ENVIRONMENTAL SCIENCE

Pollutants Capture the High Ground in the Himalayas

In high alpine areas once thought pristine, dust and soot appear to be accelerating glacier melting and may alter monsoon patterns

PYRAMID OBSERVATORY, NEPAL—On the south slope of Mount Everest, mountaineers tricked out in the latest high-tech gear and Nepalese porters trundle up the Khumbu Valley. Fragments of conversation are lost in the low rumble of the Dudh Kosi River and the tinkling of yak bells from nearby slopes. For Angela Marinoni, this is a familiar route—but she is not a typical trekker. Pausing for a drink, Marinoni, a climate scientist at the Institute of Atmospheric Sciences and Climate in Bologna, Italy, watches wisps of smoke from cookstoves and forest fires drift into the highlands. Pollution from combustion, not the summit of Everest, is her main quarry.

Since 2006, Marinoni and colleagues have been gathering climatological data at what they imagined would be a pristine site in the Himalayas. The idea was to establish a baseline against which they could measure regional pollution. What they have discovered instead, Marinoni says, was "a total surprise": dust and soot wafting high into the mountains.

The implications are troubling. The Himalayas were long presumed to form a bulwark against airborne pollutants from the Indian subcontinent. But "the barrier is leaky," Marinoni says. Heavier pollutant loads reaching Himalayan peaks and the Tibetan Plateau beyond "could increase glacier melt, pollute streams, and change monsoon patterns," threatening the livelihoods of millions of people, warns Arnico Panday, an atmospheric scientist at the International Centre for Integrated Mountain Development (ICIMOD) in Kathmandu.

Such a potent risk may have remained overlooked had scientists from the Ev-K2-CNR Committee, a nonprofit scientific association in Bergamo, Italy, and the Nepal Academy of Science and Technology not established nine outposts, including a major facility called the Nepal Climate Observatory at Pyramid, in the Khumbu Valley. The stations provide "a unique data set" of atmospheric circulation in high mountains, says Roy Rasmussen, a climate scientist at the National Center for Atmospheric Research in Boulder, Colorado. The challenge, he says, is to piece together where the pollutants come from, how they are transported to the Himalayas, and how they are influencing regional climate.

Pristine no more

After 6 arduous days trekking up the Khumbu Valley, lush forests have given way to a treeless, rock-strewn highland dusted with fresh snow. At last, 5079 meters above sea level, a two-story stone building topped with a glass pyramid comes into sight. Khumbu Glacier extrudes from a cleft in the hills, its gravel-covered tongue reaching toward Pyramid Station. Atop an adjacent rise is a cluster of instruments, including an ozone analyzer, particle counters, and photometers for measuring light absorption and scattering by aerosols.

Reaching new heights. Angela Marinoni adjusts a sun photometer for measuring aerosol properties at Pyramid.

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Fatigued by the altitude, Marinoni clambers up the station's roof to check an air sampler; the team journeys here twice a year to calibrate instruments and install sensors. One villain they are tracking is soot, called black carbon in the scientific literature. With its atmospheric persistence measured in days to weeks, black carbon, spawned by incomplete combustion of biomass, coal, and diesel fuel, is known as a short-lived climate forcer. (Carbon dioxide molecules, by comparison, can persist in the atmosphere for hundreds of years.) South Asia is a black-carbon hotspot; more than half of the estimated 8 million tons of black carbon released into the air each year across the globe originates in the Indo-Gangetic Plain mostly from the burning of wood, dung, and crop residues.

Six years of measurements at Pyramid have generated a wealth of data on black carbon and other pollutants. Marinoni and her colleagues have found that the southern slope of the Himalayas is particularly vulnerable to the pollutant-laden haze that gathers in the foothills below. "Khumbu Valley is like a big chimney," Marinoni says. "The valley breezes can effectively channel the pollutants to high altitudes."

More than 30 days a year, on average, the instruments here have recorded what Marinoni calls "acute" pollution, in which black carbon concentrations shoot up fourfold and ozone increases by one-third compared with average days. "It is particularly bad during dry spells" between January and May, before the onset of the monsoon and its cleansing rains, says Paolo Bonasoni, who heads the Bologna research team. In one out of every 5 days, a thick brown cloud settles over Khumbu Valley and black carbon may exceed 5 micrograms per cubic meter—a concentration rivaling that of an average-sized Indian city.

A looming threat

How big a punch black carbon and other pollutants may pack in the Himalayas is open to debate. At higher altitudes, greenhouse gases and particulates play an outsized role in climate, Bonasoni says. "The air is very thin and clean," he says, "so the pollutants have a much longer lifetime and can accumulate." That, in turn, could influence climate by decreasing solar radiation reaching the surface and by interfering with cloud formation and precipitation, Marinoni says. On a few occasions, elevated pollutant levels coincided with sudden breaks in the monsoon on the Indian

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subcontinent that lasted up to 2 weeks. "It's difficult to say for sure whether pollution stopped the rain," she says, "but it's certainly one possibility."

Another concern is faster glacier melting. After accounting for wind speeds and topography, Marinoni's group estimated that the amount of black carbon deposited on Himalayan slopes during the dry season reduces glacier reflectivity by as much as 5%, which increases the melting rate of a typical glacier by up to one-third. "The effects are cumulative," says Xu Baiqing, a glaciologist at the Institute of Tibetan Plateau Research of the Chinese Academy of Sciences in Beijing. His studies show that soot concentrations are magnified at least 10-fold a year in a glacier's accumulation area, where snow becomes denser after repeated partial melting and refreezing. "As snow melts, water slowly percolates through ice and leaves pollutants behind," which are then trapped in the accumulation zone during refreezing, Xu says. As temperatures rise and snow lines retreat to higher altitudes, he says, the melting of decades-old accumulation zones should liberate more and more black carbon and accelerate glacial melting. "The maximal effect of black carbon may not be now, but in the coming decades," Xu says. He and colleagues have found that black carbon and organic carbon—the unburned remains of biomass burning—in glaciers in southeastern Tibet increased 30% between 1990 and 2003, coinciding with rapid industrialization on the Indian subcontinent.

Scientists are loath to rely solely on Pyramid Station's data to gauge the regional threat. "But there are big gaps in the Himalayas where there is little observation," Panday says. As a step toward filling that lacuna, Ev-K2-CNR scientists last summer installed instruments to measure pollution at Askole in the Karakoram Mountains of Pakistan. Unlike the monsoon-dominated eastern Himalayas, the Karakoram is subjected to the westerlies, which can bring dust and pollutants all the way from Africa and the Middle East.

In the meantime, Bonasoni's team is developing computer models to simulate climate and pollutant transport in the region at resolutions of less than 10 kilometers. The models will account for more than 200 pollutants and will be driven by real-time meteorological data, says Ev-K2-CNR's Bhupesh Adhikary, an expert on air pollution and climate simulation in Kathmandu. Studies to date have been mainly descriptive and based on limited observations, he says. "They tell us what happened, but cannot tell us why or what will happen in the future." Adhikary hopes that modeling studies will help answer those questions and inform mitigation and adaptation measures.

Another challenge is coaxing Himalayan countries to work together to curb emissions of black carbon and other short-lived climate forcers. Last year, with $3.9 million in seed funding from the Swedish International Development Cooperation Agency, ICIMOD launched an initiative to boost research capacity, assess mitigation options in mountain regions, and promote collaboration of Himalayan countries in emission reductions, says Panday, who leads the effort. "Long-term observation is the key," he says. "There is an urgent need to set up stations across the entire region."

CREDIT: JANE QIU

Lab with a view. Data collected at Pyramid Observatory, on Mount Everest's south slope, have woken scientists to the threat that pollutants pose to the Himalayas and the Tibetan plateau.

Reining in black carbon would pay big dividends, and fast. "Cutting short-lived climate forcers would have immediate climate effects because they are quickly removed from the atmosphere," says Veerabhadran Ramanathan, a climate scientist at the Scripps Institution of Oceanography in San Diego, California. Turning back the pollution tide won't be easy though. Simple strategies like replacing cookstoves with cleaner burning models can be tricky in the Himalayas, as many cookstove models work poorly at high altitudes.

At Pyramid, the winds are howling as Italian and Nepalese researchers sit down for spaghetti Bolognese and a glass of red wine. They talk over plans for an expedition to repair an automated station on the South Col, the highest camp for mountaineers attempting to summit Everest. Pema Sherpa, a Nepalese technician who helped set up South Col station in 2008, is ready to give it another shot. "Mountain people are very vulnerable to climate change," he says. "This will help us better prepare for the future."

–JANE QIU

Jane Qiu is a writer in Beijing. Her trip to Pyramid Observatory was supported by a journalism fellowship from the European Geosciences Union.

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