08 BLACK CARBON

A SHORT-LIVED CLIMATE FORCER; CANNOT SUBSTITUTE CO_2 MITIGATION STRATEGIES

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BLACK CARBON

Black carbon is a component of soot, released during combustion, particularly incomplete combustion of fossil fuels or biomass. It is released when carbon is only partially combusted. The main sources of black carbon emissions are burning of biomass in inefficient cooking stoves, diesel emissions from the transport sector and from generators (especially those without pollution filters), and burning of other fossil fuels and biomass in industry and power production.

Black carbon is released as a particle and hence falls in the category of particulate matter, not greenhouse gas. All particle emissions from a combustion source are broadly referred to as particulate matter (PM) and usually delineated by sizes less than 10 micrometres (PM10) or less than 2.5 micrometres (PM2.5). Black carbon are ultrafine particles or PM0.1, and pose a strong health risk (*see box: More a health threat*). They also strongly absorb light and convert that energy to heat.

The effect that worries scientists is when black carbon is deposited on snow or ice. In snow-covered areas, the deposition of black carbon darkens snow and ice, increasing their absorption of sunlight and making them melt more rapidly. Black carbon stays in the air for a couple of days or even weeks but as it settles down, it can cover snow and ice that is otherwise the most reflective surface for sunlight on Earth. This increases heat absorption and may melt the ice and snow, creating a spiral effect – when the ice and snow melts, it reveals darker areas beneath that in turn absorb more heat.

However, because of a very brief atmospheric lifetime measured, black carbon's climate effects are strongly regional. For instance, black carbon may be responsible for a significant fraction of recent warming in the rapidly changing Arctic, contributing to the acceleration of sea ice loss. They also may be contributing to the melting of Himalayan glaciers and driving some of the recent reduction in snowpack in the U.S. Pacific Northwest.

Black carbon's short lifetime also means that its contribution to climate warming would dissipate quickly if emissions were reduced. Because black carbon remains in the atmosphere for only a short time, when emissions of black carbon are reduced, atmospheric concentrations of black carbon decrease almost immediately. Therefore, reducing black carbon emissions can help prevent near-term warming and associated effects on snow, ice and precipitation. Black carbon mitigation measures are important for minimizing short-term climate impacts and avoiding climate thresholds. Such efforts, however, would seem more like an emergency stop-gap effort: the effects of lowering black carbon emissions will probably be felt only in the first five years, after which the growing warming from CO_2 and other greenhouse gases will take over and swamp the

Black carbon: More a health threat than climate

Black carbon and organic carbon make up a substantial part of the fine particulate matter in air pollution that is the major environmental cause of ill health and premature deaths, globally (WHO, 2009). The health-damaging particulate matter is characterized as PM2.5, particles with a diameter less than 2.5 micrometres – 'fine' or 'small-sized' particles, which affect the respiratory and cardiovascular systems – and its impacts occur due to both outdoor and indoor exposure. The World Health Organization (WHO) estimates that 3.1 million people (WHO, 2009), mostly in developing countries, die prematurely each year from indoor and outdoor air pollution. The health benefits of reduced emissions from measures that focus on black carbon are mainly achieved by the overall reduction in this fine particulate matter. Reductions in black carbon emissions therefore would have significant co-benefits for human health, particularly in developing countries.

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Black carbon, short-lived v carbon dioxide, long-lived

Comparing the impact of short-lived climate forcers (SLCF) such as black carbon to that of carbon dioxide (CO_2) on global temperatures over the long term is difficult because of the difference in the atmospheric lifetimes of the two kinds of substances. SLCFs have short lifetimes and mainly affect the near-term temperature in the first few decades after being emitted, while CO_2 has a much longer lifetime and, once emitted, continues to have a major influence on the global temperature for centuries. Put another way, the shorter atmospheric lifetimes of SLCFs means that their reductions in any particular year will have a much smaller effect on global warming over the long run as compared to reducing CO_2 or other long-lived greenhouse gases.

gains. Because such reductions are likely to only make a modest contribution to longer-term climate goals, they must be viewed as a strategy that complements but does not replace carbon dioxide emission reductions.

It is clear that deep and immediate carbon dioxide reductions are required to protect long-term climate. Besides, our understanding of the impact of aerosols on climate is not as good as our understanding of the impact of greenhouse gases, such as CO_2, on the atmosphere. This is because radiative properties of aerosols vary widely and also have large temporal and spatial variations. In addition, there is a complex interaction between natural aerosols, such as dust and salt, and anthropogenic aerosols such as black carbon, organic carbon and sulphate.

Despite this, it is important to understand the science behind black carbon and address its emissions.

More regional than global: Could impact cloud formation, rainfall

Black carbon causes warming of the atmosphere by a number of different processes. These particles absorb visible light due to their dark colour. This absorption leads to a disturbance of the planetary radiation balance and eventually to warming.

Black carbon aerosols have a large impact on **regional circulation and rainfall patterns** as they cause significant asymmetry in heating patterns over a region. While not fully quantifiable, the impact of black carbon on regional weather patterns and regional warming is more certain than its impact on global warming. This is because, at the global scale, organic carbon may offset warming due to black carbon. Black carbon is a warming agent, and organic carbon, a cooling agent. They are always co-emitted, but in different proportions, depending on the source. At the regional scale, changes are more closely related to atmospheric heating, which is dominated by black carbon, and co-emitted species have less of an impact.

Black carbon particles also **influence cloud formation, cloud lifetime, rainfall and weather patterns.** They can also change wind patterns by affecting the regional temperature contrasts that drive the winds, influencing where rain and snow fall. These effects can be both local and distant.

Another regional impact of short-lived climate forcers is their effect on accelerating the melting of ice and snow. Firstly, ozone and black carbon warm the atmosphere and therefore promote melting of ice and snow in the Arctic and in heavily glaciated parts of elevated regions, such as the Himalayas. A UNEP/WMO assessment concluded that by 2040 atmospheric warming could be reduced by about 0.7°C in the Arctic by implementing black carbon and methane measures, two thirds of the warming projected for that region in that year. It also concluded that this benefit was larger in the Arctic compared to the average global climate benefit.

Deposition of black carbon has the additional effect of accelerating melting by darkening snow and ice surfaces. Increased early melting of glaciers also has subsequent effects on water supplies downstream. Glaciers and seasonal snowpacks in the Himalayas, the Tibetan Plateau, the Hindu Kush and the Karakoram region provide water to a large number of people and are near large black carbon sources in Asia. Vulnerability in this region is enhanced because of the high levels of solar radiation striking the surface as a result of the low latitude, high altitude, and low vegetation cover. Studies have indicated that black carbon is driving significant warming and increased snow and ice melt in this region, thus increasing the risks of flooding by outbursts from glacial lakes.

Black carbon emissions reduction may have a substantial effect on the Asian monsoon and on central African rainfall, and may lessen the disruption of traditional rainfall patterns. The fact that the changes to both tropospheric ozone and particle concentrations mainly occur in the northern hemisphere means that they also alter the differences in temperature between hemispheres. This in turn may cause shifts in rainfall patterns throughout the tropics.

However, the level of knowledge of how some of these processes work is limited, which leads to a level

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of uncertainty in the overall effect of black carbon on global warming.

What we don't know about black carbon is more than what we know about it

The Indian Space Research Organisation (ISRO) is currently pursuing a research campaign to understand the characteristics and impacts of atmospheric aerosols over the Indo-Gangetic Plains. The research project, called ISRO-GBP (ISRO-Geosphere Biosphere Programme) maintains 37 surface observatories covering representative locations in India to measure black carbon. It is found to be in different concentrations in different locations, but its concentration is almost always higher during winter.

A large stretch of the Indo-Gangetic Plains is influenced by emissions from postharvest agricultural-waste burning, fossil-fuel combustion (vehicular, industrial, and thermal power plants), and a number of minor sources (brick kilns and textile mills). The long-range transport of mineral dust originating from Iran, Afghanistan, Pakistan, and the Thar Desert (western India) imparts significant variability to the aerosol composition during summer months. Further, mixing of carbonaceous species, a term for black carbon (BC) and organic carbon (OC), with anthropogenic inorganic constituents has led to degradation of air quality, visibility impairment and atmospheric brown cloud formation during the winter.

What we know so far

Measurements of the abundances of carbonaceous aerosols have been conducted during the ISRO GBP study. Over urban locations, black carbon concentrations were generally less than 15 $\mu g/m^3$, however, it could be as high as 60 $\mu g/m^3$ at some locations. Although, black carbon constitutes only a minor part of PM10 mass, it is one of the major absorbing particulate species in atmospheric aerosols. The BC/PM10 mass ratio, thus, provides a qualitative assessment for the absorbing nature of aerosols and helps understand the radiative impact of black carbon. In general, BC/PM10 ratio varies from 3-10 per cent over urban locations in India, but it can be as high as 15 per cent during winter in some parts of the Indo-Gengetic Plains.

In a study conducted in Kanpur, it was found that the widespread impact of biomass burning emissions on the regional air quality was significantly pronounced in winter, due to crop harvesting season and the common practice of wood fuel burning. Also, a shallow boundary layer height during the winter, about 500-800m, and the Himalayan mountain range parallel to the Gangetic Plain confined the anthropogenic aerosols within the lower atmosphere. The black carbon concentrations showed a large temporal variability during the sampling period from January 2007 to March 2008. Its concentration varied from 0.7 $\mu g/m^3$ to 14.4 m^3. The highest black carbon concentration was recorded in March 2007.

Another factor for the assessment of direct or indirect impacts of aerosols on the regional scale radiative forcing is the relative amounts of organic carbon and black carbon, and the OC/BC ratio. These constitute about 30-70 per cent of the fine mass in urban atmospheres. During their measurements it was found that during winter, concentrations of black carbon and organic carbon over an urban atmosphere in northern India typically ranges from 2-10 $\mu g/m^3$ and 15-120 $\mu g/m^3$, whereas organic carbon and black carbon ratios (OC/BC) vary from about 5–20. Studies have found that the OC/BC ratios in the Indian urban atmosphere are higher, compared to those reported for the urban sites in the US and Europe. The OC/BC ratio over urban locations in the US is ~2, while over Europe, it is ~3.

The higher OC/BC ratios in India imply the necessity of a re-assessment of model-based aerosol radiative forcing due to black carbon over the South Asian region. Higher OC/BC ratios over urban sites suggest that comprehensive studies of organic carbon and black carbon should be carried out in varied locations influenced by different sources over India.

While enhancement in mass concentrations of carbonaceous species is largest during winter when biomass burning emission strength is highest and a shallow boundary layer height helps in trapping the aerosols, increase in their concentrations cannot be fully explained in terms of increase in their source strength. Meteorological conditions such as wind patterns and boundary layer dynamics would help explain variability in the mass concentrations. Then, depending on these and other factors such as the high-acid environment of the Gangetic Plain, the scattering properties of black carbon may change as a consequence of reaction with the high concentration of sulfate aerosols during winter. Researchers have also observed vertically extended atmospheric brown clouds, between 0.5-3 km over the Indian Ocean. Using a general circulation model, Ramanathan et al suggested that warming trends in the lower atmosphere, due to the atmospheric brown clouds, could be equivalent to the recent increase in the greenhouse gases.

The divergence of absorbing and scattering characteristics of carbonaceous aerosols assumes particular importance in the polluted regions of the

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Indo-Gangetic Plain. During the winter season prevalence of agricultural-waste burning, fossil fuel combustion and wood-fuel for domestic heating result in enormous amount of organic carbon and black carbon that modify the total particulate carbon content of the atmosphere. Therefore, factors such as optical properties of aerosols need re-evaluation for the radiative impact assessment due to aerosols.

Also, the highly acidic environment due to the presence of sulfate and nitrate aerosols over northern India may significantly alter the morphological features of soot particles. Although the aerosol absorption properties so far have been mainly attributed to the occurrence of black carbon, the absorption from humic-like substances, formed during biomass burning emissions, needs to be investigated in the Indo-Gangetic Plain. This is important in order to quantify the total aerosol absorption and the site-specific mass absorption efficiency.

In aerosol radiative forcing, the vertical distribution of black carbon has immense importance, especially in the presence of clouds (Satheesh 05). The warming potential of black carbon strongly increases when located above highly reflecting/scattering clouds, and leads to local warming, reduction in the local relative humidity and increase in stability. Direct experimental measurements though are limited over the tropics where strong convection and cloudiness coexist. In the first.ever high altitude, in.situ measurements of black carbon in the troposphere, up to 9 km, made over central India, it was found that the altitude distribution showed multiple peaks in black carbon concentration, with two large peaks at about 4.5 km and another above 8 km, probably associated with high-altitude aircraft emissions. They also found that associated with the peak at 4.5 km was a rapid environmental lapse rate and a sharp increase in the atmosphere stability, resulting out of the warming by the black carbon layers. The study thus raises new issues on the lifetime of elevated black carbon layers, their sources, radiative forcing and probable impacts in cirrus clouds.

What we need to know

The real.time and long.term measurements of carbonaceous aerosols from South Asia though are rather sparse – limited to only a few months of data. Thus, studies need to be designed to assess the regional climate effects of carbonaceous aerosols over the Indian subcontinent using the optical, physical and chemical characteristics of aerosols obtained from satellite and ground-based measurements taking into account the differences in the scale length of aerosol processes. Several studies provide an overview of black carbon emissions and how they impact, but there is still a long way to go.

The radiative impact of aerosols is one of the largest sources of uncertainty in estimating anthropogenic climate perturbations. Estimation of the aerosol radiative effects is much more complicated than the radiative impact due to well-mixed greenhouse gases. The majority of aerosol radiative impact assessments made so far are based on models, which incorporate measured aerosol properties. However, this approach involves several assumptions, which can lead to significant errors.

The areas that need more research attention, for instance, include vertical distribution of black carbon, state of mixing black carbon with other aerosols, effect of black carbon on cloud cover, impact of mitigation of black carbon aerosols and effect of black carbon on monsoon.

Not a solution for global warming

The developing world, especially India and China, accounts for the largest volume of black carbon emissions (25-35 per cent). India is particularly important in this discussion – the Himalaya are in close proximity and high levels of black carbon emissions from India are said to be deposited on the snow and ice of these mountains. The political troubles with black carbon began in 2001 when the then US president George W Bush named exclusion of black carbon from the Kyoto Protocol as one of the reasons for the American withdrawal from the agreement. The US has been stressing on black carbon as it and other developed nations have already limited their black carbon emissions. India has been very reluctant to include black carbon in any new protocol.

Even as studies show that mitigation of black carbon would not be a solution for global warming, there is a growing tendency to project mitigation of black carbon aerosols as a quick solution to climate change. In February 2012, the US launched an initiative on short-term climate forcers. The initiative is a partnership of US with Mexico, Canada, Sweden, Bangladesh, Ghana and the United Nations Environment Programme. The coalition is expected to focus on efforts to reduce black carbon, hydrofluorocarbons and methane. It plans to reduce these short-lived climate pollutants by driving the development of national action plans and the adoption of policy priorities; building capacity among developing countries; mobilizing public and private funds for action; raising awareness globally; fostering regional and international cooperation, and; improving scientific understanding of the pollutant

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impacts and mitigation.

According to former United States Secretary of State Hilary Clinton, who launched the initiative, "the project holds a lot of promise, especially in the context of our larger battle against climate change". The initiative is being showcased as a "multilateral effort to address short-lived climate forcers" and a "recognition of scientific and political realities that surround climate change" to "slow down the rate of climate change". However, it is amply clear that if reductions in carbon dioxide emissions are not undertaken urgently, the effects of reducing short-lived climate forcers such as black carbon would be lost. It is also clear that a separate mechanism should be drawn up to discuss black carbon and it should not be mixed up with greenhouse gases to stall global negotiations at the forthcoming Meeting of the Conference of Parties in Doha in November 2012.

Focusing on reducing black carbon and other particulate matter would have enormous positive health consequences along with the added benefit of slowing down only 'regional' warming.

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