» Stories of Discovery and Innovation

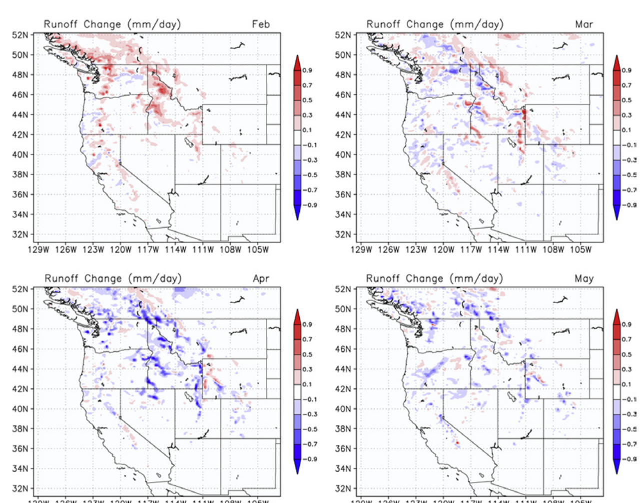
A Sooty Tale

Black carbon from combustion processes accelerates climate change effects

They rise on plumes of hot air from belching exhaust. They grime the faces of industrial workers. They fleck cars after a fire. And, these tiny particles of soot, ranging in size from a few nanometers to a few microns, have a big impact on climate.

Like dark clothing, black carbon particles, which come from combustion processes, absorb heat. So, it's no surprise that, when black carbon gets into the atmosphere, it causes the air to heat up. What came as a big surprise to researchers at the Pacific Northwest National Laboratory and their colleagues was how much black carbon affects snowmelt. On-going research sponsored by the U.S. Department of Energy's Office of Science has provided greater definition to the role of black carbon in climate change. Two sooty accounts of black carbon, published two years apart, tell the tale:

Climate models expose a sooty impact. In the western United States, regional climate models reveal how soot-covered snow affects climate and water availability. Scientists have long known that soot – the common name for black carbon – from burning fossil fuels and biomass changes the way sunlight reflects off snow. However, until 2008 little was known about how this process affects the regional climate and water cycle over a specific geographic area.



Regional climate models revealed that black carbon can increase western United States snowmelt in the late winter and decrease it in the late spring.

PNNL scientists were the first to show how a layer of soot on snow increased the surface air temperature between 0.1 and 1.0°C over the majority of the snow-covered areas in the western United States. This increase caused earlier snowmelt. Instead of happening in late

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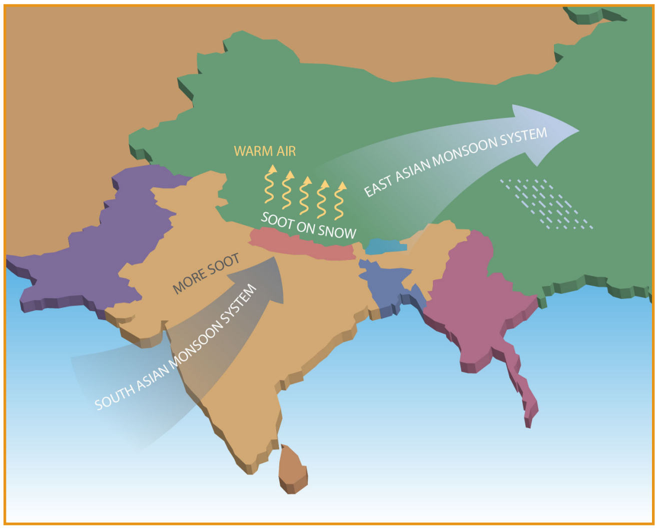

Soot on snow in the Tibetan Plateau has caused climate shifts that strengthen monsoon seasons in Asia.

spring, frigid water came rushing down rivers and streams in late winter.

In the past, scientists had used global climate models to study the effects of black carbon. But these models were not entirely effective in representing the diverse terrain and land surface types of a smaller region. Instead, the PNNL team used a regional climate model to provide the necessary spatial resolution and more accurate and realistic snowpack and stream flow results. Regional models chop the space into smaller grid squares than those used in global models, and they use local hydrologic information to drive the model.

The team's simulations showed when snow became "dirty" from soot it absorbed more solar radiation and warmed the ground and surrounding air. The mountain snowpack decreased between 2 to 50 millimeters (0.08 to 1.97 inches) during late winter to early spring. This means less snow accumulation in winter, less snowmelt in spring, and earlier spring melt dates. For regions like the western United States, which gets almost 75 percent of its water in reservoirs from mountain snowmelt, the presence of black carbon could mean earlier snowmelt – and therefore less snowpack in the summer months when water is needed most for power, municipal water, and irrigation.

Significant Asian weather impacts. In another study, researchers at PNNL, the University of Michigan and NOAA found that black carbon causes early runoff and stronger monsoons in Asia. Soot landing on snow on the massive Tibetan Plateau can do more to alter snowmelt and monsoon weather patterns in Asia than carbon dioxide and soot in the air. Their results were reported in the March 2010 online issue of *Atmospheric Chemistry and Physics*.

To find out how much soot is affecting the Tibetan Plateau's region, the research team used a global climate computer model, the Community Atmosphere Model, which DOE and the National Science

Foundation funded. The model allowed them to examine a mixture of possible scenarios, including if soot sat on the Tibetan Plateau's snow, if soot was floating in the air above the plateau, and if increased carbon dioxide was in the air as a result of industrialization.

The Tibetan Plateau acts like a natural heat pump for the region's weather. Reaching five miles high in some places, the air above it is warmer than other air at the same elevation. This warm air strengthens circulation around the plateau and causes the iconic, drenching monsoons that move through the region every year.

But the Tibetan Plateau is increasingly bare. And soot, which causes early snowmelt in the western United States, is the trigger for snowmelt leading to less snow. And less snow means the Tibetan Plateau is absorbing more sunlight. The researchers hypothesized that this condition is causing the atmosphere above the plateau to get warmer sooner than other areas that don't get a blanket of soot. They used climate models to find out if this affects the area's monsoons.

The surface temperature above the Tibetan Plateau increased by more than 2 degrees Fahrenheit in May due to soot on snow alone. The researchers found that this warmer air above the plateau rises and air

"There's a big push right now to replace cooking stoves in India with something that is cleaner and doesn't emit as much black carbon. That change would have an immediate payoff, because there is a big difference between aerosol particles and greenhouse gases. The black carbon washes out of the atmosphere within a few weeks, while CO_2 can stay for decades to centuries. If we make changes in black carbon emissions, there's virtually an immediate effect on climate forcing. And so that makes black carbon particularly attractive as a way of reducing climate effects."

– Dr. Steve Ghan, Director,
PNNL Aerosol Climate Initiative

How do aerosols get measured?

Observational data provided by the U.S. Department of Energy's Atmospheric Radiation Measurement – ARM – Climate Research Facility are used by scientists to develop and validate computer models that simulate how climate processes work. PNNL scientists use aerosol measurements, including black carbon measurements, obtained by the user facility's permanent, mobile, and aerial research platforms to examine how natural and human-made aerosols influence how clouds form and how much light they absorb or reflect.

is drawn from India to replace it. In turn, moist air hanging above the Arabian Sea and Indian Ocean blows in over India. Known as the South Asian Monsoon system, this southwest-northeast flow also brings in more soot from India to the Tibetan Plateau that perpetuates the cycle. As a result, the researchers found that the South Asian Monsoon system is starting earlier and bringing more rain to central and Northern India in May than it would without soot on the plateau's snow.

The soot-on-snow effect lingers throughout the summer and causes another weather shift in the East Asian Monsoon system over China. By July, much of the plateau's snow has already melted. The plateau's bare soil is warmer and further heats the plateau's air. Coupled with cool ocean air nearby, the plateau's heat strengthens the East Asian Monsoon. The models showed that rain increases 1 to 3 millimeters per day over southern China and the South China Sea. The strengthened monsoon advances to northern China, which also receives more rain than it would otherwise, while the rains mostly skip central East China, including the Yangtze River Basin, an important region for agricultural production.

The researchers concluded that soot on snow triggers the Tibetan Plateau's annual glacial melt to happen sooner each year, causing farmers below it to have less water for their crops in the spring and summer. In a domino effect, the melting then prods two of the region's monsoon systems to become stronger over India and China.

Black carbon – not the grimy end. Research on black carbon has demonstrated that these aerosol particles cause early snowmelt and change climate conditions. But there are still many unanswered questions about the relationship between black carbon and all other aerosol particles in the formation of clouds. Cloud/aerosol interactions are still largely undefined, and because clouds can both cool and warm the Earth, this area of study continues at DOE.

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