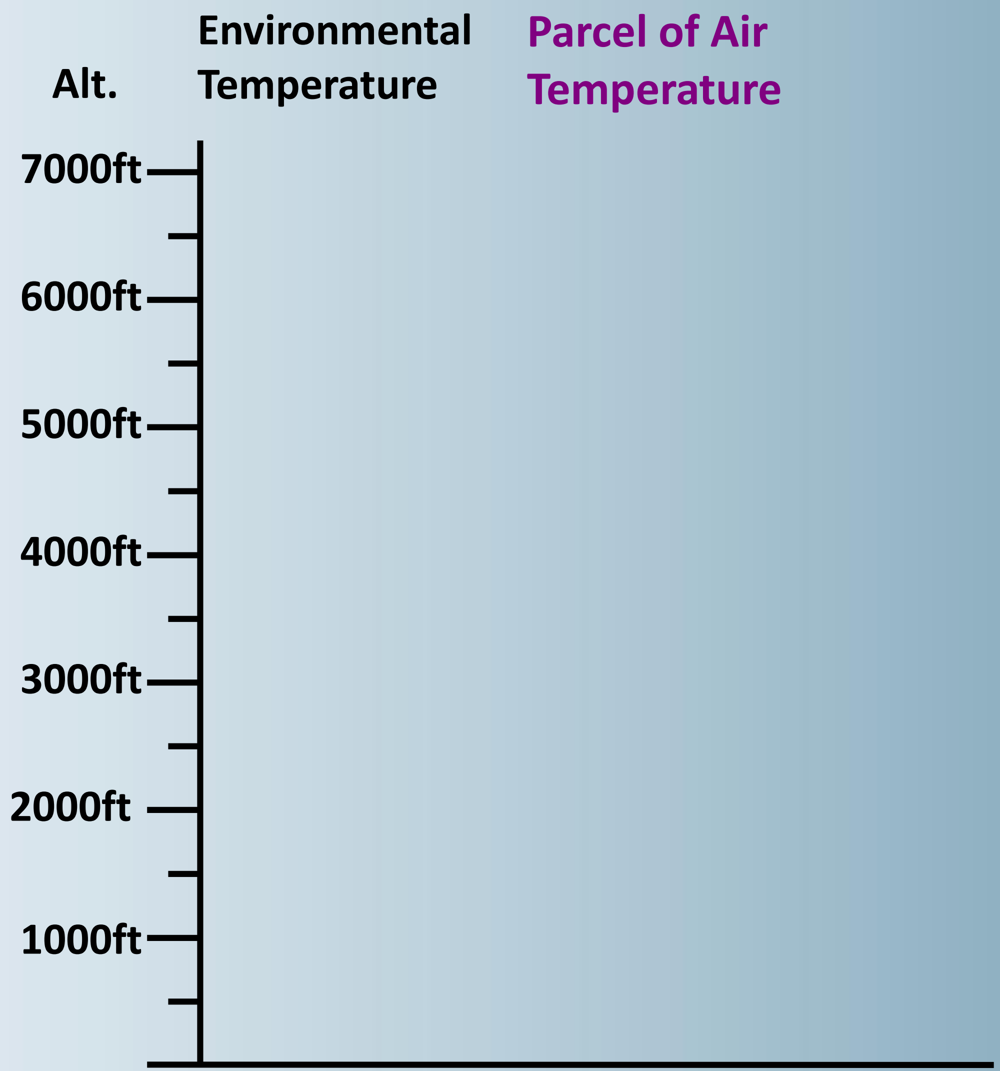
Alt.	Environmental Temperature	Parcel of Air Temperature
7000ft	1° C	
6000ft	3° C	
5000ft	5° C	5° C
4000ft	7° C	8° C
3000ft	9° C	11° C
2000ft	11° C	14° C
1000ft	13° C	17° C
	15° C	20° C

Air would stop rising as it is now equal temperature to the surrounding air

Stability vs. Instability

Unstable Atmosphere

- However, if the rising parcel of air remains warmer than its surroundings, it will continue to rise of its own accord – an unstable atmosphere



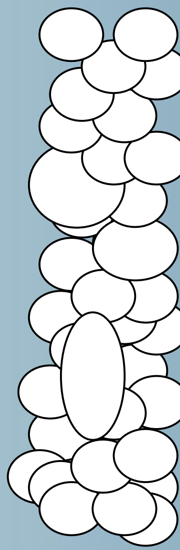
Stability vs. Instability

Unstable Atmosphere

Example:

- ***ELR = 4° C/1000ft***
- ***DALR = 3° C/1000ft***
- ***SALR = 1.5° C/1000ft***
- ***Dew Point = +5° C***
- As altitude increased, the temperature difference between the parcel of air and the environment increased
- The parcel of air reached dew point, so cloud formed and would continue to rise to a high extent due to instability

Alt.	Environmental Temperature	Parcel of Air Temperature
7000ft	-13° C	2° C
6000ft	-9° C	3.5° C
5000ft	-5° C	5° C
4000ft	-1° C	8° C
3000ft	3° C	11° C
2000ft	7° C	14° C
1000ft	11° C	17° C
	15° C	20° C



CONDITIONAL STABILITY

Conditional Stability

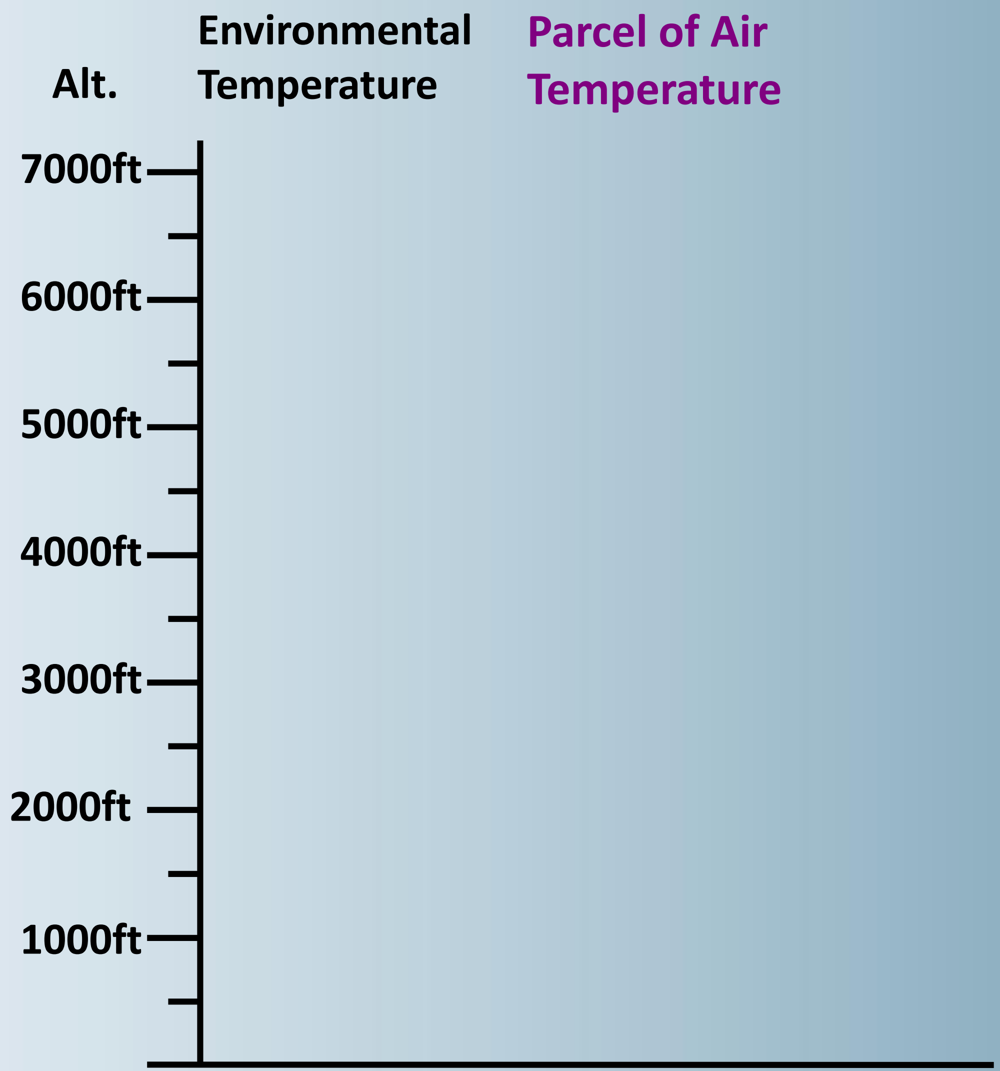
Conditionally Stable Atmosphere

- There are some cases where the stability depends on whether the air is saturated or not

- Conditional stability exists when:

1. **The atmosphere is stable for dry air**

2. **The atmosphere is unstable for saturated air**



Conditional Stability

Conditionally Stable Atmosphere

Example:

- ***ELR = 2° C/1000ft***
- ***DALR = 3° C/1000ft***
- ***SALR = 1.5° C/1000ft***
- ***Dew Point = +6° C***
- As altitude increased, the temperature difference between the parcel of air and the environment increased initially (in dry air) indicating a stable atmosphere

Alt.	Environmental Temperature	Parcel of Air Temperature
7000ft	1° C	3° C
6000ft	3° C	4.5° C
5000ft	5° C	6° C
4000ft	7° C	9° C
3000ft	9° C	12° C
2000ft	11° C	15° C
1000ft	13° C	18° C
	15° C	21° C

Conditional Stability

Conditionally Stable Atmosphere

Example:

- ***ELR = 2° C/1000ft***
- ***DALR = 3° C/1000ft***
- ***SALR = 1.5° C/1000ft***
- ***Dew Point = +6° C***
- However, as soon as the dew point was reached, the temperature difference began to increase with altitude
- Since the saturated air parcel is still warmer than the environment, it will continue to rise and is now unstable

Alt.	Environmental Temperature	Parcel of Air Temperature
7000ft	1° C	3° C
6000ft	3° C	4.5° C
5000ft	5° C	6° C
4000ft	7° C	9° C
3000ft	9° C	12° C
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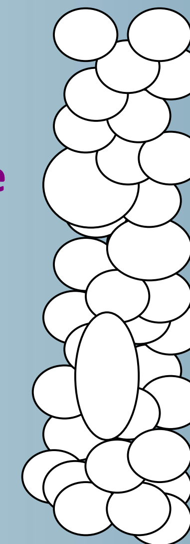


SUMMARY OF STABILITY

Summary of Stability

- The relationships between lapse rates and their associated stability condition can be summarised as follows:

Lapse Rate Relationship	Stability Condition
ELR > DALR	Unstable in all circumstances
ELR = DALR	Neutral if unsaturated; unstable if saturated
SALR < ELR < DALR	Stable if unsaturated; unstable if saturated
ELR = SALR	Stable if unsaturated, neutral if saturated
ELR < SALR	Stable in all circumstances
ELR is negative	Stable in all circumstances

Summary of Stability

- There are also certain weather characteristics associated with stability/instability:

Characteristics of Stable Air:

- Stratiform Clouds
- Steady precipitation in the form of rain/drizzle (if any)
- Poor visibility
- Smooth conditions
- Possibility of inversions/fog

Characteristics of Unstable Air:

- Cumuliform Clouds
- Precipitation in the form of showers
- Good visibility (due to rising air lifting pollutants to higher levels)
- Turbulence (especially in thermals)

INVERSIONS

Inversions – What are they?

- Whenever a layer of warm air exists above cooler air in the atmosphere, an inversion is said to exist

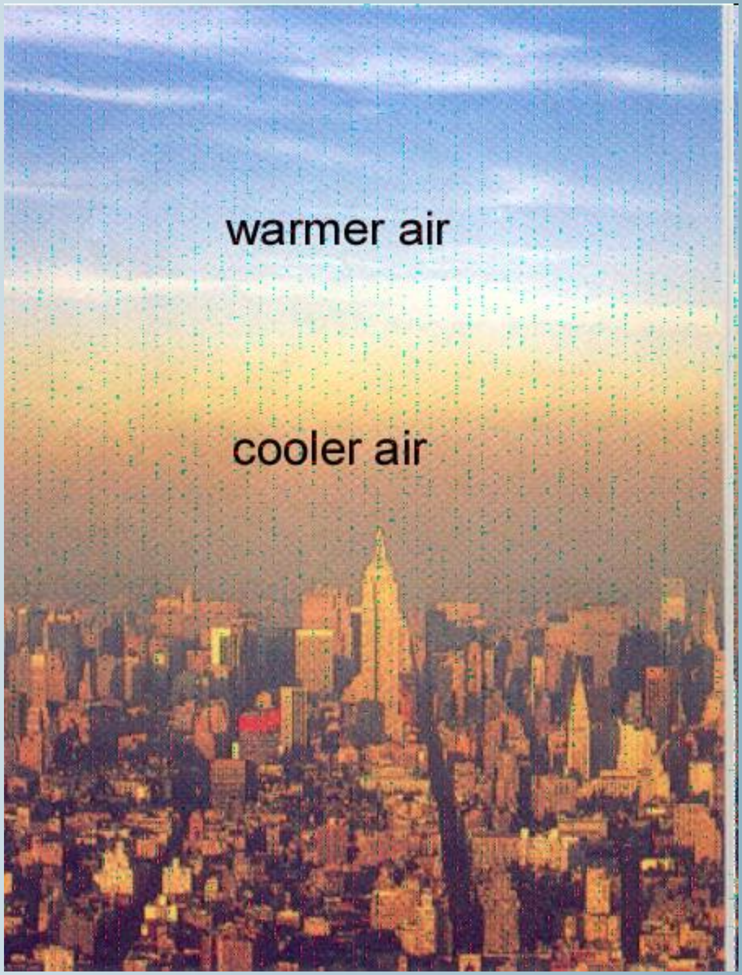
- Inversions are very common and can be formed in a number of ways:

1. Surface/Radiation Inversion

2. Turbulence Inversion

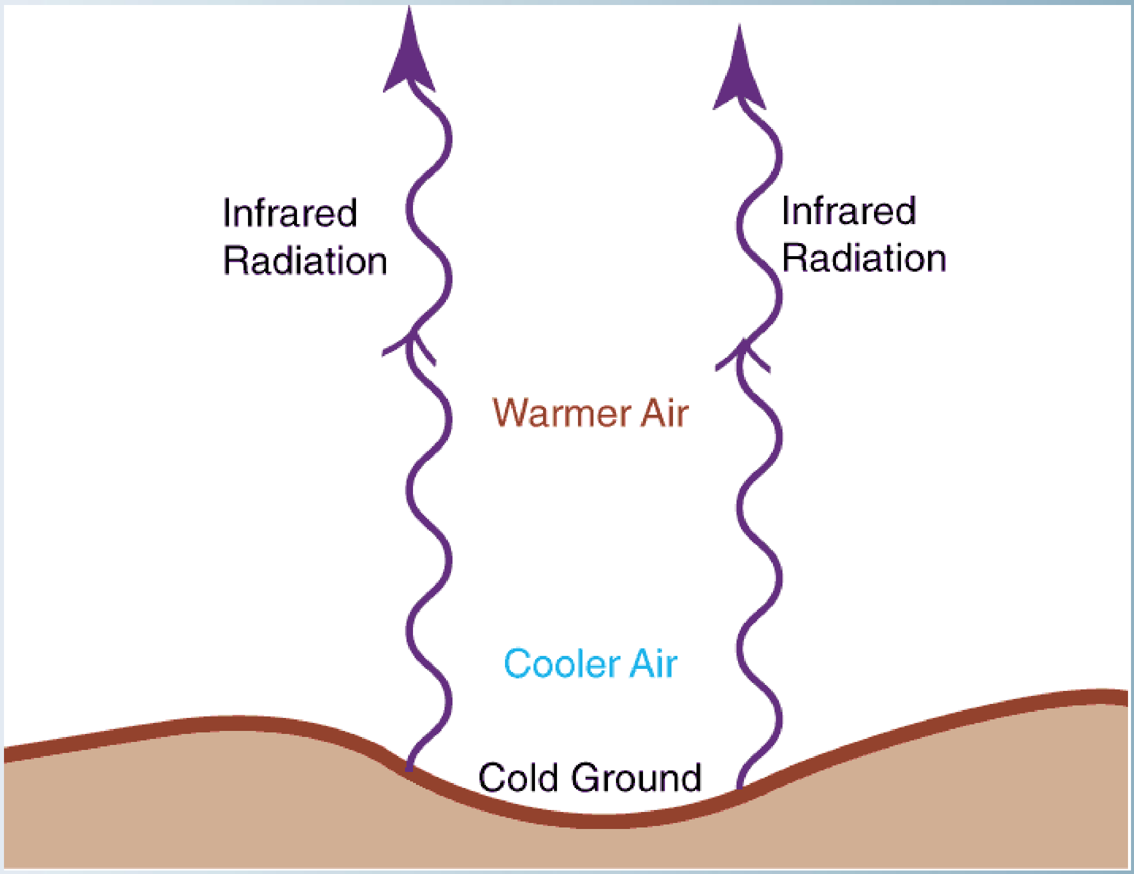
3. Frontal Inversion

4. Subsidence Inversion



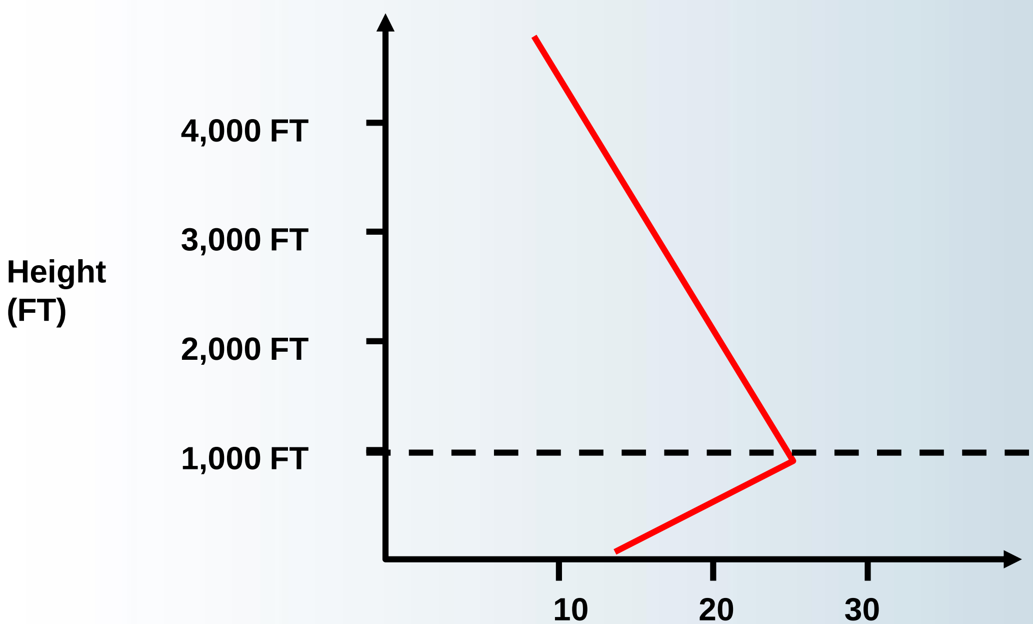
Surface/Radiation Inversion

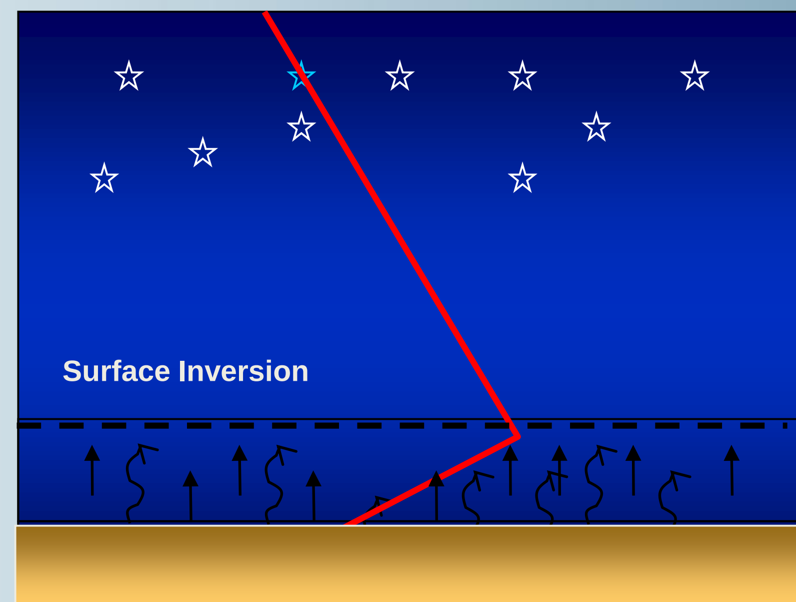
- The earth cools at night, meaning that the layer of air just above the surface will also cool – via conduction
- The effect is greatest just before dawn – when the surface temperature is the lowest
- A light wind will **weaken but deepen** the inversion layer



Surface/Radiation Inversion

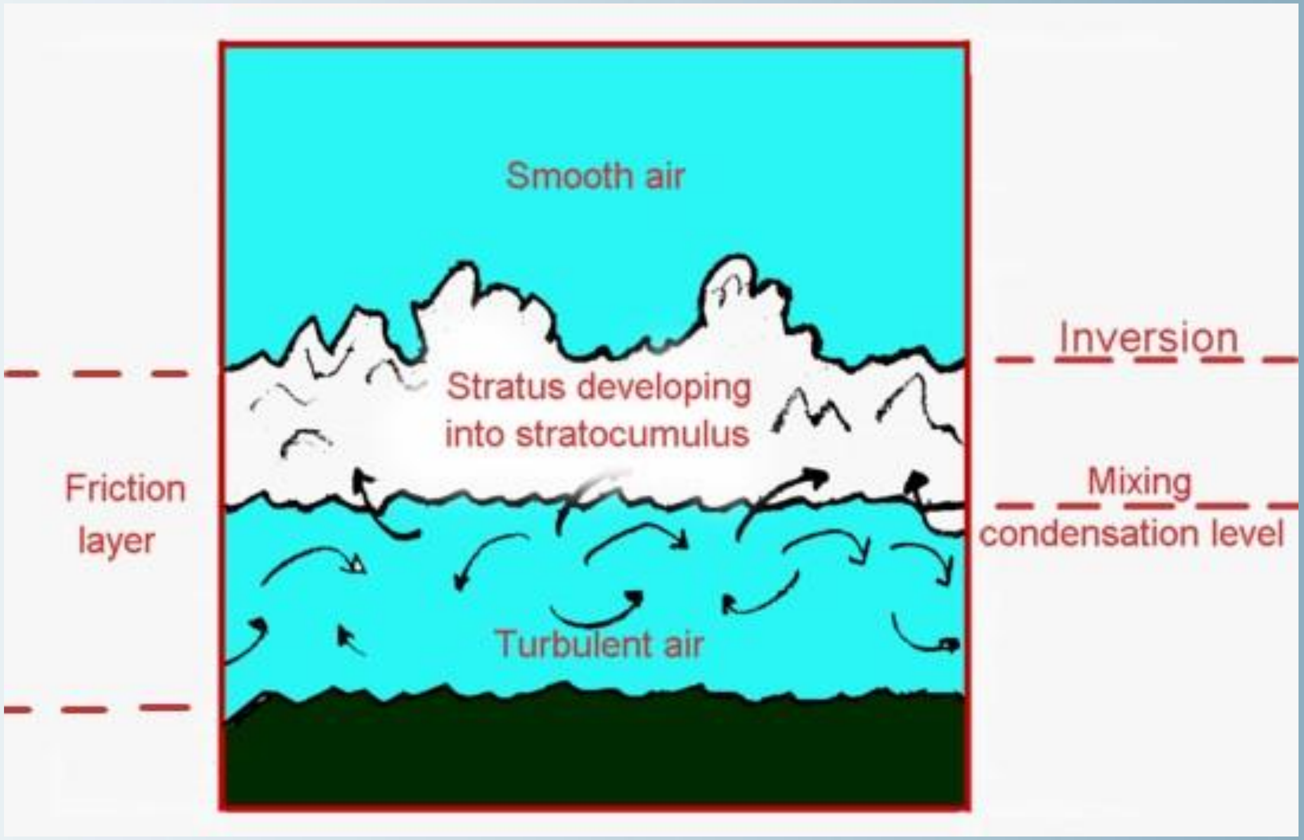
- Temperature will increase with altitude up to the **INVERSION LAYER**
- Usually several hundred feet thick with a strong temperature rise
- Above the inversion layer, wind and visibility conditions will be different





Turbulence Inversion

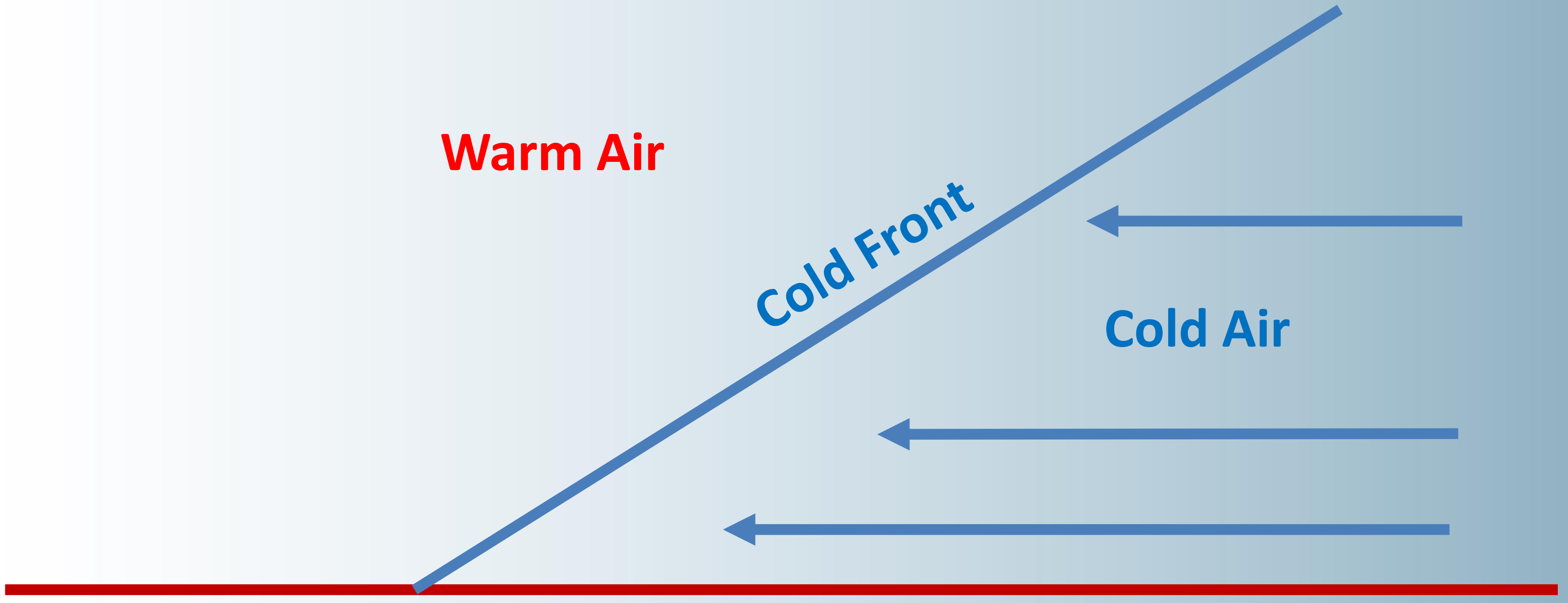
- Moderate winds at low level may cause mixing of layers of air
- The cooler air from above is carried to lower levels via the turbulence
- This will decrease the temperature of the lower levels and increase the temperature of the upper levels



- **Stratocumulus cloud** is associated with **turbulence inversions**

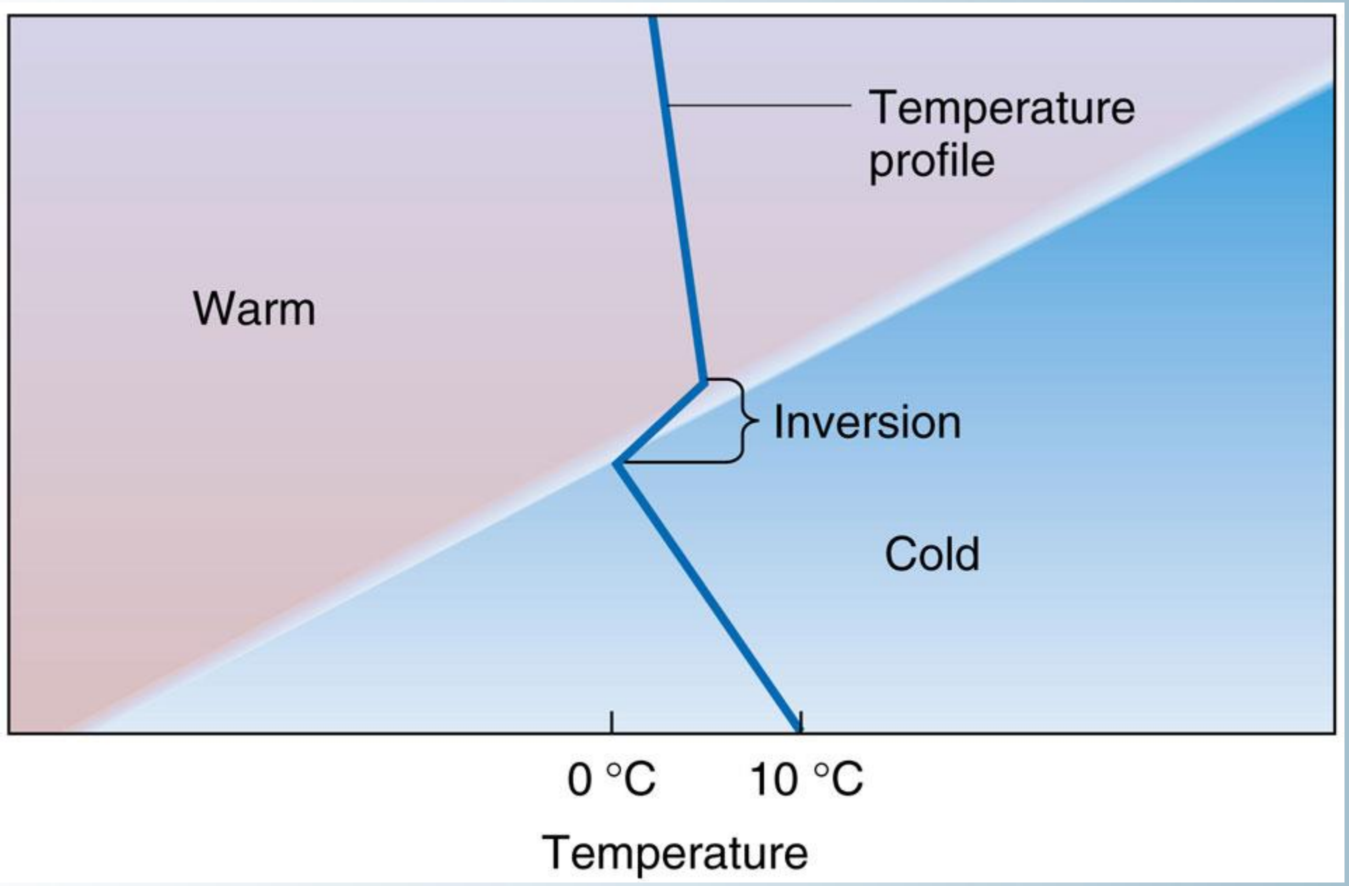
Frontal Inversion

- The boundary of two masses of different temperatures may form an inversion
- The less dense warm air will slide up over the denser, cooler air



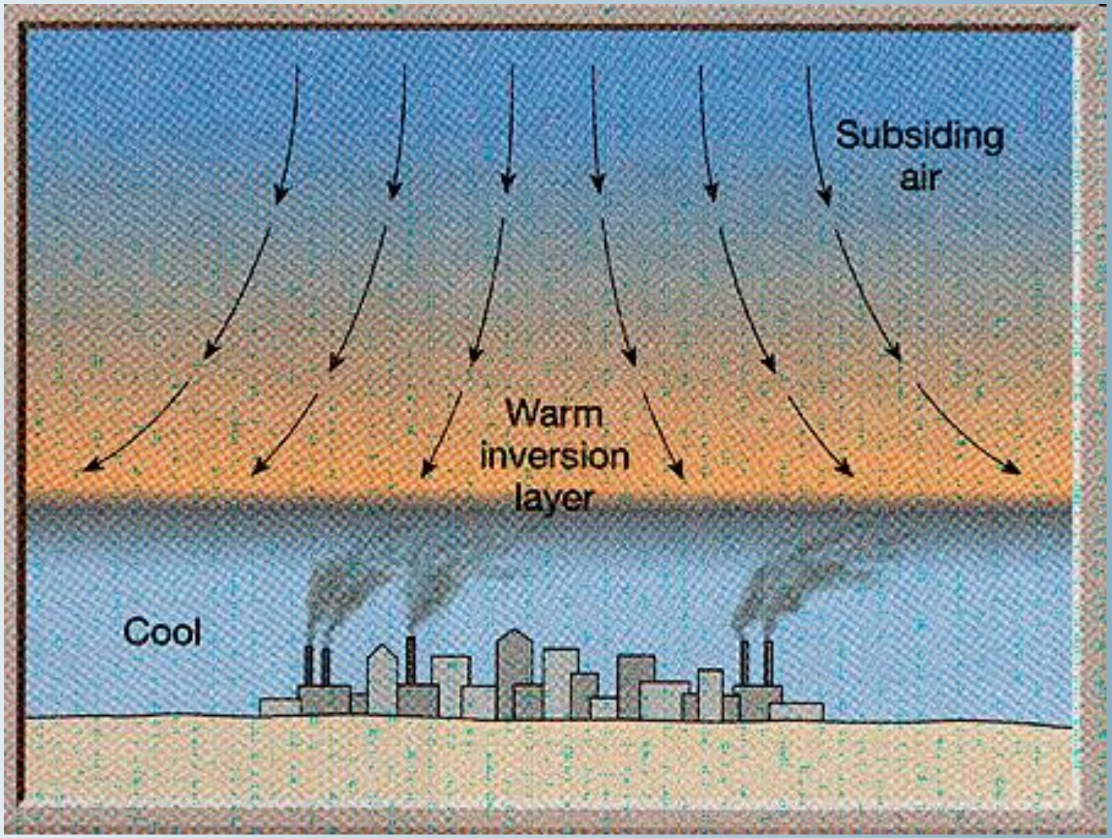
Frontal Inversion

- The actual inversion layer will be well above the surface i.e. several thousand feet
- The intensity & depth of the inversion is variable depending on the intensity of the front



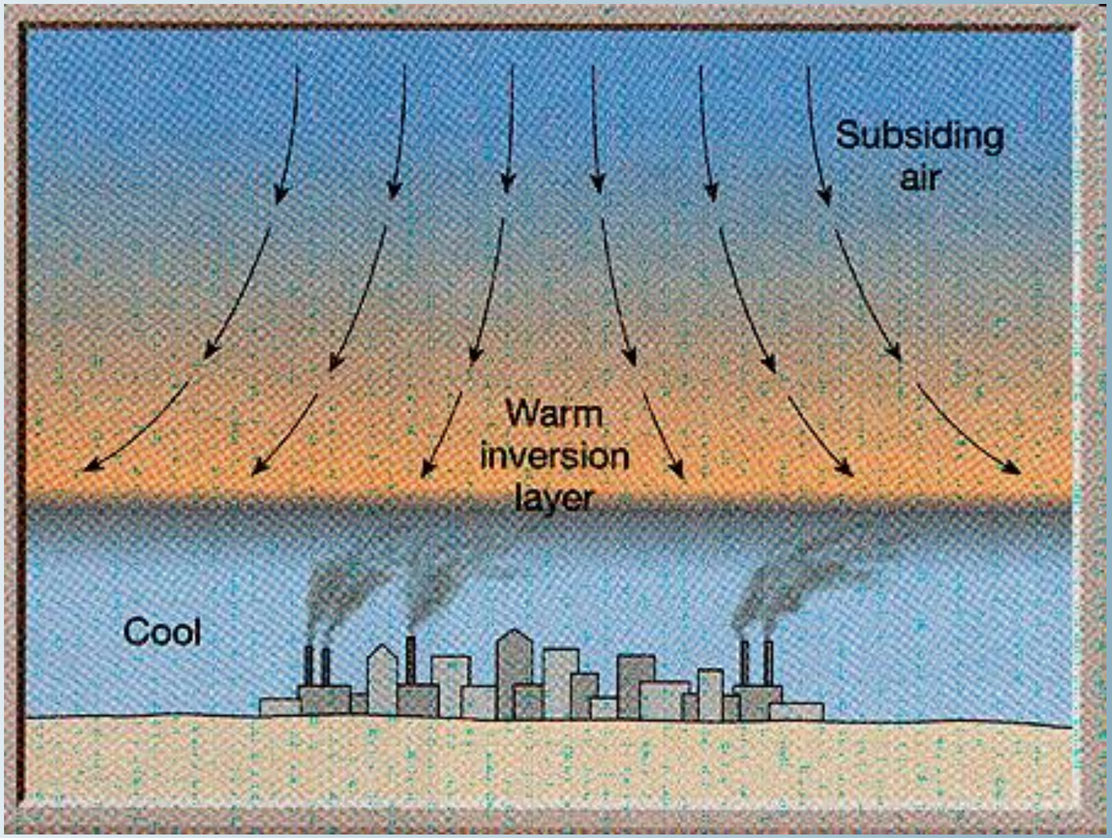
Subsidence Inversion

- Usually characteristic of a **High Pressure System**
- As a column of air subsides, the air at the top of the column subsides more than air at the bottom
- This means the air at the top will undergo more compression and heating and will ultimately achieve a greater temperature



Subsidence Inversion

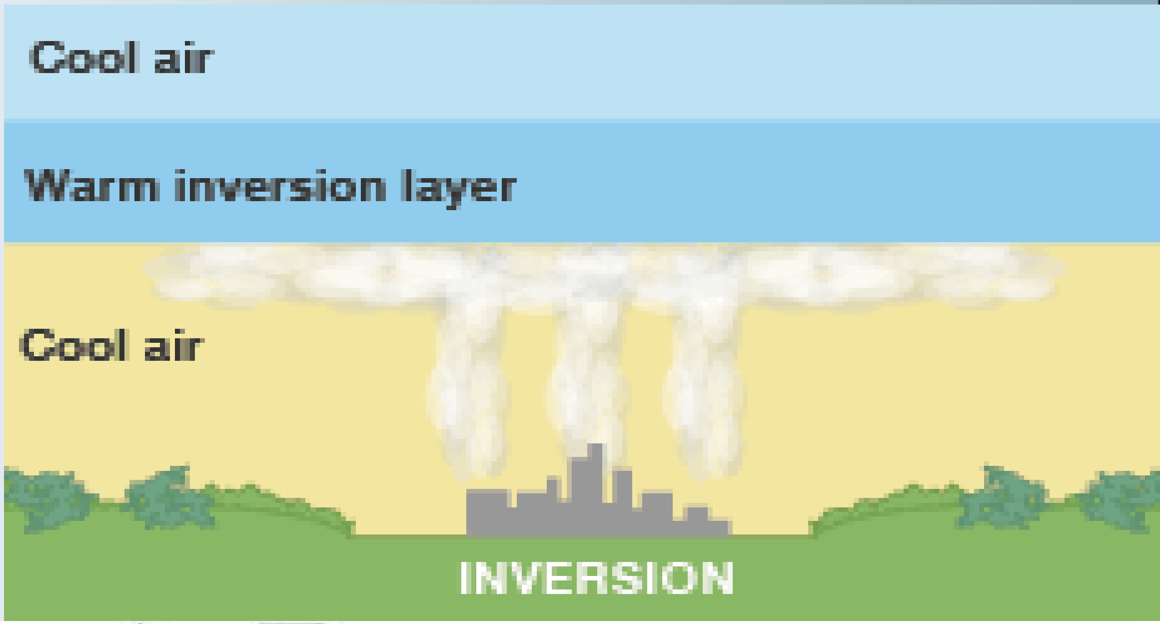
- They usually lie 4000 – 6000 ft above the surface
- Can be quite strong (as much as 15° C temperature rise)
- Inversion Layer can be up to 500ft thick

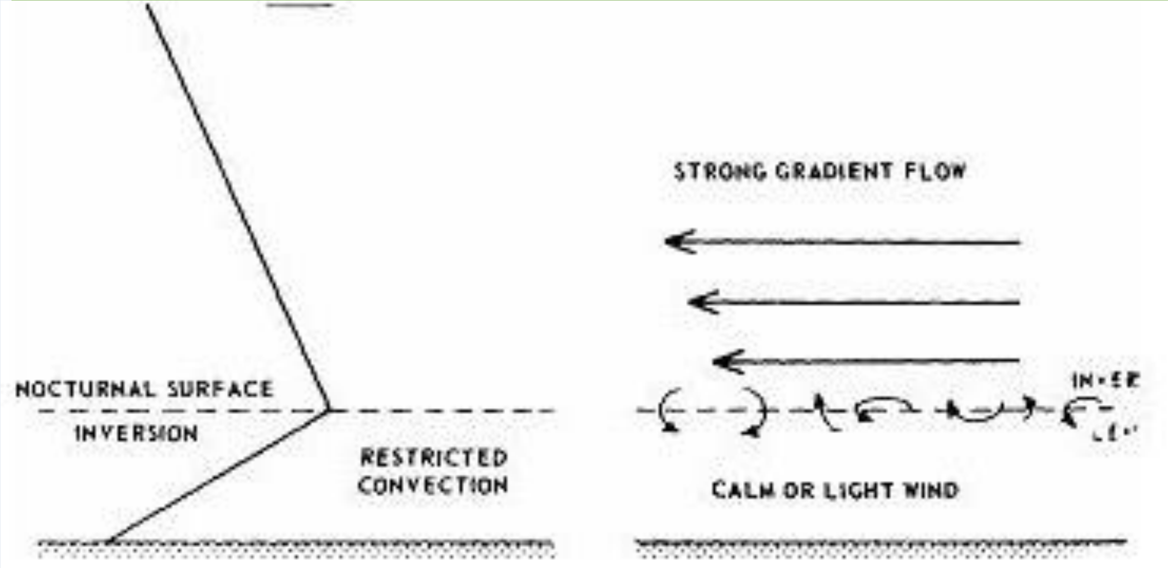


INVERSION CHARACTERISTICS

Inversion Characteristics

- Inversions are associated with **stable conditions**
- The warm air in the inversion layer stops rising air currents
- This means that smoke, dust and other pollutants will be trapped at or beneath the inversion layer
- Wind conditions may also vary above/below the inversion – pilots must be mindful of **wind shear**





Inversion Characteristics

At/Below the Inversion Layer:

- Temperature increasing with altitude
- Poor Visibility
- Bumpy Conditions

Above the Inversion Layer:

- Temperature decreasing with altitude
- Good Visibility
- Smooth Conditions