Where the greenhouse gases go

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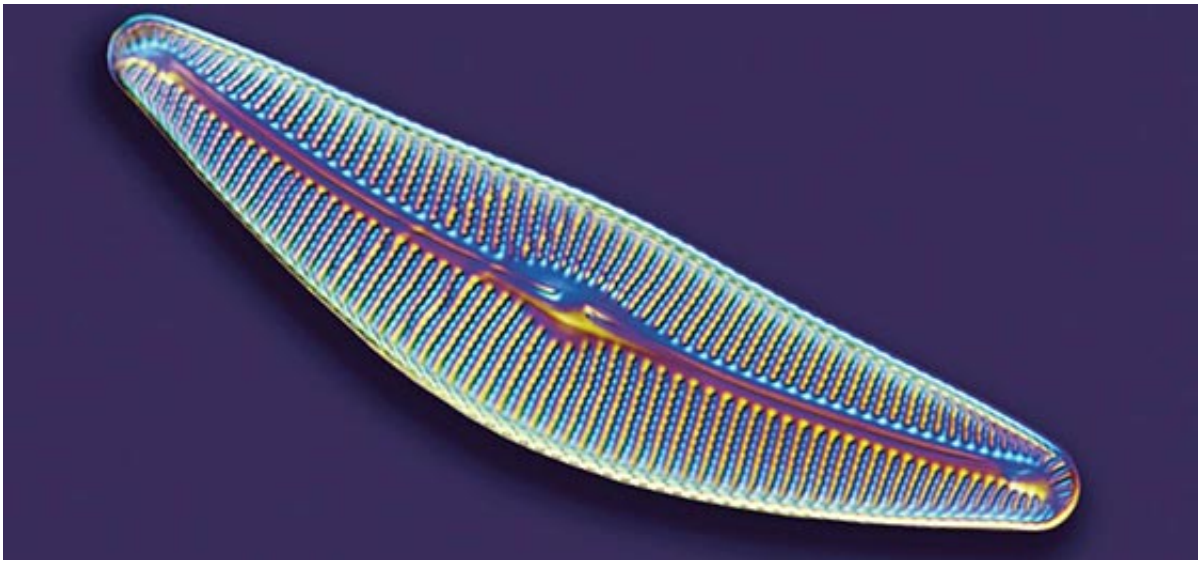

Almost half of the carbon dioxide that humans release into the environment is taken up by the world's oceans and the terrestrial biosphere. In this manner, greenhouse gases are partially extracted from the atmosphere, which alleviates the process of global warming. But will the land and the seas be able to continue storing carbon dioxide in the future? Researchers aren't sure. Changes in ocean circulation, woodland clearances and stress reactions in forests could reduce their capacity to act as carbon sinks.

On land, plants and trees take up carbon dioxide (CO_2) through photosynthesis. Carbon later returns to the soil in the form of plant

matter, which is why large quantities of it are stored there. When the climate heats up, however, the soils can emit this stored carbon again by means of microbial decomposition. Researchers are trying to find out which process will gain the upper hand in future – and Switzerland is one of the sites for their analyses.

Tree-line topsoil

How much carbon lies in the ground, and how might this change? Frank Hagedorn is based at the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) in Birmensdorf, and he's been engaged in numerous projects to find out the answers. It's the topsoil that's decisive, because it contains carbon that can be broken down especially easily. In one of their projects, Hagedorn's team was able to demonstrate that this degradation process is particularly relevant in the areas around the tree line. They flushed an ecosystem with CO2 at the tree line above Davos, marking it with special carbon isotopes so that they could trace how the materials cycles changed. The soils of alpine ecosystems are particularly rich in carbon, and it transpired that they can emit a correspondingly large amount of CO2 when the temperature rises. This process has already begun on account of man-made climate change.

In order to be able to draw conclusions about CO2 sinks on a European or worldwide scale, researchers need standardised measurements. These can then be extrapolated for larger geographical areas, using computer models. In the European consortium project 'ICOS Research Infrastructure', measurement instruments and data processing are currently being standardised. The project began officially in 2015 and Nina Buchmann of ETH Zurich is coordinating the Swiss end of it ('ICOS-CH'). Two measurement locations are participating here in Switzerland, she says: one in a spruce forest, also near Davos, and one at the Jungfraujoch research station.

Unreliable forests

Many years of measurements have already proven that forests absorb a lot of CO2. In the forests outside Davos, CO2 flows were actually measured as far back as 1997, though other instruments were used back then, says Buchmann. "The ecosystem has been a CO2 sink the whole time", she says. The same is not true of every forest in Switzerland, however. Replanted areas, for example, can be a source of CO2 at the beginning, because the soil there loses a lot of carbon. This only changes when the trees are bigger and the forest has become established, at which point it becomes a CO2 sink. The older the forest, however, the less carbon is found in the soil, and the more is found in the wood and leaves of the trees. That was proven by National Research Programme 68 'Sustainable use of soil as a resource' (NRP 68).

But will the forests also store CO2 in the future? Buchmann sees two fundamental factors of uncertainty: climate change and forest exploitation. A forest's storage function can be impaired by droughts, by changes in the way it is used, and by changes in the area it covers.

Nevertheless, forests are neither the only source of uncertainty, nor the biggest such factor. Many researchers, including those at Agroscope (the Swiss Federal Centre of Excellence for agricultural research), are concerned about the reduction of the topsoil on account of agricultural usage. In global terms, however, the most sensitive land areas with natural carbon sinks are in the far North. Methane is an especially potent greenhouse gas that is emitted by the permafrost soil as it warms up. According to Hagedorn, the amount emitted depends primarily on whether the soil warms up under humid or dry conditions. The higher the humidity, the greater the amount of methane that is released; when conditions are drier, more CO2 is emitted.

Expedition to the Antarctic Ocean

The oceans also absorb huge amounts of CO2. At present, the most important marine sink for CO2 is the Southern Ocean that stretches around Antarctica. In December 2016, the Swiss Polar Institute (coordinated by EPFL) set out on a research voyage in the Southern Ocean as part of the international Antarctic Circumnavigation Expedition (ACE).

One of the expedition's projects is devoted to studying phytoplankton, because its photosynthesis plays a significant role in the CO2 absorption capacity of the Southern Ocean. When these algae die, they sink to the bottom of the ocean, taking carbon with them. Samuel Jaccard from the Oeschger Centre for Climate Change Research at the University of Bern is one of the participating researchers. During the expedition, the team want to retrieve seawater samples from different depths down to 1,500 metres. They'll bring these samples to the surface in bottles and then subject them to geochemical tests in the lab. The data they hope to gain should explain how carbon is delivered to the ocean depths, and how quickly this occurs.

The amount of CO2 absorbed by the Southern Ocean also depends on the wind that drives the ocean currents. Cold water is good at storing CO2, but in the past, cold, deep water that is rich in CO2 has been driven to the surface by specific wind conditions – and it is at the surface where temperatures are warmer. As a result, the Southern Ocean released CO2 into the atmosphere. But we hardly know anything about the natural fluctuations of wind movements. In order to determine when the Southern Ocean has absorbed and released CO2 in the past, a further ACE project is endeavouring to reconstruct past wind movements. The director of the Oeschger Centre, Martin Grosjean, is participating in this project.

The way the wind blew

During their research voyage, Grosjean's project partners will be drilling on several sub-Antarctic islands to collect sediments from lakes. These will subsequently be analysed in the lab by Grosjean and others. Algae that used to live in these lakes are today found fossilised in this sediment, and they can provide us with information on wind intensity during the Holocene period.

Reconstructing these winds means drawing complex conclusions from the data. The salt content of the island lakes is influenced by the wind intensity, for example. Strong winds drive more spray into the air and more salt into the lakes than do lighter winds. This has an impact on the algae, as Grosjean explains: "Algae vary in their sensitivity to salt". So the species composition of the algae in the sediments can allow the researchers to determine the former salt content of the lake, and thus also the strength of the winds at the time.

In recent years, says Grosjean, the wind has become more intense around the Antarctic. No one yet knows why this has happened. It could be a result of the hole in the ozone layer, or it could be connected to global warming. So it is also difficult to make any prognosis about how much CO2 the Southern Ocean will be able to store in future.

All the same, several studies have already demonstrated that a little more CO2 has been absorbed in recent years than was earlier the case. The same is true of the land biosphere. But we cannot rely on this trend continuing. In order to estimate the danger of CO2 absorption coming to an end, the materials cycles have to be investigated more precisely – both on land and in the seas.

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