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Palo Alto, CA—Scientists have known for decades that black carbon aerosols add to global warming. These airborne particles made of sooty carbon are believed to be among the largest man-made contributors to global warming because they absorb solar radiation and heat the atmosphere. New research from Carnegie's Long Cao and Ken Caldeira, along with colleagues George Ban-Weiss and Govindasamy Bala, quantifies how black carbon's impact on climate depends on its altitude in the atmosphere. Their work, published online by the journal *Climate Dynamics*, could have important implications for combating global climate change.

Black carbon is emitted from diesel engines and burning wood, among other sources. In the atmosphere, it acts as an absorbing aerosol—a particle that absorbs the sun's heating rays. (Other types of aerosols reflect the sunlight back out into space, providing a cooling effect.) The climate effect of black carbon is difficult to quantify because these particles heat the air around them, affecting clouds even before they begin to heat the land and ocean surface.

The team's research involved idealized simulations of adding a theoretical megatonne of black carbon uniformly around the globe at different altitudes in the atmosphere. They found that the addition of black carbon near the land and ocean surface caused the surface to heat. As the altitude of black carbon increased, surface warming decreased. The addition of black carbon to the stratosphere caused the land and oceans to cool. This cooling occurred despite the fact that the black carbon caused the Earth as a whole to absorb more energy from the sun. When black carbon is high in the atmosphere, it can lose its energy to space while helping to shade the land and ocean surface.

"Black carbon lower in the atmosphere is more effective at warming the surface, even though black carbon particles at higher altitudes absorb more solar radiation," said Ban-Weiss, formerly of Carnegie and currently at Lawrence Berkeley National Laboratory. He continued: "Just analyzing instantaneous changes in absorption of radiation from black carbon cannot accurately predict changes in surface temperatures. If we want a consistent

framework for predicting changes in surface air temperature from black carbon we need to account for rapid atmospheric responses in things like clouds.”

Black carbon also had varying effects on precipitation. In the lower layers it increased precipitation and in the upper layers it decreased precipitation, a result of changes in atmospheric stability.

“We showed that black carbon near Earth’s surface has the greatest effect on global warming. Unfortunately, this is exactly where we are putting most of the black carbon that we add to the atmosphere,” Caldeira said. “This black carbon also often causes health problems, so cleaning up these emissions would help both the environment and human health.”

Major sources of black carbon emissions into the lower atmosphere include forest fires, cooking stoves, and emissions from trucks and automobiles. Aircraft are a notable source of emissions to the upper atmosphere.

“This study points out the importance of understanding the complexities of how human activities affect the globe. If we want humans to live well while protecting the environment, we need to understand how our activities affect climate,” Caldeira said.

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Carnegie Institution of Washington • 1530 P Street NW •  
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6400 • Fax +1-202-387-8092

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