National Aerosol-Climate Interactions Program

Goal:

To reduce the uncertainties associated with anthropogenic aerosol effects on climate and the hydrological cycle

Objective:

Determine the Natural and Anthropogenic Aerosol forcing and the hydrological cycle effects for the present, past and future.

Definitions:

Aerosol forcing includes the changes in the radiation budget (radiative forcing) from the direct and the indirect effect of aerosols; and the changes in the latent heating from the direct microphysical effect of aerosols.

Radiative forcing is the change in the net (down minus upward) radiative fluxes (solar and longwave) due to aerosols. We need to determine the radiative forcing at the surface and at TOA, in order to understand the hydrological cycle impacts. The radiative forcing includes the direct, indirect and semi-direct effects.

The aerosol forcing through the latent heating of the atmosphere arises from the impact of aerosols on the precipitation efficiency. Aerosols influence precipitation directly through their microphysical effect. In addition, aerosols can influence precipitation indirectly through their effects on the surface radiation budget and atmospheric solar radiative heating. This latter effect is not included in the forcing term.

Anthropogenic aerosol forcing is the changes in radiative fluxes and latent heating due to anthropogenic aerosols

2. **The January workshop: Focus and Agenda**

A. Major Focus:

What are the steps needed to significantly reduce the uncertainties associated with estimating aerosol forcing of climate?

1. Direct forcing

+ Need to be able to estimate the forcing (radiative and latent heating) at the surface and the TOA, locally and globally.

- What continued work on emissions inventories, optical properties, dust radiative properties, aerosol mixing state, wet removal, RH behavior, needs to be done?
- How do we handle the effect of clouds in changing the sign of the TOA forcing of absorbing aerosols?
- Can we estimate the past (since 1900s) changes in the single scattering albedo?
- How do we estimate the changes in precipitation due to the direct microphysical effect of aerosols?
- What is the status of GCMs in treating the forcing?

+ What needs to be done in the future to reduce uncertainty in estimates of direct forcing?
  - How to use satellite data in an ongoing way to provide constraints on global models?
  - Do we need more field experiments on direct forcing?

2. Indirect forcing

+ This is a glaring uncertainty. Presently GCMs employ only empirical relationships
+ Need to develop a fundamental link between aerosols and clouds for climate predictions
  - What field experiments need to be conducted?
  - How can satellite data be used in conjunction with models and in situ data?
  - What advances in GCM microphysical modeling are needed?
+ How important is the indirect forcing for middle and upper troposphere clouds, i.e, mixed phase and cirrus clouds?

3. Aerosol – Climate- Hydrological Cycle Interactions

What sort of model studies are required to understand the link between aerosol forcing, climate and the hydrological cycle?

Suggestions for Working Group Discussion:

Discussion of the Scientific Issues dealing with the Forcing
Measurements we need
Measurements that are already underway, which should be strengthened and should be continued into the future;
Needed model calculations and development.
Define measurements that should continue in the future so it is possible to monitor changes in the aerosol and its forcing.

It is important to recognize the international scope of the problem and take into account the plans of our colleagues from Europe, Japan, Asia, S. America and Africa. This will help us to define the full scope of the problem without the burden of doing everything by ourselves.

3. Direct Forcing:

We identify here the major factors that contribute to the uncertainties in the direct forcing.

Direct Radiative Forcing:

Need to be able to determine the forcing at the surface and TOA, locally and globally. We need to establish both the natural and the anthropogenic aerosol forcing. The forcing should be obtained with sufficient accuracy to interpret past climate changes, infer global surface temperature sensitivity to radiative forcing and develop reliable predictive capability of future climate changes. Many of the major issues raised here are for absorbing aerosols with single scattering albedos of about 0.95 or less. Almost all tropical aerosols and possibly a major portion of extra-tropical aerosols fall under this category. There are also major issues associated with mainly scattering aerosols which are also included here.

Scattering and absorption of solar radiation by aerosols can lead to either a negative or positive forcing at TOA, depending on the single scattering albedo, cloud cover and the albedo of the underlying surface. At the surface however, all aerosols (both absorbing and non-absorbing) lead to a negative forcing (i.e, a reduction in solar radiation at the surface). Depending on the SSA, the surface albedo, the cloud fraction and the aerosol vertical profile, the reduction of solar radiation at the surface can be factors of 2 to 10 larger than the TOA forcing in cloudy skies. While the global average forcing at TOA may largely determine the global average temperature changes, the surface forcing may determine the response of the hydrological cycle and regional temperature changes. Thus both the TOA and the surface forcing need to be determined.

Factors that contribute the most to the uncertainty in forcing:

- The emission inventories of organic, black carbon, dust and sea salt aerosols are uncertain by about a factor of about 2 or more. The uncertainties are even larger for the period before 1990.

- The sign of the TOA forcing for absorbing aerosols (SSA<0.95) changes from negative in clear skies to positive in cloudy skies.
- The black carbon direct forcing (which is positive) has at least a five-fold uncertainty
- Aerosol Vertical distribution.
- Aerosol mixing state, internal, external and hybrids with coating; very critical for black carbon forcing; including the inability to confidently translate mixing state to hygroscopic growth.
- The effect of black carbon in the SSA of cloud droplets and ice crystals.
- Lack of surface radiation budget observations to determine the surface forcing.
- Radiative and microphysical properties of dust;
- The relative partitioning of anthropogenic and natural dust.

<u>Direct Forcing on the Hydrological Cycle.</u>

We consider here the change in the hydrological cycle that results locally and directly from a change in the aerosol concentration. Aerosols containing large concentrations of small CCN nucleate many small cloud droplets, which coalesce very inefficiently into rain drops. One consequence of this is suppression of rain over polluted regions. The suppression of coalescence by smoke and air pollution can also induce lower freezing temperature of the cloud super-cooled water and suppression of the ice precipitation processes. The effect on precipitation has been documented so far only on the basis of case studies and furthermore, none of the GCMs have accounted for this direct effect of aerosol on the thermodynamic forcing.

Other direct thermodynamic forcing of Aerosols:

- Local heating by absorbing aerosols resulting in cloud evaporation.
- deposition of black carbon on snow resulting in increased radiative heating
- others?

The major factor contributing to the uncertainty of the direct hydrological cycle forcing and other thermodynamic forcing terms is lack of either modeling studies or regional to global scale observations of this phenomenon.

4. Aerosol Indirect Radiative Forcing

Can sub-grid parameterizations of cloud processes accurately represent cloud-radiation interactions and the role that aerosols play in that interaction?
- IPCC, Climate Change 2001: The Scientific Basis

This question was posed by the Intergovernmental Panel on Climate Change (IPCC, 2001), which identified indirect aerosol forcing as the single largest source of uncertainty in the radiative forcing of the climate system. The IPCC also suggested an approach to reduce that uncertainty: "several carefully designed multi-platform closure studies that elucidate the processes that determine cloud microphysical and macrophysical properties."

Aerosol indirect effects arise from aerosol-forced perturbations in cloud optical properties, resulting from changes in cloud drop concentration, physical thickness, effective radius, and horizontal extent (cloud fraction) that lead to a change in the earth's cloud radiative forcing. To model aerosol indirect forcing in a way that allows prediction of future climatic effects in a changed world, we must first understand the complex interactions among the aerosol physicochemical characteristics and cloud microphysics, precipitation, dynamics, and radiative transfer.

Previous field studies (e.g. INDOEX, ACE, MAST, EUCREX, FIRE, ASTEX, SCAR-B) and satellite platforms (TERRA, TRMM, ERBE, NOAA, DMSP) have made and continue to make great strides towards characterizing aerosols, clouds, dynamics, precipitation, and radiation, and in exploring the interactions among these systems, primarily in marine boundary layer cumulus systems. For a limited number of cases empirical correlations have been found that are strongly suggestive of the first (increased aerosol-->brighter clouds) and second (increased aerosol-->reduced precipitation and larger cloud fraction) indirect effects. The effect of aerosol absorption on reducing atmospheric convection and cloud development was studied only in a few cases (or one?). However, These empirical relationships observed in today's climate will not necessarily hold for future and past climates; the only consistent strategy for improving climate models' predictions is to accurately represent the physicochemical processes in the models. To date, attempts to use closure studies to quantify each of the physical processes linking aerosol to cloud albedo have been frustrated by incomplete instrument configurations, operational limitations, and non-convergent sampling problems.

Several studies used remote sensing from satellites and from the surface, to characterize the physical properties of ambient aerosol and their impact on clouds and precipitation. Remote sensing has the potential to deliver consistent global data set of aerosol, cloud and precipitation ambient parameters, and measure the radiation field. However no integrated approach emerged that combines models, remote and other measurements to systematically study the aerosol effect on clouds, precipitation and cloud radiative forcing (defined as in ERBE/CERES measurements) for a variety of aerosol, cloud and meteorological conditions.