SPACE awareness

EDUCATIONAL KIT: THE CLIMATE BOX

This kit contains a suite of activities targeted at advancing learning about the Earth’s climate, different measuring techniques and climate change.

MARKUS NIELBOCK, MARCO TÜRK

HAUS DER ASTRONOMIE, HEIDELBERG, GERMANY

Curriculum topics
Composition and structure, Orbit and rotation, Habitability Climate change, Surface, Interior, Oceans, Atmosphere, Biodiversity, Seasons, Satellites, Environmental awareness and care

Big idea of Science
The Earth is a very small part of the universe

Keywords
absorption, acidification, air, altimetry, angles, Antarctic, Archimedes, Arctic, atmosphere, atmospheric windows, average, balloons, Black Body, buoyancy, carbon dioxide, chemistry, climate change, climate chart, convection, Copernicus, Earth, earth observation, energy, equator, exoplanets, exoskeletons, expansion, extrasolar, gas, glaciers, global warming, greenhouse effect, greenhouse gases, habitable zone, heat, heat capacity, heat storage, ice, insolation, lakes, Landsat, latitude, life, light, light spectrum, limestone, marine life, methane, model, oceans, orbit, pH value, photovoltaic cell, planets, poles, radar, radar altimetry, radiation, real data, remote sensing, satellite imagery, sea levels, seasons, Sentinel, simple mean, solar constant, solar energy, solar radiation, solstice, spectral index, stars, Stefan Boltzmann Law, Sun, surface layers, temperature, thermal expansion, thermic radiation, thermocline, thermometer, updraft, vegetation, water, weather, winds

Education level
Secondary

Language
English

Content of the kit
15 individual activities

Core skills
Asking questions
Developing and using models
Planning and carrying out investigations
Analysing and interpreting data
Constructing explanations
Engaging in argument based on evidence
Communicating information

Type of learning activity
Full enquiry

CONTENTS

INTRODUCTION

The space segment of the European Earth observation programme *Copernicus*[1] consists of satellite measurements. One of the purposes of this segment is to monitor the Earth's climate and changes in it. With this in mind, our educational kit addresses the current knowledge and scientific evidence for climate change and its consequences. The *Climate Box* is a set of activities that break down complex phenomena into simple exercises and experiments to highlight specific aspects of climate change in detail. Each activity emphasizes a part of a hierarchical sequence of topics concerning the climatic system of the Earth, as outlined below.

The individual experimental settings are designed such that their components are either inexpensive or, at least, easy to obtain. The topics covered with this kit comprise basic physical processes that govern the global climate system as well as phenomena and consequences that everyone can relate to. Cross-correlations among the activities support the notion of the complex and intertwined nature of the Earth's climate.

EARTH – A UNIQUE PLANET

Earth is currently the only planet we know of where life has evolved and been sustained for billions of years. Since scientists first discovered planets outside our solar system, we know of 3560 exoplanets in 2671 stellar systems thus far[2]. However, only about a dozen are considered to be potentially habitable[3]. Therefore, it seems that planets like Earth that sustain life are very rare.

As is a requirement for any inhabitable planet, the key element that provides energy for chemical and biological processes on Earth is the Sun. How much of this energy is actually incorporated into the climatic system of the Earth depends on parameters like the intrinsic energy output of the Sun, its distance from the Earth as well as terrestrial properties such as the albedo and composition of the surface and the atmosphere.

A term that generally provides a first indication of a potential habitability of any planet is the *habitable zone*[4]. This is the range in a planetary system within which water can exist in its liquid form (Activity 1). Physically, this means that the equilibrium temperature that results from irradiation by the parent star in this zone is neither too low nor too high. However, whether or not any given planet in that zone actually possesses liquid water or hosts life is subject to individual properties like size, density, orientation of the rotation axis in space, and the existence of a planetary magnetic field.

There seem to exist many possible configurations for potentially life-bearing planets, so we can safely state that Earth – at least with our current knowledge – is rather unique.

---

[1] http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus
[2] http://www.exoplanets.eu
[3] http://phl.upr.edu/projects/habitable-exoplanets-catalog
[4] https://www.e-education.psu.edu/astro801/content/l12_p4.html

EARTH'S CLIMATE

THE ENERGY BUDGET

Solar irradiation, the energy density of the solar radiation that hits the Earth, changes with solar activity cycles and annual modulation caused by the eccentric orbit of the Earth around the Sun. The accepted annual mean value is E_0 = 1368 W/m^2 as determined by satellite measurements[5]. Averaged over the entire Earth's surface area, the mean energy input is approximately 340 W/m^2.

These are the quantities that govern the weather (Activity 2) and climate. While weather is understood to be an atmospheric phenomenon that changes on short time scales (temperature, pressure and precipitation), climate is the long-term (~30 years) average of these processes. If absorption and emission equilibria are assumed, the equilibrium temperature can be determined, which for the Earth on a global scale, is approximately 14°C. Without the atmosphere, it would actually be much colder[6].

THE CLIMATE ZONES AND SEASONS

In addition to temporal changes, we also experience spatial variations in climatic conditions, in areas known as climate zones[7]. These areas are generally aligned with the latitudes, as the incident angle of solar irradiation changes from the equator to the poles (Activities 3 and 4). The resulting variation in radiative power received on the Earth's surface leads to different reactions from the climatic system. Since solar irradiation is, on average, the strongest in the equatorial region, it is in this region where the global wind system is triggered by the principle of buoyancy and updraft.

In addition, climatic conditions show annual variation due to the obliquity of the Earth's axis. During the Earth's orbit around the Sun, the solar energy received is altered as the Sun apparently swings between the two tropics. This phenomenon gives rise to the seasons[8].

HEAT SINKS

Several constituents are affected by heat intake, most prominently, the atmosphere and oceans. More than 90% of the incoming solar energy goes into the oceans[9], but it is the atmosphere where all the weather phenomena happen. Therefore, the oceans help reduce the effect of global warming (Activities 5 and 6) but only up to a certain level, because the heat is predominantly absorbed at the surface of the oceans[10] (Activity 7).

GREENHOUSE GASES

The atmosphere can only inefficiently harvest heat from sunlight directly. If it were more efficient, the days would be quite dark. Instead, sunlight irradiates the Earth's surface and is transformed into infrared or heat radiation (Activity 8). This is then emitted and, by some percentage, absorbed

---

[5] http://education.gsfc.nasa.gov/experimental/all98invproject.site/pages/science-briefs/ed-stickler/ed-irradiance.html
[6] https://scied.ucar.edu/planetary-energy-balance-temperature-calculate
[7] https://www.e-education.psu.edu/astro801/content/l12_p4.html
[8] http://spaceplace.nasa.gov/seasons/en/
[9] https://www.carbonbrief.org/beneath-the-waves-how-the-deep-oceans-have-continued-to-warm-over-the-past-decade
[10] https://www.epa.gov/climate-indicators/climate-change-indicators-sea-surface-temperature

by the atmosphere, which heats up. In addition to simple heating, some gases within the atmosphere can absorb photons of certain energies by quantum mechanical effects. This stimulates vibrations of molecules that possess an electric dipole moment. After some time, the vibrations decay by emitting a photon of matching energy. This time, however, photons are emitted in all directions and not only upward as it happens when the surface of the earth releases infrared radiation. Therefore, part of the initially emitted infrared radiation remains in the atmosphere and contributes to the additional heating. This is why such gases are called *greenhouse gases*. The strongest and most important contributors to warming are water vapour, carbon dioxide, methane and nitrous oxide. As long as the atmospheric abundance of these gases remains constant, the energy exchange is in equilibrium. This natural greenhouse effect is desired and actually prevents the Earth from being an icy snow ball.

CLIMATE CHANGE

As long as the boundary conditions of a complex system like climate remain constant, an equilibrium can be reached. However, there is strong evidence that this is not the case anymore. For example, the carbon cycle is greatly altered by the consumption of fossil fuels[11], which removes carbon locked in the ground and releases it into the atmosphere. Such carbon pumps cannot be adequately compensated for by natural processes, so the atmosphere is increasingly enriched with carbon dioxide[12]. Similar arguments hold true for other greenhouse gases. Thus, the greenhouse effect (Activity 9) is amplified. There is broad consensus that manmade intervention currently affects the climate globally. This effect is proved by several observations.

The global mean air temperature has been rising since the beginning of the epoch of industrialisation[13]. This has happened at a level and speed that is unprecedented for the last several hundred thousand years. The additional heat captured because of the greenhouse effect leads to rising sea levels due to melting land ice and expanding water levels (Activities 10 and 11) and even to possibly more severe weather phenomena. The oceans are able to store carbon dioxide, which helps mitigate global warming. However, this comes at the price of acidification[14] (Activities 12 and 13), which endangers many important marine species and thus affects the food chain. Global warming also affects ocean temperatures. Higher water temperatures reduce the ability to store gases, which amplifies climate change.

MEASUREMENT TECHNIQUES

In situ measurements using probes and on-ground installations are increasingly supported by earth observation programmes via satellites using remote sensing[15,16]. Satellites have the advantage of being able to cover a large area of the Earth's surface in a short amount of time. Typical remote sensing instrumentation uses the spectral features of sunlight reflected by the Earth's surface and radar altimetry (Activities 14 and 15). While spectral analysis can probe the features and compo-

[11] http://earthobservatory.nasa.gov/Features/CarbonCycle/page4.php
[12] https://www.epa.gov/climate-indicators/climate-change-indicators-atmospheric-concentrations-greenhouse-gases
[13] https://www.ncdc.noaa.gov/sotc/global/201611
[14] http://www.pmel.noaa.gov/co2/story/Ocean+Acidification
[15] http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus
[16] http://eospso.nasa.gov/

nents of the atmosphere, the ground and vegetation, radar measurements precisely measure the height of ground features, e.g. the thickness and distribution of ice[17].

BUILD YOUR OWN CLIMATE BOX

The *Climate Box* is a tool box that has been conceived to provide the equipment needed to carry out 15 activities, which have been newly developed in the framework of the scope of *Our Fragile Planet*. A prototype of the box has been designed and manufactured for testing purposes. Making your own *Climate Box* is both easy and inexpensive. Its compact form allows it to be carried easily.

CONTENT OF THE CLIMATE BOX

The prices mentioned below are exemplary and valid for the prototype built at the House of Astronomy (Germany). Prices may differ, especially depending on the country you are living in.

Briefcase

- 1 briefcase for storage

Indicative price: €20.00

Strong lamp and experimental platform

This is the heart of the toolbox. The platform has been designed to fit inside the case. It is made of four simple wooden boards that build a frame. The lamp is a halogen spotlight that is attached to one of the long sides.

- 1 halogen spotlight
- 4 wooden boards
- 1 dimmer[18]

Indicative price: €20.00

Thermometers

- 1 electronic thermometer
- 2 alcohol thermometers

Indicative price: €15.00

Containers

For the experiments, several containers for water and other materials are needed. These include

- 1 transparent box to hold the equipment
- 1 transparent plastic cup
- 1 PET plastic bottle with the top removed
- black cardboard

[17] https://www.cresis.ku.edu/
[18] https://is.gd/7dbkgL

- 2 petri dishes (plastic or glass)
- 1 beaker with a screw top and some sand or soil inside
- 1 glass flask, size 250 ml

Indicative price: €22.00

Solar cell-driven electric motor

- 1 electric motor
- 1 solar cell
- ply wood for casing and some cables

Indicative price: €5.00

Measuring devices

- 1 folding yardstick
- 1 stopwatch

Indicative price: €7.00

Glass tube

- 1 glass tube
- 1 rubber stop with hole (matching the glass flask)

Indicative price: €4.00

pH colour indicator

- pH indicator solution[19] (commercial, e.g. according to McCrumb[20], hydroponics pH test kit[21], or one made of red cabbage[22])

Indicative price: €5.00

Tea lights

- 4 tea lights
- 1 lighter

Indicative price: €1.00

Miscellanea

[19] https://en.wikipedia.org/wiki/Universal_indicator
[20] F. R. McCrumb, "Use of Wide-Range Indicators for Determination of pH", Industrial and Engineering Chemistry Analytical Edition, 1931, 3 (3), pp 233–235, DOI: 10.1021/ac50075a004, http://pubs.acs.org/doi/abs/10.1021/ac50075a004
[21] http://www.ebay.com/itm/GHE-pH-Test-Kit-for-500-Tests-4-0-to-8-5-pH-/381721462540?hash=item58e05f470c:g:BXwAAOSw3xJXnv0t
[22] http://chemistry.about.com/od/acidsbase1/a/red-cabbage-ph-indicator.htm

- 1 set of balloons
- A few straws
- Wooden skewers

Indicative price: €1.00

Total amount: approx. €100.00

ACTIVITIES TABLE

#	Title	Topic	Short description
1	The Engine of Life	The Habitable Zone	The students simulate the relationship between the flux density of stellar radiation received at a revolving planet and the distance between the planet and its sun by using a lamp and photovoltaic cell that drives a motor. The voltage produced by the cell to drive the motor is high enough only for distances not too far away from the lamp.
2	The Intertropical Convergence Zone	Global wind system	This activity demonstrates one of the effects of irradiating surfaces like the equatorial region of the Earth. Heated air produces an updraft, which is the cause of a global wind system. The students build a model updraft tower. When irradiated, the upper propeller is driven by the rising air.
3	The Climate in Numbers and Graphs	Climate zones	This activity demonstrates that climate is a long-term average of weather phenomena. Real weather data of temperatures and precipitation measured on a daily basis are provided, from which the students derive climate charts. These are very indicative for evaluating the climate of a given location.
4	Climate Zones	Climate zones	This activity demonstrates that the climate zones are generated by the changing incident angles of solar irradiation along the latitudes. A lamp illuminates a photovoltaic cell that drives a motor. The voltage produced by the cell to drive the motor depends on the angle or its irradiated cross-section. The same set-up also explains the origin of the seasons.
5	Water is a Heat Sink	Energy balance	The students experience the ability of water to more effectively absorb and store heat as compared to air. This is done with a simple experiment in which two balloons, one filled with air and the other filled with water, are heated with a flame.
6	Oceans as a Heat Reservoir	Energy balance	This activity is a quantitative extension to the previous one to show how oceans store extensive amounts of heat, which the atmosphere and the continents cannot do. The students measure the temperature increase of soil and water illuminated by a strong lamp.
7	The Thermal Layers of Oceans	The oceans	On the basis of activities related to the oceans' ability to store heat, this unit demonstrates that, in fact, only the upper layers of a water body react by raising the temperature. The vertical temperature distribution of the oceans is stratified. The students carry out an experiment that simulates this effect. A cup with water is illuminated

			from above. After some time, the students probe the vertical temperature distribution using a thermometer.
8	Global Warming of the Atmosphere	Global Warming	This activity demonstrates the basic processes that heat the atmosphere. These processes are mostly driven by indirect infrared heating emitted from the illuminated ground. The experiment uses a simple model of a PET bottle blackened at the bottom. When illuminated, the air above the ground is heated up, and temperature stratification is measured at higher altitudes.
9	Greenhouse Effect	Greenhouse Effect	After they are provided the scientific background on the causes of the greenhouse effect, students carry out an experiment that mimics its consequences on the global climate. The heating of air enclosed in a container is compared with freely circulating air by temperature measurements.
10	Oceans on the Rise	Rising sea levels	The students learn that one of the consequences of climate change, the rising sea levels, can already be witnessed now. A simple experiment with water heated by a lamp shows that water expands with rising temperature. Within a confined container, this leads to a rise in the water levels. This is one component of the experiments showing the global rise of the oceans.
11	The Big Meltdown	Rising sea levels	With a simple experiment, this activity demonstrates that melting ice can lead to an increase in the global ocean levels. The students learn that although floating ice does not contribute to the rise of oceans levels, while melting continental ice indeed does.
12	Transforming Water into Acid ... and back	Carbon cycle	This activity demonstrates the temperature-dependent ability of water to dissolve carbon dioxide and form carbonic acid. The students use exhaled air to pump carbon dioxide into distilled water and monitor the change in pH with an indicator. Afterwards, the carbon dioxide is driven out again by heating the solution. The students learn that acidification is a serious threat to marine life.
13	Ocean Acidification	Carbon cycle	After having explored the acidification of water by carbon dioxide, the students now approach the problem of ocean acidification by capturing atmospheric carbon dioxide in a slightly more realistic way. This experiment demonstrates that carbonic acid is formed only in the upper layers of the oceans, where the water is in contact with the atmosphere.
14	Valleys Deep and Mountains High	Radar altimetry	The students learn how radar altimetry via satellites helps with the construction of altitude maps. They probe a landscape model that is hidden inside a box with a skewer that is lowered through the lid of the box. A grid of measuring points provides a table of heights that can be translated into various versions of maps.
15	A View from Above	Earth observation	A software tool specially designed for educational purposes (LEO Works) is used to analyse real satellite data. The students learn basic analytical procedures and apply them to imagery data. They follow the steps professionals employ to derive geophysical information like the grade of vegetation and the spatial distribution of open waters.

This resource was developed by Space Awareness. Space Awareness is funded by the European Commission's Horizon 2020 Programme under grant agreement n° 638653.