How trees influence cloud formation

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As part of the international CLOUD project at the nuclear research center CERN, researchers at PSI have identified so-called sesquiterpenes—gaseous hydrocarbons that are released by plants—as being a major factor in cloud formation. This finding could reduce uncertainties in climate models and help make more accurate predictions. The study has now been published in the journal *Science Advances*.

According to the latest projections of the Intergovernmental Panel on Climate Change (IPCC), the global climate will be 1.5 to 4.4 degrees Celsius warmer than pre-industrial levels by 2100. This figure is based on various scenarios describing how anthropogenic greenhouse gas emissions may develop in the future. So in the best case, if we manage to curb emissions quickly and radically, we can still meet the 1.5 degree target of the Paris Agreement.

In the worst case, we will end up far above that. However, such projections are also subject to some uncertainty. In the worst-case scenario, for example, with emissions continuing to increase sharply, the rise in temperature could be as low as 3.3 or as high as 5.7 degrees Celsius, rather than 4.4 degrees.

These uncertainties in predicting how temperatures will change as a result of concrete developments in greenhouse gas emissions are essentially due to the fact that scientists do not yet fully understand all the processes that occur in the atmosphere—the interactions between the various gases and aerosols in it. Establishing them is the aim of the CLOUD project (Cosmics Leaving Outdoor Droplets), an international collaboration between atmospheric researchers at the CERN nuclear research center in Geneva. PSI helped to build the CLOUD chamber and is a member of the project's steering committee.

The mystery of cloud formation

Particularly the way in which cloud cover will develop in the future remains largely nebulous for the time being. However, this is a key factor in predicting the climate because more clouds reflect more solar radiation, thus cooling the earth's surface.

To form the droplets that make up clouds, water vapor needs condensation nuclei, solid or liquid particles on which to condense.

These are provided by a wide variety of aerosols, tiny solid or liquid particles between 0.1 and 10 micrometers in diameter, which are produced and released into the air both by nature and by human activity. These particles can include salt from the sea, sand from the desert, pollutants from industry and traffic, or soot particles from fires, for example.

However, about half the condensation nuclei are actually formed in the air when different gaseous molecules combine and turn into solids, a phenomenon that experts call "nucleation" or "new particle formation" (NPF). To begin with, such particles are tiny, barely larger than a few nanometers, but over time they can grow through the condensation of gaseous molecules and then serve as condensation nuclei.


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In the Laboratory for Atmospheric Chemistry, Lubna Dada investigates the formation and chemical composition of aerosols, among other things. Credit: Paul Scherrer Institute/ Markus Fischer

Greenhouse gases that you can smell

The main anthropogenic gas that contributes to the formation of particles is sulfur dioxide in the form of sulfuric acid, mainly from burning coal and oil. The most important natural gases involved are so-called isoprenes, monoterpenes and sesquiterpenes. These are hydrocarbons that are mainly released by the vegetation. They are key components of the essential oils that we smell when, for example, grass is cut or we go for a walk in the woods. When these substances oxidize, i.e. react with ozone, in the air they form aerosols.

"It should be noted that the concentration of sulfur dioxide in the air has decreased significantly in recent years due to stricter environmental legislation and it will continue to decrease," says Lubna Dada, an atmospheric scientist at PSI.

"The concentration of terpenes, on the other hand, is increasing because plants release more of them when they experience stress—for example when there is an increase in temperatures and extreme weather conditions and vegetation is more frequently exposed to droughts."

The big question for improving climate predictions is therefore which of the factors will predominate, leading to an increase or a decrease in cloud formation. To answer this, one would need to know how each of these substances contributes to the formation of new particles. A great deal is already known about sulfuric acid, and the role of monoterpenes and isoprene is now also understood better thanks to measurements in

the field and chamber experiments like CLOUD, in which PSI has been involved.

Sesquiterpenes are rare but effective

Until now, sesquiterpenes have not been a focus of research. "This is because they are quite difficult to measure," explains Dada. "Firstly because they react very quickly with ozone, and secondly because they occur much less frequently than the other substances."

Around 465 million metric tons of isoprene and 91 million metric tons of monoterpenes are released every year, whereas sesquiterpenes account for just 24 million metric tons. Nevertheless, the new study, of which Dada is the lead author, has shown that these compounds play an important role in cloud formation. According to the measurements, they form ten times more particles than the other two organic substances at the same concentration.

To determine this, Dada and her co-authors used the unique CLOUD chamber at the European Organization for Nuclear Research, CERN. The chamber is a sealed room in which different atmospheric conditions can be simulated. "At almost 30 cubic meters, this climate chamber is the purest of its kind worldwide," says Dada. "So pure that it allows us to study sesquiterpenes even at the low concentrations recorded in the atmosphere."

This was precisely what the study set out to do. It was designed to simulate biogenic particle formation in the atmosphere. More specifically, researchers were interested in studying pre-industrial times, when there were no anthropogenic sulfur dioxide emissions. This allows the effect of human activities to be determined more clearly and projected into the future. However, anthropogenic sulfur dioxide has long since become ubiquitous in nature. This is another reason why only

the CLOUD chamber was viable. It also allows a pre-industrial mixture to be produced under controlled conditions.

Persistent particles lead to more clouds

The experiments revealed that the oxidation of a natural mixture of isoprene, monoterpenes and sesquiterpenes in pure air produces a large variety of organic compounds– so-called ULVOCs (Ultra-Low-Volatility Organic Compounds). As the name suggests, these are not very volatile and therefore form particles very efficiently, which can grow over time to become condensation nuclei.

The enormous effect of sesquiterpenes was revealed when the researchers added sesquiterpenes into the chamber with a suspension of only isoprenes and monoterpenes. Even adding just two percent doubled the rate of new particle formation. "This can be explained by the fact that a sesquiterpene molecule consists of 15 carbon atoms, while monoterpenes consist of only ten and isoprenes only five," says Dada.

On the one hand, the study reveals another mean by which vegetation can influence the weather and climate. Above all, however, the research results suggest that sesquiterpenes should be included as a separate factor in future climate models, alongside isoprenes and monoterpenes, to make their predictions more accurate.

This is particularly true in light of the decrease in atmospheric sulfur dioxide concentrations and the simultaneous increase in biogenic emissions as a result of climate stress, meaning that the latter is likely to become increasingly important for our future climate. However, other studies are also needed to further improve cloud formation predictions. These are already being planned at the Laboratory for Atmospheric Chemistry.

"Next," says Imad El Haddad, Group Leader for Atmospheric Molecular Processes, "we and our CLOUD partners want to investigate what exactly happened during industrialization, when the natural atmosphere became increasingly mixed with anthropogenic gases such as sulfur dioxide, ammonia and other anthropogenic organic compounds."

More information: Lubna Dada et al, Role of sesquiterpenes in biogenic new particle formation, *Science Advances* (2023). DOI: 10.1126/sciadv.adi5297. www.science.org/doi/10.1126/sciadv.adi5297

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