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Black Carbon Aerosols over India

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In the early 1980s in India, the Indian Middle Atmosphere Programme (I-MAP) commenced a systematic investigation of the physico-chemical properties of aerosols, their temporal heterogeneities, spectral characteristics, size distribution and modulation of their properties by regional mesoscale and synoptic meteorological processes at different distinct geographical locations. Its thrust was given a regional climate forcing focus since the 1990s under the ISRO-GBP (Indian Space Research Organization's Geosphere Biosphere Program) (Moorthy et al., 1999).

In the initial years, the focus was more on the composite aerosol characterization and microphysics of aerosols. The attention gradually shifted to their radiative implications, chemical nature and long-range transport. A mid-course stocktaking of regional efforts by the ISRO-GBP in 1998 recognized the possible importance of BC aerosols to the climate system and it was decided to pursue this direction in the second phase of the Aerosol Climatology Effects Project (Moorthy et al., 1999). Details of this research activity are also available in "IGBP in India 2000: A status report on projects", edited by R. Narasimha et al. (2000) and published on behalf of the Indian National Science Academy (INSA). This effort received a welcome boost in 1998, with the advent of the Indian Ocean Experiment (INDOEX, Satheesh and Ramanathan, 2000; Ramanathan et al., 2001), which demonstrated that despite contributing a mere 11% to the optical depth, BC could contribute as high as 60% to the radiative forcing (Satheesh and Ramanathan, 2000). Nevertheless, systematic and long-term efforts in the regional characterization of BC through a regional network commenced in mid-2000 with the first-ever long-term observation station set-up at Trivandrum, a coastal station at the southern tip of the Indian Peninsula. The first results with regards the characterization of aerosols and

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Consultation on Black Carbon Mitigation

A consultation on Soft Approaches for Achieving Co-benefits from Black Carbon Emissions Reduction was co-organized and co-hosted by the United States Environmental Protection Agency's (U.S. EPA) Office of International and Tribal Affairs (OITA), the United Nations Environment Programme (UNEP), and the International Centre for Integrated Mountain Development (ICIMOD), from 21 to 23 March 2011 in Kathmandu, Nepal. The consultation workshop gathered top experts on black carbon, local and regional community -based non-government organizations, government agencies, research institutions, and international aid agencies, to identify and assess opportunities for taking fast action on mitigating black carbon emissions in South Asia, one of the known black carbon hot spots.

After three days of deliberations, the consultation identified measures that could be promoted to reduce emissions of short-lived atmospheric pollutants from the residential, industrial and transportation sectors. The consultation noted that "reduction in short-lived atmospheric pollutants such as black carbon can be accomplished with already available, cost-effective technologies". Major discussions on each of the sectors are summarised in this article.

Residential sector

About three billion people in the world rely on traditional cooking stoves for cooking and heating, involving direct and inefficient burning of biomass. There are different types of improved cook stove models. These include Parishad model, Philips 4012 forced draft model, Oorja plus model, Philips 4008 natural draft model, Envirofit G-3300 model, the Envirofit B-1200 model, and the Arti sarai model. Several projects to promote improved cooking stoves have been implemented in South Asia (Box 1).

Past and ongoing initiatives show that adoption of improved cook stoves is difficult, as it involves changes in attitude and behavior, taking into account complex social, cultural, and gender interactions as well as affordability issues that

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Also in this Issue

Editorial:
Integrated Response to Air Pollution

Achim Steiner, Executive Director, UNEP

The United Nations Sustainable Development Conference (Rio+20), to be held in Brazil next year, provides an unprecedented opportunity for governments all over the world to address obstacles that impede progress towards achieving the objectives of sustainable development. The momentum created by the Rio+20 process is also an opportunity for the development of an integrated approach to addressing air pollution, which is inextricably linked to human health, climate mitigation, energy security, water security, food security, and poverty alleviation. The fact is, forty years after the UN Conference on the Human Environment in Stockholm, our understanding of air pollution issues has greatly increased and there is a need to review our track record in this regard, as well as to formulate strategies to address the dynamic environmental issues of air pollution.

The 1972 Stockholm Declaration clearly recognized the importance of addressing the problem of air pollution: "*We see around us growing evidence of man-made harm in many regions of the earth: dangerous levels of pollution in water, air, earth and living beings; major and undesirable disturbances to the ecological balance of the biosphere; destruction and depletion of irreplaceable resources; and gross deficiencies, harmful to the physical, mental and social health of man, in the man-made environment, particularly in the living and working environment.*"

During the period preceding the Stockholm Conference, air pollution was mainly considered as a local environmental issue that was limited to urban air pollution and indoor air pollution. At the Stockholm Conference, the phenomenon of trans-boundary air pollution, such as acidification (at that time a hypothesis referring to the long distance travel of airborne pollutants and their deposition causing damage to sensitive ecosystems), was brought to the attention of policy makers.

Several scientific studies conducted after

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the impact of anthropogenic activities in modulating their concentrations were brought out by Babu and Moorthy (2001, 2002). Through a focused field experiment, Babu et al (2002) brought out for the first time in India the radiative impact of enhanced BC absorption from an urban site. Subsequently, there has been gradual and planned proliferation of this activity in India, which eventually led to the formation of a national network called the ARFINET (note the circles in Figure 1): ARFI stands for Aerosol Radiative Forcing over India. This has resulted in a large number of publications (Babu et al., 2002; Padithurai et al., 2004; Ganguly et al., 2005; Dumka et al., 2006; Satheesh et al., 2006; Pant et al., 2006; Moorthy et al., 2004, 2007, 2008; Nair et al., 2007; Niranjan et al., 2006, 2007; Rengarajan et al., 2007; Satheesh et al., 2008, 2009). However, most of these publications pertained to BC characteristics near the surface, or within the planetary boundary layer.

With a view to characterizing spatial heterogeneity in BC distribution, a road/land campaign (LC-I) was conducted during February to March 2004, under the ISRO-GBP over Central/Peninsular India. Simultaneous measurements were made over spatially separated locations, using identical and inter-compared instruments over the course of a month from land based mobile laboratories, and generated a wealth of information on black carbon as well as other aerosol species (Moorthy et al., 2004, Ganguly et al., 2005). These observations revealed that coastal areas, in general, have higher aerosol mass concentrations (>50 μg/m^3) in case of both the east and west coasts (Moorthy et al., 2005). By comparison, the inland regions have lower mass concentrations (<40 μg/m^3). As a continuation of this experiment, to examine temporal changes, effects of long-range transport, measoscale processes and local emission, Land Campaign II (LC-II) was organized, again under the ISRO-GBP during December 2004, with concurrent measurements from a network of eight stations spread across the Indo Gangetic Plains (Dumka et al., 2006; Pant et al., 2006; Niranjan et al., 2006, 2007; Nair et al., 2007; Rengarajan et al., 2007). These studies very clearly demonstrated the role of boundary layer dynamics, passage of cold front, long-range transport, emissions from coal based thermal power plants as well as agricultural residue burning, all contributing to spatial distributions of BC across the IGP. For the first time in India, these systematic investigations revealed a very high ratio of OC/BC, implying large abundance of OC in the carbonaceous aerosol system in India (Rengarajan et al., 2007).

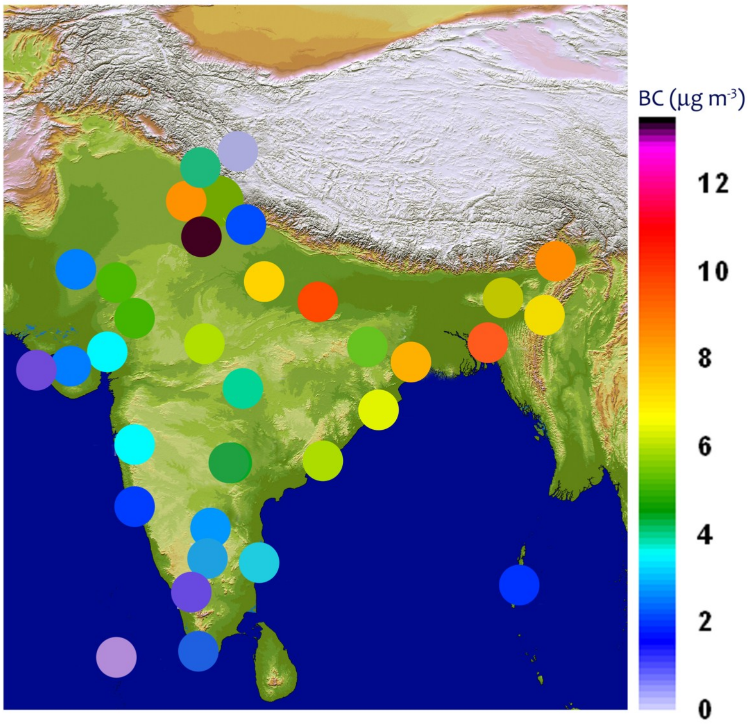

Figure 1: Location of ARFINET observatories marked on a digital elevation map where colour bar indicates annual mean BC mass concentration.

While the above efforts focused on the mainland, the oceanic region has remained less explored, especially with regards BC. The first comprehensive and exhaustive characterisation of BC over oceanic regions around the Indian mainland was made during the Integrated Campaign for Aerosols, Gases and Radiation Budget (ICARB), the largest multi-instrumental, multi-platform field experiment ever conducted over these regions (Moorthy et al., 2008). The ICARB was conceived as an integrated campaign, comprising three segments namely land, ocean, and aircraft segments. In each one of these segments, collocated measurements of the optical, physical and chemical properties of atmospheric aerosols were carried out, using respective network observatories over the mainland and island, that is, cruise measurements over 4 million km^2 in the oceanic regions, and aircraft measurements across the land-ocean interface. The experiment revealed the latitudinal and longitudinal gradients of BC over oceans, significant advection from the East Asian regions into the Bay of Bengal (BoB), and the more absorbing nature of aerosols over BoB compared to the Arabian Sea (Nair et al, 2008). More information and spatial synthesis are available elsewhere (Moorthy et al., 2008; Babu et al., 2008; Vinoj et al., 2008; Beegum et al., 2008).

Vertical profiles of BC, measured for the first time in India using instruments onboard an aircraft from Hyderabad (Moorthy et al. 2004) revealed a rapid decrease in BC concentration within the atmospheric boundary layer (ABL) up to about 500 m above ground, above which the concentration remained nearly steady, up to an altitude of 3 km. It was also seen that above the ABL, BC concentration was found to increase further from the urban centre. Following this, airborne measurements of BC were undertaken over Kanpur during the winter of 2004. However, major efforts to characterize the vertical distribution of BC took place during the ICARB (Babu et al., 2008). Based on multi-instrumented measurements during ICARB, Satheesh et al. (2008) made a quantitative estimate of the energy absorbed (by BC) in ten layers of the atmosphere. The study revealed that during the pre-monsoon season, most of the Indian region is characterized by elevated aerosol layers within which the extinction coefficients were higher (up to 3 times) than near the surface. A substantial fraction (as much as 50 to 70%) of aerosol optical depth was contributed by aerosols above the clouds. A meridional gradient in the aerosol induced heating of the lower atmosphere was also revealed.

Despite the above findings, information on BC remained limited to certain periods or locations. With a view to providing a wide database, the ISRO-GBP has setup the ARFINET, comprising 33 surface observatories across India. A sufficiently long time series can also help in inferring climate change signals. There are several unknowns related to the climate impact of BC. The ARFI (aerosol radiative forcing over India) is also envisaged to address unresolved issues, such as the state of mixing of BC with other aerosols, effects of BC on cloud cover, effects of BC on monsoon, and so on. There is still a great degree of uncertainty about the hygroscopic properties of BC particles and hence their role as cloud condensation nuclei (CCN). Recently the Ministry of Environment and Forests (MoEF) launched National Carbonaceous Aerosol Program (NCAP) to monitor key aerosol parameter by augmenting the ARFINET (MoEF Report, Black Carbon Research Initiative, March 2011).

A field experiment focusing on the interaction between aerosol warming and monsoon is underway. Ground-based and aircraft-based field experiments are being planned over the Indo-Gangetic Basin during 2011-2014, as part of the RAWEX (regional aerosol warming experiment) under the ISRO-GBP. The Ganges val-

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Surya Team Develops a Global Monitoring System for BC Using Cellphones

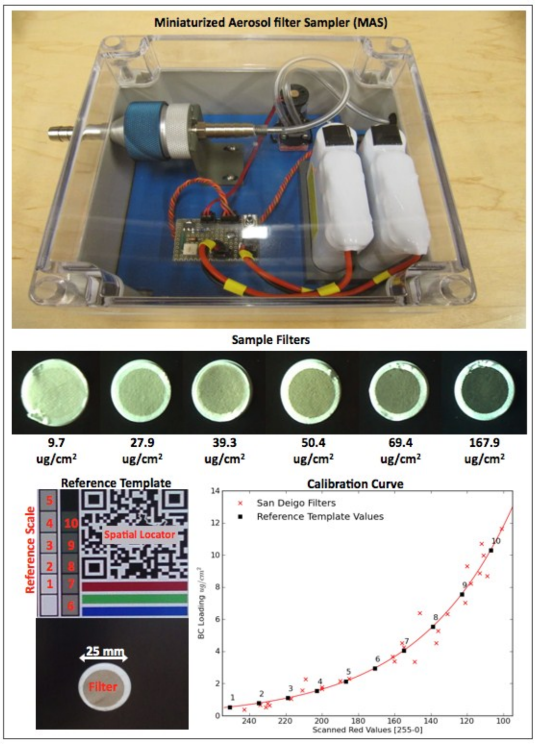
Reliable and cost-effective systems to measure near-surface black carbon (BC) concentrations globally are necessary in order to validate air pollution and climate models and to evaluate the effectiveness of BC mitigation actions.

Towards this goal, the Surya Team led by Nithya Ramanathan, developed and validated a new wireless, low-cost, ultra low-power, BC cellphone-based monitoring system (BC_CBM).

BC_CBM integrates a miniaturized aerosol filter sampler with a cellphone to carry out filter image collection, transmission and image analysis in order to determine BC concentrations in near real-time.

The Surya Team, using the BC_CBM system and working on field data collected from vastly different environments, ranging from southern California to rural regions in the Indo-Gangetic Plains of Northern India, was able to determine BC concentrations well within the experimental error of two independent reference instruments (an optical method, and a thermal optical method) for both indoor air and outdoor ambient air.

For additional details contact: Nithya Ramanathan (nithya@cs.ucla.edu).



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ley is one of the largest and most rapidly developing regions of India. The Ganges River, which provides the region with water needed for sustaining life, is fed primarily by snow and rainfall associated with the Indian summer monsoon. Impacts of changes in precipitation patterns, temperature, and flow of snow-fed rivers could be immense. Recent satellite-based observations have indicated that the upper Ganges Valley has some of the highest persistently observed high aerosol optical depth values. Concerted efforts to understand the complex features over this region have been mooted under RAWEX. These experiments would address the scenario arising from the mixing of hygroscopic aerosols containing hydrophilic and hydrophobic BC compounds at various mixing states.

In summary, last decade (2000-2010) witnessed substantial progress in understanding the microphysical, chemical and optical properties of aerosols over the Indian region and their impact on radiation. Exhaustive aircraft-based measurements of composite aerosols and aerosol black carbon have improved our knowledge about the vertical distribution of aerosols. Observations over the Indian land mass using instrument-fitted vehicles as well as network sites revealed that BC mass concentration over coastal areas is higher compared to inland regions. Measurements of BC using high altitude balloons in the upper troposphere (up to 10 km) enabled an investigation of the impacts of BC warming at higher levels on the environmental lapse rate. Comprehensive studies of the morphological features of aerosols using electron microscope have revealed that natural dust over India region is contaminated with BC. However, it appears that there is still a great degree of uncertainty about the radiative effects of black carbon aerosols over India.

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Consultation ...

are typically associated with alternative technologies. Involving or not involving users up front in cookstove design and so on was seen to play a major role in the appeal, adoption and continued use of improved cook stoves.

To mitigate black carbon emissions in the residential sector, particularly with regards indoor air pollution, those present felt the need for technological interventions, coupled with operational behavioral changes and changes in local customs and attitudes, to bring about significant reductions in black carbon emissions. It would also be useful to introduce new technologies that are culturally acceptable, desirable, and affordable with efficient options that meet emission standards sought for cook stoves in particular. While there have been major technological improvements, more needs to be done in terms of addressing local customs and norms and developing of protocols, standards and benchmarks. All these are important from the climate, health and sociological perspectives. There is also a need to set up financial mechanisms to support cook stove initiatives.

To be continued

Box 1: Improved cook stoves offer environmental and health benefits

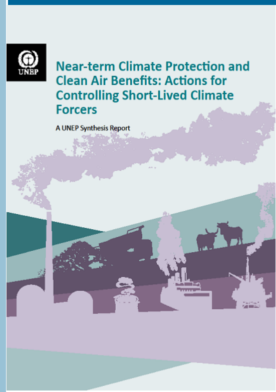
Development and testing of locally fabricated cook stoves by Project Surya shows significant socio-economic and environmental benefits of improved cook stoves:

Contribution to climatic benefits- Locally fabricated cook stove will reduce BC emission by 70% to 80% compared with traditional mud-stoves.

Improved health and living conditions for women and children- Improved stoves resulted in three immediate benefits to families: (1) significantly improved kitchen air quality, (2) reduced drudgery in collecting biomass fuel like wood chips as improved stoves require 50% less biomass fuel compared with traditional stoves, and (3) shorter cooking time.

Established **sustainable and culturally appropriate or sensitive business model** for the new technology by addressing poverty and cultural issues associated with successful stove adoption. Customization and local fabrication reduced cost and increased usage of the stoves and reduced spending for biomass.

A UNEP Synthesis Report Published



On 25 November, UNEP published a synthesis report entitled "***Near-term Climate Protection and Clean Air Benefits: Actions for Controlling Short-Lived Climate Forcers***". The Report is directed primarily at policy makers and other stakeholders who have an interest in the topic and can potentially influence policy decisions concerning air quality and near-term climate protection. A digital copy of the report can be downloaded at www.unep.org/publications/ebooks/SLCF/

Young Scientists Trained on Short-lived Atmospheric Pollutants

Once every two years, Project ABC organizes an international training school to enhance the capacity of young researchers to understand and formulate theoretical concepts concerning atmospheric science and to monitor ABCs using various state-of-the-art instruments. The 4th training school on ABCs was held in March 2011 in Kathmandu and Nagarkot, Nepal. A total of 34 participants (14 female and 20 male) from 24 institutes from seven developing countries were trained in recent theoretical advances in atmospheric science. They also participated in hands-on training in atmospheric monitoring techniques.

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the Stockholm Conference confirmed the hypothesis that air pollutants could travel several thousands of kilometres and cause damage to human health, agriculture and sensitive ecosystems that are far from their source. This demonstrated the need for international cooperation to address trans-boundary air pollution. In response to this need, governments established intergovernmental networks and agreements at sub-regional and regional levels to assess trans-boundary air pollution issues.

During the last decade, scientific studies have unveiled many significant impacts of air pollutants on climate change. For example, black carbon has been estimated to contribute as much as 27 to 55% of the warming effect caused by carbon dioxide, making it the second or third strongest anthropogenic warming agent overall. In addition, air pollutants such as tropospheric ozone and methane have been found to cause strong warming effects. Recent scientific studies suggest that air pollutants can reduce water and food security regionally through their interference with the hydrological cycle and crop growth. Scientists have also unveiled the complex nature of air pollution issues. Some air pollutants like sulfates and nitrates reflect solar radiation and have a negative forcing (surface cooling effect), while other air pollutants, in particular black carbon, absorb solar radiation and have a net positive forcing (surface warming).

Clearly, the time to take an integrated approach to different components of air pollutants and related environmental issues has come. Existing intergovernmental air pollution networks could be empowered to facilitate such an integrated approach in the context of sustainable development. It is an opportunity to act, which we should seize at Rio+20.

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