METEOROLOGY

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Table of Contents

Atmosphere and Atmospheric Pressure

Chemical composition of air: 78% nitrogen, 21% oxygen. The remaining 1%: carbon dioxide, water vapor, rare gases such as helium. **Question 001**.

The atmosphere is the envelope of air that surrounds the earth. It changes from its densest at sea level, ultimately ending the vacuum of space. The atmosphere is described in several layers. See Figure M01. We need only concern ourselves with the **troposphere**, the layer directly in contact with the earth, and which is responsible for the weather and the practice of paragliding. **Question 012.** The higher layers, such as the stratosphere, ionosphere and mesosphere do not concern us directly. The troposphere is bounded above by the tropopause. See Figure M01. In the northern latitudes this is at around 11,000m above sea level. **Question 004**. In the colder winter temperatures, the air is denser, and therefore the troposphere is slightly smaller. Conversely in summer, with warmer, less dense air, it is slightly larger.

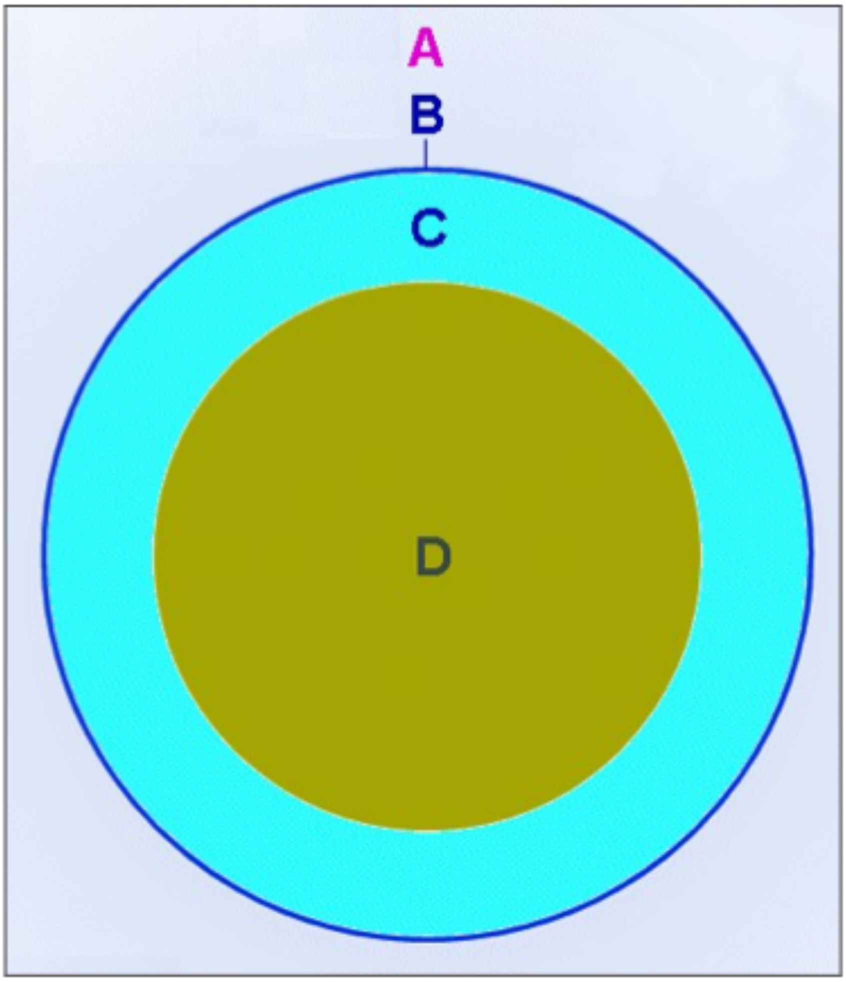

Figure M01: Layers of the atmosphere. D = ground, C = troposphere. B = tropopause. A = upper layers: stratosphere, ionosphere, mesosphere... etc.. The diameter of the earth is about 13,000 km and the thickness of the troposphere of about 10-15 Km: If the troposphere was shown to scale, it would be too thin to be visible!

Of many parameters of the troposhpere, the pressure exerted by the weight of the air (air pressure) and air temperature are among the most important. Atmospheric pressure if typically measured in hectopascals (hPa) or the multiples of standard atmosphere pressure: 1 atmosphere = approximately 1000hPa = pressure at sea level. Atmospheric pressure is due the effect of gravity on the air mass. **Question 005**. Because air is a gas (a compressible fluid), the higher the altitude, the lower the atmospheric pressure. This decrease is not linear. 2 useful reference points are: (1) at 5500m atmospheric pressure is about half that at sea level and (2) at 11,000m the air pressure is about a quarter of that at sea level. **Questions 006, 010 and 011.** See Figure M02.

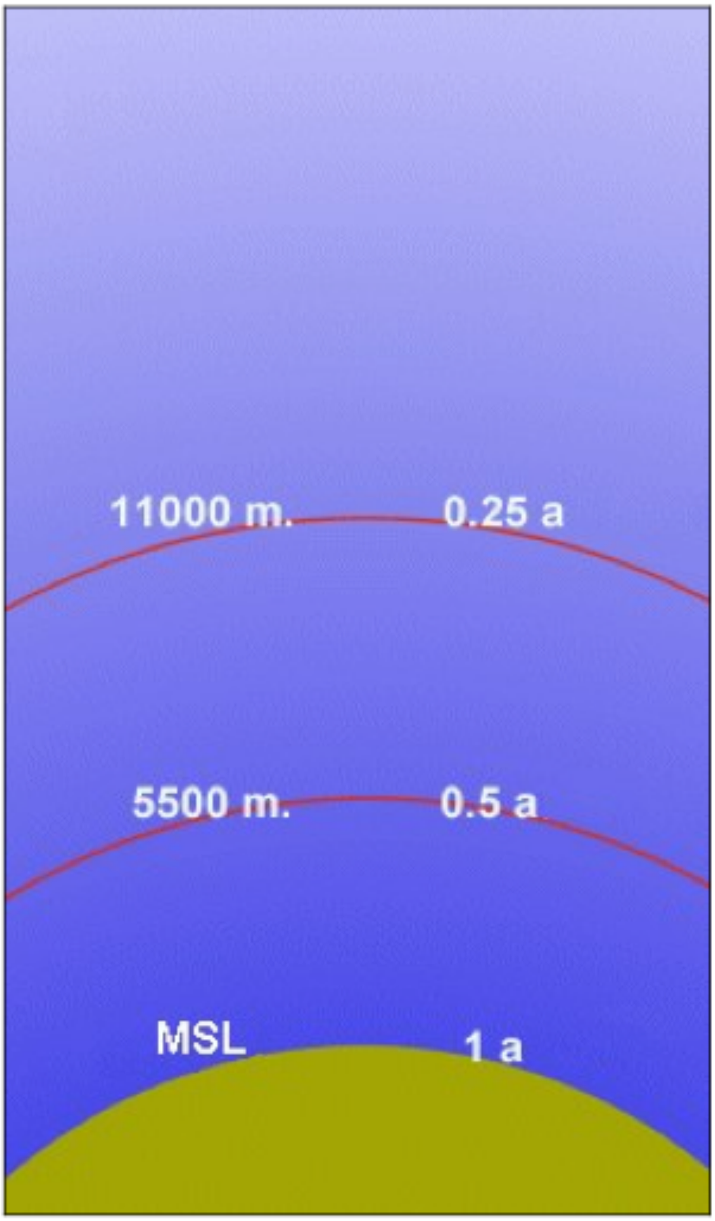

Figure M02: decrease in atmospheric pressure with altitude. Major reference points.
MSL = mean sea level = 0 m.

Questions 010 and 011 are a little more complicated: If the pressure at sea level is 980hPa at 5500m the pressure will be half of this value or 490hPa (**Question 010**).

Question 011 refers to a physics law for gases (Boyle's Law); namely that if the pressure of a gas is halved its volume doubles and vice versa. If the pressure decreases by 4x its volume increases by 4x... etc. Therefore, if a balloon has a volume of $5dm^3$ at sea level, its volume at 11,000m (where the air pressure is reduced by a factor of 4) will be 4x greater, or $20dm^3$.

Although air pressure decreases steadily and predictably with altitude, it still can vary from one place to another (with same altitudes) or from one time to another. **Questions 008 and 009**. The atmospheric pressure varies from place to place (both of equal elevation) or from one moment to another at the same location, by the redistribution of air around the earth by metrological effects.

Temperature also decreases with altitude but less directly than pressure. On average, temperature decreases by 0.65°C per 100m. However, depending on the individual air layers, it can reduce more, stay constant or even increase. **Question 002**.

In order to calibrate altimeters, standard atmospheric pressures have been defined. These correspond to the average pressure of the troposphere at sea level: pressure 1013.2hPa and temperature 15°C. Temperature gradient (rate of decrease of temperature with altitude) is 0.65 per °C. **Questions 003 and 007**.

Air Temperature, Atmospheric Warming & Temperature Curves

Air, in contact with the earth, warms up by solar radiation penetrating the atmosphere and warming the ground, which in turn warms the adjacent air. The air above the ground is not significantly warmed directly by the solar radiation. **Question 013**. Not all patches of ground have the same efficiency for heating the surrounding air. Generally, the darker & dryer the ground (e.g. a dry field), the greater its effectiveness. **Question 014**. Wet soils (e.g. swamps or deciduous forests) absorb significant solar energy by evaporation of water. In these cases, only a fraction of the solar energy warms the air in contact with the soil, and the temperature gain is therefore slower and weaker. Unlike dark ground, a clear and smooth surface (e.g. rock face), reflects a significant portion of solar radiation, and this is ineffective in warming the surrounding air.

At equivalent altitudes, hot air is less dense (and therefore lighter) than cold air. **Question 015**. At ground level, sources of efficient warming of the air generate flat, warm and light “pockets” of air. These pockets will eventually rise and gradually warm adjacent air to tens or even hundreds of meters above the ground, while cool air will descend to the ground to replace the rising warm air. **Question 019**. This vertical (up and down) movement of air is called **convection**. The layer of air in the lower troposphere where this phenomenon occurs is called the convection layer or convective boundary layer. During sunny days, its thickness varies from a few tens of meters (winter) to 2-3 km (hot summer day). See Figure M03.

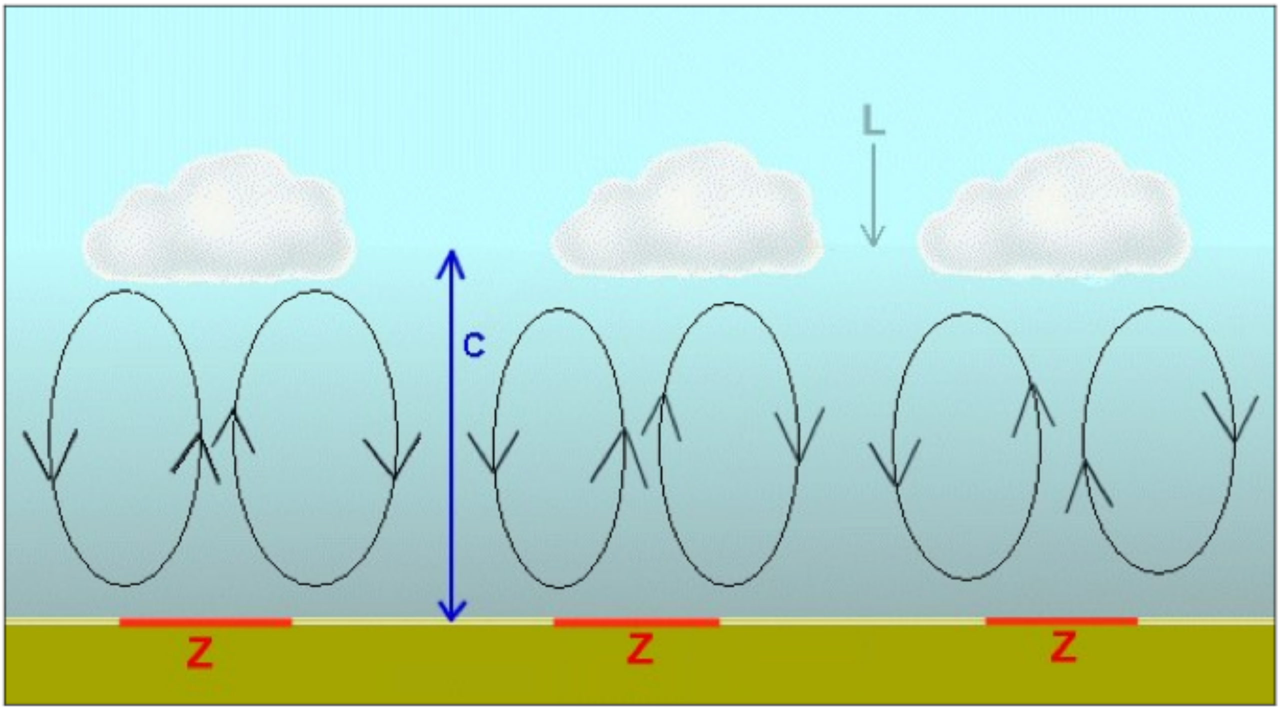

Figure M03: Movements currents. C = convective layer (foggy). L = upper limit of C.
Z = efficient heat sources on the ground.

During good weather, the convective layer is often marked by a haze (due to mixing with polluted air) whose upper limit is clearly visible at altitude and in small cumulus clouds that develop above the updrafts (or “thermals”). The thicker the convective layer, the stronger the thermals available to paragliders.

In summary, the sun **heats the atmosphere indirectly in 3 phases**: (1) Solar radiation penetrates the atmosphere without significantly heating the ground. (2) The hotter ground raises the temperature of a thin (few cm. or m.) layer of air, forming a hot “pocket”. (3) These small pockets of air will rise, creating convective movements to warm the atmosphere at altitude. See Figure M04.

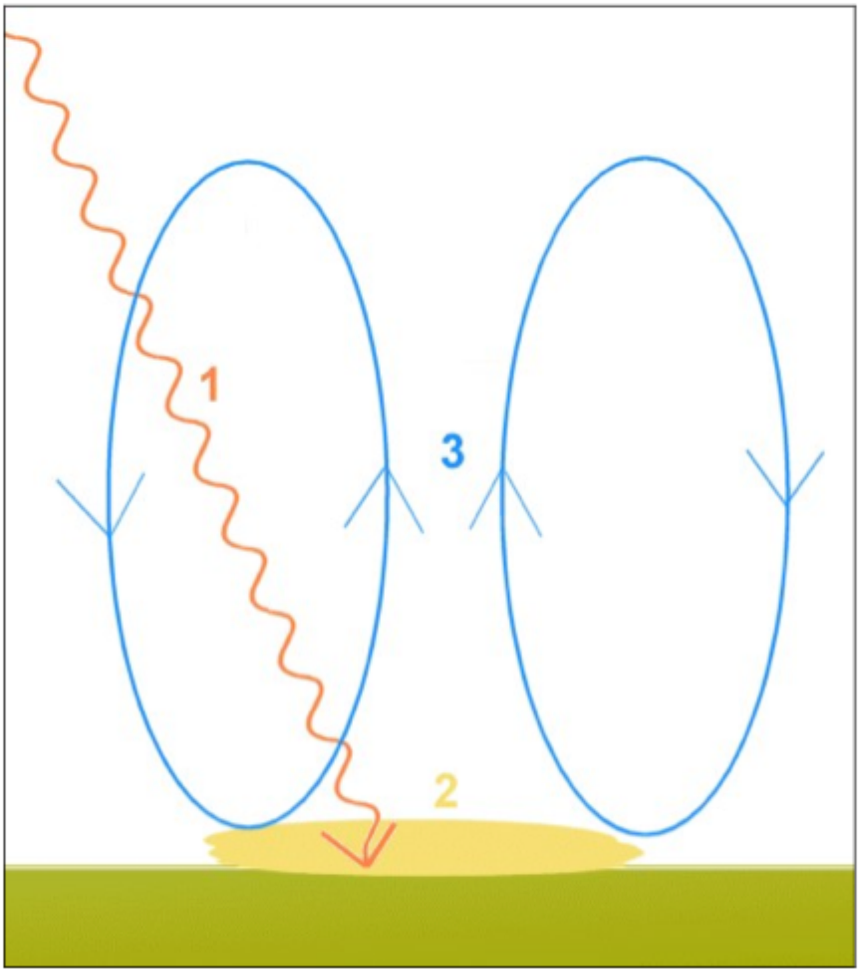

Figure M04: Indirect warming of the atmosphere in 3 phases: (1) solar radiation through the air, (2) conduction into a thin layer of air to ground, (3) convection.

The development of an air mass moving vertically: Adiabatic transformation. Because air is a poor conductor of heat, a mass of air rising or falling will undergo changes of temperature (almost) without energy exchange with the neighboring air. This is referred to as an **"adiabatic"** change. A mass of descending air experiences increasing pressure and, according to Boyle's (gas) Law, there must be a corresponding volume reduction. By decreasing its volume, the air concentrates its energy (but without exchange with the surroundings). This is observed as an increase in the temperature of this air mass. **Question 018**. Conversely, if a mass of air increases in volume (due to a pressure decreases) the volume change dilutes the energy, and its temperature drops. **Question 017**. This rate of decrease or increase in temperature ("lapse rate" or "adiabatic gradient") of an air mass in vertical is the same whatever the temperature of the ambient air. This lapse rate is always 1°C per 100m elevation. Figure M05. **Question 016.**

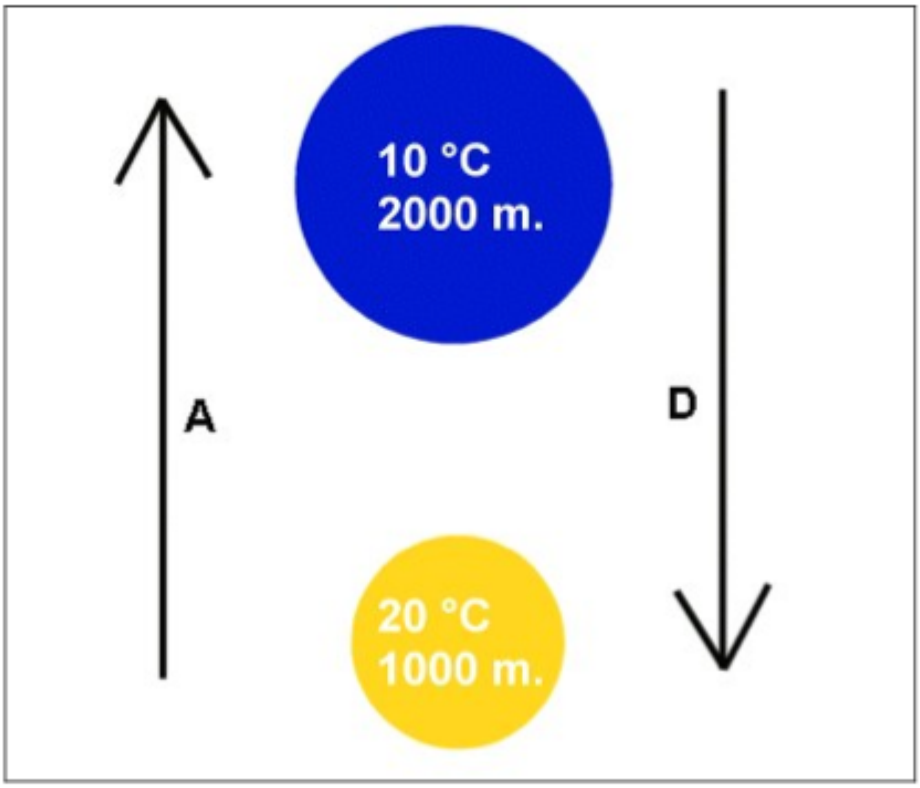

Figure M05: Lapse rate. A = mass of air rises, expands and cools 1°C/100m.
D = the air mass descends, shrinks and heats 1°C/100m.

Emagrams: A graph of temperature variation measured temperatures at different altitudes for a given time. This is effectively a snapshot of a portion of troposphere absent of significant vertical movement. While the pressure and the adiabatic temperature curve (an air mass in vertical movement) vary with altitude predictably and according to very precise rules, the emagrams are completely irregular, variable and unpredictable, vary from place to place, and time to time. Emagrams are obtained using radio sounding. These devices incorporate a balloon and measuring device, and are released into the troposhphere regularly (midnight and noon in general) from certain weather stations around the world. In Switzerland, there is only one such station is unique; the airport of Payerne. Figure M06 shows an example an emagram for a portion of troposphere.

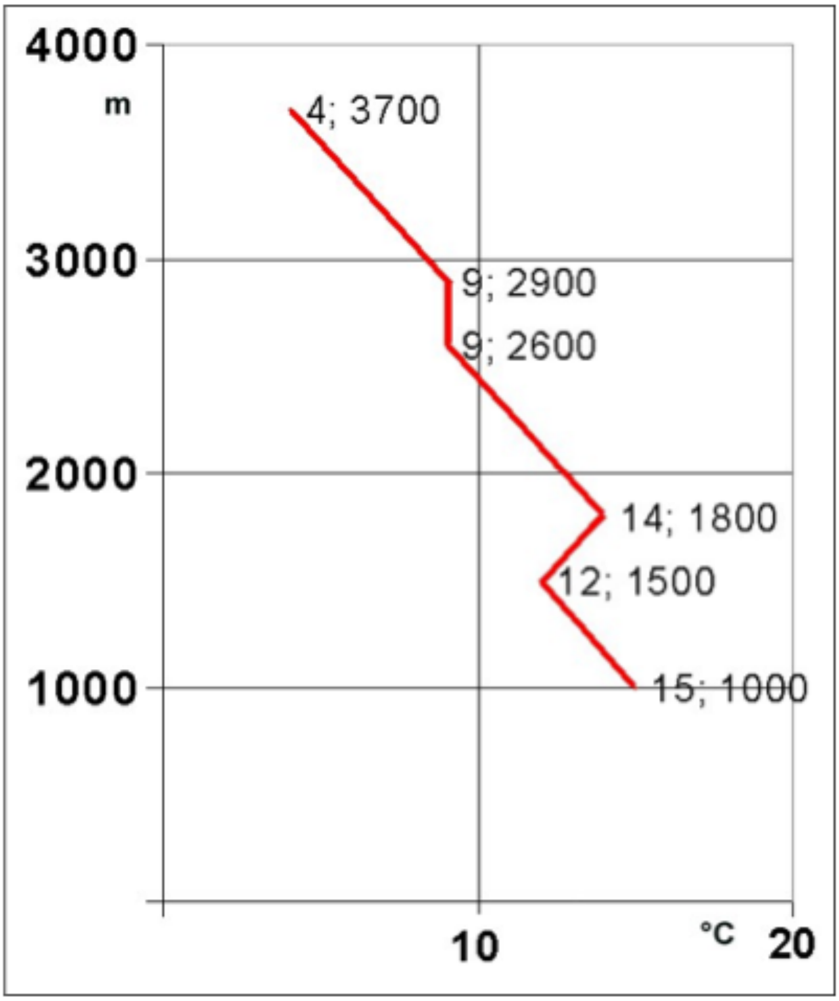

Figure M06: Sample curves of state temperatures.

Between 1000 and 3700m altitude (a 2700m altitude difference), the temperature drop is 15 - 4 = 11°C. On average the drop is 11°C / 27hm = 0.4°C per 100m. This difference in temperature per 100m is referred to as the temperature gradient. **Question 027**. Although this is the average temperature decreases with altitude, the intermediate teperatur changes are sometimes very irregularly from one layer to another. In Figure 43, the temperature gradient between 1000 and 1500m = 3°C / 5 hm = 0.6°C / 100 m; between 1800 and 2600m = 5°C / 8hm = 0.625°C / 100m; between 1500m and 1800m the temperature actually increases. This last phenomenon occurs sometimes and is called a temperature **"inversion"**. **Questions 020, 024, 029**. An inversion layer is often marked by an upper layer of could between the ground and the inversion layer, or in winter a sea of cloud. **Question 030**. Between 2600 and 2900m the temperature does not vary (a layer with a constant temperature gradient 0°C / 10m). This occasional phenomenon is referred to as an "isotherm" layer. **Questions 021, 025, 028**.

Questions 031 to 033 refer to a table (see Figure M07) with 4 emagram examples (a) to (d). Be careful with this table, as the altitude decrease from top to bottom. The task is to identify an inversion on the ground found between 500m and 800m in the column (a); an inversion at an altitude between 1900m and 2100m in column (c) and an isotherm between 1800m and 2000m. in column (d).

a)		b)		c)		d)	
500m	+ 15°C	500m	+ 16°C	500m	+ 14°C	500m	+ 15°C
800m	+ 16°C	800m	+ 14°C	800m	+ 13°C	800m	+ 14°C
1200m	+ 13°C	1100m	+ 12°C	1200m	+ 11°C	1200m	+ 11°C
1700m	+ 10°C	1900m	+ 6°C	1900m	+ 6°C	1800m	+ 8°C
2100m	+ 7°C	2400m	+ 3°C	2100m	+ 7°C	2000m	+ 8°C
3000m	+ 1°C	2900m	– 1°C	2700m	+ 3°C	2800m	+ 2°C

Figure M07: Example of data from 4 emagrams used for questions 31 to 33 in the SHV/FSVL pilot (meteorology) theory exam.

In practice, there are two main types of emagrams for unremarkable weather situations (without significant cloud or strong winds): (1) the curve for **night** and the curve for **daytime**. See Figure M08. During a clear night, the ground emits infrared radiation back into space causing a cooling of the ground and the immediately adjacent air over tens of meters in above the ground, resulting in an inverted convection: The air near the ground becomes colder than the air 500m above the ground. This forms a nighttime temperature inversion layer near the ground (blue curve). **Question 133**. For example on our chart, the air is at 6°C above the ground (altitude 500m). At 1000m, the air is 3°C higher, (it is at 9°C). This can only be explained if there is a temperature inversion at ground level. Higher up, for example above 1500m the temperature gradually decreases altitude at rate of between 0.4 to 0.8°C per 100m. At altitudes, inversion layers or isotherms can be encountered, not necessarily, and is dependant on the weather situation.

When night is accompanied by overcast cloud, the infrared radiation is reflected from the ground by the clouds, consequently the heat loss will be less and the temperature inversion at ground level will be smaller. If the conditions are windy, the cooling air/ground will be disrupted at higher altitudes because of air circulation. The temperature gradient from the earth will persist (weakly) but the ground level inversion will be greatly reduced.

From sunrise, solar radiation falling on the earth counteracts the previous night's loss to infrared radiation from earth's surface. First the ground, then the adjacent air, then the air above (by convection) quickly warms. The ground level inversion will gradually disappear during the morning. **Question 134**. During the afternoon the temperature emagram will resemble the red curve in Figure M08. On the ground, the air temperature will be significantly higher during the daytime than at night; in our example, nearly +20°C higher, or 25 to 26°C. The higher the altitude the lower the temperature difference between night (blue curve) and day (red curve).

In the red curve of figure M08, a few tens of meters from the heated ground (between 500 and 600m), the temperature decreases rapidly (25 to 21°C / 100m = a temperature gradient of 4°C / 100m). It is much more than the lapse rate of 1°C/100m. This is described as a "superadiabatic" layer. Such a phenomenon is only ever encountered close to ground level. At higher altitudes, between 600 and 1500m, the temperature gradient is 1°C / 100m (9°C / 900m), as per the normal adiabatic curve. It is an almost impossible to have this phenomenon in the convective layer due to the constant vertical convective motion of the air. At even higher altitudes, from 1500m, the emagram begins to follow the curve at night, always with a gradient of less than 1°C/100m.

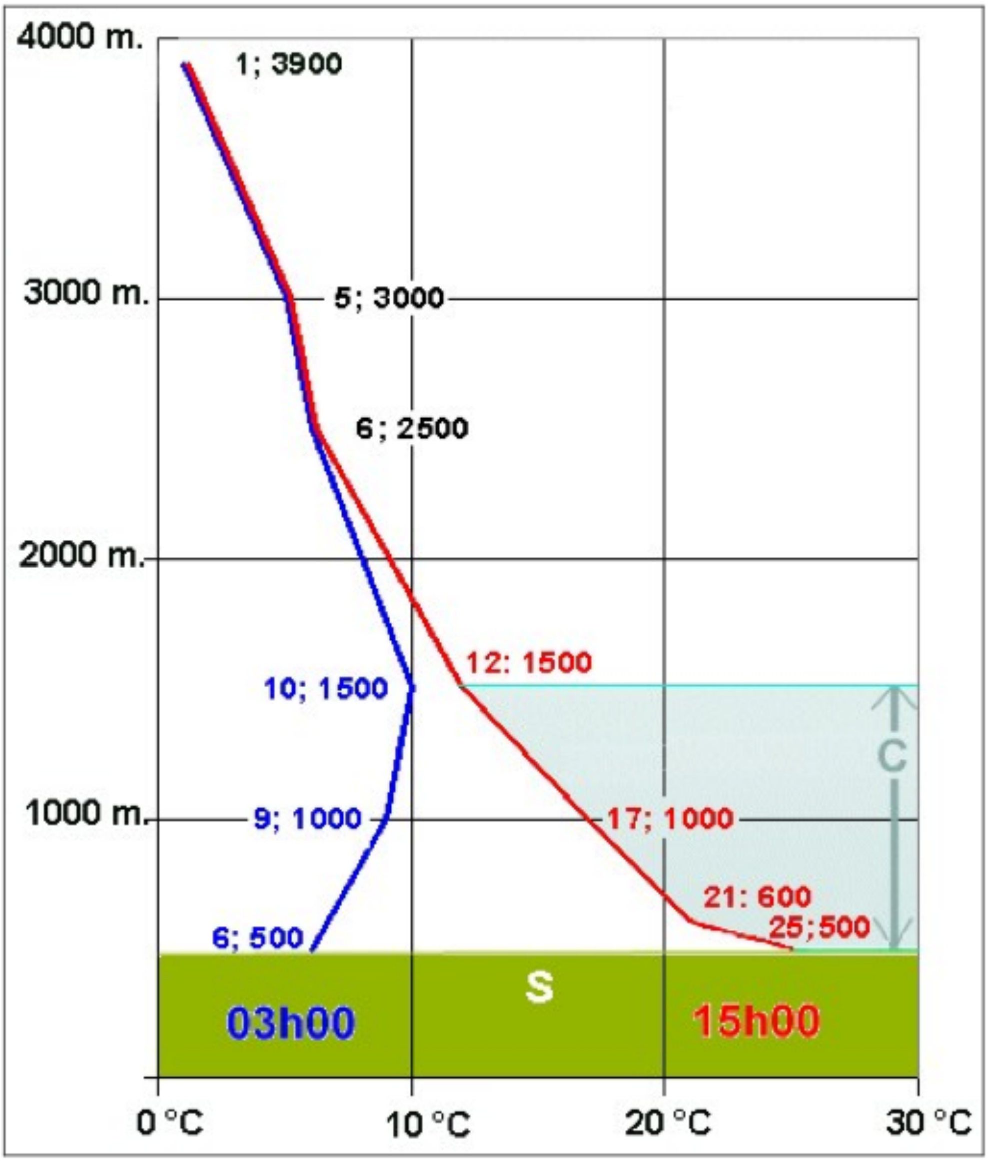

Figure M08: emgrams typical of a clear and calm night (blue) and the following sunny afternoon (red) with the same general weather situation. S = ground (soil). C = convective layer (1°C/100m).

Now consider, for conditions identical to figure M08, an air pocket forming by thermal heating at ground level. The temperature of the bubble will be a few degrees warmer than the surrounding air. See Figure M09. Catalyzed by a small movement near the heat source (e.g. from a car, a small local breeze, the shadow of a cloud, etc...), the superheated air bubble will dislodge, move upwards, and create a suction of ambient air to replace the rising air. A major air movement will ensue. The bubble will quickly cool with altitude so that at 100m above the ground (600m elevation in our example), there is more than 1°C difference between the bubble and the ambient air temperature (22°C vs. 21°C). Higher up there are only a few tenths of degrees of difference. At the upper limit of the convective layer, the temperature difference is almost nil.

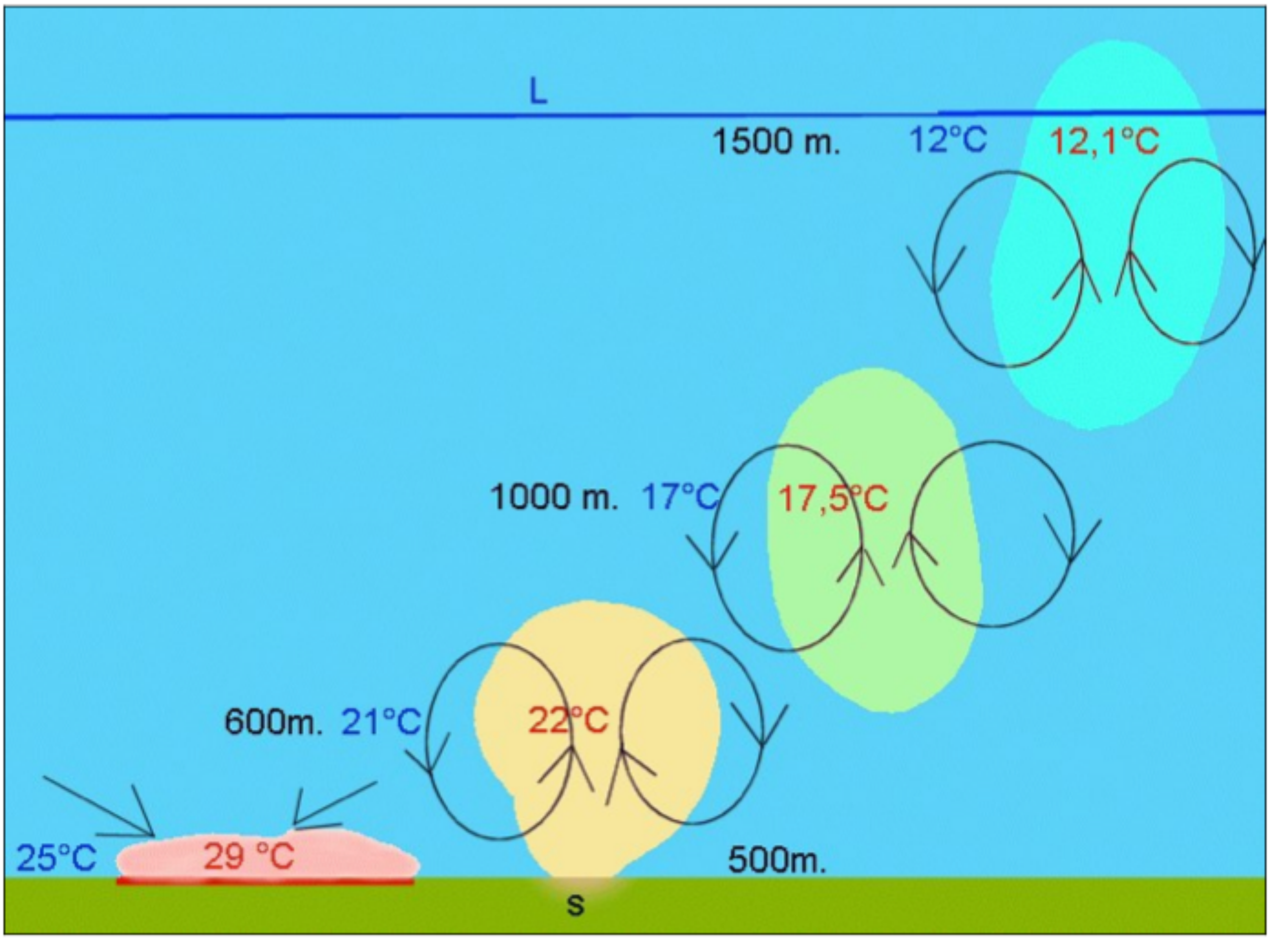

Figure M09: Evolution of the temperature of the air in a rising thermal bubble.
The upper limit = the convective layer.

While the bubble of thermal air is hotter, thus less dense and lighter than surrounding air, it rises. When the temperature difference is zero, the thermal bubble stops rising. **Question 022**.

We can summarize these developments and these differences in temperature by the emgrams in figure M10.

Above the convective layer, the rising thermal bubble quickly cools (by 1°C/100m), it is less buoyant than the ambient air and the continued temperature change is less marked. This is even more obvious if the convective layer is limited by an inversion or isothermal, which is quite frequent but not neccessary (orange dotted line). Inversion and iisothermal layers are very effective in blocking thermals. **Questions 023 and 026**. For **question 023**, refers to a layer of air in which the temperature increases with altitude. This is indeed a temperature inversion.

The layer above the convective layer is deep (by altitude difference) better (well organized with a high ceiling) and with the stronger thermals. For the convective layer to be deep, a large temperature difference between the upper and lower atmosphere must exist. In other words, it is necessary that the general temperature gradient (determined by the weather situation) at the top of the convective layer is important and there is no strong inversion or isothermal. A temperature gradient between 0.3 and 0.5°C/100m is considered low, with modest convection. A gradient between 0.6 and 0.8 is considered large with good thermals. For the Swiss Plateau, the Jura and the pe-alps, we are concerned with the gradient between 1000 and 3000m. For the Alps, the gradient between 2000 and 4000m. approx is important for thermals.

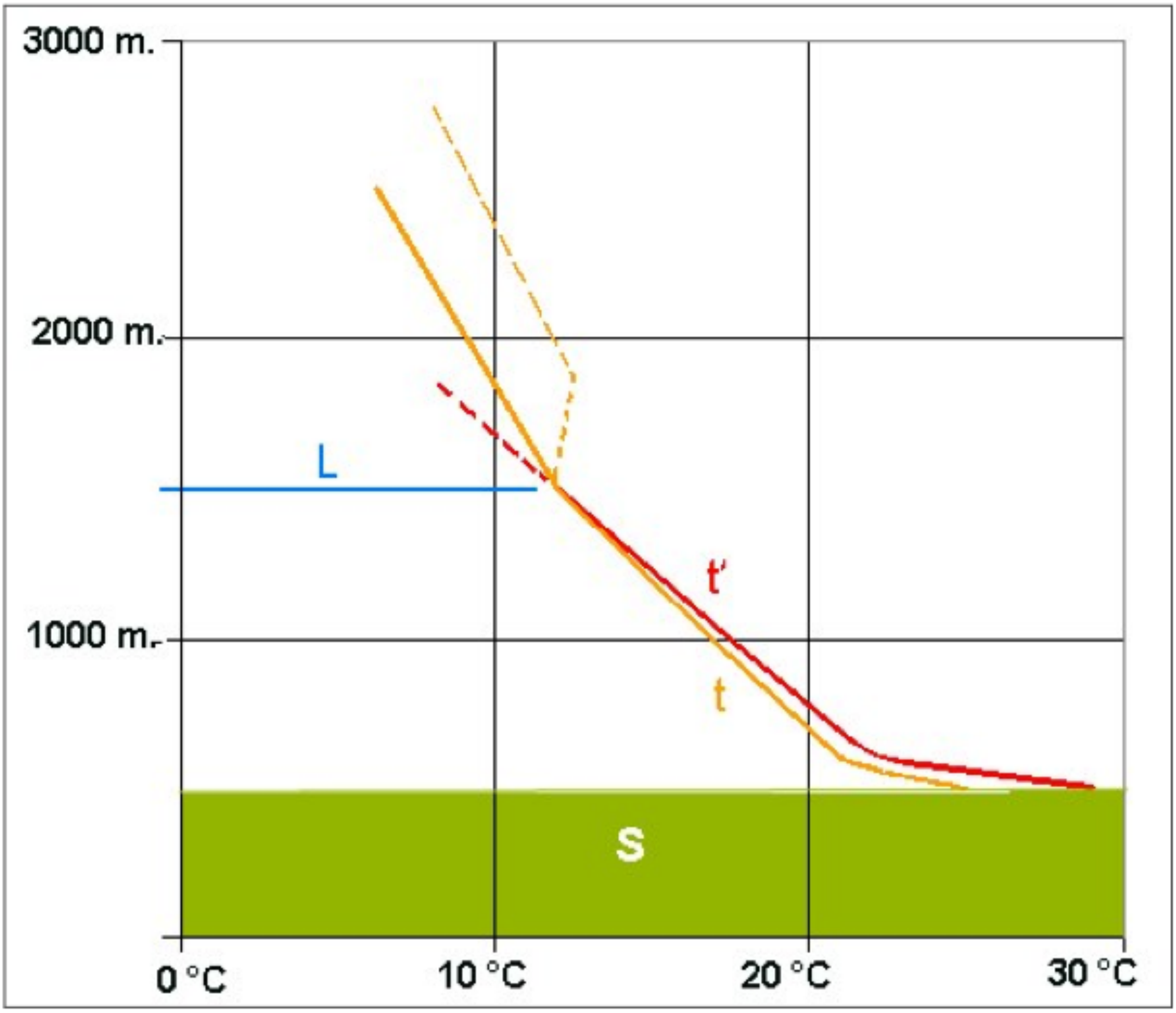

Figure M10: Graph comparing the temperatures of the ambient air compared to air in the thermals, depending on altitude. L = upper limit of the convective layer. t = static temperature curve. t '= rising thermal temperature curve. The values correspond to those of figure M09.

Physical State of Water & Humidity

Water exists in three forms (physical states): ice (solid), water (liquid) and water vapor (gas). It should be noted that water vapor is invisible (transparent in air). "Steam" is actually a hot cloud (droplets of water suspended in air).

Condensation is the effect of water vapor changing from a vapor into liquid. **Question 34**. The dew point is the temperature to which air must be cooled so that the water vapor condenses into a liquid. **Question 40**. See Figure M11. Mist and frost are thin layers of either liquid water or ice, respectively, on a solid surface. Hail and snow are both forms of solid water.

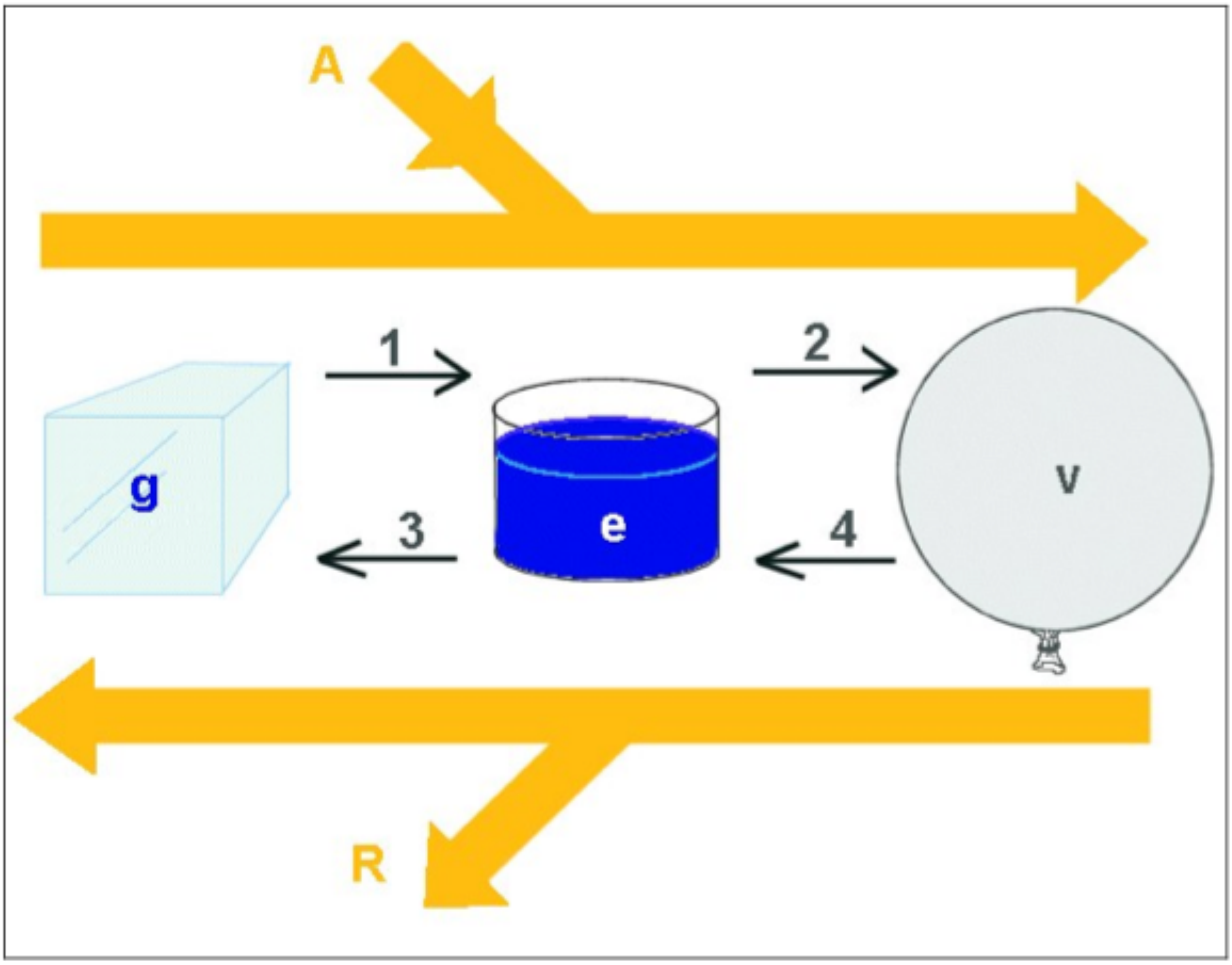

Figure M11: Physical state of water and change of state. A = input (need) heat. R = restitution heat. G = ice. E = water. V = water vapor. 1 = melt. 2 = evaporation. 3 = freezing. 4 = condensation.

The humidity of air is a measure of the amount of (invisible) water vapor contained in the air. It can be described in absolute terms by the mass of water vapor (in grams) per unit volume (m3) ("absolute" humidity). Warm air has a greater capacity to retain the water vapor before condensation. In figure M12, an air mass with temperature and humidity at the point P. The temperature is 17°C and the air contains 5g of steam per m^3. At this temperature the air is relatively dry. If the air is now chilled to -7°C (P'), the water content is still $5g/m^3$, but it will be at the saturation point. This defines the point of 100% humidity. Any reduction in temperature or increase in water vapor content will cause the formation of liquid water (cloud, fog, mist, rain) by condensation. Repeating this for all combinations of humidity & temperature results in a saturation curve (in red) which defines the conditions where water vapor condenses. The top left represents air saturated with water vapor (i.e. it can contain no more steam and has 100% humidity) mixed with mist (fine droplets of liquid water). Any excess moisture or cooling of air causes the formation of additional liquid water. To the bottom right the air is not saturated, can accommodate further water vapor. This air is clear, without visible fog caused by liquid water. Additional moisture or chilling does not generate liquid water, until the saturation point is reached.

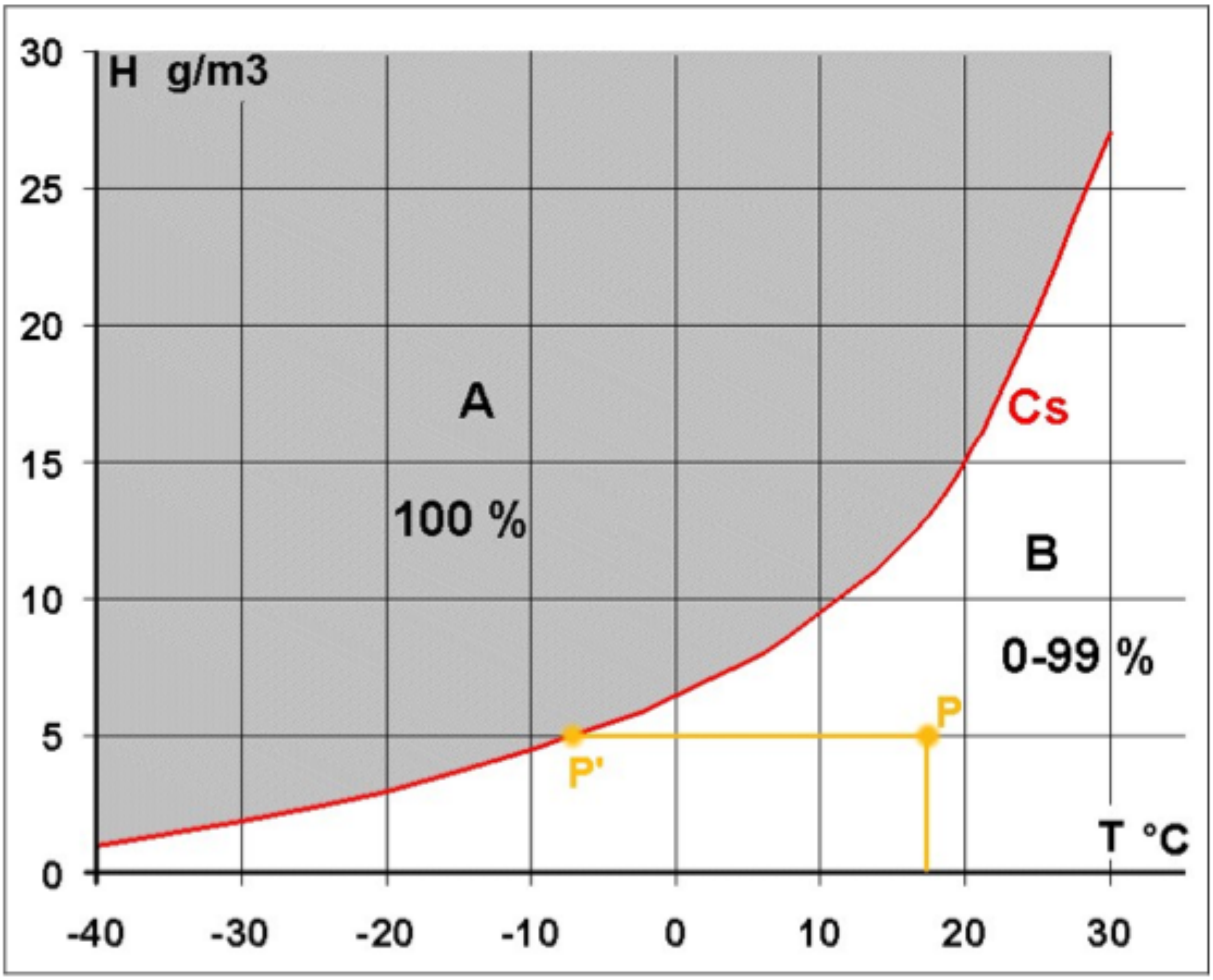

Figure M12: Relationship between temperature and humidity. Cs = saturation curve, where condensation occurs. A = area of 100% humidity and fog/mist. B = clear air with a humidity ranging from 0-99%.

To transform ice to liquid water or steam, the water needs to absorb energy in the form of heat, in order to overcome the intermolecular forces. In figure M11, changes as we move from left to right require energy in the form of heat from an external source. **Questions 35 to 36**.

When the state change is in the other direction (from vapor to liquid to solid), the reverse is true, and energy is released to the surrounding environment. In figure M11, the phase changes from right to left of the diagram provide the energy that is returned to the outside. **Questions 37 to 39**.

The practical importance of this effect can be seen in thermals (convection): A mass of dry air (not saturated with water vapor), cools with the normal lapse rate of 1°C/100m when it moves rises. A mass of air saturated with water vapor will cool as it expands if it goes up, generating further condensation. This condensation will heat the ambient air and release energy. **Question 43**. The decrease of temperature in the saturated air mass will be less important than the adiabatic lapse rate of unsaturated (dry) air (1°C/100m). **Question 41**. If the same mass of saturated air descends, it will heat up. It may accommodate more water vapor, however the evaporation of water into vapor requires energy (heat). The rate of temperature increase in the saturated air mass will be less important than the adiabatic gradient (1°C/100m) of unsaturated (dry) air. The temperature gradient within a mass of air saturated with water vapor, (i) ascending or (ii) descending, depends on the amount of water vapor that (i) evaporates or (ii) condenses respectively. **Question 42**. Be careful with **questions 41-43**, which refer to humid air. More correctly this should be specifically saturated air.

Clouds, Fog and Mist

A cloud is a portion of the atmosphere containing countless tiny droplets of liquid water suspended in the air. Cloud and fog are the same thing, fog is just a cloud viewed from inside. More precisely fog is defined as when the visibility is less than 1km. Mist (suspension of various particles) is much thinner, and is defined when the visibility is between 1 and 10km. See Figure M13. **Question 47**.

Figure M13: a = mist, b = fog.

Cloud forms in several circumstances: 2 main reasons:

(1) During long nights (fall and winter), the earth emits infrared radiation and gradually cools. The surrounding air layer also then cools. If the temperature of this air reaches the condensation temperature (dew point), fog may form near the ground. This is called radiation fog and is typical of winters and autumns**. Question 48.**

(2) Cloud can also be formed when a mass of air has an upward movement and it gradually cools until it reaches the dew point. **Question 49**. There are 3 main phenomena that might cause this. (1) Firstly convection (heat), (2) secondly wind: air is forced to rise when it encounters a topological feature (think of the phenomenon of a dam) and (3) thirdly, the meeting of two air masses of different temperatures (creating a disturbance or a front, discussed later) that causes the (lighter) hot air to rise over the (heavier) cold air. See Figure M14. The cloud base is then the lower limit of these clouds and is the altitude where condensation occurs in the rising air. **Question 50**. In general, the higher the humidity and the more likely cloud formation occurs. With very high humidity, we must expect a lot of low clouds.

Conversely, a dry atmosphere will give little or no clouds, and the cloud base will be at high altitudes.

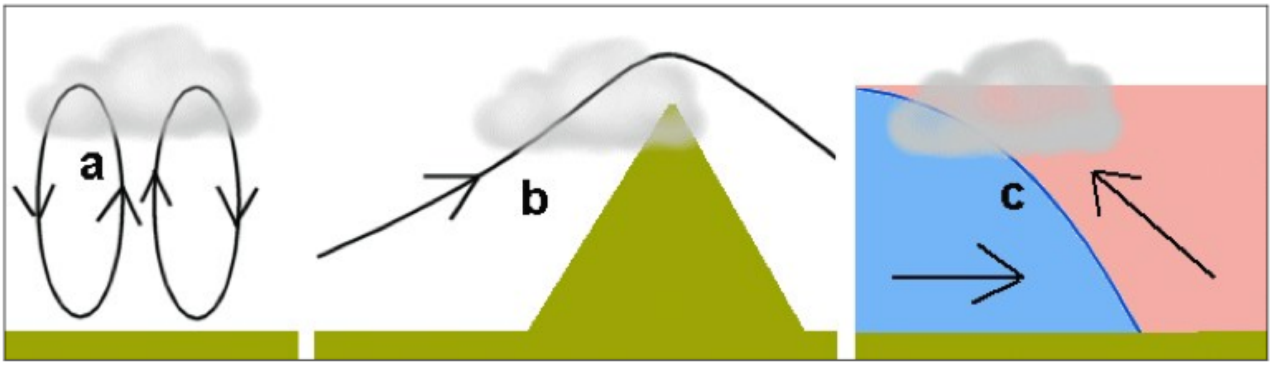

Figure M14: Clouds are due to a rising air mass.
a = convection. b = wind impacting a geographical feature. c = disruption of air masses.

The clouds have different shapes and heights depending on their formation. The nomenclature of clouds is as follows:

- **Cirrus** (prefix cirro-) are very high clouds, between 6,000 and 10,000m, and generally not very thick.
- **Alto** (prefix alto-) clouds are a little thicker located between 3000 and 6000m.
- **Cumulus** (prefix cumulus-) are ball-shaped clouds or "cauliflower" shapes.
- **Stratus** (prefix strato-) are layered clouds that appear stretched.
- **Nimbus** (prefix nimbo-), are clouds that generate precipitation (e.g. nimbostratus). **Question 56.**

There are some more specific terms, used in special circumstances, such as lenticular clouds (lens shaped) clouds and castellanus (shaped like a castle with towers).

The main clouds (see Figure M15 and M16) are (abbreviations in parentheses):

- **Cirrus (Ci):** Small thin hair-shaped clouds, located at very high altitude (between 6,000 and 10,000 meters).
- **Cirrostratus (Cs):** thin layer of clouds layered and very high (between 6,000 and 10,000 meters). This layer is translucent and you can see the sun's intensity attenuated through this cloud with a halo of colors around the sun.
- **Cirrocumulus (Cc):** Group of small clouds piled up (flakes) whose base is over 6,000m. Part of the cumulus family of clouds whose base is the highest. **Question 54.** These clouds are always made of fine ice crystals suspended in the air like dust. **Question 57**.
- **Altostratus (As):** Cloud layer whose base is about 4000m. **Question 51**.
- **Altocumulus (Ac):** Group of small clouds piled up (flakes) whose base is about 4500m. **Question 52**.
- **Cumulus (Cu):** Sign of good thermals (convection). **Question 44**. There are 3 main cases: The **cumulus humilis**, very small; **cumulus mediocris**, medium size; and **cumulus congestus** of large, dark base and may extend over several hundreds of meters high. These can cause small local showers or grow into cumulonimbus (thunderstorm cloud). The base of cumulus clouds is usually between 1,000 and 4,000m depending on location and weather: Lower than that of the family of cirrus. **Question 55**. The cumulus humilis and cumulus mediocris, especially if high, are indicators of good thermals. **Question 58.**

- **Cumulonimbus (Cb):** They respond to cumulus congestus that grow into huge thunderclouds, often mushroom-shaped, reaching very high altitudes (about 10,000m). Currents (winds), ascending, descending and horizontal are very strong (much faster than the speed of paragliders), which makes these clouds very dangerous. **Questions 59 and 64**. These clouds can generate hail but not always. **Question 64.** There is precipitation and evaporation phenomena occuring at high altitude which cools the air locally, explaining the strong downdrafts during precipitation. **Questions 63 and 64**.
- **Stratocumulus (Sc):** Cumulus closed and forming bands usually near the ground. They are common after rain.
- **Stratus (St):** A layer of clouds often in close contact with the ground and for observers on the ground, fog. The clouds are typical of autumn and winter, especially during the night and the morning when there is a strong temperature inversion to 1000-1500m. ie a stable stratification in the lower atmosphere. We can then observe a sunny day at altitude and ground fog. **Question 46**.
- **Nimbostratus (Ns):** very thick layer of closed clouds with its base is at about 1000m. altitude, and producing precipitation. **Question 53**. These clouds can grow to a very high altitude.
- **Castellanus Altocumulus (Ac cas)** having the form of a castle with ramparts and towers. They are developed early in the morning and indicate humid, unstable and conducive conditions leading to the development of thunderstorms in the afternoon. **Question 45.**
- **Lenticular Altocumulus (Ac len):** These clouds develop at altitudes above 3500m when winds are moderately high on a topographical feature that creates a wind ripple. Despite the wind, the clouds remain stationary because there is condensation on cooling the ascending, wind, and evaporation by warming the descending wind (see Figure M17). **Questions 60 and 61.**

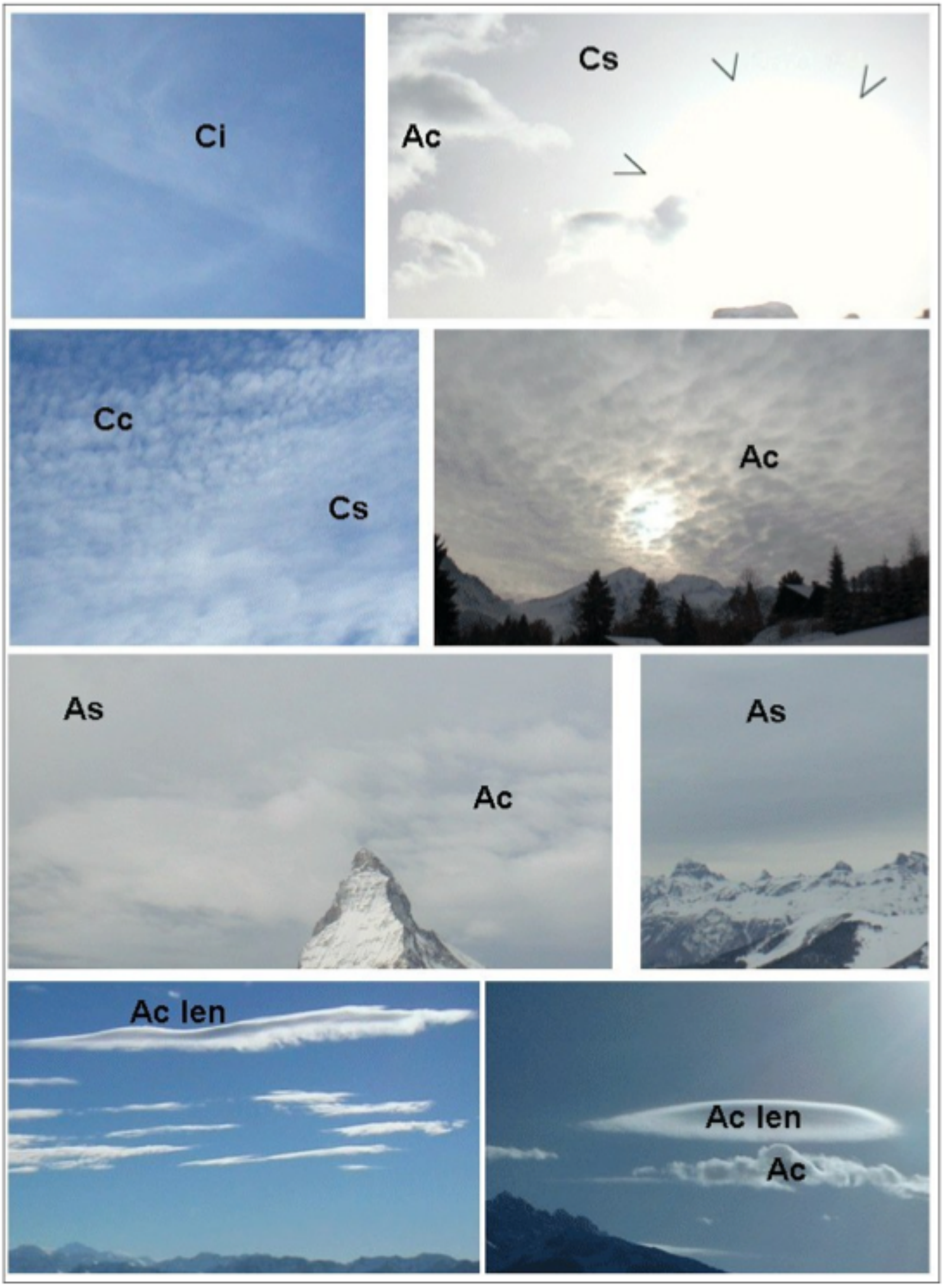

Figure M15 : Different types of clouds.
Top right, the arrows surrounding the solar halo through the layer of Cs.

Figure M16 : Different types of clouds (continued).
Top right, the arrows show the upper limit of the convective (foggy) layer.

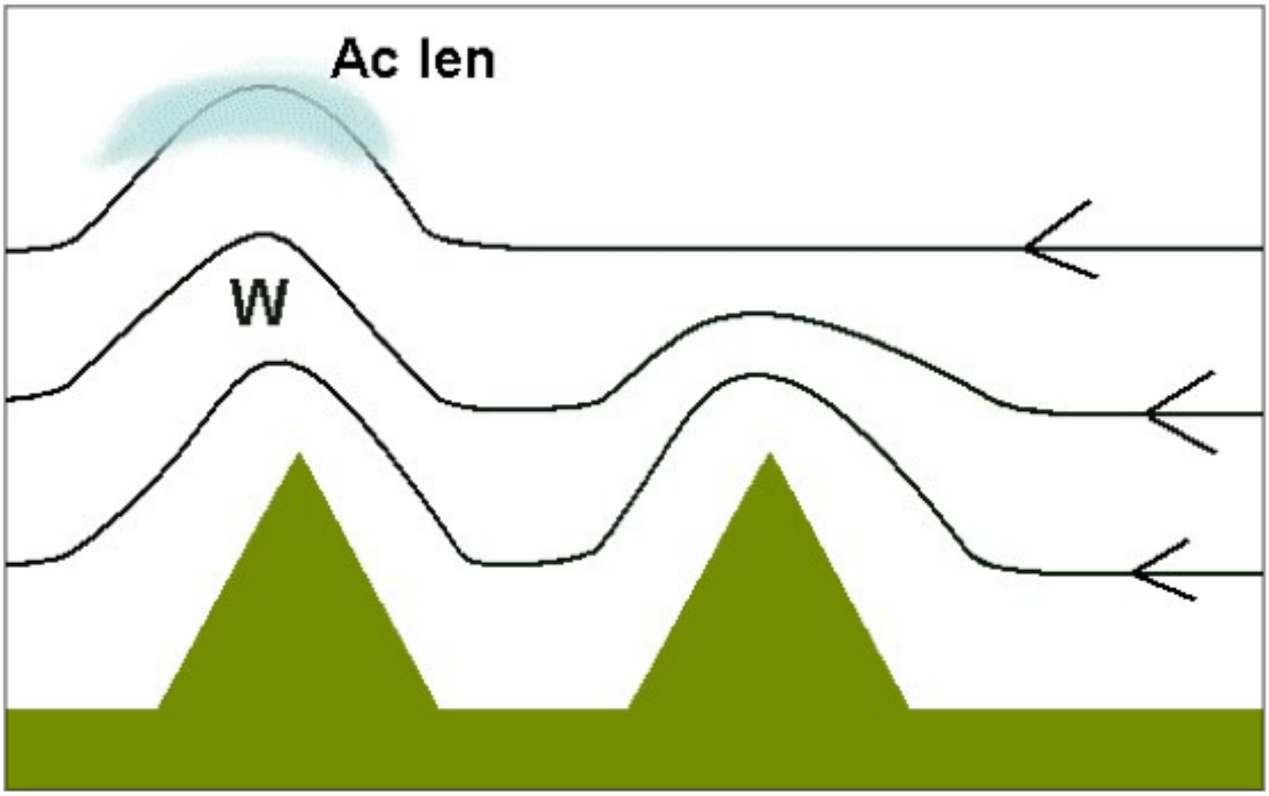

Figure M17: origin of lenticular cloud. W = wave.

A gray curtain of vertical stripes, slightly oblique, extending from the gray base of Cu cong. or Cb to the ground is a sign of precipitation, often visible from a distance. **Question 62**. See Figure M18.

Figure M18: R = curtain of rain in a Cu cong.

Wind Measurements

We define the wind direction by its origin (i.e. from where the wind blows) using cardinal directions (north - east - south - west) or the number of degrees on the "compass rose" of the winds. A north wind is blowing *from* the north and heading *towards* the south. See Figure M19.

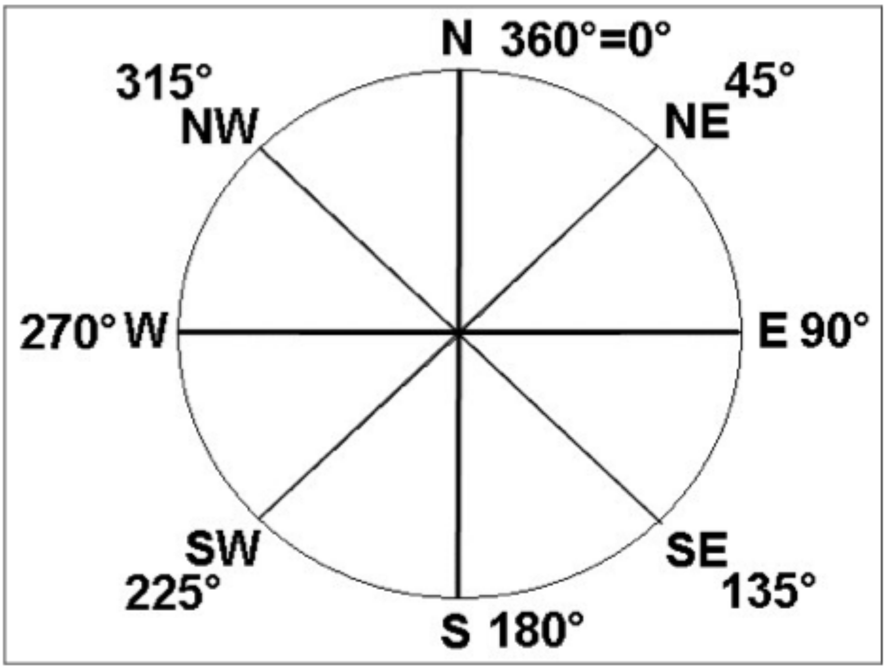

Figure M19: Compass Rose.

For example, a wind of 135° is a wind from the SE (southeast), which comes from the SE (***not*** going towards the SE). **Question 78**. A wind from the NW (northwest) is a wind direction of 315°. **Question 79**.

We define the wind speed in mph, m/s or knots. To convert to km/h for a wind speed measured in knots; multiply by 2 and subtract 10%. Example: a 25 knot wind is blowing at 45km/h (i.e. 2 x 25 = 50; 50 - (10% of 50) = 45.) **Question 80**. Another example: A wind of 270° / 10 knots is a west wind (see Figure M19) blowing at 18km/h (2 x 10 = 20; 20 - 2 = 18). **Question 81**. Final example from the statement of **question 82**; the following extract from radio soundings: 1000m: 070° / 15 knots; 2000 m: 080° / 10 knots; 3000 m: 230° / 10 knots; 4000 m : 240° / 10 knots. What is the wind at 1000m altitude? The direction is 070° and speed is 15 knots which corresponds to a wind from the NE (more exactly ENE) of 28km/h.

Action Centers, Isobars and Prevailing Winds

Not all locations on the surface of the earth are at the same altitude. It is therefore difficult to compare the ground level atmospheric pressure one place to another, since the highest point will always be at the lowest pressure. It is possible to calculate the (adjusted) atmospheric pressure at altitude sea level from measured values of pressure and temperature measured from a higher altitude. This is, however, beyond the scope of the

SHV/FSVL exam. In this section we will only refer to the adjusted atmospheric pressure at sea level

Even at sea level, the atmospheric pressure varies from place to place and time to time, as can be seen in changing barometer readings. Changes in land temperatures produce either warming or cooling the air in contact with the ground, which in turn varies in density and therefore pressure. **Question 65**. An area of high pressure might form on a land area which is cooler than its surroundings for a protracted period, such as the Arctic, Siberia or any continent in winter (low sun on the horizon), or an ocean during summer (North Atlantic), which is cooler compared to its neighboring continents (Europe). **Question 66**. Conversely, a low pressure area (depression) may occur on an area which is warmer than its surroundings for a protracted period, such as the equator, the Sahara in summer, the Atlantic Ocean during the winter (cooler than continental Europe). **Question 67**. Low and high pressure zones are called **centers of action** because they are the cause of the general atmospheric circulation. The average atmospheric pressure at sea level on land is 1015hPa. When the air pressure is higher, it is referred to as a “high pressure zone” and where it is lower, a “low pressure zone”. In the temperate regions, a pressure of 1035hPa would be typical of a strong winter anticyclone. Pressures higher than this are very rare. In summer, the pressure of high pressure regions is generally lower than this, between 1020 and 1025hPa. A pressure of 955hPa would be typical of an area of low pressure. **Questions 68 and 69**. To simply illustrate the distribution of pressure on a map, lines are plotted following the areas of equal pressure (adjusted to sea level) called **“isobars”. Question 72**. See Figure M20.

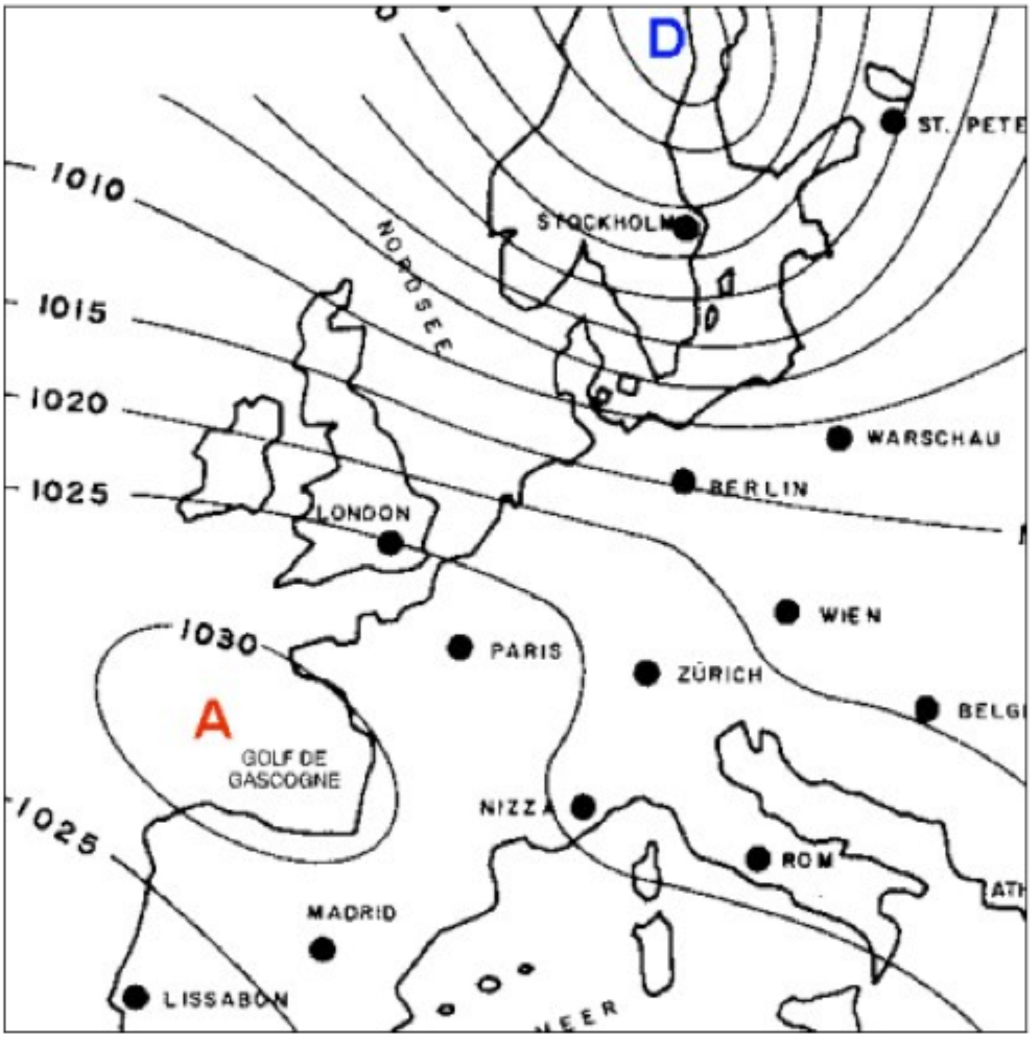

Figure M20: map with isobars and action centers. A = high pressure, D = depression.

On this map, the isobars allow the cyclone (Bay of Biscay) and anit-cyclone (Scandinavia) to be immediately obvious. Isobars are spaced at 5hPa intervals and hence shown at 1000, 1005, 1010, 1015hPa etc… London and Nice are almost on the same 1025hPa isobar. Zürich is midway between 1020 and 1025hPa, approximately 1023hPa. In the center of the anticyclone has a pressure a little above 1030hPa, as it is surrounded by the 1030hPa isobar.

All fluids (liquids and gases) move in an attempt to even out pressure differences. See Figure M21.

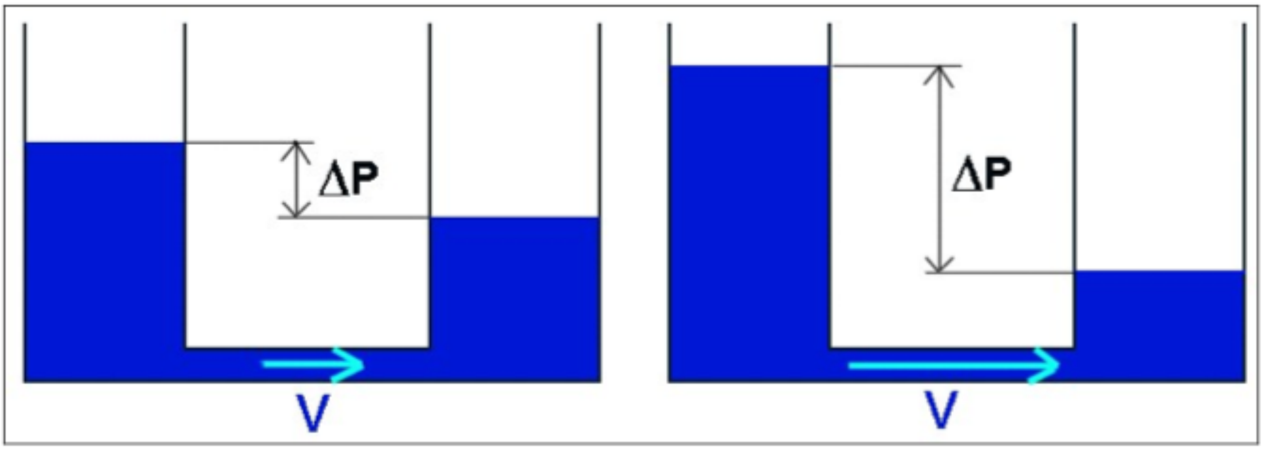

Figure M21: Connecting vessels. Liquid will move from the vessel in which the pressure (height) of the liquid is higher to the vessel where the pressure (height) of the liquid is lower. ΔP = differential pressure. V = velocity of the fluid.

The greater the pressure difference, the greater the speed of movement of the fluid. This also applies to atmospheric centers of action. If the pressure difference between an anticyclone and a cyclone (shown by many, tightly spaced isobars) is large, the surface winds will be strong. In addition to this the winds are subject to the rotation of the earth. This interferes with the direct movement of air between centers of action, introduces a rotational element to the winds around the center of action. This is called the force, called the Coriolis force. The result is that the surface winds blow more or less parallel to the isobars around the action center. The effect also responsible for the spiral formed by water exiting the drain hole of a bathtub. **Question 74**. See Figure M22. In the northern hemisphere, the air masses rise by turning anti-clockwise around the center of low pressure (cyclone), and clockwise around the center of the anticyclones. See Figure M22. **Questions 70 and 71**. A simple memory aid, is to keep the “anti-” in the middle: *“cyclone-anti-clockwise; clockwise-anti-cyclone”.* In the southern hemisphere, it is the opposite.

From the isobars, their distribution and the arrangement of the centers of action, we can ascertain the main direction and speed of prevailing winds. **Question 73**. This prevailing wind is also known as **geostrophic** wind as it links the centers of action, and it follows 3 main principles:

- Wind direction is parallel to the isobars.
- Rotation of the wind is clockwise around a high pressure and anti-clockwise around low pressure (for the northern hemisphere). For the southern hemisphere is the opposite.
- Wind strength is determined by the isobar spacing (= horizontal gradient pressure). Tight spacing (= high gradient pressure) and the wind is strong and vice versa.

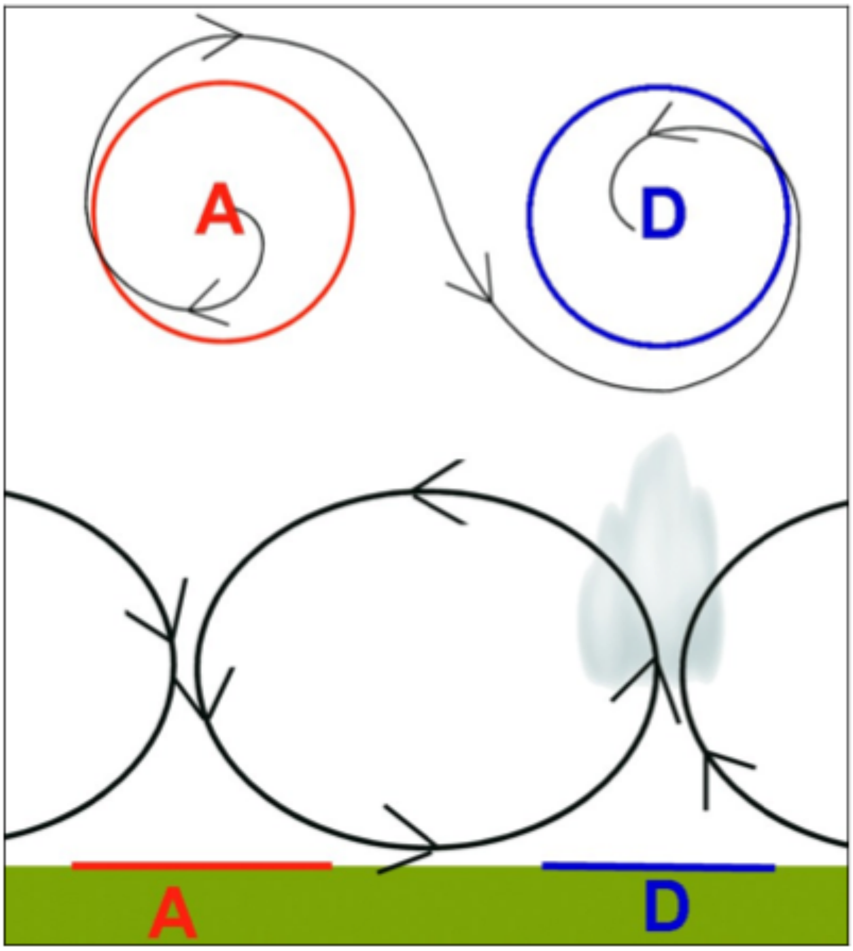

Figure M22: 3 air movements around the centers of action: Vertical (descending in anticyclones, rising in depressions), rotary (around Action Centers), horizontal (spiraling away from high pressure, and spiraling towards low pressure). A = Anticyclone. D = Depression.

In Figure M20, Stockholm has strong westerly winds, parallel to the tightly spaced isobars and rotating anticlockwise around the depression further north. In Paris the winds are weak and from the northwest, parallel to isobars spaced in the clockwise direction around the anticyclone in the Bay of Biscay. If the gap between the isobars on a weather map is small, it is often referred to as an abrupt pressure drop with high winds expected. Conversely, if the difference between the isobars on a weather map is large (isobars well spaced), it is decribed as a flat distribution of pressure and light winds are forecast. **Questions 75 and 76.**

We described two types of centers of action: anticyclones and depressions. In anticyclones, the air falls, then heats up and dries out. In Europe, there is also often a temperature inversion (typically around 1500-2000m) which accompanies a high pressure region. In a depression (cyclone), the air rises, cools and then and increases in humidity. Hence the anticyclonic weather is rather stable with a convective layer generally of modest thickness, while the weather conditions in the depressions are unsettled.

Between these two types of centers of action, there may be intermediate pressure zones (1010 to 1020hPa) distributed widely, that is with few, widely separated, isobars. This is known as barometric swamp. Here the density of air is lower and the atmosphere a little less dry and more volatile than in an anticyclone. On the other hand winds speeds are low because the pressure gradient is small or zero. This situation generates significant convection and is the best for paragliding. **Question 77**. Caution is required, however, due to the potential for local thunderstorms.

Local Winds

In addition to general atmospheric or geostrophic (macroscale) circulation due to centers of action, there is also regional air circulation on a mesoscale or microscale. An example of mesoscale effects are the winds generated by the interaction between large bodies of water (lake, inland sea) and their coastlines. On a sunny day, coastlines warm more quickly and the adjacent lake atmosphere. This causes air flow from the lake to the coast (lake winds). During the night, reverse occurs: The coasts are cooler than the lake, and the heat stored by the water (heat accumulation) is released. The airflow then is from the lake to the shore (land breeze).

A further example, similar to the previous, is that of alternation of mountain and valley winds. The valley wind is a wind that blows from the main, wide valley section to its upper reaches with small side valleys and peaks that warm up faster. **Questions 86 and 90**. The mountain wind is a wind that blows during the night from the small peaks and side valleys, which cool faster, towards the broader and deeper main valley, which cools more slowly. **Questions 87 and 91**. See figure M23. Since the valley wind is denerated by the intensity of the sun and is enhanced by a soil surface without snow, it is greatest in July and August and least in December and January. **Question 94**. It is also greatest during mid-afternoon when the sky is clear. **Question 96**. In summer the valley wind starts in the late morning and the mountain wind usually in the evening (18-19:00h). **Questions 92 and 93**. With altitude, the valley wind is stronger, **Question 95**, but in wide valleys, the valley wind gradually disappears around 2000m and is overcome by the prevailing wind.

Each sunny slope contributes a small portion of ascending air a few tens of meters thick, adhering to the slope (thin pink arrows in Figure M23). This should not be confused with the mountain thermals extending to the top of the convective layer which are generally separated from the valley walls (orange arrows). These thermals are more widely spaced, cylindrical and develop in areas that are particularly suited to heating of the ground by the sun (and thus protected from the winds of the main valley). The updraft on the slope of the valley caused by the gentle thermal movement on the valley wall is the source of the breeze that allows paragliders to take off more easily.

During the night, each valley wall is cooled (nocturnal radiation) and causes the formation of a thin layer of down-slope wind (thin blue arrows). These winds come together and finally form the descending (mountain) wind at the bottom of the valley (large blue arrows). Figure M23.

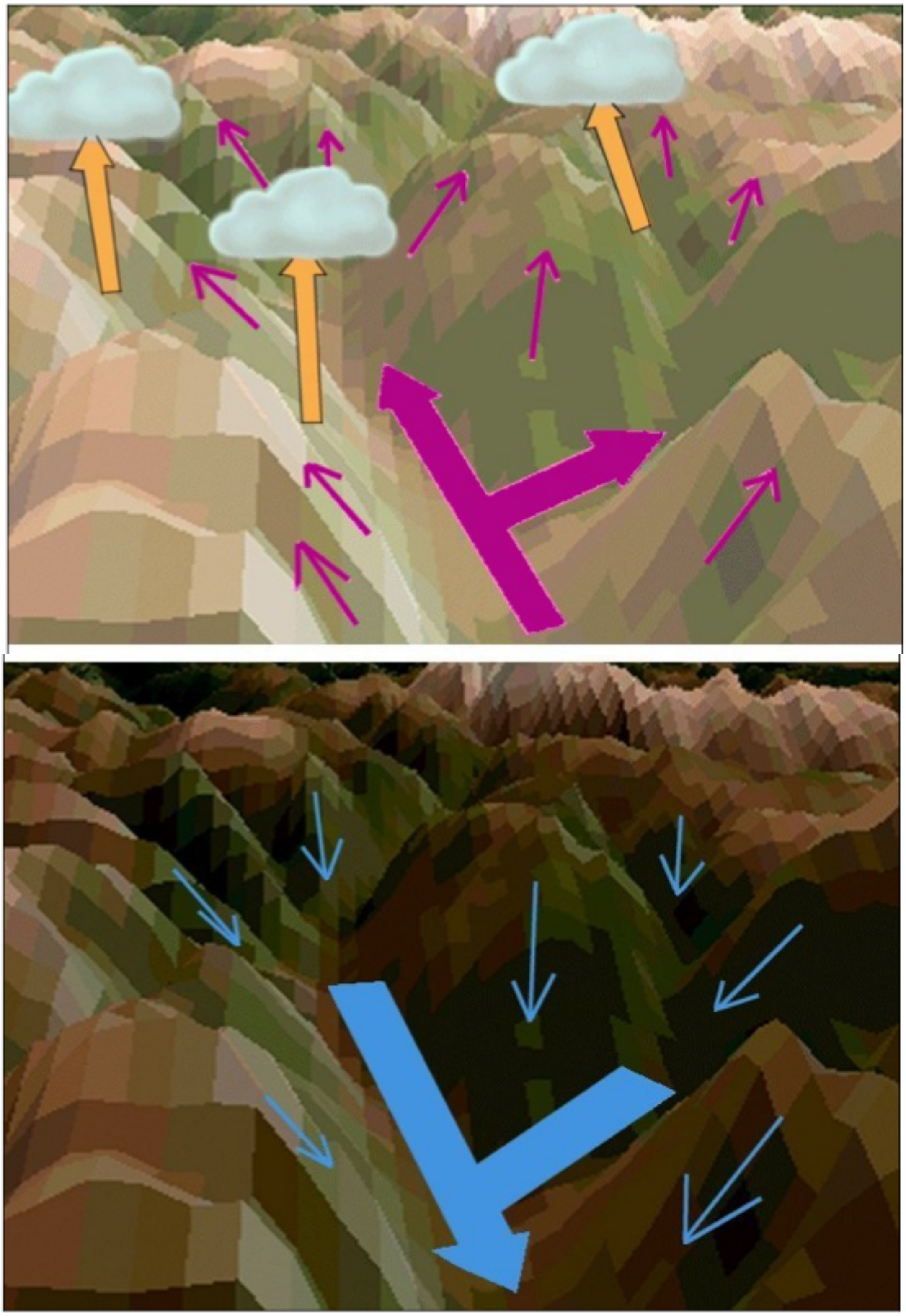

Figure M23Schematic of valley and mountain winds.

Mountain thermals (orange arrows in Figure M23) may be regarded as a variant of the slope wind (also convective in origin). However, unlike the slope wind, these detach from the wall and evolve independently in the free atmosphere. In general, mountain thermals are stronger and more constant than the thermals from open plains (a rising column rather than a bubble).

Figure 24 illustrates a section of the valley, showing the components of the system of mountain winds.

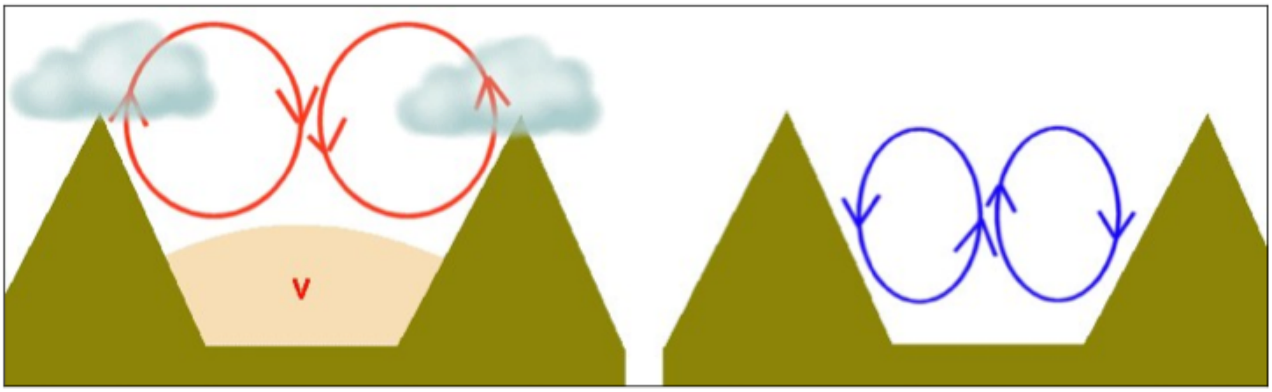

Figure M24: Cross section of the system of valley and mountain winds. V = valley wind zone, parallel to the axis perpendicular and to the valley and slope winds. Left valley wind. Right mountain wind.

During the day, slope winds rise and then cycle back to the center of the valley where the air descends slowly (similar to an anticyclone). Ths phenomenon is therefore pronounced on upper valley slopes. **Question 88**. The lower slopes are swept by the wind through the valley, which destroys the lift at this level. During the beginning of the night breezes down-slope breezes join in the middle and bottom of the valley and generate a slight upward current in the middle of the valley. **Question 89**. In the evening this upward movement may be strong enough to keep gliders aloft. This is known as rendition (**Question 143**), bu the lift only persists for a few tens of minutes.

Turbulence

Turbulence (local variations, eddies and abrupt changes in wind direction and speed) are due to winds. The stronger the wind, the greater the chance that they occur, and the greater the chance that they are violent and dangerous. It is therefore unadvisable to fly in strong winds or areas prone to strong winds (a narrowing or curvature of a valley). Similarly, it is advisable to land quickly when the weather becomes stormy. A storm is often associated with episodes of particularly strong and irregular gusts. Turbulence is classified into 3 types according to their origin:

1. Mechanical turbulence
2. Shear turbulence
3. Thermal turbulence

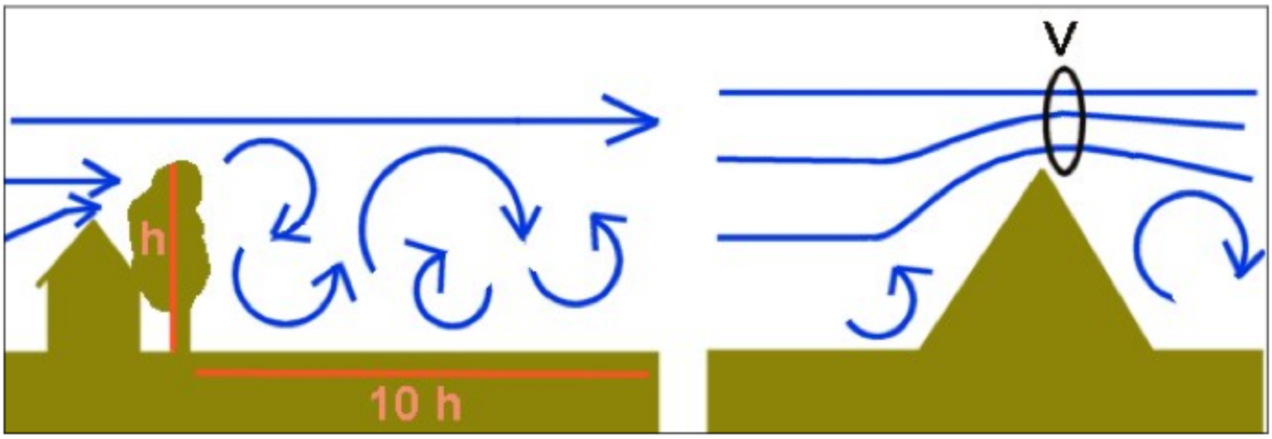

Figure M25: mechanical turbulence

Mechanical turbulence (figure M25) is the result of the conflict between the solid obstacles and wind. **Question 97**. Objects upwind of a reference point are described as **“windward”,** while objects downwind of the reference are describes as **“leeward”.** The air leeward of an obstacle has the most marked turbulence. It is therefore dangerous to fly leeward of a mountain or obstacle, and this should be avoided at all costs (including choice of landing sites). The turbulence may extend horizontally behind the obstacle up to ten times its height. See left side of figure M25. When it comes to imposing terrain, the wind before the slope is forced upwards. Over and above the edge there is a constriction in the air flow, and the air is forced to increase its speed over the edge. This phenomenon of increased air speed, with decreased space (flow area), and vice versa, is called the **Venturi** effect. See right side of Figure M25. The Venturi effect and associated turbulence does not only occur above and behind mountain peaks but also near a relief when the wind if forced round it or is forced into a valley.

Sheer turbulence occurs close to the boundary between two air masses subjected to winds of different speed and/or strength. **Questions 98 and 83**. See figure M26 left. For **question 83**, there are northeastern winds of 10-15 knots at 1000 and 2000m combining with southwest winds around 10 knots at 3000 and 4000m. So between 2000 and 3000m there is a change of direction that is likely to cause shear turbulence. When the wind speed decreases without changing direction, it is called gradient wind. This happens especially near a flat surface, where air few meters (or centimeters) above ground is hampered by the friction acting against the strong wind blowing tens of meters above. See Figure M26 in the middle.

Thermal turbulence occurs at the boundary between warm, rising, air and cool, descending, air. It also occurs at the top of the convective layer. **Question 99**. Figure M26, right is a variant of shear turbulence.

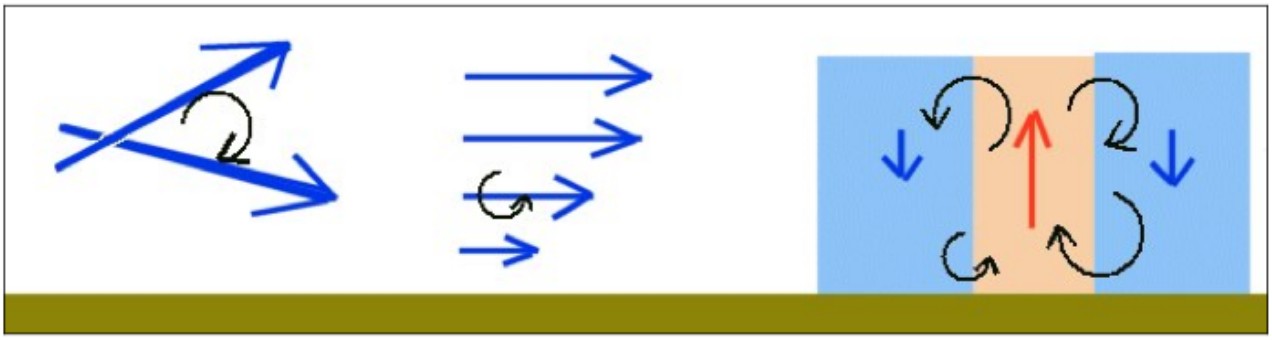

Figure M26: shear turbulence (2 figures on the left) and thermal right figure).

Questions 84 and 85, considers a wind on a surface. Near the ground the wind will be weaker (gradient wind) but more turbulent (mechanical turbulence) that the wind 300m above.

Questions 100 to 102, considers good weather conditions with a well developed valley wind in summer and early afternoon. 500m above the bottom of the valley, you may encounter sheer turbulence between the prevailing wind and the valley wind just below. At 20m above ground it is most likely to encounter mechanical turbulence. Above a sunny area (south) to 2800m there is a risk of finding mostly thermal turbulence.

Questions 103 to 105, refers to fair weather (no wind or weather) in July. Around 09:00h the temperature is still low and the valley breeze is weak, hence there is little turbulence. Around 11:00h the valley breeze is still undeveloped but convection now present. Thermal turbulence is therefore possible. Between 13:00 and 17:00, both the convection and the valley wind are well developed. At this point the turbulence (all 3 types) is strongest.

Air Masses, Fronts & Disturbances

An extensive air mass (of a continental scale) has homogeneous characteristics (especially temperature and humidity) extending horizontally to its boundaries. **Question 106**. Examples are a polar oceanic air mass (cold and wet) or a tropical continental (hot and dry). An air mass is described as hot if it has a temperature higher than its neghboring air mass(es). **Question 107**. Air masses do not mix easily, and there is relatively clear separation between two distinct air masses. The surface of separation between these is called a “front”. **Question 108**. Fronts are found mainly in temperate regions (e.g. Europe) because this is where the cold polar and warm tropical air masses meet. A **warm front** occurs when warm, less dense which moves over the top of the cold air it encounters. A **cold front** occurs when cold, denser air, slides under a warm air it encounters. In principle fronts do not occur in the polar, equatorial and tropical regions. When polar lows develop (e.g. north and central Europe) the fronts are intimately mixed. Figure M27 is a graphic of a low pressure system and front: Initially, the center of the depression is coincident with the front.

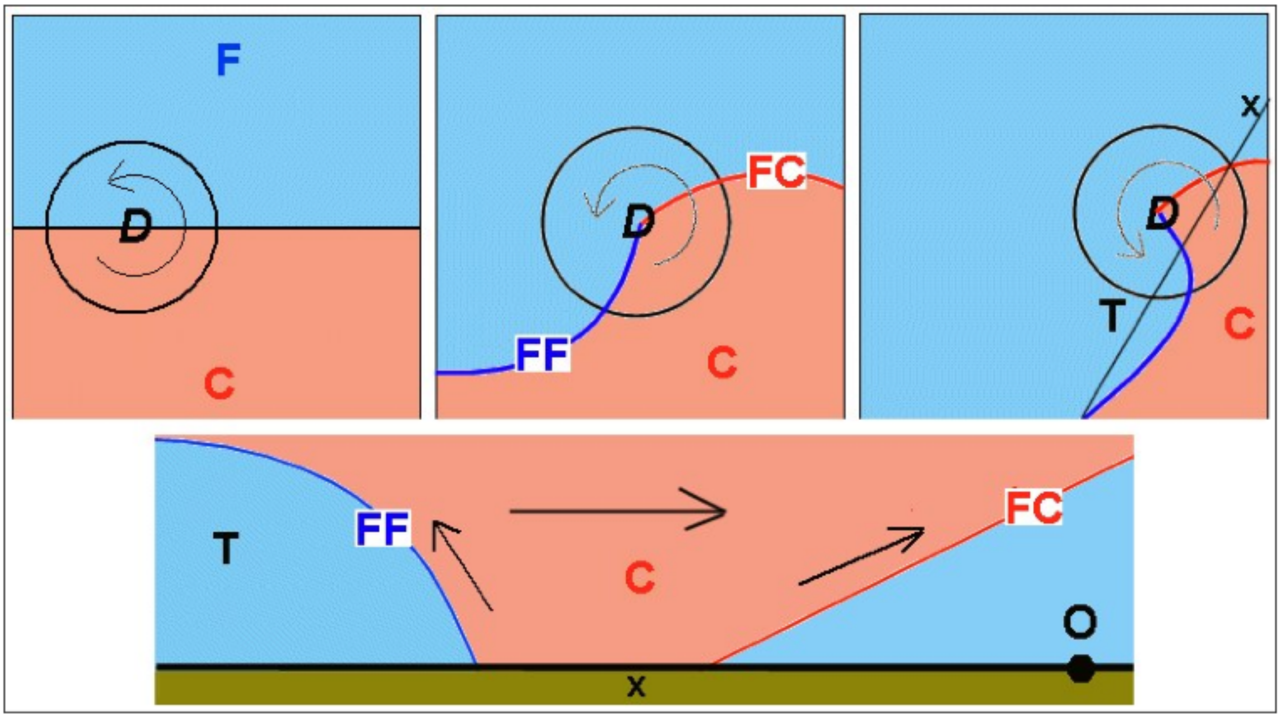

Figure M27: Fronts and polar depressions. D = depression. F = mass of cold air (blue). C = mass of hot air (pink). T = trailing movement. X = section through the frontal system. O = observer. FF = cold front. CF = warm front.

At our latitudes, depressions and frontal systems move slowly (a few km/h), usually from west to east. The anti-clockwise rotation of winds in the depression, combined with the eastern trajectory of the depression itself, causes the cold air west of the depression to move south east forming a cold front, while a warm air mass, and headed north generates a warm front. The cold front moves slightly faster than the warm front, and these can eventually combine to form an occluded front or occlusion. Figure M27 is a vertical section above the line x. We can see that both hot and cold fronts are slanted towards the cold air. **Question 109**. An observer (O) on the ground, will experience the warm front at an altitude, descending to ground level as it passes. The cold front appears firstly at ground level, then rises. **Question 110**. In both cases, the warm air rises and slides over cold air: the warm front gently and the cold front abruptly. The warm air cools by expansion, decreases relative humidity and the air becomes saturated with water vapor, resulting in clouds and (heavy) rain. Due to the change in weather they bring, fronts are also called disturbances. See Figure M28. Since a warm front is more gradual and slow, it will generate in turn (i) cirrus, (ii) cirrostratus, stratus and altocumulus and finally (iii) nimbostratus with showers. **Question 111 and 123**. Just before the arrival of the warm front on the ground, clouds (Ns) are low and with rain, visibility is poor and the wind strength increases. **Question 112**. The arrival of the cold front is more abrupt. It is characterized by a barrier of cumulonimbus clouds coming from the west. See Figure M28. **Question 121.** The preceding time (one to two hours before) can be quite calm and sunny, but not always. The front and generate thunder and lightning or a wide cloud mass extending horizontally to the east of the cumulonimbus cluster. The updrafts are reinforced by the general, and abrupt, rise warm air mass ahead of the front which makes the atmosphere unstable. **Question 113**. Behind the cold front the trailing air is fresher, with good visibility and stratocumulus and cumulus clouds which appear at low altitudes and modest vertical extension. **Question 118**. See figure M28. Due to the high temperature of the lower atmosphere, cumulonimbus (with thunderstorms) are more likely to occur in a cold front during summer (vs. winter). **Question 125**. Metrological forecasts which describe the arrival fresh polar air in the summer, and when the air is hot and stuffy, are probably referring to the arrival of a cold front with thunderstorms often accompanied by hail and gusty winds. **Question 126.**

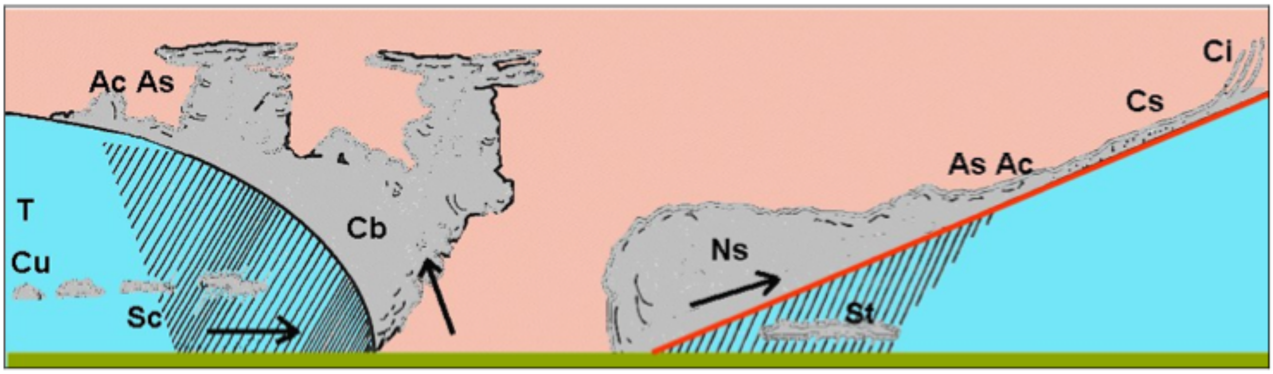

Figure M28 frontal clouds. T = “train” or trailing edge of the fontal system .

An occlusion occurs when the cold front overtakes the warm front, and the merges. **Question 119**. See Figure M29. Depending on the temperature of the cold air behind the cold front, occlusion can present either the characteristics of a warm front or those of a cold front. **Question 120**. If the cold air *behind* the cold front is warmer than the cold air *ahead* of the warm front, cold front slides over the warm front, an the latter (warm front) is what characterizes the conditions at ground level. This occlusion is described as having the character of a warm front (figure M29 (a)). **Question 122.** Conversely, when the cold air *ahead* of the warm front is cooler than the cold air *behind* the cold front, the cold front slips below the warm front. The cold front is in contact with the ground, and the occluded front is described as having cold front characteristics (figure M29 (b)). **Question 124.**

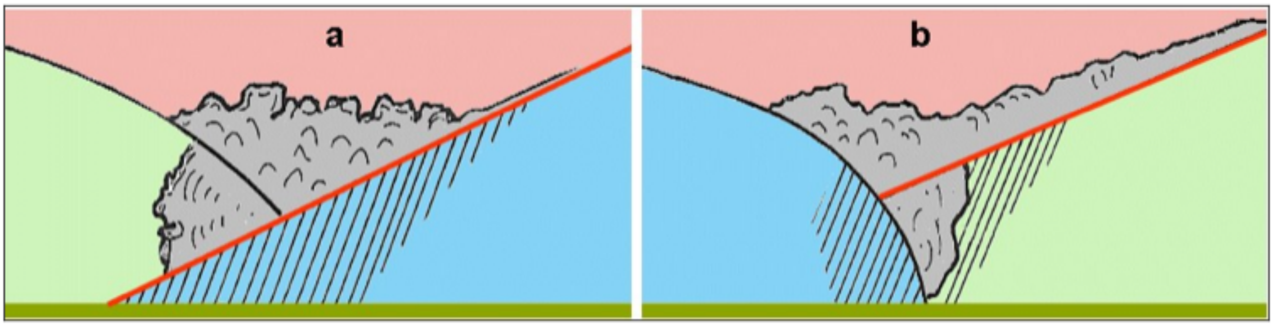

Figure M29: occlusions with a = character of a warm front. b = character of a cold front.

Heat and Storms

The following section builds on the concepts of air temperature, lapse rates and temperature curves described by emagrams.

In order for strong thermals to develop over a land surface, there should be strong solar radiation, essentially perpendicular to the land surface. **Question 135.** Examples would be mountain faces in the morning, the southern slopes or plateaus around noon and the western slopes in the afternoon. Secondly, the solar radiation should be absorbed strongly by the ground (e.g. dark and rough land), so it can warm up effectively and convey the heat to the surrounding air. If the sunlight reflected, by a reflective and smooth surface (e.g. snow), the solar energy is not useful for thermals. The surface should also be sheltered from wind and dry. **Question 136.** A wind swept does not allow the formation of a pocket of hot air on the ground that would required to initiate a well-organized convection cell. Wet soil is subject to high evaporation, consuming energy (heat), and reducing the warming of the soil, and thus the overlying air.

Figure M30 depicts a mountain thermal developing on a slope protected from the prevailing the wind (i.e. downwind). **Question 139**.

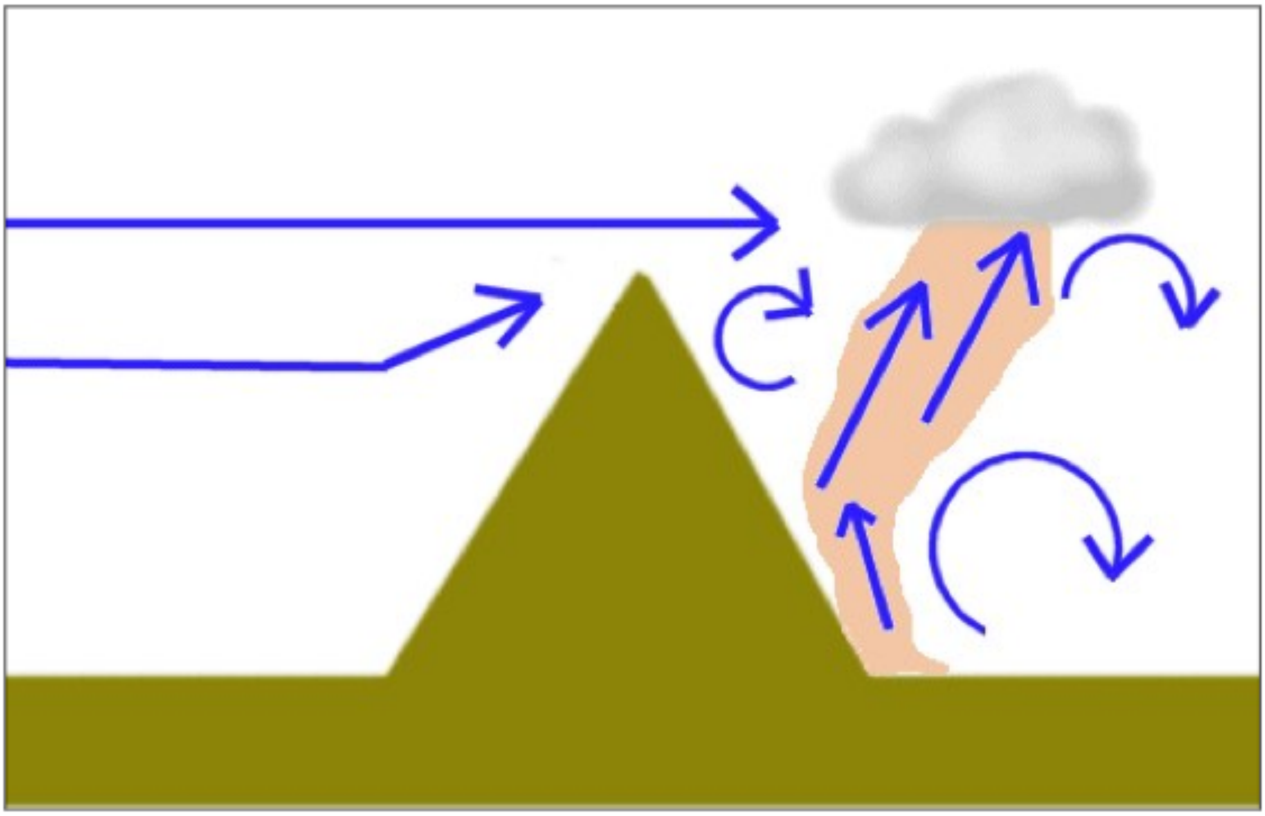

Figure M30: thermal downwind of a relief.

Depending on the terrain, the strength of the wind and that of the termal, the lift can be difficult, turbulent or dangerous. Since the southern slopes are the sunniest, thermals downwind occur mainly on slopes with northerly wind. **Question 140.**

A "blue thermal" is convection which does not result in cumulus cloud formation at the top. The thermal occurs when the air is very dry (low humidity or significant difference between the temperature and dew point) so that condensation is not possible. **Questions 141 and 142.**

In general, the convective activity is better in Europe from April to August, because solar radiation is stronger and the longer during this period. Due to differences average altitude, the snowmelt (and hence thermals) occurs earlier in the pre-Alps than in the Alps.

thermals are therefore best in May in the pre-Alps and in August in the Alps. **Questions 137 and 138.**

A powerful convection in a humid atmosphere may cause the formation of a cumulus congestus and cumulonimbus (rain, gusts and thunderstorms). This forms a heat storm, a local storm or thermal storm. It is therefore logical that this type of storm usually occurs in late afternoon when it is hottest. **Question 127.** The storm clouds of a cold front are more extensive (widespread thunderstorms) and can, in principle, occur at any time of day and night when the front passes through. **Question 128.**

Analysis of Synoptic Maps (European)

The synoptic charts are maps summarizing the status of various meteorological features at a given time. Traditionally this is the pressure in the form of isobars and the fronts. It may also reference winds, temperature, cloud, etc… The commonly used symbols are the letter H ("high", or "A" in French) to show the center of the cyclone and the letter L ("low", or T = "tief" or D = "depression" in French) to mark the center of a depression. Figure M31 shows the symbols for; warm front (a); cold front (b); occluded front (c) and isobar (d) with the number indicating the pressure. **Questions 144 to 147**. Reminders: (1) The pressures refer to corrected to sea leve. (2) isobar spacing indicates the pressure gradient, and hence the wind strength (3) The winds rotate clockwise around the highs and anti-clockwise around the lows (northern hemisphere). **Questions 148 to 153** are based on one example of map and without depicting the fronts. See figure M32.

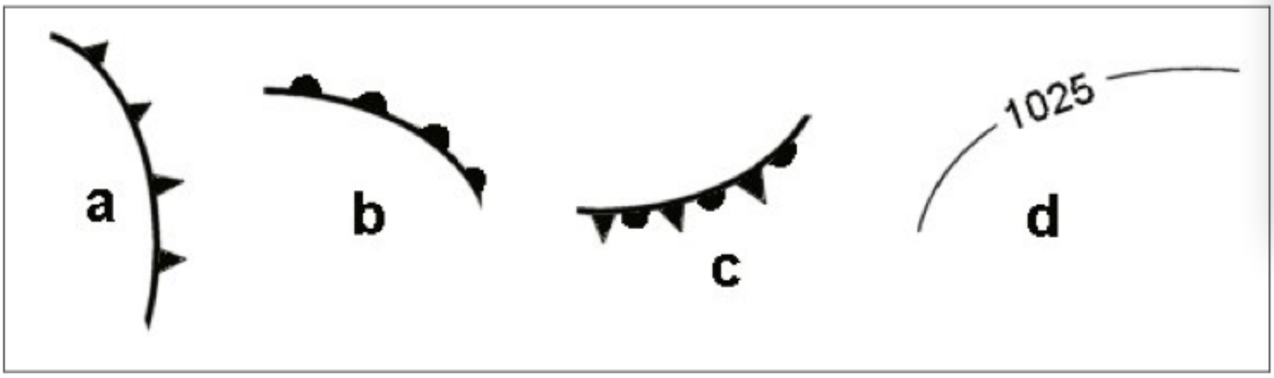

Figure M31: Some symbols used in the synoptic charts, a = cold front, b = warm front, c = occlusion, d = isobar at 1025hPa.

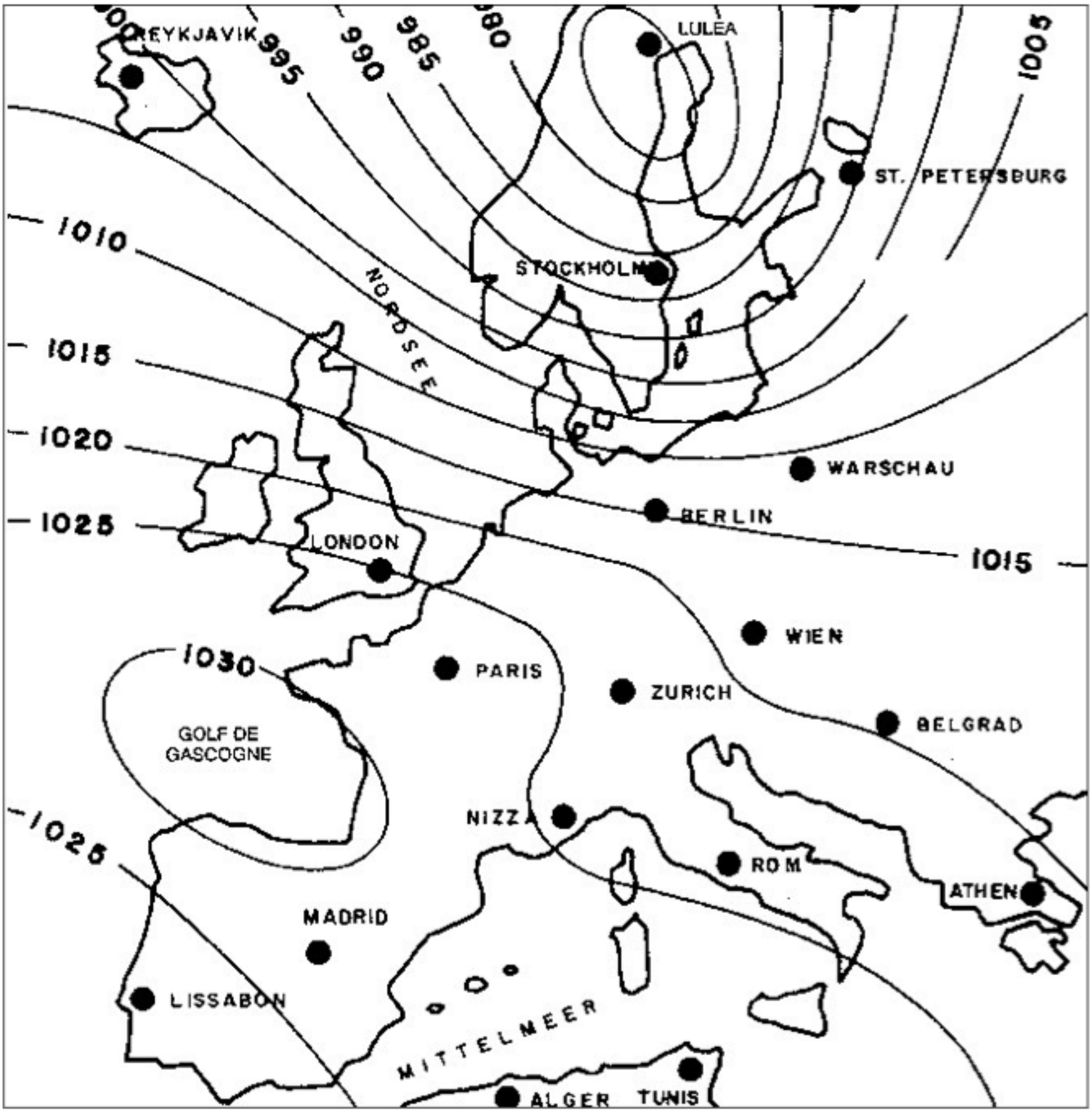

Figure M32: Example weather map without fronts market, used forquestions 148 to 143 (meteorology) from the SHV/ FSVL pilot theory test.

The center of the depression is located near Lulea with a low of about 975hPa, the high pressure towards the Bay of Biscay is around 1030hPa. The pressure differences are the lowest located in North Africa where the spacing between the isobars is the greatest. This is where the winds are weakest, as well as at the center of the anticyclone. The pressure differences are the largest in southern Scandinavia, where the spacing between the isobars is the smallest. This is where the winds are strongest, from west to northwest, parallel to the isobars, due to the anticlockwise rotation around the low northern Scandinavia.

Questions 154 to 166 based on another example of map and with fronts market. See Figure M33.

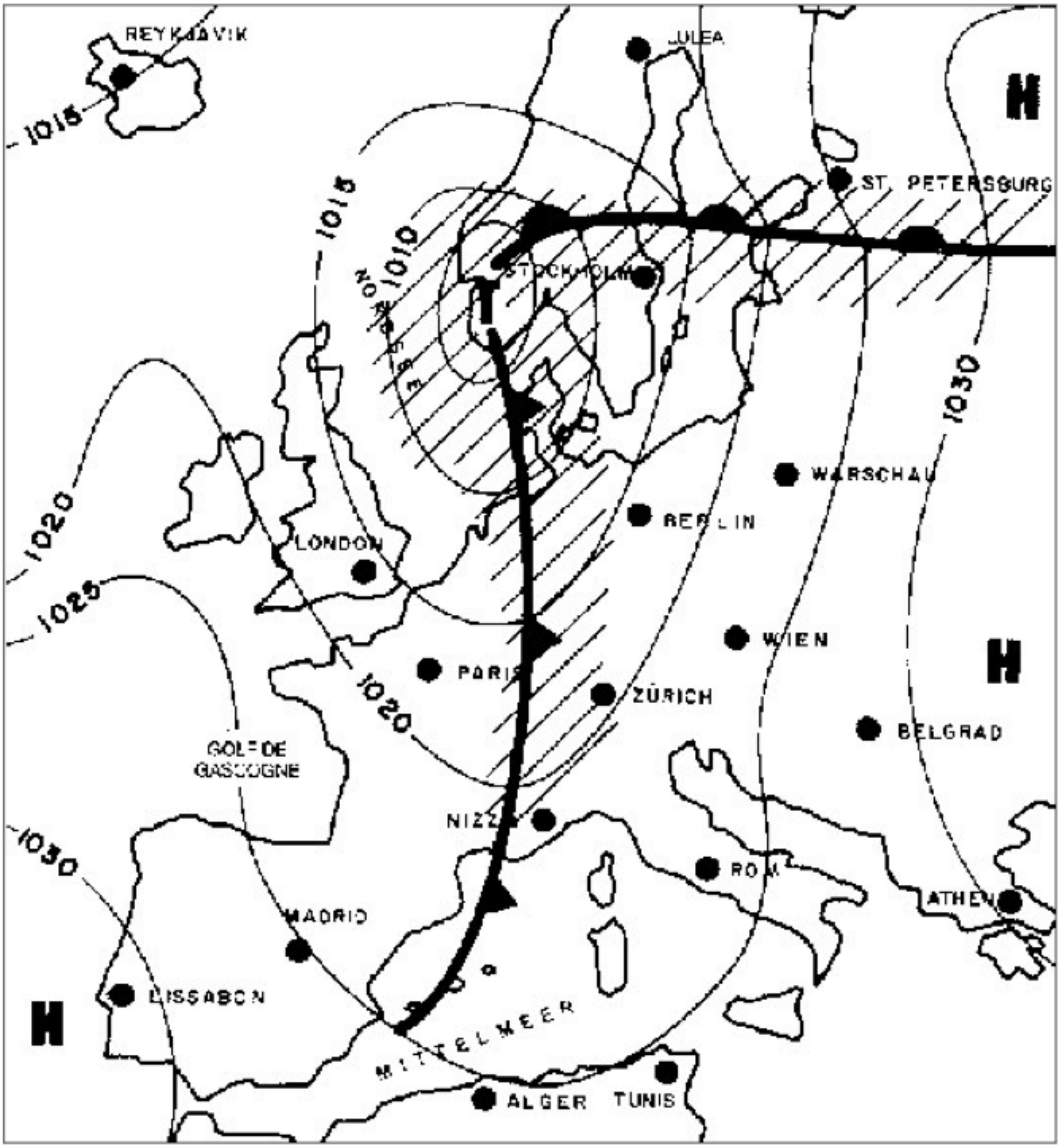

Figure M33: Example weather map with fronts market, used for questions 154 to 166 (meteorology) from the SHV/ FSVL pilot theory test.

Taking into account the direction of the isobars, the spacing between them and the situation of highs and lows; Algiers experiences weak westerly winds (280°); London has fairly strong winds from the north west (310°); Athens has weak south-easterly winds (130°); Zurich has fairly strong winds from the south west (210°); Lisbon has weak winds from the north west (320°).

Zurich and Stockholm are between the warm front and cold front in the warm section. Paris and London are behind the cold front under the influence of the “train”. Lulea and St.

Petersburg lie ahead of the warm front, anticipating its arrival. Lisbon is influenced by the anticyclone over the Atlantic. Athens is influenced by the large anticyclone over Russia.

At Lulea, hundreds of miles north of the warm front, we can see many cirrostratus, heading north. In Paris, in the train of the cold front, we can see many cumulus. In Switzerland, ahead of the cold front, we can see and cumulonimbus clouds and, to the east, lenticulars formed by the wave of the strong wind blowing south-west along the ridges of the Alps. In St. Petersburg, just before the warm front, there will nimbostratus.

We will see later that the map in figure M33 actually represents a situation generating the south foehn with strong southwest prevailing winds and a strong difference in air pressure at ground level between the south and north of the Alps (south pressure).

Some Weather Situations Typical For Switzerland

From synoptic maps of Europe, we can define 6, frequent weather patterns typical for Switzerland. Any weather situation is unique but we can also define typical trends. See Figure M34.

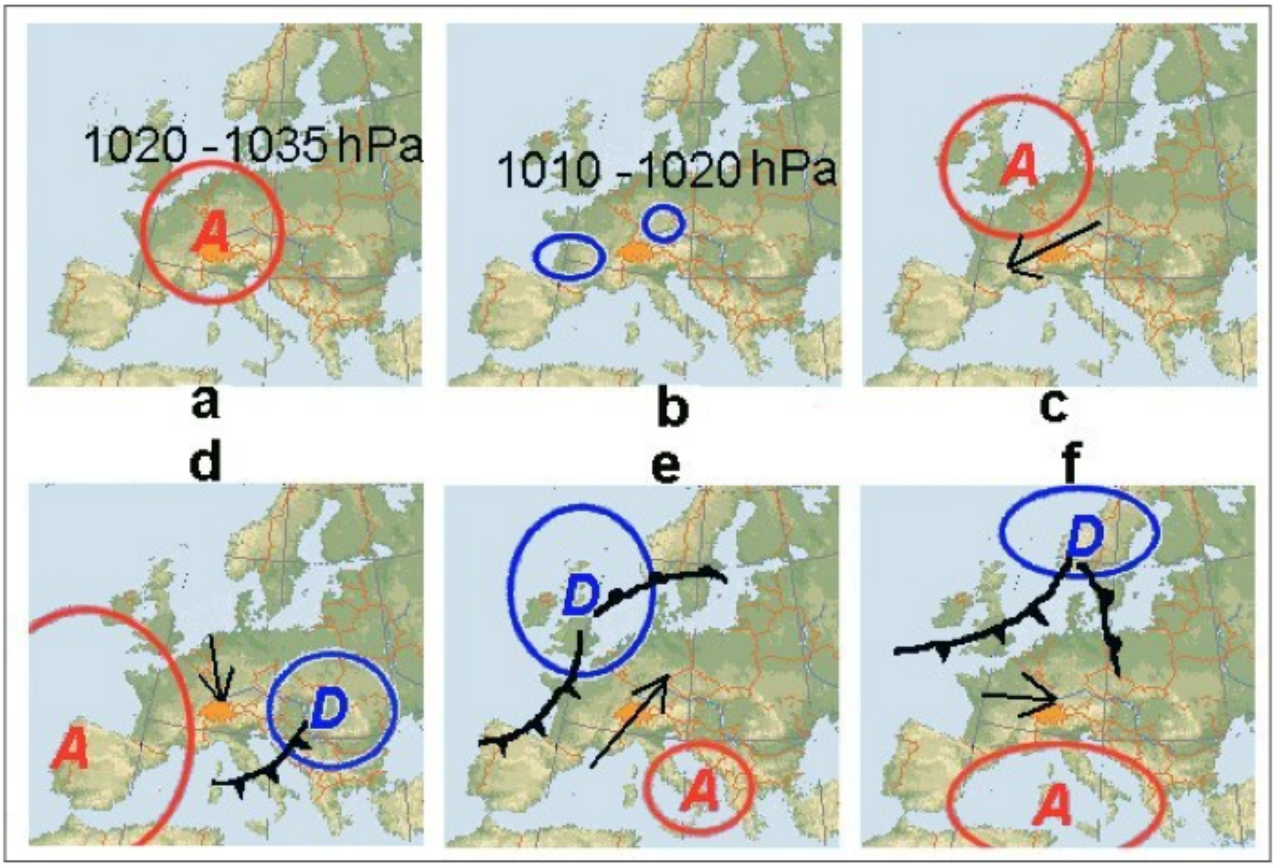

Figure M34: 6 weather patterns typical for Switzerland, as defined by the synoptic charts. a = high pressure, b = barometric plateau, c= bise, d = north foehn north, e = south foehn, f = westerly wind.

Anticyclone (a): an anticyclone is centered on the Alps. In winter (cold and dense), pressures are around 1030 - 1040hPa. In summer (hot air) the values are around 1020 - 1025hPa. In winter, the ground air is often very wet and there is a strong temperature inversion between 1000 - 2000m. This often leads to a thick stratus on the plateau. In summer usable updrafts occur mainly in the Alps since the temperature gradient is generally not very high, but sufficient for a small pressure drop and the atmosphere gets wet resulting in potential development of local thunderstorms (Local Cb). Aside from the possibility of gusty thunderstorms, the winds are low even at high altitude. Therefore, apart from the risk associated with dense stratus (loss of vision) in winter and possible thunderstorms in (hot) summer, these are ideal conditions for paragliding. **Question 132.**

Barometric plateau (b): Also referred to as pressure distribution platform. In such a situation, there is almost no horizontal pressure difference over a wide area of Europe. The winds are weak. The ground pressure is typically between 1010 and 1020hPa. There is no circulation, so the atmosphere is more unstable, more humid and with a vertical temperature gradient steeper than in anticyclonic situations. This is a typical situation where a cyclone is weakening (slight decrease of pressure) caused by overheating of the atmosphere. Thermals are often good with a high ceiling, but the risk of local thunderstorms in the afternoon is quite high. **Question 132.**

Bise (c): There is typically a pronounced wind from the north east on the central plateau around 2000m. Wind can range from northeast to northwest. This is caused by a pronounced high pressure, centered on the north of Germany. **Question 129**. The hazards are the wind (turbulence) and stratus on the plateau in winter (visibility). If the cyclone then moves east or south-east winds can weaken and turn east to south-east or south. The flight conditions can be excellent if the winds are not strong and the pressure difference on either side of the Alps is low.

North Foehn (d): Questions 116, 130 and 131. A wind from the north, often humid across the Alps, generated by an anticyclone from the west (Azores) and extending over Europe. Depression is often centered over Eastern Europe and Switzerland is generally behind a disturbance. On the ground we see a strong horizontal pressure difference north-south above 5hPa, for example 1023hPa (Zurich) to 1015 hPa (Lugano). The effect of the northe foehn is clouds and rain barrier on the north and strong winds, high temperatures and good weather in the south (see below). This situation represents a very high risk due to high winds and severe turbulence, especially south of the Alps where the fine weather could entice you to fly.

South Foehn (e): **Questions 114, 115, 117 and 167**. A current (often humid) from the southern sector of the Alps because driven by a depression over northwest Europe and a higher pressure zone over northern Italy. Switzerland may be faced with a disturbance, itself located (for example) on the Jura, and lying in the warm sector. Figure M33 shows a situation for the south foehn. On the ground we see a strong horizontal pressure difference north/south above 5 hPa, for example 1010hPa (Zurich) to 1019hPa (Lugano). The effect of the south foehn is clouds and heavy rains on the southern slopes and strong winds, high temperatures, dry and relatively sunny north. This situation represents a very high risk due to high winds and severe turbulence, especially in the Alpine valleys where the fine weather could entice you to fly. High altitude winds often cause waves so lenticular clouds are typical in the sky during outh foehn.

Westerly Wind (f): Because of a depression over Scandinavia, a stream of western, sometimes strong, wind pervades Switzerland, with succession of short periods of good weather (mobile anticyclones) interspersed with periods of bad weather (disturbances). In addition to frequent bad weather, strong winds and turbulence can be dangerous for paragliders.

The foehn effect: This effect occurs whenever current passes through a mountainous wetland. See Figure M35. Across the mountain range there is condensation with numerous clouds and rain. This cloud clings to the mountain range and forms a compact band at the vertices called the dam. Moist air rises rapidly, condenses and then cools slowly by the wet adiabatic lapse rate (approx. 0.6°C/100 m). At the peak, the current of air has lost its moisture due to rain. When the air descend on the opposing, it warms faster at the dry adiabatic lapse rate (1°C/100 m). Therefore, the windward side of the mountain is much cooler and wetter than the leeward side. Another feature of the foehn wind is that it is strong and gusty with violent turbulence, thus often very dangerous for paragliding, particularly downwind of the mountain. Conclusions: If the Foehn is active = do not fly even if it is "good weather".

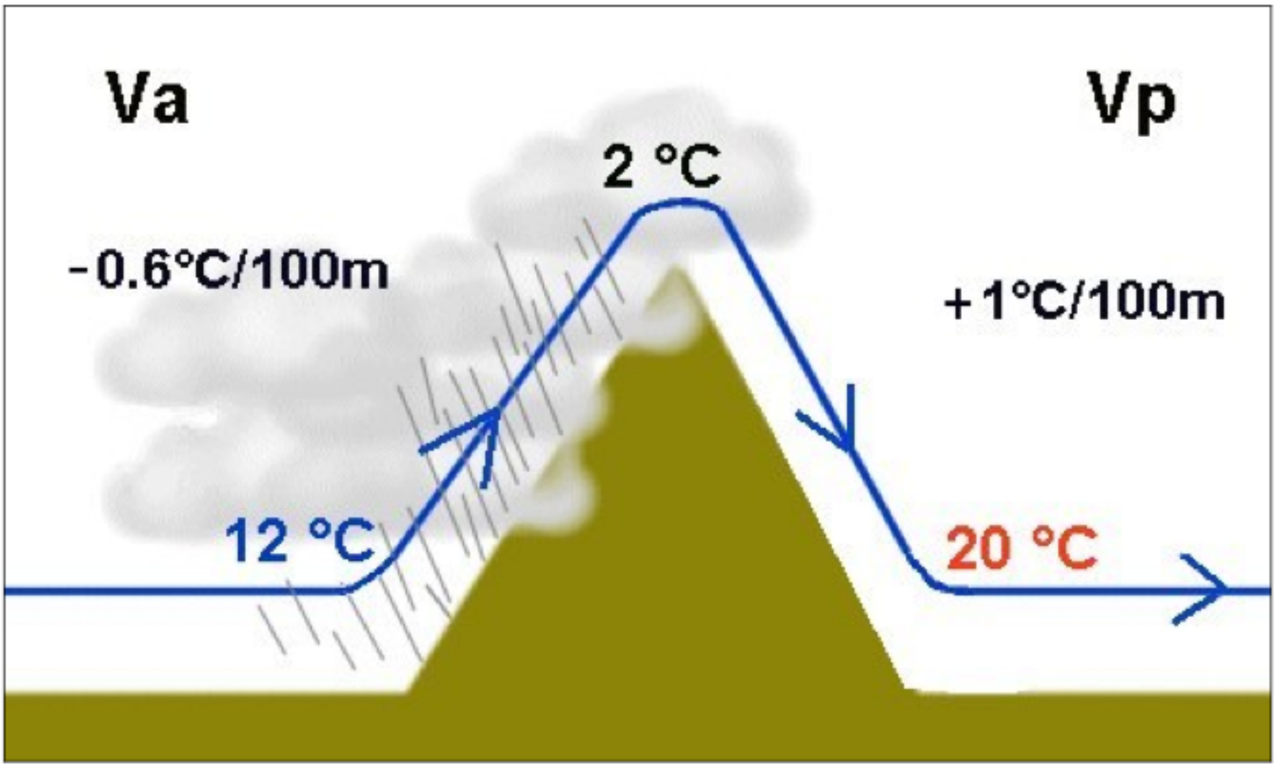

Figure M35: Effect of the foehn. Va = humid and cold mountain wind, with poor visibility and heavy rains. Vp = air dry and warm in the lee of the mountain, with good visibility, strong, turbulent winds despite the sun.

Answers & commentary for SHV/FSVL theory exam for paragliders
Part 2: Meteorology.
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Jean Oberson, March 2005 & Andy Piers, April 2010