Urban pollution enhances up to 400% formation of aerosols over the Amazon rainforest

June 4 2019, by Maria Fernanda Ziegler

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A study by an international team of researchers, including Brazilian scientists, shows that urban pollution from Manaus, the capital of Amazonas State in Brazil, increases the formation of aerosols via the Amazon Rainforest far more than expected.

This sharp increase in aerosols produced by the forest has a significant impact on key drivers of global climate change, such as radioactive balance, production of clouds and rain, and the rate of plant photosynthesis. Where urban pollution does not affect the forest, organic aerosols are produced by soil in the region, but in far smaller quantities, according to the study.

Similar research concerning boreal forests, which were used as a basis for global climate modeling, have shown a maximum increase in levels of secondary organic aerosols of 60 percent due to pollution from nearby cities.

"For the first time, we were able to model and predict aerosol levels in the Amazon. Climate models based on the Northern Hemisphere are known not to apply to the Amazon Rainforest. We realized that the numbers derived from other studies didn't add up. The results of this new study will therefore make meteorological models more accurate and refine regional as well as global climate modeling," said published in *Nature Communications*, urban pollution results in an average increase of 200 percent in the formation of secondary organic aerosols, with spikes of up to 400 percent. FAPESP supported the study as part of the Green Ocean Amazon Experiment and a Thematic Project linked to the Research Program on Global Climate Change.

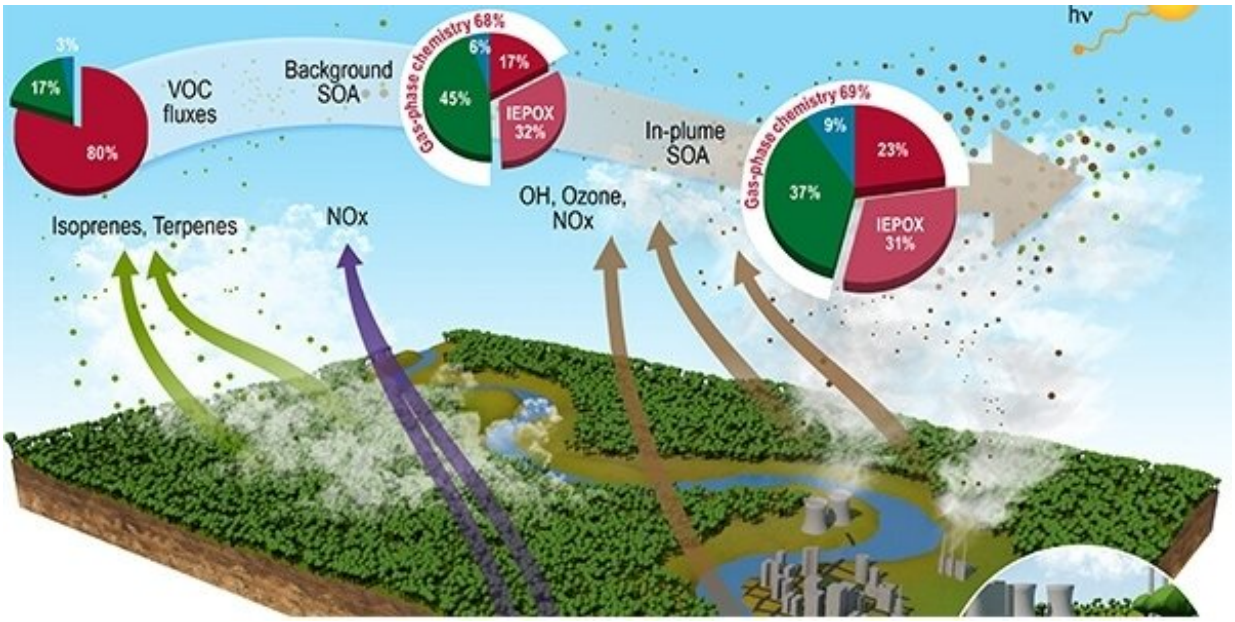
Paulo Artaxo, full professor at the University of São Paulo's Physics Institute (IF-USP) and one of the authors of the article, says the next step is to include tropical aerosol chemistry in global climate models, such as those used by the U.N. Intergovernmental Panel on Climate Change (IPCC), for example, so that they more accurately forecast hydrological cycles in the Amazon and detect changes in rainfall patterns throughout Earth's tropical region.

Small alteration, major impact

An aerosol is a suspension of fine solid particles or liquid droplets in the air. Primary aerosols are produced naturally by forests, comprising dust, pollen, ash and carbon particles from wildfires, for example. Secondary aerosols are formed in the atmosphere by the chemical reactions of primary aerosols and gaseous precursors or volatile organic compounds (VOCs) emitted by forests and human activities, such as the burning of fossil fuels.

The increase of up to 400 percent in secondary organic aerosols due to the Manaus pollution plume has a significant effect on the environment. These aerosols play a major role in solar radiation absorption by the atmosphere to form rainclouds, among other things.

The Manaus plume contains high levels of ozone (O3), nitrogen oxide, sulfur dioxide (SO2) and hydroxyl radicals (OH). "When levels of sulfur and nitrogen compounds from urban pollution build up in the atmosphere, biogenic vapors in the forest are oxidized much more rapidly, forming many new aerosols—far more than would be the case if the process were purely natural," said Henrique Barbosa, also a professor at IF-USP and a coauthor of the article.



This phenomenon affects cloud production and rainfall, with consequences for the local and global climate, which researchers have warned about in the study published in *Nature Communications*. Credit: *Nature Communications*

In this study, the international research group analyzed the consequences of these changes observationally and experimentally using mathematical models. They also performed computer simulations on the formation of this large quantity of aerosols, identifying the processes associated with their origin and the chemical mechanisms missing from the models used.

"The Amazon region is mostly quite pristine and free of pollution. A tiny increase in nitrogen compounds, for example, triggers a huge rise in forest aerosol levels," Barbosa said. "The disturbance caused by anthropogenic emissions is very violent and affects the climate of the region, the hydrological system and the global climate."

The strongest impact of this change is on cloud formation in the

Amazon. "We saw how high levels of ultrafine aerosols in the clouds change the velocity of the ascending air, making the clouds more vigorous with more precipitable water," he added.

Photosynthesis

The quantity of aerosols also strongly influences photosynthesis via the forest, which depends on solar radiation to fix carbon levels. "We observed that to a certain extent, the rise in the levels of secondary aerosols makes photosynthesis more efficient. Then, the reactions take place more slowly," Barbosa said.

He explained that this occurs because of the interaction between aerosols and solar radiation. The aerosols circulate freely in the air and change the amount of both direct (sunlight that creates shade) and diffused radiation received by the forest.

Diffused radiation in the forest penetrates deeper into the vegetation, from the canopy down to the lowest leaves, so plants can use it for photosynthesis. Direct radiation only reaches the highest leaves, and from there down, it creates shade.

"When aerosol levels in the atmosphere rise, photosynthesis increases, but if these levels become excessive, they hinder photosynthesis. Ultimately, it makes no difference if diffused radiation increases, as the aerosols block the sunlight, and the plants are unable to use much carbon," Barbosa said.

Isoprene

According to researchers, the study shows that tropical forests are significantly more dynamic than was originally thought. "The increase in

aerosols caused by pollution is far greater in tropical forests [400 percent] than in boreal forests [60 percent]. This is due to different emission and oxidation mechanisms, as well as the presence of isoprene only in tropical forests," Artaxo said.

Isoprene is one type of VOCs naturally emitted by vegetation in tropical forests as part of the metabolism of vegetation. Isoprene is emitted in large amounts by the Amazon Rainforest and has a short half-life in the atmosphere, where it is converted into aerosol particles. "The transformation of isoprene into particles is greatly accelerated by the presence of pollution from Manaus, especially nitrogen oxide emissions," Artaxo said.

In boreal forests, there are no isoprene emissions, although these forests emit low levels of terpene (another VOC). However, the atmospheric chemistry of this gas is entirely different from that of isoprene.

"This makes tropical forest emissions the key to particle production and ozone formation, with a chemistry that was unknown before the GOAmazon experiment," Artaxo said. "Now that we know the chemical mechanisms, we can include them in global climate models to advance our understanding of the role played by tropical forests in the planet's climate."

He added that the increase in secondary organic aerosols is not only associated with urban pollution, such as vehicle emissions. This may also be due to other activities that produce nitrogen oxide, such as forest fires and the use of generators in small towns across the Amazon region.

"We discovered that nitrogen oxide is the catalyst for secondary organic aerosol formation. If this compound is present in pollution, regardless of the cause or origin, the production of particles will intensify," Artaxo said.

More accuracy

Most climate models are currently based on data and processes typical of the Northern Hemisphere. In the case of secondary organic aerosols and their impacts, the models do not accurately reflect conditions in tropical forests, such as the Amazon.

To produce a new model including data for the Amazon, the researchers used measurements taken by aircraft owned by the US Department of Energy (DoE), data obtained at the surface by a number of sampling stations, and sophisticated computer software that simulated atmospheric chemistry and meteorology at a regional scale to detect correlations between weather and chemical processes in the atmosphere over this forest.

This approach enabled the researchers to use the data on the chemical reactions involved to calibrate the WRF-Chem model, an existing model that couples atmospheric dynamics and chemistry, so that they could simulate the dispersion of the Manaus pollution plume and additional aerosol production due to the interaction between this pollution episode and natural (biogenic) emissions from the forest.

The next step will be to integrate these processes into global climate models to enhance long-range weather forecasting and projections of rainfall and particle formation while advancing scientists' understanding of the role of tropical forests in climate change.

More information: Manish Shrivastava et al, Urban pollution greatly enhances formation of natural aerosols over the Amazon rainforest, *Nature Communications* (2019). DOI: 10.1038/s41467-019-08909-4

Provided by FAPESP