News & views

Biogeochemistry

Southeast Amazonia is no longer a carbon sink

Scott Denning

Atmospheric measurements show that deforestation and rapid local warming have reduced or eliminated the capacity of the eastern Amazonian forest to absorb carbon dioxide — with worrying implications for future global warming. **See p.388**

Since at least the inception of modern records of atmospheric carbon dioxide levels in the 1950s, there has been a small global excess (about 2%) in the amount of CO_2 taken up by land plants for photosynthesis, compared with the amount emitted as a result of the decomposition of organic material. This land carbon sink has absorbed around 25% of all fossil-fuel emissions since 1960 (ref. 1), offsetting some global warming. Tropical forests have been a major component of the land carbon sink, and the largest intact tropical forest is in Amazonia. On page 388, Gatti *et al.*[2] report extensive direct sampling of the atmosphere over this region. Their data reveal that western Amazonia is still a relatively weak carbon sink, but suggest that deforestation and warming over eastern Amazonia have degraded — or even reversed — regional uptake of carbon by the forest.

The sink arises from a combination of the increased vegetation growth that occurs in response to rising levels of CO_2 and other nutrients, changes in land management and ecosystem responses to climate change[3]. Tropical forests are Earth's most productive ecosystems, but they are not recovering from past human disturbance as their counterparts at mid-latitudes have done, nor are they benefiting from the markedly longer growing seasons associated with climate change, as are boreal and arctic ecosystems.

Carbon has accumulated in the biomass of Amazonian forests for decades[4], but studies in the past few years suggest that Amazonian carbon sinks are threatened by deforestation and forest degradation[5], progressive drying of the climate, and fires[6]. However, it is difficult to make direct measurements that reflect the local carbon balance of many Amazonian ecosystems, because access to those regions is limited. And it is hard to extrapolate available local data[7,8] across the whole region, because Amazonian ecosystems vary enormously.

Satellite measurements of atmospheric levels of CO_2 and carbon monoxide (a tracer of combustion), and of solar-induced fluorescence from vegetation (a proxy for photosynthesis), show that the year-to-year carbon balance in Amazonia is quite sensitive to drought and fire[9]. However, persistent cloud cover in this region complicates the acquisition of such measurements, and the collection of these data began only about a decade ago. Direct measurements of the atmosphere could constrain estimates of regional carbon balance, but are sparse for Amazonia.

Enter Gatti and colleagues, who have directly measured the atmosphere in four regions across Amazonia for nine years (2010–18; Fig. 1). The authors used aircraft to collect air samples from near the surface up to an altitude of 4.5 kilometres at each region, then analysed the samples to produce a vertical profile of the concentrations of a suite of gases, including CO_2 and CO. The authors produced 590 vertical profiles during their study, with a typical sampling period of about twice a month at each region.

Gatti *et al.* also used data from several sites on remote islands and coastal headlands around the South Atlantic Ocean to establish background concentrations of gases. This allowed them to compute spatial gradients of CO_2 and CO concentrations between the background sites and each of the profiled regions in Amazonia. The authors analysed their data by season and by year, and determined how the spatial patterns of CO_2 and CO concentrations varied according to the region over which sampled air had passed before collection. Finally, they used the seasonal CO_2 concentration gradients to estimate regional carbon flux associated with forest growth and decay, and estimated carbon emissions produced by fires from the CO gradients.

Northwestern Amazonia is almost always very wet, and shows little seasonal variation in growth and decay. Gatti and colleagues' atmospheric profiling indicates that this

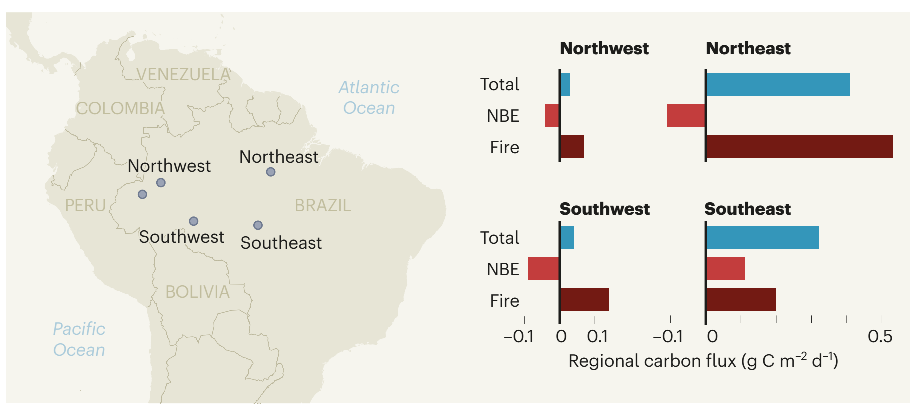

Figure 1 | Carbon fluxes in different Amazonian regions. From 2010 to 2018, Gatti *et al.*[2] measured vertical profiles of atmospheric concentrations of carbon dioxide and carbon monoxide above four regions in Amazonia (the two locations shown in northwestern Amazonia were counted as one region), and thereby calculated regional carbon fluxes upwind of each site, measured in grams of carbon per square metre per day. In the bar charts, net biome exchange (NBE) represents the average annual balance of CO_2 absorbed by forests for photosynthesis compared with the amount of CO_2 produced by the decay of organic matter (negative NBE values indicate that the forest acts as a carbon sink); 'fire' represents the average carbon emissions produced by fires; and 'total' represents the sum of NBE and fire emissions. The NBE values indicate that most regions of Amazonia are weak carbon sinks, but southeastern Amazonia is actually a carbon source.

region was close to carbon balance during the period of the study — about as much carbon was taken up by plants for growth as was emitted from decay processes.

However, the moisture and fertility of Amazonian forests changes substantially farther south and east. Dry seasons (periods with rainfall of less than 100 millimetres per month) get progressively longer, eventually lasting for 5 months or more as the forest grades into savannah[10]. Gatti and colleagues find that the drier forests in the northeastern and southeastern regions studied were close to carbon balance during the wet season, but that carbon release from decomposition and fire tended to exceed carbon uptake by photosynthesis during the dry season. The observed regional and seasonal patterns of carbon uptake in the northwest transitioning to carbon release in the drier east were consistent with the year-to-year variability of the data — which revealed that greater carbon releases, associated with decomposition and fire, occurred during hotter and drier years.

Gatti and co-workers show that the transition of eastern Amazon forests from carbon sink to carbon source during the dry season is associated with strong regional warming trends. Eastern Amazon sites have warmed by as much as about 0.6 °C per decade during the dry season over the past 40 years. This is more than three times the rate of global warming and about the same rate as for the Arctic. Wet-season and western Amazonian forests have warmed, too, but at a much slower rate. Warming rates in the dry season for eastern Amazonia might have been amplified by deforestation and forest degradation. Gatti *et al.* conclude that increases in fires, and in physiological stress, mortality and decomposition of trees in this area, are associated with increasing carbon loss from regional ecosystems.

The authors have documented the accelerating transition of forests from carbon sinks to sources using direct measurements of large-scale gradients of atmospheric gas concentrations. The overall pattern of deforestation, warmer and drier dry seasons, drought stress, fire and carbon release in eastern Amazonia seriously threatens the Amazon carbon sink. Indeed, the results cast doubt on the ability of tropical forests to sequester large amounts of fossil-fuel-derived CO_2 in the future.

For decades, ecologists have been surprised that the fraction of fossil-fuel emissions absorbed by land ecosystems has remained fairly constant[11], even though these emissions have increased. Forests at high latitudes have continued to accumulate carbon because their growing seasons have lengthened as a result of climate change. Mid-latitude forests have done so because they have been recovering from past clearance, and because they have benefited from the increased availability of nutrients (produced as a result of human activities, or mobilized in soils by climate warming).

By contrast, increased carbon sequestration by tropical forests must be driven largely by an increase in photosynthesis associated with rising CO_2 levels — but regional atmospheric profiling[12] suggests that this carbon sink is threatened by forest degradation and warming. Another complication is that fossil-fuel emissions must be quickly reduced to meet international climate targets, but it is not clear how the CO_2-driven carbon sinks of tropical forests will respond to a rapidly warming world in which CO_2 levels are no longer rising[13]. The future of carbon accumulation in tropical forests has therefore long been uncertain. Gatti and colleagues' atmospheric profiles show that the uncertain future is happening now.

> **"The results cast doubt on the future ability of tropical forests to sequester large amounts of carbon dioxide."**

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Microbiology

Deciphering metabolism, one microbe at a time

William F. Kindschuh & Tal Korem

Small molecules produced and modified by gut microorganisms can influence human physiology. An atlas of metabolic outputs of diverse gut microbes offers new ways to decipher the microbial mechanisms behind their production. **See p.415**

The microorganisms in our gut can have far-reaching effects — on our liver[1], arteries[2] and potentially even on our behaviour[3]. One way these microbes exert their effects is through the generation or consumption of small molecules, termed metabolites. Measuring metabolite levels, an approach called metabolomics, has led to ever-increasing recognition of their importance. And yet only rarely do we understand the underlying mechanisms driving these levels: namely, which microbes, enzymes and interactions are involved in the production and uptake of a specific metabolite. This task is further hindered by the complexity of microbial communities such as the gut microbiome, studies of which have to take into account the large number of microbes, the interactions between them, their diverse metabolic capabilities and several hard-to-measure non-microbial factors, such as host diet[4]. On page 415, Han *et al.*[5] present a comprehensive approach to