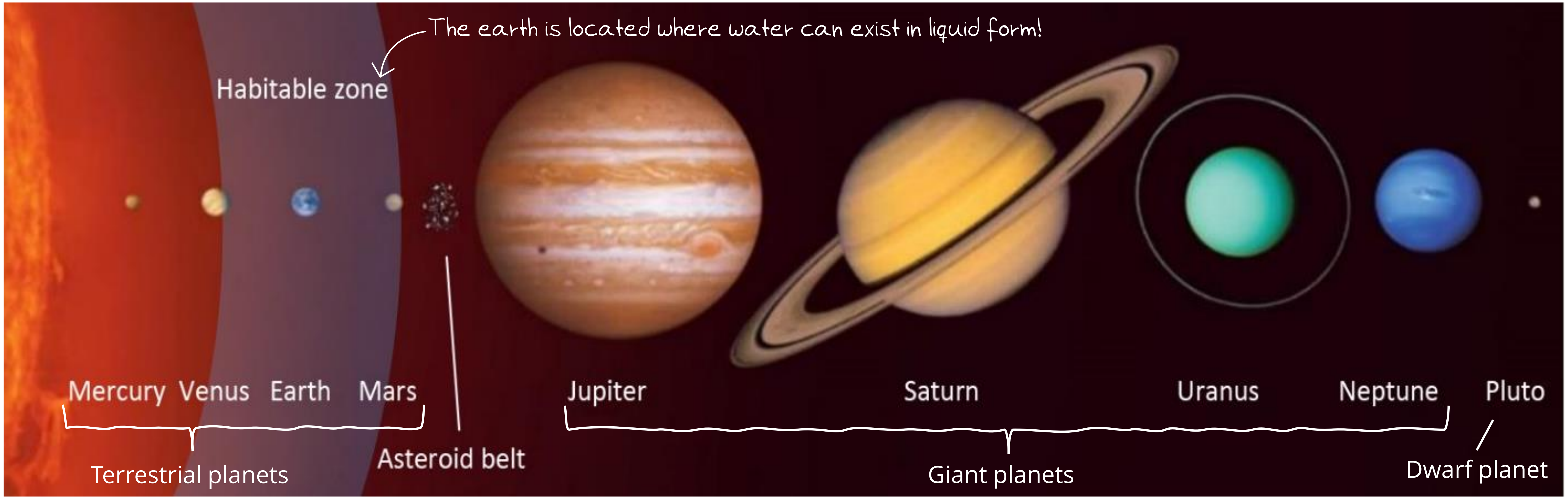
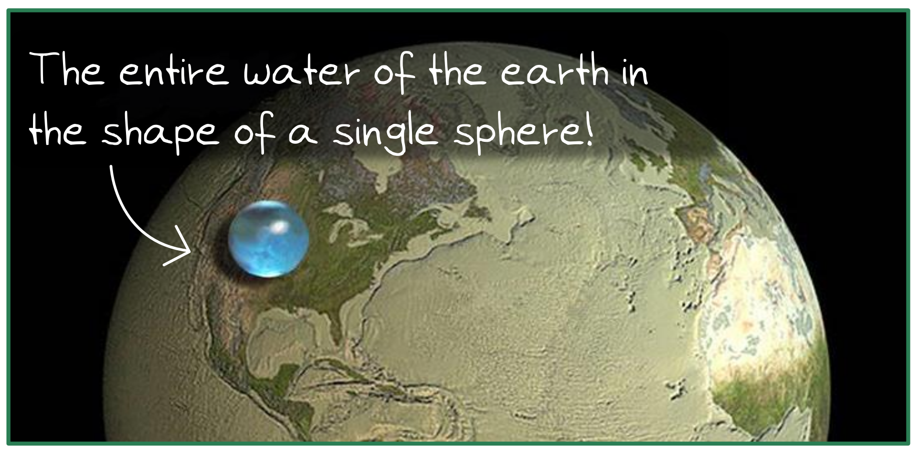
1. The earth in the solar system

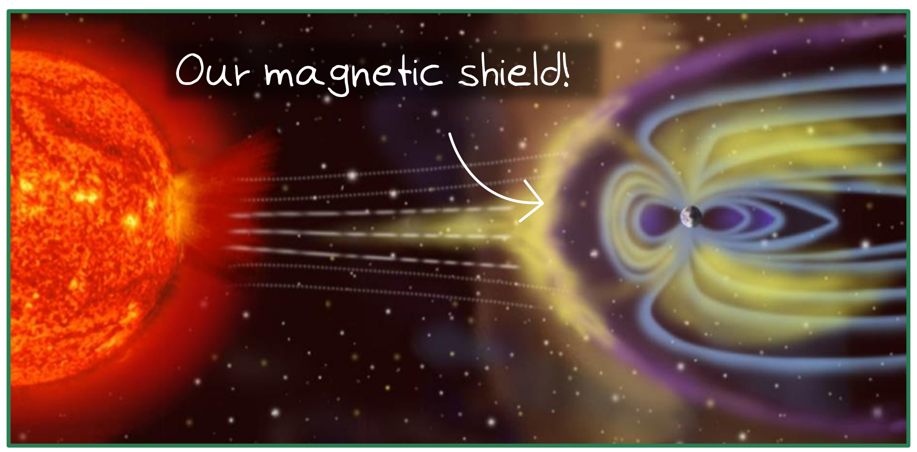
What makes our Earth a habitable planet?



The planets of our solar system in scale. The distances between the planets, however, are shown here clearly too small! (Credits: Scorza); Water on Earth: Perlman&Cook; Magnetic Shield: NASA; Earth and Moon: NASA

Backround:
The Earth, like Mercury, Venus, and Mars, is one of the inner rocky planets of the Solar System. The inner rocky planets are followed by the asteroid belt (with about 650,000 asteroids) and the four gas giants Jupiter, Saturn, Neptune and Uranus as well as many dwarf planets such as Pluto. Around all stars, and thus also around our Sun, there is a so-called habitable zone - an area where water can exist in liquid form. The Earth and Mars are situated in the habitable zone, but only the Earth is habitable. Why?





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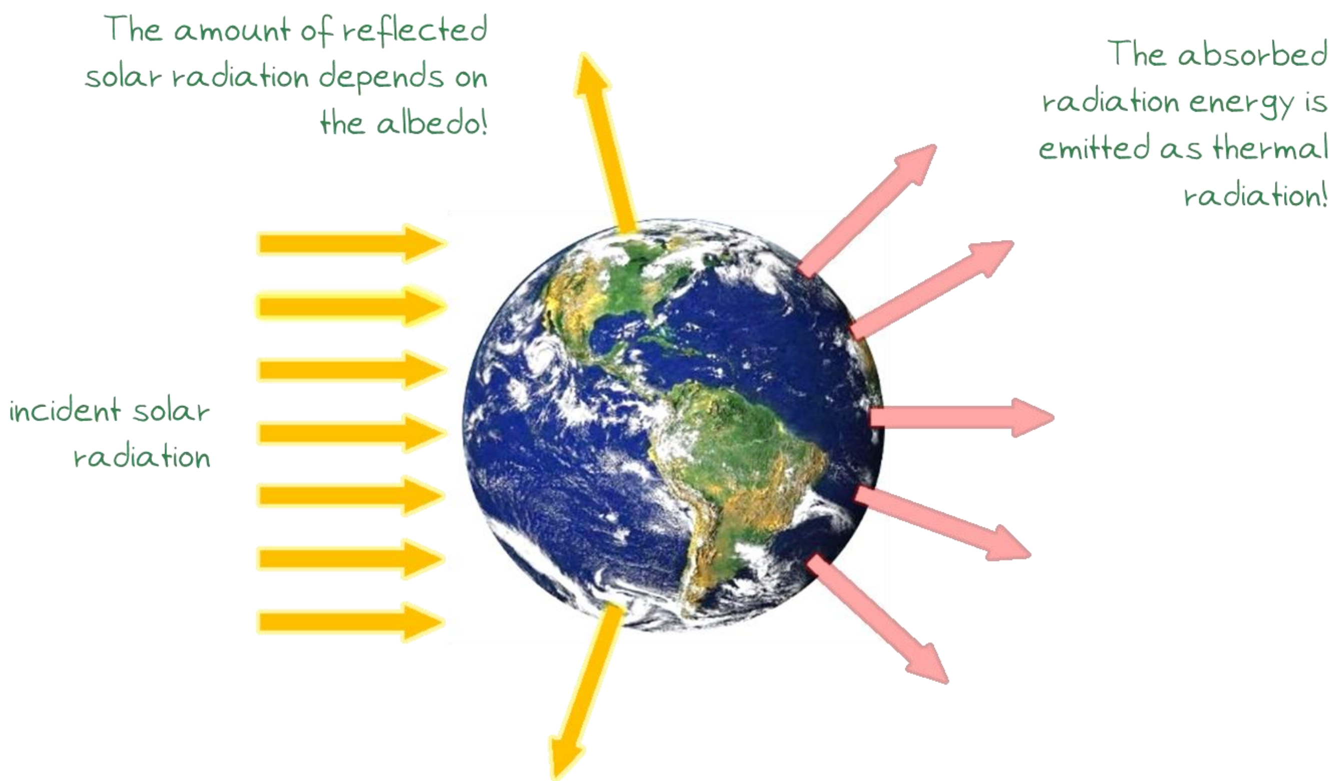
2. The Earth is irradiated

Klimawandel verstehen und handeln

Why is the Earth not getting hotter and hotter?



Sources of illustration: Earth globe: NASA modified by Strähle; Athabasca glacier: Pixabay; Albedo diagram: Hannes Grobe, Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany

Backround:

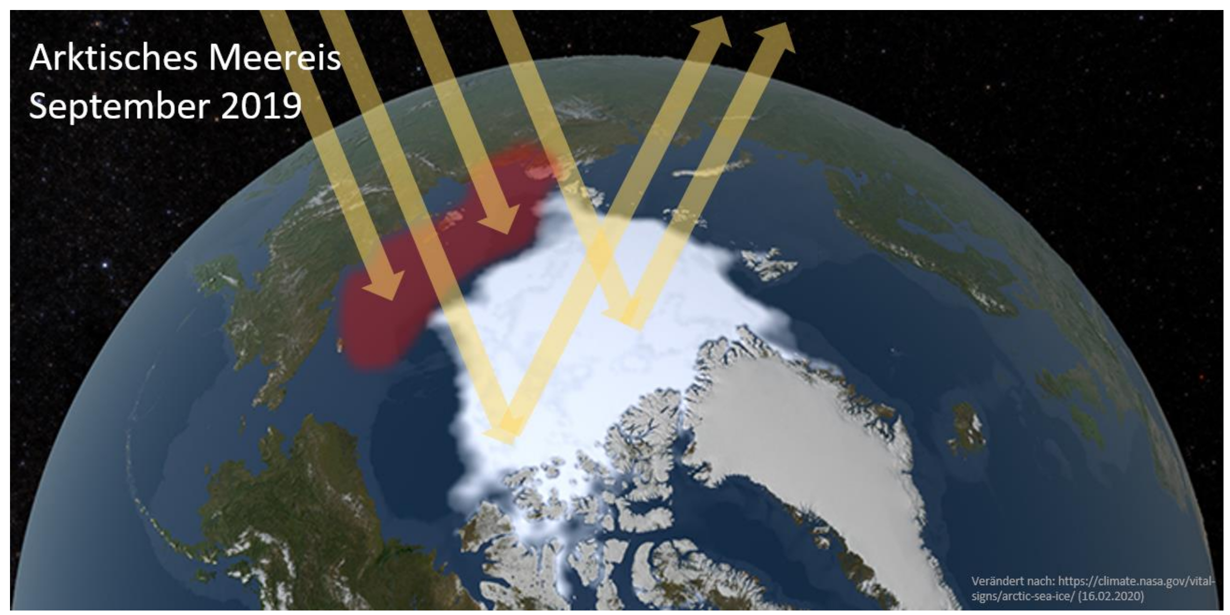
The higher the temperature of a body, the more energy it emits in the form of thermal radiation (compare, for example, cold and blazing iron). If a body is irradiated, it becomes progressively warmer and thus also radiates more. If the absorbed and radiated energy are equal in a certain period of time, it is in radiation equilibrium and has reached an equilibrium temperature. The earth as well as all planets are in radiation equilibrium.

What role do ice surfaces play in the temperature of the Earth?

If ice melts, it becomes water - this is obvious, but has serious consequences, because water barely reflects sunlight!!!

Backround:

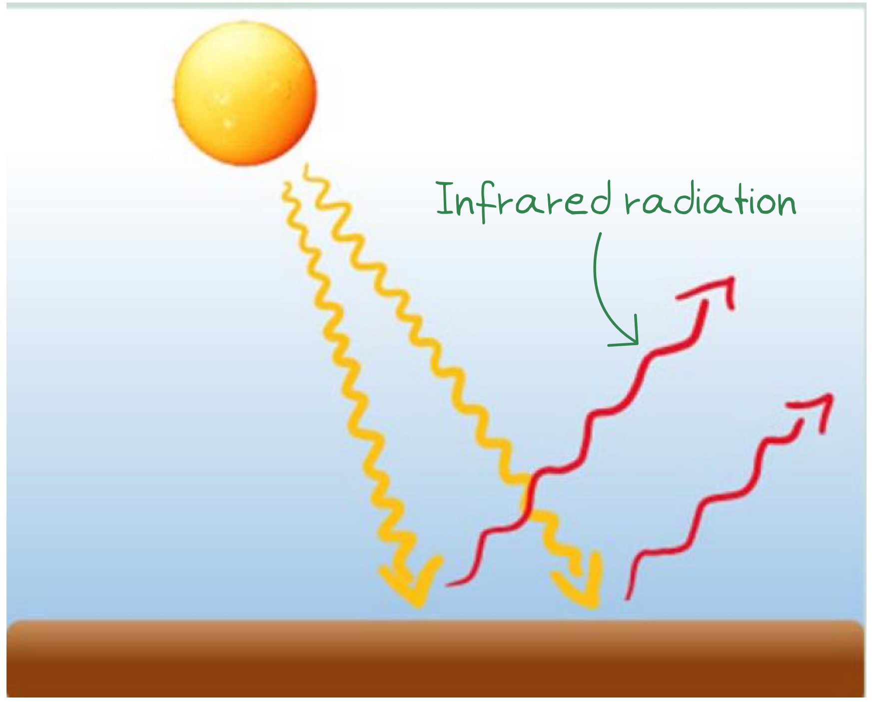
Bright surfaces on the Earth, such as ice and snow, reflect the incident light of the Sun more strongly than, for example, water or the ground. This reflectivity of a surface is called albedo α (lat. "white"). For the Earth applies α=0,3. This means that 30 % of the incident radiation energy is reflected and does not contribute to heating. The loss of white space due to global warming has devastating effects on the Earth's climate.



3. The Earth, a radiating Planet

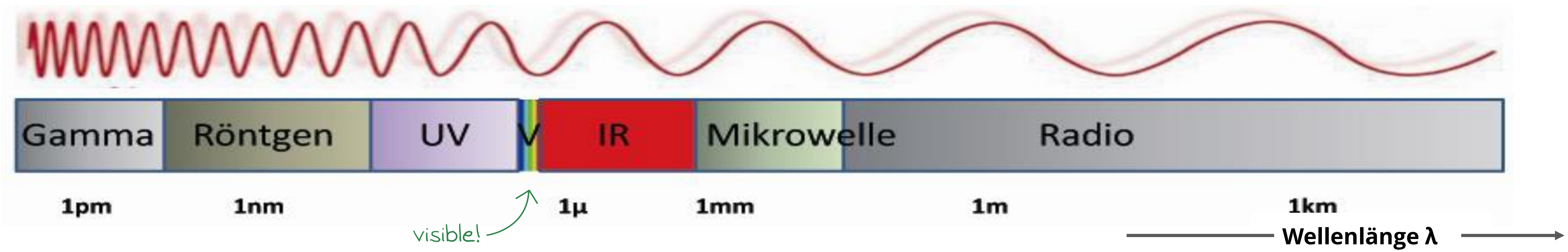
Klimawandel verstehen und handeln

Is it possible to make the invisible infrared radiation visible?



Backround:

Energy is transported from the Sun to the Earth via electromagnetic waves. The largest part of solar radiation consists of short-wave electromagnetic waves (the light visible to us), which reach the ground almost without hindrance from the atmosphere, where they are then absorbed to a large extent. The ground of the Earth then radiates this received solar energy as heat radiation in the -form of long-wave infrared radiation towards space. In total, the earth absorbs as much solar energy as it radiates into space as thermal radiation - it is in radiative equilibrium. The heat radiation of the earth is invisible to us. Can it be made visible and can it be researched?



Backround:

Visible light and infrared radiation have different properties. Some materials are transparent to infrared radiation (IR radiation) but not to visible light. Other materials absorb (i.e. trap) infrared radiation and allow visible light to pass through without hindrance. We explore these properties ourselves.

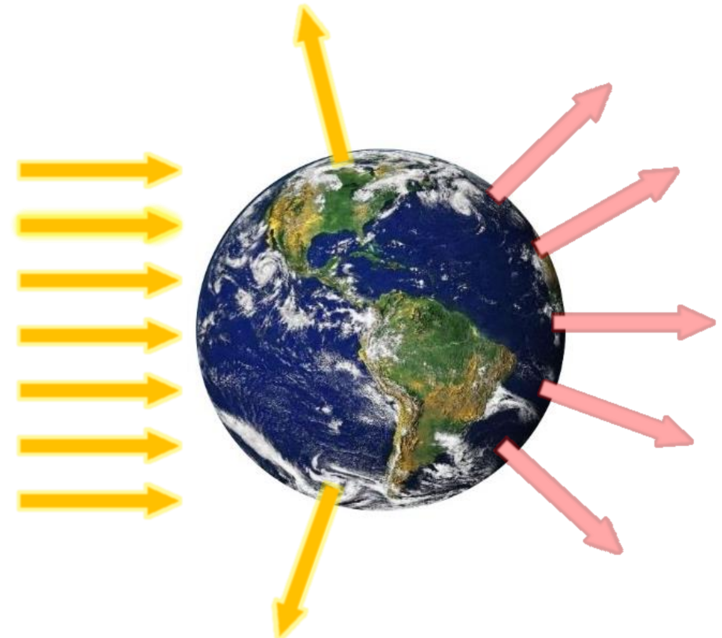
Image taken with a thermal imaging camera

The hotter the iron, the brighter and whiter it glows!

Imaging sources:
Thermal imaging camera image: pxhere.com,
light bulb: Pixabay; glowing iron: Pixabay;

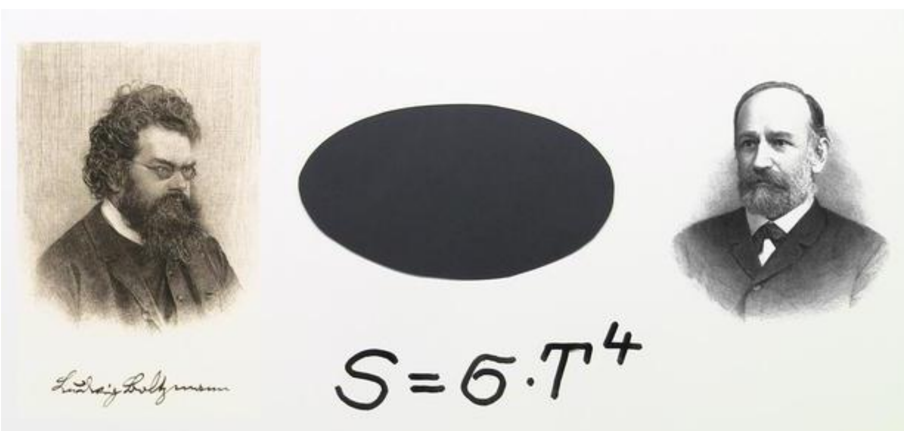
4. Greenhouse gases as regulator of the earth's temperature

What influence do greenhouse gases have on the Earth's temperature?

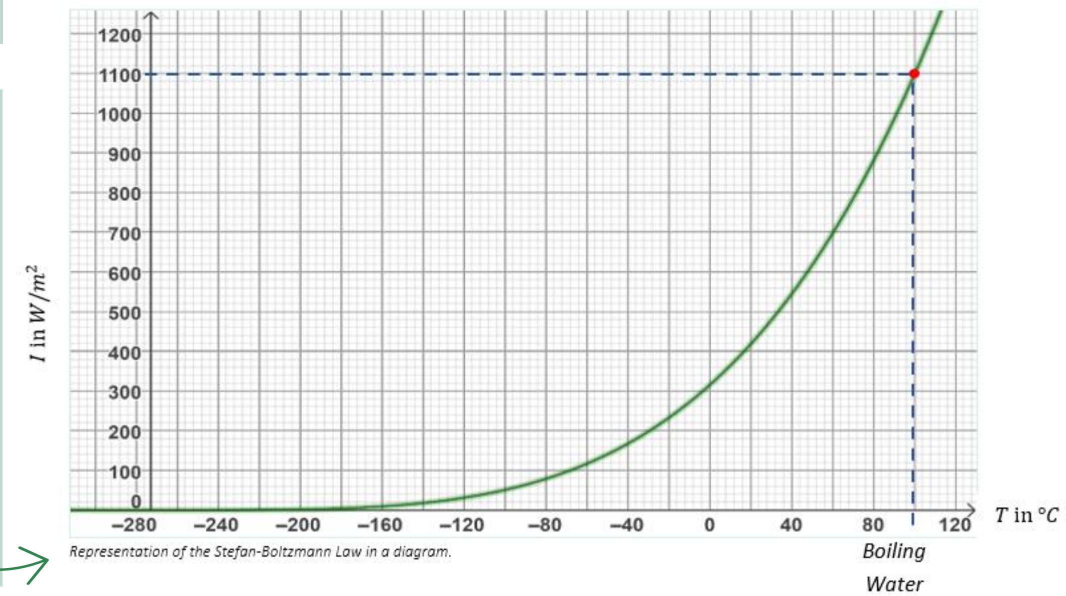


The radiation power of the sun at the upper edge of the atmosphere at perpendicular irradiation is about 1366 W/m^2, the so called solar constant. However, since only half of the earth is illuminated by the sun and it has a spherical shape, it is only illuminated by an average of **340 W/m^2** (watts per m^2) . Approx. 30% of the solar radiation is reflected e.g. by ice surfaces and white clouds in the direction of space. The remaining energy of **238 W/m** is then absorbed by the ground and re-radiated in form of invisible heat radiation (in the infrared spectrum). The amount of radiated energy is equal to the amount of radiated energy - the earth is in radiation equilibrium!

Unsere Frage lautet: Welche Temperatur hätte eine Erde ohne Atmosphäre und im Strahlungsgleichgewicht ?



The answer is provided by **the Stefan-Boltzmann law**, which describes how much energy a body radiates per m^2 of its surface area per second at a certain temperature T. This law can be represented in diagram form (right). There we can read, for example, that boiling water emits a radiation intensity of 1100 W/m^2.



Representation of the Stefan-Boltzmann Law in a diagram.

We can now determine the temperature of the earth in radiation equilibrium and without atmosphere in the diagram: It would be very cold! According to the diagram **-18°C**! Without atmosphere the earth would be a white ice ball! But earth is a beautiful planet with an average temperature of **15°C**! Where does this difference come from? It is proved that the heat radiation of the earth's surface is not completely radiated into space, but is absorbed by the hothouse lanes of the earth's atmosphere to 76 % and is radiated again evenly in all directions - approx. half in the direction of the universe, the other half in the direction of the earth's surface. The latter provides a difference of 33 °C and much more heat!

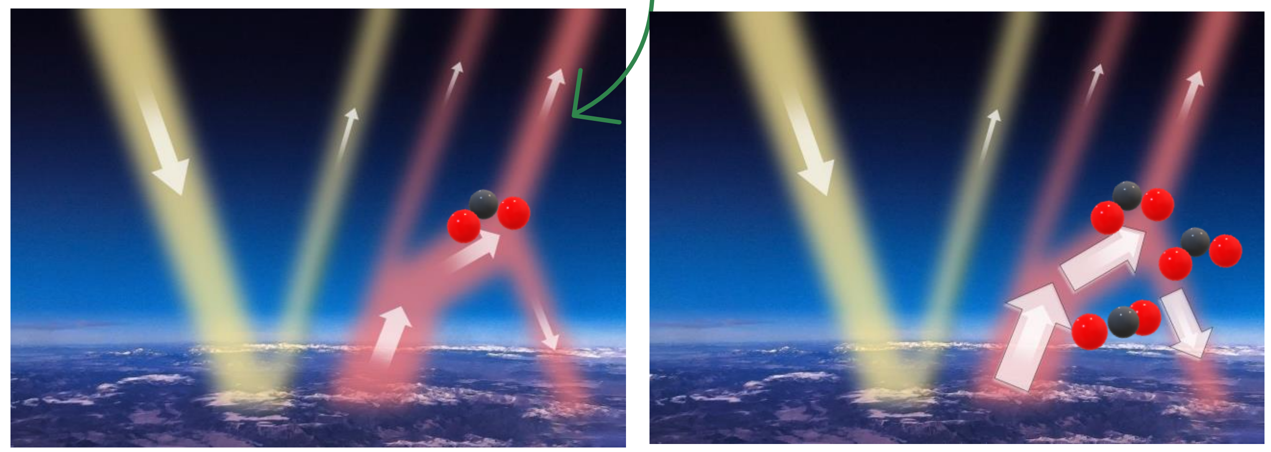
5. The Effect of Greenhouse Gases

Absorption in the atmosphere

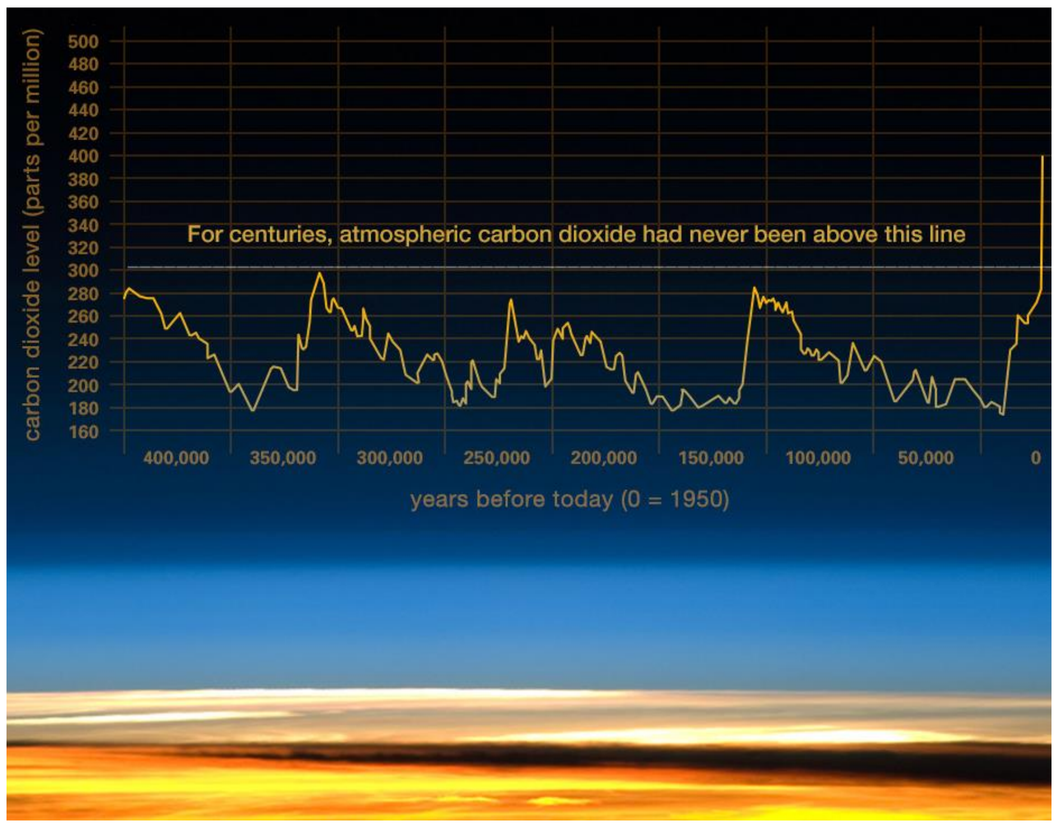
Backround:

The Earth's atmosphere consists mainly of nitrogen (78%) and oxygen (21%). Greenhouse gases such as carbon dioxide (0.04%) and methane (0.0002%) are only present in trace amounts, but nevertheless have a major impact! The molecules of the greenhouse gases absorb the invisible infrared radiation emitted by the Earth's surface and thus vibrate. This oscillation energy is then transferred to particles in the environment in the form of kinetic energy - the atmosphere warms up! What happens to the temperature of the atmosphere when people release large quantities of CO_2 into the atmosphere by burning fossil fuels?

Only the **greenhouse gases** absorb the heat radiation of the earth and send it partially back to the earth's surface

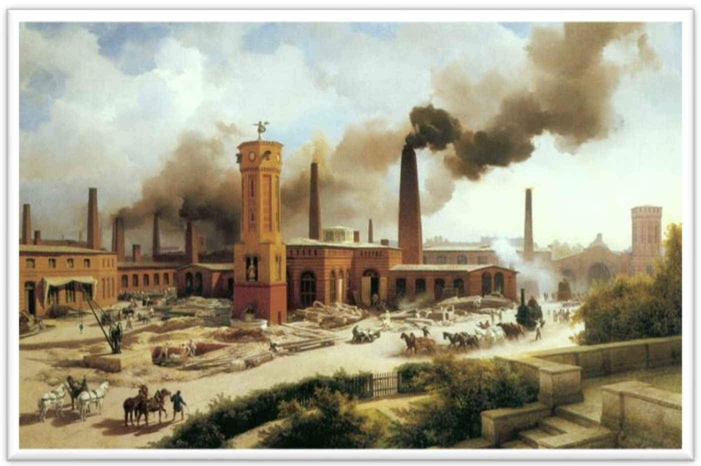


Human induced climate change



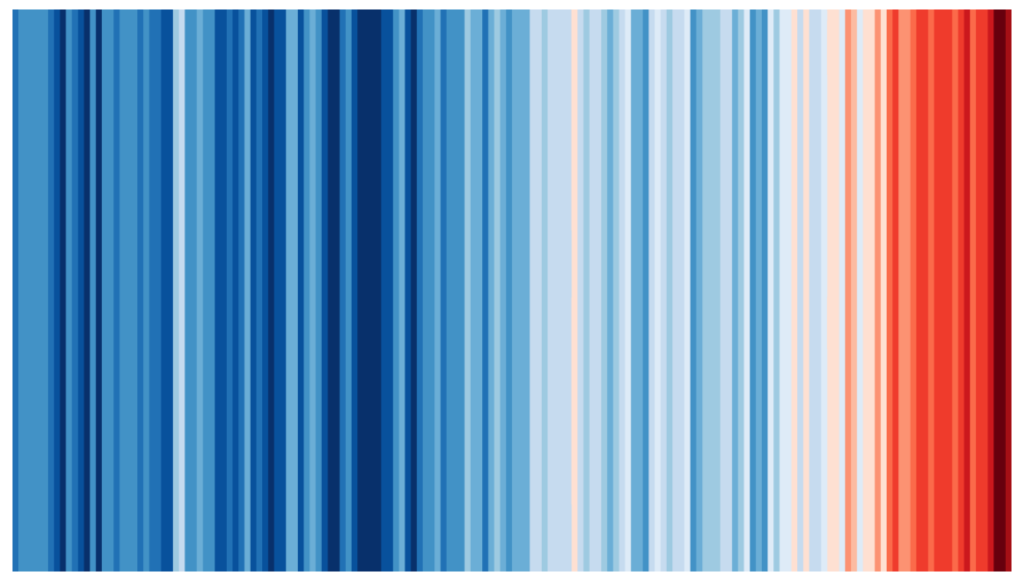
Source: climate.nasa.gov/evidence/

Extreme increase in atmospheric CO_2 concentration caused by humans, since the industrial revolution.



Karl Eduard Biermann 1847
Source: Preußen Kunst und Architektur, Wikimedia (11.02.2020)

Direct correlation of extreme CO_2 emissions and temperature increase on Earth.



Annual global temperatures from 1850-2017
Source: https://www.climate-lab-book.ac.uk/2018/warming-stripes/ (13.12.2020)

6. The Rise in Sea Level

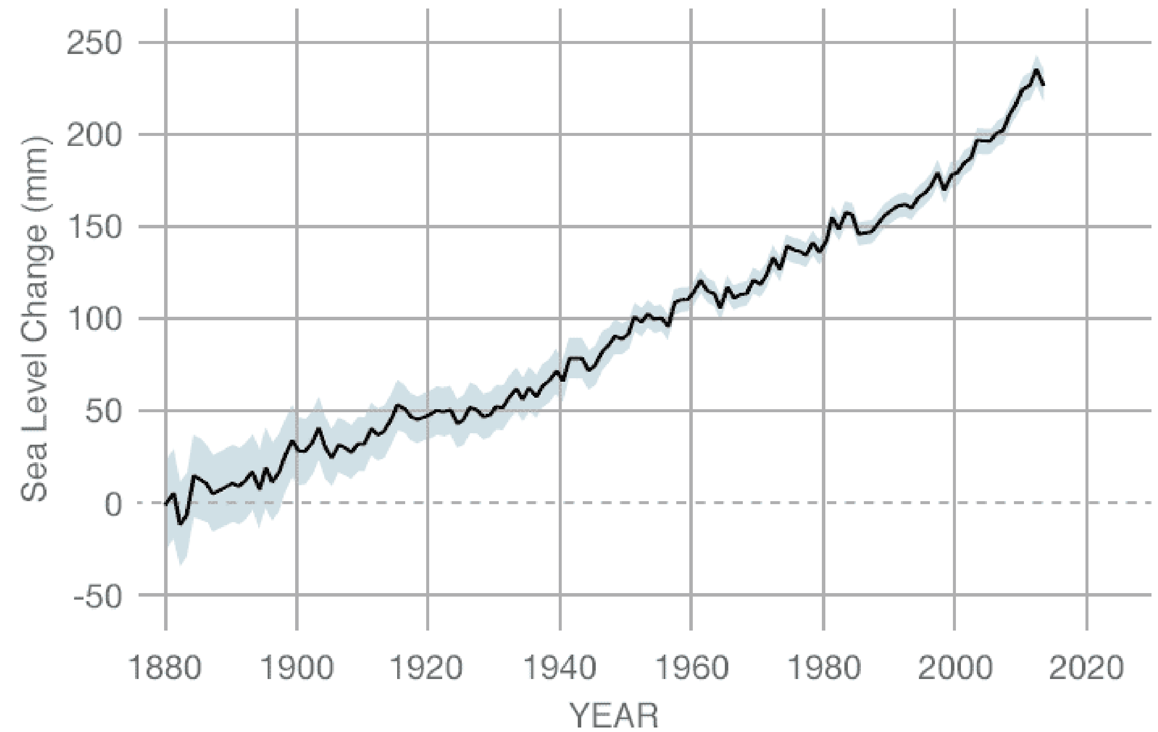
What are the origins and effects of sea level rise?

Backround:

Due to global warming, large masses of ice are currently melting on land, such as the Greenland ice sheet or glaciers in the Alps. The water temperature of the oceans is also rising. This also means that icebergs floating in the water are melting faster.

The image shows the extent of Arctic sea ice today (white area) and 30 years ago (yellow outline).

In a special report, the Intergovernmental Panel on Climate Change expects sea levels to rise by up to 110 cm by the year 2100 and by up to 5.4 m in 2300!



During a storm surge, the sea rises several meters above the mean water level, which continues to rise due to melting continental ice masses. Such extreme weather events are becoming more frequent due to climate change. In the short term, the land can be protected by raising the height of the seawalls.

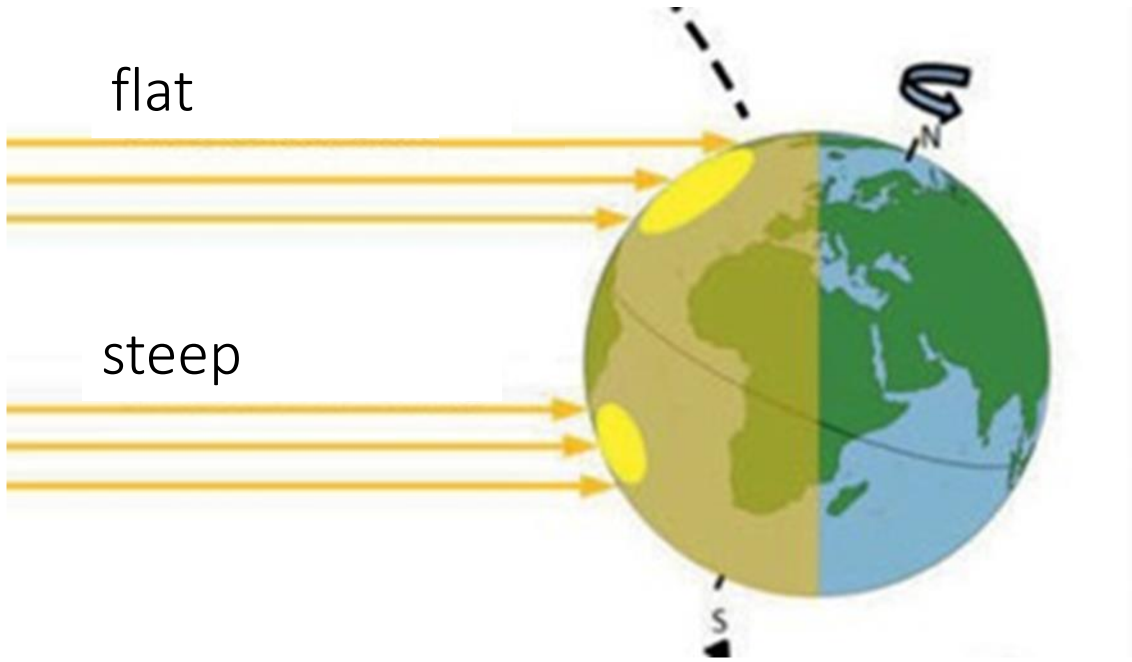
Illustration sources: Arctic sea ice: NASA; sea level rise: NASA; land protection dike: wikimedia

7. Climate Zones and Climate Change

What are the consequences of a shift in climate zones?

Backround:

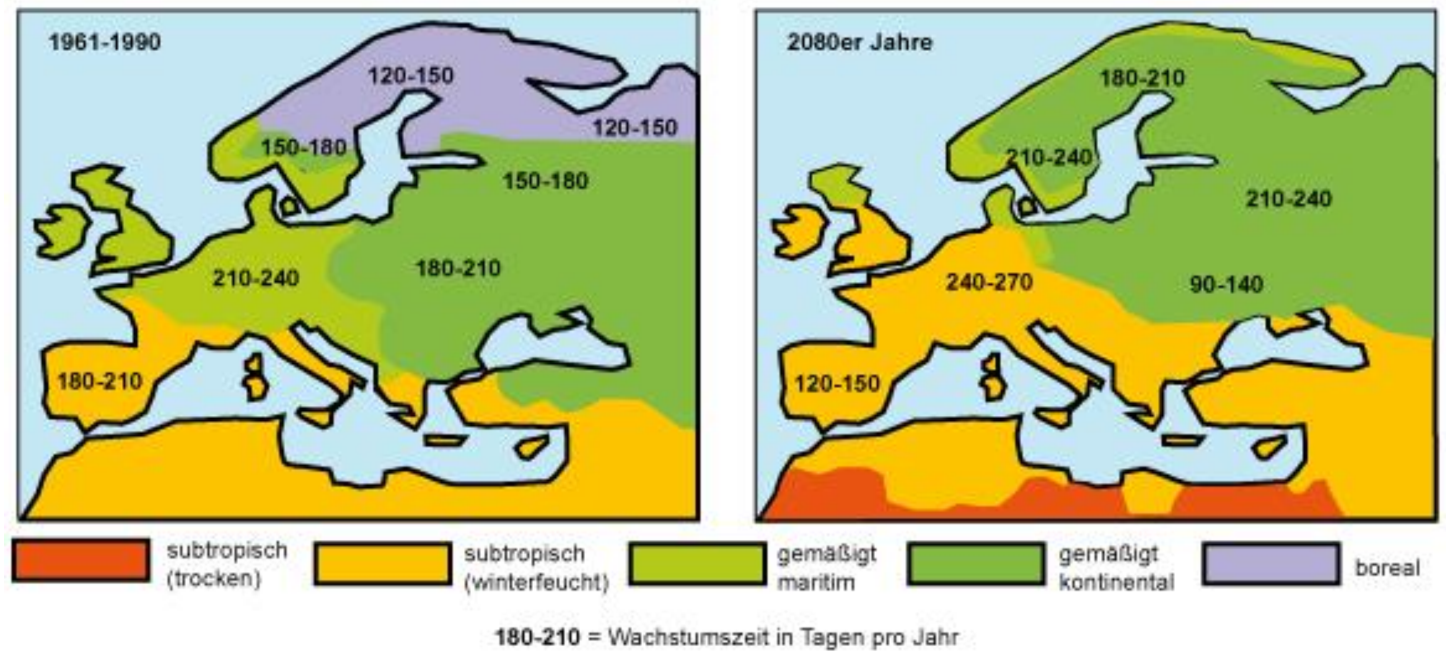
The climate zones of the Earth are created by the difference in intensity of solar radiation depending on the geographical latitude. Near the equator, the angle of incidence of the Sun's rays is relatively high all year round and at certain times even perpendicular to the Earth's surface. With increasing geographical latitude, the Sun's rays reach ¬the Earth's surface at an increasingly flat angle, so that the irradiated energy is distributed over a larger area (see figure).



Shift of climate zones with the example of Europe

The map clearly shows the shift of climate zones towards the north (in the northern hemisphere) by the end of this century.

At their current locations, today's trees will then no longer be adapted to the future climate. In less than a century, however, no vegetation can develop in Bavaria, for example, similar to the vegetation we see in the south of France.



According to one study, the climate in Madrid in 2050 will resemble the climate in Marrakech today, and the climate in London in 2050 will resemble the climate in Barcelona today!

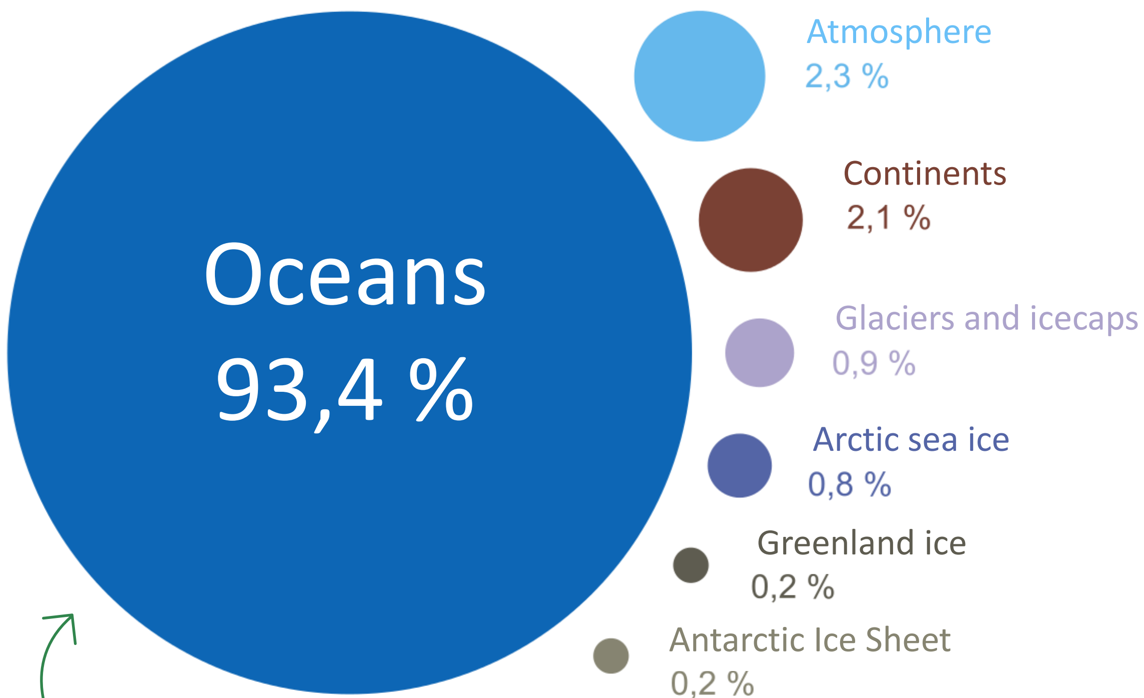
Figure sources: Shifting climate zones: bildungsserver.hamburg.de

The seasons are created by the inclination of the Earth's axis of 23.5° relative to the orbital plane of the Earth around the Sun, the so-called ecliptic. Thus, the northern hemisphere tends to tilt towards the Sun in summer and away from it in winter. (In the figure, the northern hemisphere is in winter).

8. The Oceans as a Climate Buffer

How do the oceans protect us from even greater climate change?

Where is global warming directed to?



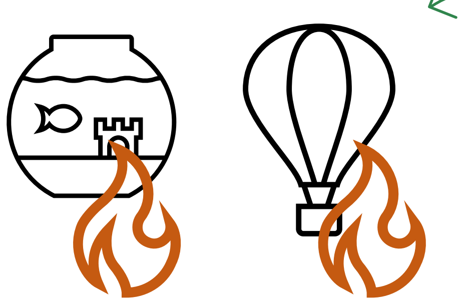
93% of the additional energy in the climate system due to the greenhouse effect goes into the oceans!

Backround:

About 2/3 of the earth's surface is covered with liquid water, and this has an impact on the earth's climate. This is because water is a very effective heat accumulator: a certain mass of water can absorb significantly more energy per Kelvin increase in temperature than, for example, the same mass of air. For example, a kilogram of water heats up by 1 K with an energy increase of 4.2 kJ. Water therefore has a heat capacity of 4.2 kJ/kgK. Air and dry earth, on the other hand, have a heat capacity of about 1 kJ/kgK. It therefore takes about one kilojoule to heat one kilogram of these substances by 1 K.

The human-induced greenhouse effect adds energy to the earth's surface, and thus to the oceans.

Water is an extremely effective heat storage medium! It can absorb a lot of energy without heating up much.



If you add ten kilojoules of energy to a kilogram of air, it heats up by ten Kelvin, whereas 1 kg of water heats up by only 2.3 K!

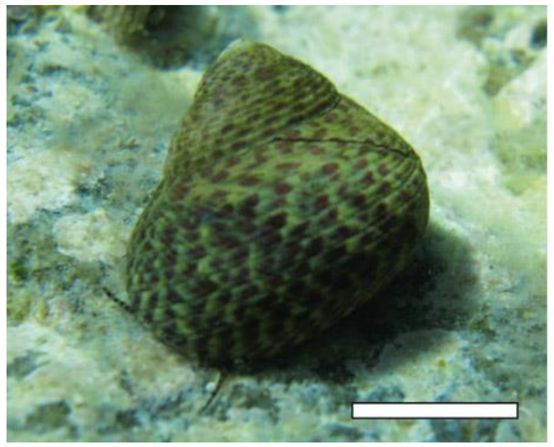
However, the oceans do not only extract thermal energy from the atmosphere, but also CO_2, which dissolves in the water. The oceans thus buffer the human-induced greenhouse effect twice - but with serious consequences!

Figure sources: Where is global warming going?: IPCC AR4 5.2.2.3; Ocean Temperature: NASA Near Earth Observations.

9. The Acidification of the Oceans

Why are the oceans turning acidic with climate change?

Dotted snail shell still intact at a pH of 8.2

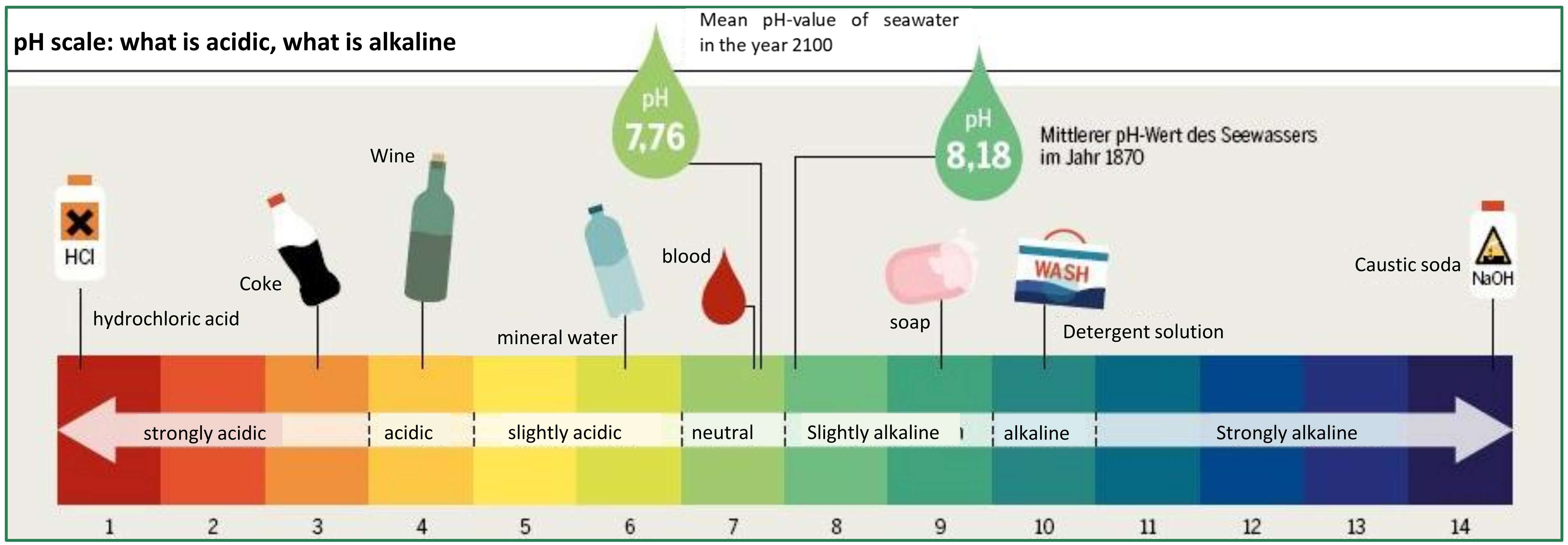


Snail shell at a pH of 7.3 shows clear signs of dissolution

Backround:

Measurements of the pH value in the oceans show an increasing acidification of the water. If the content of the greenhouse gas CO_2 in the Earth's atmosphere rises (for example due to the burning of fossil fuels), it will also increasingly be dissolved in seawater, where it chemically reacts to carbonic acid ($H_2O + CO_2 \rightleftharpoons H_2CO_3$). This has fatal consequences for the life of algae and animals living there, which are not adapted to the increasingly acidic environment.

In addition, the shells of calcareous algae, for example, become thinner (see figure) and corals lose their calcareous skeleton. The CO_2 fixing of the oceans is decreasing overall.



Measurements of pH in the oceans show increasing acidification of the water.

Sources of illustration: pH scale: Heinrich Böll Foundation (2017) Ocean Atlas. Facts and figures on ocean stewardship.; pH globe (IPCC (2013): Climate Change 2013, Working Group I: The Science of Climate Change, Figure 6.2.8; Snail shell (Hall-Spencer et al. (2008) at https://worldoceanreview.com/de/wor-1/meer-und-chemie/ozeanversauerung/ (12.10.2020)).

10. Consequences of Ocean Warming

Klimawandel verstehen und handeln

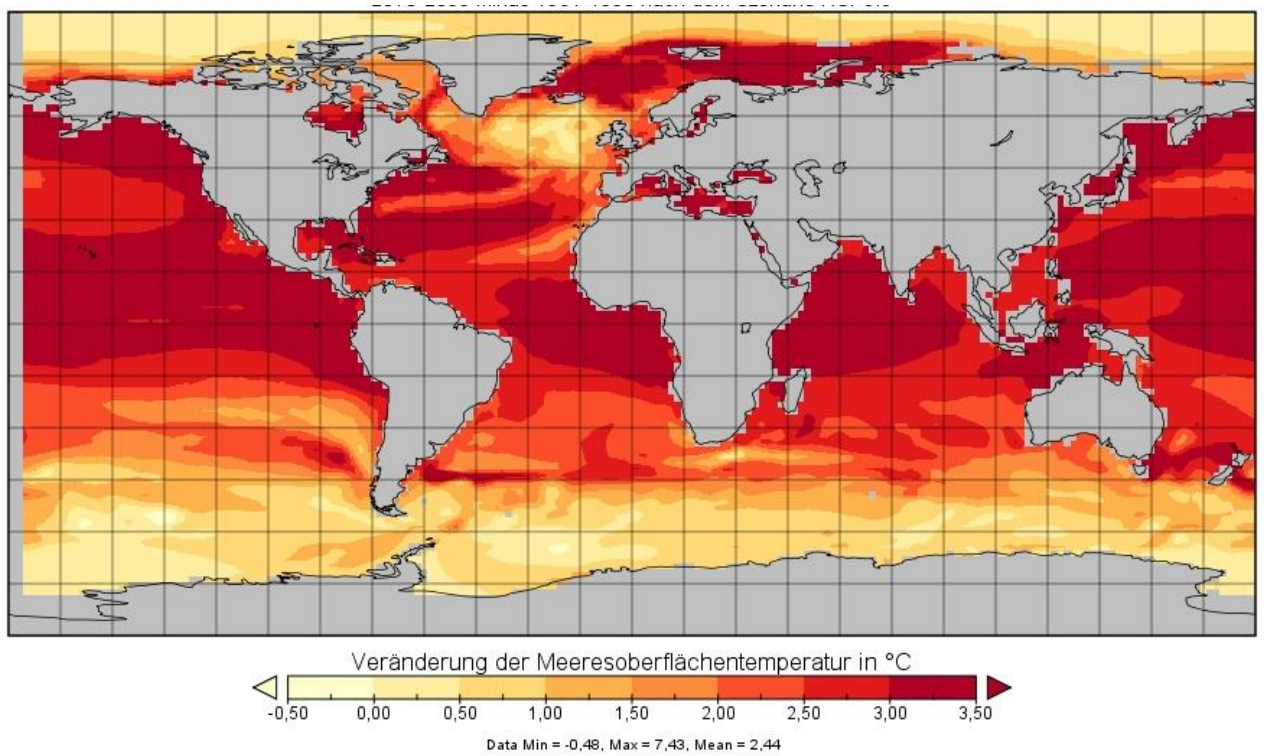
Why does ocean warming increase global warming?

Backround:

The oceans have a dual role in tempering global warming: On the one hand, they store heat and, on the other, they absorb CO_2 from the atmosphere. However, when the temperature of the water in-creases, these buffers lose their effect: Warm water absorbs less heat as the temperature difference with the environment becomes smaller, and it can also dissolve less CO_2. It even releases it again at higher temperatures! Acidification also leads to the dissolution of lime, which releases additional CO_2 into the atmosphere. The water vapour, which is produced to a greater extent as a result of the increased water temperatures, is as a greenhouse gas much stronger than CO_2 and thus leads to an additional increase in the greenhouse effect.

Change in annual mean sea surface temperature

2070-2099 minus 1961-1990 according to the scenario RCP8.5



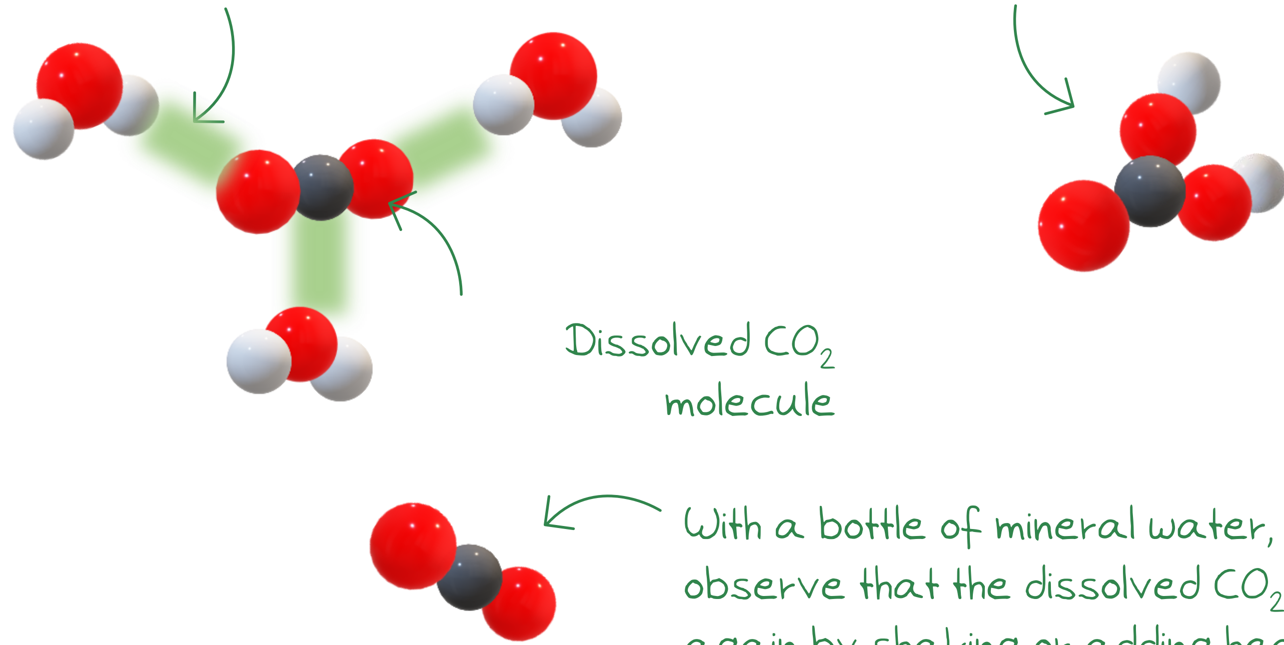


Figure sources: Annual mean sea surface temperature change: wiki.bildungsserver. de/klimawandel; ocean: Pixabay.

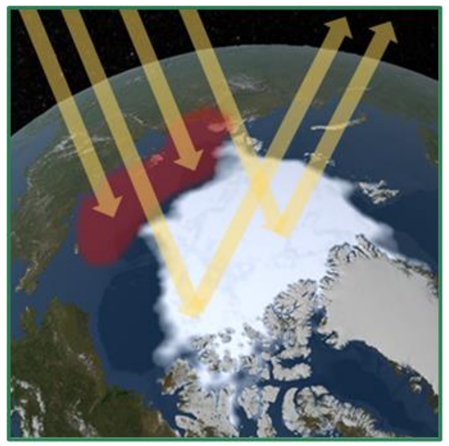
11. Tipping Points: When the Climate Changes

Feedback processes and vicious cycles

Hintergrund:

When "tilting" with a chair, you can get yourself into a tilted position by pushing yourself against a table - the more you push, the more you can tilt. If you stop pressing against the table, you return to your starting position. But woe betide you if you push yourself off just a little too much... Unfortunately, the Earth's climate system behaves in a similar way and could irrevocably collapse in the near future if even one gigaton too many greenhouse gases are emitted.

Melting ice surfaces



Dark and thus highly absorbent surfaces such as water or rock appear under melting ice.

Permafrost

Thousands of years of carbon and methane deposits are frozen in it.

Methane hydrates in the oceans

Up to several thousand gigatons in ocean sediments on the seafloor.

Water vapor

Warmer air can hold more water vapor than cold air and water vapor is a powerful greenhouse gas

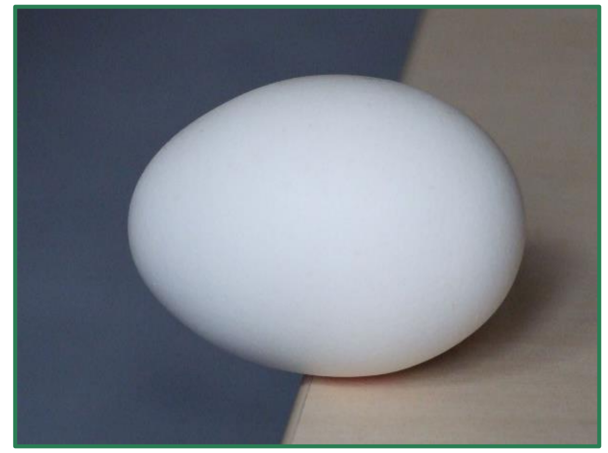
Tipping points are crucial to the catastrophic dynamics of climate change: When a tipping point is trig-gered, it is not immediately noticeable in reality, but a process is set in motion that is no longer re-versible! An example: The ice on the Arctic Ocean reflects sunlight. If parts of the ice melt, more so-lar energy can warm the sea because of the lower reflection. The remaining ice then melts more quickly. At some point, the vicious circle can no longer be stopped. As in the game of dominoes, there is a cascade of tipping points in the Earth's climate system. One can trigger the next one at a time, making the temperature increase incalculable.

Figure sources: Arctic sea ice: NASA modified by Strähle; gas hydrate: Wikimedia by Wusel007; permafrost soil: NASA; Geyser: Pixabay

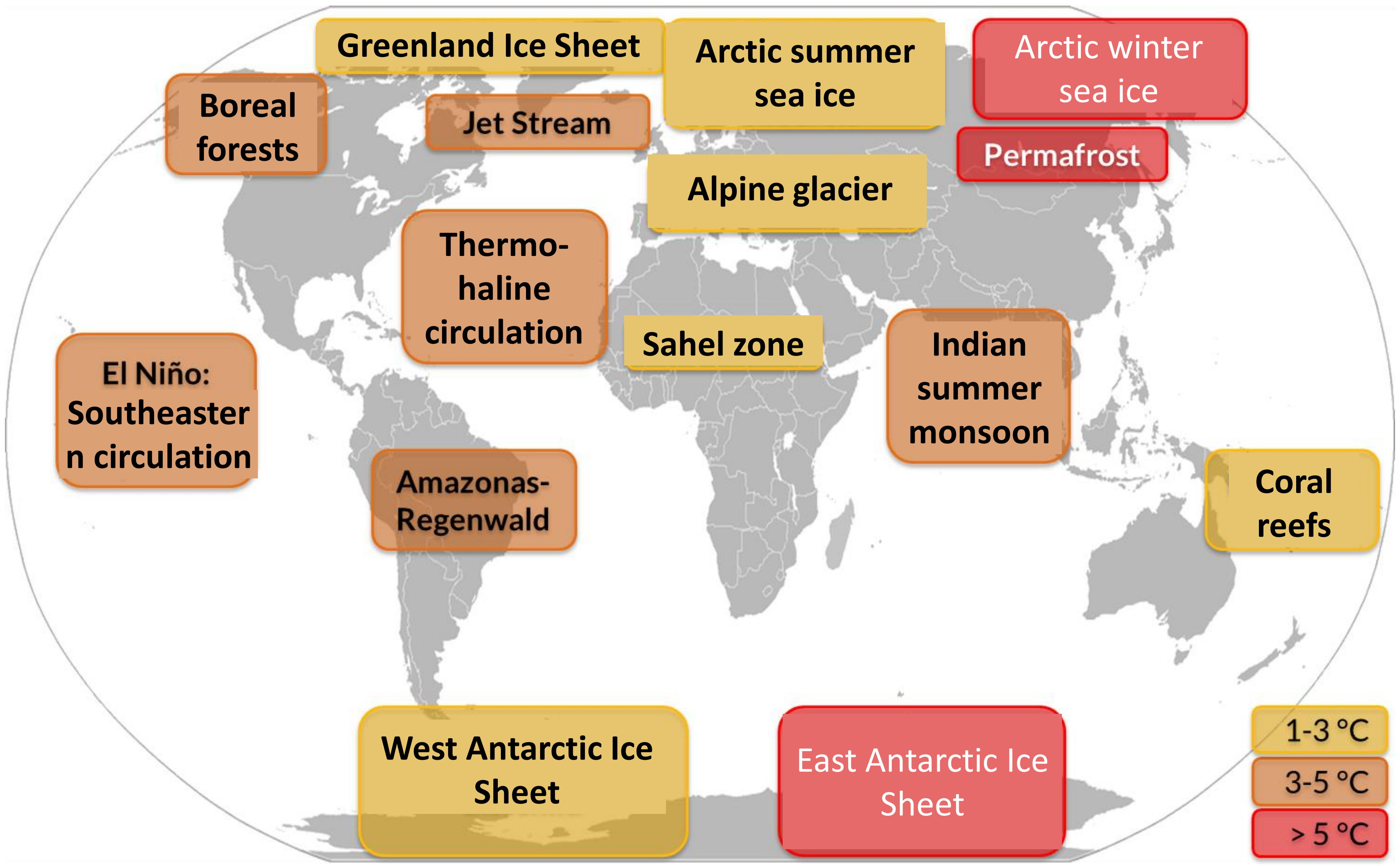
12. Tipping Points: Achilles' Heel in the Climate System

Backround:

The **Earth's global climate system** is determined by the interaction between the main components of the climate system: **hydrosphere** (water), **atmosphere** (air), **cryosphere** (ice and snow), **pedosphere** and **lithosphere** (soil and rock) and the **biosphere** (living organisms). Global warming sets processes in motion that influence and change these different elements in different ways. Some of these processes are self-reinforcing: For example, global warming leads to increased evaporation of water; and since water vapour is a greenhouse gas, it increases the temperature of the atmosphere, which in turn ¬leads to increased evaporation of water.



If an egg rolls on a table, nothing will happen until it reaches the edge. But then a little nudge is enough and the egg falls irreversibly to the floor!



Because of these self-reinforcing feedback processes, when a certain threshold is exceeded, the Earth's climate system can enter the uncontrollable state of a hot period. This is known as a tipping point. "Tipping" fmeans that these changes, as they become more and more self-reinforcing, will then be unstoppable or irreversible. The environmental effects of tipping points are far-reaching and could endanger the livelihoods of many millions of people.