Flourishing vegetation increases carbon dioxide amplitude

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Amplifiers of an atmospheric oscillating movement: As boreal forests like the ones here in Siberia keep expanding due to global warming, and the vegetation at higher latitudes photosynthesizes to a greater extent, seasonal fluctuations in atmospheric carbon dioxide concentrations are increasing, particularly in the North. © Michael Hielscher, MPI of Biogeochemistry

All over the world, monitoring stations are registering rising atmospheric levels of the greenhouse gas carbon dioxide. However, in high northern latitudes another trend can also be seen: seasonal variation in carbon dioxide concentration has been increasing since the 1960s. This is mainly due to increasing plant growth in the North, according to a paper published in the latest issue of *Science* by researchers from the Max Planck Institute of Biogeochemistry in Jena and their colleagues at the Potsdam Institute for Climate Impact Research (PIK) and from the US. Higher temperatures allow more forests to expand, enhancing photosynthesis. In summer, the vegetation absorbs more carbon dioxide.

The team working with the Jena-based scientists has now solved a tricky climate riddle. Until now, the observed trend could not be reproduced using conventional climate models, and therefore could not be explained – presumably because the models did not represent processes in the vegetation and climate dynamics accurately enough.

Since 1958, measurements at the Mauna Loa volcano in Hawaii have documented the year-on-year rise in atmospheric CO2 levels. Back then, the concentration was 315 ppm (parts per million); by now, it has increased to a good 400 ppm. However, the famous Mauna Loa trend is not growing steadily, but rather oscillates during the year. Every year in spring, a new record high is registered. This is due to the fact that the photosynthesis taking place during boreal winter is very limited. For months, the vegetation hardly takes up any CO2 from the air, while human emissions accumulate. In addition, plants and soils release some of the previously absorbed carbon dioxide to the atmosphere through respiration, in which carbohydrates are degraded.

Several hypotheses relating to the increased CO2 amplitude

"In September, CO2 levels drop to a minimum because the vegetation in the northern hemisphere has been taking up carbon dioxide from the air during the whole summer", explains Matthias Forkel. He recently moved from the Max Planck Institute in Jena to TU Wien in Austria. He and Nuno Carvalhais from the Max Planck Institute of Biogeochemistry are the first authors of the study.

In the early 1960s, the seasonal carbon dioxide amplitude in Hawaii amounted to 6 ppm. In the meantime, it has risen to approx. 7 ppm. The increase in northern regions has been even greater. For instance, in Barrow, Alaska, the annual CO2 values in the beginning of the 1960s varied by 15 ppm. This variation has now increased to 18 ppm, which corresponds to an increase of nearly 25 per cent. Using aircraft measurements, a team working with British scientist Heather Graven in 2013 proved that these changes in the northern latitudes are wide-ranging, even at altitudes of around 6 kilometres.

Graven and her colleagues did not provide an explanation for the trend in the article they published in *Science* back then, as the increase did not show up in climate models. According to Markus Reichstein, Director at the Max Planck Institute of Biogeochemistry in Jena and co-author of the new study, there were several hypotheses on why the amplitude increases. At that time, many scientists already suspected that the phenomenon was related to observed increased greening in the Arctic. Some blamed the intensified agriculture and its higher yields; others thought that the CO2 fertilisation effect might be the cause.

Higher temperatures boost plant germination in northern ecosystems

The aim of the Jena scientists was to investigate the matter by combining observations with modelling techniques. "We improved our vegetation

model, which was developed in Jena, Potsdam and Lund, using satellite data from the last 30 years. This way, we were able to correctly simulate the trend in the CO2 amplitude", Matthias Forkel says.

As they report in Science, climate change is the main cause of the greater CO2 amplitude. The higher temperatures allow plants north of the 45th latitude to germinate more intensively than before. Boreal forests are spreading. Bushes and shrubs are starting to cover the once bare tundra and the vegetation period begins earlier in the year everywhere. All this means that more CO2 is taken up from the atmosphere in summer than 50 years ago. "However, the respiration of plants and soils has not augmented to the same extent", Matthias Forkel explains. Therefore, the difference between summer and winter has become greater.

Huge climate–vegetation feedbacks

The scientists also discovered that plant productivity in the North is hardly affected by the increased amount of CO2 available to the plants. "At higher latitudes, the CO2 fertilization effect is an insignificant factor", reports Markus Reichstein. A further finding: Agriculture does not contribute nearly as much to the increase in the seasonal CO2 amplitude as was previously calculated by other scientists.

"It is very clear that there are huge feedbacks between climate and vegetation," Markus Reichstein recaps. The vegetation model, which was to a large extent developed at the Potsdam Institute for Climate Impact Research and is being tested at the Max Planck Institute in Jena using observations, describes these complex relationships more accurately than conventional earth-system models. For instance, it is better at registering that plants sprout earlier when temperatures increase, or that there is more water available to vegetation in permafrost areas as the climate becomes warmer.

Whether the increase in seasonal CO2 fluctuations will continue in the future and which repercussions this will have on global warming, cannot be concluded from the study. The expansion of boreal forests will probably also have a negative impact on climate change, according to Matthias Forkel: "The land surface is becoming darker and absorbs a larger part of incident solar radiation. It therefore warms up more than in the past." This, in turn, could cause forest fires and droughts to become more frequent or pests to become more prevalent. It is therefore not clear whether the greening of the North will continue.

More information: M. Forkel et al. Enhanced seasonal CO2 exchange caused by amplified plant productivity in northern ecosystems, *Science* (2016). DOI: 10.1126/science.aac4971

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