Black Carbon:

Impacts and Mitigation in the Hindu Kush Himalayas

ICIMOD

FOR MOUNTAINS AND PEOPLE

Whereas climate change on a global scale is driven largely by greenhouse gases, with a smaller contribution from absorbing and scattering aerosols in the atmosphere, there are indications in the Hindu Kush Himalayan (HKH) region that absorbing aerosols containing large amounts of black carbon are playing a significant, perhaps even dominant, role in changing the region's climate. This information sheet provides a brief description of black carbon in the atmosphere, its sources, and its impacts in the HKH region.

Climate change in the Hindu Kush Himalayan region

Recent decades have shown increasing evidence of climate change in the Hindu Kush Himalayan region: rising temperatures; changes in the timing, location and amount of rain, snowfall, and cloud cover; retreating glaciers; and reduced snow cover. These are starting to have profound impacts on the lives and livelihoods of people living in the mountains and downstream as they affect water availability, agriculture, ecosystems, infrastructure, and disaster vulnerability. The region is particularly vulnerable to changes in the timing, amount, and spatial distribution of monsoon rainfall, and in the availability of snow- and ice-fed river water during the dry season. Temperatures appear to be rising particularly rapidly at higher elevations, with a consequent decline in glaciers and snow fields.

Part of the climate change taking place in the Hindu Kush Himalayan region can be attributed to the global increase in atmospheric concentrations of long-lived greenhouse gases, which warm the Earth's surface by absorbing some of the earth's outgoing infrared radiation and radiating it back down to the surface. However, recent studies point to the fact that a large part of the observed change in the region's climate is being driven by the presence of aerosols containing black carbon in the atmosphere.

What is black carbon and where does it come from?

Black carbon is a product of incomplete combustion (burning that gives off smoke). It is the solid, mostly pure carbon component of soot that is capable of absorbing light at all wavelengths, hence its black appearance. Emission inventories and analyses of aerosol samples indicate that more than half of the black carbon emitted in South Asia comes from the burning of biofuels, especially in traditional cook stoves. Other large sources include burning of coal (for example in brick kilns), exhaust from diesel vehicles and generators, waste burning, and forest fires. Black carbon absorbs light more strongly than any other substance in the atmosphere. Many sources of black carbon also co-emit other substances that are less light-absorbing, or that scatter light, including brown carbon, organic carbon, and sulfate. Emissions from diesel trucks have a higher percentage of pure black carbon than emissions from open fires.

Himalayan mountains and the southern parts of the Tibetan Plateau receive much of their black carbon from emissions in the Indo-Gangetic Plain and from within the hilly regions of the Himalayas, but they do occasionally get black carbon from as far away as Africa (from biomass burning) and the Middle East (from fires of burning fossil fuel). Further north, the eastern and northern parts of the Tibetan Plateau receive

much of their black carbon from central China, while the Karakoram region receives a large contribution from the Middle East, Europe, and North Africa.

Once the black carbon particles have risen into the air, they can be transported over long distances by prevailing winds. They are slowly removed from the atmosphere (in days to weeks) either by slow settling and deposition onto surfaces or in raindrops and snowflakes. We see black carbon aerosols in the form of a dark haze – the 'atmospheric brown cloud' visible in satellite images. We see the deposited particles as black dust that settles inside and outside, and in the sooty marks left by 'dirty' rain.

How does black carbon affect the climate of the HKH region?

The strong light-absorbing property of black carbon affects the climate in multiple ways. First, black carbon in the atmosphere absorbs sunlight and infrared radiation, warming the nearby air. This is called the direct effect. Second, through the indirect effect, the presence of larger numbers of aerosols means that the same amount of water in clouds condenses into a larger number of smaller cloud droplets, suppressing the formation of drops that are large enough to rain out, thus increasing the cloud's lifetime. Clouds with larger numbers of smaller droplets also scatter light more, appearing whiter. Meanwhile, the presence of absorbing black carbon particles within cloud drops might make the individual drop darker, more light absorbing, and thus more likely to evaporate. This is called the semi-direct effect. The indirect and semi-direct effects vary greatly in time and space, and are a great source of uncertainty in climate prediction.

In areas with snow and ice, black carbon is also responsible for the snow/ice albedo effect: when black carbon is deposited onto white surfaces it darkens the surfaces, allowing them to absorb more sunlight and warm up, leading to more rapid melting. Black carbon deposited onto glaciers in China has been found to darken them by up to 5%, accelerating their melting. Black carbon can also make snowfields melt quicker, exposing darker surfaces underneath to sunlight sooner and allowing them to heat up even faster. It is hypothesized that black carbon may accelerate the spring melting of snow on the Tibetan Plateau, which will warm up the Plateau earlier in the year, changing atmospheric circulation patterns and affecting monsoon patterns.

During winter and spring, haze layers extending more than three kilometres above the earth's surface are often seen over the Indo-Gangetic Plain extending into the foothill valleys of the Himalayas. Through the direct effect, black carbon in the upper parts of the layer absorbs sunlight and warms the air, while reducing the sunlight reaching the surface underneath. The result can be cooling of valleys and lowland areas, contributing to the increased build-up of winter fog observed in river valleys and over the northern Ganges Plains, as well as a lowering of winter temperatures. The reduced sunlight also affects crop and other biomass yields. As people light more fires to stay warm they contribute to a whitening and extended persistence of the fog through the indirect effect. The effect in high mountain areas is different; the air heated by black carbon in the upper parts of the haze layer is in contact with the mountains, warming them. This is the likely explanation for the more rapid increase in temperatures seen at higher altitudes in recent decades, contributing to additional the melting of the Himalayan cryosphere. Although we don't yet know the exact contributions of black carbon versus carbon dioxide, it is clear that through the direct effect and the snow/ice albedo effect, black carbon is responsible for a significant contribution to glacial retreat in the Hindu Kush Himalayan region.

Effects on the monsoon

There has been significant debate among scientists in recent years about how black carbon may be affecting the monsoon circulation in the Hindu Kush Himalayan region. Studies suggest that black carbon aerosols may substantially alter precipitation patterns, and affect cloudiness and temperature. A number of specific ideas have been put forward. For example, by cooling the land surface, black carbon might reduce the land-sea thermal gradient and reduce the strength of the circulation. On the other hand warming up of the air over the Himalayan foothills might drive stronger convection (the 'elevated heat pump hypothesis').

Black carbon over the ocean might cool the ocean surface, reducing evaporation and thus the amount of water available to the monsoon. Black carbon might also suppress rainfall by seeding a larger number of smaller water droplets, leading to clouds that are less likely to rain out (indirect effect). On the other hand, clouds with water droplets that have been unable to rain out might store the water longer and eventually create larger precipitation events, with more intense downpours. To date, there is still very little field data available from the region which can be used to test these hypotheses, and much more research is needed to fully understand the effects of black carbon on the monsoon.

Aerosols

Aerosols are fine solid or liquid-covered solid particles suspended in air. Atmospheric aerosols can absorb or scatter some of the incoming solar radiation. Highly reflective aerosols, such as those composed mainly of sulphate, scatter back to space solar radiation that would otherwise reach the earth's surface and have a cooling effect. In contrast, dark coloured aerosols, like those that contain a high fraction of black carbon, can absorb solar radiation: thus they heat up the atmosphere, while cooling and darkening the earth's surface below. Other aerosols, such as fine windblown dust, have intermediate effects, reflecting part of the sunlight, and absorbing part of it. Black carbon is of particular concern because it is emitted in large quantities downwind of the Hindu Kush-Himalayan region, and because it is already showing a large climate impact.

Other effects of black carbon aerosols

The increased heating of the upper atmosphere and cooling of the surface can have other effects. First, it suppresses atmospheric convection. This can affect air quality and human health by reducing ventilation of pollutants away from the surface, leading to the formation of a visible layer of trapped pollutants with a high proportion of black carbon over cities and in valleys. The surface cooling can increase the need for heating, which is often done with fires that burn dirty fuels and emit more black carbon. Black carbon contributes significantly to haze which obscures visibility. This impacts both the livelihoods of people who depend on mountain viewing tourists and aviation safety.

Black carbon itself can have a direct impact on health: inhaled black carbon has a greater impact on the lungs than the average aerosol. It is emitted into the atmosphere in the form of ultra-fine particles smaller than 2.5 micrometres (called PM 2.5), which can penetrate deep into people's lungs. The World Health Organization has recently recognized black carbon as a carcinogen. Because women and children spend more time indoors in kitchens, there is a strong gender dimension to the health impact of black carbon from traditional cook stoves.

Mitigating black carbon

Together with the gases ozone, methane and some halocarbons, black carbon is called a 'short-lived climate pollutant' (SLCP), or a 'short-lived climate forcer'. SLCPs are air pollutants that affect climate, but that have a short residence time in the atmosphere in contrast to the greenhouse gas carbon dioxide (CO_2). CO_2's residence time of centuries means that even if its emissions were drastically cut today, it would take a very long time for the CO_2 already in the atmosphere to decrease, and for the climate impact of the cuts to be seen. SLCP's short residence time allows the impact of emission cuts to be felt within days to weeks. In addition, the short residence time also means that SLCPs don't have time to spread uniformly around the globe; their impact on climate is felt more near the emissions source, and thus the benefits of cutting emissions are also felt closer to the emissions sources. Reducing black carbon aerosols would both reduce the climate impact, and benefit human health. Ways to reduce black carbon emissions include using alternative fuels for cooking, and/or stoves that burn more cleanly; reducing emissions from smokestacks, from industries using coal, and from diesel-powered vehicles and generators; switching to more modern brick making technologies; and reducing open burning of waste through improved waste disposal procedures.

ICIMOD and black carbon

In January 2013 ICIMOD established its Atmosphere Initiative as a part of the Regional Programme on Cryosphere and Atmosphere. With a growing interdisciplinary in-house team of professionals, and an extensive network of partners and collaborators, the Atmosphere Initiative aims to improve scientific knowledge about emissions, about atmospheric processes and change, and about impacts of SLCPs in the HKH region, as well as to study, pilot, and disseminate effective mitigation options; to disseminate knowledge and contribute to capacity building; and to contribute to policy making at the national, regional and global levels. The Initiative has begun work to establish world-class atmospheric observatories on two ridge-tops in Bhutan and Nepal, as well as satellite observatories at lower and higher elevations, and to establish an in-house atmospheric modelling centre at ICIMOD.

In 2013 two case studies were initiated. 'Sustainable Atmosphere for the Kathmandu Valley' (SusKat), conducted in partnership with the Institute for Advanced Sustainability Studies (IASS), Potsdam, Germany, ran the second largest international field research campaign in South Asia since 1999, collecting six months' of atmospheric data within and outside of Kathmandu, including measuring black carbon simultaneously at eight locations. A second case study, in collaboration with private sector donors and medical students from the Patan Academy of Health Sciences, examines the social, health, indoor air pollution and outdoor air pollution impacts of introducing clean cookstoves in an entire valley.

As the only intergovernmental organization mandated to focus on environmental issues in the mountain areas of the HKH, ICIMOD also has an important role to play in coordinating the formation of networks of scientists and practitioners who collaborate across borders. In 2013 it co-hosted an international workshop on Atmospheric Composition and the Asian Summer Monsoon as well as the First Annual Regional Atmospheric Science workshop. ICIMOD also co-hosted a clean cook stove marketplace and is co-sponsoring a clean cookstove design competition. ICIMOD is also a non-state partner in the Climate and Clean Air Coalition, playing an especially active role in the CCAC's Brick Kiln Initiative.

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