



Climate Change: Understanding and Acting

A STEM-Project for the School
with experiments in the climate kit

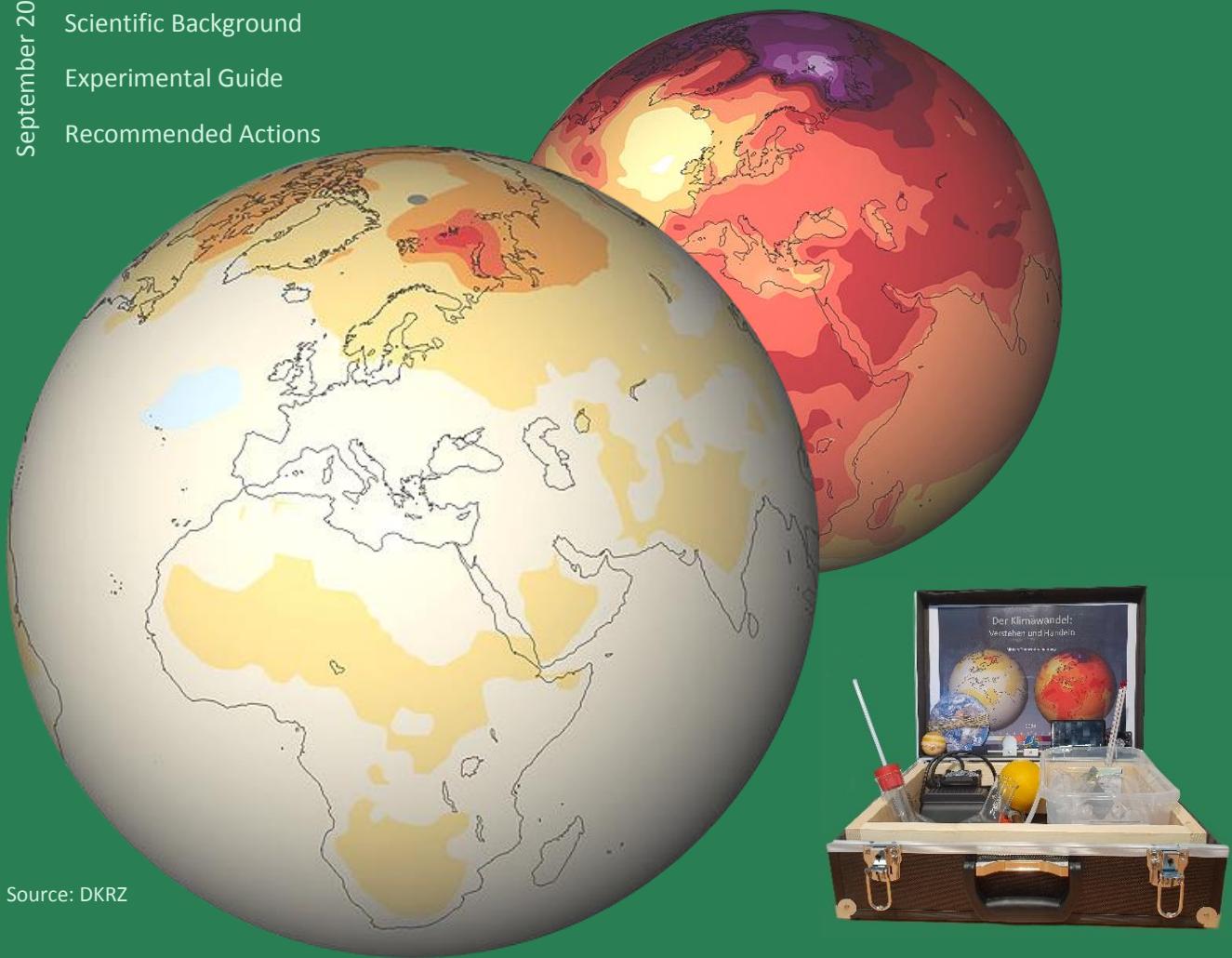
Handbook

September 2019

Scientific Background

Experimental Guide

Recommended Actions



Source: DKRZ

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The chart on the title page illustrates two simulations of the DKRZ (German Climate Computing Centre) and the associated temperature increases (see scale) on Earth in 2090 compared to the pre-industrial age.

In the more positive scenario (globe in the foreground, RCP2.6), the mean global temperature rise remains below 2 °C. In the other scenario, an average global temperature increase of 4.8 °C can be expected, with considerable regional fluctuations.

Mankind's efforts in the coming years will determine which scenario will be implemented.

Preface

Climate change is the greatest global challenge of the 21st century. Although the history of our 4.6-billion-year-old planet has seen repeated climate fluctuations, there is no doubt that mankind is responsible for the largest share of current global warming as a result of carbon dioxide emissions. It is precisely the high speed at which climate change is progressing that poses an enormous problem. Neither flora and fauna nor humans can adapt that quickly to the changed environmental conditions. The destruction of animal and plant species, wars over water and other resources, famines and migratory flows are all areas of conflict which are mainly caused by climate change. Climate change is the topic of this century and thus also the decisive part of the future of today's pupils

The global climate system and hence climate change are an interplay of different physical processes. These, and the resulting consequences, are presented in this handbook and illustrated with the help of experiments. The most important keywords are here: Greenhouse effect, energy, energy balance, equilibrium temperature, heat radiation, radiation equilibrium, absorption behaviour of atmospheric gases, weather and climate and heat capacity. Cross-references between these topics support the idea of the complex and intertwined character of climate change. Due to the many points of contact, the topic is ideally suited for interdisciplinary and interdisciplinary work at schools, not only in the MINT area.

At least as important as a basic understanding of the context is the urgent call for action. Now, only those who are informed of the scientific background can do this in a well-founded, motivated, argumentative, and responsible manner. Therefore, not only an understanding of the scientific processes behind climate change should be conveyed, but also possibilities for acting should be offered in order to shape the individual life and environment of the students.

The Authors

Call for Participation!

This handbook and the accompanying experimental kit is part of the project *Climate Change: Understanding and Acting*, initiated by the Faculty of Physics of the Ludwig Maximilian University of Munich and endorsed by the Bavarian State Ministry of the Environment and Consumer Protection.

The general aim of this project is to bring the topic of climate change more into the focus of the younger generation, to work out the necessity for ethical action through an understanding of the scientific background, and to motivate students to take concrete action.

We cordially invite you to participate!

To this end, the Climate Change Teacher Network will be founded in 2019. Within this framework, concrete teaching modules, materials and projects for different grades and subjects are to be developed and made available to schools as an educational package, so that they can be used flexibly over the course of a school year, especially in the form of interdisciplinary work.

If you are interested in working with towards this goal, we look forward to hearing from you at:

kontakt@lehrernetzwerk-klimawandel.de

We are also very grateful for any comments, suggestions for changes and improvements, additions etc. to this handbook and the related experiments.

„We will [...] conclude on the absolute need to keep global warming well below 2°C, if we want young generations to be able to adapt to future climate change in the second part of this century and beyond. We will argue that research, innovation and creativity are essential for going towards this low carbon society but that this transition also requires large dedicated private and public investments.

Jean Jouzel, Member of the IPCC and as such Nobel peace prize laureate, in his opening lecture at the conference “Climate Change & Water 2018” in Tours, France, on February 5, 2018.

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Chapter 1

Our Earth: An Extraordinary Planet

The Earth is the only planet in the solar system on which complex life has developed and survived over billions of years. Since the first discovery of planets outside the solar system in 1995, nearly 4000 exoplanets have been discovered (June 2018). However, only about a dozen of them are considered potentially life friendly. It follows that planets on which life seems possible are rare and must have special properties. By realizing how many seemingly random events had to come together to create a planet like Earth, we see how special our home planet really is! Therefore, our handbook begins with the description of the astronomical peculiarities of the earth.

1.1. A Quiet Place in the Galaxy

Our home galaxy, the Milky Way, is a spiral galaxy that contains about 200 billion stars. The solar system is located in a quiet region of the Milky Way, outside a spiral arm and far away from the galactic centre (see Figure 1). It is thus also far away from areas with high star density and thus out of reach of stars that explode as supernovae and could have destroyed life on Earth with their gamma rays. This zone is called the "Habitable Zone of the Galaxy".



Figure 1 - Position of the Solar System in the Galaxy (Credits: Mandarao/edited by Scorza)

1.2. The Life Zone of the Solar System

Activity 1

Our solar system consists of one star (Sun), four terrestrial planets (Mercury, Venus, Earth and Mars), four gaseous planets (Jupiter, Saturn, Uranus and Neptune), five dwarf planets like Pluto, the moons of the planets, asteroids and comets. A measure of the vitality of a planet is its distance from the mother star: If the planet is located in the life zone of the star, i.e. where water can exist in liquid form, this increases the chance that life will develop. In the solar system, the life zone extends from Venus to Mars (see Figure 2), so the Earth is in the middle of it.



Figure 2 - Earth is in the Middle of the Solar System's Life Zone (Credits: NASA/edited by Scorza)

1.3. The Formation of the Solar System and the Earth

Despite all present-day differences, the planets of the solar system, together with the sun, were all formed from a protoplanetary gas and dust disk about four and a half billion years ago (see Figure 3). This disk was formed from the residual matter of a supernova explosion, in which all elements generated in the nucleus of the star by nuclear fusion and during the supernova explosion were present: from helium to carbon to iron, gold and uranium. After the supernova explosion, these elements and fine dust (consisting of silicates and graphite) mixed with hydrogen-containing gas clouds of the environment.

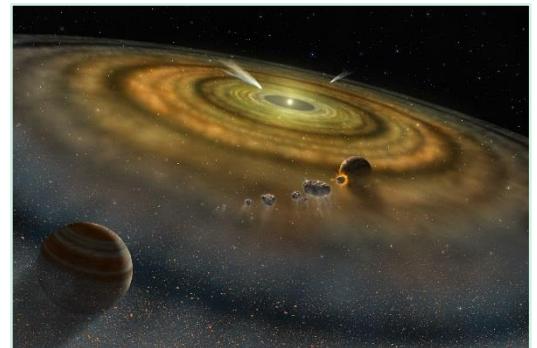


Figure 1 – The Formation of the Solar System
(Credits: NASA)

First the gaseous planets Jupiter, Saturn, Uranus, and Neptune were formed in the protoplanetary disk. Since this happened at a great distance from the sun, they were able to bind large amounts of gas around their large terrestrial nuclei relatively quickly due to the low temperatures and the gravitational force. Later, the nuclei of the rock planets Mercury, Venus, Earth and Mars were formed from fine dust, which subsequently accumulated material through countless impacts of other celestial bodies and grew to planetary size. This formation process took about 100 million years.

1.4. Only the Earth Kept its Water

Due to the many collisions in the early development phase of the solar system, all rock planets were formed as very hot, glowing spheres. Once cooled down, they were dry. So, where did the water come from?

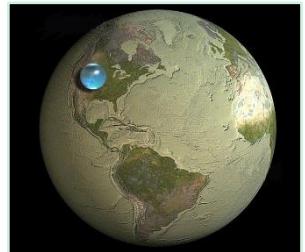


Figure 2 – The Water of the Earth
(Credits: Cook and Perlman)

Water existed already in the protoplanetary disk. The element accumulated in remote areas beyond Mars (closer to the sun it would have evaporated quickly) in the form of ice in porous asteroids and comets.

Due to migratory movements of the gaseous giants Jupiter and Saturn, many water-containing asteroids were catapulted out of their orbits. Some were attracted to the sun and hit the surface of the inner rock planets, bringing them water.

This accumulated on the three planets in the life zone (Venus, Earth and Mars) in the form of water vapour. Due to the proximity to the Sun, the water vapor in the Venus atmosphere was split by the Sun's UV radiation and the volatile hydrogen component escaped into space. Mars, on the contrary could not hold the water vapour due to its little mass. Only on Earth, more and more water vapour accumulated in the atmosphere over time. As a result, the atmospheric pressure increased and as the Earth's surface cooled, the water fell as rain onto the surface. The seas and oceans were formed on earth in this way. Large quantities of CO₂ were washed out of the air by the rain and stored on the seabed in the form of limestone. Rain has thus made the earth's atmosphere more life friendly. Much later, when plants began to absorb more CO₂ and convert it into oxygen through photosynthesis, an

ozone layer was formed that protected the earth's surface from UV radiation - an important prerequisite for the Earth's biological diversity.

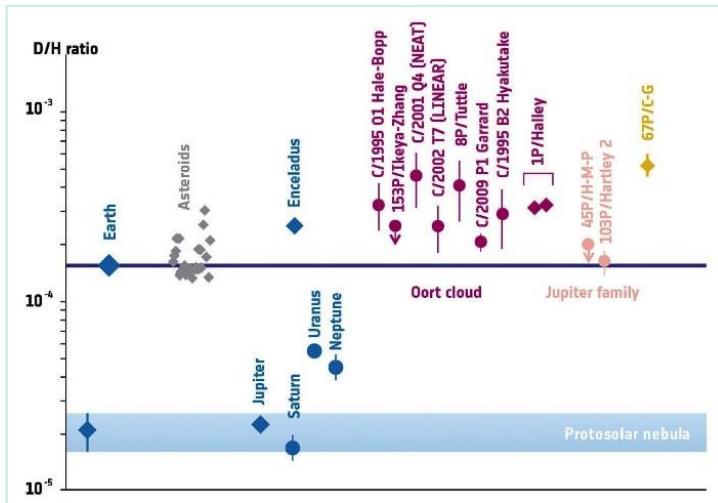


Figure 5 - Deuterium to Hydrogen (H/D) in the Solar System (Credits: ESA, after: Altweig, K. et al., Science 10.1126/science.1261952, 2014, fig. 3)

An important indication for the origin of water on earth is its chemical analysis: Our H_2O has a characteristic mass ratio of normal hydrogen to deuterium (heavy hydrogen) of $H:D = 1:1,5 \cdot 10^{-4}$, which can also be found in the water of asteroids.

1.5. How the Moon Made the Earth Life-Friendly

Our moon formed about 4.5 billion years ago from the collision of the Earth with the protoplanet Theia, which was twice as heavy as Mars. After the collision, a large part of the matter that had been cut off gathered and clenched in orbit around the Earth - the moon was born.

Previously, the Earth needed only three to four hours for one revolution and its axis of rotation staggered back and forth. On an earth rotating so fast, the atmosphere would sweep over the surface at up to 500 kilometres per hour. Only the presence of our natural satellite slowed down the Earth's rotation to today's 24 hours per revolution. The axis of rotation was also stabilized by the moon and today is slightly inclined at 23.5° in relation to the ecliptic. This inclination causes the seasons and weakens the weather fluctuations of the earth.

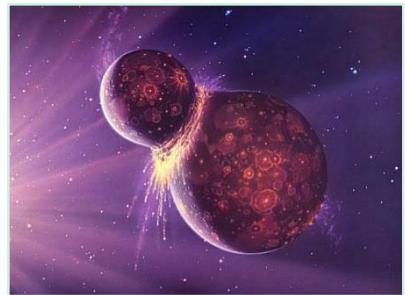


Figure 3 - The Formation of the Moon (Credits: NASA)

1.6. A Magnetic Field as a Protective Shield for the Earth

Many planets have a weak, permanent magnetic field. The earth, on the other hand, has a dynamic magnetic field, which is maintained by processes inside the earth. In these, like a dynamo, kinetic energy is converted into electromagnetic energy. The underlying physics is not easy to understand. Roughly explained, the heat inside the earth causes several thousand degrees hot and ferrous fluid to rise towards the earth's surface. When cooling down, it partially sinks again and is forced onto screw tracks by the Coriolis force, thus generating the magnetic field.

Why does the earth of all planets have such a strong and dynamic magnetic field? Most probably, the impact energy of the protoplanet Theia plays an important role. Its iron core sank practically completely into the centre of the earth when it collided. It is thus jointly responsible for the heat inside the Earth and thus allows the build-up of a magnetic field. Without this protective shield, the earth's surface would be at the mercy of the solar wind and its high-energy, destructive particles.

Without the large-scale magnetic field, life on the earth's surface would be exposed to the destructive cosmic particle radiation of the sun, the solar wind which consists of very fast charged particles that can destroy molecules and make it impossible to build more complex living beings. Our earth's magnetic field protects us from this cosmic danger, because the charged particles of the solar wind are deflected by it. Sometimes one can see the sky shining in the far north and in the Antarctic; these are the northern and southern lights. They arise during storms of the solar wind. One then practically sees the earth's magnetic field during its work as a protective shield. The kinetic energy of the solar wind particles is absorbed by the magnetic field lines of the earth. As electric currents in the high atmosphere, they make the air glow, like a fluorescent tube. Small note: If anyone wants to visit Mars - it has no magnetic field. A dangerous endeavour.

All the astronomical events and geological characteristics and processes described above led to a dry rocky planet becoming a habitable world – the Earth.

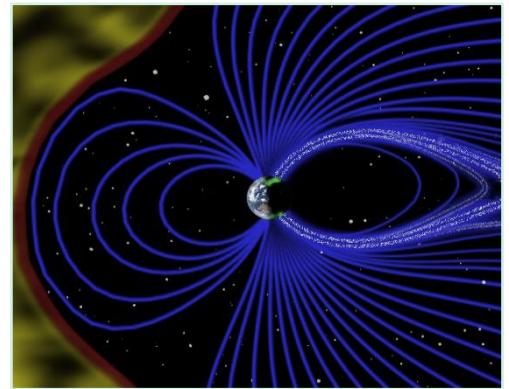


Figure 4 – The Magnetic Field of the Earth (Credits: NASA)

Chapter 2

Understanding the Greenhouse Effect

2.1. The Sun as an Energy Source

As all stars, our sun is also a massive, self-luminous celestial body made up of very hot ionized gas, a so-called plasma. Due to the strong pressure exerted by the gas mass on the centre of the star, the temperature in the inner core of the sun is about 15 million degrees Celsius. Nuclear fusion takes place at these high temperatures: First helium is formed from hydrogen and then, in further fusion steps, nuclei with a higher mass are formed. According to Einstein's equation $= m \cdot c^2$, an immense amount of energy is released in the form of electromagnetic radiation. Every second, the sun converts 500 million tons of hydrogen into helium.

The sun emits electromagnetic waves (which can be divided into gamma radiation, X-rays, ultraviolet radiation, visible light, infrared radiation, and radio waves according to their wavelength) as well as a stream of particles (including protons, electrons and helium atom nuclei), the so-called solar wind.

Due to its surface temperature of about 5 700 °C in accordance with Planck's law of radiation¹, the sun emits mainly electromagnetic radiation with wavelengths of about 400 (violet) to 750 nanometres (red) (see Figure 8) with a maximum of yellow-green. In the course of evolution, our eyes have adapted to this part of the spectrum so that we can see electromagnetic waves in this range.

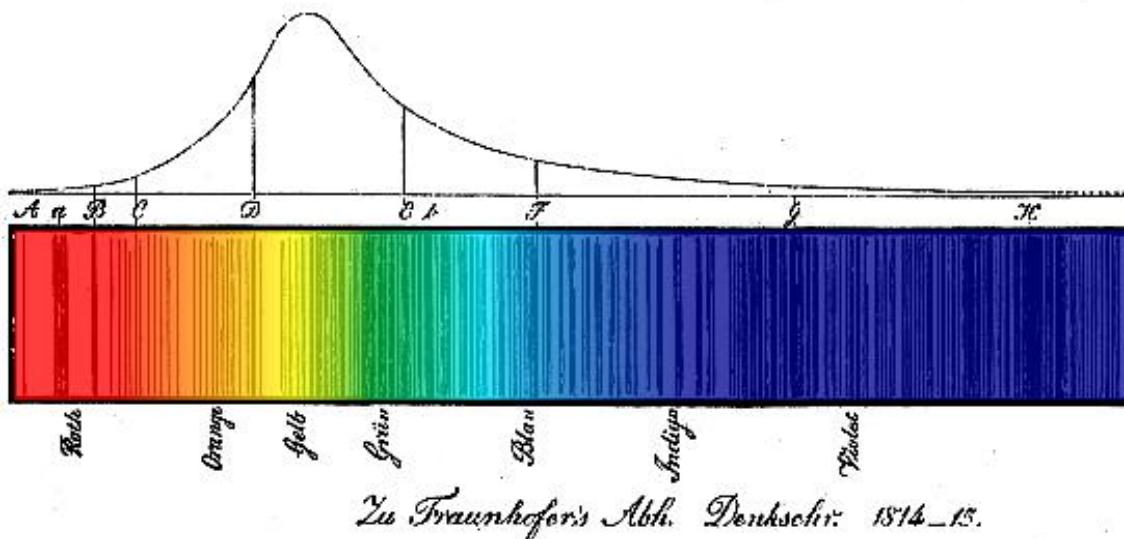


Figure 5 – Fraunhofer's Spectral Lines and Energy Distribution

¹ Planck's law of radiation describes the spectral energy distribution of a black body of a certain temperature as a function of the wavelength or frequency.

How Much Energy Does the Earth Get from the Sun?

The energy of the sun is radiated evenly in all directions. How much of it arrives at a certain planet depends on its distance from the sun.

The *solar constant* S_0 is the irradiance that arrives on Earth, at a mean distance from the Sun and without the influence of the Earth's atmosphere, perpendicular to the direction of radiation. Measurements show that on an area of 1 m^2 above the Earth's atmosphere a radiant power of 1368 W occurs (see Figure 9)².

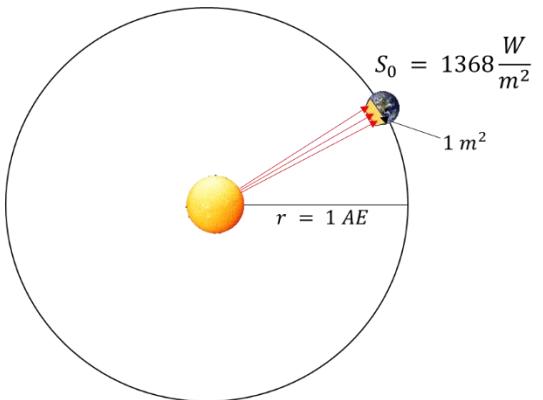
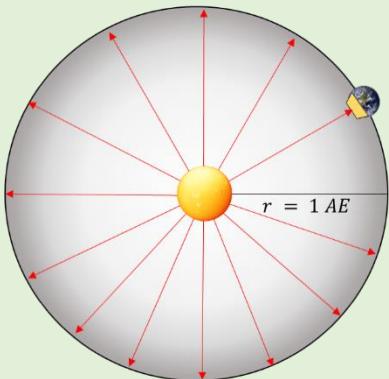


Figure 9 - Measuring the Solar Constant on Earth (Credits: Scorza, Strähle)

Excusus: Estimating the Total Radiant Power of the Sun

When the sun's radiation propagates into space, the total radiant power of the sun is increasingly distributed over a larger area ($\sim r^2$, Figure 10). To calculate the total radiant power of the sun, generally called luminosity L_\odot , imagine a sphere with the sun at its centre and a radius corresponding to the distance between the earth and the sun.

The radiation of the sun is distributed on the surface of this imaginary sphere. The radius r of the sphere is known (1 AU) and thus the area A of the sphere can be calculated. The luminosity of the sun L_\odot is then determined by multiplying this area A by the solar constant S_0 :



$$S_0 = 1368 \frac{\text{W}}{\text{m}^2}$$

$$r = 1 \text{ AE} = 149,6 \cdot 10^6 \text{ km} = 149,6 \cdot 10^9 \text{ m}$$

$$A = 4 \pi r^2$$

$$L = A \cdot S_0$$

$$L = 4 \pi r^2 \cdot S_0$$

$$L_\odot = 4 \pi (149,6 \cdot 10^9)^2 \text{ m}^2 \cdot 1368 \frac{\text{W}}{\text{m}^2}$$

$$L_\odot = 3,85 \cdot 10^{26} \text{ W} = 3,85 \cdot 10^{23} \text{ kW}$$

Figure 10: The Total Solar Radiation is Distributed on the Imaginary Surface of the Sphere (Credits: Scorza, Strähle)

With the calculated luminosity L_\odot and the known distances of the other planets to the sun, the solar constant on Mercury, Venus, Mars etc. can be determined. This can then be used, for example, to estimate the possibility of extra-terrestrial life.

²1AU = 1 Astronomic Unit = Distance Earth–Sun

2.2. A Planet is irradiated

Activity

The transport of energy from the sun to the earth takes place via electromagnetic waves. In the visible spectral range, i.e. in the wavelength range from 400 to 750 nm, the gases in the atmosphere hardly absorb solar radiation. This relatively short-wave, visible part of the solar radiation therefore reaches the ground almost unhindered, is then partly absorbed there and thus contributes to the warming of the earth's surface. The warm earth radiates this absorbed energy as invisible infrared radiation (heat radiation) back to the universe.

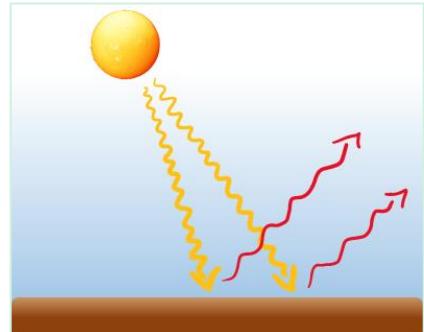


Figure 6 – The Short-Wave Solar Radiation is Re-emitted from the Ground as Infrared Radiation.
(Credits: Scorza, Strähle)

A simple model³ can be used to describe the influence of the earth's atmosphere on the irradiation and radiation of the earth. To do this, we first look at a fictitious earth without an air shell: In the long run the average energy of the heat, which is radiated from the earth into space, must correspond exactly to the absorbed radiation energy from the sun. The Earth is therefore in what is known as the *radiation equilibrium* with its surroundings. If this were not the case and if, for example, the earth absorbed more energy than it radiated, it would continue to warm up over time. But since a body radiates even more energy, the warmer it is, this would only happen until the absorbed and radiated energy are at the same level again and the earth is eventually in the radiation equilibrium.

In the radiation equilibrium, the solar radiation absorbed by the earth's surface must be entirely radiated back into space again as long-wave heat radiation.

The energy radiated vertically by the sun on Earth is $S_0 = 1368 \text{ W/m}^2$ (solar constant, see page 6). However, not the entire globe is irradiated vertically, but towards the poles, increasingly flatter. In other words: Per m^2 surface less and less energy is absorbed, the closer we get to either pole. Further, the other hemisphere is in darkness. The average energy per m^2 radiated over the earth's surface can be estimated by determining the ratio of cross-sectional area $Q = \pi \cdot r_{\text{Erde}}^2$ (is irradiated vertically) to the earth's surface $O = 4\pi \cdot r_{\text{Erde}}^2$. This is obviously exactly 1/4. Thus, $I_S = \frac{1368 \text{ W}}{4 \text{ m}^2} = 342 \frac{\text{W}}{\text{m}^2}$ results for the average intensity of solar radiation on earth.

Back to the rock earth. The mean temperature can be estimated with the Stefan-Boltzmann law:

$$I = \sigma \cdot T^4$$

The law describes what radiation intensity I (in watt per m^2) a body radiates at a certain temperature T . The hotter a body, the more heat it emits, proportionally to the fourth power of its temperature. At twice the temperature (measured in Kelvin), a body radiates 16 times more energy per second. The radiation constant $\sigma = 5,67 \cdot 10^{-8} \frac{\text{W}}{\text{m}^2 \text{K}^4}$ is to be regarded as a conversion factor between temperature and radiation intensity.

³ Model after Buchal and Schönwiese (2010)

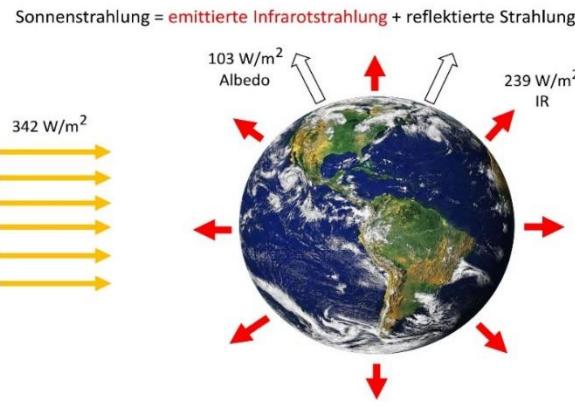


Figure 7 – The Energy Balance of the Earth (Credits: Scorza)

Of the irradiated 342 W/m^2 approx. 30 % are directly reflected into space. This reflectivity of surfaces is called *albedo* α and is particularly high in ice, for example. It results thus, for the energy transferred from the sun really on the earth per second and per m^2 :

$$I_{S \rightarrow E} = (1 - \alpha) \cdot I_S = 0,7 \cdot 342 \frac{\text{W}}{\text{m}^2} = 239 \frac{\text{W}}{\text{m}^2}$$

The average radiation power of the earth's surface $I_{E \rightarrow}$ is equal due to the equilibrium of radiation and depends on the temperature of the earth's surface:

$$I_{S \rightarrow E} = I_{E \rightarrow} = \sigma \cdot T^4$$

$$T = \sqrt[4]{\frac{(1 - \alpha) \cdot I_S}{\sigma}} = \sqrt[4]{\frac{239 \frac{\text{W}}{\text{m}^2}}{5,67 \cdot 10^{-8} \frac{\text{W}}{\text{m}^2 \text{K}^4}}} = 255 \text{ K} = -18^\circ \text{C}$$

By solving the equation, we see that on this rocky earth, the average temperature would be -18°C !

Activity

Changes in the intensity of solar radiation I_S or changes in the albedo α always have a direct effect on the temperature of the earth. I_S and thus $I_{S \rightarrow E}$ would increase for any reason, the temperature of the earth would increase until the radiation equilibrium would be restored at a new equilibrium temperature.

2.3. The Atmosphere and the Greenhouse Effect

Without its warming atmosphere, today's blue planet would be a white ice ball with an average temperature of -18°C . Fortunately, the Earth's atmosphere partially absorbs the heat radiation of the Earth and radiates it back towards the surface. We will look at the underlying processes now:

Let's assume that the atmosphere allows the entire relatively short-wave solar radiation I_S to pass through but would absorb a large part of the infrared heat radiation of the earth's surface $I_{E \rightarrow}$ say 80 %. As a result, the atmospheric temperature rises and begins to radiate the absorbed heat towards the earth's surface ($I_{Atm \rightarrow E}$) and towards space ($I_{Atm \rightarrow W}$). Since the atmosphere does not radiate preferentially in any direction, we find that

$$I_{Atm \rightarrow E} = I_{Atm \rightarrow W}.$$

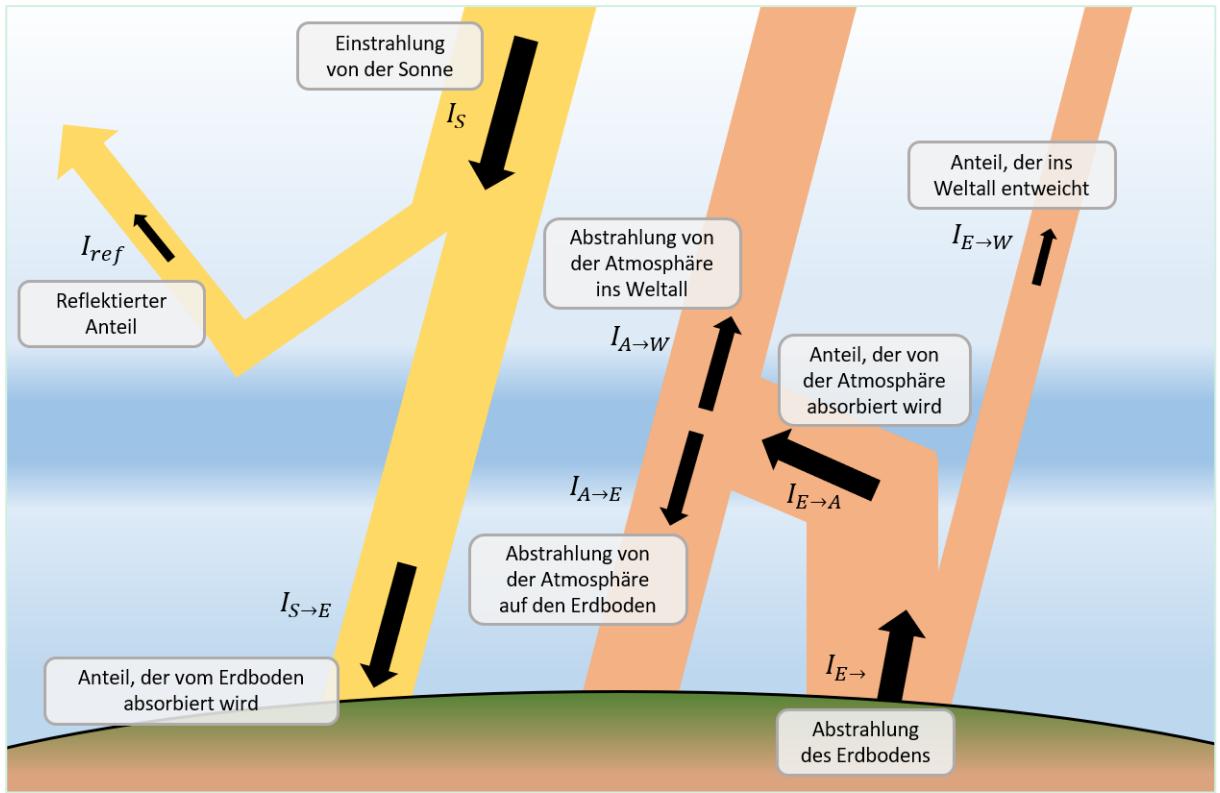


Figure 8 – Radiation Model with Atmosphere (Credits: Strähle)

The new radiation model (see Figure 13) now looks as follows:

The incident solar radiation is still $I_S = 342 \text{ W/m}^2$.

Directly diffusely reflected is the fraction α , which we again apply with 0.3, corresponding to a radiation of $I_{ref} = 103 \text{ W/m}^2$. The earth's surface thus absorbs the fraction

$$I_{S-E} = (1 - \alpha) \cdot I_S = 239 \text{ W/m}^2.$$

This radiation, absorbed by the earth's surface, is radiated upwards again in this model in the form of heat radiation (I_{E-}). Then 80 % of this is absorbed by the atmosphere:

$$I_{E-Atm} = 0,8 \cdot I_{E-}.$$

However, the atmosphere will not continue to warm up forever, since a radiation equilibrium is also established at a certain equilibrium temperature. The absorbed energy is radiated again. This happens, as we have already mentioned above, upwards and downwards in equal parts. So, it follows:

$$\frac{I_{E-Atm}}{\text{energy absorbed by the atmosphere}} = 0,8 \cdot I_{E-} = \frac{I_{Atm-E} + I_{Atm-W}}{\text{energy radiated by the atmosphere}} = 2 \cdot I_{Atm-E}$$

So, we immediately receive as a result:

$$0,4 \cdot I_{E-} = I_{Atm-E} \quad (1)$$

40 % of the radiation emitted by the earth is therefore sent back to the earth. The fundamental difference between this radiation model and the rocky earth is that the thermal radiation I_{E-} emitted by the Earth is now fed not only by the absorbed solar radiation I_{S-E} , but also by the reflection of the atmosphere. So, it applies:

$$\frac{I_{E \rightarrow}}{\text{energy radiated from the earth}} = \frac{I_{S \rightarrow E} + I_{Atm \rightarrow E}}{\text{energy absorbed by the earth}} = \frac{I_{S \rightarrow E} + 0,4 \cdot I_{E \rightarrow}}{\text{with equation (1)}}$$

Solving for $I_{E \rightarrow}$ results in:

$$I_{E \rightarrow} = \frac{1}{1 - 0,4} \cdot I_{S \rightarrow E} = \frac{1}{1 - 0,4} \cdot 239 \frac{W}{m^2} = 398 \frac{W}{m^2}$$

This may come as a surprise because the earth radiates more energy than it absorbs directly from the sun ($239 \frac{W}{m^2}$). This is because of the atmosphere: The solar energy is stored in it via the earth's surface and then sent back and forth, also driven by the sun. The atmosphere is thus charged with energy (and the earth-atmosphere system is heated up more and more) until a balance of radiation is achieved. This is comparable to pushing a freight wagon on a circular track: if the friction losses do not completely consume the drive power, the wagons become faster and faster, i.e. their kinetic energy increases constantly.

This new energy balance provides the temperature of the earth's surface:

$$T = \sqrt[4]{\frac{398 \frac{W}{m^2}}{5,67 * 10^{-8} \frac{W}{m^2 K^4}}} = 289K = 16^\circ C$$

In comparison to the rocky earth, an atmosphere that absorbs 80% of the earth's heat radiation causes a back radiation that warms the earth by $34^\circ C$ ⁴. This process is the so-called greenhouse effect, having a great influence on the climate. Without it, life on earth would probably not be possible.

Activity 4

The temperature on Earth depends on the ability of the atmosphere to absorb (and thus remit) the heat radiation from the Earth's surface. What happens, if we humans increase the absorption ability?

Let us assume that the concentration of CO_2 in the atmosphere has risen due to exhaust gases and that it now absorbs 85 % of the heat radiation of the earth instead of the 80 % assumed above. According to the above argumentation, $\frac{85\%}{2} = 42,5\%$ of the heat radiation absorbed by the atmosphere is now sent back to earth. We receive:

$$I_{E \rightarrow} = \frac{1}{1 - 0,425} I_{S \rightarrow E} = \frac{1}{1 - 0,425} 239 \frac{W}{m^2} = 416 \frac{W}{m^2}$$

$$T = \sqrt[4]{\frac{416 \frac{W}{m^2}}{5,67 * 10^{-8} \frac{W}{m^2 K^4}}} = 293K = 20^\circ C$$

Activity 5

An increase in the temperature of the earth's surface by $4^\circ C$!

One could improve our radiation model step by step and, for example, simulate a temperature profile, i.e. the radiation would be absorbed to different degrees at different heights. Or we could let the atmosphere absorb some of the incident solar radiation, just as the ozone layer in our atmosphere does. And one could also consider the influence of clouds, water vapour and dirt particles (aerosols)

⁴ Contrary to the scientific agreement to indicate temperature differences in Kelvin, they are written here, as is usual in this context, in $^\circ C$.

in the air. This is best done in large-scale simulations, which also correctly represent the dynamics of the sea of air above our heads. But no matter how far we improve our model, the connections shown above retain their indisputable validity:

The more heat radiation our atmosphere absorbs, the warmer it gets on earth!

The absorption capacity of the atmosphere is therefore *the* adjusting screw in which the whole problem of climate change is hidden. And mankind is currently turning this adjusting screw at a rapid pace!

Figure 14 shows the actual energy flows in the complex atmosphere resulting from long-term global measurements and a complex atmospheric mode. The earth's surface radiates $I_{E \rightarrow} = 390 \text{ W/m}^2$, which corresponds to an average temperature of 15°C . In contrast to the model used above, the atmosphere absorbs about 20 % of the incident solar radiation. In addition, the earth's surface releases energy not only through heat radiation, but also through evaporation of water (latent heat) and air currents (convection). 86 % of the heat radiation of the earth's surface is absorbed by the atmosphere. The model considers the fact that the real air temperature decreases sharply when altitude increases, i.e. the lower atmosphere radiates more strongly. In fact, 66 % of the counter-radiation comes from heights around 100 m. Deep clouds form a particularly good heat deck

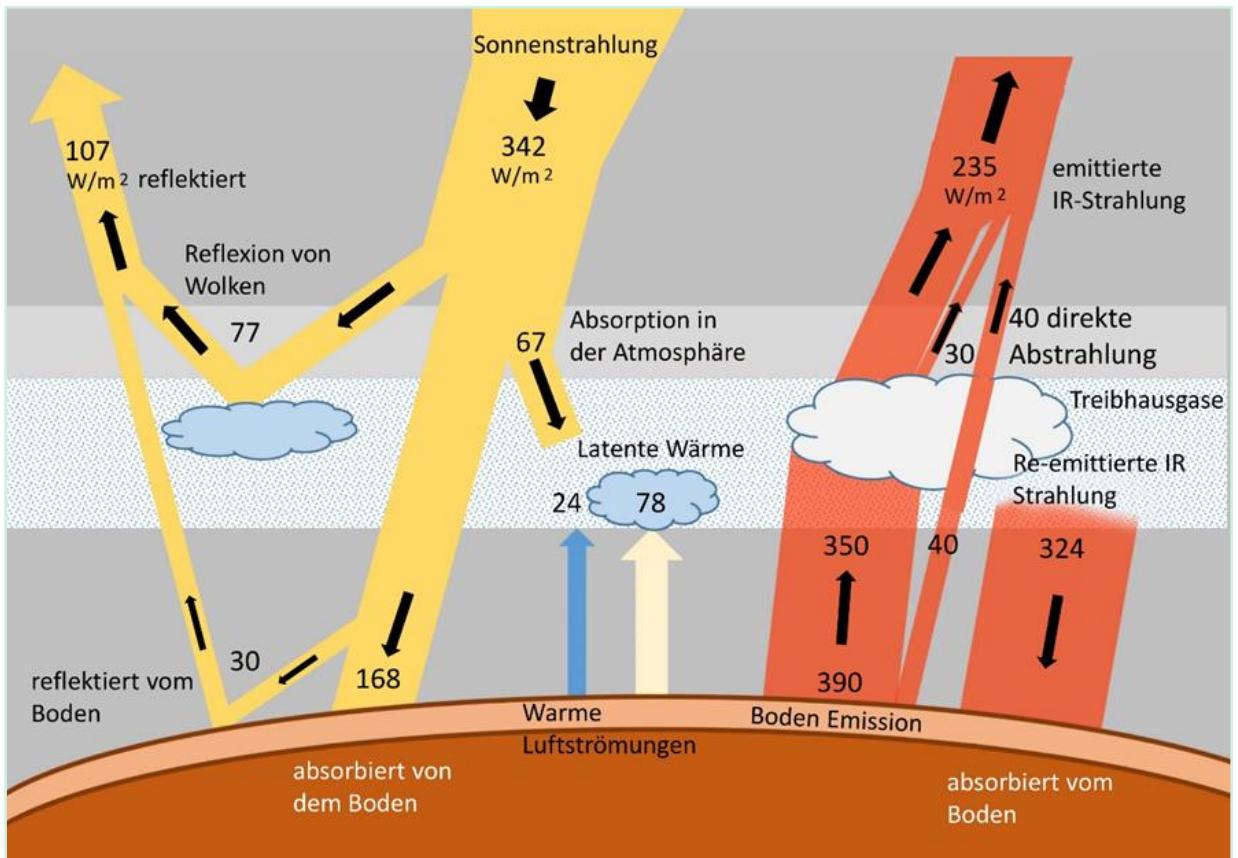


Figure 14 - Energy Flows in the Complex Atmosphere. The balances above the atmosphere (342 W/m^2) and above the ground (390 W/m^2) are balanced. (Credits: Scorsa, Lesch)

2.4. What Defines a Greenhouse Gas?

The natural greenhouse effect described above increases the global mean temperature of the earth from –18 °C to approx. 15 °C. This makes liquid water and thus life on earth possible.

The chemical composition of the atmosphere plays a major role in the greenhouse effect. In the case of the earth, the main components nitrogen (78.1%), oxygen (20.9%) and argon (0.93%) are not relevant as they do not absorb the heat radiation of the earth's surface. The trace gases water vapour, carbon dioxide, methane and nitrous oxide, which occur in small quantities, have this ability and can absorb energy from heat radiation.

In simple terms, the molecules vibrate due to the incoming radiation, converting radiant energy into vibrational energy, which can be transferred to other particles as kinetic energy - the gas heats up.

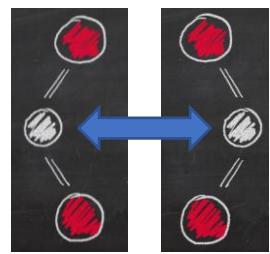


Figure 15 - Bending Vibration of a CO_2 Molecule (Credits: Prof. B. Mayer)

Quantum Physics Excursus: How Do Molecules Do That?

Atoms and molecules absorb energy by changing their quantum mechanical state. In the case of atoms, the energy absorption occurs through excitation of the electrons in the atomic shell. In the case of molecules, it can also occur through a change in the oscillation or rotational state. Electromagnetic waves in the visible wavelength range excite electrons in the atomic shell, light in the upper microwave range excites molecules to rotate. The slightly less long-wave infrared radiation in the wavelength range in between stimulates oscillation transitions of molecules.

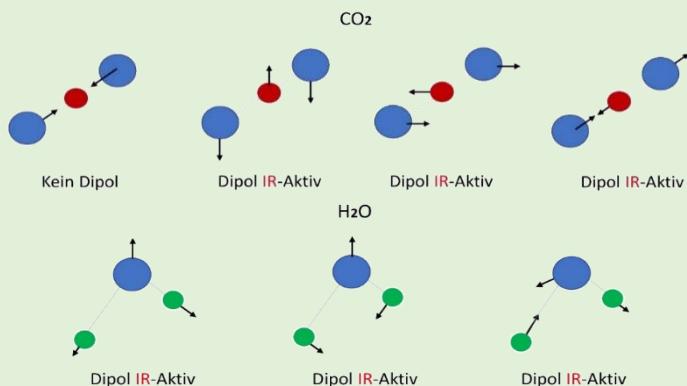


Figure 9 – IR-active Dipole-Molecules (Credits: Scorza)

However, this absorption of infrared radiation can only occur if the electrical dipole moment⁵, which acts as a "lever" for the incoming radiation, changes during the oscillation. Molecular oscillations with this property are called IR-active. All symmetrical molecular oscillations in which the charge centre does not shift are therefore IR-inactive.

Dipole molecules have a constant dipole moment because the electrons are not distributed symmetrically. An example of this is the water molecule (see Figure 16, bottom row). Here, in addition to the polar H-O bonds, two free electron pairs reinforce the permanent dipole moment and all oscillation and rotation transitions are IR-active.

In contrast, the symmetrical CO₂ molecule has no constant dipole moment, since it is linear and the charge centres for positive and negative charges coincide. Despite this, bending vibrations of this molecule cause the symmetry to be broken up (Fig. 16, upper row). The resulting dipole moments cause CO₂ to absorb infrared radiation and to act as a greenhouse gas.

⁵ A molecule has an electrical dipole moment when the charge centres of the positive and negative charges do not coincide.

Chapter 3

The Earth's Climate System

3.1. Distinction between Weather and Climate

In order to understand how human actions, influence the climate, we will first establish an overview of the Earth's climate system. A clear distinction between the terms climate and weather is essential:

The current state of the earth's atmosphere at a certain time and place is called weather. The weather takes place on time scales from hours to weeks - i.e. in relatively short periods (see Table 1) and is determined e.g. by solar radiation, high- and low-pressure areas, convection, and precipitation.

The climate, on the other hand, refers to the average weather over many years, usually over a period of at least 30 to several thousand years. Short-term rashes or anomalies are therefore not decisive.

Charakteristische Zeit	Zeitskala Jahre, Stunden	Atmosphärische Phänomene
Mikroturbulenz	Minuten - Sekunden	Staubteufel Windbö Hitzeblitzen
Wetter	Tage – Stunden	Tiefdruckgebiet Tropischer Sturm Schönwetter Wolken (Cumulus)
Witterung	Wochen - Monaten	Kalter Winter
Klima	Jahre 10^4 (12.500 J) 10^2 (200 J) 10^2 (100 J)	Holozänes Klimaoptimum Kleine Eiszeit Gletscherrückzug im 20 Jahrhundert

Table 1 – Distinction between Weather and Climate (Credits: Scorza)

3.2. The Earth's Climate System and its Components

The Earth's climate is mainly determined by solar radiation on the Earth's surface and by the interactions between the main components of the climate system. These are:

- Atmosphere (air)
- Hydrosphere (oceans, lakes, rivers)
- Cryosphere (ice and snow)
- Biosphere (life on land and in the ocean)
- Pedosphere and Lithosphere (soils and solid rock)

These components have different reaction rates to changes and thus decisively determine the dynamics of the climate system. We now take a brief look at each of them:

Activity 6

Climate Moderation through Oceans (Hydrosphere)

The oceans play an essential role in the Earth's climate system. They cover about 2/3 of the earth's surface and absorb a large part of the incident solar radiation.

From a physical standpoint, water is an effective heat accumulator. A certain mass of water can absorb significantly more heat energy at the same temperature increase than, for instance, the same mass of air. The central physical term in this context is *heat capacity*. It is different for each substance, indicating how much energy is needed to heat one kilogram of a substance by one Kelvin. Water requires 4,182 kJ of thermal energy, so it has a specific thermal capacity of $c_{\text{Water}} = 4,182 \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$.

Air, on the other hand, has a significantly lower specific heat capacity of $c_{\text{Air}} = 1,005 \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$.

We know the following relationship of energy input ΔQ , mass m , and temperature increase ΔT :

$$\Delta Q = c \cdot m \cdot \Delta T$$

The different heat capacities mean that our oceans considerably buffer the energy brought in by the anthropogenic greenhouse effect. This becomes clear in the following simple model:

Two cuboids, each filled with 1 kg of air, are to be heated by supplying energy around $\Delta T = 1\text{K}$. According to the above formula, the following energy quantity is necessary.

$$\Delta Q = c_{\text{Luft}} \cdot 2\text{kg} \cdot 1\text{K} = 2,01\text{kJ}$$

If one of the cuboids is replaced by a cuboid filled with water (also 1 kg), we get a quite simple model of the Atmosphere-Ocean system. To heat this system by 1 K much more energy is needed:

$$\Delta Q = c_{\text{Luft}} \cdot 1\text{kg} \cdot 1\text{K} + c_{\text{Wasser}} \cdot 1\text{kg} \cdot 1\text{K} = 5,19\text{kJ}$$

In other words: If the energy quantity of 2,01 kJ from the first model is added to this system, both atmosphere and water only heat up by approx. 0,4 K !

The oceans extract not only heat energy from the atmosphere, but also O_2 , which dissolves in the water. The oceans thus buffer the anthropogenic greenhouse effect twice - but not without consequences, as we will see later.

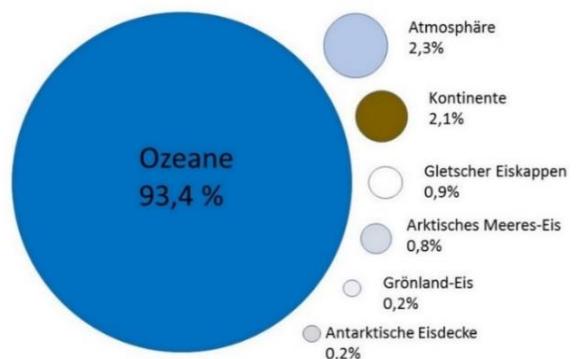


Figure 10 – Heat Accumulators in the Earth System (Credits: Scorsa)

The Changeful Atmosphere

The atmosphere is the most unstable component of the climate system. Above all, its lowest layer, the troposphere, is a place of very changeful weather events. Temperature differences are quickly balanced out and air masses that collide can lead to violent weather reactions such as storms, thunderstorms and heavy precipitation.

With its ability to absorb long-wave heat radiation, the atmosphere provides pleasant temperatures on Earth (see "The Role of the Atmosphere and the Greenhouse Effect" on page 9). Unfortunately, since industrialisation it has been increasingly used as a landfill for gaseous waste, leading to the greenhouse effect and other problems (e.g. ozone hole, fine dust pollution, etc.).

Clouds form in the atmosphere when water vapour cools down. They can have a strong local influence on the permeability of both the sun's radiation and the ground's thermal radiation. Hence, they are a decisive factor in the climate system. A distinction is made between different types: High cirrus clouds are almost completely permeable to solar radiation, whereas low and dense stratus clouds reflect the sun's radiation during the day and have a cooling effect; at night, they reflect the ground's heat radiation and have a heating effect. For instance, a deep cloud cover on a winter night prevents the heat radiation from escaping into space; compared to a starry, cloudless winter night, it remains significantly warmer.

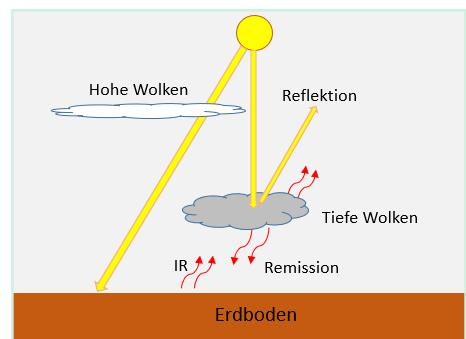


Figure 11 – Effects of High and Low Clouds (Credits: Scorza)

The Role of the Cryosphere Regarding the Radiation Balance

Ice and snow surfaces play an important role in the Earth's radiation balance, since both have a much higher reflectivity (albedo) than soil and water. While the oceans and the ground have an albedo of 10-20 %, accordingly absorbing up to 90 % of the incident solar radiation and converting it into heat radiation, the albedo of ice and snow is 50-90 %.

Activity 2

With a growing ice and snow cover on earth, the global albedo increases. Due to the stronger reflection, less energy is absorbed by the earth. This cooling further increases the formation of ice and snow, which in turn increases the albedo. Geologists and climate researchers are currently discussing whether our planet has even experienced phases of complete icing in the course of its history, as was the case according to the hypothesis of the "Snowball Earth" some 750 to 600 million years ago. It is assumed that volcanism which caused massive CO_2 emissions and thus the associated greenhouse effect, liberated the Earth from its ice shell.



Figure 12 – Experiment for Measuring the Albedo (Credits: O. Fischer)

Of course, this effect can also occur in the opposite direction: Melting ice and snow reduce the albedo and thus increase the ground warming of ground, air and water, which further accelerates the melting process. The size of a planet's ice and snow surfaces therefore has a major impact on its climate.

The Pedosphere and Lithosphere in the Climate System

It has already been shown that the energy exchange from soil to atmosphere takes place via the emission of heat radiation. Another form of energy release, latent heat, occurs through the evaporation of water near the ground: energy is extracted from both the surrounding ground and the air in order to evaporate water, which enters the atmosphere as water vapour. If the soil is relatively dry, less latent heat can be released into the atmosphere, since due to the lower occurrence of evaporation, less energy can escape as latent heat, which leads to an increased temperature of the soil. Since less water vapour also enters the atmosphere, fewer clouds form and the radiation on the ground is intensified - the ground becomes warmer and drier and a positive feedback begins.

The Role of the Biosphere

The influence of the biosphere on the climate is determined by the gas exchange with the atmosphere, especially in the carbon dioxide cycle. Originally, the Earth's atmosphere consisted mainly of carbon dioxide and nitrogen. The primitive algae of the primordial oceans added oxygen via photosynthesis, enabling more developed forms of life.

Even today, the significance of the biosphere regarding climate lies primarily in its influence on the chemical composition of the atmosphere and thus on the strength of the greenhouse effect: plants constantly remove carbon dioxide from the atmosphere by means of photosynthesis. The concentration of methane and nitrous oxide, which also act as greenhouse gases in the atmosphere, is also partly controlled by processes in the biosphere. The greenhouse gas methane is produced naturally mainly by the anaerobic decomposition of organic material (e.g. in the stomach of a cow) while the formation of nitrous oxide is strongly influenced by the activity of bacteria in soil and water. Furthermore, a plant cover on the earth's surface increases the albedo.

3.3. The Origin of Climate Zones

The term "climate" is derived from "klinein", the Greek word for "incline", since the seasons are a consequence of the inclination of the earth's axis relative to the orbital plane of the earth around the sun. The inclination causes the northern hemisphere to be irradiated more vertically and thus more intensively by the sun during the northern summer (position a. in Figure 20), while the sun's rays in the southern hemisphere are relatively oblique. Six months later, the southern hemisphere is irradiated more intensively (position b. in Figure 20) and winter prevails in the northern hemisphere.

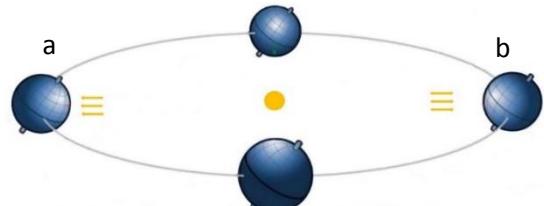


Figure 13 – The Four Seasons (Credits: Scorza)

A second consequence of the inclination of the earth's axis is that the mean temperature is highest around the equator during the year and decreases towards the poles. Thus, the different angle of incidence at which solar radiation hits the globe is also the reason why different climate zones exist on Earth.

Climate zones are groups of areas which extend around the earth in an east-west direction, having common features (e.g. regarding vegetation) due to the climatic conditions.

In the tropics it is warm and humid all year round. Depending on the location, tropical rainforests as well as tropical steppes and deserts can be found. There are only a dry and a rainy season while the temperature fluctuations within one day are greater than the annual ones. On the other hand, the seasons are clearly distinguished in the climate zone where Germany is located. In the interior of continents, it is dry and coniferous, deciduous, and mixed forests grow. In the polar regions, the sun comes in relatively shallowly all year round and it is therefore much colder on an annual average. The vegetation is less luxuriant with grasses and low shrubs. A characteristic of this zone is the three-month polar day in summer and the three-month polar night in winter.

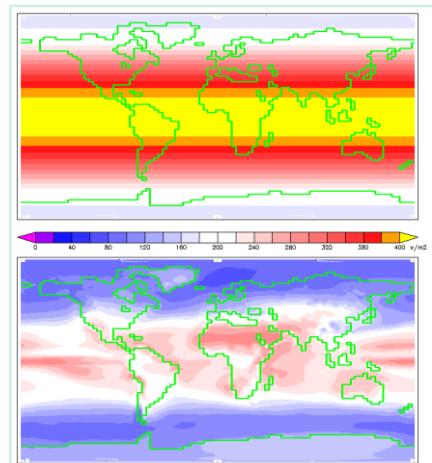


Figure 21 - Annual Mean Value of Solar Radiation outside the Earth's Atmosphere (Top) and on the Earth's Ground (Bottom) in W/m^2
(Credits: William M. Conolley)

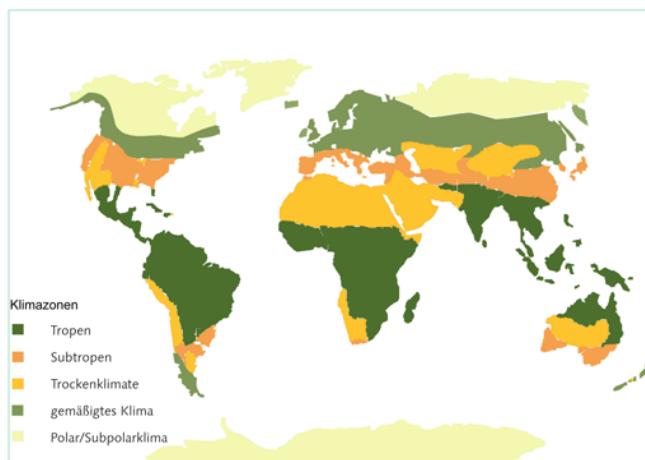


Figure 14 – Earth's Climate Zones (Quelle: ecobine.de)

With the climate zones it becomes visible what effects it has if the earth's surface is supplied with different amounts of energy. Thus, for example, the average angle of solar radiation on an annual average has a significant influence on vegetation. The additional energy flow towards the earth's surface caused by the anthropogenic greenhouse effect will change the position of these climate zones and shift them from the equator towards the poles - a movement that most of the species, specialized in their respective ecosystem, won't be able to follow.

Excursus: Weather and Climate Models

Meteorologists derive the weather forecast from calculation results of computer simulations (so-called weather models). A high-performance computer calculates from a given initial state of the atmosphere the state at a later point in time, using equations based on physical correlations. The initial state results from numerous station observations, such as measurements with buoys, ships, airplanes and weather balloons, as well as from satellite and radar data (see Figure 23). The aim is to be able to give as accurate a forecast of local weather as possible.

The difficulty with weather calculations lies in the fact that the atmosphere is a complex system with partly chaotic behaviour. This means that the future state of the atmosphere depends strongly on the initial conditions, which cannot be determined exactly. Model calculations therefore become increasingly uncertain with increasing prediction time. For this reason, the weather is generally predictable for about seven days on average.

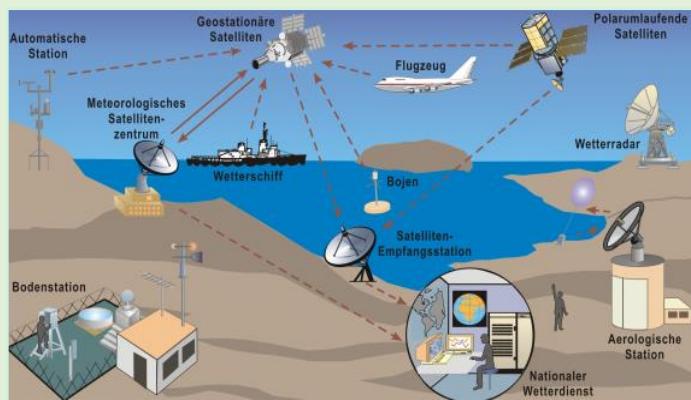


Figure 15 – The Global Meteorological Observatory System (Quelle: Wetterdienst.de)

Global climate models are just as complex physical models; they represent the Earth's climate system in simplified form. The climate simulations calculate with linked atmosphere-ocean models the reaction of the system to changed conditions, such as changes in solar radiation or changed energy flows in the climate system. For this purpose, the atmosphere and oceans are divided into a three-dimensional grid. The exchange of mass and energy between adjacent lattice points is solved step by step by fundamental physical differential equations from fluid dynamics, hydrology and chemistry. In this way, for example, it can be investigated how increased greenhouse gas emissions affect the future climate.

While the prognosis of a weather model can be checked directly by observation, the results of climate simulations can only be compared with averaged weather values. In order to check whether a climate model delivers plausible results, it is fed with measured data and plausible assumptions and then tested whether it can correctly simulate the current climate, but also, for example, that of past ice ages. In order to make a climate forecast, different climate models are fed with a range of available data and assumptions to predict the range of future developments.

Chapter 4

Climate Change

4.1. The Anthropogenic Greenhouse Effect

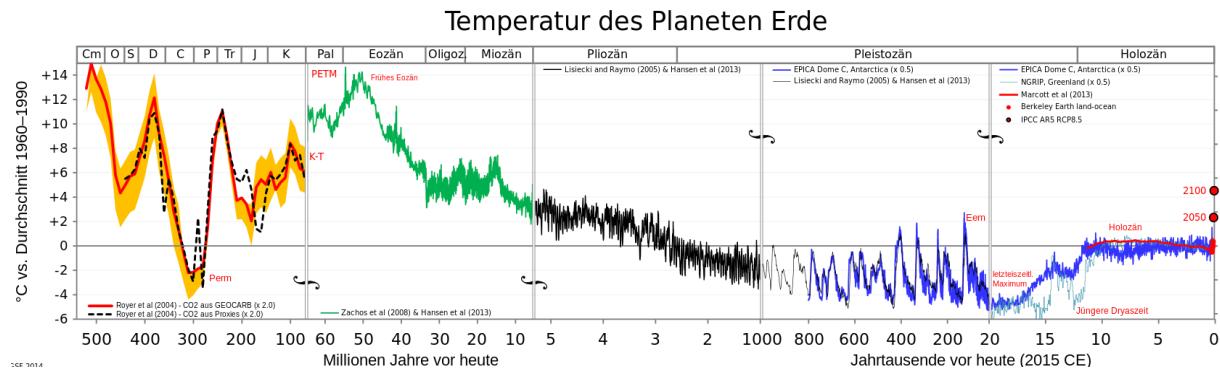


Figure 24 - Global Surface Temperature Estimates for the Last 540 Million Years and Calculated Temperatures for 2050 and 2100 from the IPCC's 5th Assessment Report (Quelle: palaeotemps G2)

The Earth was formed about 4.6 billion years ago. Since then it has seen climatic fluctuations and large changes again and again. Since the beginning of the Holocene about 12,000 years ago and thus since the last ice age, our climate has been relatively stable compared to earlier periods (see Figure 24). Since 1980, however, a significant increase in the mean atmospheric temperature has been observed. Today, there is a consensus in climate research (summarized evidence from over 34,000 scientific publications) that the current climate change cannot be explained without human activity.

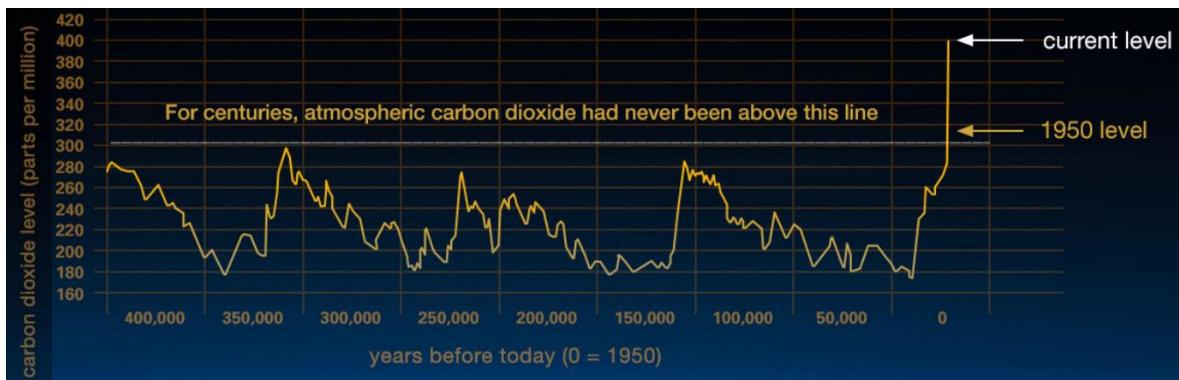


Figure 25 - Diagram of CO₂ Concentration in the Atmosphere with Data from Current Measured Values and Reconstructions Using Ice Cores (Source: NASA - Global Climate Change; climate.nasa.gov/evidence/called on 20.01.2019)

Carbon dioxide plays a decisive role in the anthropogenic greenhouse effect. For thousands of years, the CO₂ level in the Earth's atmosphere has been below the 300ppm⁶ mark (see Figure 25). Since the Industrial Revolution of 1800, however, the concentration has risen sharply by more than 40 % from around 280 ppm to over 400 ppm today and is now higher than at any time in the last 400,000 years.⁷

⁶ ppm stands for parts per million, i.e. the number of CO₂ molecules per million molecules of dry air.

⁷ How do you know that? Drilling cores from a depth of more than 3 km were taken from the hundred-thousand-year-old ice of Antarctica. From the air bubbles it contains, conclusions can be drawn about the composition of the atmosphere in different eras of the Earth's history.

The main reason for this is that humans burn carbonaceous fossil fuels to produce usable energy, which releases carbon dioxide, among other things, when oxygen is supplied. Initially, this happened mainly in Europe and North America, later also in Russia, China, India and Brazil. In 2017, humans released 32.5 gigatons of CO₂, the largest amount ever measured within a year. Compared to 1990 (the reference year of the Kyoto Protocol), this represents a 65% increase in emissions.



Figure 26 - Global Carbon Dioxide Emissions in 2015 (Credits: International Energy Agency, European Environment Agency)

This is a drastic setback. While annual CO₂ emissions (not the CO₂concentration!) remained relatively constant in the years before 2017, this value represents a further increase of around two percent.

Figure 27 illustrates the global increase in carbon dioxide concentration over the past 150 years. The objection often raised by sceptics of anthropogenic climate change, stating that the fluctuations of sunspots with their increased radiation values would be responsible for the measurable rise in temperature over the last four decades, can be clearly contradicted. Solar activity is decreasing, while the temperature and carbon dioxide content of the atmosphere are increasing. Solar activity and global warming are decoupled, they even develop in the opposite direction

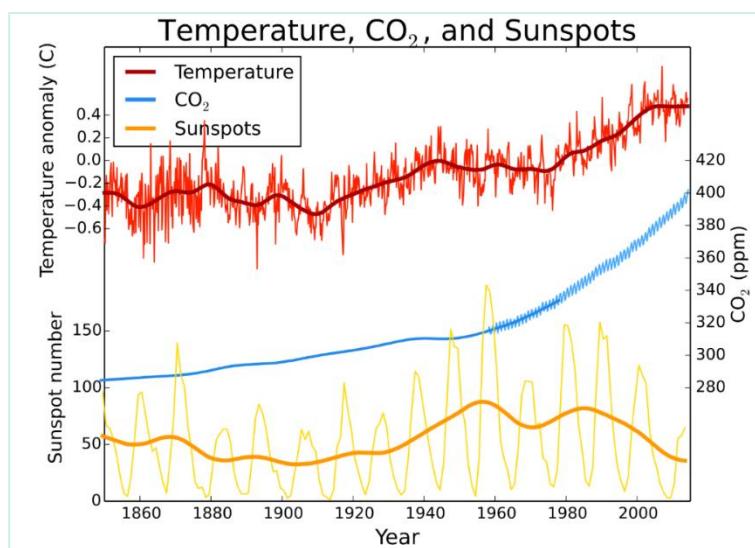


Figure 27 - Temperature and CO₂ Increase (Credits: Leland McInnes)

Methane (CH_4) also plays an important role for the increased greenhouse effect, as it is a 28 times more effective greenhouse gas than CO_2 . Since the Industrial Revolution, the concentration of methane in the Earth's atmosphere has increased from around 700 ppb⁸ to over 1800 ppb today. 37% of global methane emissions can be attributed directly or indirectly to livestock farming, and today methane contributes about 20% to the anthropogenic greenhouse effect. This figure could soon rise sharply due to the thawing of the permafrost soil in Siberia and Canada (see "Water vapour and feedback effects" below). In the Earth's atmosphere, however, methane with a life span of 10 to 15 years lasts significantly less long than CO_2 (50 to 200 years).

Another greenhouse gas is nitrous oxide (N_2O), which has a 265 times higher greenhouse potential than carbon dioxide. In the Earth's atmosphere, the concentration of this gas has risen by about 20 % since the Industrial Revolution and today contributes about 5 % to the anthropogenic greenhouse effect. The emission of N_2O occurs both naturally and in ways influenced by humans: In nature, N_2O is released by bacteria in soil, in water and in primeval forests. However, humans contribute to the increased release of this greenhouse gas by nitrogen-based fertilizers, the industrial production of chemicals, and by burning fossil fuels.

Fluorinated greenhouse gases also play a role. Unlike the gases mentioned above, they are not produced during natural processes, but were developed specifically for industry. Although their share in the total greenhouse gas emissions of the industrial nations is rather low at 1.5%, their effects are 12,000 to 25,000 times stronger than those of CO_2 due to their long residence time in the atmosphere (possibly several thousand years) and their effectiveness as greenhouse gases.

In order to be able to compare the harmfulness of different greenhouse gases, one assigns a CO_2 equivalent ($\text{CO}_{2\text{e}}$) or a global warming potential to each. For example, with a CO_2 equivalent of 28, 1kg methane contributes 25 times more to global warming over 100 years than one kilogram of CO_2 .

4.2. Water Vapour and Feedback Effects

Water vapour is the strongest natural greenhouse gas. However, it has only a very short residence time in the Earth's atmosphere, usually lasting only a few days and then returning to the earth as rain (due to the higher absorption capacity of a warmer atmosphere, increasingly also as heavy rain). In total, its contribution to the natural greenhouse effect is about two to three times as high as that of CO_2 . In contrast to CO_2 , however, water vapour is not a direct cause of the human-induced increase in the greenhouse effect (the anthropogenic greenhouse effect is not caused by the increased emission of water vapour). However, due to the warming of the earth's atmosphere by other greenhouse gases, more water evaporates and the hotter it gets, the higher the water vapour concentration in the atmosphere is. This increases the greenhouse effect, which in turn leads to higher global warming. In addition, the warmer the atmosphere gets, the more water vapour it can absorb. Water vapour thus acts as an amplifier of the greenhouse effect induced by humans.

These feedback processes represent the actual "crux" of climate change. Something shifts and the climate system reacts with changes. The natural processes in the interplay of the atmosphere, the seas and oceans, the ice masses, and the biosphere have always taken place, even in times when there were no humans. Depending on the land mass distribution, volcanism and various astronomical

⁸ ppb stands for parts per billion, so one molecule per one billion air molecules

parameters, the climate changed constantly - the change of the climate is therefore completely natural. In recent decades, however, the concentration of molecules with the ability to absorb heat radiation has been drastically increased by anthropogenic influences. In the middle of a networked, multi-layered and therefore complex natural event, humans change the boundary and initial conditions of the atmosphere through the extraction of fossil resources. Carbon, which was buried deep in the soil hundreds of millions of years ago, is first brought to the earth's surface by coal, oil and gas extraction and then finally released into the atmosphere by combustion processes. Every natural system reacts to this gradual change through feedback effects quite naturally.

Here are the four most obvious feedback processes:

1. Global warming leads to the melting of ice surfaces and thus reduces the earth's albedo. The earth absorbs a greater proportion of solar radiation, which further drives global warming.
2. The temperature of the oceans rises due to global warming. As the absorption capacity for carbon dioxide decreases with increasing water temperature, the atmospheric CO₂ concentration. This further increases the greenhouse effect and thus global warming (see page 28).
3. Global warming is thawing the permafrost soil in large parts of Siberia and Canada. This causes large quantities of methane to enter the atmosphere. Methane acts as a greenhouse gas and thus continues to heat the earth.
4. As already mentioned, increased warming increases the concentration of water vapour in the atmosphere, which as a greenhouse gas further intensifies the greenhouse effect.

Chapter 5

Effects of Climate Change

5.1. Global Effects of Climate Change

Activity 10

Current global warming is the result of rising concentrations of carbon dioxide, methane, nitrogen oxides and other greenhouse gases. The increased greenhouse effect leads to changes in temperature, precipitation, cloud cover, snow cover, and the sea mirror, as well as to a significantly higher incidence of weather extremes of all kinds, e.g. long periods of drought, extreme precipitation, and increased atmospheric activity (storms). Some of these impacts are based on simple physical relationships, such as the rising sea level, the acidification of oceans or the albedo reduction. Others are complex, non-linear consequences, such as changes in sea currents with their impact on ecosystems, the habitability of earth regions, and agriculture. In the following, the effects connected with water are discussed. Further consequences are shown in a table below.

The higher the temperature, the faster water evaporates. This leads to the feedback mentioned in the previous chapter. Due to the increased air humidity and the increased energy supplied to the atmosphere by condensation, the probability and strength of extreme weather events such as thunderstorms, hail and storms up to hurricanes is also increased.

Activity 8

One of the risks posing a direct threat to humans is the rising sea level. Between 1993 and 2010, the consequences of the greenhouse effect led to an increase of 3.2 mm per year. In its 5th climate report from 2013, the Intergovernmental Panel on Climate Change (IPCC) predicts that sea levels will rise by 52 to 98 centimes by 2100 if greenhouse gas emissions continue unabated. One reason for this increase is that water (like all liquids, solids and gases) occupies a larger volume at higher temperatures⁹. The share of this thermal expansion in rising sea levels is estimated at 30 to 55 %. The rest is mainly due to melting continental ice, such as that of the Antarctic ice sheet or the glaciers in Greenland¹⁰. Current measurements conclude that the continental ice is degrading much faster than previously assumed: the melting of ice causes a sliding layer which forms between the ice and the ground, resulting in huge areas of ice slipping into the sea.

⁹ Excluded from this, of course, is the density anomaly around 4 °C, which plays no role for our considerations.

¹⁰ Melting sea ice, on the other hand, does not lead to an increase in sea level

The forecasts until 2100 are only the beginning; this is shown by the comparison of temperature and sea level in recent Earth history (Figure 28). If the entire Greenland ice were to melt, this would result in a rise in sea level by seven metres. The ice from the West Antarctic Ice Sheet would lead to a rise by six metres, and if the entire Antarctic ice were to thaw, sea level could rise by up to 65 metres!

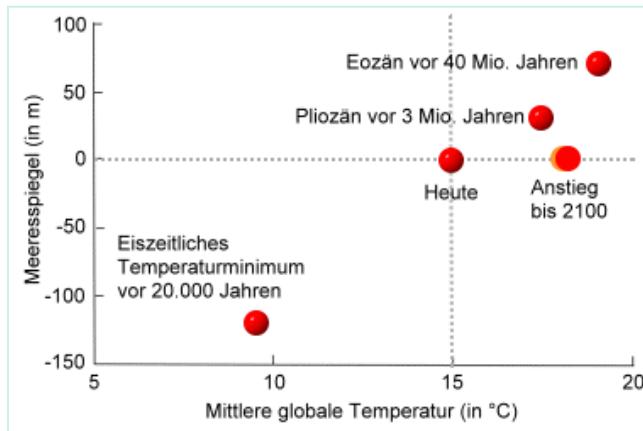


Figure 28 - Earth Temperature and Sea Level in Earth History: The Rise by 2100 is Only the Beginning of a Much Stronger Long-Term Rise (Credits: Rahmstorf and Richardson)

This would result in catastrophic flooding, especially for low-lying coastal regions and cities which include the world's most densely populated regions: 22 of the world's 50 largest cities are located by the coast, including Tokyo, Shanghai, Hong Kong, New York and Mumbai. In Bangladesh, 17% of the country's land area currently stands out of the water less than a metre - with a population of around 35 million. Other countries such as the island state of Kiribati are not expected to be habitable by 2050 and completely flooded by 2070. The Kiribati government is already taking steps to resettle the over 100,000 inhabitants.

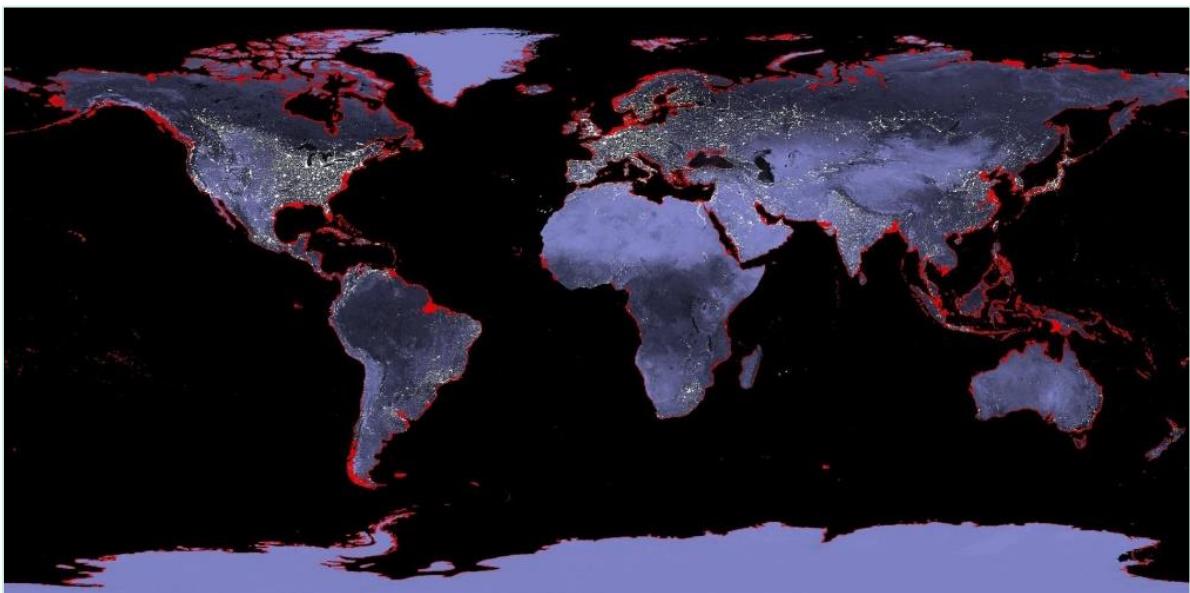


Figure 29 - Coastal Areas Affected by a Sea Level Rise of One Meter

Global warming also has extensive consequences for the water supply of many people. If the temperature were to rise by 4 °C, the melting of huge glaciers in the Himalayas would affect around a quarter of China's population and around 300 million people in India. In the Mediterranean region and in the southern regions of Africa, the drinking water supply would be severely restricted. Around two billion people worldwide would suffer the consequences of recurring droughts and dryness.

The following table examines further effects on the components of the Earth's climate system:

Component	Changes	Effects
Hydrosphere	Global warming leads to the thermal expansion of the oceans. Melting continental ice flows into the sea. The sea level rises.	Flooding of coastal areas and coastal cities; mass extinction of fish, algae and other marine animals, to some extent due to the rise in water temperature.
Atmosphere	Hot dry air increases erosion in some regions, while in others a higher water vapour content increases cloud formation and precipitation.	Extreme weather; heat waves with considerable damage to flora and fauna, and effects on humans; heavy rainfall with sudden floods.
Cryosphere	Melting ice and snow reduce the albedo (reflectivity).	More solar radiation is absorbed by the soil which leads to stronger global warming.
Biosphere	With global warming, plant and animal species become extinct (e.g. due to shifts in climate zones, changes in ecosystems, drought, forest fires).	Disappearance of CO ₂ sinks. Less CO ₂ is absorbed by photosynthesis and transformed into O ₂ .
Pedosphere and Lithosphere	Unveiling of dark areas due to melting ice and snow.	Reduction of albedo, reinforced global warming.

Table 2 - Changes in the Components of the Climate System due to Global Warming (Credits: Scorsa)

Tipping Points

Tipping points are regarded as the Achilles' heel of the climate system. This refers to components of the Earth system which can be put into a completely new state by small changes, if the threshold is almost reached. If this happens, drastic consequences await. One tipping point, for example, is the reduction of albedo through the melting of ice surfaces: As a result, more solar radiation reaches the earth's surface, which leads to further heating. Figure 30 shows some of these tipping points.

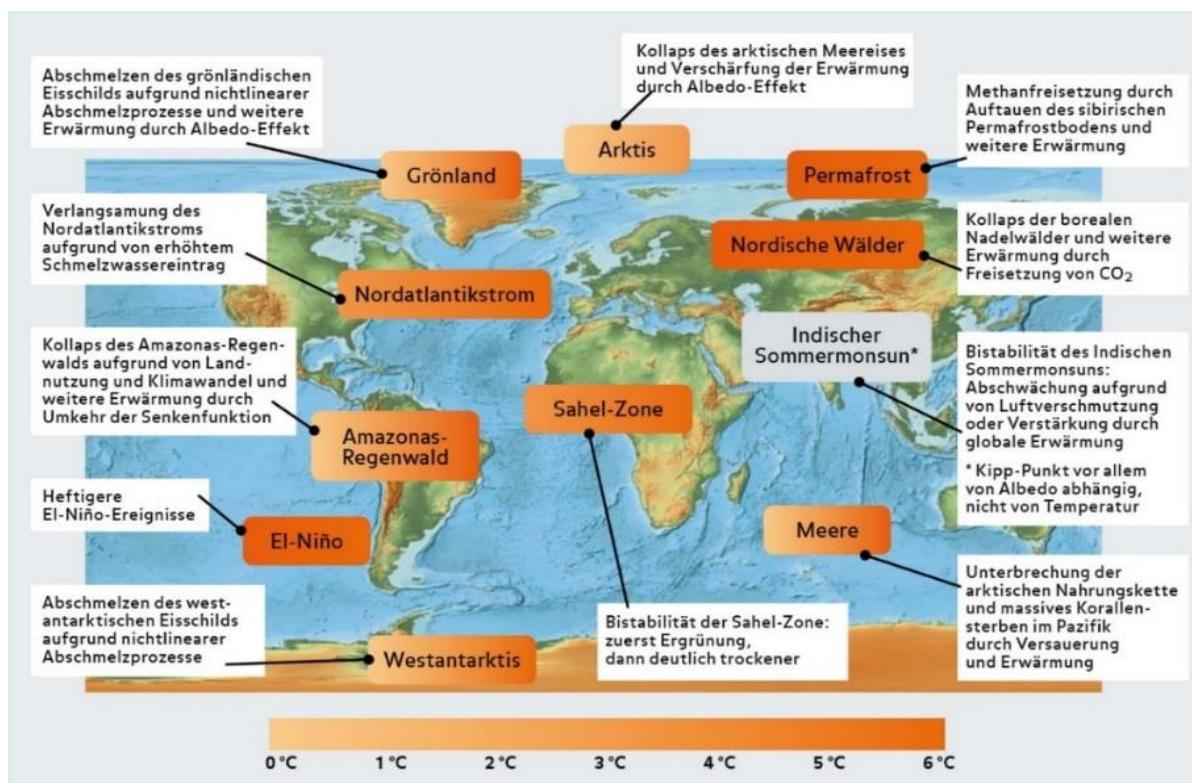


Figure 30 - Tipping Points of the Climate System (Credits: Global Climate Change, Germanwatch changes according to Lenton et al.)

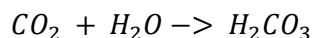
The Acidification of the Oceans

Activity 10

Perhaps it should be mentioned in this somewhat "apocalyptic" chapter that the capacity of water for the absorption of gases decreases with temperature. Today, the oceans still buffer over 90% of global warming through heat absorption (see hydrosphere on page 16) and carbon dioxide dissolution. This will decrease in the future. Because of the difference in the partial pressure of CO₂, the atmosphere exchanges CO₂ with the ocean. The partial pressure corresponds to the proportion of CO₂ of the total pressure within a gas mixture. If the pressure of carbon dioxide in the Earth's atmosphere is higher than the partial pressure in the ocean, the surface water of the ocean binds carbon dioxide. However, the partial pressure of CO₂ in seawater is strongly dependent on temperature: the warmer the water, the higher it is. This means that a warmer ocean can absorb less carbon dioxide from the atmosphere than an ocean with a lower temperature. In other words, an increase in the temperature of the oceans leads to a higher concentration of CO₂ in the atmosphere.

Activity 9

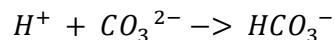
In the Earth's atmosphere, CO_2 does not react with other gases. In seawater, this is different: the dissolved carbon dioxide forms compounds and carbonic acid (H_2CO_3), for example, is formed:



The carbonic acid is split into H^+ ions and hydrogen carbonate ions (HCO_3^-) by the following reaction:



The resulting H^+ ions in turn form a compound with carbonate ions (CO_3^{2-}) again forming hydrogen carbonate ions:



In summary, the concentration of carbonate ions decreases due to the dissolution of carbon dioxide in the oceans. However, these carbonate ions are of great importance for the formation of calcium carbonate (CaCO_3) which is a building material for limestone skeletons and shells (e.g. for mussels, corals, snails, and sea urchins).

5.2. Climate Change in Germany

But what are the specific impacts of climate change on Germany? A global comparison shows that Germany is hit particularly hard.

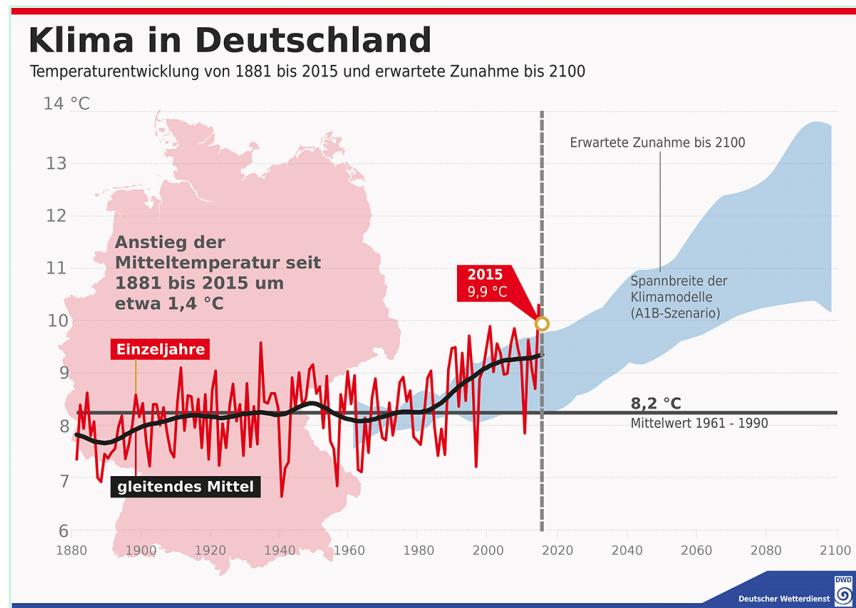


Figure 31 - Temperature Development in Germany from 1881 to 2110 (measured or expected)
(Quelle: Wetterdienst.de)

While the global average surface temperature rose by 0.8 °C between 1901 and 2012¹¹, a warming of 1.4 °C was observed for Germany during this period. Globally, the decade from 2001 to 2010 is the warmest since 1861 and, as Figure 31 shows, there has been a strong acceleration of the temperature rise in Germany since the 1980s. This is a trend that, according to climate models, will continue.

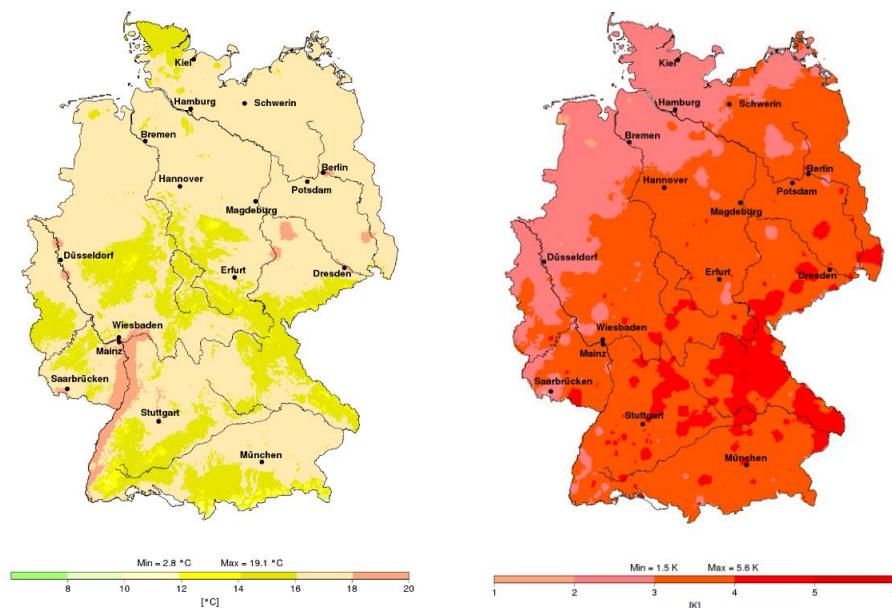


Figure 32 - Deviations of the Air Temperature in August 2018 (right picture) from the Mean Values (1961-1990, left picture)
(Quelle: www.dwd.de/DE/klimaumwelt/)

¹¹ Umweltbundesamt: <https://www.umweltbundesamt.de/themen/klima-energie/klimawandel/beobachteter-klimawandel> called on 19.01.2019.

The rise in temperature has already resulted in a decrease in frost days in winter throughout Germany, as well as an increase in summer days (temperatures $> 25^{\circ}\text{C}$), hot days (temperatures $> 30^{\circ}\text{C}$) and tropical nights (night temperatures $> 20^{\circ}\text{C}$) in summer. Summer heat periods become longer and hotter, increasing the danger of droughts¹². Illustrating the increase in temperature anomalies for the month of May, Figure 33 shows that such weather extremes occur more and more frequently. Another extreme occurred in August 2018 (see Figure 32). It is getting hotter and hotter in Germany.

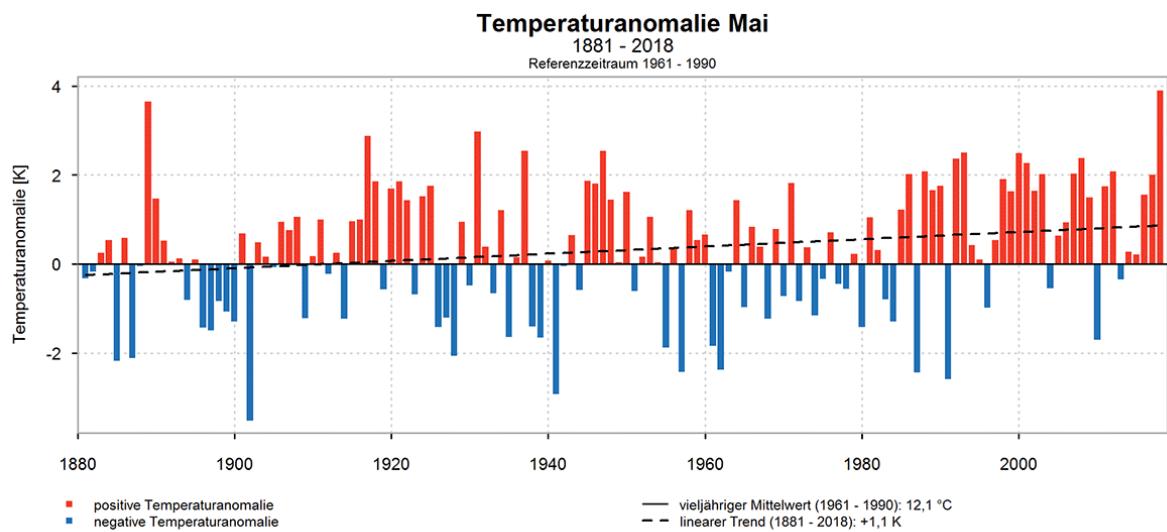


Figure 33 - Deviations of Temperature for the Month of May in Germany, compared to the Long-term Mean (1961-1990)
(Source: www.dwd.de/DE/klimaumwelt/ called on 19.01.2019)

With regards to precipitation, the picture is regionally much more complex. Current measurements tend to show a decrease in precipitation in summer and an increase in winter, although this development is subject to regional fluctuations¹³.

As a lower proportion of winter precipitation falls in the form of snow due to rising temperatures, the risk of floods increases since the water amount is not temporarily buffered. This is exacerbated by the increase in heavy rainfall events, which can already be observed throughout Germany today.

In addition, the risk of storms increases especially in the winter months, which increases the probability of storm tides in the North Sea and Baltic Sea, for instance.

¹²<https://www.umweltbundesamt.de/themen/klima-energie/klimawandel/beobachteter-klimawandel> called on 19.1.2019.

¹³<https://www.umweltbundesamt.de/themen/klima-energie/klimafolgen-anpassung/folgen-des-klimawandels/klimafolgen-deutschland/klimafolgen-handlungsfeld-wasser-hochwasser> called on 19.1.2019.

Considering the complex interactions of the various spheres of the earth, it can be deduced that changes in the atmosphere and the hydrosphere caused by climate change will have a variety of effects on ecosystems in Germany.

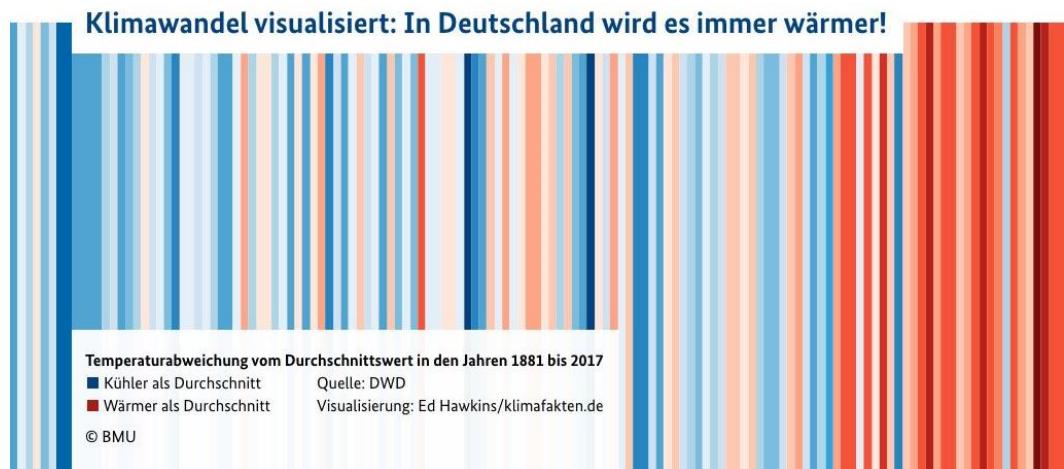


Figure 34 - Temperature Deviation from the Average Value in Germany from 1881 to 2017 (Credits: BMU)

One can expect, for example, that the amount of precipitation will decrease in the summer months and that the heat periods will prolong, causing the soils to dry out and harden in summer and the water storage capacity to decrease. In the winter months, during which precipitation will increase in the future, the soils will be able to discharge less water into the groundwater-bearing layers, resulting in moisture and soil compaction. The altered soil structure changes its properties as filter, habitat and agricultural land. For example, it can now store fewer nutrients or filter out fewer pollutants, which has a negative effect on soil fertility. This will have an impact on agriculture and forestry, for example, especially on yields, usable seed varieties or the use of fertilisers. Natural vegetation will also adapt to changing soil characteristics, leading to changes in the flora and fauna of ecosystems.



Figure 35 - Low Water in the Rhine during the Drought of 2018 (Source: SWR Rheinland Pfalz)

Figure 36 shows an overview of the various interactions between the spheres and it becomes clear what far-reaching effects climate change can have on the atmosphere and hydrosphere.

In Germany, for example, they include a decreasing water level in rivers and an increase in temperature of water bodies (the Rhine had a temperature of 28°C in some places in summer 2018). This has an impact on water quality, leads to a rise in sea levels in the North and Baltic Seas, accelerates the thawing of the permafrost in the Alps, and changes forms of land use with corresponding feedback effects on both ecosystems and biodiversity.

Together with the extreme weather conditions described above – such as heat waves, heavy rainfall events and storms, whose probability of occurrence continues to increase – there are numerous consequences for humans and nature.

Among others, water management, coastal and marine protection, tourism, spatial and regional planning, construction, energy, agriculture, forestry, industry, and commerce will face new challenges.¹⁴

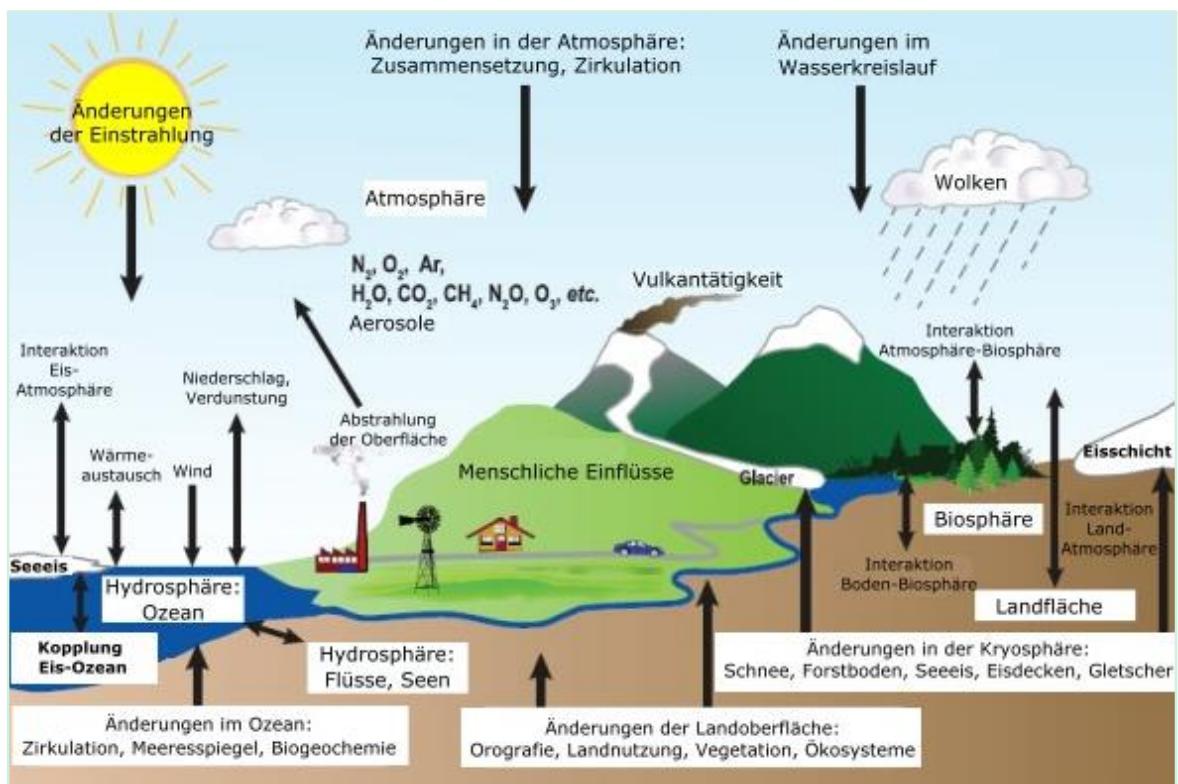


Figure 36 - Components of the Climate System and their Interactions
(Source: <http://www.oekosystem-erde.de/html/klima-02.html> called on 19.01.2019.)

¹⁴<https://www.umweltbundesamt.de/themen/klima-energie/klimafolgen-anpassung/folgen-des-klimawandels/klimafolgen-deutschland#strap-15396> called on 19.01.2019.

5.3. Climate Change in Bavaria

In Bavaria, too, the effects of climate change can already be clearly felt and measured. According to the Bavarian State Ministry of the Environment and Consumer Protection, the annual average temperature rose by more than 1.1°C between 1931 and 2010. In the Alpine region, temperatures have risen twice as fast as the global average over the past 100 years¹⁵.

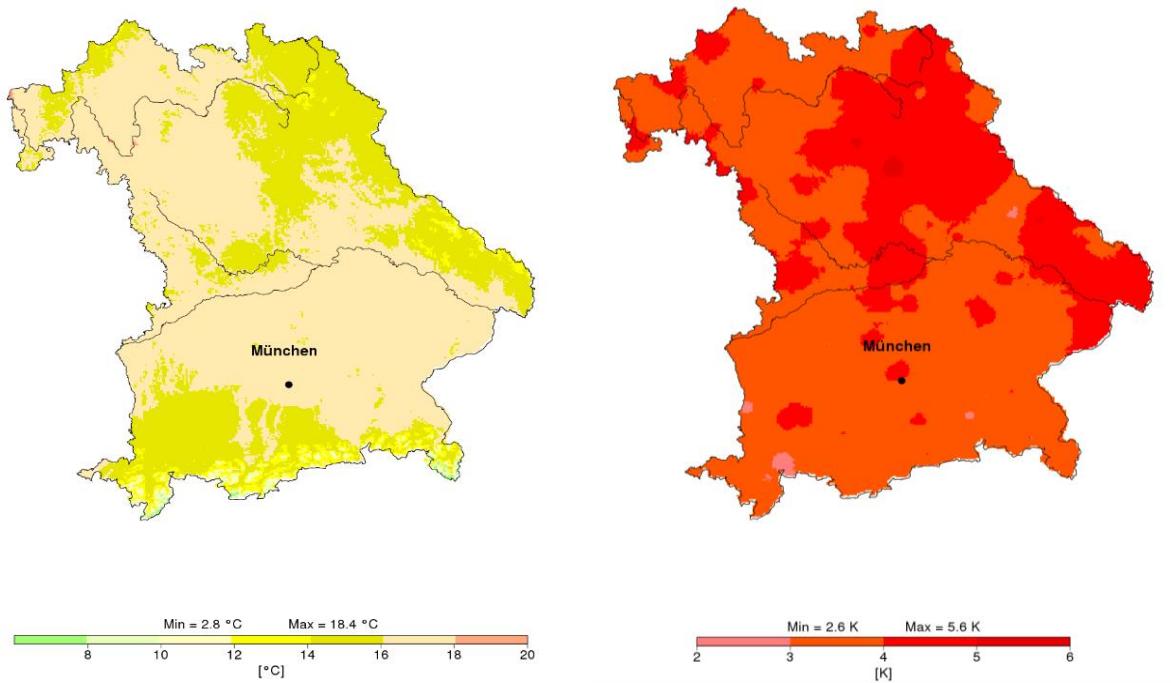


Figure 37 - Deviations of the Air Temperature in August 2018 (right picture) compared to the Mean Values (1961-1990, left picture)
(Source: www.dwd.de/DE/klimaumwelt/)

This trend has been increasing since the turn of the millennium. Figure 37 shows the deviations of the air temperature in August 2018 from the mean values of the years 1961 to 1990 for Bavaria. In summer 2018, for example, temperatures in the month of August in both the Upper Palatinate and parts of Franconia were five to six degrees Celsius above the long-term average. The frequency and severity of such extreme weather events has also increased rapidly in Bavaria in recent years.

In Bavaria, the consequences of climate change are already affecting all ecosystems of characteristic landscapes, such as high and low mountain ranges, forests, grasslands, wetlands and lakes. In addition, these developments also influence the lives of people in Bavaria's cities and municipalities. If the heat waves - as in the summer of 2018 - are accompanied by a pronounced drought, this will have serious consequences for Bavarian water, agriculture, and forestry. In August, for example, 70-90 % less precipitation fell in the Upper Palatinate and in Franconia than the average, which in some cases resulted in massive crop failures and a shortage of fodder in many places.

¹⁵ stmuv.bayern.de called on 05.01.2019

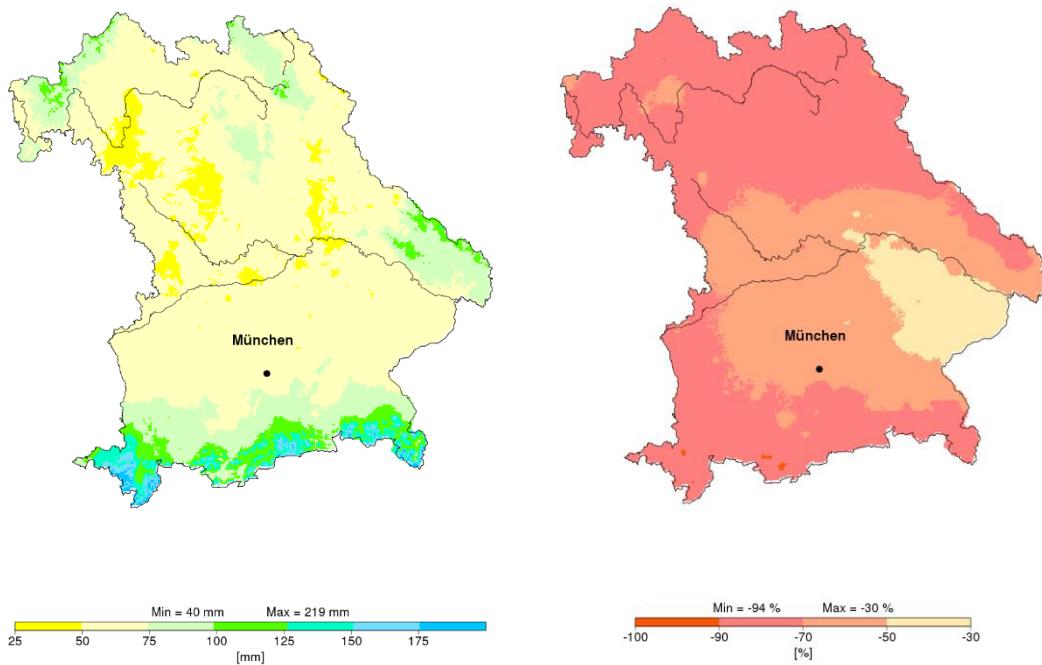


Figure 38 - Deviations of Precipitation in November 2018 (right picture) Compared to the Mean Value (1961-1990, left) in Bavaria (Source: www.dwd.de/DE/klimaumwelt/ called on 05.01.2019)

As climate change has an increasing impact on precipitation distribution and volumes, the risk of floods and droughts has increased. In summer, this means that low water levels can be expected in the Bavarian rivers, with effects on the biosphere, but also on water and energy management.

In conjunction with rising temperatures, a decrease in precipitation leads to a reduction in groundwater recharge. If it rains little in summer, the soil dries out and cannot absorb heavy rain in winter, so it drains off superficially, which may cause severe flooding (see Figure 39). This leads to increased soil erosion, while at the same time the groundwater reserves are only recharged to a limited extent.

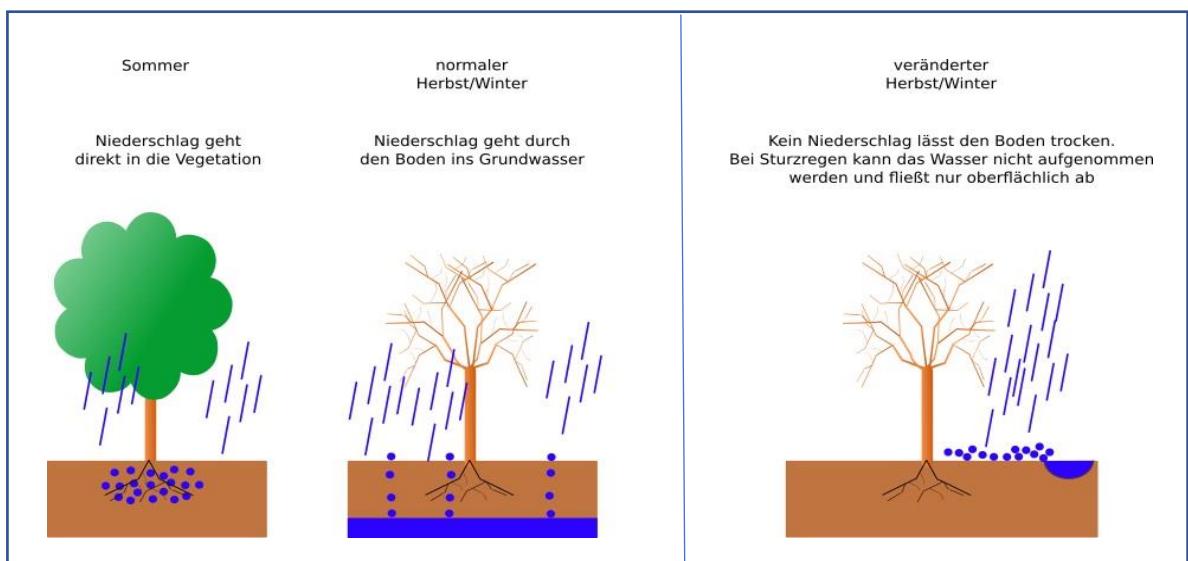


Figure 39 - Reduction of Groundwater Recharge by Hardened Soil (Credits: Lamparter)

This problem is exacerbated by the fact that, due to the higher temperatures, less precipitation in the form of snow falls and the thin layer of snow also disappears more quickly if it has snowed. As a result, less water is stored in the winter months, and important water reserves are lacking to compensate for the summer drought. Figure 40 shows the days with snow cover of at least 15 cm in the winter months between 1961 and 2002.

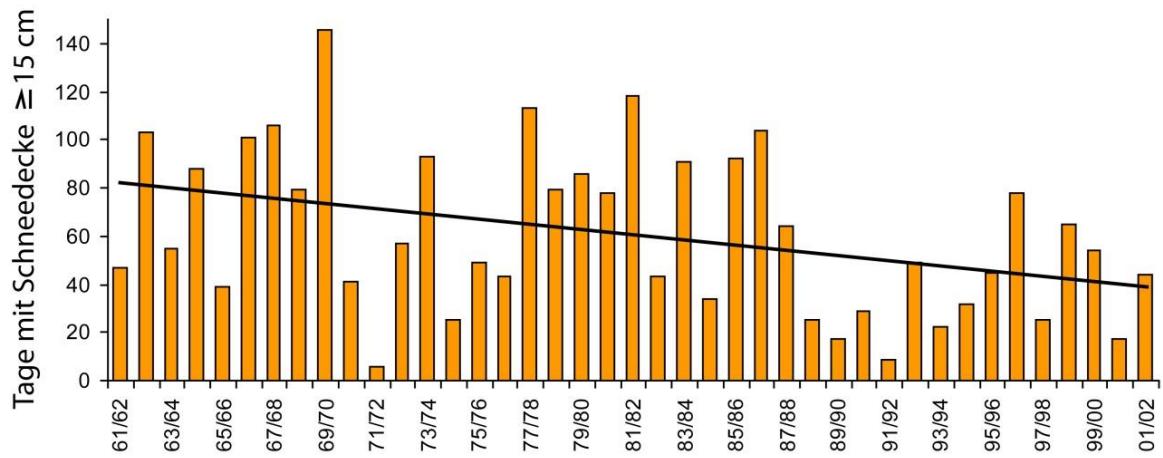


Figure 40 - Days with Snow Cover in Fichtelberg/Ofr. 685 m above sea level (Credits: Seifert)

The consequences of this water shortage can already be felt today: because groundwater has become scarce in northern Bavaria, water had to be pumped from Upper Bavaria to Lower Bavaria. But the situation will also change in Upper Bavaria, which is still rich in water. The five Alpine glaciers in Bavaria have increasingly lost volume since the beginning of industrialisation. Today, only a quarter of the originally covered area is glaciated. In addition to the intensification of high-water events, the main consequences are a threat to drinking water reservoirs, mountain forests and alpine flora and fauna.



Figure 41 - Dried-out Soil and Dried Grapes on Vine Branches in Bavaria (Credits: Alana Steinbauer)

The increase in summer drought thus leads to an increased demand for water, especially in agriculture, which cannot always be covered and thus leads to an impairment on fruit formation and consequently to a loss of yield. These effects are exacerbated by soil erosion and increasing extreme weather events such as heavy precipitation, hail and storms.

Excursus: Restoration of Moorlands in Bavaria

Moors are permanent wetlands with special biotopes. The constant excess of standing water, fed by precipitation (raised bogs) or by leaking mineral soil water (low bogs), seals the soil, keeps it low in oxygen and prevents complete decomposition of organic material. The carbon originally bound in the organic matter is thus retained in the soil. Over time, the undecomposed remains are deposited as peat and the moors grow in height by approx. 1 mm per year. Worldwide, peat-forming bogs store about a quarter of a billion tons of carbon dioxide. To put it in relation: More carbon is stored in bogs than in all forests globally.¹⁶ The drainage of moors for agricultural or other purposes leads to the release of large quantities of carbon dioxide, but also of other greenhouse gases such as nitrogen oxides, into the atmosphere. Therefore, the conservation of bogs and their rewetting is an important instrument for climate protection. Moreover, due to their storage and cleaning capacity, bogs are of particular importance for high and groundwater protection. Unfortunately, of the 1.5 million hectares of moorland originally native to Germany, today up to 75,000 hectares are lost. They were drained, the peat got extracted, or they were otherwise cultivated and used for agriculture and forestry. This is a fatal development since bogs obviously store large amounts of carbon and are therefore very important for climate protection. In addition, they slow down runoff during floods and are above all important biological repositories of biodiversity. In total, drained bogs contribute approximately 5.1 million tons of CO₂ equivalents to Bavaria's greenhouse gas emissions. This effect is to be significantly reduced by the new master plan.

To reactivate them as carbon sinks, 50 bogs in Bavaria will be renaturalised, i.e. submerged in water. Ten moorland areas have already been rehabilitated accordingly, and measures have been planned or begun in 30 other areas. Through the renaturation of moors, a positive climate effect of 25,000 tons of CO₂ per year is already achieved in Bavaria.¹⁷



Figure 42 - Moor Walsrode (Credits: Poul Krogsgard)

¹⁶ German Peat Society (Ed.) (2009): Was haben Moore mit dem Klima zu tun?

¹⁷ See further: www.stmuv.bayern.de/themen/naturschutz/biodiversitaet/artenschutz/arten_biotopschutz.htm.

Chapter 6

Effects of Climate Change

6.1. The Urgency of Action

At the World Climate Conference in Paris (COP21), a climate protection agreement was reached with the binding goal of limiting global warming to 2 degrees Celsius. In order to comply with this upper limit, greenhouse gas emissions must be reduced as quickly as possible, because the later the turnaround starts, the less time remains (see Figure 43).

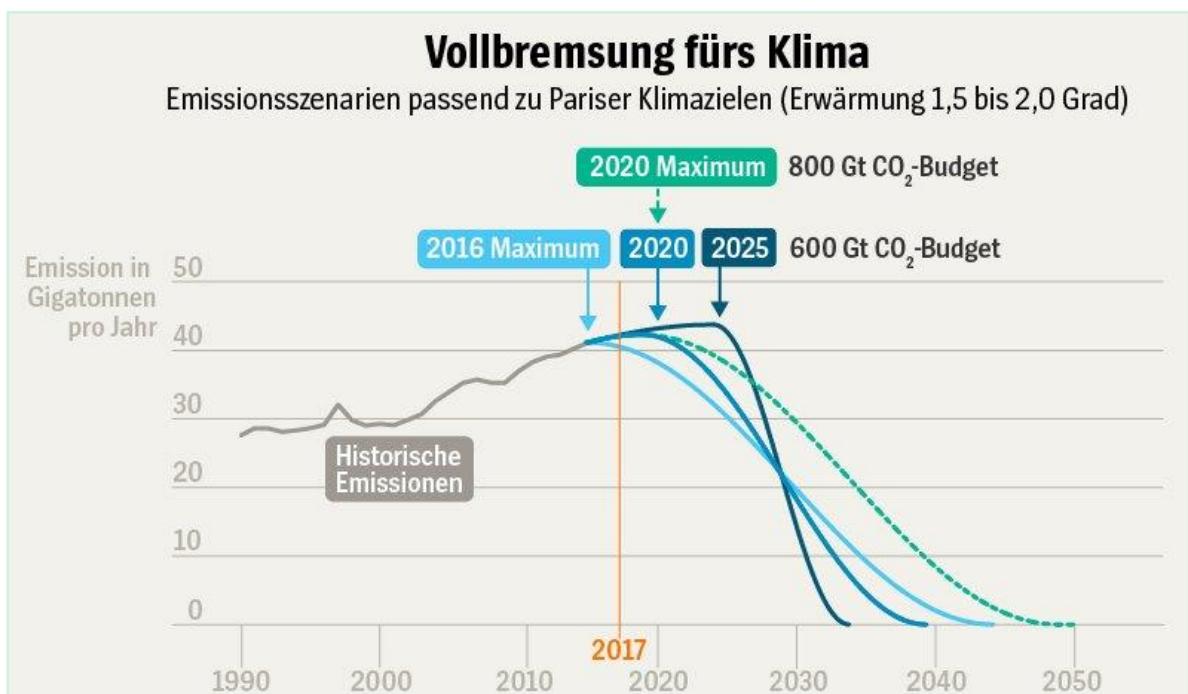


Figure 43 - Emission Scenarios for Achieving the Paris Climate Targets Klimaziele
(Source: Spiegel Online; The Global Carbon Project, Nature, Rahmstorf)

One certain fact, as the agreement states, is that the global community must become greenhouse gas neutral in the second half of the century if this goal is to be achieved. Despite the climate protection efforts of some countries, the global consumption of coal, natural gas and oil still increases. Economic interests are preventing the implementation of the climate agreement in many cases.

If we take these decisions seriously, we will have very little time to stabilize the Earth's climate and prevent the activation of tipping points, from which the climatic conditions on Earth would drift into chaos through feedback effects.

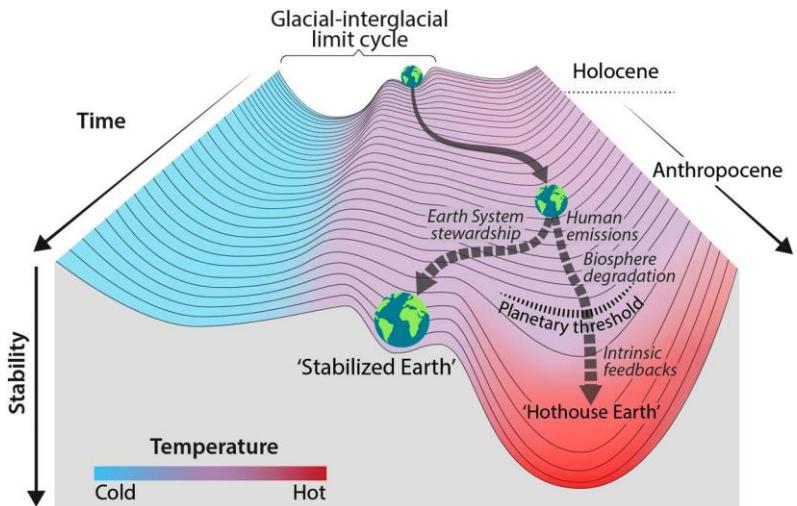


Figure 44 - Trajectories of the Earth System in the Anthropocene. Due to Human Impact, the Earth is close to a Dangerous Tipping Point (Credits: Steffen et al.).

Despite all this knowledge and warnings from science, only one in seven Germans considers climate change to be one of their three greatest concerns (see Figure 45). And even if one is aware of the problem, the step towards concrete action often seems enormous.

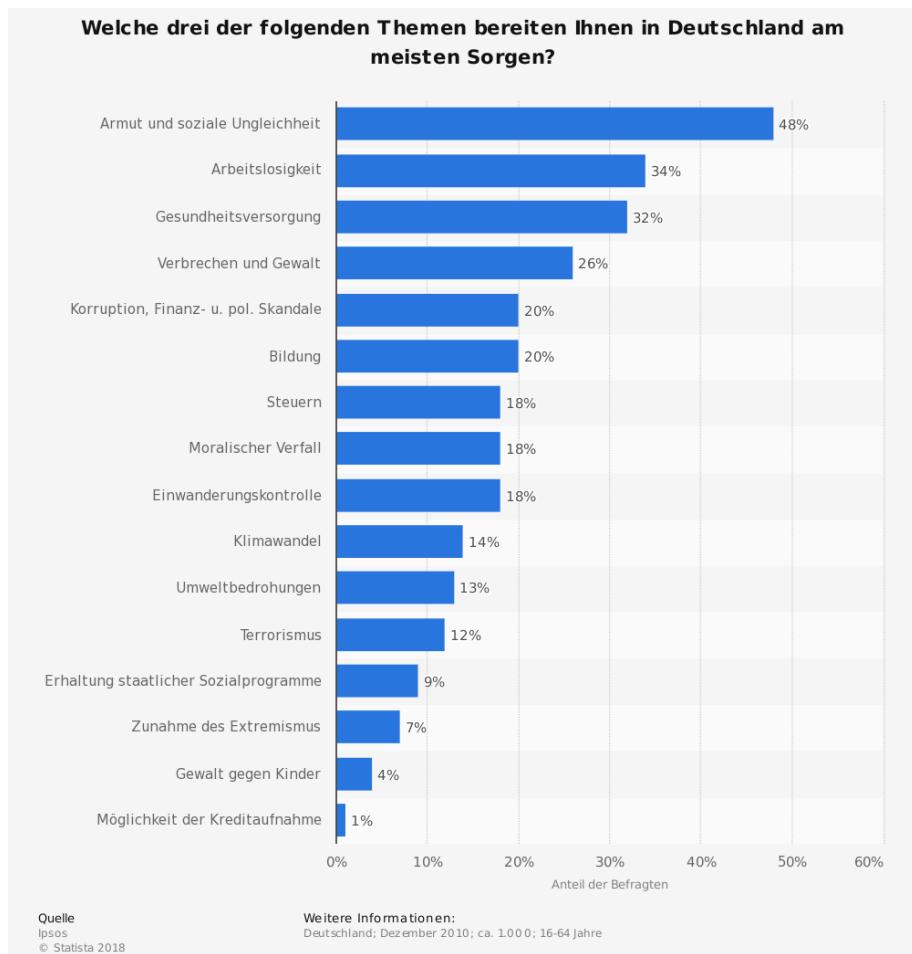


Figure 45 - Survey on German Concerns (Source: Statista 2018)

So how can teachers motivate pupils to actively combat climate change? Before we turn to concrete proposals, we would like to briefly ask: Why does knowledge about climate change does not play a role in everyday life for many? What ethical values do people possess? Which of these should they use for successful climate protection? And what psychological barriers prevent people from acting?

6.2. Why Should we Behave Ethically?

In his work "The Imperative of Responsibility", the natural philosopher Hans Jonas writes that the environmental problem is not a surface phenomenon that can only be mastered with modified rules and regulations. Rather, it represents a problem of depth at the foundations of the relationship between man and nature, even of contemporary culture as a whole, according to his diagnosis.

Jonas combines his considerations in his responsible ethical imperative: "Act so that the effects of your action are compatible with the permanence of genuine human life". Jonas sees man as a part of nature, which he simultaneously treats according to his norms and values.

"Values", which are based on cultural norms and conventional rules as regulatory ideas and groundbreaking ideals, are particularly suitable for application to the topic of climate change due to their positive connotation, orientation function, and motivational power. They allow options for action, goals and wishes to be weighted and weighed up. Values are conscious ideas about what is ultimately and absolutely good, valuable and important. The nature surrounding us is good, valuable and important to us. It is the condition of being able to live as a human being at all. Its protection represents an unconditional value. But how are such values formed? According to Dr. Hutflöz of the Munich School of Philosophy, the formation of values is a formative social and emotional orientation experience. Values cannot be conveyed but must be exemplified. The active engagement with climate protection and corresponding measures is an exemplary value-building project.

6.3. Psychological Barriers to Combating Climate Change

We are now addressing the psychological barriers that, according to psychological studies, prevent people from acting¹⁸:

1. Risks and Consequences Seem Far Away

It seems that for most people it is still unclear what climate change means for them. Climate change seems to be far away in time and space, "nobody expects disastrous catastrophes"¹⁹. People do not associate it with any acute risk. If this is the case, then the direct, regional and local impacts of climate change must be discussed in class. For those who are to be encouraged to act must feel, see, and be directly confronted with reality.

2. Underestimating the Own Influence

Some others hide behind the argument that if, for instance, the USA and China do not reduce their CO2 emissions and millions of cars accelerate climate change, any individual effort is pointless. The feeling that we cannot do anything on our own is dragging us out of our responsibilities - the problem is delegated to politicians. If, however, we invite school groups to actively pursue climate protection,

¹⁸ Swim et al. 2011, van der Linden 2014.

¹⁹ Quote from Dr. Gerhard Hartmuth, Environmental psychologist at the Helmholtz Centre for Environmental Research in Leipzig.

to get involved, and to orient themselves on role models such as the Swedish schoolgirl Greta Thunberg²⁰, for example, then a group dynamic and an identification with values can emerge that can overcome the individual feeling of being alone.

3. Habits

Deep-rooted behaviour is also an obstacle to environmental awareness. Well-rehearsed behavioural patterns are rarely questioned and are reeled off on autopilot day after day: be it a trip to school or work by car, a coffee to take away, meat for lunch or a shopping trip at the weekend. It is difficult, but possible, to change this. Everyday actions should be questioned: "How much CO₂ does it cost?".

6.4. Implementation at School

Considering the psychological hurdles described above, it is now possible to act at school, whether in class or within the framework of school projects. The following procedure is possible:

1. Understanding Climate Change

The students understand the scientific causes and correlations of climate change while exploring the interconnections between physics, chemistry, biology and geography. Climate change is an excellent topic for interdisciplinary work in the STEM field. This handbook and the experiments that accompany it are intended to be an aid here.

This handbook can also be used as a basis for successful work in a W seminar. Due to the wide range of possible seminar topics, many interests can be addressed.

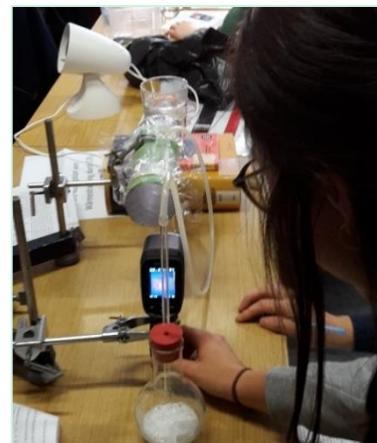


Figure 46 - A Student Measures Heat Absorption by CO₂ (see Activity 5). Physics Day 2018, LMU
(Credits: Scorz)

2. Research and Discuss Concrete Examples of the Regional Impacts

Activity 11

The environment ministries of the Länder offer information on local changes and effects of climate change in their portals (e.g. deviations of air temperature from the 30-year average, precipitation, scarcity of groundwater for agriculture, occurrence of storms and heat waves). In addition, the German Meteorological Service's climate atlas²¹ offers vivid interactive maps that allow the effects of climate change to be explored in the individual federal states in Germany (see also Figure 37 and Figure 38).

²⁰ Her brief speech at the World Climate Conference in Katowice is, by the way, worth seeing.

²¹ Climate atlas address: https://www.dwd.de/DE/klimaumwelt/klimaatlas/klimaatlas_node.html.

Witnesses to climate change, such as farmers, can be interviewed to learn directly from those affected how nature has changed in recent years. You can also, for example, give a task to search daily newspapers for regional events related with climate change.

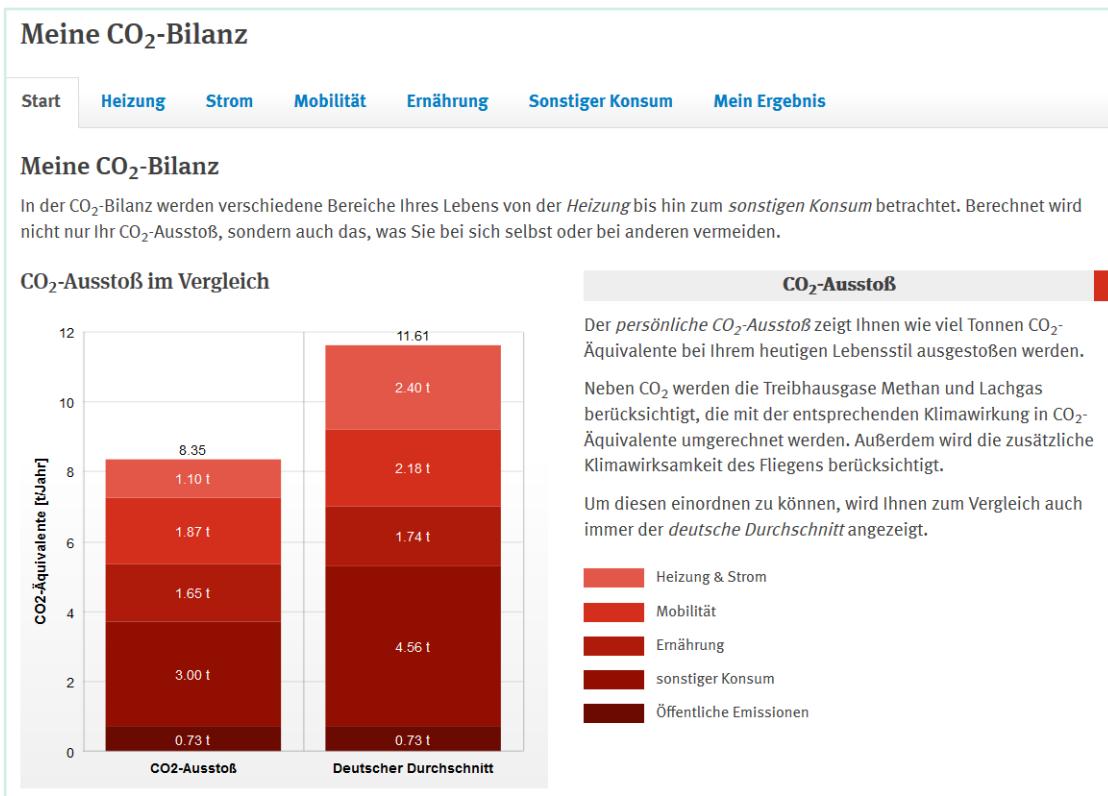


Figure 47 - CO₂ Calculator of the Federal Environment Agency. Comparison of individual CO₂ emissions with the German average broken down by sector (Source: www.uba.co2-rechner.de called on 28.01.2019).

3. Encourage the Urgency of Individual Action

In the next step, students can reflect on emissions in Germany in the light of the Paris Climate Agreement. If the increase in the earth's temperature is to be limited to two degrees, the *Öko-Institut* and its partners estimate²² that from 2015 to 2050 a maximum of 890 billion tons of CO₂ equivalent may be emitted into the atmosphere worldwide. For Germany, a per capita key would leave a total of 9.9 billion tons and, considering emissions to date from 2015 to 2017, approx. 217 million tons for 2018. However, according to the Federal Environment Agency, Germany emitted a total of 905 million tons of CO₂ in 2017, the day on which Germany used up its budget for 2018 was 28 March.

This approach of breaking down the global problem of climate change can now be continued down to the individual. According to data from the Federal Environment Agency, an average German citizen currently emits almost 12 tonnes of CO₂ equivalent. A value that must be reduced to approx. one tonne by 2050 if climate protection targets are to be achieved. Using a CO₂ calculator, the students can calculate their personal CO₂ balance, which can be used as the starting point for acting (see Figure 47). It is also interesting to consider the emissions in the individual areas (heating and electricity, mobility, nutrition, other consumption, public emissions) and the potential savings in each case.

²² <https://zukunft.erdgas.info/fileadmin/public/PDF/Presse/co2-tag-2018-faktenblatt.pdf> (called on 28.01.2019).

4. Concrete Action

In order to motivate the students to act, it is possible to report on individual students or groups of students who have achieved a lot through their commitment. Worth mentioning here are for example Felix Finkbeiner, who founded "Plant for the Planet", Xiuhtezcatl (pronounced "Schuh-tess-kat") Martinez, who together with other students is suing the US government for its climate policy or, of course, Greta Thunberg, who launched a worldwide protest wave for climate protection. Various authors also deal with the contradictions described above and explain how to deal with them constructively and present approaches to solutions and possibilities for action (e.g. "Wenn nicht jetzt, wann dann?: Handeln für eine Welt, in der wir leben wollen" by Harald Lesch and Klaus Kamphausen).).

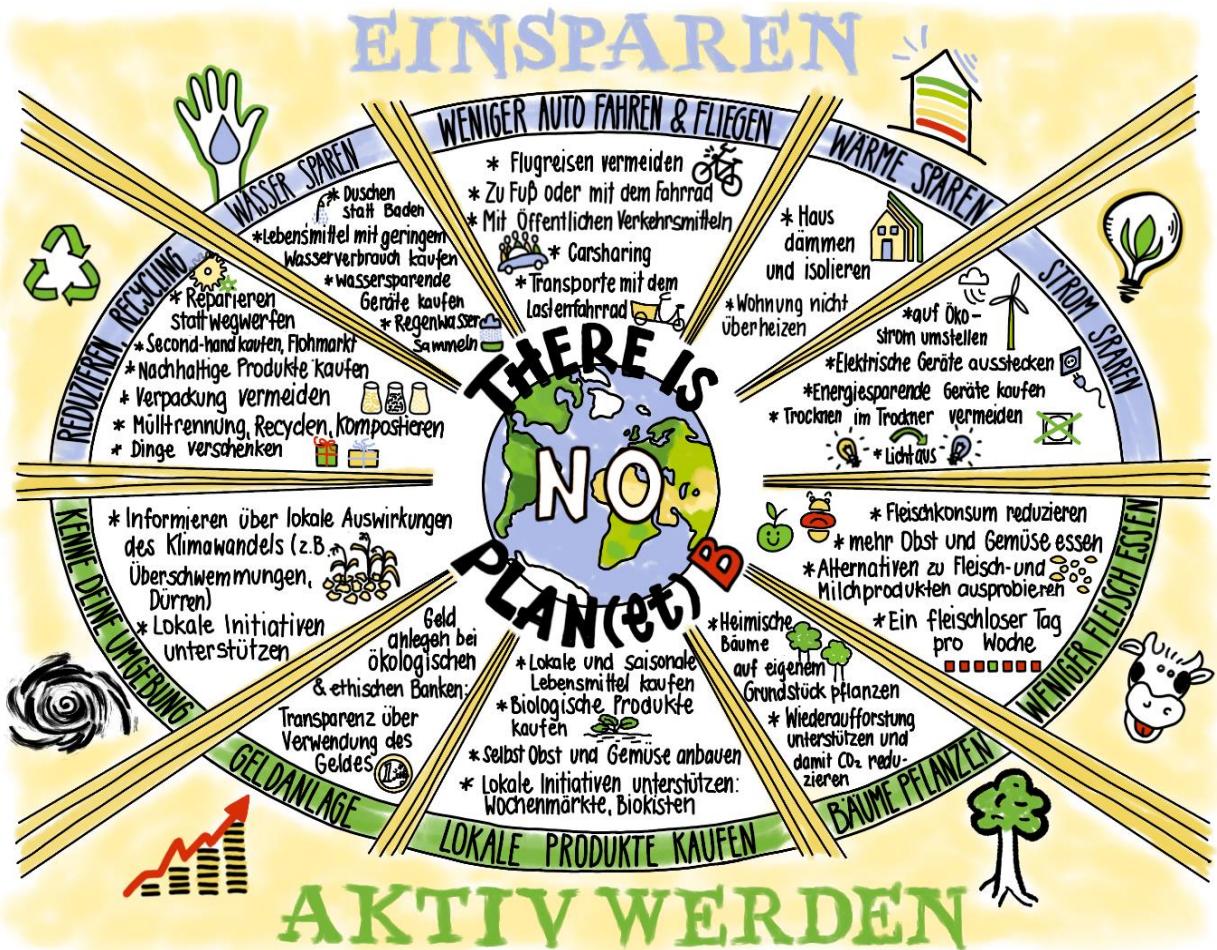


Figure 48 - Getting Active and Saving Energy (Credits: Theis-Bröhl)

Within the framework of the Climate Change Teacher Network, concrete teaching modules, materials and project ideas for various grades and subjects are to be developed and made available to schools as a whole so that they can be used flexibly in the course of a school year, especially in the form of interdisciplinary work (see "Call for Participation!"). Here the help of committed teachers is needed!

The following approaches would be possible:

1. In group work, possibilities can be researched and worked out as to how one can contribute to climate protection. For example, a graphic can be created, as shown in Figure 48.
2. The students join as a class to reflect together on their behaviour for a certain period of time in a "climate pact" and then adapt it. Here, the model character can be used to motivate: Can I prove that as an individual you can live in a climate-friendly way? Can I contribute to my

school, household, village or Germany becoming a role model in climate protection? In a joint debate on these issues, new ways of thinking and patterns of behaviour can gradually creep into everyday life, which in the long term will be understood as values.

3. The creation of info graphics, in which, for instance, the CO₂ emissions of a hamburger, a curry sausage and a plate of spaghetti with tomato sauce are compared, is a nice project. How much does my food cost in "CO₂ units"?
4. Regarding traffic and mobility, reference can be made to holidays and graduation trips. Because every year thousands of German high school graduates fly across the oceans - now gladly to New Zealand or Australia - with an output of 10.2 tons CO₂ per passenger and per flight. Alternatives to such long-haul trips can be discussed in the graduation classes: How would it be to explore Eastern Europe, or to make a voluntary social year nearby?

10 Climate-Saver-Tips for Everyone

The Ministry of Environment, Energy and Nature Conservation in Thuringia has compiled 10 climate saver tips in a climate saver savings book.²³ Here is a slightly modified version adapted for pupils:

1. Use your muscle power and stay fit on foot or by bike. Use the public transport and leave the car behind. If you can do without air travel, you can also save several tons of CO₂ per year!
2. At home, switch to an electricity provider that offers 100% green electricity. This will not only significantly improve your CO₂ balance; it will also promote the energy revolution!
3. Become a part-time vegetarian. That is healthy and consumes much less resources than meat-rich food. According to a British study, frequent meat eaters cause 2.5 times more CO₂ than vegans. Emissions from agriculture are the second largest cause of greenhouse gases in Germany after the energy industry and the mobility sector (84.5%). This is mainly due to the methane emissions of cows for meat and milk production and the use of fertilizers.
4. The consumption of regional, seasonal and organic food improves your balance and is both soil and environment friendly as well as animal friendly. And by the way, fewer trucks would be driving on Europe's motorways.
5. Heat systematically. A rule of thumb says: If the temperature is only reduced by 1 °C, this already saves around 6 % energy. However, the room temperature should not be reduced to less than 15 to 16 °C at night.
6. Buy things that you will enjoy for a long time. Use Second-Hand shops and used-good-exchanges on the internet. Repair, sell or give away things instead of throwing them away.
7. Check if you and your family really need a car. If you can't avoid it, check if size, consumption and equipment are appropriate for the use.
8. Let your invested money work only for things that are good for man and nature and change, if necessary, the bank. There are also financial investments and current accounts with ecological-ethical financial institutions that transparently show what their money is used for.
9. Living better: You will achieve the best CO₂ balance in well-insulated, small apartments with modern heating and lighting technologies. If your parents are homeowners, it's worth replacing the heating pump. The earlier they bring it up to date, the less energy is lost.
10. Wash correctly! By avoiding prewashing and drying and washing at 40 °C instead of 60 °C (2-3 loads per week) you can save up to 250 kg CO₂ per year and lots of electricity costs!

²³ Download at: www.thueringen.de/de/de/publikationen/pic/pubdownload1726.pdf.

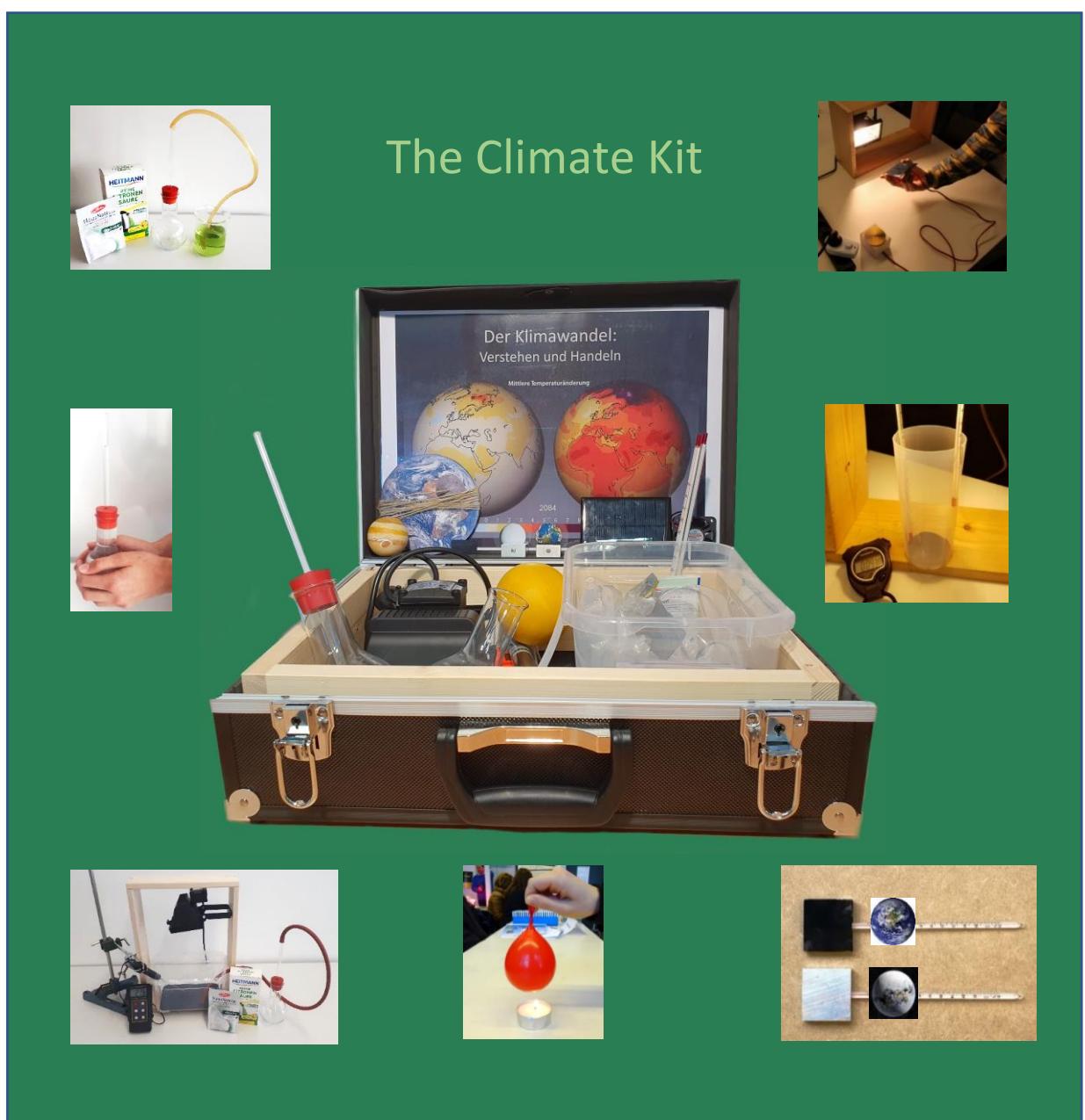
6.5. Activities and experiments inside the Climate Kit

The activities presented in the following can be carried out with simple means as student experiments. The costs of all materials, including suitcase for storage, are approx. 100 Euros.

The experiments and work orders ought to be processed by pupils from the 8th grade upwards.

The form and scope of these activities will be left to the teachers until further notice. Teaching units specifically tailored to certain grades and subjects are to be developed and made available within the framework of the Climate Change Teacher Network (see "Call for Participation!").

As a method, most activities can be carried out with station learning, where the laminated work orders can be laid out at the stations.



Activity 1

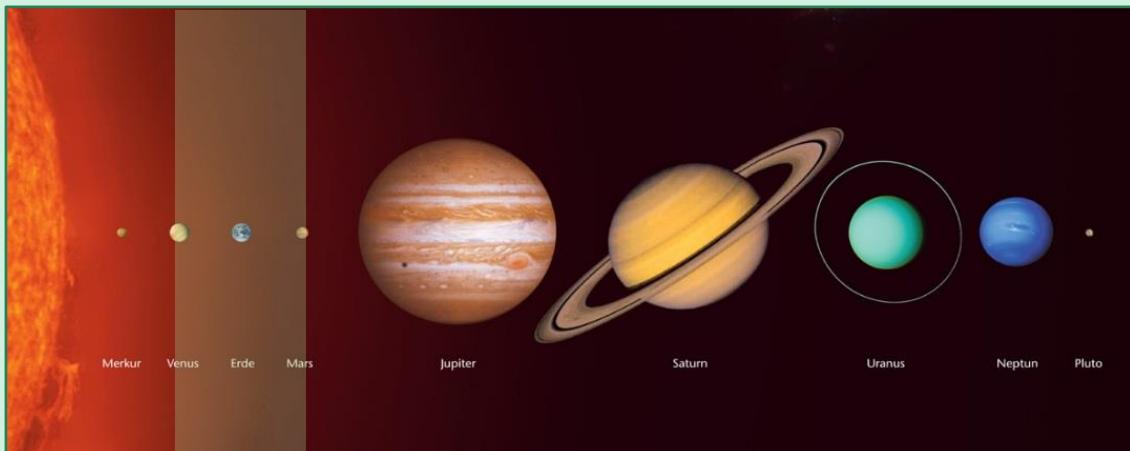
The Earth in the Solar System: How special is our Earth?

Aim:

With this activity the distances and proportions in the solar system are illustrated by different models.

Background:

Our solar system consists of one star (the Sun), eight planets, dwarf planets, many moons (orbiting the planets), asteroids and comets. However, there are only three planets in the life zone, where water can exist in liquid form: Venus, Earth and Mars.



The Solar System and its Life Zone (Credits: NASA/Scorza)

Material:

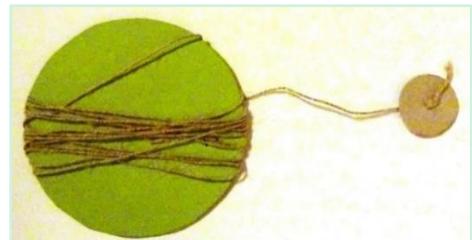
- ✓ 4 Cardboard Models
- ✓ Wooden Planetary Models
- ✓ Tape Measure

Conduct:

1. Earth and Moon

The first cardboard disc (1) has a diameter of 10 cm and represents in the first model the Earth. It is connected with a disk representing the Moon. The proportions are true to scale.

- ! Estimate, before you unwind the string: How far away is the Moon from the Earth in this model?
- ! Unwind the string and check your estimate.



Cardboard Model to Demonstrate the Distance Earth-Moon (Credits: Scorza)

It took the Apollo astronauts three and a half days and three nights to cover this distance of almost 400,000 km!

2. Moon Orbit and the Sun

In order to represent larger distances, we reduce the scale in the second model so that the distance Earth-Moon shrinks to 10 cm. In the centre of the red cardboard disk (2) we imagine the Earth; the edge corresponds to the Moon's orbit.

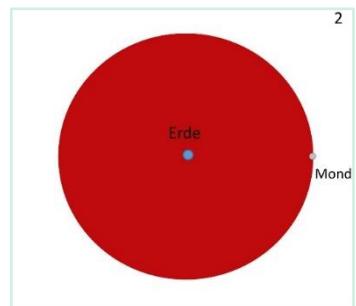
Estimate the size of the sun at this scale and compare it with the yellow cardboard disk (3), which corresponds to the size of the sun at this scale!

In this model the earth would have a distance of 19 metres to the sun!

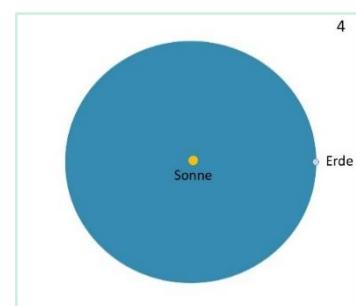
3. The Sun and the Planets

We further shrink the scale and this time set the distance between sun and earth at 10 cm. This distance is called the Astronomical Unit (AU) and corresponds to about 150 million km. The radius of the blue disk corresponds to one AU.

Place the blue disk on the ground and determine the model distances for the other planets (table). Place the planetary models and the life zone at the correct distance along a line on the ground. Note: The sizes of the planets and the sun are no longer true to scale in this model!



Moon Orbit – Size Comparison (Credits: Scorza)



Earth Orbit – Size Comparison (Credits: Scorza)

Planet	Distance from Sun (in AU)	Distance in Model (in cm)
Mercury	0,4	
Venus	0,7	
Earth	1,0	10
Mars	1,5	
Jupiter	5,2	
Saturn	9,5	
Uranus	19,2	
Neptune	30,1	

Activity 2

Radiation Equilibrium and Albedo of the Earth's Surface

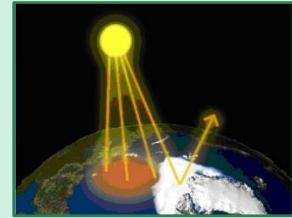
Aim:

With this experiment we illustrate the influence of the albedo on the Earth's temperature.

Background:

White surfaces such as ice and snow reflect the incident light of the sun much stronger than, for example, water or the ground. The Albedo α provides a measure of this reflectivity. For fresh snow, for example, $\alpha = 0,85$, i.e. 85 % of the incident light is reflected.

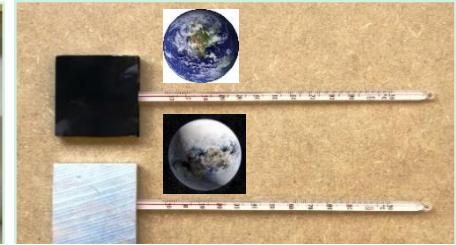
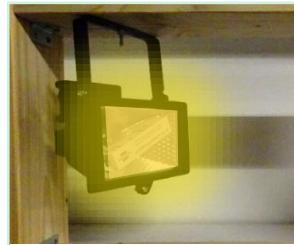
The higher the temperature of a body is, the more energy it emits in the form of heat radiation to its environment. If radiant energy is supplied to an initially cool body, it warms up and radiates itself ever more energy, reaching an equilibrium temperature at some point. At this temperature it absorbs the same amount of energy per second as it radiates itself - it is in *radiation equilibrium*.



The Earth's Albedo (NASA)

Material:

- ✓ Spotlight
- ✓ 2 Aluminium Blocks (sooty and white)
- ✓ 2 Thermometers
- ✓ Stopwatch



(Credits: Scorza, Fischer)

Conduct:

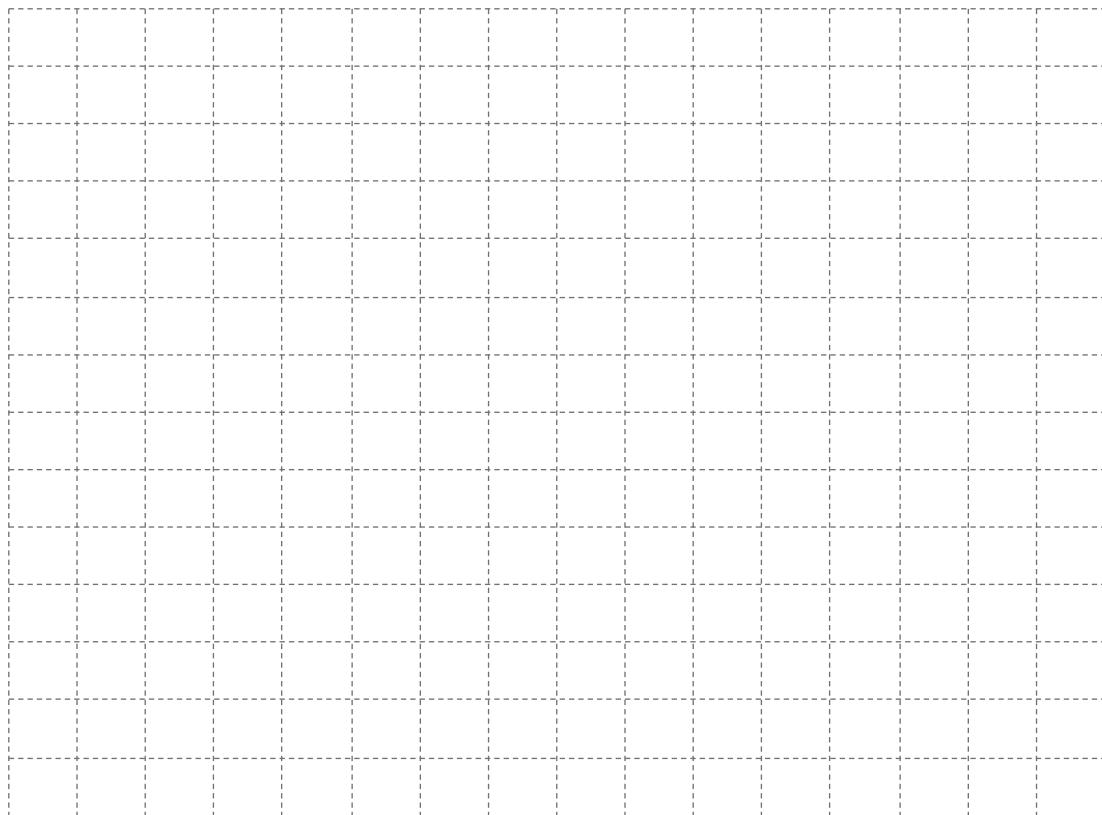
In each of the two aluminium blocks a thermometer is inserted. One represents an earth with neither ice nor snow surfaces, the other the almost completely icy "snowball earth". Both test bodies are placed under the spotlight in a way that they are irradiated with the same intensity.

! Measure the temperature of the two blocks every 30 seconds and note the results in the table.

Time in s	0	30	60	90	120	150	180	210	240	270	300
Temperature Black in °C											
Temperature White in °C											

- Plot the results graphically in a diagram (see next page).
- Discuss your result and explain why the temperature of the aluminium blocks does not continue to rise. Use the terms *albedo*, *equilibrium temperature* and *radiation equilibrium*.
- What influence does the melting of ice on earth have on the albedo?

Diagram for Activity 2



Activity 3

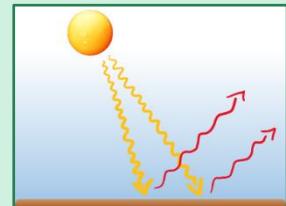
Heating of Different Atmospheric Layers: What Heats the Air?

Aim:

With this experiment we show that the direct radiation of the sun warms the air only slightly, in contrast to the heat radiation emitted from the ground.

Background:

The relatively short-wave solar radiation reaches the ground almost unhindered, as it is scarcely absorbed by the atmosphere. It is absorbed by the soil and thus contributes to the warming of the Earth's surface. The ground radiates this energy back to space as long-wave heat radiation (infrared radiation, IR). On the way, part of this heat radiation is absorbed by the greenhouse gases in the atmosphere.



Short-Wave Solar Radiation
and Long-Wave Heat Radiation
(Credits: Scorza, Strähle)

Material:

- ✓ Spotlight
- ✓ Cup with Black Cardboard
- ✓ 2 Thermometers
- ✓ 2 Clothes Pegs
- ✓ Stopwatch



(Credits: Nielbock)

Conduct:

→ Attach one thermometer just above the bottom of the cup, the second at half height.

→ Place the cup as vertically as possible under the spotlight.

! Start the measurement and note the values in the table below.

Time in s	0	30	60	90	120	150	180	210	240	270	300
Temperature Bottom in °C											
Temperature Middle in °C											

→ Briefly summarize your observations and explain them afterwards.

Activity 4

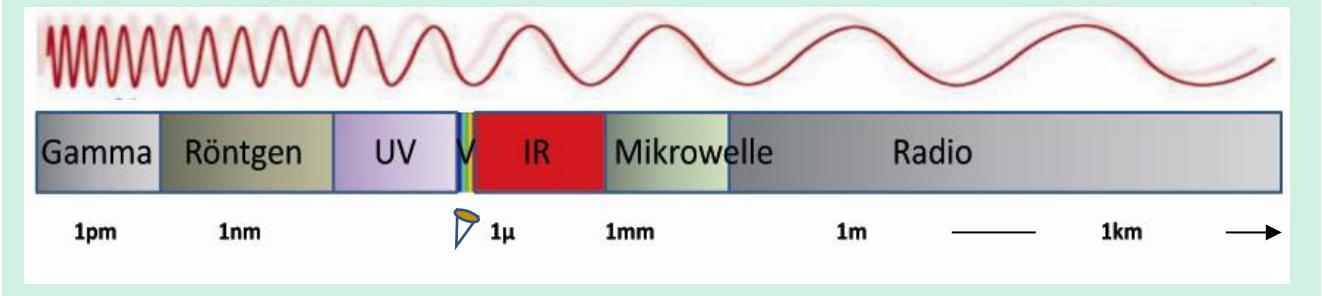
Detecting Invisible Infrared Radiation

Aim:

Investigating the properties of infrared radiation.

Background:

The Solar radiation consists of electromagnetic waves divided into gamma, X-ray, ultraviolet, visible, heat/infrared and radio radiation. Our eyes can only perceive a tiny part of this spectrum! However, our skin feels invisible infrared radiation as heat. An important parameter of waves is the wavelength λ (the distance between two wave crests/troughs). In the figure λ grows from left to right.



Material:

- ✓ Small Infrared Camera (Available for lending at the Faculty of Physics)
- ✓ Black Plastic Bag
- ✓ Water Container
- ✓ Air Balloons



Conduct:

Examine different objects - including your body - with a thermal camera:

- Observe people without and with glasses. What can be determined and why?
- Rub the flat hands against each other for 10 seconds. Then press them firmly on a table for five seconds. Use the infrared camera to look at the position of contact directly after removing your hands from the table. What can be determined and why? Where does the heat escape?
- Take a cooled beverage bottle and press it against your cheek for ten seconds. Then look at your face with the infrared camera.
- Hold a black garbage bag in front of a classmate's face. Repeat the experiment with an inflated balloon. What happens?

Activity 5

Moritz Strähle

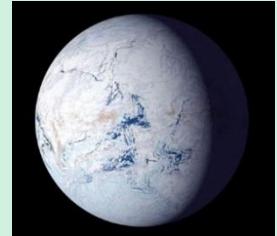
Absorption of Heat Radiation by CO₂ - The Greenhouse Effect

Aim:

This experiment shows how the temperature of air rises with an increase in the concentration of CO₂.

Background:

Objects radiate energy as heat radiation. The following applies: the warmer the body, the more energy it radiates per second. If, for instance, a park bench is irradiated by the sun, it heats up. The more it warms up, the more energy it radiates back to the environment. At the point where the absorbed and the emitted energy are the same, the bench does not heat up any further - it has reached its equilibrium temperature and is in radiation equilibrium.



The Earth as a planet is also in radiation equilibrium. It radiates as much energy as it receives from the sun. If the earth had no atmosphere at all, it would have an average temperature of only -18°C - in this state it would be a white ice ball! However, greenhouse gases in the atmosphere absorb the heat radiation emitted by the ground and thus ensure an average temperature of 15 °C on our planet. This is the so-called natural greenhouse effect, which we will now explore.

Materials:

- ✓ Spotlights
- ✓ Plastic Tub with Black Cardboard
- ✓ Cling Film
- ✓ Citric Acid (Powder), Sodium (Powder), and Water
- ✓ Flask with Rubber Stopper and Tube
- ✓ Thermometer (preferably digital)
- ✓ Infrared Thermometer



Model Experiment on the Greenhouse Effect
(Credits: Strähle)

Conduct:

- Preparation: The black cardboard lies in the plastic tub which is covered with cling film in such a way that the contents are protected from breezes, but not completely airtight. The thermometer is positioned so that the temperature can be measured approx. 1 cm above the ground. The spotlight irradiates the tub vertically from above.
 - Mix 1 tablespoon each of Citric Acid and Sodium (still without water) in the flask, insert the tube into the tub.
 - Measure the temperature several times over a period of a few minutes and check whether an equilibrium temperature has already been reached.
- ! Measure the temperature of the cardboard through the air-filled tub with the infrared thermometer. Write down the measured value.
- ! Explain briefly why the temperature remains relatively constant despite constant energy supply.

- Carefully add some water to the acid-sodium mixture and close the piston immediately with the rubber stopper. The resulting, relatively heavy CO_2 is led through the tube into the tub and sinks to the bottom.
- ! Repeat the measurement with the infrared thermometer. Write down the measured value.
- Remove the tube from the tub.
- ! Measure the temperature in the tub again after a few minutes. Briefly note your observations.

Evaluation:

1. Measurement with the Infrared Thermometer

- The experiment represents a model by which certain processes in nature can be represented. Specify which parts of the construction (cardboard, air, O_2 , measurement location of the infrared thermometer) correspond to which objects in reality.
- What would happen if you added more CO_2 ? What parallel do you see between this experiment, the natural greenhouse effect and the man-made greenhouse effect?

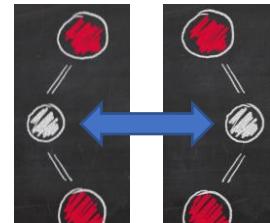
2. Measurement with the Thermometer in the Tub

- To explain the observations, put the cut-out sentences in the correct order.

Excursus Greenhouse Gases: How do Molecules do this?

CO_2 , methane and water vapour have a special property: they can absorb (absorb) heat radiation and are thus triggered to oscillate. The absorbed radiation energy is then transferred to oscillation energy and finally transferred to particles in the environment as kinetic energy - the gas heats up!

The Earth's atmosphere consists of 78% nitrogen, 21% oxygen, 0.93% argon and trace gases, including CO_2 (currently 0.04%), methane (CH_4), ozone (O_3), etc. Nitrogen and oxygen are not put into oscillation by heat radiation. Only CO_2 , CH_4 and water vapour are responsible for the greenhouse effect.



Bending Oscillation of a CO_2 Molecule (Credits: B. Mayer)

Your Thoughts and Notes:

Activity 6

Where the Heat is Stored: Oceans as Climate Buffers

Aim:

This experiment demonstrates that a certain volume of water, compared to the same volume of air, needs much more energy to heat up its temperature by a certain amount.

Background:

Water is a very effective heat accumulator: A certain mass of water can absorb significantly more energy per Kelvin temperature increase than, for example, the same mass of air.

One kilogram of water heats up by 1 K with an energy supply of $4,182\text{ kJ}$. Water therefore has a heat capacity of $4,182 \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$. Air and dry earth, on the other hand, have a heat capacity of approx. $1 \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$. Just 1 kJ is enough to heat a kilogram of these substances by 1 K .



Our Blue Earth (NASA)

The greenhouse effect caused by humans provides the Earth's surface with additional energy. Fortunately, $2/3$ of the Earth's surface is covered with water. Due to its large heat capacity, this water can absorb a great deal of the energy without significantly increasing its temperature. The global warming is thus buffered considerably!

Material:

- ✓ Balloon (filled with air)
- ✓ Balloon (filled with water)
- ✓ Candle and Matchstick



Water-filled balloon over a candle
(Credits: Scorza)

Conduct:

- Light the candle. Bring the air-filled balloon close over the candle and hold your ears shut :-)
- Now hold the balloon filled with water close over the candle and wait again some time.

Evaluation:

- Briefly explain why the air-filled balloon bursts.
- Explain the result of the second test and why the temperature of the balloon hardly changes.
- The greenhouse effect caused by humans provides the atmosphere with additional energy. Explain why the effects would be even more drastic than they are today without our oceans.

Activity 7

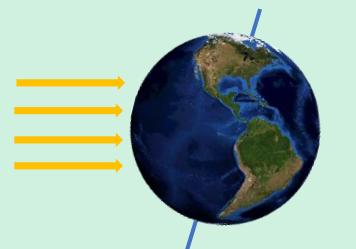
Solar Radiation and the Earth's Climate Zones

Aim:

This experiment demonstrates that the angle of incidence of solar radiation defines the climate zones.

Background:

The Sun causes the different climate zones on Earth. With increasing latitude, the Earth's surface is more inclined to the sun's rays. The intensity is distributed over a larger area of the Earth's surface. The seasons are also a consequence of the inclination of 23.5° of the Earth's axis relative to the orbital plane of the Earth around the Sun, the so-called ecliptic.



Material:

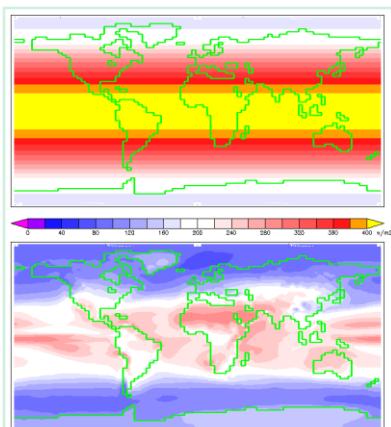
- ✓ Spotlight
- ✓ Solar Cell with Ventilator
- ✓ Earth Globe



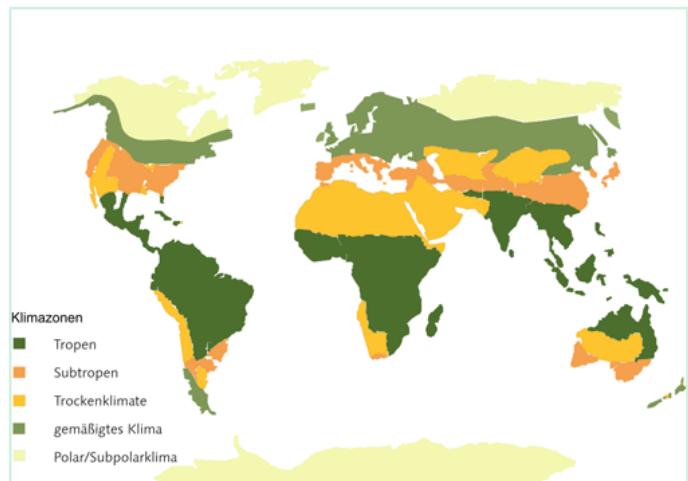
(Credits: Marco Türk)

Conduct:

- Take the solar cell with the ventilator. The rotation speed indicates the intensity of the incident light. The radiator represents the sun.
 - Switch the spotlight on and hold the light-sensitive surface of the solar cell at a distance of 5 cm in its direction. The motor should rotate. Now change the angle of inclination of the solar cell following the curvature of an earth globe and observe the rotation speed.
- ! Note your observation. Explain the relation of this experiment to the seasons and the climate zones of the Earth.



Annual Mean Value of Solar Irradiance outside the Earth's Atmosphere (above) and on the Earth's Ground (below) in W/m^2 (Credits: William M. Conolley)



Climate Zones of the Earth (Quelle: ecobine.de)

Activity 8

Rise of the Sea Level

Aim:

Two processes are responsible for the rise in sea level in particular. The following experiments are intended to reproduce these processes.

Background:

Temperature in the Particle Model: The temperature of a body is a measure of the average kinetic energy of its particles.

Density Anomaly of Water: Water has its greatest density at 4 °C. When liquid water freezes, it increases significantly in volume while its density decreases.

Archimedes' Principle: The buoyancy force on a floating body is just as great as the weight force of the liquid displaced by the body.

Equilibrium of Forces: A body on which two forces act is in equilibrium of forces if the forces acting are of the same amount and point in opposite directions.

Materials:

- ✓ Flask with Rubber Stopper and Glass Tube
- ✓ Water Based Marker
- ✓ Beaker Glass
- ✓ Ice Cubes



(Credits: Strähle)

Conduct:

Experiment 1:

- Fill the beaker with cold water and add an ice cube. Mark the water level with the marker.

Experiment 2:

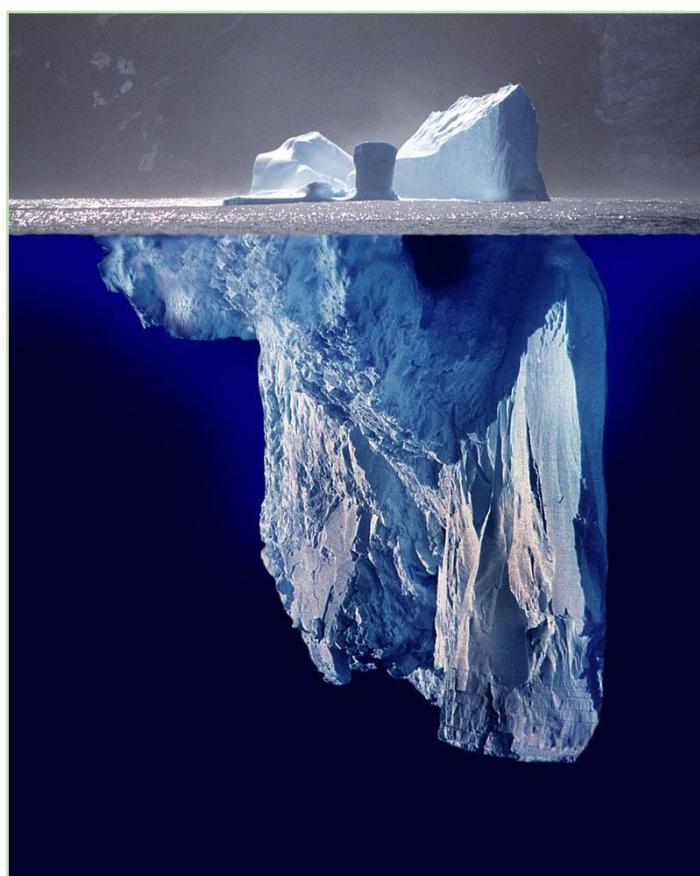
- Fill the flask with water and seal it with a rubber stopper and glass tube so that the water in the tube is halfway up and no air bubbles form (some attempts may be necessary).
- Mark the level and heat the water in the flask with your hands.

- ! Write down your observations and then give a brief explanation using the particle model.
- ! Evaluate experiment 1, if the ice cube is largely melted. Note your observation and then describe in which of the two images on the next page the melting of ice does **not** lead to a rise in sea level.
- ! Addendum: Explain your observation from experiment 1 with the hints to the Archimedean principle and the equilibrium of forces.

Pictures for Activity 8



Great Aletsch Glacier (Credits: Dirk Beyer)



Iceberg Photomontage (Credits: Uwe Kils)

Activity 9

Acidification of Oceans

Markus Nielbock, Moritz Strähle

Aim:

The following experiment demonstrates that the solution of CO₂ in water changes the pH value.

Background:

If the concentration of CO₂, in the Earth's atmosphere increases, for example due to the combustion of fossil fuels, it is increasingly bound in seawater. This leads to an acidification of the sea water as carbonic acid results from the reaction of CO₂ and H₂O. Another product of this reaction further reacts with carbonate ions which are of great importance for the formation of calcium carbonate (CaCO₃), a building material for limestone skeletons and shells (e.g. for mussels, corals, snails, and sea urchins).

Material:

- ✓ Distilled or Demineralised Water
- ✓ Heat-Resistant Beaker
- ✓ Universal Indicator with pH Value Plate
- ✓ Citric Acid (Powder), Sodium (Powder) and Water
- ✓ Flask with Rubber Stopper and Tube



(Credits: Strähle)

Conduct:

- Add water to the beaker and then a few drops of the indicator until the solution turns green.
- ! Compare the colour of the water with the pH table of the indicator. Determine the pH value.
- Mix one tablespoon each of citric acid and sodium, carefully add some water and lead the resulting CO₂ into the water.
- ! Compare again with the pH table of the indicator and describe the test result in one sentence.
- ! Read the background article and answer the following questions in a coherent text.
 - To what extent do the oceans mitigate man-made climate change?
 - What consequences does this have for the oceans and marine animals?

Material for Activity 9

Sea too Acidic for Blue Mussels

| November 29, 2017

Source of text and images: www.solarify.eu/2017/11/29/260-meer-zu-sauer-fuer-miesmuscheln (called on 17.10.2018, translated)

"Gigantic Chemical Experiment in the Oceans"

"Creepy"- that is what FAZ author Ulf von Rauchhaupt calls the impact of modern civilization's CO₂ emissions: "A gigantic chemistry experiment in the oceans". Slowly it becomes clear what the result will be. The author describes a German research association for ocean acidification called BIOACID (Biological Impacts of Ocean Acidification) that has just come to an end after eight years of intensive scientific work. From 2009 to 2017, BIOACID investigated how marine communities react to ocean acidification and what consequences this has for the food web and the material and energy turnover in the ocean, as well as for human economy and society.

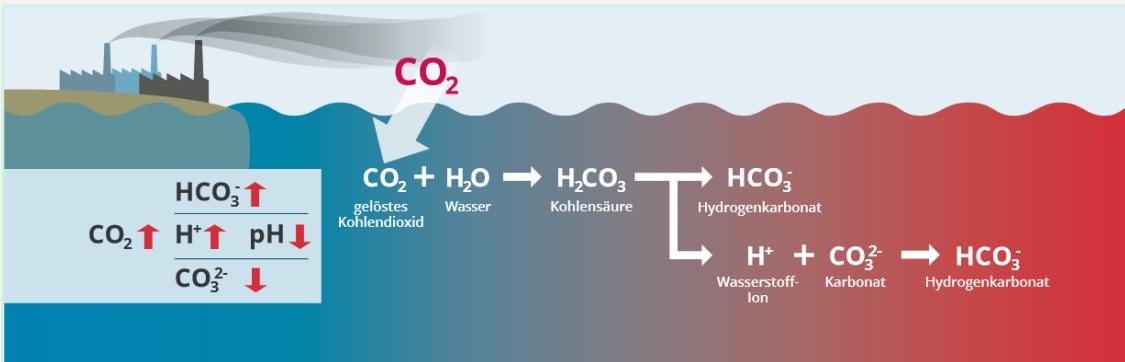


The excess carbon dioxide that humankind pumps into the atmosphere is partly transmitted to the oceans, where it is converted into carbonic acid. Despite the increasingly intense climate debate, "the other CO₂ problem" had long remained unexplored. "Even the reports of the Intergovernmental Panel on Climate Change (IPCC) have only mentioned the topic starting in 2007."



Today, "ocean acidification is the fastest growing field of geoscientific research", according to von Rauchhaupt. Acidification of the world's oceans is the downside of an effect without which global warming would already be even more serious. Since the oceans are huge carbon reservoirs and contain 50 times more carbon than the atmosphere - where CO₂ concentrations have climbed to 400 ppm²⁴ in the meantime: 400 of one million air molecules are now carbon dioxide. Before the onset of industrialization, the level was 280ppm, and without the oceans it would already be 455 ppm today.

²⁴ Remark: ppm stands for "parts per million" so the amount of CO₂ molecules per million molecules of dry air



Two chemical reactions are particularly important for the process of ocean acidification: If carbon dioxide dissolves in seawater, carbonic acid is formed. This releases hydrogen ions and hydrogen carbonate. Some of the hydrogen ions react with further carbonate and hydrogen carbonate is formed. Lime-forming organisms such as mussels, corals or certain plankton species separate carbonate in order to build up their shells and skeletons. The more carbonate is lost through the chemical reactions in seawater, the more complicated the lime formation becomes – Graphic © Christoph Kersten / Rita Erven, GEOMAR

After all, the oceans have swallowed 30 percent of the anthropogenic CO₂ so far; however, von Rauchhaupt writes, this does not transform the seawater into an acidic effervescence to the same extent: "With an original pH of 8.2, the oceans are naturally slightly alkaline. They owe this above all to the salts of carbon dioxide dissolved in seawater. They originate mainly from the weathering of rocks on land and are constantly washed into the oceans together with calcium ions. CO₂, on the other hand, forms carbonic acid in water, which immediately releases protons. These would immediately acidify the sea if they were not largely intercepted by the carbonate ions. Ocean water, as chemists call it, is a buffer solution." Ocean acidification does not mean that the sea water transforms into an acid, but that it becomes too little alkaline to be healthy for the sea creatures..



Activity 10

Release of CO₂

Aim:

This experiment demonstrates the influence of temperature on the pH value of an acid solution.



Heating of an Acidic Carbon Dioxide Solution (Credits: Nielbock)

Material:

- ✓ Acid Solution from Activity 9 in Heat Resistant Beaker
- ✓ Universal Indicator with pH Value Plate
- ✓ Heating Plate

Conduct:

- ! Determine the pH value of the solution.
- Put the glass containing the solution on the heating plate. Heat the solution without boiling it.
- ! Observe the colour change and determine the pH value.
- Briefly summarize the result.
- Explain what is meant by the following statement:

"The ocean's heating by the Earth causes further heating of the atmosphere."

Activity 11

Cecilia Scorza

Tracing Signs of Climate Change in Bavaria

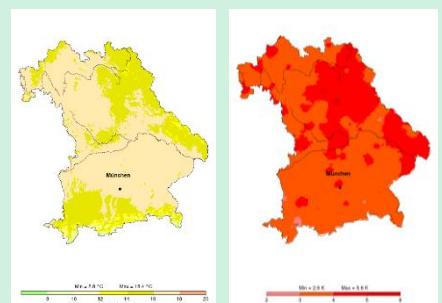
Aim:

Using interactive maps of the German Weather Service, clear signs of climate change in Germany can be detected through identifying and graphically displaying deviations of the temperature and precipitation values of recent years compared to the mean value of the years 1961-1990.

Background:

Climate is the term used to describe the long-term, averaged weather events in a location, usually over a period of at least 30 years. According to predictions of climate models, however, there is a direct connection between climate and weather. For example, a long-term increase in temperature due to climate change increases the probability of extreme weather events, such as temperatures and precipitation that deviate significantly from the average.

These effects of climate change vary greatly from region to region in Germany. In some parts, for example, the danger of flooding increases in spring, while in summer droughts and heat waves threaten. In Lower Bavaria, groundwater became scarce in the summer of 2018, so that water had to be pumped there from Upper Bavaria.



(Source: www.dwd.de/DE/klimaumwelt/)

Material:

- ✓ Computer with Internet Connection
- ✓ Worksheet

Conduct:

- Open the climate atlas of the German Weather Service:
https://www.dwd.de/EN/climate_environment/climateatlas/climateatlas_node.html
- Select Bavaria as the Land and the air temperature in August as a comparative value. Then load the maps of the last seven years one after the other (map on the right). Compare them with the map of the mean values (map on the left) and note in the table the deviation of the air temperature from the long-term mean value for one town.
- ! Plot the temperature deviations with the year on the x-axis and the temperature deviation on the y-axis.
- Repeat this procedure with the precipitation values for November.
- Now summarize your results and evaluate them. Include the given graph in the evaluation as well.

Worksheet for Activity 11

1. Data for Location: _____

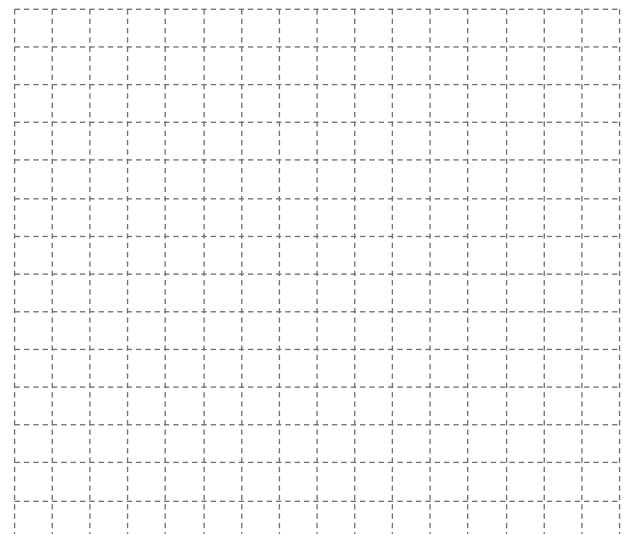
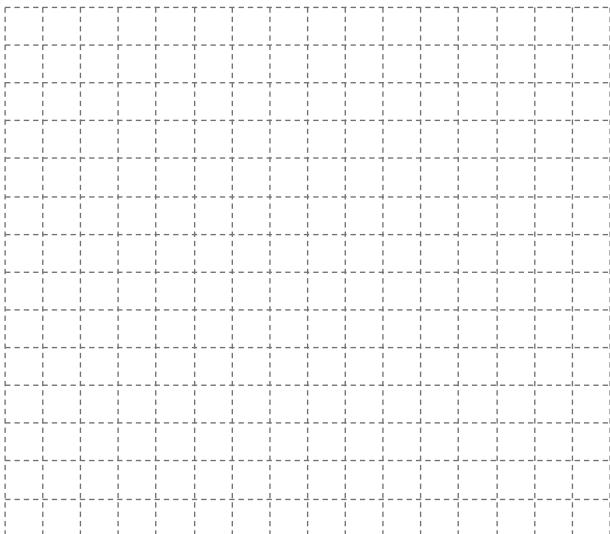
Temperature in August

Deviation in °C	Year
	2012
	2013
	2014
	2015
	2016
	2017
	2018

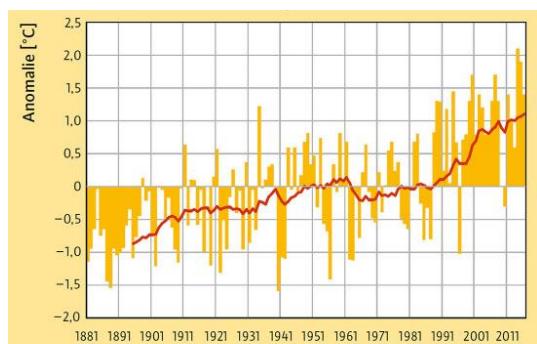
Precipitation in November

Deviation in %	Year
	2012
	2013
	2014
	2015
	2016
	2017
	2018

2. Plot



3. Summary of Results and Evaluation



Mean Value of Temperature Deviations in Bavaria
(Source: Deutscher Wetterdienst)

Activity 12

Cecilia Scorza

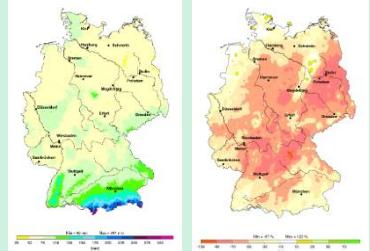
Tracing Signs of Climate Change in Germany

Aim:

Using interactive maps of the German Weather Service, clear signs of climate change in Germany can be detected through identifying and graphically displaying deviations of the temperature and precipitation values of recent years compared to the mean value of the years 1961-1990.

Background:

Climate is the term used to describe the long-term, averaged weather events in a location, usually over a period of at least 30 years. According to predictions of climate models, however, there is a direct connection between climate and weather. For example, a long-term increase in temperature due to climate change increases the probability of extreme weather events, such as temperatures and precipitation that deviate significantly from the average.



(Source: www.dwd.de/DE/klimaumwelt/)

These effects of climate change vary greatly from region to region in Germany. In some parts, for example, the danger of flooding increases in spring, while in summer droughts and heat waves threaten. In the summer of 2018, for example, the Rhine carried a historic deep water and in places heated up to 28 °C - as a result, tons of fish that died of oxygen deficiency had to be salvaged.

Material:

- ✓ Computer with Internet Connection
- ✓ Worksheet

Conduct:

- Open the climate atlas of the German Weather Service:
https://www.dwd.de/EN/climate_environment/climateatlas/climateatlas_node.html
- Select the air temperature in August for comparison. Load the maps of the last seven years one after the other (map on the right). Compare them with the map of the mean values (map on the left) and note in a table the deviation of the air temperature from the long-term mean for a town.
- ! Plot the temperature deviations with the year on the x-axis and the temperature deviation on the y-axis.
- Repeat this procedure with the precipitation values for November.
- Now summarize your results and evaluate them. Include the given graph in the evaluation as well.

Worksheet for Activity 12

4. Data for Location: _____

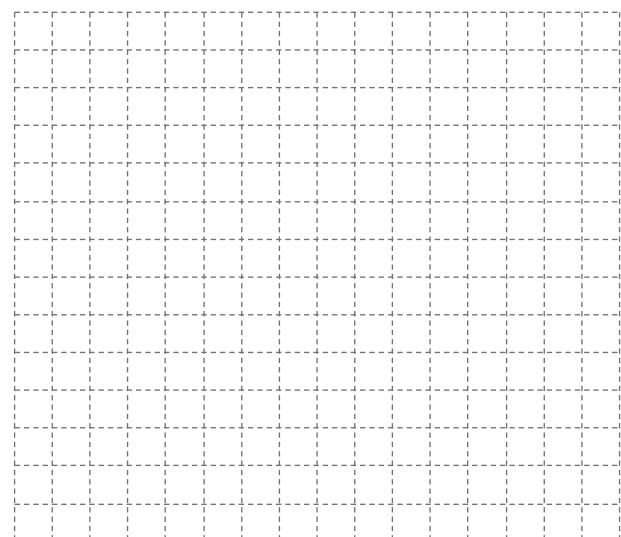
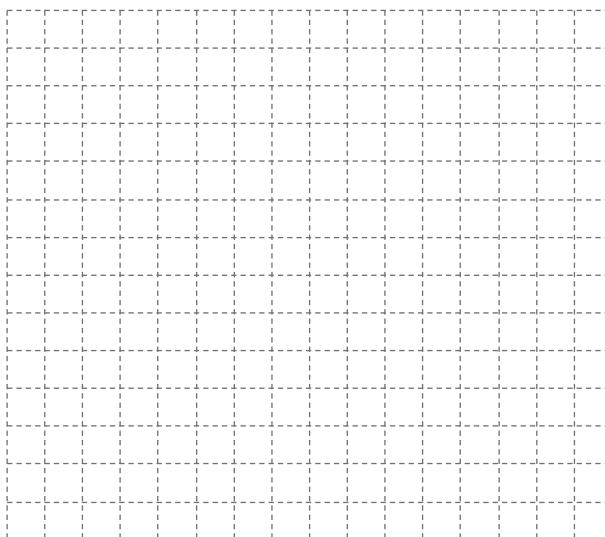
Temperature in August

Deviation in °C	Year
	2012
	2013
	2014
	2015
	2016
	2017
	2018

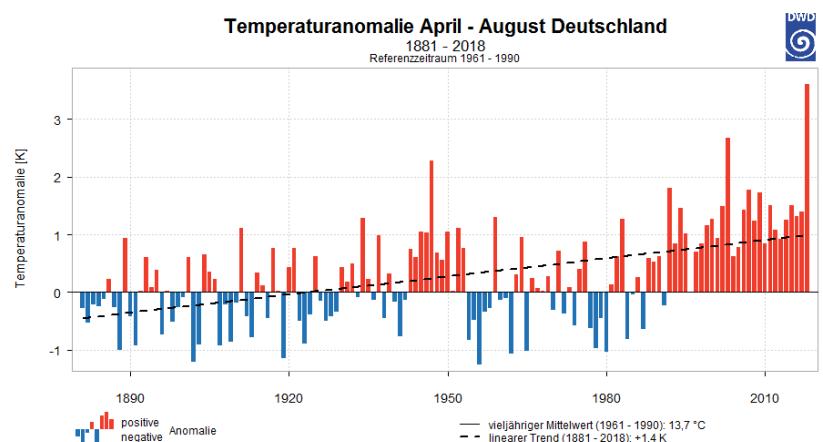
Precipitation in November

Deviation in %	Year
	2012
	2013
	2014
	2015
	2016
	2017
	2018

5. Plot



6. Summary of Results and Evaluation



(Source: Deutscher Wetterdienst: 2018 wärmster Sommer im Norden und Osten Deutschlands. Hintergrundbericht des Deutschen Wetterdiensts, 6. September 2018, called on 02.02.2019).

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