# Aerosol Direct Radiative Effects over the Northwest Atlantic, Northwest Pacific, and North Indian Oceans: Estimates Based on in-situ Chemical and Optical Measurements and Chemical Transport Modeling


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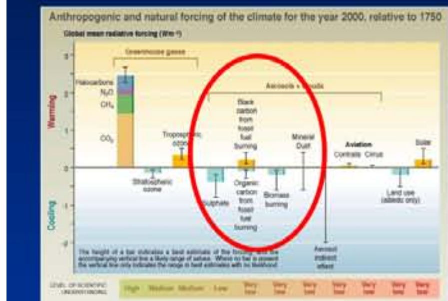
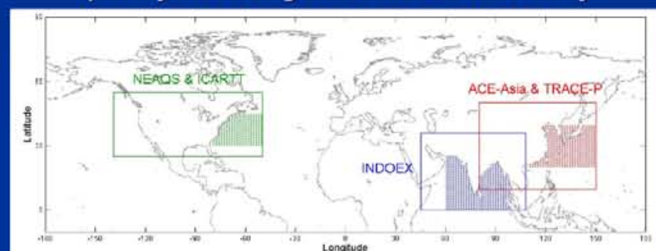
BASED ON THE MANUSCRIPT: Aerosol Direct Radiative Effects over the Northwest Atlantic, Northwest Pacific, and North Indian Oceans: Estimates Based on in-situ Chemical and Optical Measurements and Chemical Transport Modeling, T.S. Bates, T.L. Anderson, T. Baynard, T. Bond, O. Boucher, G. Carmichael, Clarke, C. Erlick, H. Guo, L. Horowitz, S. Howell, S. Kulkarni, H. Maring, A. McComiskey, A. Middlebrook, K. Noone, C.D. O'Dowd, J.A. Ogren, J. Penner, P.K. Quinn, A.R. Ravishankara, D.L. Savoie, S.E. Schwartz , Y. Shinozuka, Y. Tang, R.J. Weber and Y. Wu. Manuscript submitted to *Atmospheric Chemistry and Physics*, http://www.copernicus.org/EGU/acp/acpd/recent_papers.html, August 28, 2005.


## The Issue



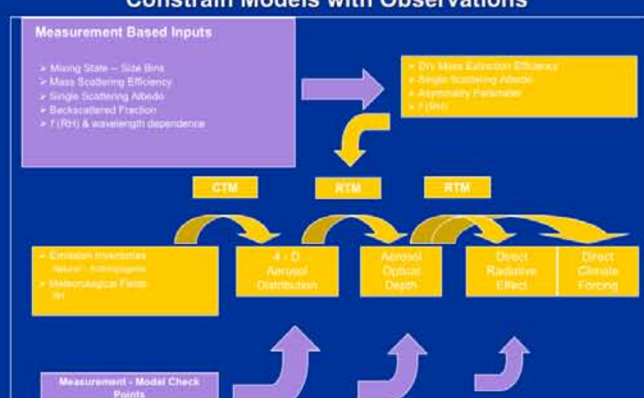

The largest uncertainty in the radiative forcing of climate change over the industrial era is that due to aerosols, a substantial fraction of which is the uncertainty associated with scattering and absorption of incoming shortwave (solar) radiation by anthropogenic aerosols in cloud-free conditions [*IPCC*, 2001]. Quantifying and reducing the uncertainty in aerosol influences on climate is critical to understanding climate change over the industrial period, to improving predictions of future climate change for assumed emission scenarios, and assessing the regional impact of emissions.

### Our Approach: Take advantage of observations to quantify the forcing and reduce its uncertainty




Measurements of aerosol properties during major field campaigns in several regions of the globe during the past decade are contributing to an enhanced understanding of atmospheric aerosols and their effects on light scattering and climate. The present study focused on the available results from three regions downwind of major urban/population centers (North Indian Ocean (NIO) during INDOEX, the Northwest Pacific Ocean (NWP) during ACE-Asia, and the Northwest Atlantic Ocean (NWA) during ICARTT) and incorporated understanding gained from field observations of aerosol distributions and properties into calculations of perturbations in radiative fluxes due to these aerosols.

### Key Element of our Approach: Constrain Models with Observations




### Constraining Models with Observations

- In-situ measured and remotely sensed aerosol properties for each region (mixing state, mass scattering efficiency, single scattering albedo, and angular scattering properties and their dependences on relative humidity) were used as input parameters to two radiative transfer models (GFDL and University of Michigan) to constrain estimates of aerosol radiative effects.
- Measurements of burdens, extinction optical depth (AOD), and direct radiative effect of aerosols (DRE - change in radiative flux due to total aerosols) were compared to two chemical transport models (STEM – University of Iowa and MOZART – GFDL) and radiative transfer models to assess uncertainties.

#### Definitions

**Climate Forcing by Aerosols (DCF)** – the change in the net flux due to scattering and absorption of shortwave (solar) radiation by aerosols of anthropogenic origin in cloud-free conditions

**Aerosol Direct Radiative Effect (DRE)** – the change in the net flux due to scattering and absorption of shortwave (solar) radiation by aerosols of anthropogenic and natural origin in cloud-free conditions.

**Aerosol Optical Depth (AOD)** – the vertical integral of the aerosol extinction coefficient (sum of the light scattering coefficient and light absorption coefficient).

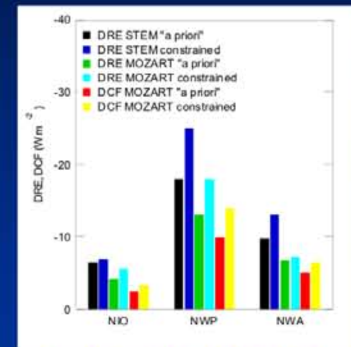
**Single-scattering albedo ($\omega_o$)** – the ratio of the light scatting coefficient to light extinction coefficient ($\omega_o = \sigma_{sp} / (\sigma_{sp} + \sigma_{ap})$).

**Mass scattering efficiency** – the ratio of the light scattering coefficient to the mass concentration of the pertinent aerosol type.

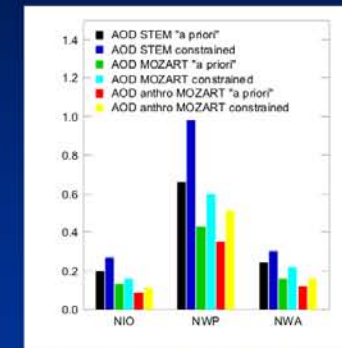
***f*(RH)** – the dependence of aerosol light scattering coefficient on relative humidity.

**Asymmetry parameter** – the angular distribution of light intensity scattered by a particle.

## Model Results

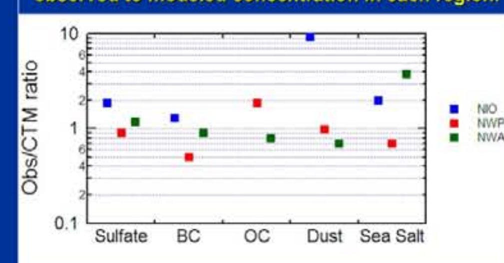



Constrained AOD 34±8% higher than "a priori" AOD

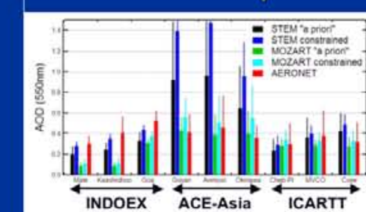



Constrained DCF 37±7% higher than "a priori" DCF

Comparison of mean concentrations of the observed (RV *RHB*) and modeled (STEM) aerosol components. The points show the mean ratio of the surface observed to modeled concentration in each region.

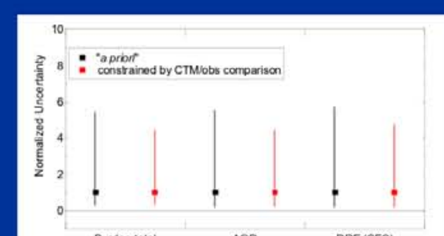



Comparisons of model and AERONET AOD [mean (bars) and standard deviation (lines)] over the time period of the intensive field experiments.

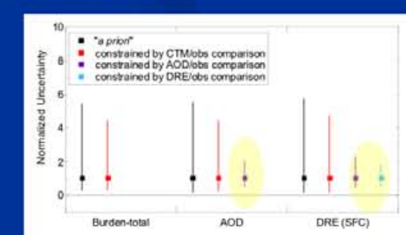



The large differences between the results of the two models and between the models and measurements are generally due to column burdens of dust and sea salt.

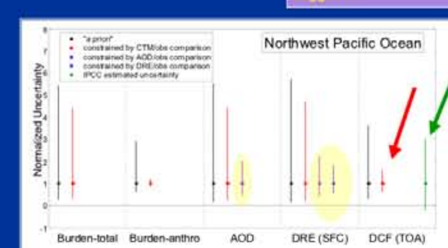
## Assessment of Uncertainties - NWP




Large CTM/observation differences of dust concentrations, especially aloft, limit our ability to constrain uncertainties based on CTM/observation comparisons.




However, the campaign mean comparisons with AOD and radiative flux measurements suggest that the models can capture the time averaged AOD and DRE with greater certainty than the "a priori" estimates suggest.



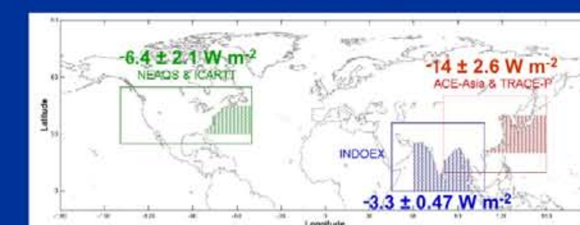

With the use of constrained quantities (extensive and intensive parameters) the multiplicative uncertainty in DCF in these regions (red arrow) can be reduced by a factor of 2 from IPCC-2001 global estimates (green arrow).

## Summary

### Generalizations and Parameterizations

- **Mixing state.** AOD, DRE and DCF, can be accurately calculated by categorizing aerosols into four externally-mixed subgroups: submicrometer sulfate/carbonaceous aerosol, submicrometer mineral dust, supermicrometer mineral dust, and supermicrometer sea salt.
- **Hygroscopic growth.** The hygroscopic growth factor for the sulfate/carbonaceous aerosol can be parameterized as a function of the organic mass fraction.
- **Optical properties.** Observed wavelength-dependent mass scattering efficiencies, single scatter albedo, and asymmetry parameter for the various aerosol subgroups in the three regions can be applied in RTMs in lieu of "*a priori*" optical properties.

### Observationally Constrained Values




Constraining the aerosol properties employed in the radiative transfer calculations based on measurements resulted in TOA DCFs that were, on average, 37±7% larger than those obtained using the "*a priori*" optical properties.

### Uncertainties

With the use of constrained quantities (extensive and intensive parameters) the multiplicative uncertainty in DCF was reduced by a factor of 2 from an initial multiplicative uncertainty of X÷3.1 without such constraints (IPCC, 2001) to a multiplicative uncertainty of X÷1.6.

### Conclusion

Intensive in-situ measurements of the loading, distribution, and chemical, microphysical, and optical properties of atmospheric aerosols over several regions of the globe during the past decade are contributing to an enhanced understanding of these properties and improved quantitative estimation of the effects of these aerosols on shortwave radiative fluxes resulting from scattering and absorption of solar radiation. Such quantitative understanding is essential for accurate representation of these aerosol effects in climate models. These quantifications can be further extended using observations over a wider range of time and spatial scales in the coming years.


This study was a CCSP Scientific review and was funded by the NOAA Climate Program and the NASA Radiation Science Program.