Black Carbon e-Bulletin

Volume 2, Number 2 | July 2010

High Concentration of Black Carbon Observed in the High Himalayas

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The transport of atmospheric pollutants and climate-altering substances can significantly impact high mountain areas, which are generally considered "clean" regions. An important component of such atmospheric pollution is black carbon (BC), an aerosol produced by the incomplete combustion of biomass, coal and diesel fuels and able to contribute to climate change by altering the Earth's radiative balance and cloud properties. Once deposited in snow and ice, BC can considerably reduce the surface albedo, possibly resulting in increased glacier retreat and earlier seasonal snowpack melt and therefore impacting water resources, agriculture, and human health. Knowledge of BC concentrations and variability in high mountain regions is therefore essential to better understand the transport of pollutants and their vertical distribution, and to evaluate their impacts on the environment. This knowledge can also contribute to the design of efficient policies on emission abatement strategies by quantifying their effect in controlling global and regional climate.

Recent Himalayan observations (Figure 1) revealed a new negative record linked to high concentrations of pollutants measured at the Nepal Climate Observatory - Pyramid (NCO-P, 27.95 N, 86.82 E). The NCO-P, situated at an altitude of 5,079 m a.s.l at the base of Mt. Everest, is part of the Ev-K2-CNR SHARE network and of the UNEP Atmospheric Brown Clouds (ABC) surface climate observatory network, in the framework of the ABC project.

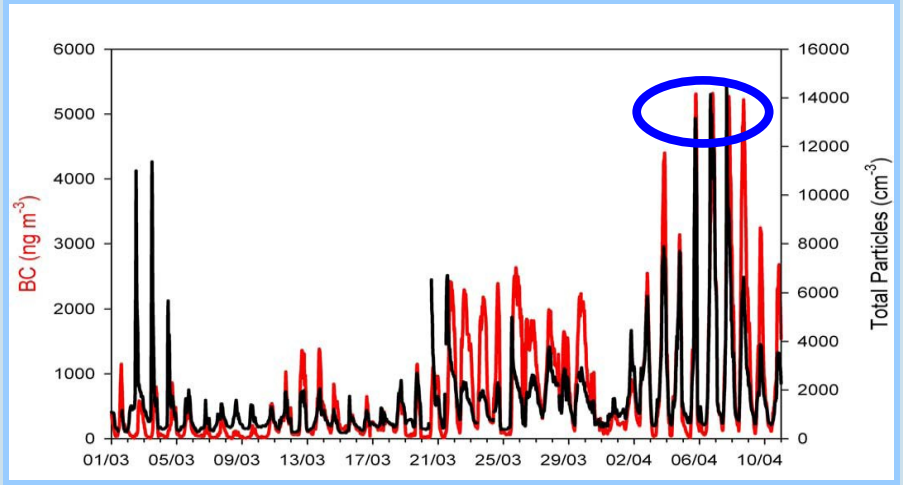

Figure 1: Concentrations of black carbon (red line) and total particles (black line) during 1 March -10 April 2010[5]

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Also in this Issue

Editorial:

Black Carbon and the Third Pole

Achim Steiner, Executive Director, UNEP

As we have documented in previous issues of this Bulletin, while the health impacts of black carbon are clear, their climate impacts are not nearly as simple. With different studies using different metrics, it can be quite difficult to nail things down. However, there is a body of knowledge that points to aerosols as being a greater component of climate change than previously thought, and to black carbon contributing disproportionately to the warming of the Himalayas. More headlines on the impacts of black carbon in glacier melt, such as, "Cutting Black Carbon Soot Could Save Arctic" (July 29, 2010); and "Black Carbon, a Significant Factor in the Melting of Himalayan Glaciers" (February 3, 2010), continue to appear.

Indeed, recent studies indicate that the regional impacts of black carbon may be even more significant than its global warming effect. Researchers from the Energy and Resources Institute in Delhi have found black carbon concentrations in glaciers in normally pristine areas. These deposited particles accelerate melting by absorbing sunlight that would normally be reflected from the snow and ice. Recently, a scientist at the Lawrence Berkeley National Laboratory stated that simulations indicate that "greenhouse gases alone are not

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Published by the United Nations Environment Programme (UNEP) in collaboration with the Science Team of Atmospheric Brown Cloud (ABC)

Testimony on Black Carbon

A US congress hearing on Black Carbon (BC) by the Select Committee on Energy Independence and Global Warming was held on March 16, 2010. Prof. Veerabhadra Ramanathan, ABC International Science Team Chair, was one of the principal witnesses at the hearing. A summary of Prof. Ramanathan's testimony is provided below.

Status of Current Understanding on BC

It is important to distinguish between issues that are well understood and those that require confirmation. The first definitive study on the global warming magnitude of CO_2 increase was published 45 years ago and it required hundreds of model studies by numerous groups since then to reach the current level of consensus on the importance of CO_2 to climate change. In comparison, observational studies on the climate effects of BC were begun in earnest about 15 years ago. There is reasonable consensus on the following issues:

- Black carbon in the air has a lifetime of several days to a few weeks.
- Fossil fuel combustion, bio fuel cooking and biomass burning are sources of BC.
- BC adds solar heating to the atmosphere and causes dimming at the surface. The atmospheric solar heating is much larger than the surface dimming, and as a result, BC leads to a net warming of the surface and the atmosphere.
- BC deposition on sea ice and snow darkens the surface and leads to more solar absorption and melting of sea ice and snow.
- Atmospheric Brown Clouds (i.e., BC and other manmade particles) cause dimming at the surface, leading to a global average effect of decreasing rainfall.
- Globally, BC has a net warming effect on the climate system. The magnitude of its current warming effect is subject to a large uncertainty, ranging from about 20 per cent to as much as 60 per cent of the warming effect of CO_2 increase since the 1850s.

Rationale for Mitigating BC Emissions

BC offers an opportunity to reduce projected global warming trends in the short-term. BC in the air has a lifetime of few days to several weeks. As BC concentrations and their solar warming effect will decrease almost immediately after their emissions are reduced, policy makers introducing mitigation measures will have a unique opportunity to witness the success of their efforts during their term of office. Considerations of public health, air quality and regional climate change also warrant reductions of BC emissions.

Other Considerations for Policy Makers

Unmasking of the Greenhouse Effect: A blanket keeps us warm on a cold winter night by trapping the heat from our body. Similarly, greenhouse gases surround the planet like a blanket and trap the infrared heat generated by the planet's surface and the atmosphere. BC particles enter this blanket and heat it by trapping sunlight. Sources that generate BC also co-emit other particles made of organics, which act like mirrors on the blanket and cool the surface by reflecting sunlight. In addition, some fossil fuels generate other mirror particles, such as sulphates and nitrates. Because of the concern over sulphate pollution, SO_2 emissions have been reduced by 30 to 50 per cent in developed nations since the 1980s, thus eliminating their cooling effect. This unmasking has been observed as increased sunlight in most of Europe and USA during the last few decades, and needs to be offset by corresponding decreases in BC.

Complementing CO_2 Emission Reductions: CO_2 enhances the greenhouse effect by as much as 55 per cent. At the current rate of emission (35 billion tons per year) and a current growth rate of 2 to 3 per cent, the manmade greenhouse effect can double during this century. BC reductions, even at 50 per cent, cannot offset the CO_2 effect. However, BC reductions when combined with reductions in other short-lived climate warming gases, can delay large warming by a few decades and complement CO_2 mitigation efforts.

Diesel and Cookstoves are Prime Targets for Mitigation

BC generated by diesel combustion has greater warming potential than bio-fuel cooking or biomass burning. This is because diesel generates less of the cooling organic aerosols. With respect to biomass fuel cooking, limited studies suggest that this source is also a net climate warmer but we need to conduct a careful and well documented scientific study on the impact of biomass cookstoves. Towards this goal, this author along with a multidisciplinary team of experts, has proposed Project Surya (http://wwwramanathan.ucsd.edu/ProjectSurya.html).

Major Source of Uncertainties

The basic input data for most models is the inventory of BC emissions from various parts of the world. This has about a three-fold uncertainty, particularly for Asia, Africa and South America. The second major uncertainty is the interaction of BC and organic aerosols in the cloud. Relying on just observational work, BC-cloud interactions seem to have a net warming effect.<

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nearly enough to be responsible for the snow melt. Most of the change in snow and ice cover is from aerosols. Black carbon alone contributes at least 30% of this sum", further adding that "we maybe underestimating the amount of black carbon by as much as a factor of four." [1] The study concludes that "preserving the present snow/ice cover in the third polar ice cap would require concerted efforts to reduce both greenhouse gases and black carbon emissions from coal as well as transportation and residential cooking/heating sources."[2]

The snow glaciers of the Himalayas, considered the "third pole", are the third largest store of water on the planet and accelerated melting could have far reaching effects, such as flooding in the short-term and water shortages in the long-term as the glaciers shrink. It is timely to consider appropriate mitigation actions, if we pay attention to estimates, such as those by Stanford University researcher Mark Jacobson (published in the *Journal of Geophysical Research – Atmospheres* on July 29, 2010*),* which state that cutting black carbon produced by burning fossil fuels, vegetation, dung and other sources over a 15-year period could reduce the warming which the Earth has experienced since the Industrial Revolution—about 0.8 degrees Celsius—by 17 to 23 per cent,

Studies on black carbon are sufficiently varied to engender some uncertainty. However, as new information begins to emerge, UNEP continues to work with our partners to monitor and review recent findings and to inform forward-looking policy decisions. We continue to emphasize that mitigation of non-carbon dioxide climate warmers, like black carbon must be understood as broadening of the range of climate change related actions with quick impact. It should not detract from the necessity of reducing CO_2 emissions but represents an additional measure that increases our chances of keeping global warming below 2°C above the pre-industrial temperature.

1. DOE/Lawrence Berkeley National Laboratory (2010, February 4). Black carbon a significant factor in melting of Himalayan glaciers. ScienceDaily. Retrieved August 4, 2010, from http://www.sciencedaily.com- /releases/2010/02/100203161436.htm

2. Menon,., Koch,D., Beig,., Sahu,., Fasullo,., and Orlikowski,D.: Black carbon aerosols and the third polar ice cap, Atmos. Chem. Phys. Discuss., 9, 26593-26625, doi:10.5194/acpd-9-26593-2009, 2009.

What are ABCs?

Atmospheric brown clouds (ABCs) are regional scale plumes of air pollution that consist of copious amounts of tiny particles of soot, sulphates, nitrates, fly ash and many other pollutants.

Basically, ABCs are the same as the aerosols that are mentioned in reports by the Intergovernmental Panel on Climate Change (IPCC). In principle, tropospheric ozone should be part of ABCs. Soot results from the incomplete combustion of fuels and consists of nano- to a few micro-metre (millionth of a metre) size particles. Black carbon (that is, light absorbing elemental and organic carbon particles) and many organic acids are the main constituents of soot.

The brownish colour of ABCs is due to the absorption and scattering of solar radiation by anthropogenic black carbon, fly ash, soil dust particles, and nitrogen dioxide gas. Typical background concentrations of aerosols are in the range 100 - 300 cm^{-3}, whereas in polluted continental regions the concentrations are in the range 1 000 - 10 000 cm^{-3}.

ABCs start as indoor and outdoor air pollution consisting of particles (referred to as primary aerosols) and pollutant gases, such as nitrogen oxides (NO_x), carbon monoxide (CO), sulphur dioxide (SO_2), ammonia (NH_3), and hundreds of organic gases and acids. These pollutants are emitted from anthropogenic sources, such as fossil fuel combustion, biofuel cooking and biomass burning.

Gases, such as NO_x, CO and many volatile organic compounds (VOCs), are referred to as ozone precursors since they lead to the production of ozone, which is both a pollutant and a strong greenhouse gas. Gases, such as SO_2, NH_3, NO_x and organics, are referred to as aerosol precursor gases, and these gases - over a period of a day or more - are converted to aerosols through the so-called gas to particle conversion process. Aerosols that are formed from gases through chemical changes (oxidation) in the air are referred to as secondary aerosols.

Source: V. Ramanathan and others (2008), Atmospheric Brown Clouds: Regional Assessment Report with Focus on Asia.

Upcoming Events

- **23 August 2010: ABC– Africa Consultation meeting.**
- **24 August 2010: ABC-International Science Team meeting.**

High Concentrations ...

As pointed out by several studies[6] analysing NCO-P measurements since their establishment in March 2006, the pre-monsoon season is usually characterized by large amounts of fine particles, BC and ozone. These pollutants can be transported up to the world's highest region both by long-range and regional transport phenomena the push this haze towards the Himalayan ridge, where mountain wind systems favour air-mass transport to high altitudes. Since April 2, 2010, the circulation of valley winds have favoured the transport of large amounts of BC, particulate matter and ozone to this station in the upper Khumbu valley, leading to high concentrations of pollutants during the afternoon-evening hours. This thick haze is clearly discernible by NCO-P images (Figure 2) during afternoon conditions, attesting to the extension of the ABC and its influence in reducing visibility in the high Himalayas.

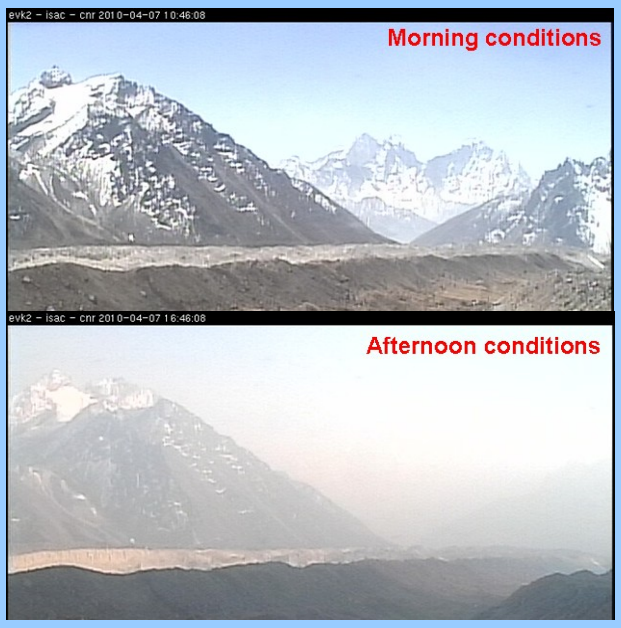

Figure 2. A thick haze is clearly discernible by NCO-P images taken on April 7 during morning and afternoon conditions, testifying the afternoon extension of the ABCs up to the high Himalayas[5]. (Source: http://evk2.isac.cnr.it/)

Daily during 2 – 10 April, very high pollutant values were observed in the afternoons (Figure 1), with BC concentrations often exceeding 5 µg/m^3 (30-minute mean value) constituting the highest BC concentration ever recorded at the NCO-P since the research activity began. In the same period, the aerosol mass (PM_1, $PM_{2.5}$, PM_{10}) exceeded 100 µg/m^3 and ozone concentration peaked at 90-95 ppbv (i.e. 180-190 µg/m^3), indicating that air-masses affected by combustion emissions, rich in particulate matter and photochemically produced ozone, were transported to the high Himalayas. The presence of a large amount of aerosol was further supported by in-situ AERONET measurements that showed Aerosol Optical Depth (AOD) values higher than 0.25 at 500 nm, a sixfold increase with respect to typical pre-monsoon measurements at the NCO-P. AOD measurements conducted at the Nepal Climate Observatory - ICIMOD HQ (Kathmandu, about 1400 m a.s.l.), characterize the Himalayan foothills with values at 500 nm higher than the 0.9, indicating wide-spread extension of the pollution event detected at NCO-P.

An analysis of the total number of daily hot spot fires obtained by the Moderate Resolution Imaging Spectroradiometer (MODIS) on board NASA's Aqua and Terra satellites showed large fire occurrences over South Asia from the beginning of April 2010. The increased number of fires over South Asia in the early days of April could have contributed to high concentrations of BC and other pollutants observed in the high Himalayas. The possible influence of fire emissions on large pollutant concentrations observed in the high Himalayas was corroborated by a preliminary analysis of the chemical properties of aerosol. In fact, in-situ atmospheric aerosols in the PM_{10} and PM_1 size fractions sampled in quartz-fiber filters confirmed the very high concentrations of organic matter (especially levoglucosan), compared with previously unpolluted conditions. Levoglucosan is one of the typical species of wood smoke aerosol emissions. Because of its relative chemical stability during atmospheric transport, it is used to trace vegetation smoke, forest fires, biomass and campfire burning and residential wood combustion, differentiating rural air pollution from urban air pollution. In South Asia, the fire season in forested areas is typically from February to May, while in croplands it varies with geographical location, with peaks in April and October, corresponding to the two major harvest seasons. An analysis of atmospheric circulation indicated that valley winds transported pollutants to the high Khumbu valley and to the Everest glaciers. These observations clearly indicated that a large amount of BC and other pollutants may be transported up to the medium and high Himalayan troposphere, where they considerably increase their lifetime and may then accumulate for transport over long distances.

Atmospheric observations conducted at high mountain sites, characterised by a large "area of representativeness", are key for obtaining an accurate picture of atmosphere and climate conditions at regional and global scales. They encompass the impacts of BC depositions that favour possible increase in the melting of Himalayan glaciers and snowpacks, and are able to strongly influence the hydrological cycle, with consequences on agriculture and human subsistence. In this context, continued monitoring of atmospheric pollutants under an integrated framework, with the aim of providing high quality, long-term climatic and environmental data to the scientific community and to decision makers, is vital for thoroughly assessing the processes and impacts of climate change in mountain areas.<

1. *ISAC-CNR, Bologna, Italy*
2. *Ev-K2CNR Bergamo, Italy*
3. *ICIMOD, Kathmandu, Nepal*
4. *LGGE-CNRS, Grenoble, France*

5. *http://www.rrcap.unep.org/abc/userfiles/file/ABC_April2010_NCOP.pdf*
6. *Http://www.atmos-chem-phys-discuss.net/special_issue103.html*

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