Measuring how the Arctic responds to climate change

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Researchers at the University of East Anglia have helped develop a new way to measure how Arctic plants respond to climate change.

Over the past few decades, the Arctic has been warming more than twice as fast as the rest of the planet. At the same time, long-term atmospheric carbon dioxide measurements have shown substantial increases in the amount of carbon absorbed into and emitted by plants and soil—the terrestrial ecosystem—in the Arctic every year.

Scientists had assumed this terrestrial ecosystem was playing a large role in the changes they're seeing in the Arctic carbon cycle.

But they lacked a technique to measure carbon uptake and release independently. And this is key for understanding how the biosphere is responding to climate change driven by fossil fuel emissions.

Now, a new study, published in the journal *Proceedings of the National Academy of Sciences*, provides new insights into this important process over the Arctic and boreal region, based on the modeling of atmospheric measurements of a related chemical—carbonyl sulfide.

Led by researchers at the National Oceanic and Atmospheric Administration (NOAA), the international team of scientists developed a new way of analyzing atmospheric measurements of the trace-gas carbonyl-sulfide, together with atmospheric CO_2 measurements, to provide information on the total amount of carbon taken up by land-vegetation during photosynthesis.

Dr. Parvadha Suntharalingam, from UEA's School of Environmental Sciences,and a co-author on the study, said: "This work gives us new and valuable information about the processes controlling CO_2 uptake by land-based vegetation in the boreal area of the Arctic.

"Carbonyl sulfide is taken by plants during photosynthesis, but unlike CO_2, it is not released back into the atmosphere by the ecosystem respiration processes. It therefore gives us a way of separating the two key processes—photosynthesis and respiration—that control how CO_2 is exchanged between the land-vegetation and the atmosphere.

"This research provides new estimates of the uptake of carbon by terrestrial ecosystems in North American high-latitude regions.

"It reduces the uncertainties in comparison to previous assessments, and also investigates the influence of other environmental factors—such as temperature and solar radiation—on the processes controlling carbon uptake by these high-latitude ecosystems.

"Our analysis shows the potential of using measurements of carbonyl-sulfide as an independent means of obtaining additional information on key carbon cycle processes," she added.

Lead researcher Lei Hu, a Cooperative Institute for Research in Environmental Sciences (CIRES) scientist working at NOAA in Colorado, said: "We now can study how Arctic terrestrial ecosystems react to climate change at process levels, because we are able to separate photosynthetic uptake and ecosystem respiration on regional scales."

What is carbonyl sulfide?

Scientists have long known plants absorb carbon dioxide, or CO_2, to fuel photosynthesis during the growing season, and then emit it back to the atmosphere during fall and winter when plant tissue decays. This give-and-take, set against rapidly rising atmospheric CO_2 levels, makes it impossible for scientists to directly estimate how CO_2 uptake by photosynthesis is changing over time based on measurements of CO_2 alone.

However, plants need other nutrients, including sulfur—which is not released at the end of the growing season. Carbonyl sulfide, or COS, is a simple molecule that is very similar to CO_2.

While CO_2 is made up of one carbon atom and two oxygen atoms, COS consists of one carbon atom, one oxygen atom and a sulfur atom. Continually produced by oceanic processes, it can also be found in volcanic gases, crude oil combustion, sulfurous marshes and soils, as well as diesel exhaust, natural gas, and refinery emissions.

It is present in the atmosphere in tiny amounts (parts per trillion). Uptake by plants is the dominant process that removes COS from the atmosphere.

How are Arctic ecosystems changing?

In the new study, Hu and a team of researchers from NOAA, the University of Colorado, Colorado State University, University of California—Santa Cruz, NASA/Universities Space Research Association, Rutgers University, and UEA analyzed atmospheric measurements of carbonyl sulfide collected from NOAA's Global Greenhouse Gas Reference Network from 2009 to 2013 to investigate carbon cycling in the North American Arctic and boreal regions.

The UEA contribution provided data and information on the oceanic sources of carbonyl-sulfide to the atmosphere. Oceanic emissions provide the largest global source of COS to the atmosphere—so accurate knowledge of these fluxes is needed when using atmospheric measurements to identify and quantify the uptake of COS and CO_2 by vegetation during photosynthesis.

The team estimated plants over this region took up 3.6 billion metric tons of carbon from the atmosphere during photosynthesis each year. They also found that warming temperatures were causing increases in both net uptake in spring and net off-gassing in fall, but not equally, due to regulation by both temperature and light.

From 1979–1988 to 2010–2019, the annual spring soil temperature in the region increased by an average of 0.9°F, while the autumn temperature increased by 1.8°F. The researchers found that in spring, the soil temperature increase helps to ramp up photosynthetic uptake of carbon as sunlight floods the region. In the autumn, the amount of carbon taken up by plants is reduced by the dwindling amount of sunlight, despite soil temperatures remaining elevated until late autumn.

In contrast, when it came to giving off CO_2, the scientists found the rate was mainly controlled by temperature.

The results were also consistent with satellite remote-sensing-based gross primary production estimates in both space and time, boosting confidence in the findings.

Implications for the future

One of the big unknowns about the future Arctic is whether plant communities around the Northern Hemisphere will continue to increase their carbon uptake as atmospheric CO_2 rises. One way to obtain a clearer picture, Hu said, would be to make more COS measurements from the region.

If Arctic surface temperature continues to increase, especially in the fall and winter, the Arctic may start emitting more CO_2 than it takes up, exacerbating climate change.

Expanding the atmospheric COS observing system could improve scientists' ability to monitor how much carbon land plants are removing from the atmosphere as CO_2 levels increase and climate changes, which would improve understanding of the climate-carbon cycle feedbacks and climate projections in the Arctic and Boreal regions.

"COS-derived GPP relationships with temperature and light help explain high-latitude atmospheric CO_2 seasonal cycle amplification" is published in the *Proceedings of the National Academy of Sciences*.

More information: Lei Hu et al, COS-derived GPP relationships with temperature and light help explain high-latitude atmospheric CO2 seasonal cycle amplification, *Proceedings of the National Academy of Sciences* (2021). DOI: 10.1073/pnas.2103423118

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