When Green Turns Gray: How Heatwaves Turn Plants into Unexpected Polluters

New UC Irvine research reveals how extreme heat events can make everyday greenery a hidden contributor to air pollution.

Friday, February 07, 2025
Lurui Niu
UC Irvine Physical Sciences Communications

California Sedge, an important study species in the new research.

Picture Credit:
Yan Xia

The afternoon sun beats down on a city as temperatures climb. On hot days like this, air quality tends to worsen. A mother notices her child start to wheeze and decides to head indoors. Across town, a haze builds, making it harder to see the skyline, and a weather app sends out an alert: "Unhealthy air quality. Limit outdoor activity."

Many associate poor air quality with traffic emissions or industrial pollution, but there's another invisible culprit: plants**.** A team of scientists led by Professor Alex Guenther of the UC Irvine Department of Earth System Science reports that plant emissions known as Biogenic Volatile Organic Compounds (BVOCs) can impact air quality and climate warming, particularly during intense heat waves. The group's findings, published in *Nature Communications*, *Science of the Total Environment* and *Proceedings of the National Academy of Sciences (PNAS),* highlight how heat waves can turn usually-low-emitting plants into substantial air pollution contributors.

Quantifying the impact of BVOC emissions has long been a challenge. Guenther, a leading expert in BVOC research at UC Irvine, has spent the past 40 years studying their role in air pollution and climate. “My initial interest was driven by their potentially significant impact – but the difficulty in quantifying them at that time had led to considerable skepticism about their importance,” he said.

In the *PNAS* study, Guenther's postdoctoral researcher Hui Wang reveals how heatwaves and droughts driven by climate change can dramatically shift the way BVOCs fuel the formation of ozone – a harmful pollutant that can trigger respiratory issues and damage ecosystems. Such emissions also contribute to airborne particles that can penetrate deep into the lungs and exacerbate health problems like asthma and cardiovascular disease.

“Biogenic Volatile Organic Compounds (BVOCs) are an important link between climate change, atmospheric chemistry, and the climate system,” said Wang. The release of BVOCs from plants is affected by climate conditions, and once in the atmosphere BVOCs can influence the climate in indirect ways. As extreme weather events become more frequent as human-driven climate change unfolds, the intensified release of BVOCs could further worsen air quality and amplify climate feedback.

Scientists are still uncovering how these emissions behave under such conditions, making it a critical area of research in our rapidly warming world.

Plants Become Urban Polluters

BVOCs include molecules like isoprene – a compound naturally released by many trees, including oaks and poplars. Isoprene is highly reactive, and it plays a pivotal role in forming ground-level ozone as well as secondary organic aerosols (SOA), both of which influence air quality and climate. Unlike the protective ozone layer in the stratosphere, ground-level ozone is a major air pollutant that can trigger respiratory issues and exacerbate conditions like asthma. It forms when BVOCs react with nitrogen oxides in the presence of sunlight, leading to the formation of smog. SOAs also form in the atmosphere from the reactions of atmospheric oxidants with BVOCs, and can make up a significant fraction of airborne particulate matter and can create potential health risks.

“The role of BVOC emissions in influencing air pollution and climate change is not well understood,” said Sanjeevi Nagalingam, a postdoctoral researcher in Guenther’s lab. “Some plants usually emit very low levels of BVOCs, but during stressful events like heat waves, these plants become super-high emitters.”

Nagalingam’s *Science of the Total Environment* study found that under heat stress, BVOC emissions from Cupressaceae trees can increase by up to 20 times their usual levels. Similarly, in Wang’s *PNAS* study, his team highlights how rising BVOC emissions from sedges (*Carex praegracilis*) in urban cities can worsen ground-level ozone and aerosol pollution.

BVOC emissions play a significant role in driving climate warming trends. SOAs, which BVOCs help create, can scatter sunlight and promote cloud formation. Clouds can cool the atmosphere by reducing the amount of solar radiation reaching the Earth's surface – but their overall impact remains less understood compared to long-lived greenhouse gases like carbon dioxide.

Gaining a clearer picture of how BVOC emissions respond to extreme conditions, Guenther explained, is essential for improving air quality models and predicting climate feedbacks. He added that his research community hopes to integrate a deeper understanding of processes like BVOC emissions into global climate models, so they can improve forecasts and uncover new interactions within the climate system.

“My motivation has always been to develop a quantitative understanding that enhances the predictability of BVOC emissions in air pollution and climate models,” said Guenther, who explained that simplifying such processes for global models often works well across many landscapes, and that unexpected variations can lead to novel insights into how complex systems operate.

Wang's other paper, published in *Nature Communications*, highlights how different plant species can exhibit different BVOC emission patterns. Arctic sedges, the species examined in the paper, exhibit distinct temperature response patterns in their BVOC emissions compared to the behavior of temperate trees that form the basis for current BVOC models. Such a strong temperature response suggests that current models may be underestimating Arctic isoprene emissions, and failing to account for this sensitivity yields a 20% underestimation of isoprene emissions in high-latitude regions of the Northern Hemisphere predicted between 2000 and 2009 in the Community Land Model. Additionally, the model underestimated the long-term trend of isoprene emissions in these regions by 55% from 1960 to 2009, signaling a need for a reassessment of the current emission models, Wang explained.

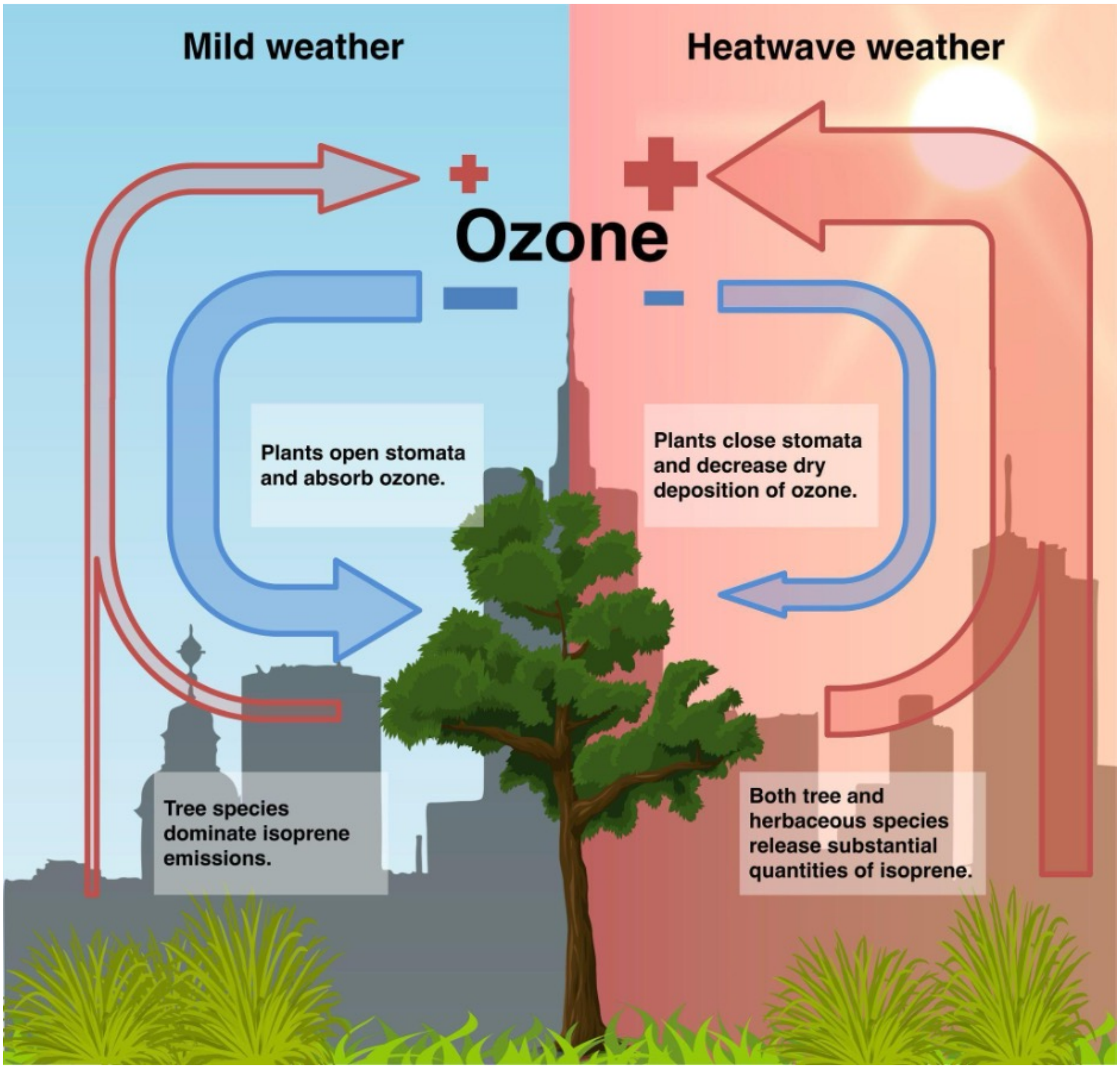
Wang hopes the work inspires others to rethink what they know about BVOCs. "People have been studying isoprene for decades, and the scientific community thought it might be the most well-understood BVOC species," he said. "However, our research has expanded our understanding of isoprene emissions from plants, and it seems like we still have a long way to go to fully understand these processes."

Future Directions

Scientists are still working to understand why plants release BVOCs, especially when they're stressed by extreme heat or drought. Figuring this out could help improve climate models and predict how air pollution might change as the planet continues to warm. Guenther's lab plans to study more types of urban plants in order to see which ones are most affected by heatwaves – an important step in identifying species that may worsen air quality, particularly as communities around the world move to create greener living environments.

"These UC Irvine-led studies underscore the need to integrate BVOC emissions into air quality management strategies," said Wang.

Guenther agrees: "We need to consider the potential for including urban BVOC emission controls in air quality management plans," he said, "This requires a more quantitative understanding of BVOC emissions and the controlling processes, including stress-induced emissions."



Under mild weather conditions (left blue scenario), tree species dominantly release isoprene – a precursor of ozone formation. At the same time, trees absorb ozone, creating a recycling process that helps regulate ozone levels. But under extreme heat scenarios (right red scenario), plants, including trees and herbaceous species, release substantial quantities of isoprene. This leads to a significant reduction in ozone absorption, causing ozone to accumulate in the atmosphere. During heatwaves, the combination of increased isoprene emissions and decreased ozone uptake through dry deposition exacerbates the formation and accumulation of ozone. These dynamics may have significant regional air quality implications, warranting careful consideration and management strategies. *Hui Wang / PNAS*

This article was written by Ph.D. student Lurui Niu from the UC Irvine Department of Earth System Science. Niu is a 2024-2025 UC Irvine School of Physical Sciences Science Communication Fellow.

Feature Stories
Earth System Science
Climate Change
The Future of Energy and the Environment
View PDF