Climate Impacts of Black Carbon

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*Testimonial to the House Select Committee on Energy Independence and Global Warming
Chair: The Honorable Edward J. Markey
Ranking Member: The Honorable F. James Sensenbrenner, Jr

House Hearing entitled:
Clearing the Smoke: Understanding the Impacts of Black Carbon Pollution
March 16, 2010

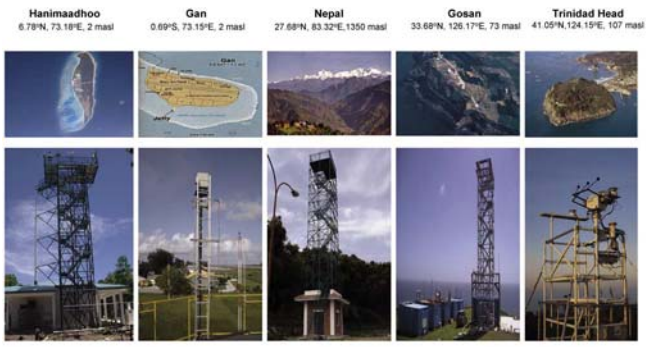
2175 Rayburn House Office Building
Washington D.C.

**The views expressed here are those of the author and do not necessarily represents the views of the author's institution or the funding agencies.*

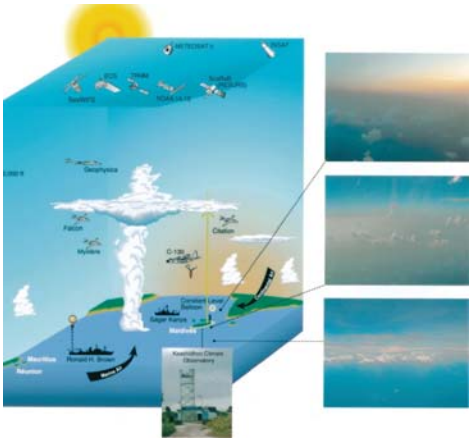
My Background

I am an atmospheric physicist. My work on black carbon and its radiative warming is largely based on experimental and observational studies. I Co-Chaired the Indian Ocean Experiment in the 1990s which looked at long range transport of black carbon from S Asia and its regional radiative forcing. I also chair the United Nations Environmental Program's Atmospheric Brown Clouds (ABC) project and set up regional observatories in the Arabian Sea, Nepal and western Pacific to observe long term variations in black carbon and other manmade particles. With researchers in my group, I have developed autonomous unmanned aerial observing systems (UAS) with miniaturized black carbon and radiometers instrumentation to measure directly how black carbon and other aerosols modify the heating of the atmosphere. UAS campaigns have been conducted in the Arabian Sea, in S California and in the western Pacific during the Beijing summer Olympics to examine the impact of the 'great pollution shutdown' in Beijing.

ABC Observatories



Indian Ocean Experiment



Unmanned Aerial Vehicle Observing Systems

I. SYNOPSIS

This testimony is largely based on a synthesis article published in 2008: Ramanathan, V. and G. Carmichael (2008).

What is Black Carbon(BC)?: Black carbon is the particle (also known as Aerosol) which gives the darker color to smoke from diesel vehicles or fires. BC is generated through cooking with solid fuels (wood, cow dung, crop residues), by bio mass burning (savanna burning, forest fires and crop residue burning) and fossil fuel combustion (diesel, solid coal and others).

Atmospheric Brown Clouds (ABCs): In the atmosphere, BC is mixed with other particles such as sulfates, nitrates, dust and other pollutants, and together, the mix of manmade particles are sometimes referred to as Atmospheric Brown Clouds (ABCs). The name "Brown Clouds" is due to the fact that the mixture of BC and other aerosols gives a brownish color to the sky.

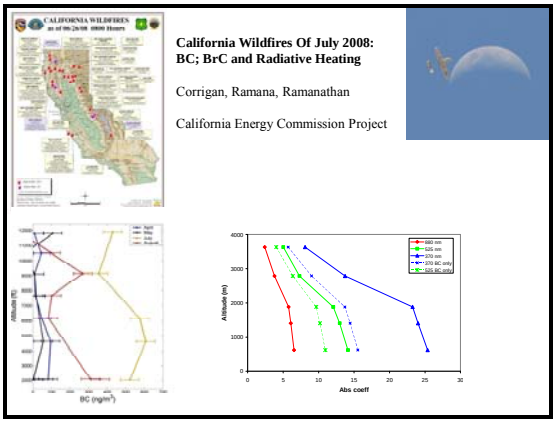
Physics of Climate Warming Effects by BC: BC is one of the strongest absorbers of solar radiation in the atmosphere and thus it is a source of global warming. In addition to BC, smoke also contains some organic aerosols which also absorb visible and UV solar radiation and such organic aerosols are called as Brown Carbon. Black carbon is removed from the atmosphere by precipitation. When BC is deposited on snow and ice, it darkens them which in turn increases absorption of sunlight by snow and ice. This darkening effect contributes to surface warming of the arctic and the alpine glaciers.

Observationally Constrained Estimate of Heating: The estimate of BC heating by this author's group is constrained by ground based, aircraft and satellite observations. We estimate that the current (2000-2003) global warming effect of BCs may be as much as 60% of the current (2005) CO_2 greenhouse warming effect. Most model based estimates of BC warming effect are smaller and are in the range of 20% to 50%.

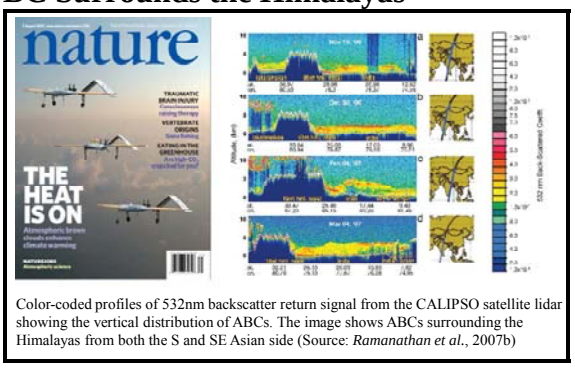
Global Water Budget: Digressing to all particles in ABCs, ABCs enhance scattering and absorption of solar radiation and also produce brighter clouds that are less efficient at releasing precipitation. The net result is a large reduction of sunlight at the surface, popularly known as dimming. The interception of sunlight in the atmosphere by BC and the surface dimming, along with the micro-physical effects can lead to a weaker hydrological cycle and drying of the planet. ABCs and black carbon are thus linked with the availability of fresh water, a major environmental issue of the 21st century.

Regional Climate Impacts: The regional effects of BC are estimated to be particularly large over Asia, Africa and the Arctic. Since the dimming and atmospheric heating are non-uniform in space and time, BC leads to changes in north-south and land-ocean contrast in surface temperatures, in turn disrupting rainfall patterns. For example, the Sahelian drought, the decrease in the monsoon rainfall over India and the drying of northern China are attributed by models to BC and other aerosols in ABCs. Recent studies employing unmanned aerial vehicles showed that BC enhances atmospheric solar heating by about 25% to 50% in S.Asia, E. Asia and in California. Model studies suggest this heating to have contributed as much as greenhouse warming to the large warming observed over elevated regions of the Himalayan-Tibetan glacier region. In addition, the deposition of BC over the bright snow and ice surfaces darkens these

BC from Fires Heats the Air

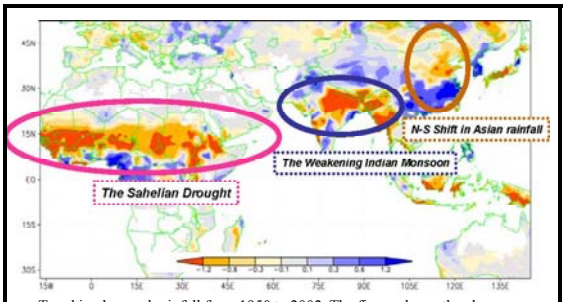


BC Surrounds the Himalayas



Color-coded profiles of 532nm backscatter return signal from the CALIPSO satellite lidar showing the vertical distribution of ABCs. The image shows ABCs surrounding the Himalayas from both the S and SE Asian side (Source: *Ramanathan et al.*, 2007b)

BCs and ABCs Can Decrease Rainfall



Trend in observed rainfall from 1950 to 2002. The figure shows the change in rainfall between 1950 and 2002; It was obtained by multiplying the year linear trend in mm/day/year by 52 years. The precipitation data is the Hadley center CRU data (Source: *Mitchell and Jones*, 2005)

surfaces. The resulting increase in absorption of solar radiation is estimated to be a major source of warming and melting of the arctic sea ice and the eurasian snow mass including the Himalayas and the Tibetan regions.

Status of Current Understanding: It is important to distinguish issues that are well understood from 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 climate effects of BC were begun in earnest about 15 years ago. There is reasonable consensus on the following issues:

- Life time of black carbon in the air is of the order of several days to few weeks.
- Fossil fuel combustion, bio fuel cooking and biomass burning are the 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.
- Deposition of BC 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) lead to dimming at the surface and the global average effect of this is to decrease 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% to as much as 60% of the warming effect of CO2 increase since the 1850s.

Rationale for Mitigating BC Emissions: BC offers an opportunity to reduce the projected global warming trends in the short term. The life time of BC in the air is of the order of days to several weeks. The BC concentration and its solar warming effect will decrease almost immediately after reduction of its emission. Policy makers will have a unique opportunity to witness the success of their mitigation efforts during their tenure. Reductions of BC emissions are also warranted from considerations of public health, air quality and regional climate change.

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. Likewise, the greenhouse gases surround the planet like a blanket and trap the infrared heat generated by the planet's surface and the atmosphere. Black carbon particles enter this blanket and heats 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 also generate other mirror like particles such as sulfates and nitrates. Because of the concern over sulfate pollution, emission of SO_2 has come down by 30% to 50% 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 is the major factor (as much as 55%) contributing to the enhancement of the greenhouse effect. At current rate of emission (35 billion tons per year) and the current growth rate of 2% to 3%, the manmade greenhouse effect can double during this century. BC reductions, even at 50%, 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 few decades and complement CO_2 mitigation efforts.

Diesel and Cook stoves 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 of the impact of biomass cookstoves. Towards this goal, this author along with a team of NGOs and public health experts, has proposed Project Surya (http://www-ramanathan.ucsd.edu/ProjectSurya.html). Cooking with solid fuels (wood and cow dung) is a major source of BCs over S Asia and has major health impacts on women and children. Surya will adopt a large rural area of about 50,000 population, in India, and provide alternate cooking with biogas plants, smoke free cookers and solar cookers.

Major Source of Uncertainties: The basic input data for most models is the inventory of emissions of BC from various parts of the world. This has about a three-fold uncertainty, particularly for Asia, Africa and S America. The second major uncertainty is the inter-action of BC and organics aerosols in clouds. Relying on just observational work, BC-Cloud interactions seem to have a net warming effect.