Born to modulate: Researchers reveal origins of climate-controlling particles

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Aerosol particles are tiny. Swirling suspended in the air around us, most are smaller than the smallest bug, thinner than the thinnest hair on your head, gossamer specks practically invisible to the naked eye. Newly formed ones are nano-sized. Yet their influence is gargantuan.

They determine the color of sunsets. They inflict over three million premature deaths each year. And the power they hold over our climate is massive.

Despite their outsized effect, aerosols are shrouded in mystery. How do new aerosol particles come to be? Where are they born, and under what conditions? Such questions have troubled climate scientists for decades and imbued climate models with lingering uncertainty.

In new work, a team led by scientists at the Department of Energy's Pacific Northwest National Laboratory have finally answered some of the most fundamental questions about how new aerosol particles come to exist. By accounting for molecular-level interactions between substances that make up these tiny particles in an Earth system model, the team, whose work is carried out under the project named EAGLES (Enabling Aerosol-cloud interactions at GLobal convection-permitting scalES), achieved three major milestones.

They integrated 11 new pathways by which new aerosol particles form into a global climate model, identified where in the world those pathways are unfolding, and assessed their potential impacts on Earth's climate.

"Properly representing new particle formation has been a thorn in our sides for quite some time," said Earth scientist and the principal investigator of EAGLES, Po-Lun Ma. "Now that we've identified these new mechanisms, our results stand to do two important things: substantially dial down what has been the largest source of uncertainty in aerosol-climate science to date and improve our ability to predict how the Earth system could change."

Their results were recently published in *Nature*. The work represents a collaborative effort across many institutions.

Particle hotspots

Aerosol particles come about in different ways. Some, known as primary aerosols, are ejected straight into the atmosphere, like dust from a desert or ash from a volcano. Others are born in the sky, products of gases that intermingle in the atmospheric milieu—these are the particles that claim the EAGLES team's attention.

New particles aren't born just anywhere; there are hotspots. Much of the action happens above forests, like the rainforests of the Central Amazon and Southeast Asia.

There, "clean" air free of primary aerosols allows for the right kind of chemical intermingling that gives way to new particles. Scientists have detected huge concentrations of new particles above these forests.

But climate models today are partly blind to these big particle peaks. When pressed to estimate how many particles are present or where in the atmosphere they show up, even the best models greatly underestimate their abundance or misidentify at which altitudes they appear.

Thanks to the new pathways put together by the EAGLES team, however, this blind spot is now being made clear. When the team plugged the pathways into DOE's Earth system model, E3SM, the particle peaks matched what they had seen in real-world observations.

Not only did the revised model correctly simulate the quantity of these particles, it also matched where researchers had found them during field campaigns, correctly identifying that many of the new particles show up in the upper troposphere. The team found similar success in matching model predictions to real-world measurements in other hotspots, like above oceans and cities.

When they took a worldwide view, the team found the average global concentration of these particles was nearly triple the amount estimated using traditional methods.

Climate-controlling clouds

Aerosols and clouds have a close-knit relationship. Aerosol particles are the seeds of clouds. Atmospheric moisture condenses on aerosol particle surfaces, one water molecule clotting after another like strands of cotton candy layering atop a cone.

A particle's properties—its chemical composition, its size and structure—shape the traits of the resulting cloud that forms around it. One particle type might make its corresponding cloud more or less likely to rain. Another might determine whether a cloud reflects more or less sunlight, in turn determining whether the Earth's atmosphere warms more or less.

In this way, clouds and aerosol particles control much of our weather and climate. They can warm, cool or even alter the structure and flow of the Earth's atmosphere.

Many scientists believe that new particles—the kind the EAGLES team is trying to understand—make up roughly half the world's seeds that later become clouds. In the new work, however, the team shows that these particles could, in some regions, be responsible for even more.

Over the tropical and mid-latitude oceans, locally generated new particles could account for up to 80 percent of the material upon which clouds condense. Over Europe and the Eastern United States, they could account for 65 percent of the seed material for clouds.

The role particles play in the climate response

Understanding how aerosols influence Earth's climate is a key part of forecasting how our world will change. As nations seek to curb global warming by reducing emissions, the climate will respond in turn. And improving climate models to closely mirror the complexity of the Earth system, said Ma, is imperative in predicting the climate response.

"Our overarching goal is to create increasingly realistic representations of the climate system," said Ma. "And aerosols have been a major hurdle in our path toward that goal. We rely so much on Earth system models—to test emissions scenarios and predict climate responses. The more closely they mirror reality, the more confident we can be in our predictions."

Although much mystery remains around aerosol particles, said Earth scientist Hailong Wang, a co-author of the new work, researchers are continually chipping away at that uncertainty.

"We can't confidently say what the full impact of their presence or absence will be until we have a solid, mechanistic understanding of aerosol particles," said Wang. "And this research marks a significant step toward that understanding."

More information: Bin Zhao et al, Global variability in atmospheric new particle formation mechanisms, *Nature* (2024). DOI: 10.1038/s41586-024-07547-1

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