I-T-10

"EMERGING TRENDS IN AEROSOLS: TECHNOLOGY AND APPLICATIONS"

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"AEROSOL BLACK CARBON"

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Aerosol Black Carbon ("**BC**") is a ubiquitous particulate pollutant species released from the incomplete combustion of almost all fuels. At a molecular level it has a graphitic microstructure with a carbonaceous core that is chemically inert and strongly optically absorbing. The surface of the microstructures may have active sites that can participate in heterogeneous or catalytic reactions in the presence of adsorbed water and other species. The aerodynamic size is usually small (often less than 0.5 μm) and so these particles have a long lifetime in the atmosphere; can travel great distances; and can penetrate into the smallest structures of the human lung.

Atmospheric Effects

The presence of BC in the atmosphere can lead to numerous adverse effects. These include:

- Public Health impacts.
  - BC particles are frequently coated with adsorbed organic compounds including toxic and mutagenic materials such as PAH species. Inhalation of fine particles is known to lead to detrimental health effects.

- Climate Change impacts.
  - Direct Radiative Forcing. BC particles are very highly optically absorbing and lead to heating of the atmosphere by absorption of incident sunlight. When deposited on formerly-reflecting surfaces (such as snow and ice), the black coating leads to accelerated melting.
  - Indirect Radiative Forcing. Depending on surface affinity, some BC particles may become incorporated into cloud droplets, changing the albedo of the clouds and leading to additional radiative forcing.
  - Modification of Cloud Microphysics and Effect on Precipitation. Depending on surface affinity, some BC particles may act as Cloud Condensation Nuclei. Some of the chemical compounds associated with the particles may also act as surfactants. These may subdivide the available moisture in the atmosphere, leading to a larger number of smaller, non-precipitating droplets and reducing the occurrence of drizzle or moderate rain. When the suspended water content reaches a critical value, catastrophically-heavy rain may occur.

Emission Factors

The emission fraction of BC from carbonaceous fuels varies over an extreme range, being controlled by the nature and technology of the combustion process. An oxygen-poor conflagration in a pile of discarded automobile tires can result in the emission fraction of up to 10^{-1} of the available [Fuel C] as [Particulate BC]. The well-controlled combustion of natural gas in industrial-scale boilers can be so well mixed and optimized that the emission index of [Particulate BC] is as low as 10^{-7} of the available [Fuel C]. Typical modern gasoline-powered cars produce BC with an emission index of 10^{-5}; yet poorly-maintained diesel vehicles may emit BC with an index of 10^{-3} or greater. These differences in emission indices span many orders of magnitude.

Differences in Nature and Effects

Thus, [BC] emissions are far harder to predict or model than those of [CO_2] or other stoichiometric species, which are essentially quantitative in relation to the amount of fuel or trace constituents consumed. Emissions models developed for one geographic region may be completely useless for a different region with a different level of combustion technology, even if both regions consume similar total quantities of fuel. Furthermore, [BC] from different categories of sources may have different toxicity; particle size; atmospheric lifetime; surface characteristics of hygroscopicity *versus* hydrophobicity, thereby determining likelihood of interaction with cloud droplets; etc. In simple terms, "coal smoke" is not the same as "biomass-burning smoke" and neither are the same as "diesel smoke". All of them are black, and absorb sunlight; but their differences in particle size and surface activity mean that some smokes have greater interactions closer to the sources, but shorter atmospheric lifetimes; other smokes have lesser interactions, and consequently longer atmospheric lifetimes.

Need for Monitoring: Different Strategies

For the above reasons, it is clearly necessary to perform actual monitoring of the concentrations and nature of carbonaceous aerosols at as many locations as possible, since their emissions and properties can not be simply predicted. The design of the monitoring program will be strongly influenced by the intended application of the data: different research needs require data taken over different spatial and temporal domains.

- Health Effects Studies are frequently driven by requirements for determination of chronic exposures, rather than acute (event-driven) threshold exceedances. For these studies, 24-hour average concentrations are sufficient for dose-response estimates. These measurements need to be taken in the human-exposure domain (i.e. at ground level, or indoors), and to exclude large particles (typ. $d > 2.5\mu m$) which are removed by the upper respiratory tracts.

- Source Attribution Studies require data to be taken at high time resolution (typically 5 minutes, ideally < 1 minute) in source-impacted areas, in conjunction with meteorological variables such as wind speed and direction, atmospheric mixing layer height; etc. These studies combine this data in statistical models in order to arrive at estimates of the contributions from various point sources or

categories of source such as traffic emissions. Temporal and spatial resolution allows for separation of these contributions even if only one gross attribute (e.g. total BC mass) is measured.

- Climate Change Studies frequently seek long-term data sets from sites that are representative of whole regions, ideally together with measurements of vertical profiles of particulate concentrations. These studies require data that can be input into gridded models of forcing, aerosol-cloud interactions, and meteorological transport. The temporal and spatial resolution of the data does not need to be finer than the grid and time-step scale of the models. Especially for studies of radiative transfer, absorption data across a spectrum of optical wavelengths is useful.

Aerosol Black Carbon is a complex pollutant with many sources, many emission factors, and effects in the atmosphere that can not be reduced to a small number of parameters. Widespread and detailed measurement is necessary before source-receptor-effect models can be of use. **Control Strategies** and **Public Policy** can not be formulated until there is a clear understanding of the sources and emission types in the geographic region of concern. This presentation will outline some of the above topics and provide an opportunity for discussion.

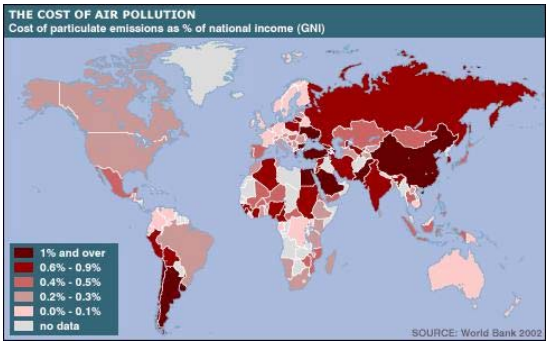

Figure 1: Estimated economic cost of all combined aspects of 'Air Pollution Particulate Emissions', expressed as percentage of Gross National Income. (*World Bank, 2002*)

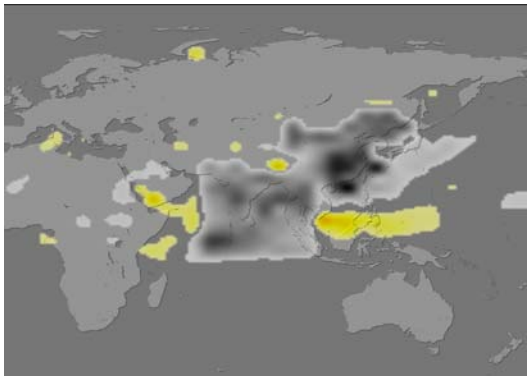

Figure 2:
Taken from *'Climate Effects of Black Carbon Aerosols in China and India'*
S. Menon, J. Hansen et al.: **Science 27**, (2002), p. 2250

"Modeling of Aerosol Black Carbon haze over Asia: up to 40% of sunlight absorbed. Crop yields reduced; local rainfall changed."

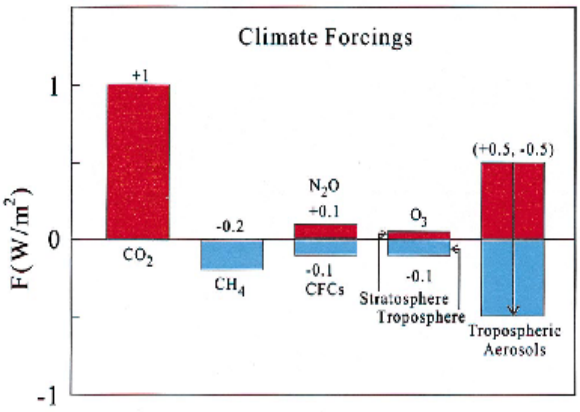

Fig. 5. A scenario for additional climate forcings between 2000 and 2050. Reduction of black carbon moves the aerosol forcing to lower values.

Figure 3:
Taken from '*Global warming in the twenty-first century: An alternative scenario'*:
J. Hansen et al.: **Proc. Natl. Acad. Sci. USA 10**, (2000), p. 1073

"Climate forcing by anthropogenic aerosols may be the largest source of uncertainty about future climate change. Black carbon reduces aerosol albedo, causes a reduction of cloud cover, and reduces cloud particle albedo. All of these effects cause warming."

Figure 4:
Illustration of use of high-time-resolution data to identify emission groups.
Measurements at roadside in Central London.

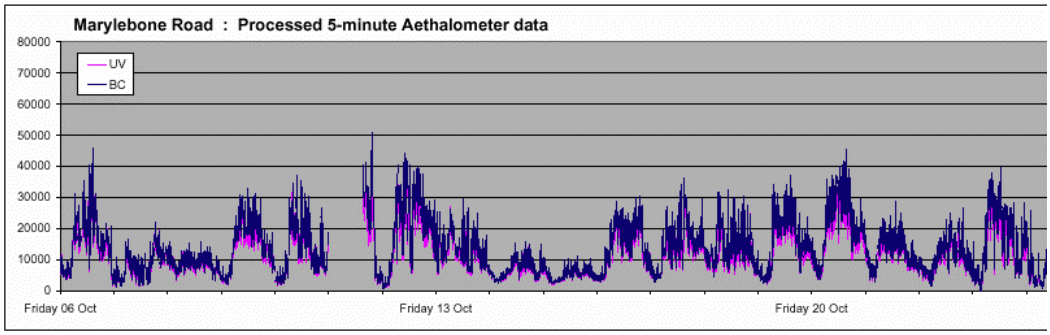

Figure 4a: excerpt from 3 months of 5-minute data.
Extremely large variability with many peaks due to individual vehicles.

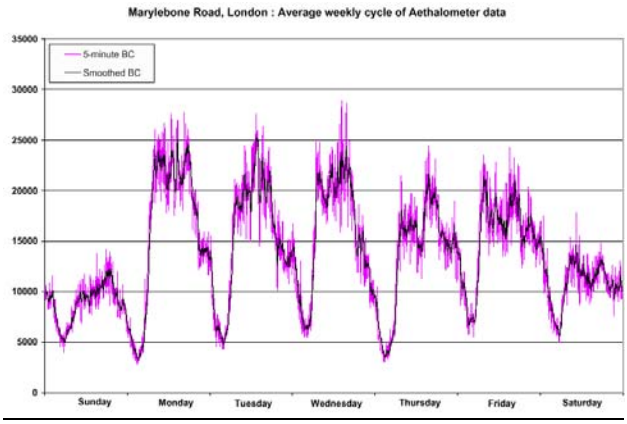

Figure 4b: Gather all data into averages according to exact time and day of week.
Individual events merge into clear daily pattern.

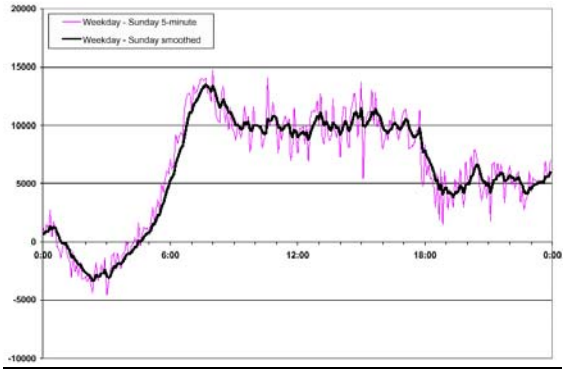

Figure 4c: Subtract [*Average Sunday*] from [*Average weekday*] to reveal characteristic pattern of weekday traffic emissions. High-time-resolution data allows for matching of BC data with known patterns of bus and truck activity.

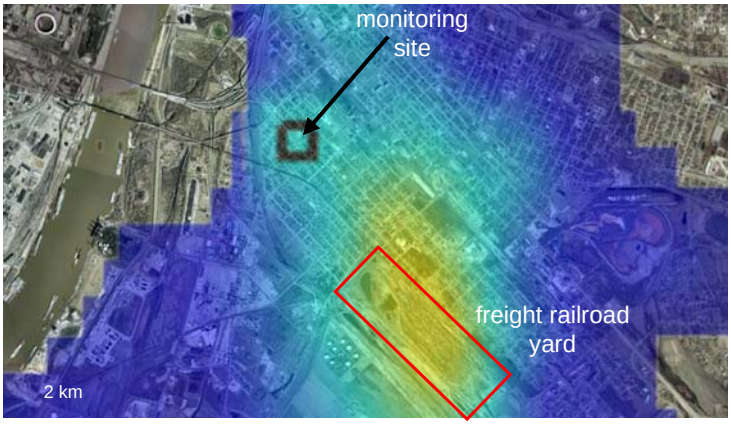

Figure 5: Temporal-spatial analysis combining high-time-resolution BC data with meteorological parameters (wind speed and direction), to identify candidate source areas based purely on measurements at one point. Data and figure courtesy of Prof. J. R. Turner (Washington University, St. Louis). Two-dimensional nonparametric wind regression analysis by Dr. R. Henry (University of Southern California). Areas with color have an average concentration greater than the quarterly average; higher concentrations have "hotter" colors. The map of spatial contributions to the observed BC clearly identifies a freight railroad yard as a major contributor to BC at the monitoring site approximately 5 km distant.