



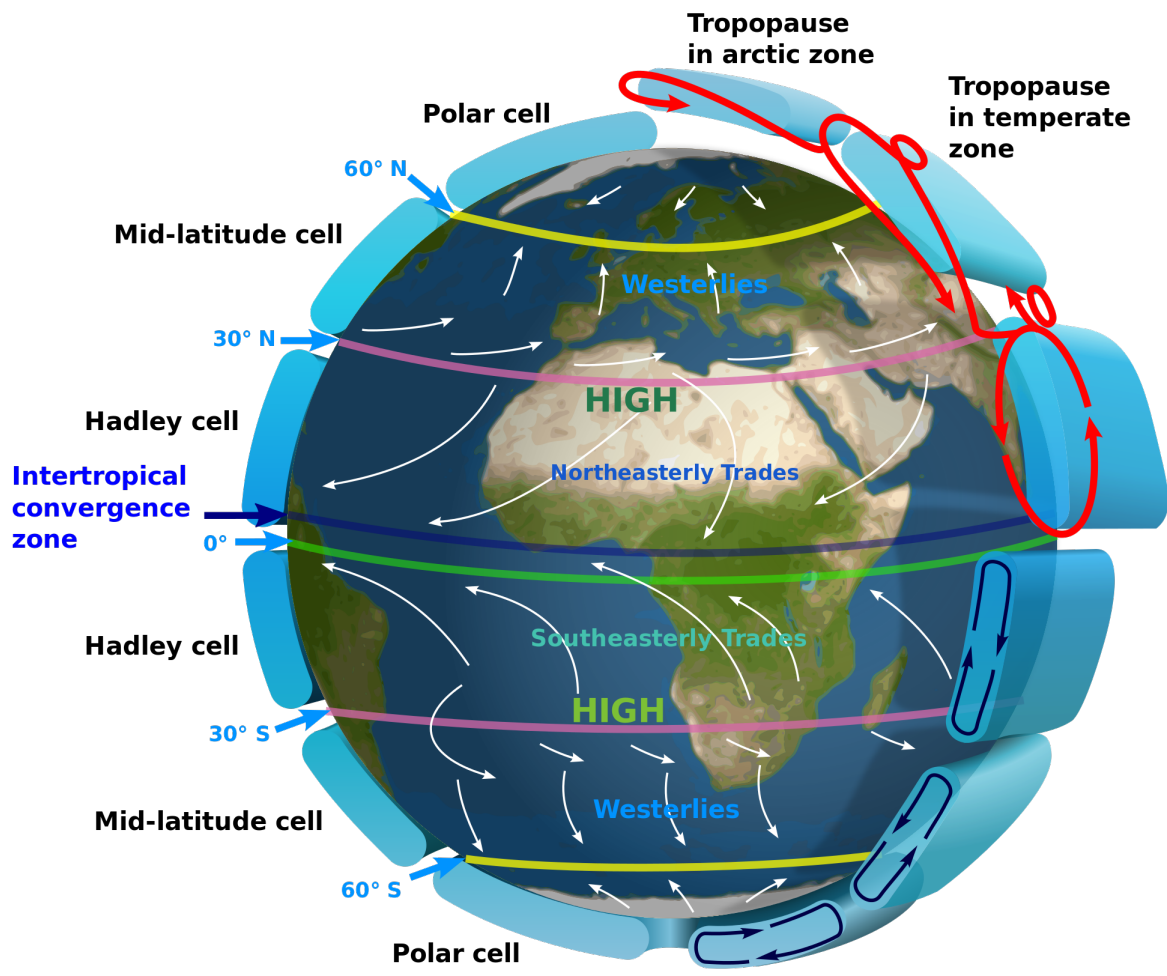
ASTROEDU

Peer-reviewed Astronomy Education Activities

The Intertropical Convergence Zone

How are winds created?

Markus Nielbock, Haus der Astronomie



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|--|---|
|  AGE 12 - 16 |  LEVEL Middle School, Secondary |
|  TIME 1h |  GROUP Group |
|  SUPERVISED Yes |  COST PER STUDENT Medium Cost |
|  LOCATION Small Indoor Setting (e.g. classroom) |  CONTENT AREA FOCUS Earth Science |
|  ASTRONOMY CATEGORIES Planetary systems |  EARTH SCIENCE KEYWORDS Geoscience, Atmospheric Sciences |
|  SPACE SCIENCE KEYWORDS Communications | |

CORE SKILLS

Developing and using models, Planning and carrying out investigations, Constructing explanations, Engaging in argument from evidence, Communicating information

TYPE(S) OF LEARNING ACTIVITY

Structured-inquiry learning, Discussion Groups, Modelling

KEYWORDS

Equator, Atmosphere, Updraft, Winds, Convection



GOALS

- Students will learn how the Sun drives the main engine of atmospheric circulation.
 - They will experience hands-on, how irradiation and heat can drive convection. Students learn that warm air rises over cold air.
 - They will understand that this basic phenomenon is the cause for the large-scale air circulation systems on Earth and the warm and humid climate near the equator.
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LEARNING OBJECTIVES

- **Desired Student Outcomes for Activity 1:**
After this activity, the students will be able to explain that warm air rises above the surrounding cooler air and that the uplift can be strong enough to launch objects up into the air.
 - **Desired Student Outcomes for Activity 2:**
After this activity, the students will be able to explain that a continuous convection stream can be produced, provided the energy source injects heat constantly. They will also understand that a supply of fresh air is needed to keep the engine going.
 - **Desired Student Outcomes for Activity 3:**
This worksheet helps students to contrast the knowledge obtained through the first two activities to the situation on Earth, where the Sun is the main heat source. Students answer questions on how the air on Earth is heated and the effects of this. They will understand that the Intertropical Convergence Zone is only a part of a larger air circulation system that is the cause for the climate zones between the tropics and the subtropics.
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EVALUATION

- The answers given by the students to the questions as listed in the activity – partially stimulated by discussion – are the gauge by which the teacher can evaluate the learning outcome.
- The teacher could ask students to draw a labelled diagram for the first two activities to show what they saw and write a couple of sentences about what happened and why.

- The final activity, a worksheet, summarises what has been illustrated and
- discussed in the first two parts and puts it in the perspective of the global system on Earth. From this, it should be straightforward to judge to what degree the individual elements have been understood.
 - For a solution for the drawing, see Figure 2 in the background information.
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MATERIALS

The activities are best carried out in groups of two. The items listed below are indicated per group.

Common items:

- paper handkerchief, napkin or dual chamber tea bag
- matches or lighter
- china plate or tinfoil (or any other non-flammable flat surface)
- strong lamp (common bulb or tungsten halogen bulb, min. 100 W)
- scissors
- flat nose pliers, if available
- glue (for cardboard)
- pencil or similar pointed object
- aluminium wrap of a tea light
- drawing pin

For either of the following alternatives:

Alternative 1

- cardboard tube (inner part of a kitchen roll)
- black paint and brush or black coloured paper
- one piece of cardboard (approx. 1 cm wide, 8 cm long)

Alternative 2

- construction template provided with this sheet
 - black cardboard (22 cm × 20 cm)
 - one piece of card board (approx. 1 cm wide, 12 cm long, see template)
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BACKGROUND INFORMATION

Temperature, density and buoyancy

We all know from experience that the density of gases depends on their temperature. Cold air is denser than warm air. This is the reason why hot air balloons can fly and even lift cargo.

Scientifically, this phenomenon is described by the ideal gas law and the buoyant force according to the Archimedes' principle.

Hence, the buoyant force is equivalent to the gravitational force that is exerted on the displaced air.

$$F_{up} = F_{g,air,out} = m_{air,out} \cdot g$$

Here, $m_{air,out}$ is the mass of the displaced air. In the case of hot air balloons with volume V and the density of the air outside the balloon that was displaced ρ_{out} ,

$$F_{up} = \rho_{out} \cdot V \cdot g$$

Buoyancy is reached when the buoyant force is equivalent to the gravitational force (only the air is considered):

$$F_{up} = F_{g,air,in} = m_{air,in} \cdot g = \rho_{in} \cdot V \cdot g$$

Hence:

$$F_{res} = F_{up} - F_{g,air,in} = \rho_{out} \cdot V \cdot g - \rho_{in} \cdot V \cdot g = (\rho_{out} - \rho_{in}) \cdot V \cdot g$$

So the resulting force is governed by the difference between the densities of air inside and outside the balloon. For a hot air balloon, this density inside is changed by heating the air. This is where the gas law steps in. One way of writing it is as follows:

$$p \cdot V = m \cdot R_s \cdot T$$

m is the total gas mass and R_s is a constant. Therefore,

$$(p \cdot V) / (m \cdot T) = p / (\rho \cdot T) = \text{const.}$$

Since a hot air balloon is open, the pressure inside and outside the balloon remains the same during the heating process. It is a constant as well. Therefore,

$$\rho \cdot T = \text{const.}$$

When heating of the air inside the balloon begins, both the density and temperature inside and outside are the same. Afterwards, both quantities differ. Therefore, we can write the equation as follows:

$$\rho_{in} \cdot T_{in} = \rho_{out} \cdot T_{out} \Leftrightarrow \rho_{in} = \rho_{out} \cdot T_{out} / T_{in}$$

Let us now get back to the resulting buoyant force:

$$F_{res} = (\rho_{out} - \rho_{in}) \cdot V \cdot g$$

The two densities are now connected to the temperature change. Therefore,

$$\rho_{out} - \rho_{in} = \rho_{out} - (\rho_{out} \cdot T_{out} / T_{in}) = \rho_{out} \cdot (1 - T_{out} / T_{in}),$$

which leads to final expression for the resulting force of uplift as follows:

$$F_{res} = \rho_{out} \cdot (1 - T_{out} / T_{in}) \cdot V \cdot g.$$

In order for F_{res} to be positive, we need

$$1 - T_{out} / T_{in} > 0 \Leftrightarrow T_{in} > T_{out}.$$

So, the hot air balloon (in fact, only the air inside it) rises if the air temperature inside the balloon is higher than the outside temperature.

The Sun and the global wind system

The atmosphere of the Earth consists of air. We know that whenever it is heated, it rises up (see above). The atmosphere is heated by the Sun, which mainly heats the surface first, and this in turn heats the air close to the ground. Since warm air has a lower density than cool air, it produces an updraft which by convection drags the air up into the highest layers of the troposphere, about 10-15 km above the ground. While the air rises, it constantly cools down, which reduces the buoyant force. At some point, the uplift stops, and the air is diverted horizontally north and south.

This process is most effective at latitudes where the Sun is at its zenith, i.e. in a belt around the equator. This area is called the Intertropical Convergence Zone (ITCZ). It follows the apparent annual path of the Sun northward and southward during the seasons.

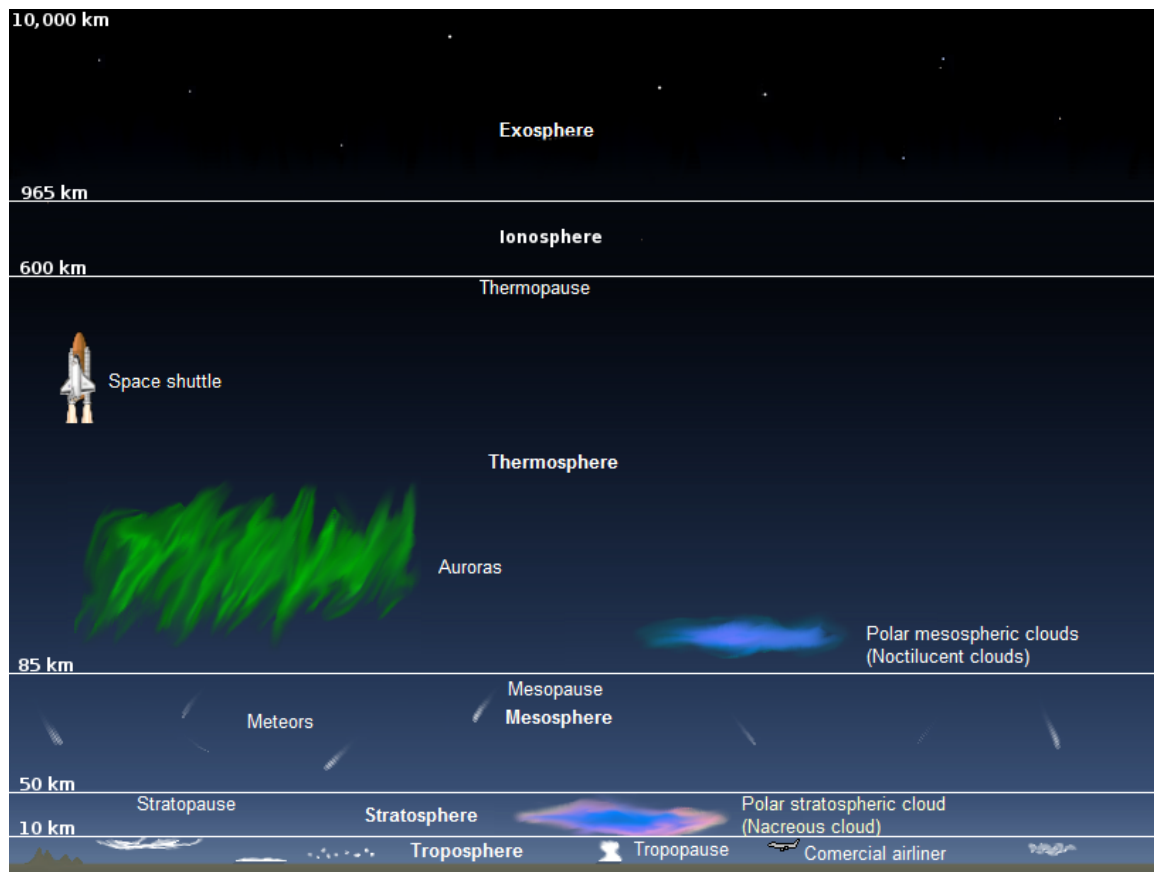


Figure 1: Layers of the atmosphere (The High Fin Sperm Whale, https://commons.wikimedia.org/wiki/File:Layers_of_the_atmosphere.PNG, 'Layers of the atmosphere', altitudes according to NASA (https://www.nasa.gov/mission_pages/sunearth/science/atmosphere-layers2.html) added by M. Nielbock, <https://creativecommons.org/licenses/by-sa/3.0/legalcode>).

Cool air can store less water than warm air. Therefore, the rather humid air that rises in the ITCZ continuously loses its ability to store water. As a result, clouds

form, from which water is eventually released as rain. In extreme cases, the convection can lead to severe weather phenomena like thunderstorms or even cyclones and hurricanes. This is the reason why the low latitudes around the equator are strongly affected by a humid, tropical climate with low-pressure areas and lots of rain. On satellite images, the ITCZ appears very prominent because of the cloud belt along the equator (see Figure 1). This demonstrates that satellite imagery can be an important tool to monitor the climate of the Earth.

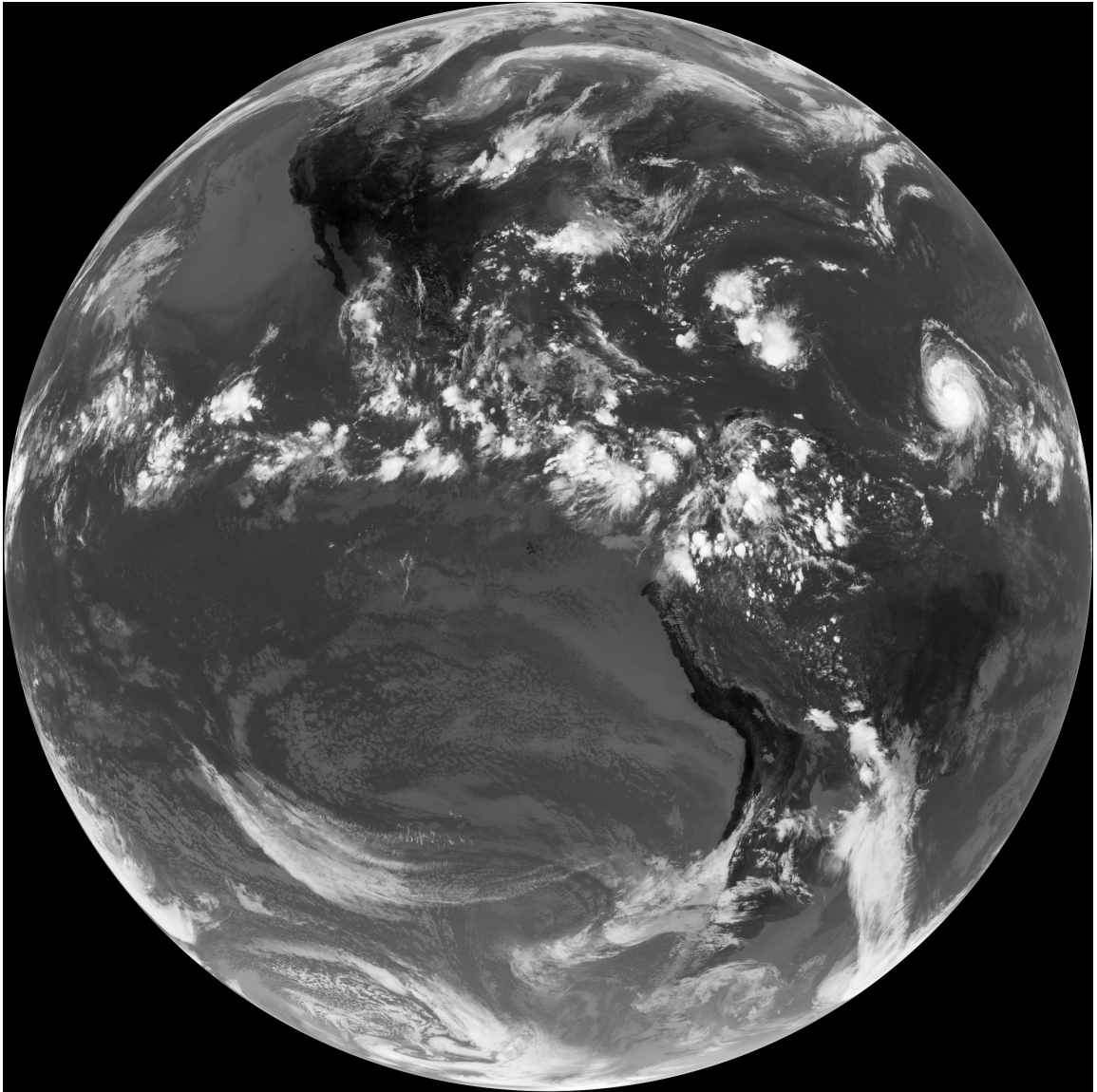


Figure 2: Image obtained with the GOES 14 satellite. The belt of cloud formation around the ITCZ is clearly visible (NASA/GOES Science Team).

The air has now become dry. While it is pushed north and south to latitudes around 30° north and south, the already dry air drops, heats up and is dried even more. This gives rise to the arid, subtropical climate we find in this region.

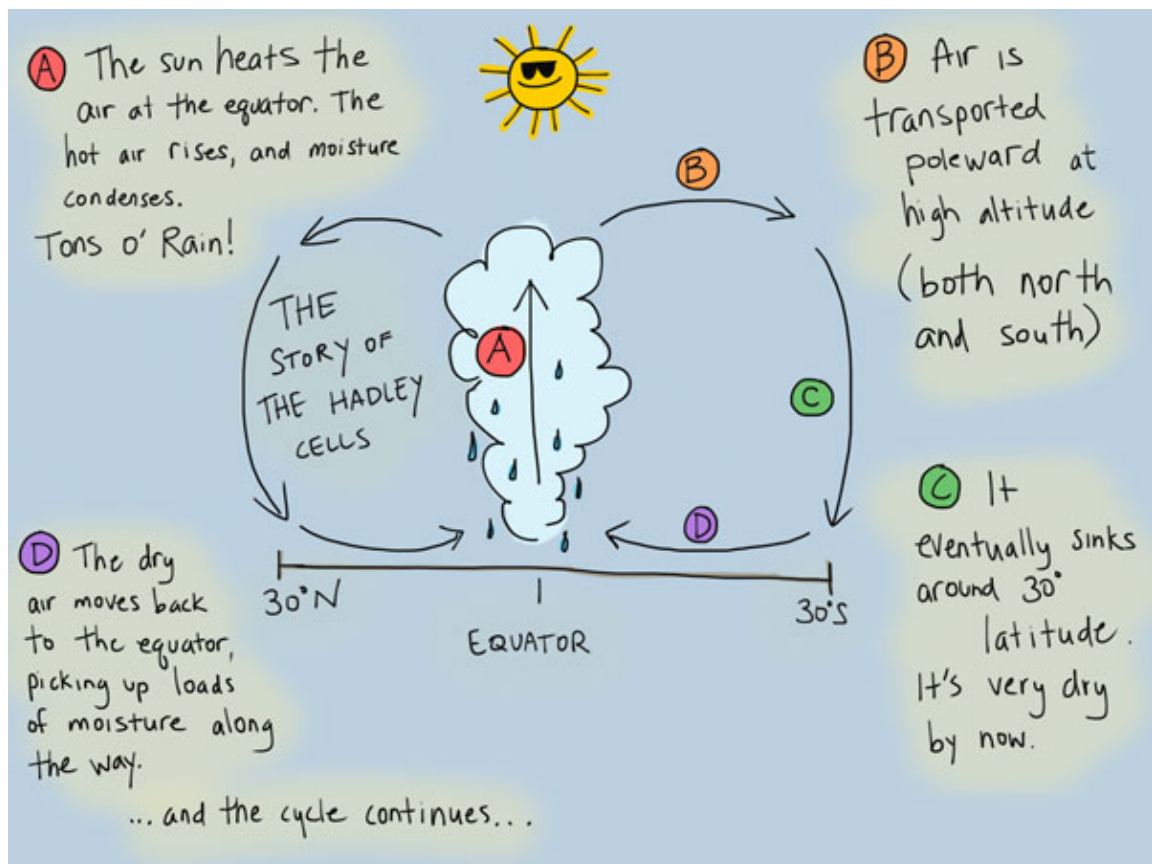


Figure 3: Schematic of the Hadley cell ('The Waveform Diary' blog, The mystery of the shifting tropical rain belt, M. Weirathmueller, permission for reproduction granted).

The cycle of circulation closes with the air currents flowing back to the equatorial region and the ITCZ where they feed the convection again. Thus, we have seen that the ITCZ with the rising air causes a global belt of air circulating roughly between the tropics around the equator and the dry desert at approximately 30° north and south. This belt is called the 'Hadley Cell' (see Figure 2).

The convection zone at the ITCZ and the connected Hadley zone is only a part of a much larger global air circulation system (see Figure 3).

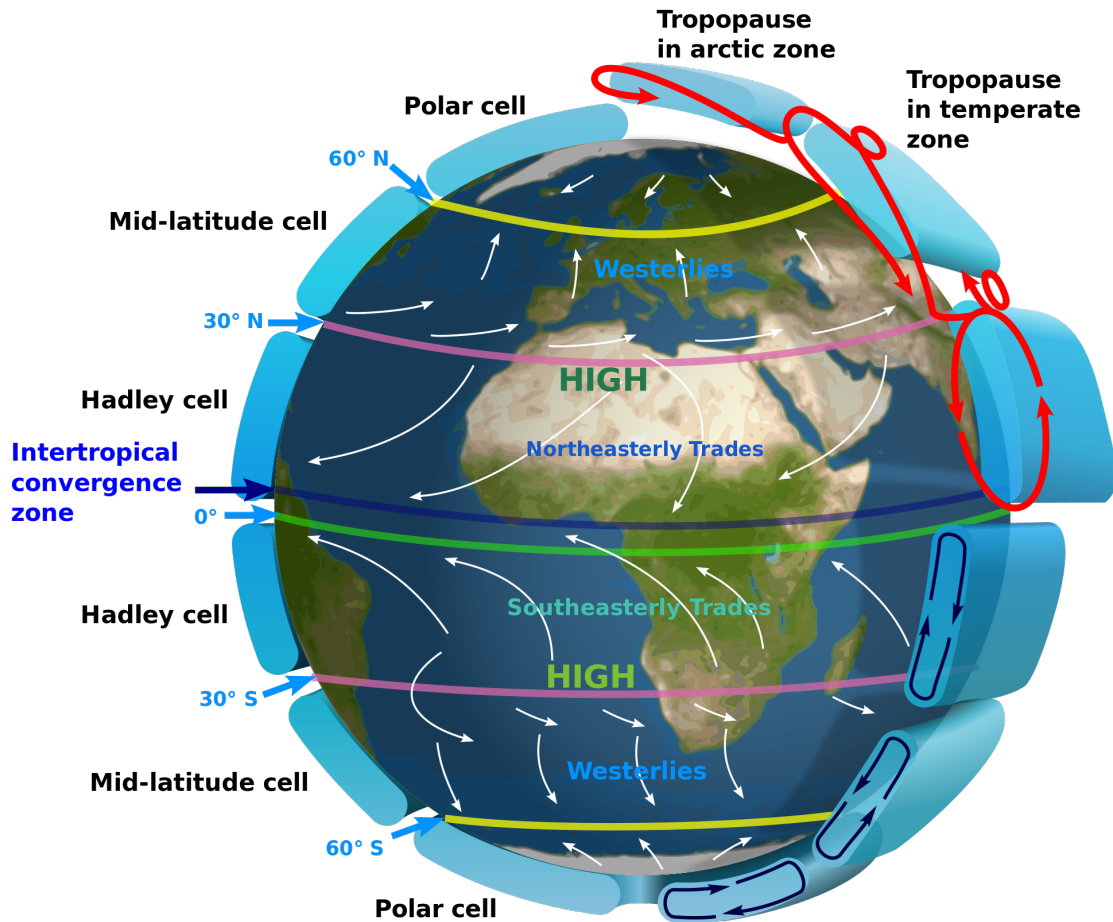


Figure 4: Global circulation of the Earth's atmosphere (Kaidor (https://commons.wikimedia.org/wiki/File:Earth_Global_Circulation_-_en.svg), 'Earth Global Circulation - en', <https://creativecommons.org/licenses/by-sa/3.0/legalcode>)

Possible influence of climate change

We have seen that thermal energy is drives wind, rain and temperature, i.e. the weather. Therefore, it seems plausible that the more the heat stored in the atmosphere, the greater is the energy available to influence the weather. Since the resulting buoyant force depends on temperature differences, especially between the Earth's surface and high altitudes, we should expect that processes like the ones seen in the ITCZ would be amplified.

In fact, there are already indications that along with the phenomenon of a gradual increase in global mean air temperatures through recent decades (global warming), extreme weather situations have increased in number and severity (http://www.ucsusa.org/global_warming/science_and_impacts/impacts/global-warming-rain-snow-tornadoes.html). This is supported by the findings of recent climate studies (<https://www.sciencedaily.com/releases/2017/03/170307100337.htm>).



FULL ACTIVITY DESCRIPTION

INTRODUCTION: QUESTIONS AND ANSWERS

Show the students a globe or a global map and ask them if they can identify the equator.

Q: Where are the poles? Where does the equator lie relative to the poles?

A: The equator is the line or circumference on the globe half way between the poles.

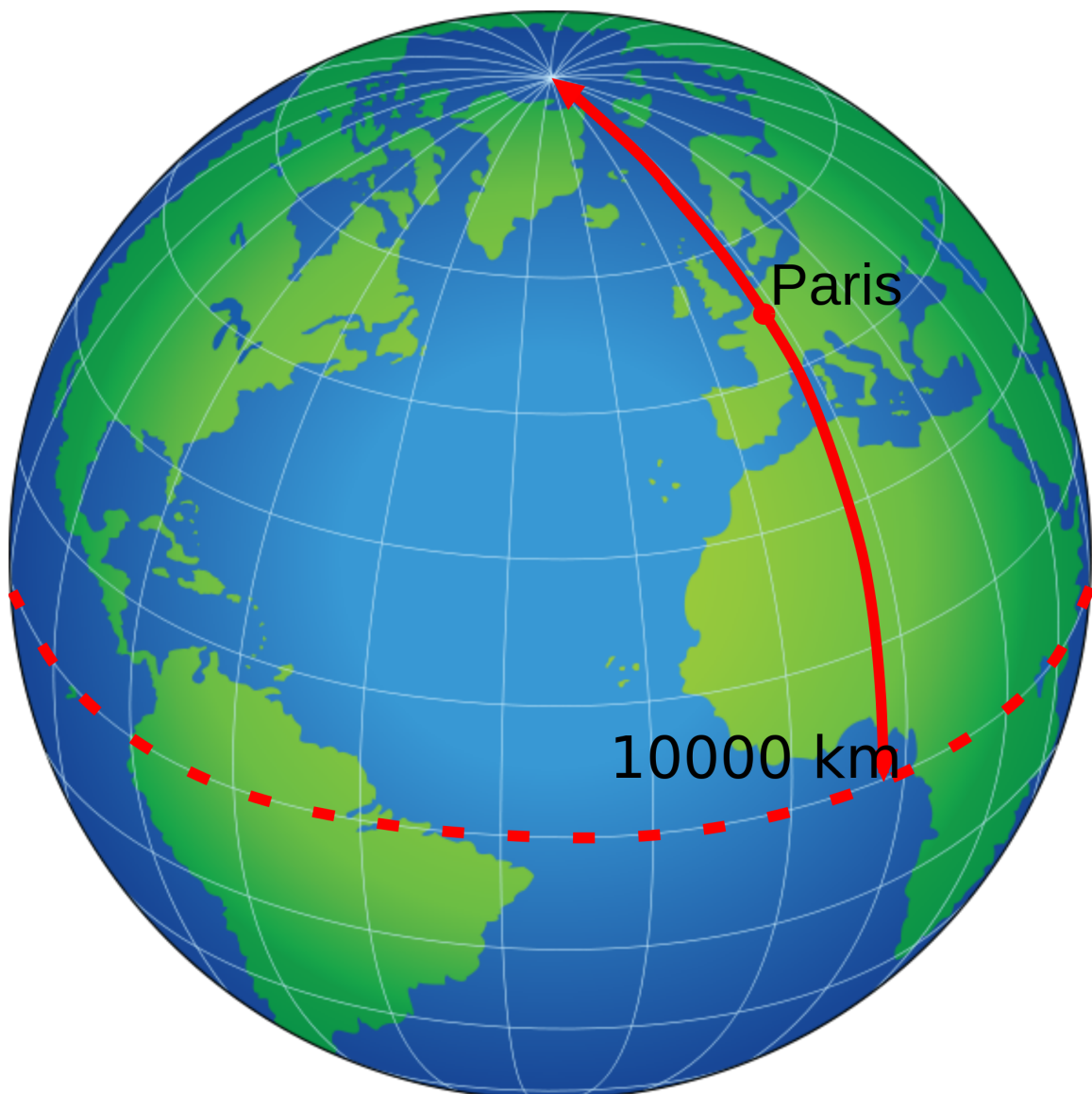


Figure 5: Illustration of a globe and the position of the equator relative to the North Pole (US Government).

If possible, let the students use an online map tool to investigate geographic and satellite images of the equatorial region. The map tool may also be projected on

a single computer. Here are some possible map services with satellite imagery:

<https://maps.google.com>

<https://www.arcgis.com/home/webmap/viewer.html?useExisting=1>

Q: Can you name countries that touch the equator? Do you know any cities close to it?

A: e.g. Ecuador (Quito, Galapagos), Brazil, Gabon (Libreville), Congo, Uganda (Kampala), Kenya, Malaysia, Indonesia.

Q: What is the typical vegetation there?

A closer look at the satellite images helps to answer the question.

A: Rainforest.

Q: What is the typical weather there (humid or dry, cold or warm)?

A: Humid and warm, with lots of rain.

Q: Can you think of a reason for why it is so warm there all year? Show them a model of the Sun-Earth-System (Figure 5).

A: The Sun is the main heating source. Near the equator, it is always almost directly above.

Q: The air is heated by the hot surface of the Earth. What happens with hot air? Imagine a hot air balloon.

A: Warm/hot air rises above cold air.

Q: How would you be able to recognise that air rises?

A: Wind

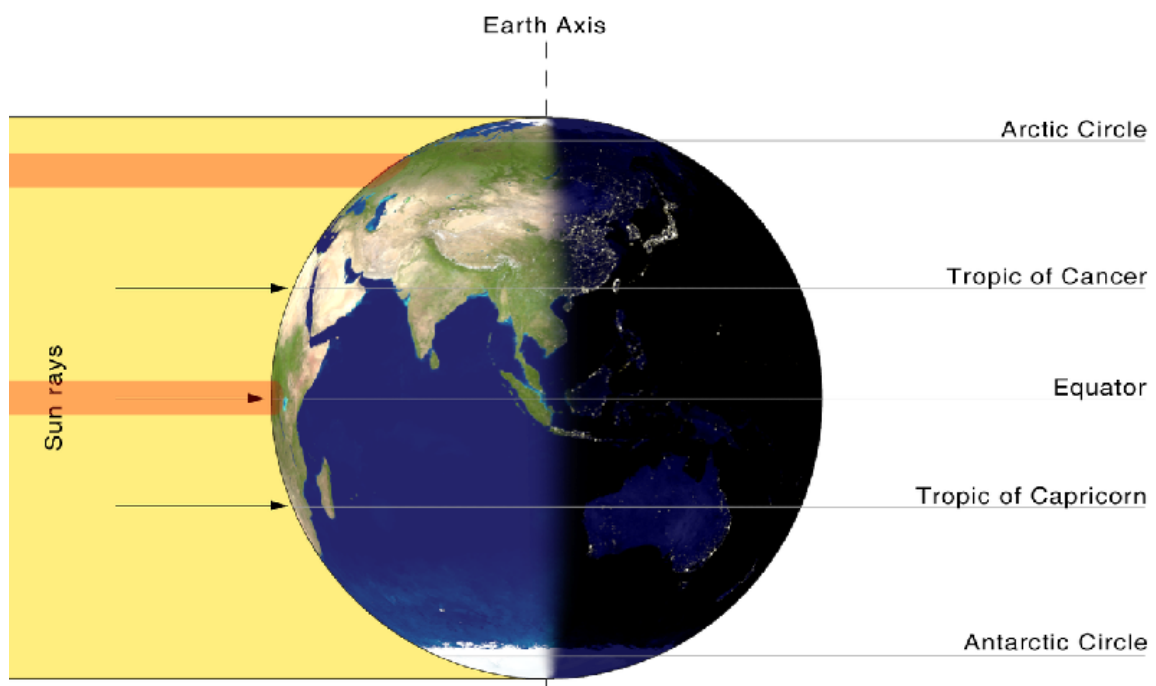


Figure 6: Illustration of the Earth by the Sun. Looking from the equator, the Sun is almost always directly above (Przemyslaw 'Blueshade' Idzkiewicz, http://commons.wikimedia.org/wiki/File:Earth-lighting-equinox_EN.png, 'Earth-lighting-

equinox EN', solar light beams at different latitudes added by Markus Nielbock, <https://creativecommons.org/licenses/by-sa/2.0/legalcode>).

ACTIVITY 1: FLYING FLAMES

WARNING! This activity is only suitable for students who are responsible enough to handle a flame. Be sure to provide a fireproof environment and to supervise the students during the experiment. Lighters or matches should be distributed only to small groups of students at a time. If in doubt, the experiment should be demonstrated by the teacher.

Smoke detectors may have to be disabled for this activity.

Use a fireproof surface. A china plate or a piece of tinfoil may be used to protect the surface of normal desks or tables.

In this activity, the students will experience how warm air rises above cool air. The hot air produced by a burning piece of very light paper produces its own uplift and rises up. This experiment should produce a qualitative result, that is, the exact uplift force is not so important.

Gather the following items, one set per group (or one for the teacher only, if carried out as a demonstration):

- paper handkerchief, napkin or dual chamber tea bag
- matches or lighter
- plate or/and tinfoil
- scissors



Figure 7: Illustration of the instructions (own work).

A video with instructions and explanations is available at [\[link\]](#)

Distribute the students in groups of two (suggested).

1. Prepare the wick:

a. Paper handkerchiefs and napkins consist of several layers. Take only one and cut off one quarter.

b. If a tea bag is used, cut off the top and empty the bag. Unfold it.

2. Form a tube (napkin, handkerchief, tea bag) of a few centimetres and put it on the plate, standing upright. It should stand stably. Avoid abrupt and fast movements to prevent the moving air from blowing the wick away.

3. Light it.

Discuss with the students what happened. Let the students describe in detail what they saw. While the wick burns down, the paper lifts off at some point.

Q: What happened to the air around the burning paper?

A: It was heated.

Q: What happens with heated air?

A: It rises.

Q: Can you explain why in the end, the burning paper lifted off?

A: It was dragged along with the rising air.

ACTIVITY 2: UPDRAFT TOWER

This activity demonstrates how heated air rises. As long as the heating source is present, a continuous updraft of the heated air is generated. The students will experience this phenomenon by building a model of an updraft tower. Subsequently, the concept of air circulation can be used to explain the process of terrestrial atmospheric circulation systems and the Intertropical Convergence Zone.

Tell the students that they will now build a model of such a tower. Tell them that it is a good way to demonstrate vertical wind on a small scale.

Gather the following items, one set per group:

- scissors
- flat nose pliers, if available
- glue (for cardboard)
- pencil or similar pointed object
- aluminium wrap of a tea light
- drawing pin

For either of the following alternatives:

Alternative 1

- cardboard tube (inner part of a kitchen roll)
- black paint and brush or black coloured paper
- one piece of cardboard (approx. 1 cm wide, 8 cm long)

Alternative 2

- construction template provided with this sheet
- black cardboard (22 cm × 20 cm)
- one piece of card board (approx. 1 cm wide, 12 cm long, see template)

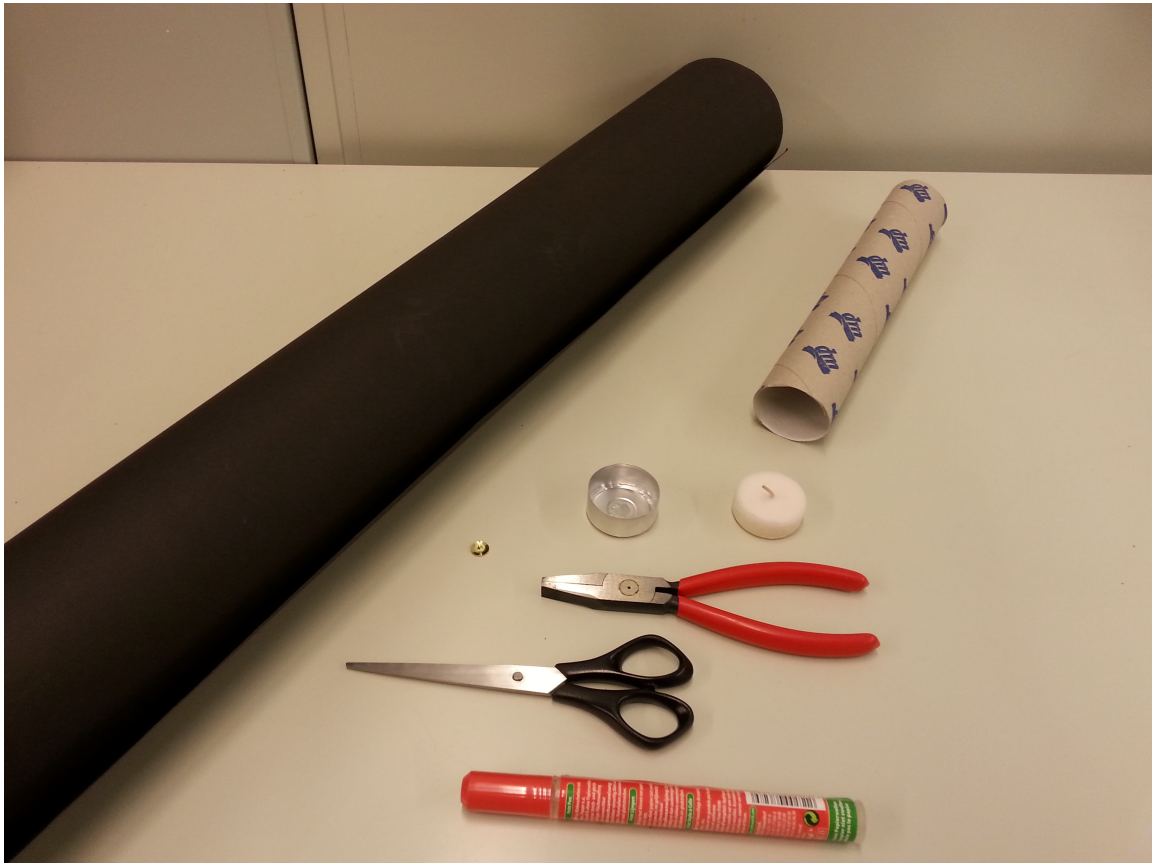
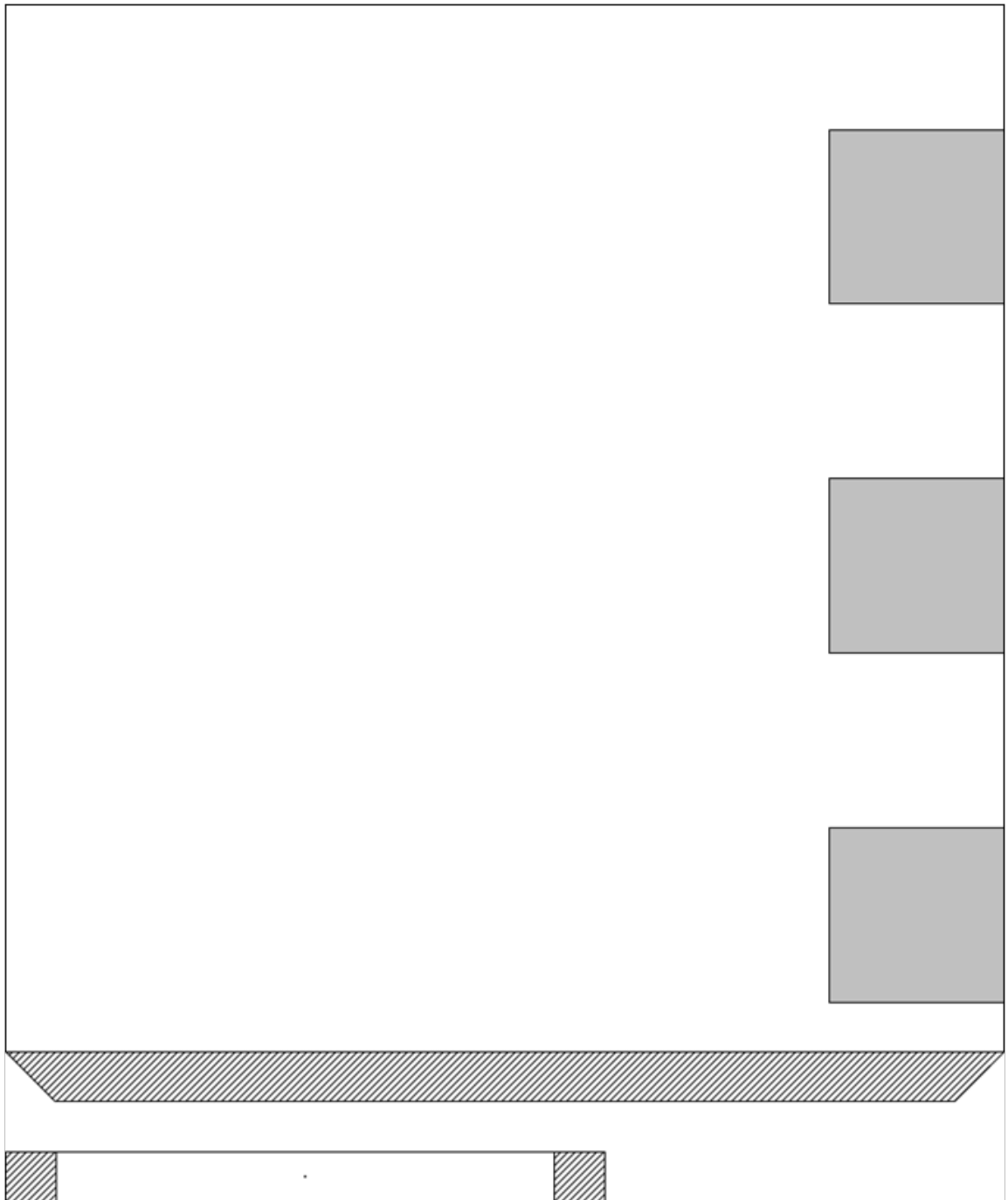


Figure 8: Items needed for building an updraft tower model (Picture: M. Nielbock).

Construction Template (scaled down version, original version to be attached)



Building Instructions

Alternative 1:

The first version may be simpler to produce but may not be as effective, because the cardboard tube used in this example may be a bit too narrow.

1. Paint the outside of the cardboard tube black or glue it with black paper.

Alternative 2:

The second version is especially designed to match the diameters of the tower and the fan.

1. Prepare the black cardboard according to the construction template provided.
2. Roll the cardboard perpendicularly to the hashed area.
3. Glue the tube at the hashed area.

4. Cut out the grey areas or cut them from bottom to top and fold them up to form flaps.

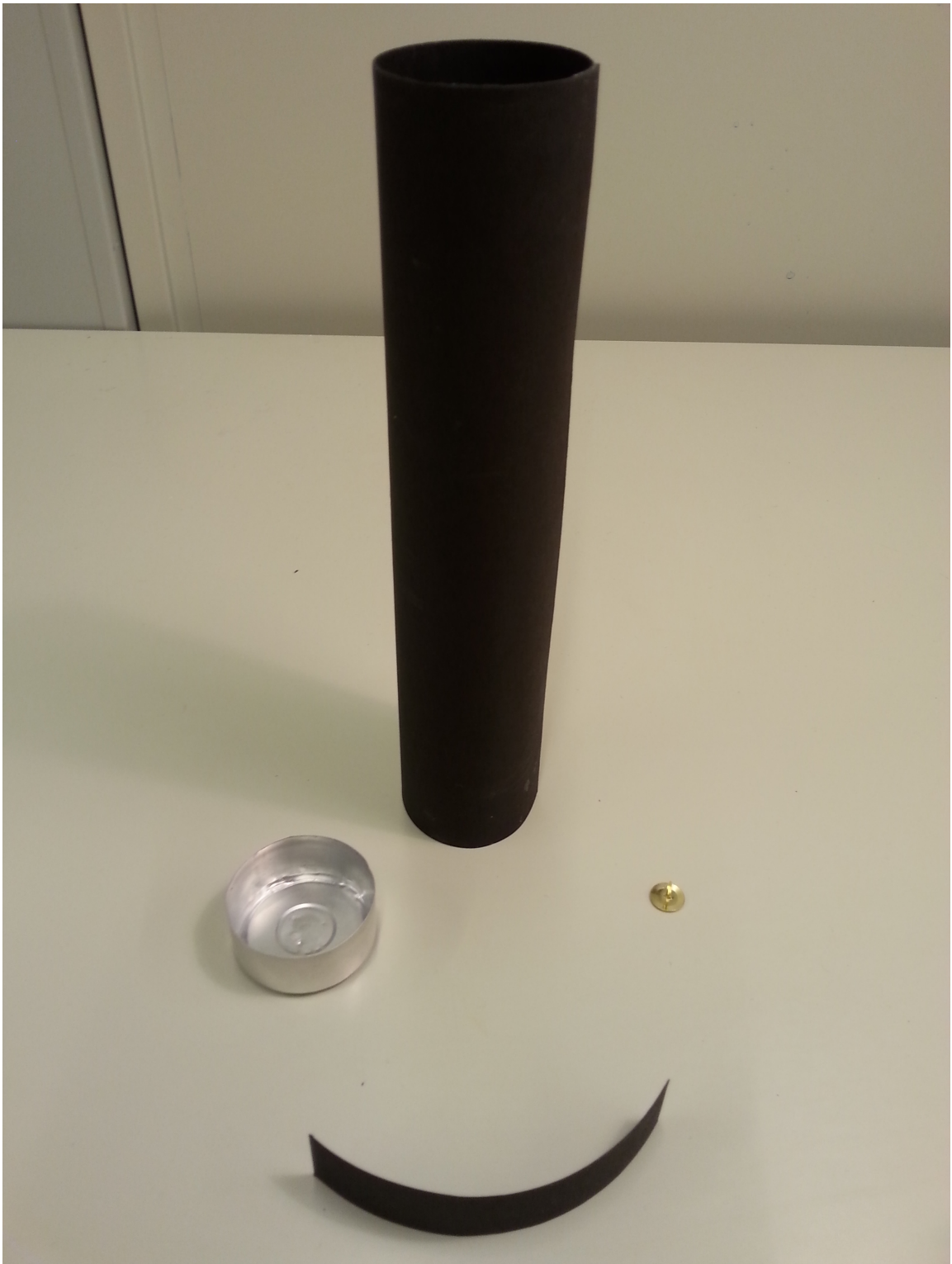


Figure 9: Set of items with the tower already built (Picture: M. Nielbock).

Common steps:

5. Now we produce the fan using the tea light wrap. This part is quite delicate and has to be done very carefully.
6. Cut 16 equal sections into the walls of the tea light wrap.
7. Flatten the sections outside to the bottom of the wrap.
8. Extend the cuts to the inner circle of the bottom of the wrap.
9. Press the pencil exactly at the centre of the fan to form a small dent. Be

careful not to punch a hole.

10. Bend all 16 wings of the fan around an axis from the centre to the edge. Use the pliers if available.

11. Punch the drawing pin through the centre and from the back of the small piece of cardboard.

12. Glue the small piece of cardboard to the inside at the top of the tube. It should form an arc.



Figure 10: Set of items with the tower and the fan (Picture: M. Nielbock).

13. Put the fan on top of the drawing pin.
14. Balance the fan by bending the wings up and down.



Figure 11: The finished updraft tower model (Picture: M. Nielbock).

15. Illuminate the side of the tower with a strong lamp.
16. Watch the fan rotate.

Discuss the results with the students.

Q: Why does the fan rotate?

A: The air inside the tower is heated up and streams upward.

Q: How is the air heated? Remember that the lamp does not shine inside the tower.

A: The lamp heats the black tower, which in turn heats the air inside.

Q: What are the holes at the bottom for?

A: They permit the tower to be replenished with fresh air.

Q: If you compare this with the situation on Earth, what does the Sun do in the belt around the equator? What happens with the surface and the air above?

A: The Sun heats the ground which, in turn, heats the air. Just like the model of the updraft tower, the heated air rises and produces a continuous updraft of air.

Q: Can you imagine what happens with the air when it reaches high altitudes?

A: The air cools down and the moisture condenses to rain.

Q: Coming back to the updraft tower: it had flaps at the bottom to allow the air in the tower to be replenished. The same happens on Earth. What do we call horizontal air flows?

A: Wind.

ACTIVITY 3: WORKSHEET- THE WIND ENGINE OF THE EARTH

We have seen in the experiments that a heat source can heat up air and cause an upward flow. The same process happens on Earth.

Q: Look at Figure 5. Where on Earth does the Sun heat most efficiently?

A: Around the equator

Q: Heating the air directly is quite inefficient. When you think about the updraft tower experiment, the lamp did not heat the air. Describe the process by which solar energy eventually heats the air.

A: The irradiation from the Sun heats the ground, which in turn heats the air. This is more efficient next to the surface than at higher altitudes.

Q: Which part of the atmospheric layers is heated strongest?

A: The one next to the surface.

Indicate the correct attributions:

The air close to the surface of the Earth is ~~warm~~/cold.

The air at high altitudes above the ground is ~~warm~~/cold.

Q: What happens with the air close to the surface? Consider the temperature differences between low and high altitudes.

A: It rises above cooler air.

Q: Warm air can store more water than cold air. What happens when air rises into the higher layers of the atmosphere? Think of boiling water at home when the hot air meets the cold air or cold surfaces.

A: The water vapour condenses, first to clouds and eventually to larger drops and rain.

Q: Can you explain why the equatorial regions of the Earth experience so much rain during the year?

A: Warm humid air is driven up to cooler atmospheric layers where the water condenses to rain. This is a process that works almost all year.

Q: This region around the equator is also called the Intertropical Convergence Zone, abbreviated as ITCZ. At some point, the air cannot rise any higher. It is diverted north and south. At these high altitudes, the air constantly cools down. What happens with cold air?

A: Cold air drops closer to the ground.

Q: We just mentioned that cold air can store less water than warm air. Can you explain why the desert areas north and south of the equator are so dry? What happens with the air when it drops back to the surface?

A: When the warm air rises up to cooler layers, it cannot store water as efficiently falls down as rain. The air is dried by this process. When this air drops, it is heated up and potentially can store more water. Without replenishment with humid air, the air becomes even drier.

Q: Back at the surface, the air streams towards the equatorial region, where they converge (ITCZ). These are winds we call 'trade winds'. Can you imagine why they are called this?

A: Trade winds are a fairly constant phenomenon that helped cargo ships to sail long distances. Its direction is fairly stable as well, so ships do not get lost often.

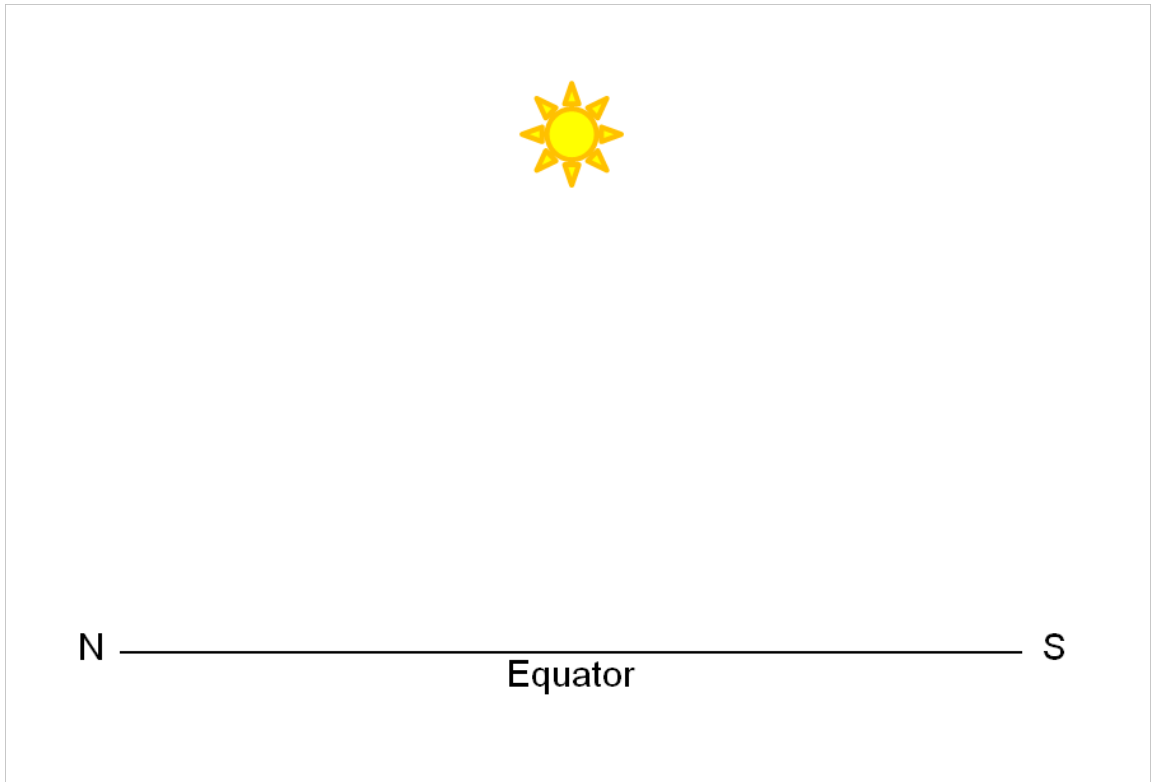
Q: Try to predict what would happen with the winds and weather, in general, if the temperature continues to rise.

A: Temperature is the main engine of updraft. Higher temperatures also cause more water to be evaporated and enrich the air. As a result, one should expect more extreme phenomena related to the ITCZ.

Q: This is actually happening right now. It is called global warming. Explain what would happen if we do not stop this process.

A: This aspect of the climate change will lead to more severe weather, especially near the tropics.

We have constructed an entire circulation system that begins and ends at the equatorial region. This system is called the Hadley Cell. Can you draw a schematic with the most relevant elements and processes? Use the prepared sketch below as a starting point.



CURRICULUM

Country | Level | Subject | Exam Board | Section

— | — | — | —

UK | KS2 | Geography | - | **Physical geography**

* Describe and understand key aspects of physical geography, including climate zones, biomes and vegetation belts, rivers, mountains, volcanoes and earthquakes and the water cycle.

UK | KS3 | Geography | - | **Locational knowledge**

* Expand their locational knowledge and deepen their spatial awareness of the world's countries using maps to focus on Africa, Russia, Asia (including China and India), and the Middle East, focusing on their environmental regions, including polar and hot deserts, key physical and human characteristics, countries and major cities.



ADDITIONAL INFORMATION



CONCLUSION

This activity consists of three parts that illustrate the power of the Sun that drives a global air circulation system that is also responsible for tropical and subtropical climate zones. Through experiments, students learn how heated air rises above cool air and how a continuous heat source produces air convection streams that can even drive a propeller. Students then apply what they have learnt to complete a worksheet that presents the big picture of the global air circulation system in the equatorial region in a large-scale context.

ATTACHMENTS

- [Worksheet](#)
- [Editable worksheet](#)
- [Construction Template](#)

ALL ATTACHMENTS

[All attachments](#)

CITATION

Nielbock, M., 2018, *The Intertropical Convergence Zone*, [astroEDU](#), , doi: [10.14586/astroedu/1619](#)

ACKNOWLEDGEMENT

Haus der Astronomie
