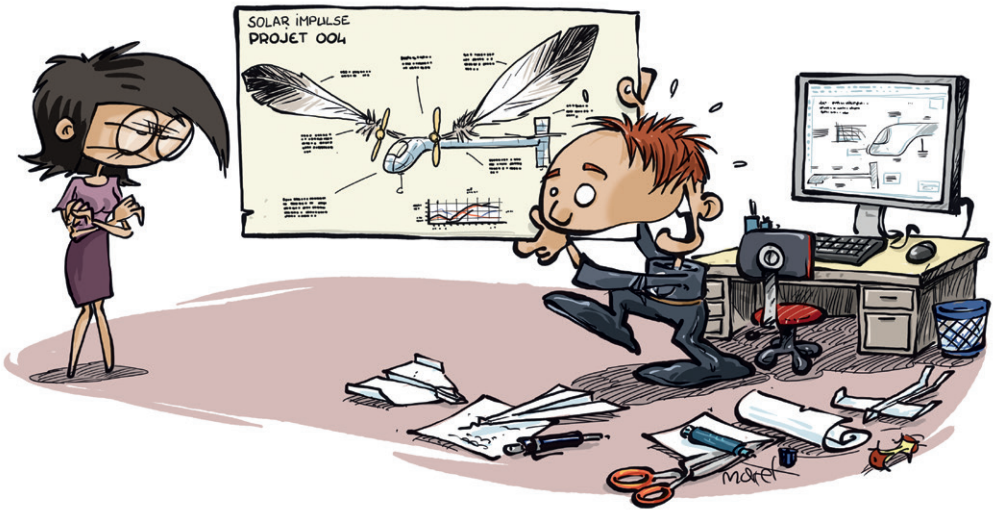
CLOUDS
Get out of the fog!

Solar Impulse needs plenty of sunshine to fly and charge its batteries optimally. High altitude frost or towering cumulonimbus clouds can be fatal obstacles for the airplane. That's why the weather team and the pilots have to understand and anticipate these phenomena to avoid taking unnecessary risks.

So let's go ahead and work our way through this worksheet. For once, your teacher will let you have your head in the clouds!



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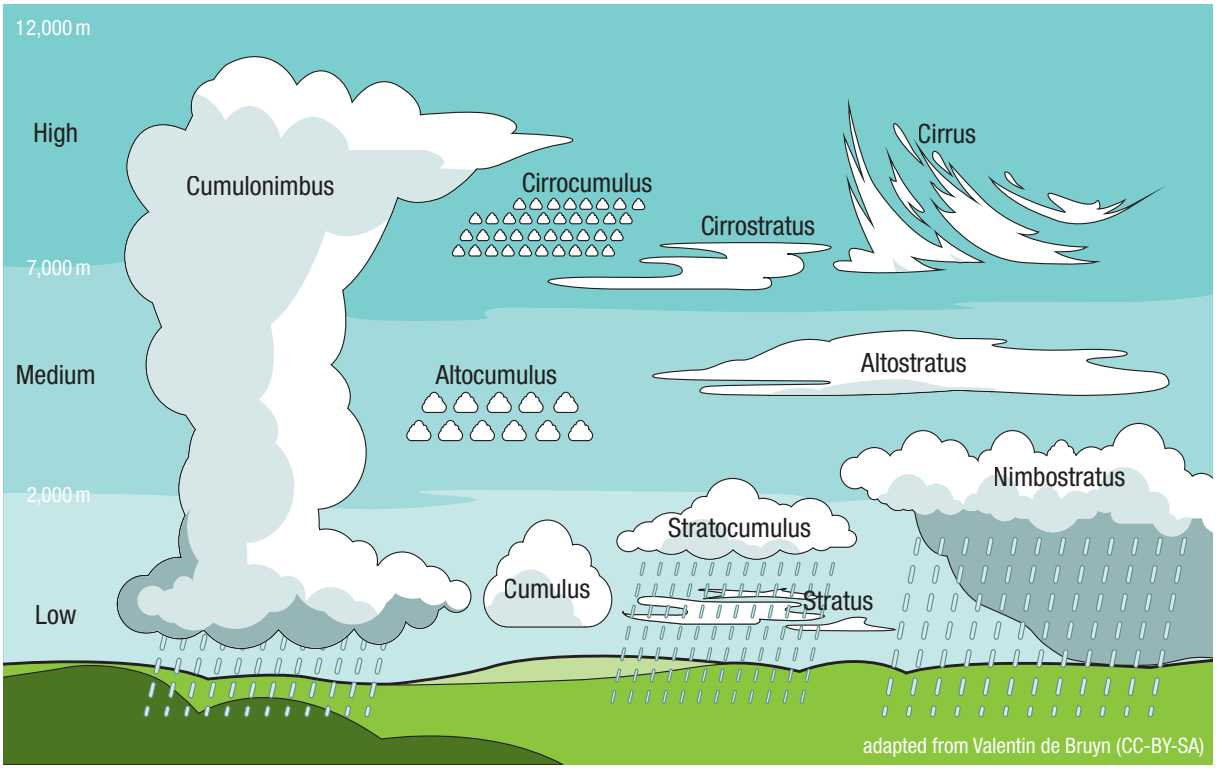
IS IT A CUMULUS, A STRATUS OR A CUMULONIMBUS?

Look at the clouds in the sky and you will probably be amazed by the richness of their forms, by their constant transformations, and by the way the interact with light. By analyzing haze, people understood long ago that clouds were made up of condensed water vapor. However, it was not until the 19th century that this complex and poetic subject was studied more scientifically. Luke Howard (1772 - 1864), the "godfather of clouds," created a classification system with three main families: cumulus, stratus and cirrus clouds. This nomenclature became successful because it could be applied to clouds everywhere in the world. And because the words are in Latin, they could cross language barriers. Howard wasn't the first person to attempt to classify all clouds, but he was the first to succeed. What makes his system great is that it takes into account the transformations of clouds from one type to another. Indeed, clouds change constantly, and over time, a cumulus can become a stratocumulus, for example.

From that day I did not look down anymore
I devoted my time to contemplate the skies
To watch the clouds go by
To spy on the stratus, to ogle the nimbus
To make eyes at the smallest cumulus
But she did not come back

Fragment of the song "The storm" by Brassens

Clouds are classified according to their shape, but also according to the altitude of their base. They are classified into ten basic types.

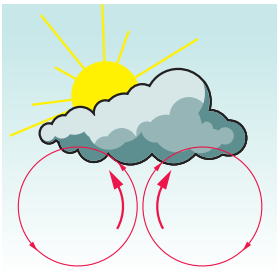


High clouds carry the prefix cirro or are called cirrus. The prefix for medium altitude clouds is alto. Low altitude clouds that touch the ground are called mists. Vertically developed clouds (cumulonimbus) spread across all altitudes and can be several thousands of meters high! Stratus clouds are stratified, or layered. Cirrus clouds look fibrous and cumulus clouds are puffy.

CLOUD FORMATION

But how do clouds form? Air always contains some water vapor, but the amount of vapor that the air can hold without it condensing, or turning liquid, depends on the atmospheric pressure and temperature. The dew point is the temperature to which a volume of air has to be cooled, at constant pressure and humidity, so that it becomes saturated with water vapor. Once the dew point is reached, condensation can occur, but only if there are so-called condensation sites. These can be dust, dirt, or micro-droplets that the water molecules can organize around to make the transition from a vapor to a liquid or solid state. This phenomenon is behind the formation of clouds, mist, dew, rain, hail or snow.

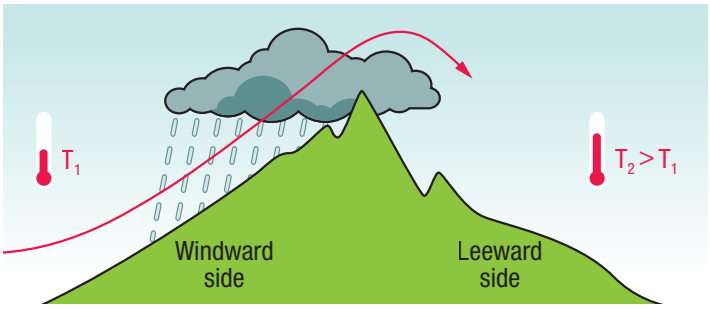
If there is a sharp drop in the temperature of moisture-laden air, the water vapor condenses out, forming a cloud. This usually happens through one of the following three processes:



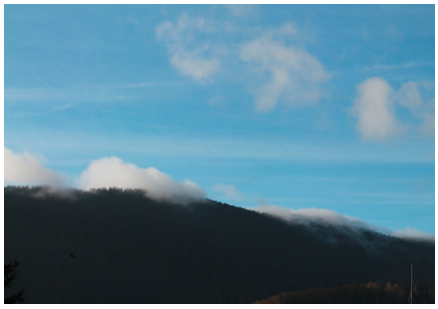
Convection

- Through **convection**. The Archimedes force causes warm, moist air to rise, cooling it down in the process.

- Through **orographic lift** (orogenic clouds). Strong winds push moist air over the flanks of a mountain range.

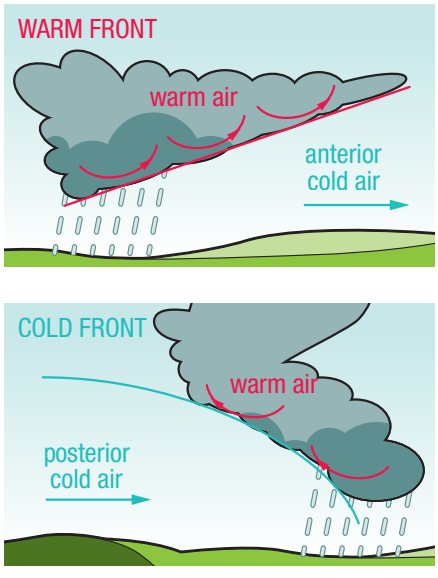


Orographic lift



- Through **frontal lift**. When a warm front runs into a mass of cold air, it rises above the cold air mass. The air rises slowly, first forming cirrus clouds, then thicker and thicker medium altitude clouds, until finally a low-level stratus forms. These clouds will discharge as rain. This situation can last up to 24 hours.

  If, on the other hand, a cold front encounters a warm air mass, the warm air is forced to rise quickly, causing strong convection currents. These conditions lead to the formation of cumulonimbus clouds and thunderstorms along the front, generating a low-pressure area, which maintains the winds.



Frontal lift

Chal!enge

Collect clouds!

By the end of the school year, will you and your classmates manage to take a photo of a cloud from each of the cloud groups?

SOLARIMPULSE

Solar Impulse is a high-tech prototype built using cutting-edge technology. Its structure has been optimized to fly day and night using only energy from the sun. The aircraft is designed to fly in very specific conditions and it is important to make sure that it does not encounter too heavy winds or rainfall that would damage its structure. Solar Impulse can only fly in:

- Headwinds of up to 10 knots
- Crosswinds of up to 5 knots

It is important to pay particular attention to wind shear (vertical winds that develop under cumulus clouds), which would strain the wings and damage the aircraft.

Each mission is prepared taking into account very detailed weather forecasts to ensure that the flight can take place under good conditions.

canton de vaud

Quiz

Identify the type of cloud in the photos below.

THE CUMULONIMBUS, THE AVIATOR'S SWORN ENEMY!


Versageek (CC-BY-SA)

Pilots fear the cumulonimbus – especially those flying an aircraft as light as Solar Impulse. They are the clouds behind thunderstorms and severe storms. Cumulonimbus clouds develop vertically. Their base is generally at a low altitude and their top can reach heights of up to 6,000 to 18,000 meters, extending all the way into the stratosphere! They form through powerful convection currents. When the ground has accumulated a lot of heat through radiation from the sun, it warms the air above it. Because the density of the heated air close to the ground is lower than that of the cooler air above it, it rises, leading to the formation of a convection current. These currents can be accentuated in mountainous terrain. As the air gains in altitude, it cools down and the moisture it contains condenses. The process of condensation releases heat. This heat is transferred to the saturated air, which becomes warmer than the surrounding air, creating a suction that strengthens the convection currents. These updrafts can reach speeds of 140 km/h. Once the cumulonimbus cloud is completely formed, its peak looks like an anvil, as it reaches the stratosphere, where a temperature inversion begins.

On cloud nine...

Look carefully at the clouds over the next few days. You will notice that, even if their peaks are budding or disheveled, their bases are very regular. Indeed, they are all at the same altitude.

The higher you go in altitude, the cooler the air becomes. At one point the temperature drops below the dew point. Then water vapor condenses and clouds appear.

Why do you think the upper edge of the "sea of fog" (stratus) on the photo is so flat?

HYDROMETEORS

Hydrometeor is the generic name for all the particles composed of water that are present in the atmosphere. We have already seen that the excess water vapor in a cloud condenses. The formed droplets are microscopic, measuring a tenth of a millimeter. They are so light that a feeble updraft keeps them in midair. Once enough droplets are formed, the cloud becomes visible.

In the case of a cumulonimbus, which his held up by strong convective currents, the droplets freeze and grow as they move up in the cloud. This leads to the formation of **hailstones**, whose size may exceed 5 mm in diameter. When the can no longer be held aloft by the updraft, the hailstones fall in a hailstorm.

Ice crystals also form in the clouds. For them to form, the cloud must contain supercooled water, or water that cools down slowly to below 0 °C without freezing. Dust particles in the air act as condensation nuclei, to which water molecules can attach and crystallize. When the crystals start their fall, they agglomerate to form flakes or even partially melt depending on the temperature of the air. If the air on the ground is cold and dry, the snow can fall as beautiful individual crystals! Snow, just like rain, is usually formed in altostratus or nimbostratus clouds.

When the weather is humid and the temperature is below 0 °C, water does not only crystallize on dust particles to form crystals, but also against objects. This is called **frost**. Just like a car driver has to scrape ice off his car's windshield in the morning, an aircraft needs to be de-iced. If an aircraft flies across an area with supercooled water, the droplets will form layers of ice on its wings, which can be a problem. In addition to weighing down the plane, the ice will change the shape of the wings, reducing the plane's lift. While most planes are equipped with a defrosting system, Solar Impulse is not, which is why it has to stay out of areas with supercooled water at all cost!

It is also interesting to note that when Solar Impulse descends at night during its flight, it could very well cut its engines and glide. Even though this would save some of the precious energy stored in its batteries, the pilot keeps the engines running. The reason it does so is to prevent the frost and the cold from causing any problems the next morning. By keeping the engines running, the pilots can ensure that the systems continue to run properly under such frigid conditions.

LIGHTNING

During a thunderstorm, heavy precipitation, strong winds or hail can be dangerous to an aircraft. But there is one more phenomenon that can put an aircraft into a critical situation: the electrical charges that build up in the clouds. The high voltage that develops between the cloud and the earth creates an electric field strong enough to ionize the air and make it conductive. This field is most intense at sharp points.
The air becomes ionized in response to the large difference of electric potential.

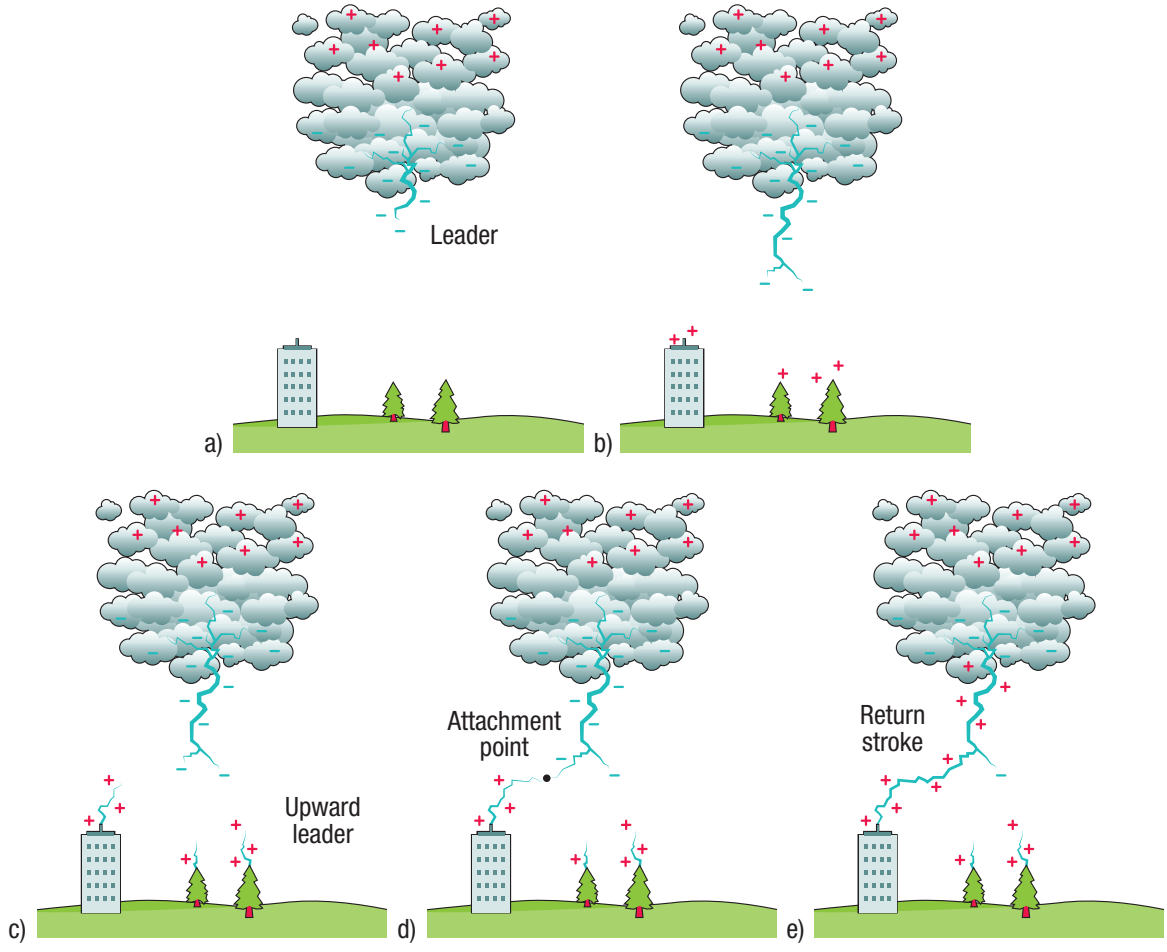
a) A conductive channel (leader) emerges and seeks its way to the ground along the most conductive path.

b) Since the cloud's base has a negative charge, the electrons on the ground below it are repelled. As a consequence, that section of the earth's surface becomes positively charged.

c) Upward leaders are also formed, especially from pointy objects.

d) When two leaders meet, the circuit closes and the cloud discharges as lightning.

e) There may be several successive discharges that allow different areas of the cloud and the ground to neutralize each other.



Not all lightning starts with a negative leader going towards the ground, even if cloud-ground lightning is the most frequent type. Sometimes the charges are reversed or the lightning ascends. The most abundant type of lightning is intra-cloud lightning. Intra-cloud lighting occurs between cloud areas of different polarities. Even if we cannot see their flashes, they light up the clouds.

The blinding lightning flash we see is caused by the ionization of air, which in some cases can reach over 30,000 °C – hotter than the surface of the sun. The thunder comes from the sudden expansion of the air when it is rapidly heated, creating a vibration that our ears perceive as a grumbling roar (thunder).

So what should you do to stay safe during a lightning storm? First of all, avoid being the tallest object around by staying clear of open spaces. Metal umbrellas increase the danger. Also, don't stand under a tree to avoid offering the lightning an easier path to the ground than through the tree trunk and to avoid being hit by the tree if it is struck by lightning.

Here is a site with more information on measures to take to stay safe in thunderstorms:

http://www.apfoudre.com/20recom.htm

Association Protection Foudre, *Les 20 recommandations en cas d'orage*

A car with a metal structure offers good shelter against lightning. It forms a Faraday cage. The same is true for airplanes. Still, planes get hit by lightning on average once every 1,000 flight hours. When this happens, the electric current flows through the metal walls and the passengers are protected. However, the resulting magnetic field can disrupt or damage the aircraft's equipment. For this reason, the equipment is protected and there are backup systems to take over. So here is another reason why Solar Impulse has to avoid turbulent areas where thunderstorms could form: it was designed to contain as little metal as possible!

ALL THIS IN NUMBERS…

Exercise 1

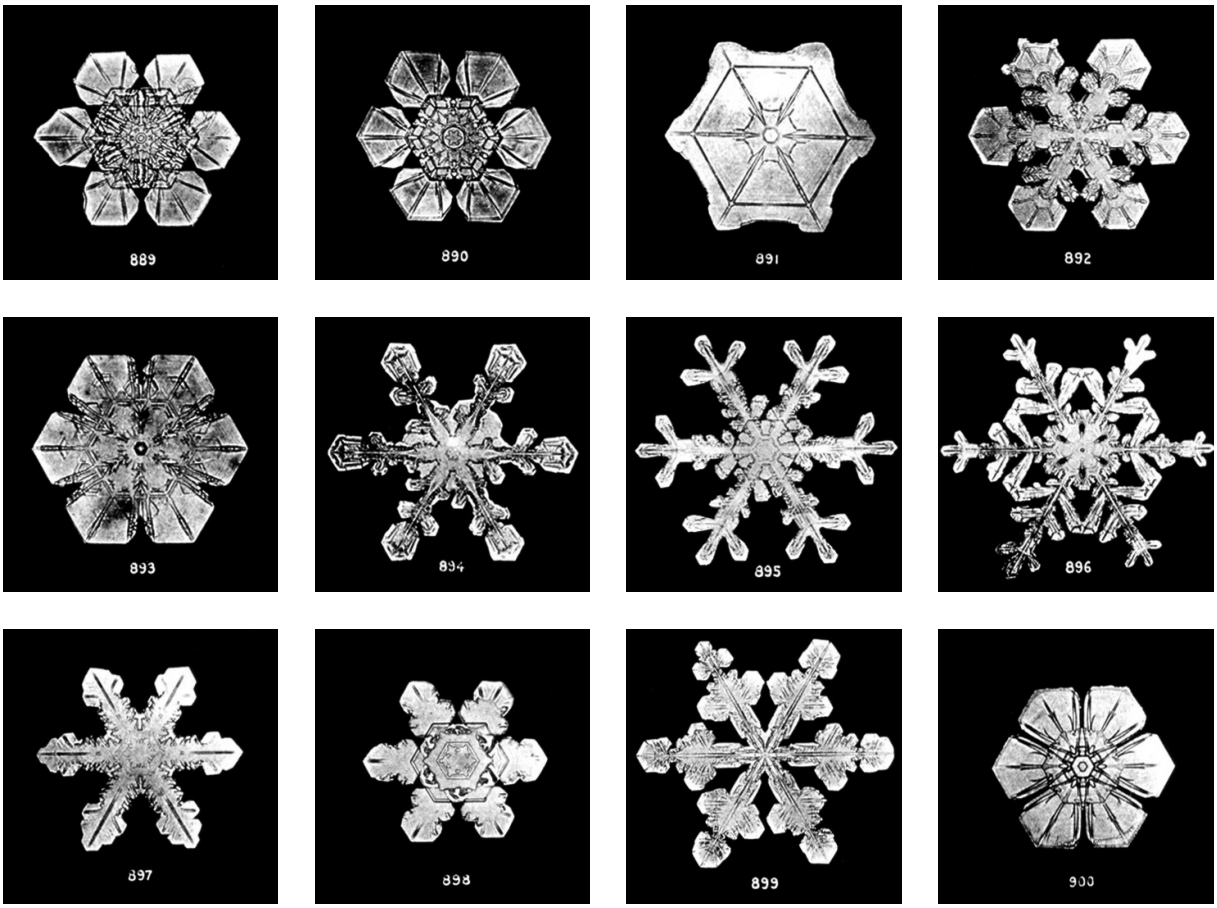
Sound and light propagate through the air at different speeds. We first see the lightning, and then we hear the sound. The longer the gap between the lightning and the thunder, the further way is their source. To estimate how far way you are from a storm, you can count the number of seconds between the flash and the thunder. Three seconds correspond more or less to one kilometer.

a) I counted eight seconds between the lightning and the thunder. How far am I from the storm?

b) If the storm is 7 km away, how many seconds will I count?

Exercise 2

Here are some pictures of snowflakes taken by Wilson Bentley (1865-1931), the first known snowflake photographer. What do they have in common?

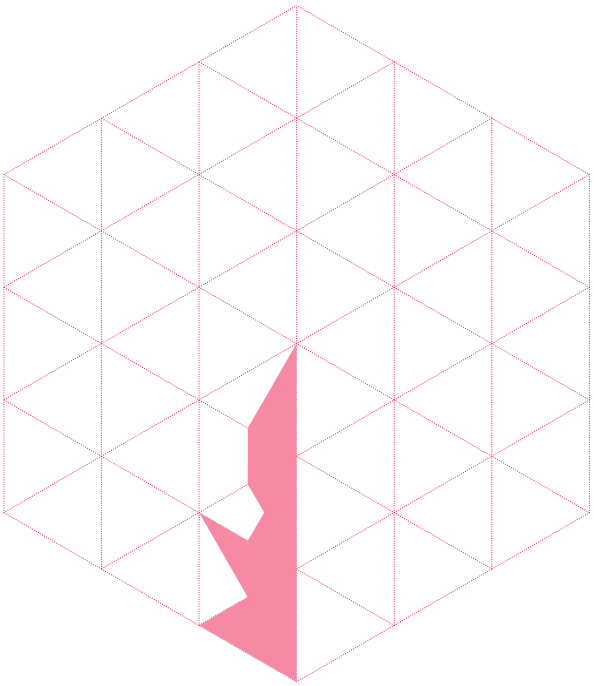


Exercise 3

What types of isometries can you identify in the snowflakes? Are they common to each flake?

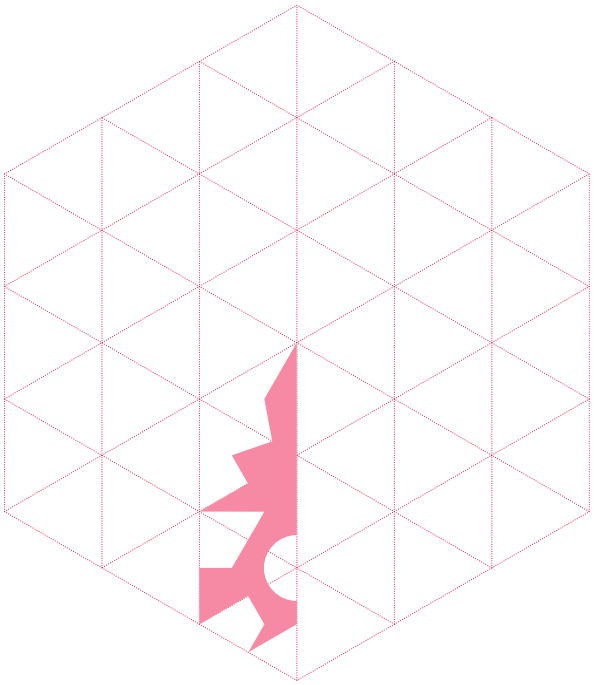
Exercise 4

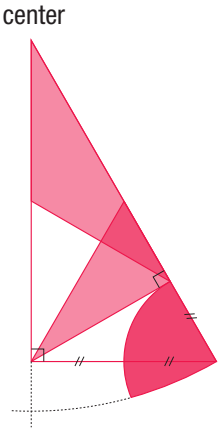
Here is a portion of a snowflake. Complete the drawing!



And now without the dotted lines!

Do the same with this drawing:

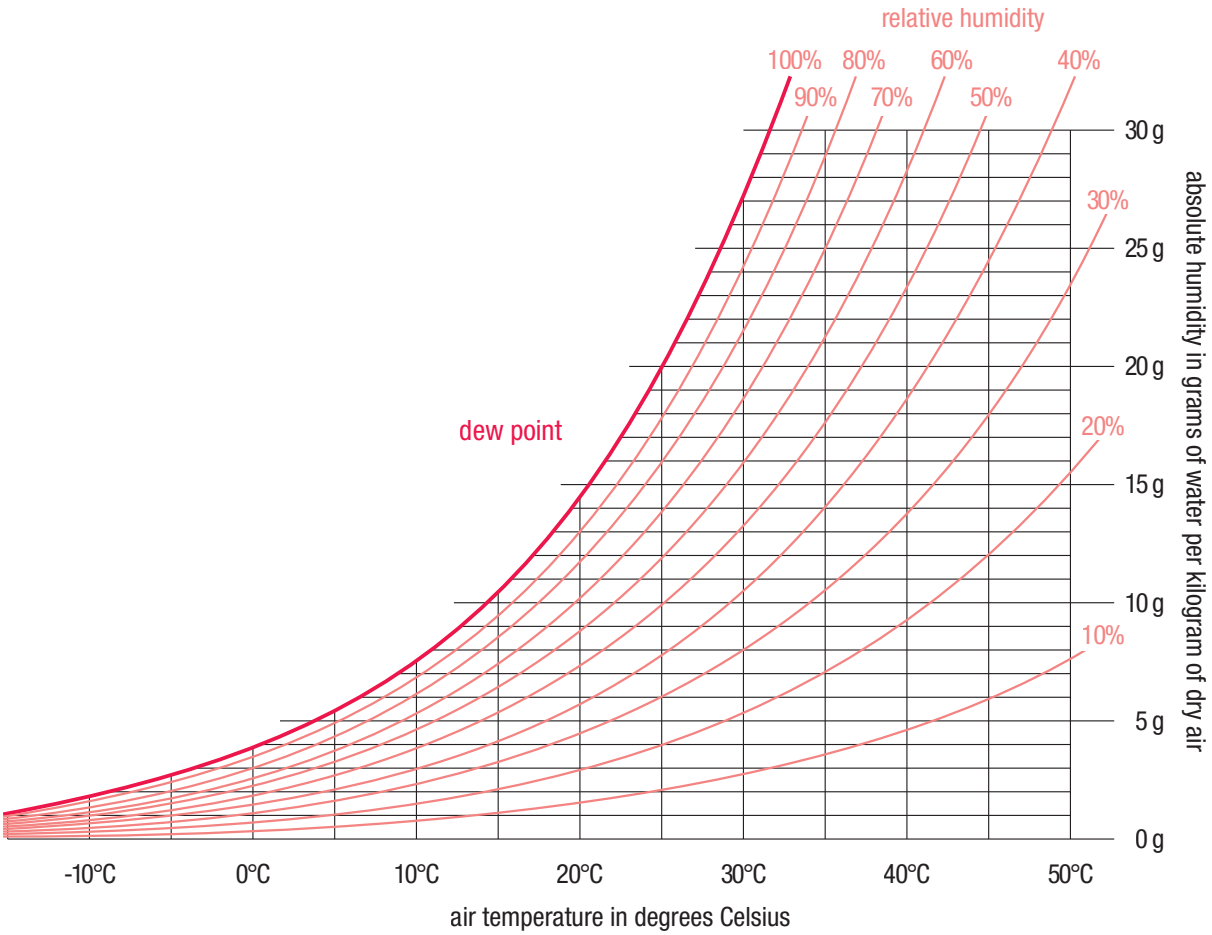




The combustion of fuel in an aircraft's engines mainly produces CO_2 (carbon dioxide) and water vapour. When steam is expelled out of the burning reactor into the icy high-altitude air, it immediately condenses to form either droplets or ice crystals. If the air is dry, they are quickly absorbed. This is not the case when the air is already nearly saturated.

Exercise 5

Here is a graph that shows air humidity according to temperature.

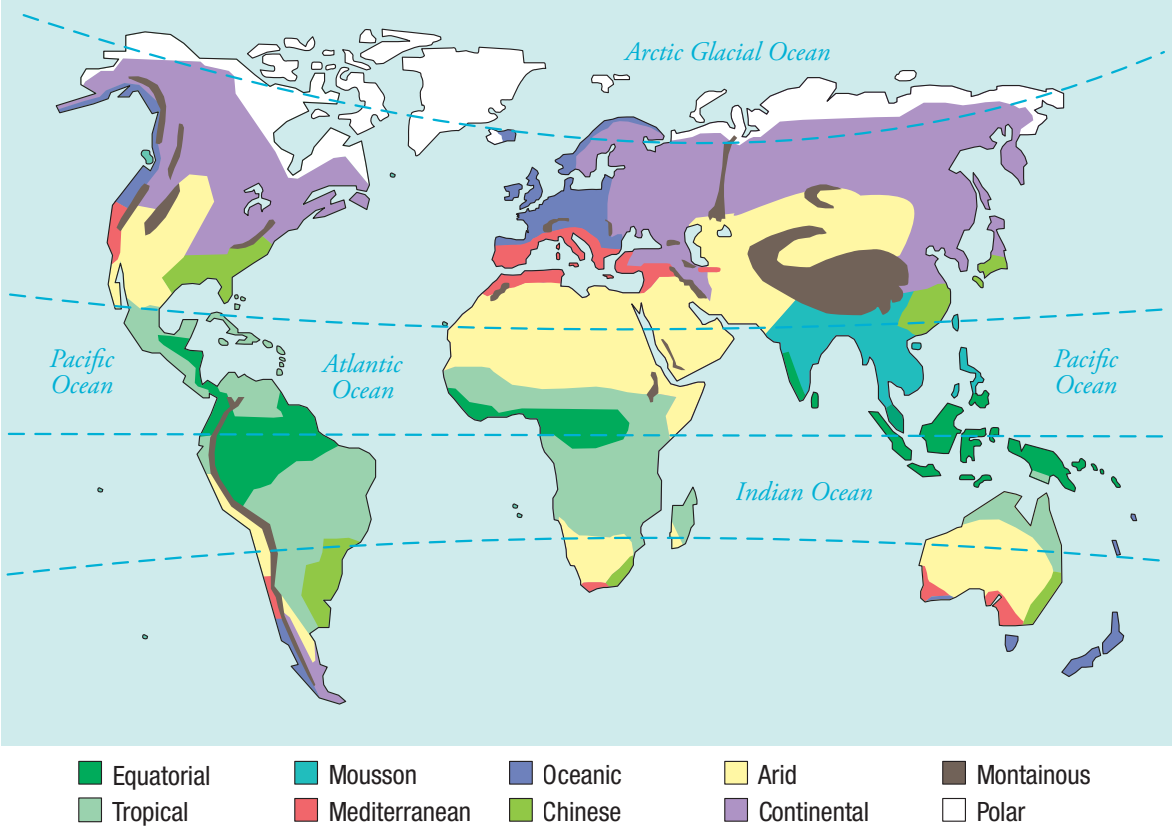


When the relative humidity is 100%, the air contains the maximum amount of water vapor it can absorb without condensing.

a) How many grams of water are there in 5 kg of air at a temperature of 30 °C and a relative humidity of 30 %?

b) At what temperature can one kilogram of air contain at most 15 g of water?

c) If you have had the opportunity to travel, you will have noticed that some countries have very different climates. Countries with tropical climates, for example, can have grueling sweaty summers. In such cases, the humidity can exceed 95 %.



On the contrary, in some drier areas, the relative humidity may drop below 20 % during the day, as in the Sahara. The most appropriate humidity for our body is around 50 %. It is suggested not to exceed 60 % in homes, to prevent mould growth.

How many grams of water are there in 1 kg of air in Malaysia if the relative humidity is 95 % and the temperature is 30 °C in the evening?
During the day, I measured an absolute humidity of 9 grams of water per kilogram of dry air in my apartment, where the temperature was 25 °C. What was the relative humidity at that time?
If the temperature were to drop suddenly during the night, at what temperature would I start to have condensation problems?

d) It is estimated that for every 100 m increase in altitude, the temperature drops by 1°C (this value depends on the humidity of the air). If the relative humidity is 70 % and the surface temperature is 15 °C, how high above the ground will stratus clouds start to form?

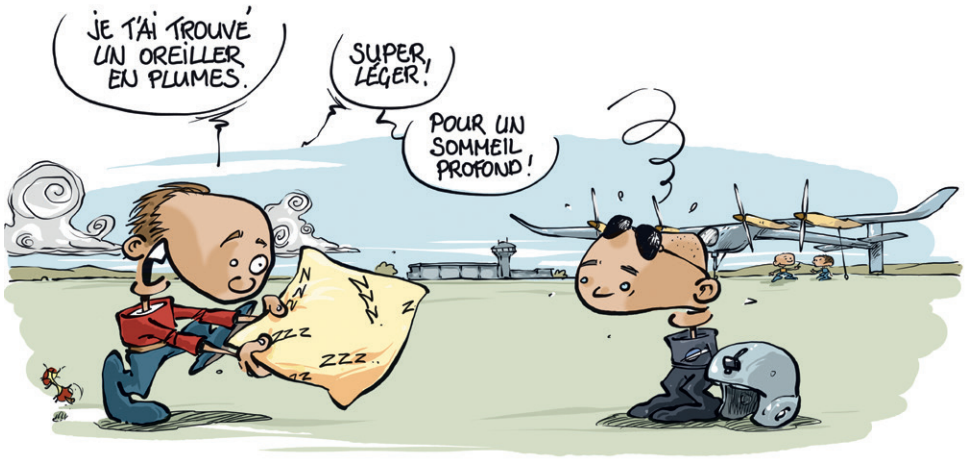
TO EXPLORE FURTHER…

Exercise 6

Let's go back to assessing the distance to a lightning strike. We estimated that a lapse of 3 seconds between the lightning and the thunder implies that the lightning struck at a distance of 1 km. How did we find this value? Knowing that the speed of sound is 340 m/s and that the speed of light is 299,792,460 m/s, calculate the distance between an observer and the lightning if the observer measures a lapse of time of exactly three seconds.

Exercise 7

I took a shower and condensation formed on my bathroom mirror. The temperature in the bathroom is 25 °C. What is the maximum mass of water vapor in the room?
The dimensions of the bathroom are $2.5 \times 3 \times 2.5$ m.
At 25 °C, the density of the air is 1.17 kg/m^3.



RECREATIONAL ACTIVITY

Make a snowflake by cutting a folded sheet of paper.