The Amazon is reaching its carbon tipping point

Johanna L. Miller

Citation: Physics Today **74**, 9, 12 (2021); doi: 10.1063/PT.3.4828
View online: https://doi.org/10.1063/PT.3.4828
View Table of Contents: https://physicstoday.scitation.org/toc/pto/74/9
Published by the American Institute of Physics

ARTICLES YOU MAY BE INTERESTED IN

Better ways to store energy are needed to attain Biden's carbon-free grid
Physics Today **74**, 20 (2021); https://doi.org/10.1063/PT.3.4831

Computed tomography turns 50
Physics Today **74**, 34 (2021); https://doi.org/10.1063/PT.3.4834

An unconventional superconductor isn't so odd after all
Physics Today **74**, 14 (2021); https://doi.org/10.1063/PT.3.4829

Improving science education: It's not rocket science—it's harder!
Physics Today **74**, 26 (2021); https://doi.org/10.1063/PT.3.4833

How does the wind generate waves?
Physics Today **74**, 38 (2021); https://doi.org/10.1063/PT.3.4880

The demons haunting thermodynamics
Physics Today **74**, 44 (2021); https://doi.org/10.1063/PT.3.4881

The Amazon is reaching its carbon tipping point

The tropical forest can no longer be counted on to help clean up humanity's environmental mess.

Greta Thunberg, the Swedish environmental activist, points out in her social media profiles that she was "born at 375 ppm"—a reference to the atmospheric concentration of carbon dioxide at the time of her birth in January 2003. By January 2021, that concentration had reached 415 ppm. The 40 ppm increase means that the atmosphere's carbon content rose by 85 billion tons over those 18 years.

As destructive as that increase has been, as evidenced by the increasing incidence of severe weather all over the world, it could have been a lot worse. Anthropogenic carbon emissions average roughly 10 billion tons a year, which is twice as much over 18 years as the amount that ended up in the atmosphere.

Where did the rest of it go? Half of it dissolved in the ocean—where it's doing its own damage by acidifying marine waters, but at least it's not warming the whole climate. The rest was taken up by land ecosystems, with tropical forests such as the Amazon thought to be doing an outsize share of the work.

But forests' role as carbon sinks is not inevitable. Trees and other plants absorb carbon during photosynthesis, but they also release it again when they die and decay. Over the long term, those processes must be in near equilibrium. Humankind has been fortunate, so far, that forests have responded to rising atmospheric CO_2 levels by taking in more carbon than they release, thereby shielding us from the full impact of our emissions.

That protective effect may already be waning, concludes a research team led by Luciana Gatti of Brazil's National Institute for Space Research in São José dos Campos.[1] Just in the past decade, a large portion of the southeastern Amazon appears to have flipped from carbon sink to carbon source—even after the researchers discount the substantial carbon emissions from the many fires that are deliberately set to clear the land (as shown in figure 1) for cattle ranching and other agriculture.

FIGURE 1. DELIBERATE BURNING to make way for agriculture destroys thousands of square kilometers of the Amazon rainforest every year, mostly in the more populated east. The fires themselves are considerable sources of carbon emissions, and the deforestation also upsets the carbon balance of the remaining forest through its effect on the local climate. (Photo by guentermanaus/Shutterstock.com.)

Airborne

It's not easy to measure how much carbon is flowing into or out of a forest the size of the Amazon. More than two decades ago, Gatti and her colleagues noticed a scale gap in the understanding of carbon fluxes: Most studies focused on either extremely small scales (tracking the growth and carbon content of individual trees, for example) or extremely large ones (inferring the net carbon balance of all the world's land ecosystems put together by estimating the fluxes through the atmosphere and ocean).

To bridge the gap, they took a clever but laborious approach. Starting in December 2000, they hired a light aircraft to repeatedly fly above the small northern Brazilian city of Santarém and collect flasks of the air that was wafting over the Amazon.[2] The samples carried a record of all the trace gases emitted or absorbed by the parts of the forest they traversed: If a parcel of air passed through a carbon source, it would pick up more CO_2 than the atmospheric average; if it passed through a carbon sink, it would have less. Because the Brazilian trade winds blow reliably from east to west, with a variable north–south component, the Santarém samples probed a region of the northeast Amazon making up some 10% of the forest's area.

As the results came in, two things stood out. The first was how large the forest's CO_2 emissions were: The air above Santarém consistently contained more CO_2, not less, than the fresh Atlantic air entering the Amazon from the east. "It was much more than we expected," says

Gatti, "and the community was skeptical at first." The excess carbon was coming from deliberately set fires: Cutting and burning of the Amazon, although unlawful, is common. (See PHYSICS TODAY, May 2004, page 24.) To separate the fire emissions from the ecosystem's carbon flux, the researchers tracked the samples' concentrations of carbon monoxide—released in combustion but not in biological processes—along with their CO_2 content.

The second striking observation was the variability of the numbers. Fire emissions showed a seasonal pattern, as trees were cut during the region's wet season from January to June and burned during the dry season from July to December. The ecosystem's carbon flux also varied a lot from season to season and from year to year. "It was clear that we needed long-term measurements to really understand what was going on," says Gatti.

It was also clear that understanding the whole Amazon would entail sampling beyond just Santarém. The vast forest is regionally heterogeneous: The east is more populated than the west, so deforestation and fires are concentrated there. The eastern Amazon is also dry for half the year, with the dry-season months averaging not much more than 50 mm of rainfall, whereas monthly rainfall in the western Amazon seldom dips below 100 mm. Those differences could easily affect the regions' carbon balance.

Spreading out

In 2010 the researchers began a new project to take their measurements Amazon-wide. Twice a month they'd collect air samples from above not one but four sites around the Brazilian Amazon. In addition to Santarém in the northeast, the sites included Rio Branco in the southwest and Alta Floresta in the southeast—both population centers with plenty of air commerce and easy access.

Sampling from the northwestern Amazon proved far more of a challenge. Few commercial airports serve the sparsely populated, impoverished area, and few local pilots were available to collect and transport the samples. Initially, from 2010 until 2012, the researchers contracted with a one-airplane company in the town of Tabatinga. That relationship came to an end when the plane crashed. In 2013, they restarted sampling in the city of Tefé, a few hundred miles away, and they've been collecting samples from there ever since.

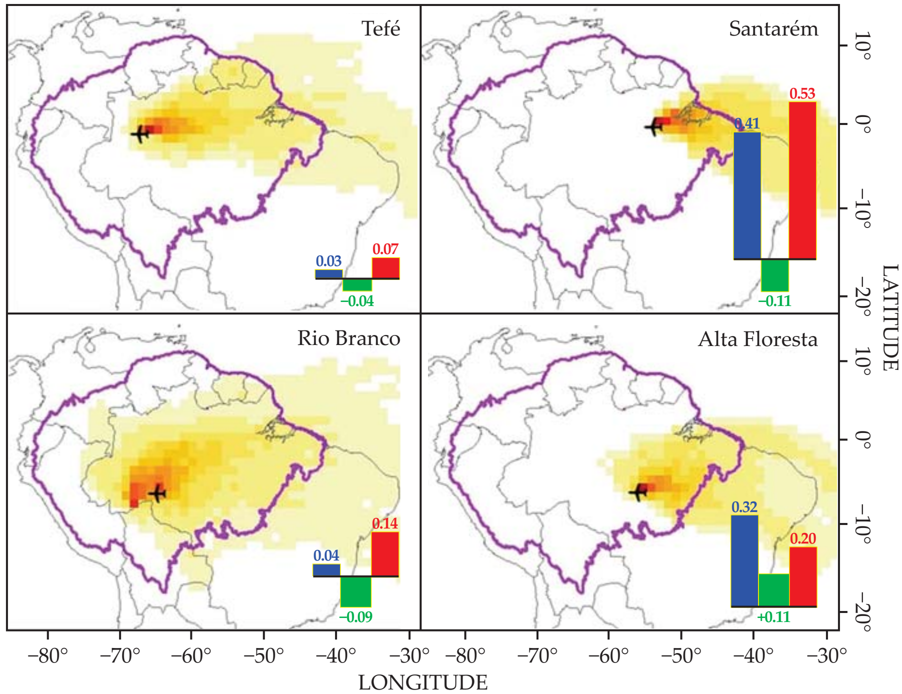

FIGURE 2. AMAZONIAN AIR Carries a record of all the atmospheric gases absorbed or emitted at points upwind of the sampling site. Based on an analysis of wind patterns from 2010 through 2018, the shaded areas on the maps show the average regions of influence for four sites throughout the Amazon. The bar charts show the carbon fluxes for each region in units of tons of carbon per square kilometer per day: Total carbon emission is shown in blue, carbon emitted by fires in red, and carbon exchange by the ecosystem in green. In the region around Alta Floresta in the southeast, even the ecosystem is now a net carbon source, not a sink. (Adapted from ref. 1.)

The project's first paper, published in 2014 and covering data from 2010 and 2011, highlighted the Amazon's year-to-year variability.[3] Whereas 2010 was a major drought year in Brazil, 2011 was relatively wet. Fires in both years caused significant carbon emissions—but in 2011 the emissions were roughly compensated by the ecosystem's carbon sink, whereas in 2010 the ecosystem absorbed almost nothing. When the forest dried out, its capacity to absorb carbon was hindered.

The current paper[1] analyzes the samples collected from January 2010 through December 2018. During that time, the researchers periodically reran a model of wind trajectories to assess what parts of the Amazon their samples were probing. Those average regions of influence are shown in figure 2. (Tabatinga isn't shown, but its region of influence is similar to Tefé's.)

The bar charts in the figure show the carbon fluxes for each region averaged over the nine-year period: net carbon balance (blue), as measured by the samples' CO_2 concentrations; fire emissions (red), as inferred from the samples' CO; and the ecosystem flux (green), which is the difference between the two. As the measurements show, the western Amazon (Tefé and Rio Branco) is nearly carbon neutral: The ecosystem absorbs most of the carbon that the fires emit. In the eastern Amazon (Santarém and Alta Floresta), fire emissions are more significant. And not only are they not balanced out by the ecosystem absorptions, but the ecosystem around Alta Floresta is itself a net carbon emitter.

Out to dry

That alarming result appears to be a new development. At the beginning of the study period—perhaps even in the drought year of 2010—the researchers' measurements indicated that the Alta Floresta–area ecosystem was probably a net absorber of carbon. But the trend since then has been progressively in the direction of net carbon emission.

Why the change, and could the rest of the Amazon follow suit? Part of the explanation may lie in the southeast Amazon's physical geography. Despite its overall wetness, the region is unusually devoid of large lakes and rivers, so it relies heavily on evapotranspiration from trees and other plants to supply the atmosphere with moisture that falls again as rain. When part of the area is deforested, the remaining forest is deprived of rainfall, and its health suffers.

Evapotranspiration is also important for regulating temperature: The energy of converting water into vapor helps cool the forest, so the loss of a moisture source makes the region hotter. Compared with other parts of the world, tropical forests don't usually experience wide temperature swings, so their organisms are adapted to narrow temperature ranges (see PHYSICS TODAY, September 2019, page 16). Even a small amount of warming can threaten species' ability to thrive. Dry-season temperatures in the southeast Amazon have already risen by a whopping 2.5 °C in just the past four decades.

The changing climate, the researchers conclude, creates a feedback cycle. As the forest becomes hotter and drier, organisms die off, and the ecosystem grows less resilient and less able to keep itself cool and moist in years to come. All the while, it's emitting more and more carbon than it can absorb.

The southeast Amazon is especially vulnerable due to its paucity of water sources, but all parts of the Amazon are trending toward higher temperatures and drier dry seasons. "Every quantity in every region has been linear for 40 years," says Gatti, "except for the temperature change in the southeast, which is accelerating. Other regions could start accelerating too, because all the processes are interconnected."

The researchers' current analysis extends only through 2018, so it doesn't cover the effects of the devastating 2019 wildfires or the ongoing COVID-19 pandemic. But apart from some disruptions—one of the pilots they were working with died of COVID-19—they've kept collecting samples and are continuing to analyze them. "We can't stop," says Gatti. "The Amazon is changing very quickly, and going on with these measurements is very important."

Johanna Miller

References

1. L. V. Gatti et al., *Nature* **595**, 388 (2021).
2. J. B. Miller et al., *Geophys. Res. Lett.* **34**, L10809 (2007); L. V. Gatti et al., *Tellus, Ser. B* **62**, 581 (2010).
3. L. V. Gatti et al., *Nature* **506**, 76 (2014).

An unconventional superconductor isn't so odd after all

NMR measurements and previously published specific-heat data rule out earlier claims of strontium ruthenate's spin-triplet superconductivity.

As electrons move through a Bardeen-Cooper-Schrieffer (BCS) superconductor, they attract positive charges in the lattice, and the subsequent deformation leads to an attractive interaction between time-reversed electron states. Below some critical transition temperature T_c, that electron–phonon interaction forms Cooper pairs of electrons with *s*-wave symmetry, and their collective behavior constitutes a macroscopic quantum state of matter. That is, the electrons stay paired and flow through a superconductor without any resistance. (See the article by War-

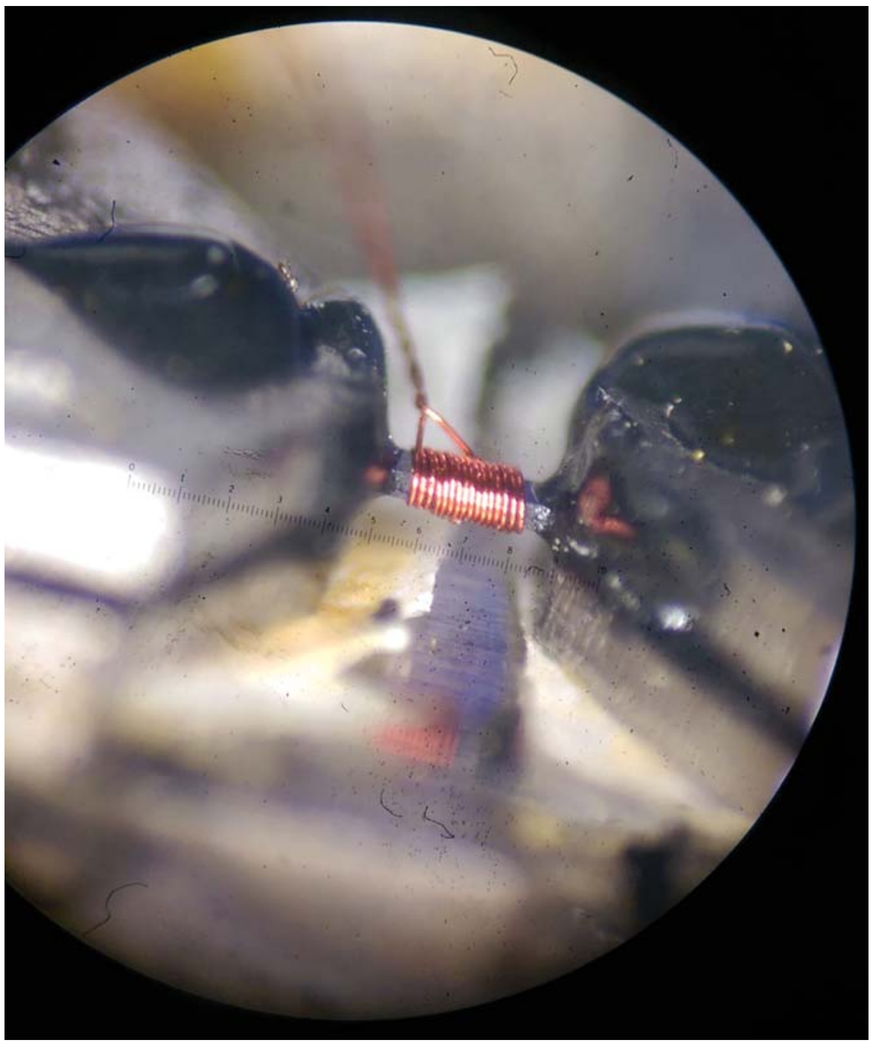

FIGURE 1. STRONTIUM RUTHENATE is superconducting below a critical transition temperature of 1.5 K. Researchers explored its unconventional superconducting state by wrapping a crystalline sample in an NMR coil and observing its response to a magnetic field. The results showed no detectable magnetic response from the superconducting condensate. That finding rules out previously postulated theories of odd-parity superconductivity in which paired electrons have the same spin. (Courtesy of Andrej Pustogow.)