Take-home Messages

- **Understanding aerosol processes and effects**
  - many process studies, on spatial scales from laboratory to plume to intercontinental;
  - importance of soot and secondary organic aerosols
  - effects of cloud interactions on aerosol properties
- **Evaluating direct radiative forcing**
- **Evaluating indirect aerosol effects**
- **Modeling aerosols for climate and air quality**

Take-home Messages

- **Understanding aerosol processes and effects**
- **Evaluating direct radiative forcing**
  - importance of optical depth, angular scattering, absorption fraction, and hygroscopic growth
  - rich data sets: pristine to highly polluted, hours to decades, surface and vertical profiles
  - application of closure studies for quantifying uncertainties in measurements and models
- **Evaluating indirect aerosol effects**
- **Modeling aerosols for climate and air quality**

Take-home Messages

- **Understanding aerosol processes and effects**
- **Evaluating direct radiative forcing**
- **Evaluating indirect aerosol effects**
  - significant improvement in understanding of albedo and higher-order effects through observations and modeling;
  - GCMs that use remote-sensing estimates of aerosol-cloud interactions likely underestimate the albedo effect.
  - GCM representation of the higher order indirect effects is inadequate since it prescribes an increase in cloud lifetime and cloud fraction responses.
- **Modeling aerosols for climate and air quality**

Take-home Messages

- Understanding aerosol processes and effects
- Evaluating direct radiative forcing
- Evaluating indirect aerosol effects
- **Modeling aerosols for climate and air quality**
  - ESRL has led the development of a state-of-the-art coupled modeling system (WRF-Chem)
  - modular approach lets advances in WRF-Chem benefit other models (e.g., FIM-Chem)
  - on-line coupling of aerosol radiative effects and meteorological response is crucial

Future Directions

- **Enhance our successful approaches for measurement and modeling studies**
- **Apply these approaches to explore win-win solutions for climate and air quality policy**
- **Focus on integration of measurements and models**
  - development and testing of parameterizations
  - testing model results with data
    - case studies and statistics
    - systematic and repeated evaluation of uncertainties
  - develop chemical data assimilation system

Outstanding Questions

- **Importance of absorption indirect effect ("semi-direct")**
- **Importance of feedbacks in a system with non-monotonic responses (to what extent is the aerosol/cloud/climate system self-regulating?)**

IPCC(2007) Assessment of Potential Magnitudes of Aerosol Indirect Effects

Table 7.10a. *Overview of the different aerosol indirect effects and their sign of the net radiative flux change at the top of the atmosphere (TOA).*

Effect	Cloud Types Affected	Process	Sign of Change in TOA Radiation	Potential Magnitude	Scientific Understanding
Cloud albedo effect	All clouds	For the same cloud water or ice content more but smaller cloud particles reflect more solar radiation	Negative	Medium	Low
Cloud lifetime effect	All clouds	Smaller cloud particles decrease the precipitation efficiency thereby presumably prolonging cloud lifetime	Negative	Medium	Very low
Semi-direct effect	All clouds	Absorption of solar radiation by absorbing aerosols affects static stability and the surface energy budget, and may lead to an evaporation of cloud particles	Positive or negative	Small	Very low

Table 7.10b. *Overview of the different aerosol indirect effects and their implications for the global mean net shortwave radiation at the surface, F_{sfc} (Columns 2-4) and for precipitation (Columns 5-7).*

Effect	Sign of Change in F_{sfc}	Potential Magnitude	Scientific Understanding	Sign of Change in Precipitation	Potential Magnitude	Scientific Understanding
Cloud albedo effect	Negative	Medium	Low	n.a.	n.a.	n.a.
Cloud lifetime effect	Negative	Medium	Very low	Negative	Small	Very low
Semi-direct effect	Negative	Large	Very low	Negative	Large	Very low
Glaciation indirect effect	Positive	Medium	Very low	Positive	Medium	Very low
Thermodynamic effect	Positive or negative	Medium	Very low	Positive or negative	Medium	Very low

Absorption effect small at TOA, but large at surface?