Pilot Manual

3- Weather part I

ASSOCIATION of PARAGLIDING PILOTS and INSTRUCTORS

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Association of Paragliding Pilots and Instructors

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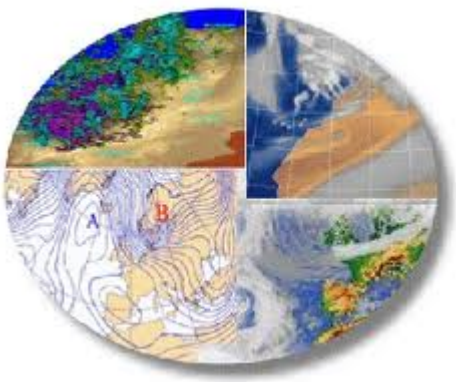
3.1 - Introduction

Apart from the choice of land and equipment, it is important to know the weather conditions to safely fly a paraglider.

This chapter gives an insight to the basic principles of meteorology.

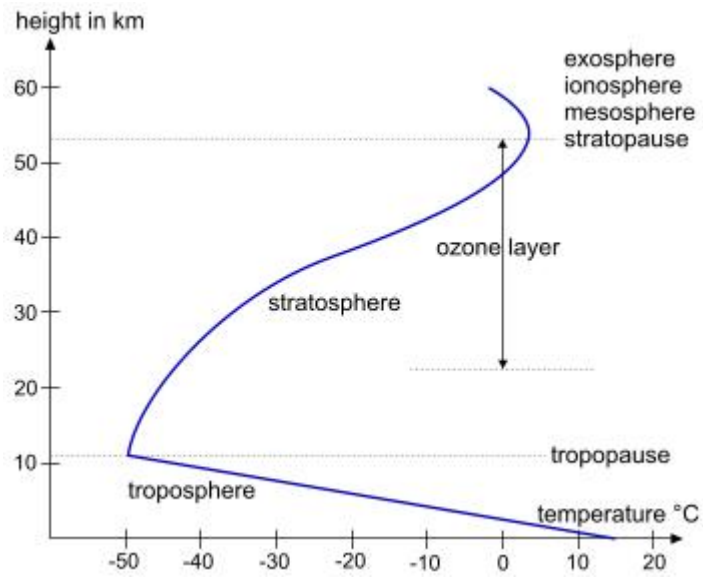
This theoretical information can be put into practice in different ways:
• by checking several meteorological services at home.
• by a wise observation of the weather when going to the flying site (increasing wind for example), as sometimes there are different conditions locally.
• by questioning the locals. Don't be shy to ask information about the specific weather of the area, they can provide important information.
• by a systematic observation of the weather and know the forecast, make a personal weather analysis and prediction and comparing it to the actual weather evolution.



3.2 - The atmosphere

The air layer surrounding the Earth is called the **atmosphere**. It goes to an altitude of 1000 kilometers and then melts in

the outer space with no definite boundary.

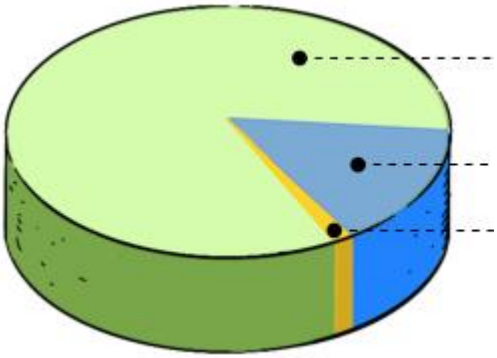


The atmosphere is composed of different layers called spheres.
All the weather phenomena happen in the lowest layer, the **troposphere**.
Toward the outside, this layer is in contact with the **stratosphere**.
The boundary between these two layers is called the **tropopause**, a very efficient inversion layer that does not allow moisture to pass. For this reason clouds almost don't exist in the stratosphere, only horizontal flows.

The **ozone layer**, at an altitude of about 50 km, prevents much of the harmful UV rays (ultraviolet) of reaching the Earth's surface.
This protective belt is strongly affected by pollution: gases, such as engine exhaust gases, eventually create holes on it.
The troposphere reaches an altitude of 6 kilometers at the poles, 11 kilometers in mid latitudes and rises until around 16 kilometers at the equator.

3.3 - The air

The air mass: This name is given to a certain part of the atmosphere which has always the same criteria of temperature and humidity. (For example: the Arctic air mass).
Pure air is a gas mixture consisting mainly of 20% **oxygen** and 80% **nitrogen**.



nitrogen 78%
oxygen 21%
carbon dioxide and rare gases 1%

Oxygen is a vital gas for breathing. Carbon dioxide (C02) lets the sunlight energy pass through but holds the heat re-emitted by Earth (greenhouse effect). If there is too much C02 in the air, there will be a general warming of the Earth's surface. This will involve long-term changes in climate.

In addition, microscopic particles, called condensation nuclei shear, are suspended in the air. They come from the combustion residues, pollen and sea sprays. They play an important role in the condensation phenomenon that we will see later.

3.3.1 Atmospheric pressure

Just like any other body under Earth's magnetic influence, the weight of air exerts pressure on the soil surface. This pressure depends on the thickness of the air column above the measuring point. The higher the altitude the lower the pressure is. But because the air is compressible this pressure decrease is not linear but exponential. At 3000 meters the pressure has decreased by one third to be no more than half at 5500 meters and a quarter at 11,500 meters.

- Unit of measure: **kilopascals** (kPa)
- Average pressure at sea level (standard atmosphere): **101.3 kPa**
- Measuring instrument: barometer

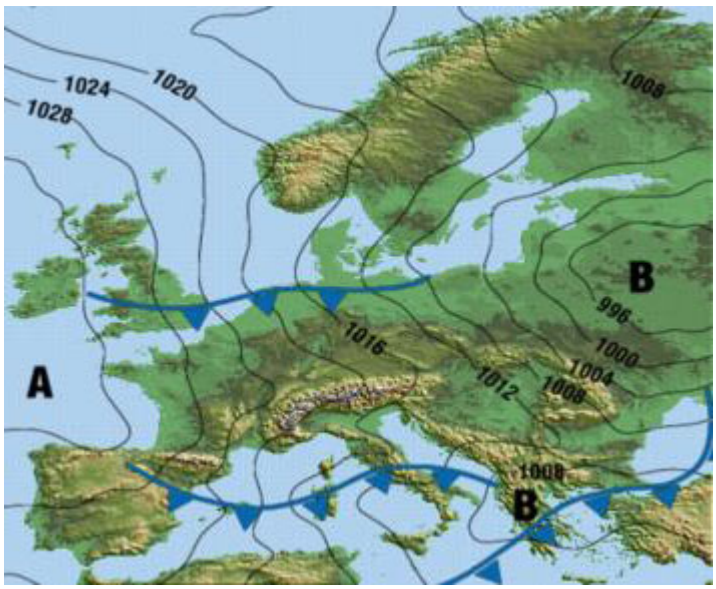
When paragliding at high altitudes you must monitor the effect on your health and mental fitness. High altitude sickness can occur. As altitude increases, the concentration remains the same but the number of oxygen molecules per breath is reduced. At 12,000 feet (3,658 meters) the barometric pressure is only 483 mmHg, so there are roughly 40% fewer oxygen molecules per breath. In order to properly oxygenate the body, your breathing rate (even while at rest) has to increase.

This extra ventilation increases the oxygen content in the blood, but not to sea level concentrations. Since the amount of oxygen required for activity is the same, the body must adjust to having less oxygen. In addition, for reasons not entirely understood, high altitude and lower air pressure causes fluid to leak from the capillaries which can cause fluid build-up in both the lungs and the brain. Continuing to higher altitudes without proper acclimatization can lead to potentially serious, even life-threatening illnesses.

If you are paragliding and finding you are climbing quickly to very high altitudes you must watch yourself carefully to see how you are reacting. If you start to feel unwell then it is time to go down. Also make sure you are properly hydrated as you can cause long term damage to your body

The paraglider will fly faster and more dynamically at higher altitudes. Take offs and landings will be faster, any incidents that happen will be quicker but your reactions may be slower.

Special features: **Isobars** are lines of equal pressure on weather maps. The measuring stations are located at different altitudes (example: Geneva and Jungfrau). To get comparable results, the measured pressure is converted by calculation to a standard level, which may be the sea level for instance.
In this drawing, the units are represented Hectopascals (hPa).



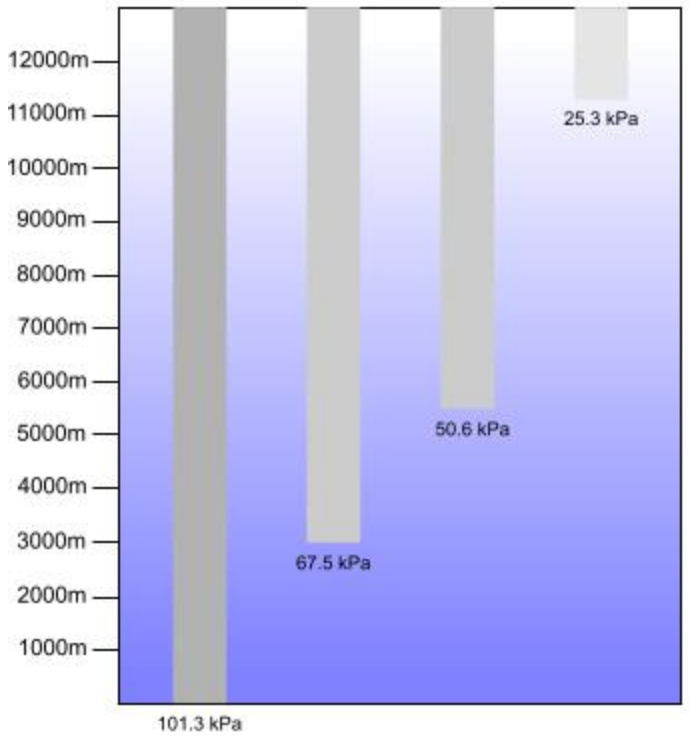


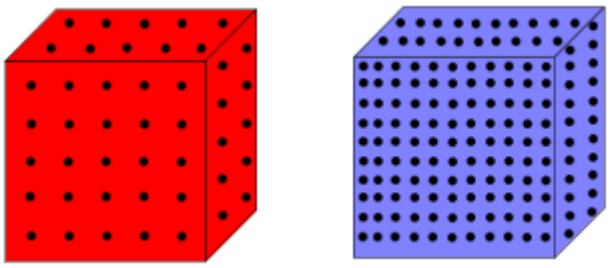
Figure 3-3: Graphical representation of the average air pressure at different altitudes above sea level.

3.3.2 Density

Density is the mass per unit of volume, i.e., the number of air molecules per cubic meter. It depends mainly on temperature and pressure. Like almost all the materials, the air expands as it warms. Thus we have more particles in a cubic meter of cold air than in a warm one. This is the reason why the same volume of air is lighter if it is warm than if it's cold. We will return to this theme in the thermals.

With a decrease in pressure, there is a decrease in density. Thus the density of air also decreases with altitude. At 6600 meters the density is only by half compared to that of sea level.

- Unit of measure: **kg / m³**
- Average density at sea level (standard atmosphere): **1,225 kg / m³**



hot air cold air

Links with practice:

Given the lower density, flying at high altitude means flying faster and therefore, during takeoff, you will have to run faster. On the other hand the altitude flight allows for stronger winds.

3.3.3 Air humidity

The water is in the form of three states: **solid**, **liquid**, **gas**.

→ **solid** (ice)	**fusion** melting point: 0°C	→ **liquid** (water)	**evaporation** boiling point: 100°C	→ **gaseous** (vapor)
←	crystallization point: 0°C **crystallization**	←	dewpoint: 100°C **condensation**	←

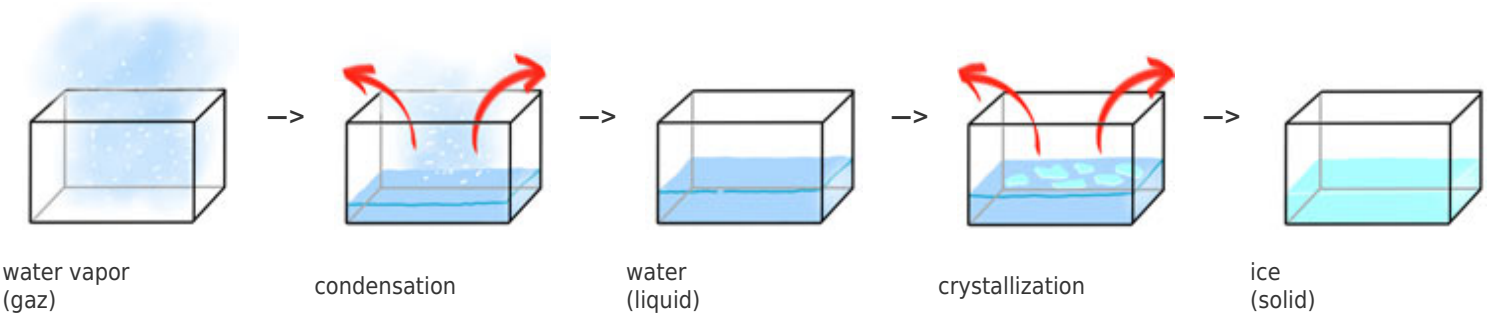
Latent Heat Energy:

If a substance is changing from a solid to a liquid, for example, the substance needs to absorb energy from the surrounding environment in order to spread out the molecules into a larger, more fluid volume. If the substance is changing from something with lower density, like a gas, to a phase with higher density like a liquid, the substance gives off energy as the molecules come closer together and lose energy from motion and vibration.

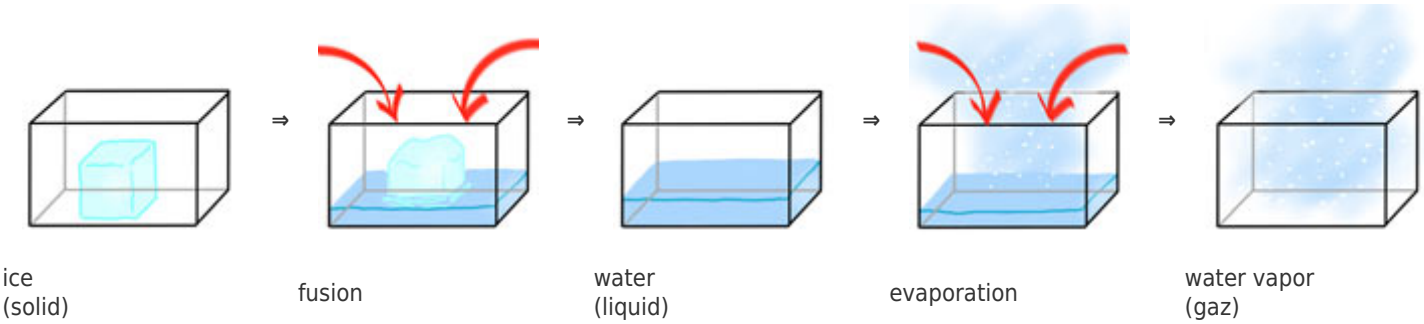
If water is changed from a Solid to a liquid, or from a liquid to a gas then latent heat energy is absorbed from the atmosphere. If water is changed from a gas to a liquid, or from a liquid to a solid latent heat energy is released into the atmosphere.

One might think there is evaporation or, in the reverse, condensation only occurs when reaching 100°C. But this is not the case in meteorology, as we will see.

Water vapor as a gas contains more energy (heat) that liquid water because the change from solid to gaseous state releases energy. It is the same between liquid water and ice. We can say that the condensation and crystallization emit energy in the environment.



Unlike the energy return during fusion and evaporation because these transformations of states require energy.



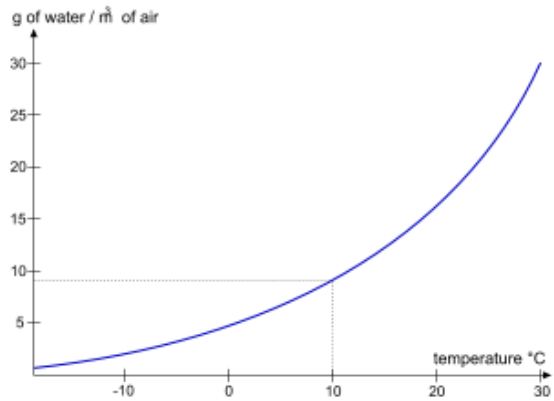
In weather phenomena the water changes from liquid to gas state without reaching the boiling point. We experience this phenomenon everyday through sweating. Sweat drops appear on the skin surface and evaporate thereby cooling the immediate environment of the epidermis, implying a decrease in body temperature. In nature, water (lakes, seas, rivers) and soil humidity evaporate below 100°C by the fact that the air soaks up this moisture depending on its temperature as a more or less tight sponge. For every air mass three types of humidity will be referred:

- Saturation humidity (**SH**)

  Is the maximum amount of moisture (grams per cubic meter) that an air mass can contain at a given temperature.
  - Unit of measure: g (water vapor) / m^3 (air) at a °C temp
  - Application: by experimental curve

    Depending on temperature and pressure an air mass contains more or less water vapor.

*Fig. 3-9: **Water vapor curve**: It shows the maximum grams of water a cubic meter can contain at a given temperature. As there are fewer particles of air in a cubic meter of warm air than in a cold one, we can imagine it has more free space for water particles. Using the sponge example again, we can say it soaks up more if it has an airy texture.*

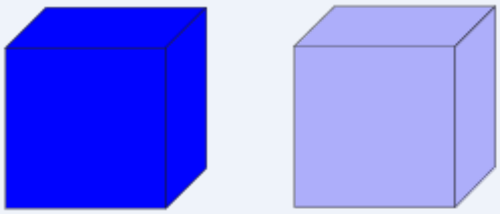


- **Absolute humidity** (AH)
  It is the quantity of water actually contained in an air mass.
  - Unit of measure: g (water) / m^3 (air)
  - Application: by measuring instruments such as the hair hygrometer, psychrometer or, in altitude, the radiosondes.

- **Relative humidity** (RH)
  It is the ratio between absolute and saturation humidity.
  - Unit of measure: ratio in %
  - Application: by formula AH: SH x 100
  - Average at sea level (standard atmosphere): 70%

Dewpoint: It is the temperature at which a cooling air mass reaches 100% of relative humidity. If saturated air cools again the relative humidity remains at 100%, but microscopic water droplets appear, they gather and form a cloud. Since every ascending air mass has its own dew point, the height of cloud bases varies.

Example: 1m^3 of air at a temperature of 10 ° C may contain at most 9.5 g of water vapor (along curve of water vapor).



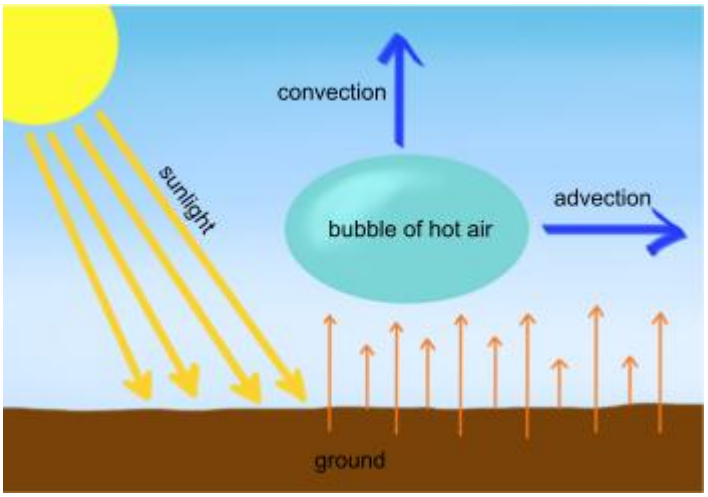
temperature:	10°C	10°C
absolute humidity:	9.5g	4.75g
relative humidity:	100%	50%

3.3.4 Temperature

The air is mainly heated in contact with the earth's surface which gets the majority of the sun's energy. In fact, the soil gets warm with the absorption of solar radiation and transfers this heat to its environment in different ways:

⇒ **by Conduction**: Through direct contact heat is transferred through the vibration of molecules in a substance. As something gets warmer, it begins to increase the vibration and movement of the molecules that it consists of. Only the air layer surrounding the soil is warmed by conduction.

⇒ **by Radiation**: heat propagation in wave form. The heat absorbed by the soil during the day spreads into the atmosphere during the night by radiation. On an overcast day this cooling is lower than in a clear one as the clouds form a shield that returns this radiation to the earth.
⇒ **by Convection**: The transfer of heat from a warmer region to a cooler one by moving air from the heated area to the unheated area. The vertical movements of air masses happen by convection.
⇒ **by Advection**: horizontal movement of air masses. A moist air mass moving horizontally towards a cold surface will create advection fog.

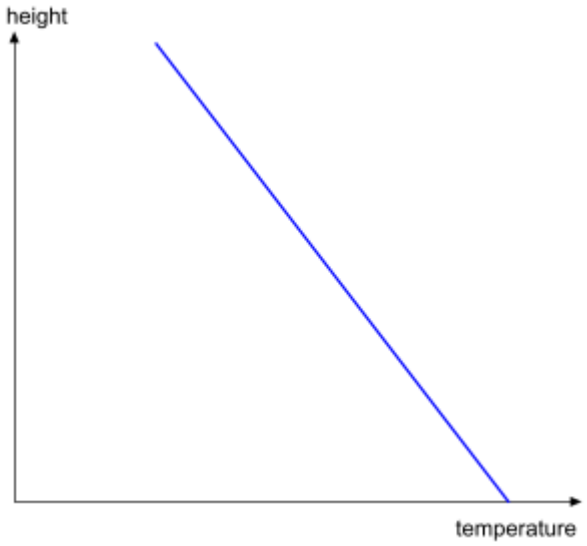


- **Unit of measure**: °C (Celsius)
- **Average at sea level** (standard atmosphere): 15°C
- **Measuring instruments**: thermometer (it should never be exposed to direct sunlight or to direct contact with objects that could influence the measurement). In altitude radiosondes are used.
- **Vertical thermal gradient**:
  The temperature variation according to altitude is called the vertical thermal gradient (sometimes called standard

temperature gradient). Because air is a poor conductor temperature decreases with altitude. Till the tropopause the temperature, that normally decreases, may either remain stable (isothermal) or increase (thermal inversion).

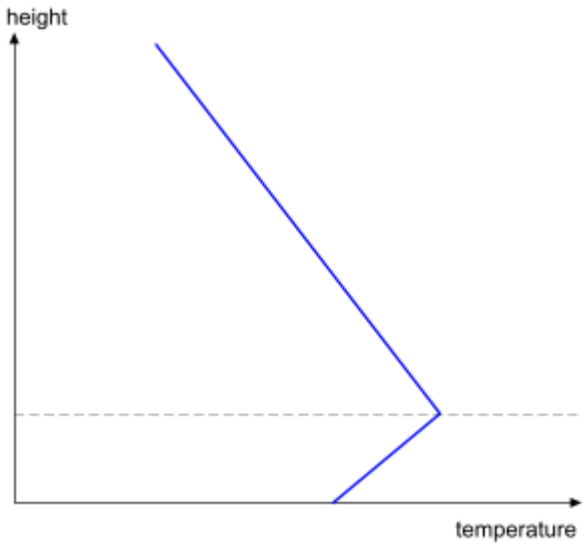
- **Average rate** (standard atmosphere - Environment Adiabatic Lapse Rate - EALR): 0,65°C / 100 m

- **Curve of a homogeneous stable air** (standard temperature gradient)
Regular decrease of temperature with altitude (negative temperature gradient)



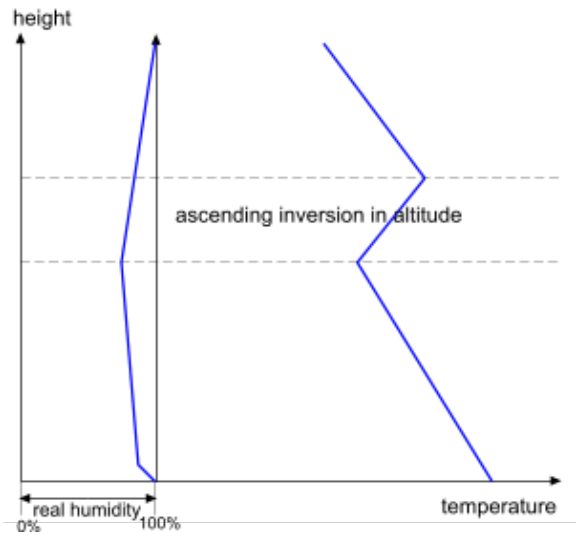
When the temperature increases with altitude, this is called **inversion**.

- **Inversion on the ground**:
A cloudless sky allows the heat to radiate since the sunset. As a result, the air layers near the ground cool down. As we already saw, because the air is a poor conductor, the cooling is only on the lower layers. In comparison with the standard curve the temperature increases with altitude and only from a certain altitude it cools again.



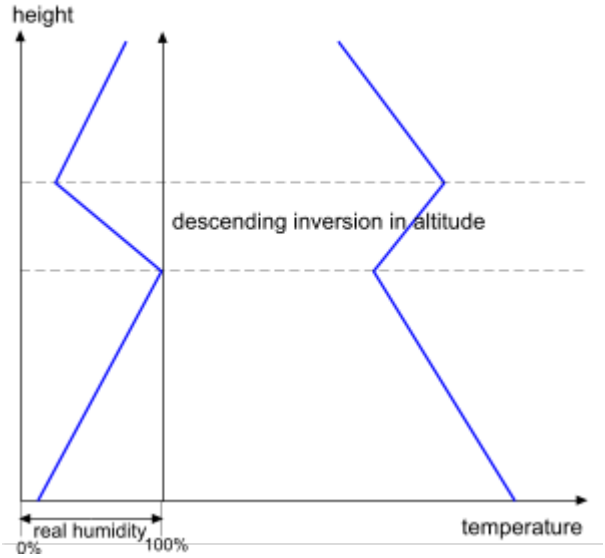
Upward inversion layer

In a warm front there is, at a certain altitude, a warmer air layer than that prevailing on the ground. It has a high relative humidity that makes the air in this layer to heat instead of cooling and then it decreases again from a certain altitude (See fronts explanation)



Downward inversion layer

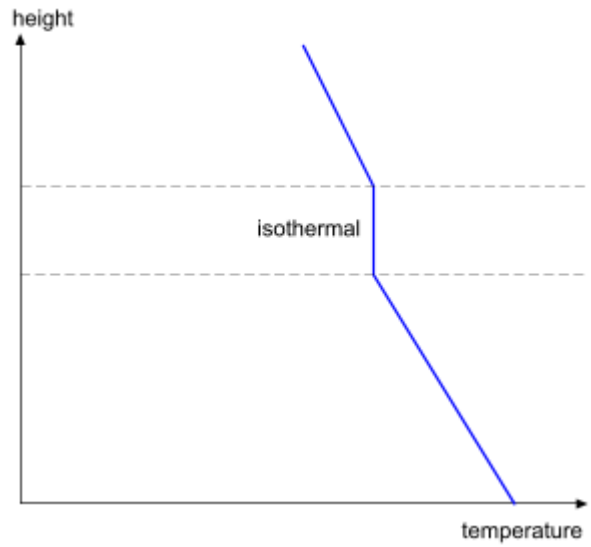
When unsaturated air descends from high altitudes, it warms 1°C per 100 meters (see explanation on adiabatic). During this descent its relative humidity decreases. The absolute humidity remains constant, but with the warming it moves away from its dew point. In most cases this descent (subsidence) stops by the presence of a layer of cold air on the ground. At this limit we find typical clouds of this situation, namely the stratus. Above this barrier layer we have a good horizontal visibility. One can often notice this situation during the winter high pressures.

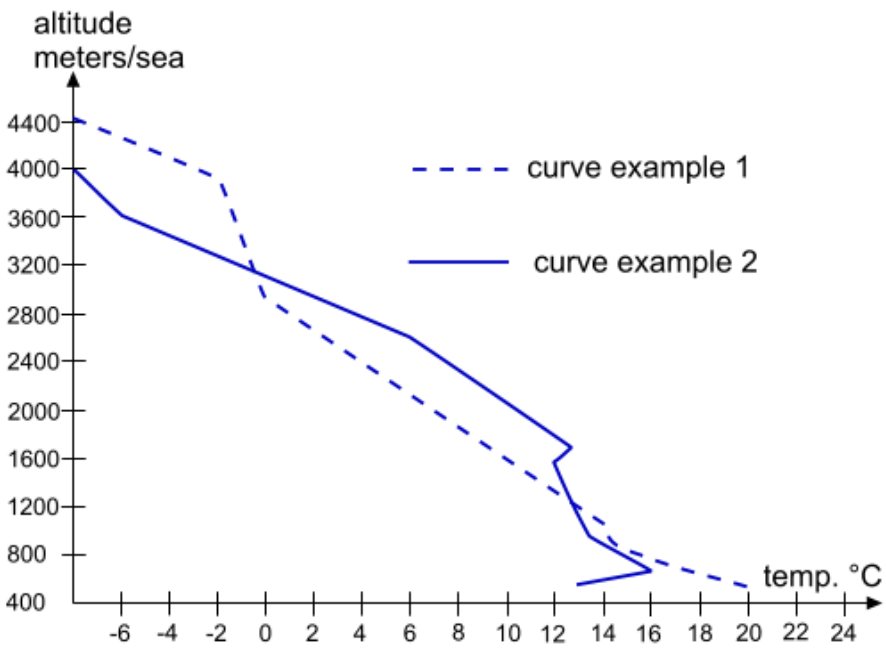


Inversion in altitude:

Isothermal

This is an air layer whose temperature does not change with altitude, so its temperature gradient is 0°C / 100 m. **Links with practice:**
Inversions and isothermal are air stable layers. They are a thermal barrier because the warm rising air loses its relative advantage of heat and thus ceases to rise.





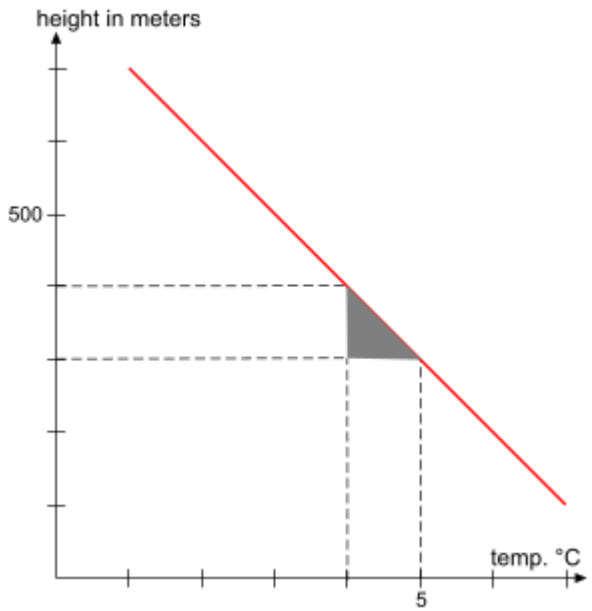
The two curves in this graphic show the temperature evolution in the atmosphere. These temperatures are measured by radio sensors, dropped in specific locations, which continuously send, to very high altitude, data to the ground stations.

- **Environment Adiabatic Lapse Rate - EALR** Average rate of cooling is 0,65°C / 100 m. But this will vary considerable on a daily basis. Till the tropopause the temperature, that normally decreases, may either remain stable (isothermal) or increase (thermal inversion).

- **The adiabatic temperature gradient**
  The adiabatic temperature gradient expresses the change in temperature within an ascending or descending air mass. Adiabatic means: without heat exchange with the outside environment. The higher an air mass rises, the lower the pressure is, so the air expands and therefore it cools. On the opposite, if the air mass descends, it compresses and thus it warms.

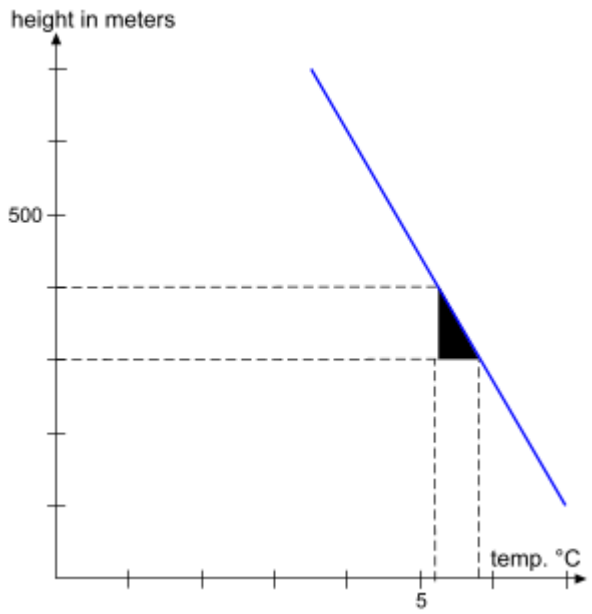
Dry Adiabatic Lapse Rate - DALR

As the air humidity is not saturated, i.e. with a relative humidity below 100%, the ascending air mass cools down by 1°C / 100 meters above sea level.



Saturated Adiabatic Lapse Rate - SALR (or moist adiabatic)

If ascending air reaches its dew point, i.e. 100% relative humidity, it will have too much water vapor compared to its temperature, there is an excess of moisture that will condense. We are witnessing the formation of clouds. When water vapor condenses, it releases latent heat energy, that is the reason why its cooling is lower than the 1°C / 100 m of dry adiabatic. This value fluctuates with the temperature of the dewpoint. The average is around 0.6°C / 100 m.



- In addition we must differentiate if the air is saturated or not because there are two types of adiabatic temperature gradient:

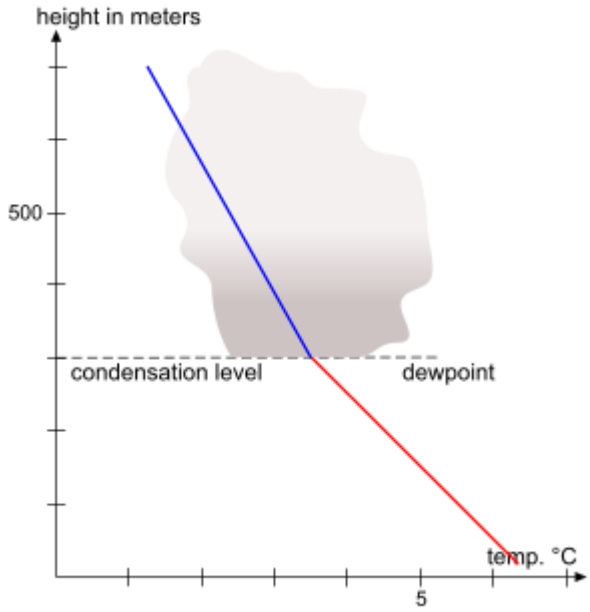
As we already know, warm air can hold more moisture than cold air. The warmer an air mass is when it reaches the dew point, the larger the amount of condensed water vapor and the more latent heat energy is released from condensation.

When an air mass reaches its dewpoint.

dewpoint	moist adiabatic temperature gradient
high	low
low	high

⇒ The higher the dewpoint temperature of a rising air mass, the lower is the Saturated adiabatic temperature gradient.
⇒ The lower the dewpoint temperature of a rising air mass, the greater is the Saturated adiabatic temperature gradient.
⇒ Thus the saturated adiabatic lapse rate varies between 0.4°C and 0.9°C / 100 m.

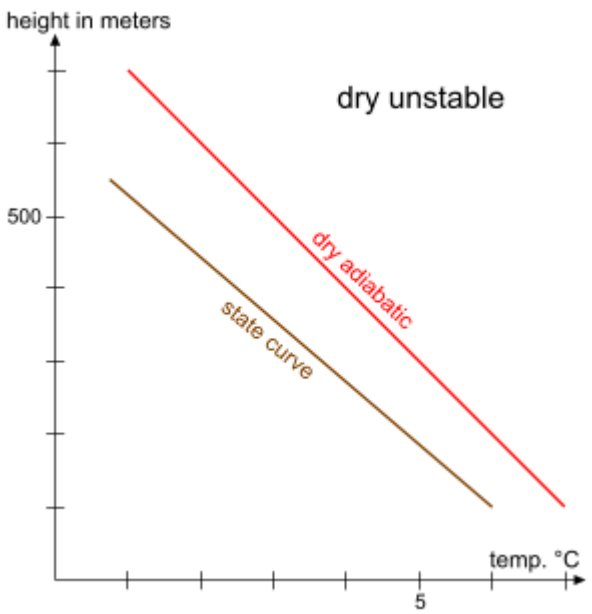
Abstract:
⇒ The saturated and dry adiabatic describe temperature changes in an ascending or descending air.
⇒ At the condensation level or dew point, the cooling of ascending air passes from dry adiabatic gradient to humid.
⇒ Descending air masses that get warm by dry adiabatic involve dissolution of the clouds.
⇒ The dry adiabatic temperature gradient is 1°C / 100 m.
⇒ The average value of humid adiabatic temperature gradient is 0,6°C / 100 m.

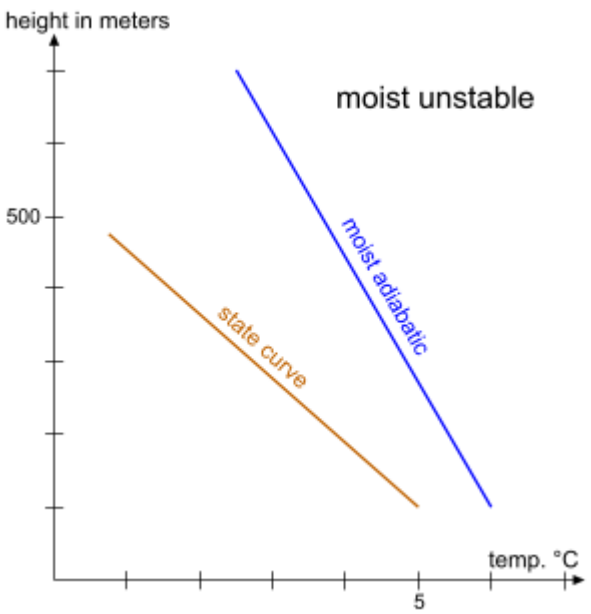


⇒ When an air mass rises (less pressure) the volume increases (expansion) and therefore its temperature decreases.
⇒ Conversely when an air mass descends (high pressure) the volume decreases (compression) and therefore its temperature increases.

- **The state of the atmosphere**:
  By comparing the curve of the atmosphere with the adiabatic one, it's possible to determine the atmosphere stratification with its stability or instability characteristics or indifferent situations. This technique of graphical representation of the atmosphere layers is called emagram.

- **Unstable layer in the atmosphere**:
  An unstable equilibrium happens if the atmosphere part within which an air mass is rising cools down more than the ascending air. The state curve is less inclined than the adiabatic one. The temperature difference between ambient air and ascending air increases so steadily that the bubble continues to rise and accelerate. The dry-unstable equilibrium, where the atmosphere cools down more than 1°C / 100 m, is found almost exclusively in the layers near the ground.

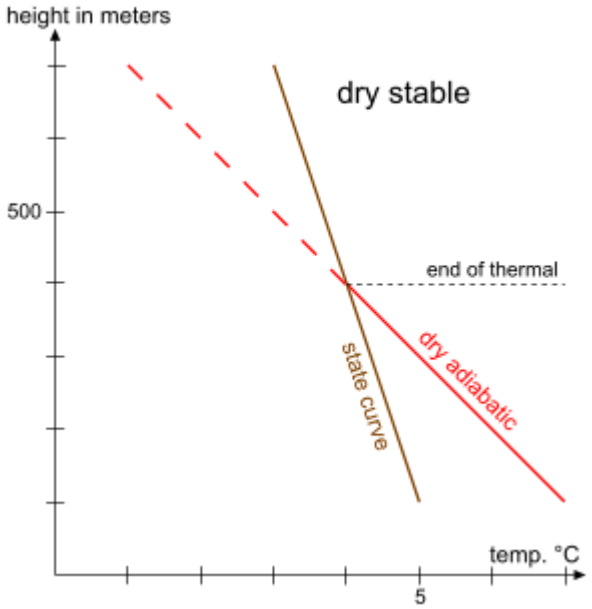


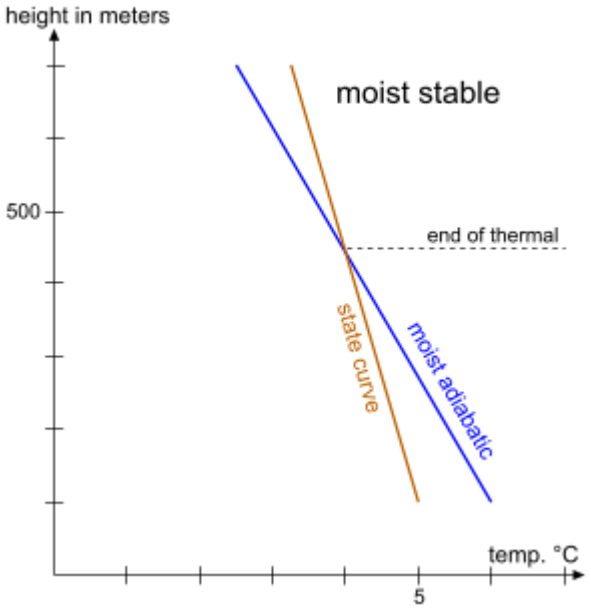


Links to practice: The unstable layers of the atmosphere mean in practice:
1. that the thermal improves with altitude
2. that the thermal is short
3. A rapid formation of clouds means a **threat of storm**

- **stable layer in the atmosphere**

The state curve of the atmosphere being steeper than the adiabatic one, the ascending air cools down faster than the air mass in which it operates. The thermal relative heat advantage decreases and when its temperature reaches that of the ambient air this one stops.

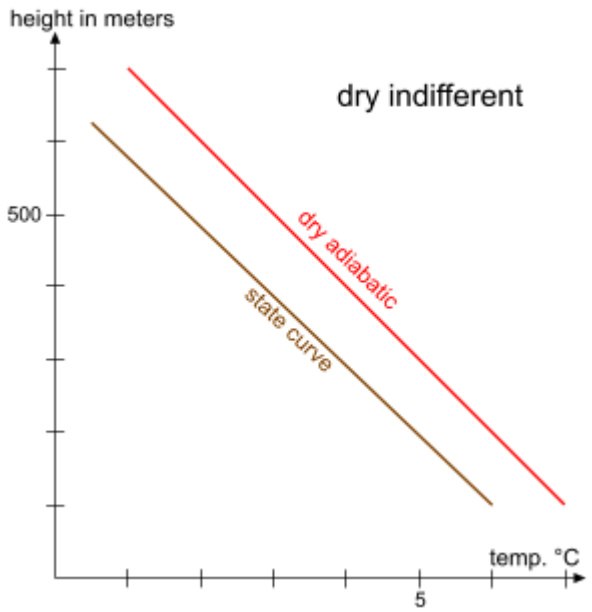


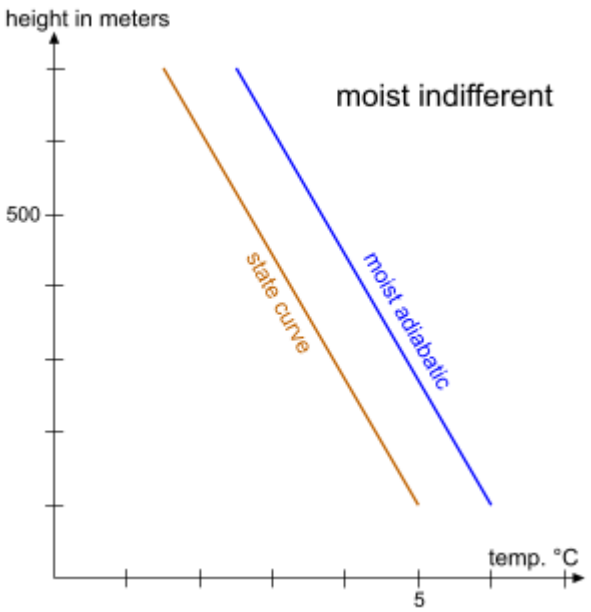


Links to practice: The stable layers of the atmosphere mean in practice that:
1. thermal quality decreases with altitude
2. the thermal does not rise very high
3. there is little or virtually no clouds, then called blue thermal (the dry ascending air doesn't cool down enough to reach its condensation level).

- **neutral layer in the atmosphere**

The state curve and the adiabatic one are parallel. The ascending air evolves always at the same speed.





Links to practice: The neutral layers of the atmosphere mean in practice that:

- the thermal is often steady and quiet till high altitudes
- there is little cloud formations
- the thermal holds often for long

  This situation is unfortunately very rare

Example: (This explanation is in relation with the graphic below)

⇒ Lets suppose that at the ground (400 m / sea) a specific surface heats a volume of air at 25°C. The ambient air mass has the following characteristics: temperature 20°C, absolute humidity 6 g / m^3, relative humidity 26%.

⇒ Given its caloric advantage this volume will start to rise

⇒ When rising it cools down according to dry adiabatic curve (1°C / 100 m)

⇒ At 2400 meters this ascending air mass has 5°C, it reaches its dew point or 100% of relative humidity (the 6 grams of water vapor saturate a cubic meter at this temperature according to the diagram)

⇒ We find the cloud base at this altitude

⇒ At this altitude this thermal bubble still has a caloric advantage of 1.5°C on the surrounding air mass so it continues to rise

⇒ It is now advancing according to the moist adiabatic curve as there is condensation (energy release) and cloud formation.

⇒ Its cooling is then only 0.6°C / 100 m

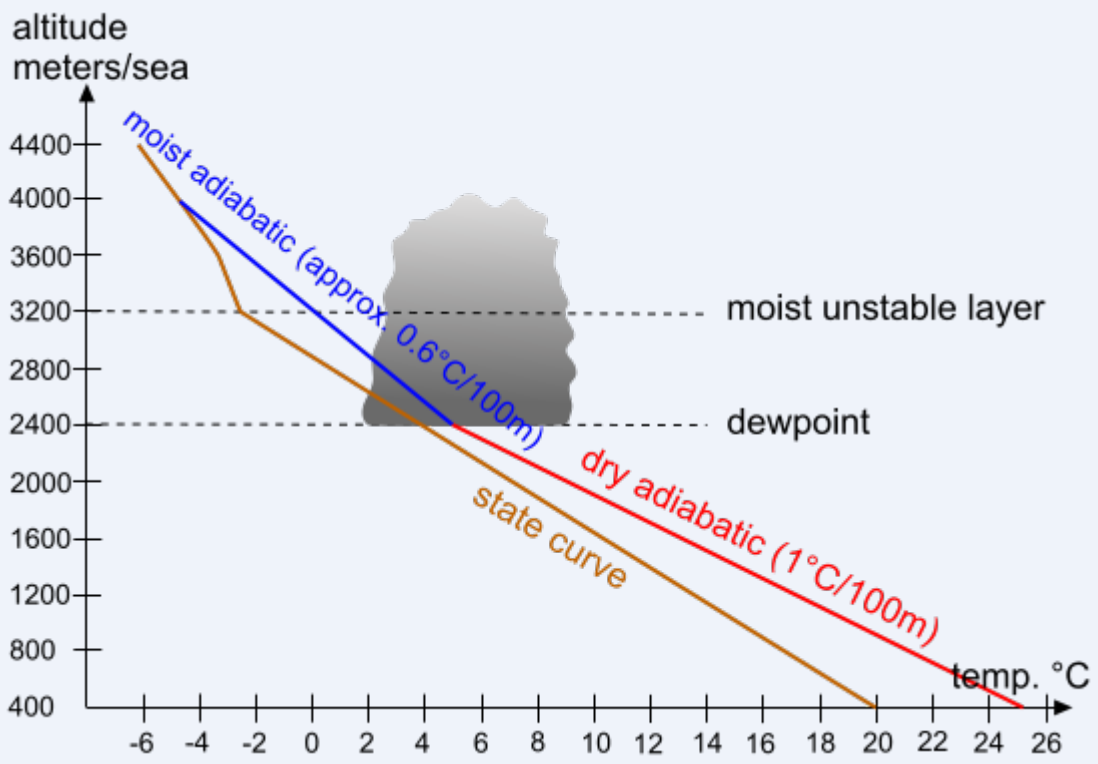
⇒ As up to 3200 meters the caloric advantage is in favour of the air bubble, the ascent becomes faster.

⇒ We're talking about the unstable humid layer

⇒ At 4000 meters the ascending air mass loses its caloric advantage and stops rising

⇒ The upper limit of the cloud is reached

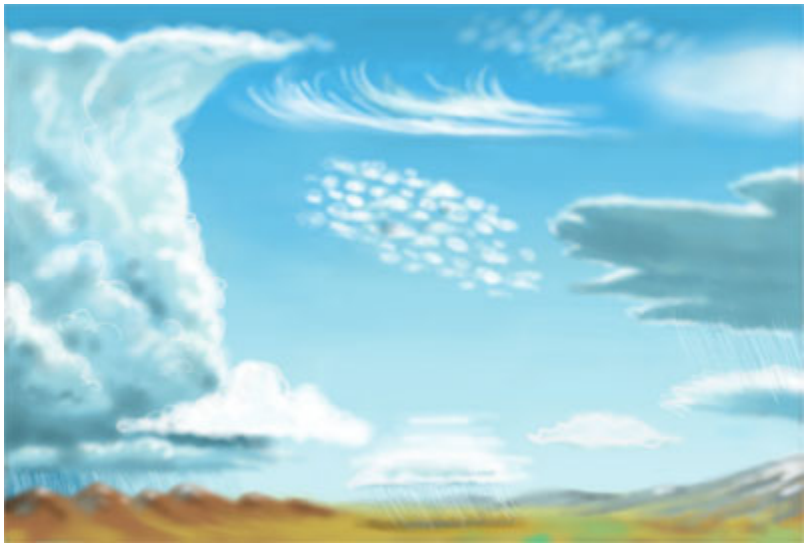
⇒ If the unstable humid layer had gone to high altitude, we would have an ascent to the tropopause and the formation of a cumulonimbus.



value of the rising air mass		thermal advantage over the surrounding air mass
saturating humidity	relative humidity	
3g	100%	0°C
4g	100%	2.8°C
4.5g	100%	3.3°C
5.5g	100%	2.6°C
3g	100%	1.5°C
6g	70%	2°C
6g	55%	3°C
6g	42%	4°C
6g	33%	4.5°C
6g	26%	5°C

3.4 - The clouds

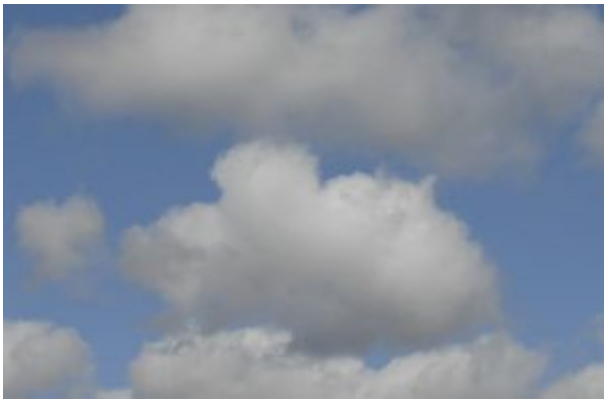
When the air cools to the dew point, there is cloud formation. Water vapor condenses around condensation nuclei. It is this formation of small and light water droplets or ice crystals floating in the air that make the cloud visible.



This cooling until condensation occurs in different ways:

- Orographic lift ⇒ orographic clouds ⇒ orographic rains
- Frontal lift ⇒ frontal clouds ⇒ regular rains during warm fronts ⇒ front storms during cold fronts
- Thermal lift ⇒ thermal clouds ⇒ thermal storms
- Earth's surface radiation on clear nights ⇒ fog or dew ⇒ drizzle or frost
- Contact with cold surfaces ⇒ advection fog ⇒ drizzle or frost

We differentiate two kinds of cloud types:



• Heaped clouds (cumulus)
They are synonymous of unstable layers in the atmosphere: warm air rises, the cold gets down ⇒ vertical movements of air ⇒ unstable atmosphere
*Photo 3-1: **Cumulus**. Cloud of fine weather; if it evolves to rain situation, we talk about overdevelopment.*

• The stratum-shaped clouds (stratus)
They are synonymous of stable layers in the atmosphere: no tendency to mix, for instance: fog in the valleys and beautiful weather in the mountains.
*Photo 3-2: **Stratus**.*

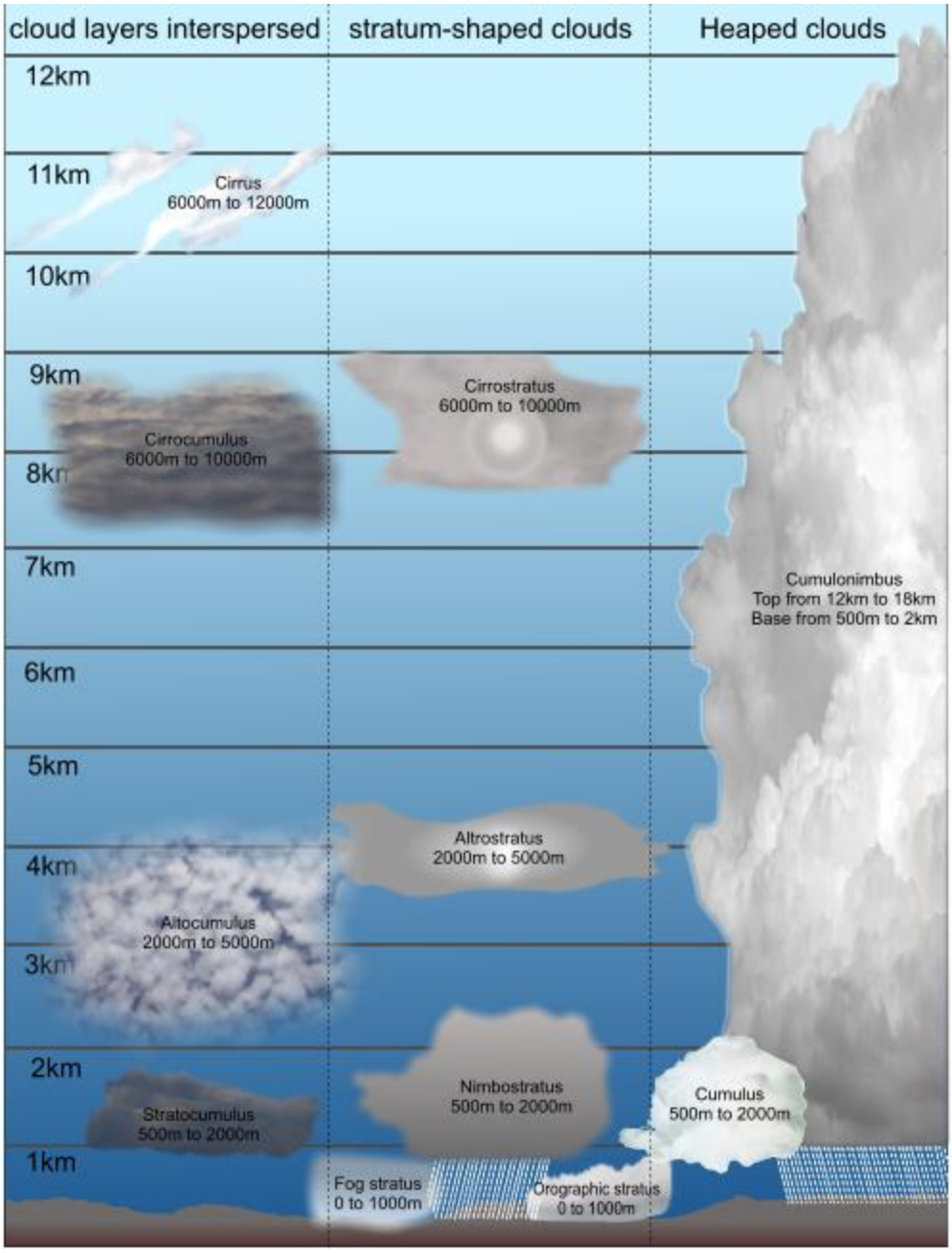


Fig. 3-28: Another distribution of clouds according to altitude. Troposphere is divided in three ranges: strato (up to 2-3 km), alto (up to 5-7 km) and cirro (up to 13 km).

Photo 3-3: ***Cirrus****.*

Photo 3-4: ***Cirrocumulus****.*

Photo 3-5: ***Cirrostratus****.*

Photo 3-6: ***Altocumulus****.*

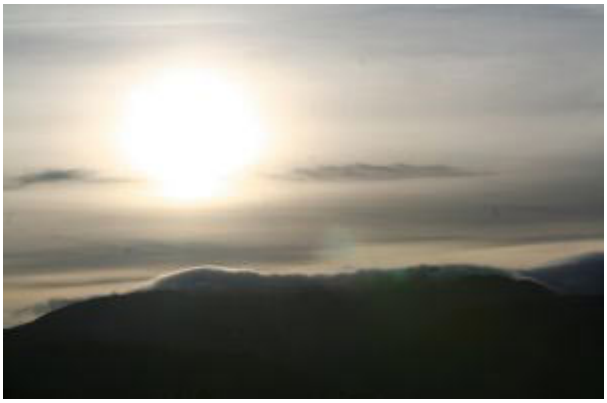


Photo 3-7: ***Altostratus****.*

Photo 3-8: ***Stratocumulus****.*

Photo 3-9: ***Nimbostratus****.*

Photo 3-10: ***Cumulonimbus with piliouscloud****.*

Photo 3-11: ***Cumulus****.*

Photo 3-12: ***Cumulonimbus***
CB = storm cloud that can cause hail.

Photo 3-13: ***Lenticulars****.*

Photo 3-14: ***Lenticulars****.*

3.5 - The fog

3.5.1 Radiation fog

During the night, the ground cools the lower air layers to their condensation level. Clear skies, little wind and air temperature near the dew point make fog formation easier. This is often the case in autumn and winter when high-pressure situations occur. Its dissolution during the day is due to wind and sunlight.

3.5.2 Advection fog

It is formed when humid air layers near the ground go on a cooler surface and cool down to the dew point. This happens in the mountains along the glaciers.

Photo 3-15: Upper limit of the fog layer.
Flying in a sea of fog represents danger of life due to the complete loss of orientation and sense of balance. It is also not allowed by law (Paragliders fly by VFR Visual Flight Rules: Clear of cloud, in sight of the ground and flight visibility of 1500m).

Photo 3-16: Lower limit of the fog layer.
It's called fog when visibility is less than one kilometer, between 1 and 5 km is called mist.

3.6 - Precipitation

Definition: The different forms by which the solid or liquid water contained in the atmosphere falls or settles on the earth's surface (rain, fog, snow, hail, dew).

Droplets gather together and become heavier and heavier until reaching a weight that the updraft is not able to maintain in suspension. At this time they fell as rain. If pressure and temperature allow crystallization, it snows. Due to very strong suck phenomena in the clouds (CB), the droplets are often propelled at high altitudes where they freeze. When they come down, new ice crystals or droplets stick on their melting outer layer. If they are aspirated again and this operation is

repeated many times hailstones are formed.

Photo 3-17: ***Nimbostratus***
NS = cloud of persistent and general rains