AEROSOLS AND CLIMATE

I. INTRODUCTION

Direct and indirect forcing by aerosols is the largest uncertainty in estimating current radiative forcing. As such, it is of central importance to efforts to constrain calculations of climate change. Aerosol research at ESRL falls within three themes: aerosol composition, direct radiative forcing, and aerosol-cloud interactions including indirect radiative forcing. These three themes are integral parts of national and agency strategic plans for understanding climate change, with the broad goal of the U.S. Climate Change Science Program "*Develop reliable representations of the climatic forcing resulting from atmospheric aerosols*" being reflected more specifically in the NOAA/OAR Strategic Plan as "*Reduce the uncertainty in model simulations of the influence of aerosols on climate*".

NOAA/ESRL has persistently built the necessary long-term capabilities to advance aerosol research and the links to climate. These special capabilities include (a) a global monitoring network; (b) integrated payloads (aerosol and gas-phase) on multiple platforms; (c) instrument development and calibration; (d) model development.

II. KEY ACHIEVEMENTS

- *Long-term climatologies of aerosol radiative properties* have been obtained at surface sites around the globe [Delene and Ogren, 2002; Fiebig and Ogren, 2006; Augustine et al., 2008]. An important addition has been vertical profiles in the U.S., providing information that complements both surface data and satellite observations of column aerosol properties [Andrews et al., 2004]. Both surface and vertical profile data have been analyzed to reveal systematic relationships among aerosol properties, providing input for developing model parameterizations and testing model results.

- *Development and calibration of measurement methods*. Calibration of light absorption measurements has been especially problematic for the community. ESRL scientists were lead authors in the Reno Aerosol Optics Study that evaluated many aerosol light absorption instruments [Sheridan et al., 2005]. We have also led efforts to put incandescence measurements of light absorbing particles on a strong foundation and compare them with other instruments [Gao et al., 2007; Slowik et al. 2007]. Calibrations of the Aerodyne Aerosol Mass Spectrometer (AMS) instrument have revealed potentially strong effects of relative humidity and organic coatings on sensitivity [Middlebrook et al., in preparation].

- *Aerosol-cloud interactions and aerosol indirect effects* have been studied. Large eddy simulations have shown that evaporation of cloud droplets into entrained air can change the sign of the aerosol effect on cloud fraction, a finding with important implications for aerosol indirect effects [Jiang et al., 2006; Xue and Feingold 2006]. Aerosol effects on clouds have been studied using surface remote sensing [Feingold et al., 2006] and in-situ data during the 2006 GoMACCS field program over the Gulf of Mexico [Jiang et al., in press].

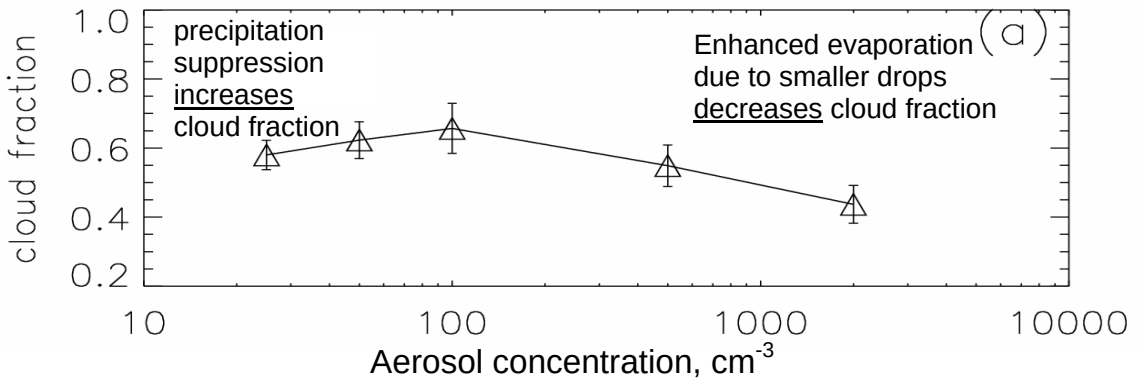

Figure 1. Cloud fraction as a function of aerosol concentration based on aerosol-cloud interactions in large eddy model simulations [after Xue et al., 2008]. The figure suggests two distinct regimes: 1) a clean regime where cloud fraction increases with increasing aerosol as a result of precipitation suppression; and 2) a polluted regime where the trend reverses as a result of the more rapid evaporation of smaller drops. Overall, the model results show that the indirect effect of aerosols on cloud fraction can change sign depending on the situation.

- *Systematic measurement and understanding of aerosol radiative properties* is necessary to extrapolate measurements of highly variable local aerosol concentrations to a global scale. An example is the dependence of aerosol light scattering on relative humidity [e.g. Quinn et al., 2005].

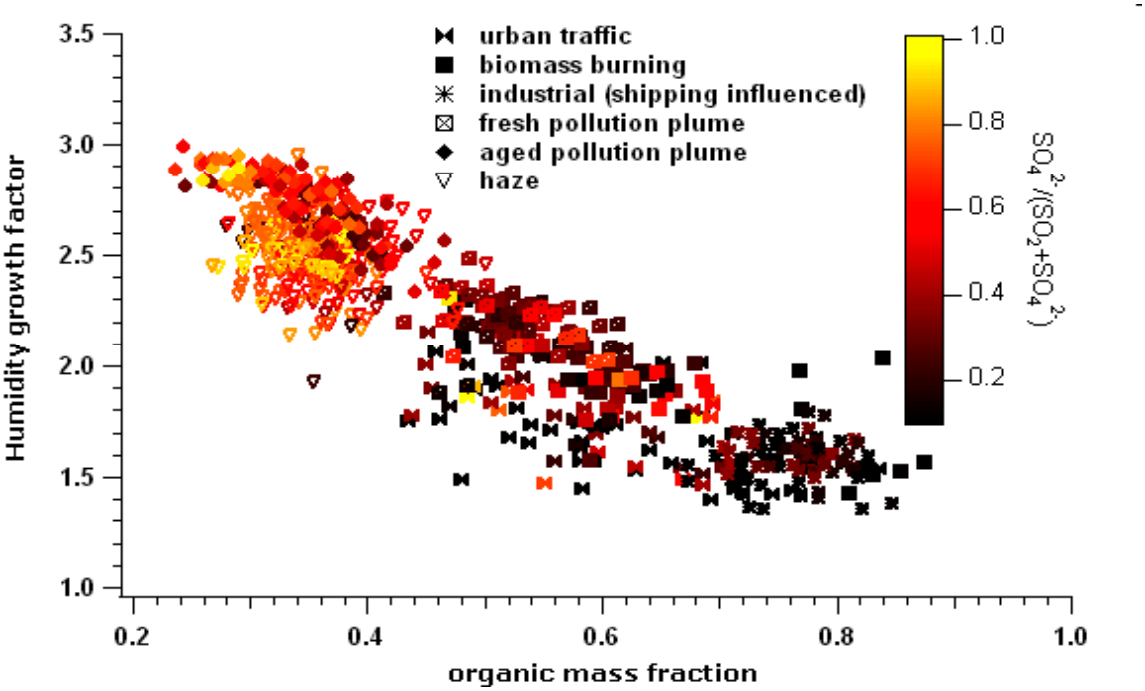

Figure 2. Aerosol hygroscopic growth versus organic mass fraction. These shipborne (*Ron Brown*) data from the 2006 Texas Air Quality study show how the aerosol composition translates to an optical property that is relevant to models of radiative forcing. An additional dimension combines gas and aerosol phase measurements of SO_2 and sulfate to show a systematic variation in aerosol properties with atmospheric processing [Massoli et al., in preparation].

- *Aerosol composition in the upper troposphere* has been measured using the Particle Analysis by Laser Mass Spectrometry (PALMS) and Soot Photometer (SP2) instruments. The SP2 data help constrain, by a factor of 10 or more, global model estimates of black carbon in the radiatively important upper tropical troposphere [Schwarz et el., 2006]. The PALMS data show high organic content in aerosols in the region where air enters the stratosphere. The PALMS data have also shown a large organic contribution to aerosols throughout the free troposphere, and that almost all particles in the free troposphere contain both organics and sulfate [Murphy et al., 2006].

- *Aerosol scavenging by clouds* has been seen in fire, Asian, and regional plumes. These measurements require the strong combination of gas and particle data built up on the NOAA P3: a low particle concentration could be due either to clean air or scavenging in a plume, and only gas-phase data can quantify the scavenging [Brock et al., 2004]. Field studies have shown the effects of cloud scavenging on aerosol radiative properties [Andrews et al., in preparation].

III. PAYOFFS

Policy decisions to mitigate and adapt to climate change require reliable regional and global climate models, which in turn needs enhanced understanding of aerosol composition, spatial distributions, radiative forcings, and cloud interactions. ESRL's research on aerosols and aerosol-cloud interactions is helping to meet this need, as evidenced by

- improved confidence in aerosol radiative forcing predictions and attributions in the IPCC AR4 assessment;
- achieved NOAA goals for the Government Performance and Results Act;
- published assessment of the performance of regional chemical transport models using NOAA data [Bates et al, 2006]

IV. FUTURE PLANS

- Continue with, and enhance current efforts in long-term measurements, process studies, modeling, instrument development, and calibration.
- Evaluate chemical transport models with measurements. Models have now achieved prognostic capability for aerosol properties that ESRL measures directly (e.g., light absorption coefficient), and comparisons from both short and long-term observations are proceeding in conjunction with the AEROCOM project (global models) and with the Texas Air Quality study (regional models).
- Continue conducting field studies, often combining studies of climate and air quality. The next major field programs in 2008 are ARCPAC (NOAA P3 in Fairbanks) and ICEALOT (research vessel *Knorr* in the Norwegian Sea). These will investigate radiative forcing by aerosols and the processes controlling Arctic haze as well as springtime Arctic halogen chemistry. ESRL will have a lesser role in the VOCALS (2008) study in the South East Pacific, with a focus on the role of aerosols in generating open vs. closed-cell convection. The CalNexus aircraft and ship field program in California in 2010 is on the horizon.
- Aerosol-Precipitation interactions (measurements and models), recognizing concerns about future water supplies, is an emerging emphasis.

Select Publication Highlights

Augustine, J. A., G. B. Hodges, E. G. Dutton, J. J. Michalsky, and C. R. Cornwall, An aerosol optical depth climatology for NOAA's national surface radiation budget network-SURFRAD. *J. Geophys. Res*., submitted and tentatively accepted, 2008.

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