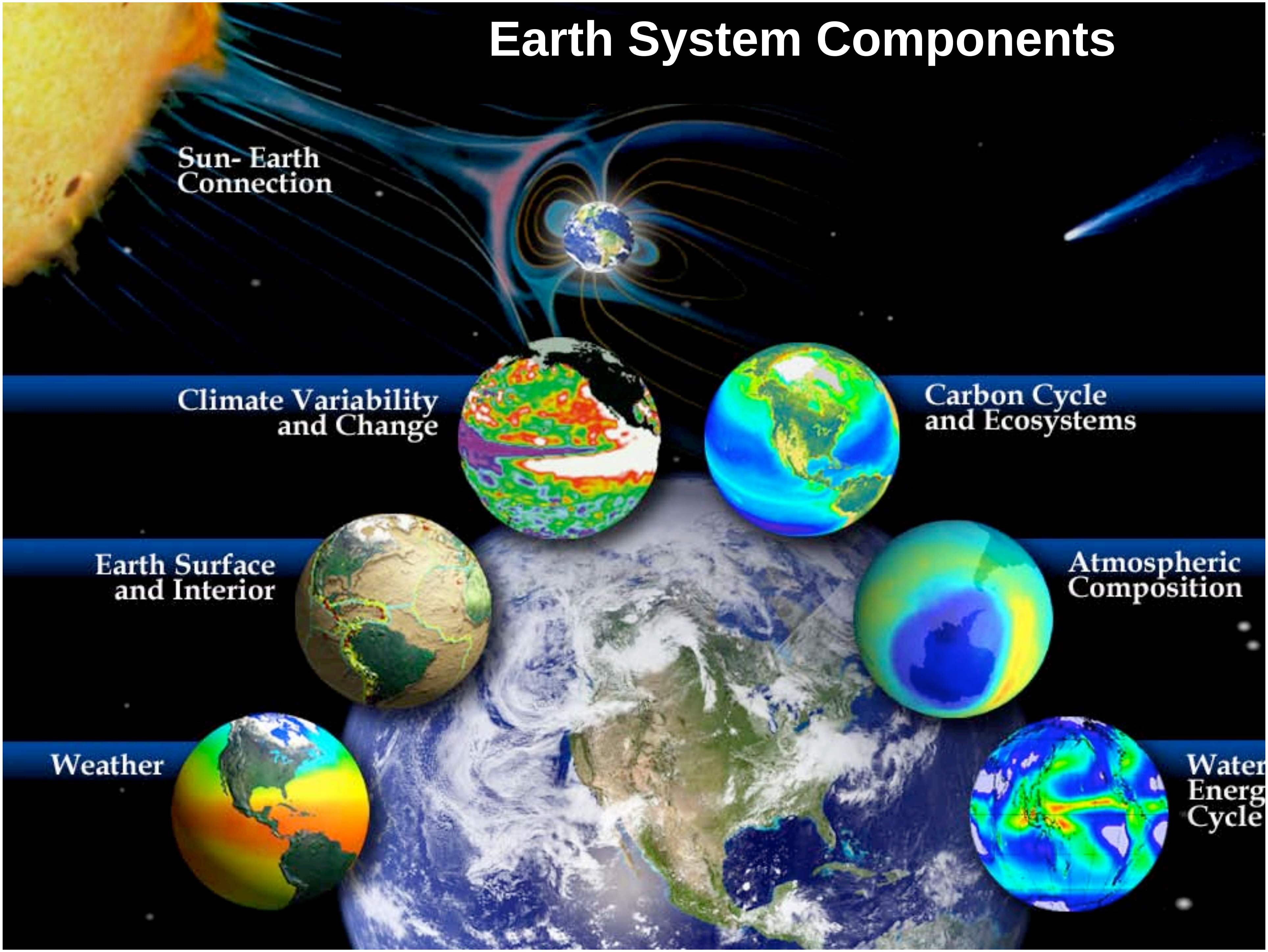
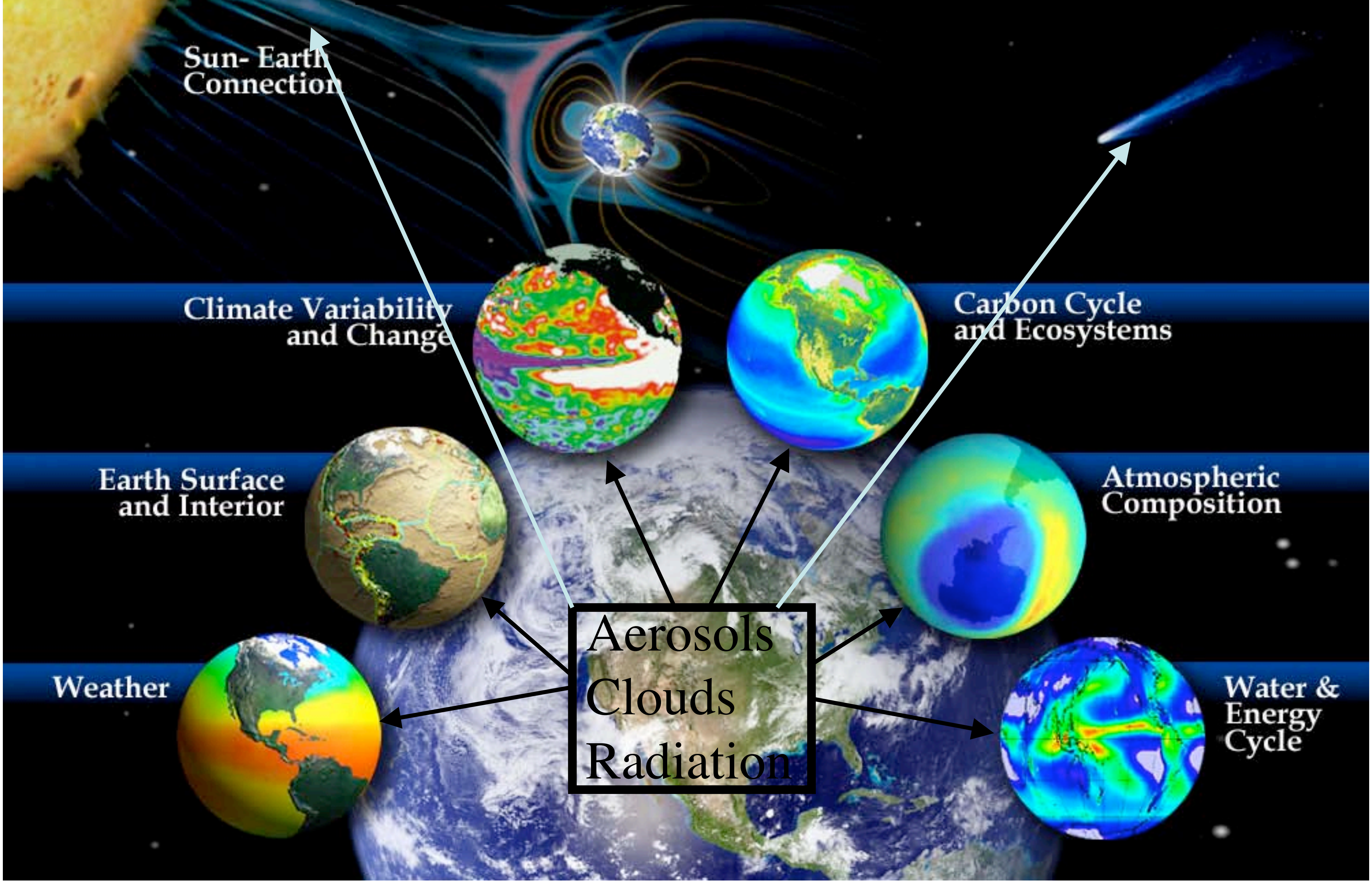
Aerosol Properties and Their Impacts on Climate: S&A Product 2.3

Phil DeCola
NASA Headquarters
Washington, DC


Earth System Components
Sun- Earth Connection
Climate Variability and Change
Carbon Cycle and Ecosystems
Earth Surface and Interior
Atmospheric Composition
Weather
Water Energ Cycle

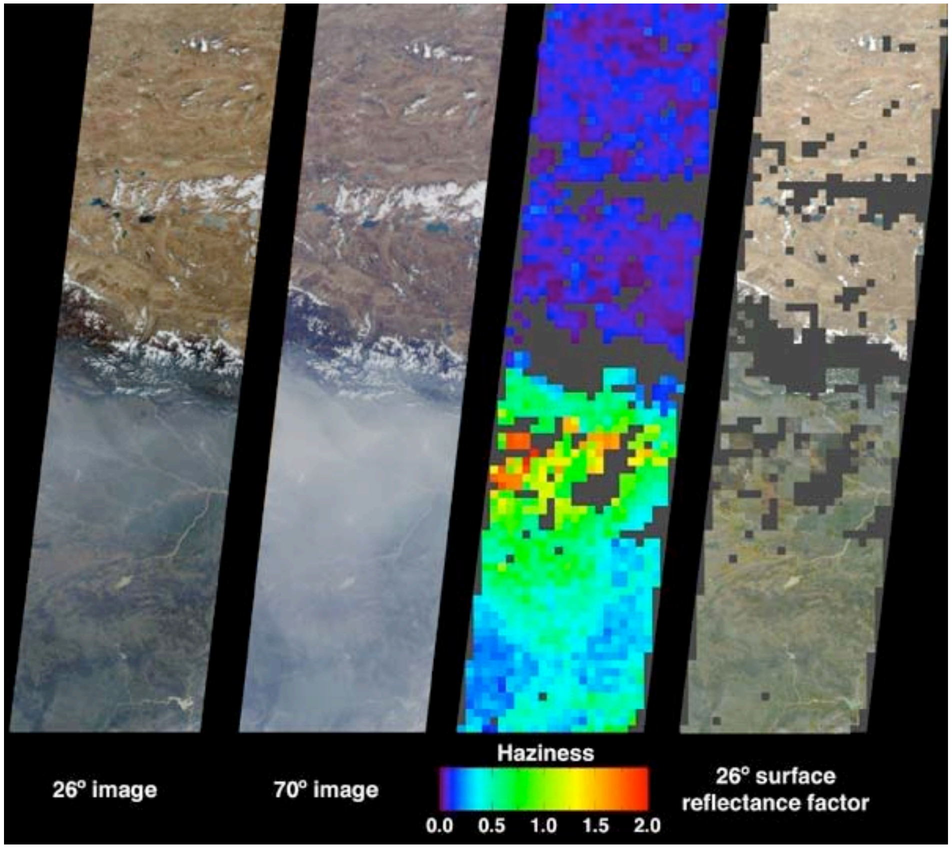
Aerosol Forcing Links
Earth System Components



Science context:

A Regional Problem on a *Global* scale…

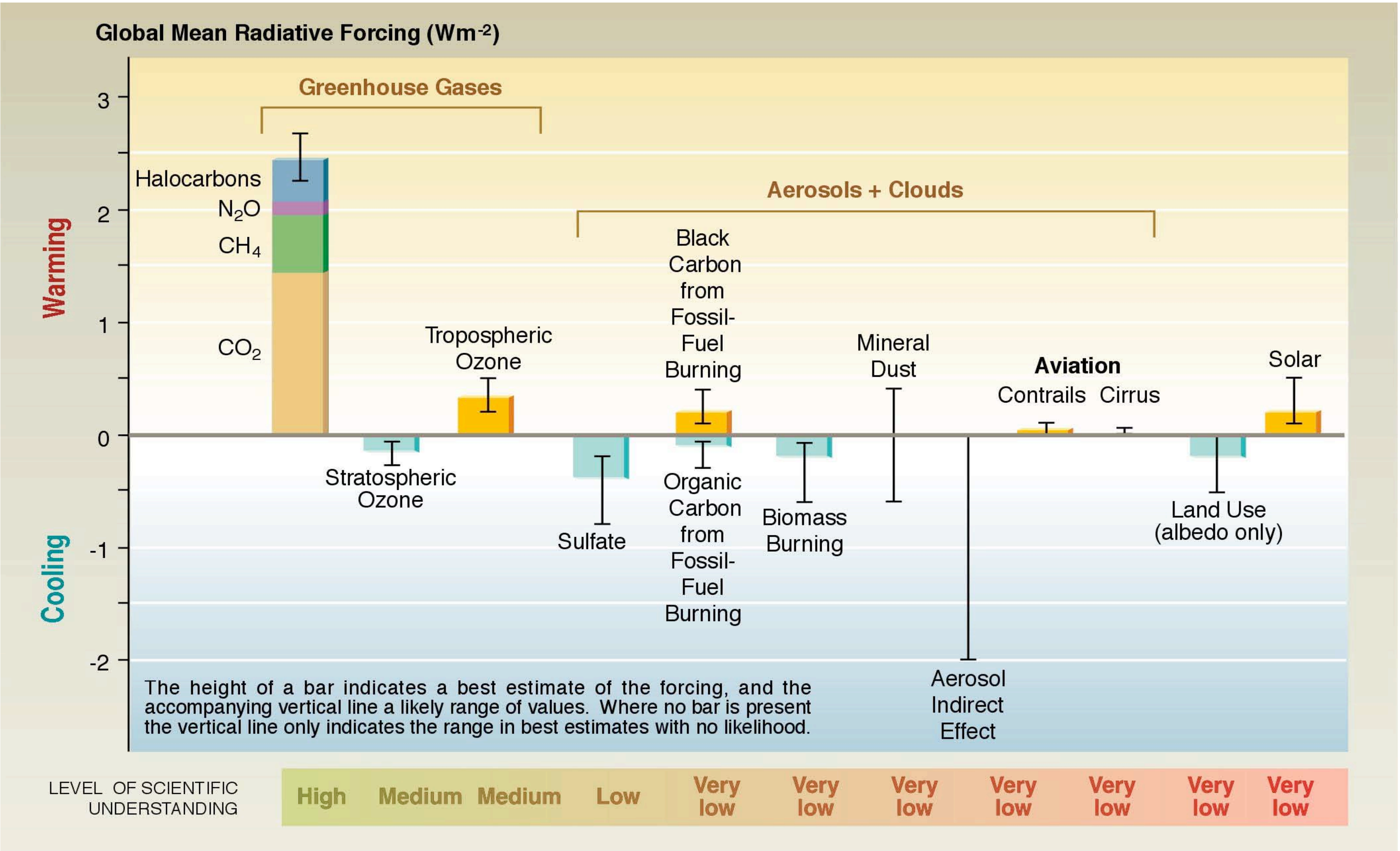
- **Biomass Burning**
- **Urban and Industrial Pollution**



Ganges Valley Pollution, India, Oct. 2001, observed by MISR

Biscuit Fire, Oregon, 2002, observed by MODIS

Pre-industrial to present-day contributions to radiative forcing: 1750 to 2000



Approach For Synthesis and Assessment Product

Phase I: CCSP-Stimulated Major Reviews of Aerosol – Climate Science

- A few *explicit and focused* scientific *reviews* in the near term
- Stand-alone CCSP-facilitated accomplishments
- Useful input to subsequent, community-wide assessments like the IPCC.

Phase II: CCSP-Stimulated Aerosol – Climate Decision-Support Synthesis Assessment Product

- Produce assessment-synthesis product at the end of 2007
  - World community's IPCC will be close to their last draft.
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- Use broader-community-assessment information to craft *explicit* CCSP decision-support information and tools.

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Three Reviews

Phase I: CCSP-Stimulated Major Reviews of Aerosol – Climate Science

Phase-I. Three explicit and focused scientific reviews that are useful input to community-wide assessment e.g., IPCC:

(1) Dependence of radiative forcing by tropospheric aerosols on aerosol composition in the North Atlantic, North Pacific, and North Indian Ocean based on in-situ observations.

(2) A review of measurement-based understanding of aerosol radiative forcing and aerosol sources derived from the analysis of remote-sensing observations

(3) A model intercomparison study to quantify the uncertainties associated with indirect aerosol forcing.

Useful scientific spectrum associated with aerosols and their roles in climate.

(1) and (2): Direct absorption and scattering of radiation by aerosols - aerosol-related chemical measurements (largely in-situ) and radiation measurements (largely remotely-sensed).

(3): Indirectly influence of aerosols on climate system by influencing clouds. A modeling study.

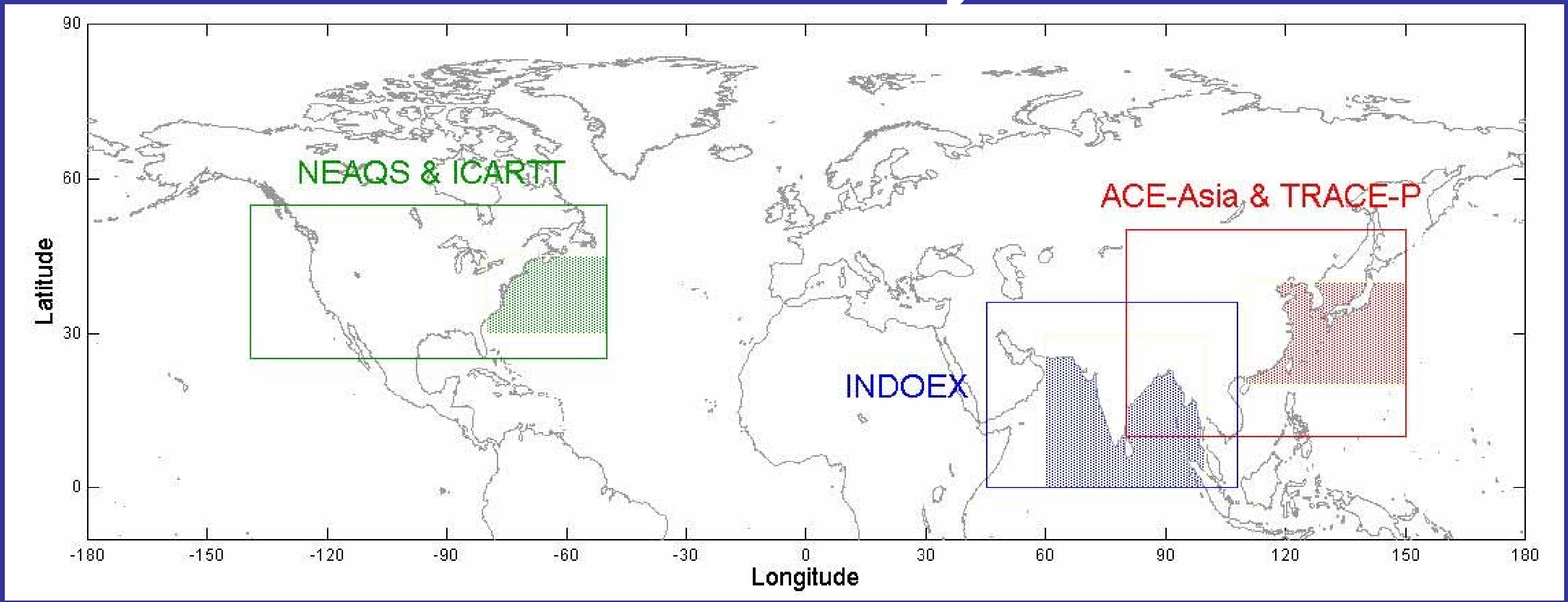
Aerosol Direct Radiative Effects over the Northwest Atlantic, Northwest Pacific, and North Indian Oceans: Estimates Based on in-situ Chemical and Optical Measurements and Chemical Transport Modeling

T.S. Bates, T.L. Anderson, T. Baynard, T. Bond, O. Boucher, G. Carmichael, A. 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 accepted in *Atmospheric Chemistry and Physics*

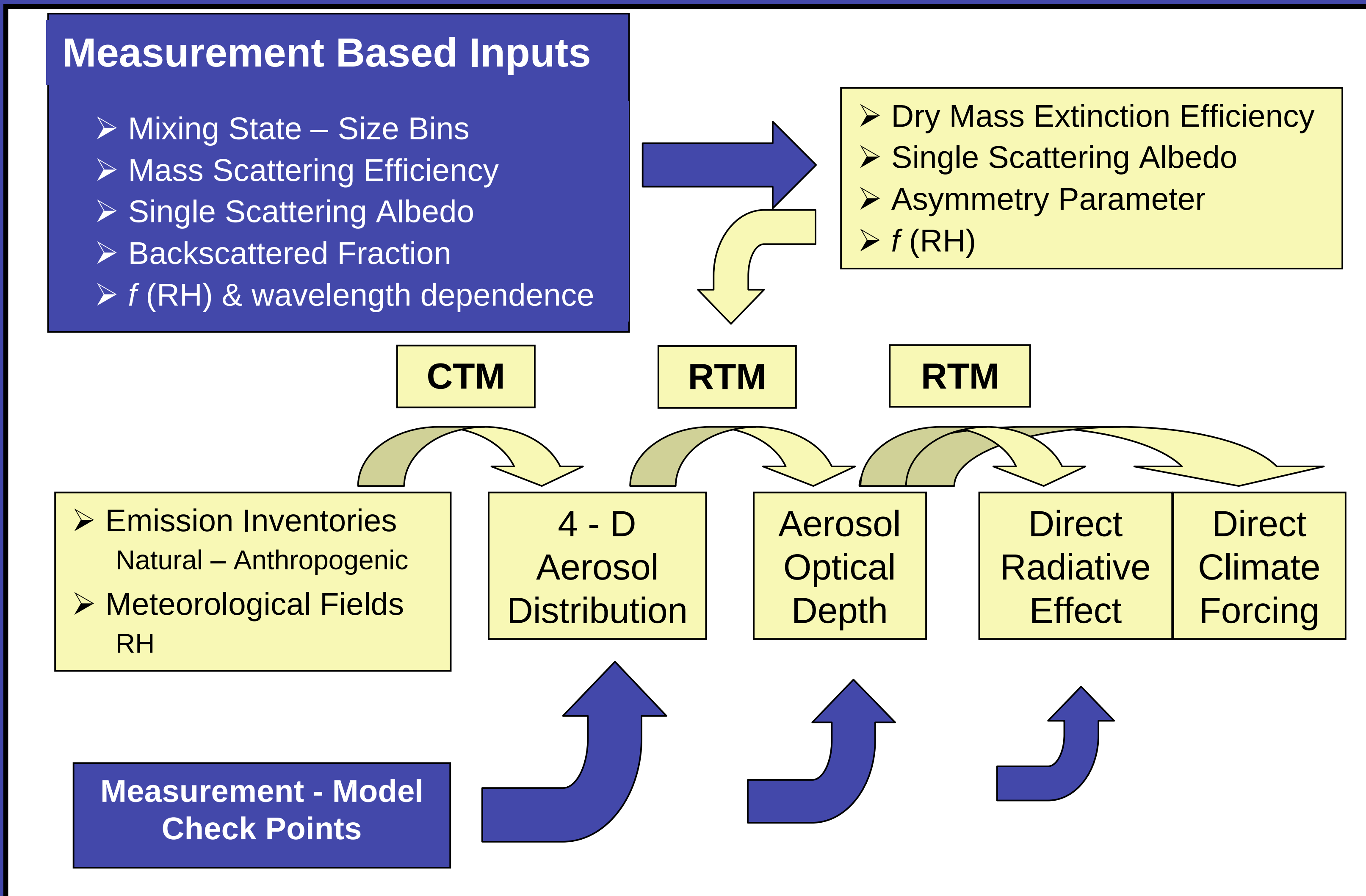
http://www.copernicus.org/EGU/acp/acpd/recent_papers.html

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



Atmos. Chem. Phys. Discuss., 5, 1–122, 2005
www.atmos-chem-phys.org/acpd/5/1/
SRef-ID: 1680-7375/acpd/2005-5-1
European Geosciences Union

Atmospheric Chemistry and Physics Discussions

A review of measurement-based assessment of aerosol direct radiative effect and forcing

H. Yu[1,2], Y. J. Kaufman[1], M. Chin[1], G. Feingold[3], L. A. Remer[1], T. L. Anderson[4], Y. Balkanski[5], N. Bellouin[6], O. Boucher[6,12], S. Christopher[7], P. DeCola[8], R. Kahn[9], D. Koch[10], N. Loeb[11], M. S. Reddy[12,13], M. Schulz[5], T. Takemura[14], and M. Zhou[15]

- Assess the global aerosol distribution and direct radiative effect using satellites supplemented by chemical transport models.
- Assess the anthropogenic component, using satellite data and models.
- Evaluate these assessments against surface network data and field experiments and compare them to model estimates.

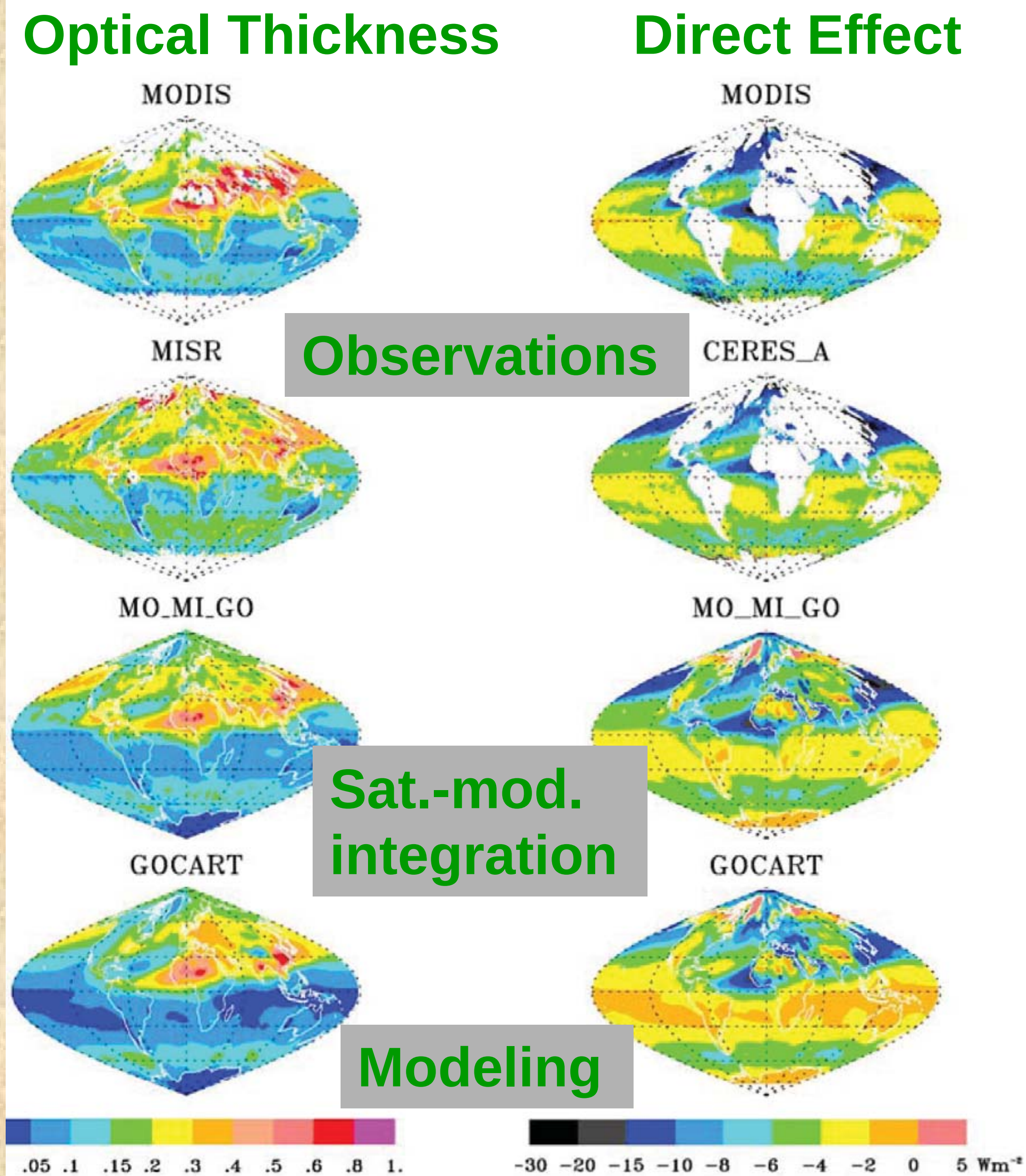
CAPABILITIES:

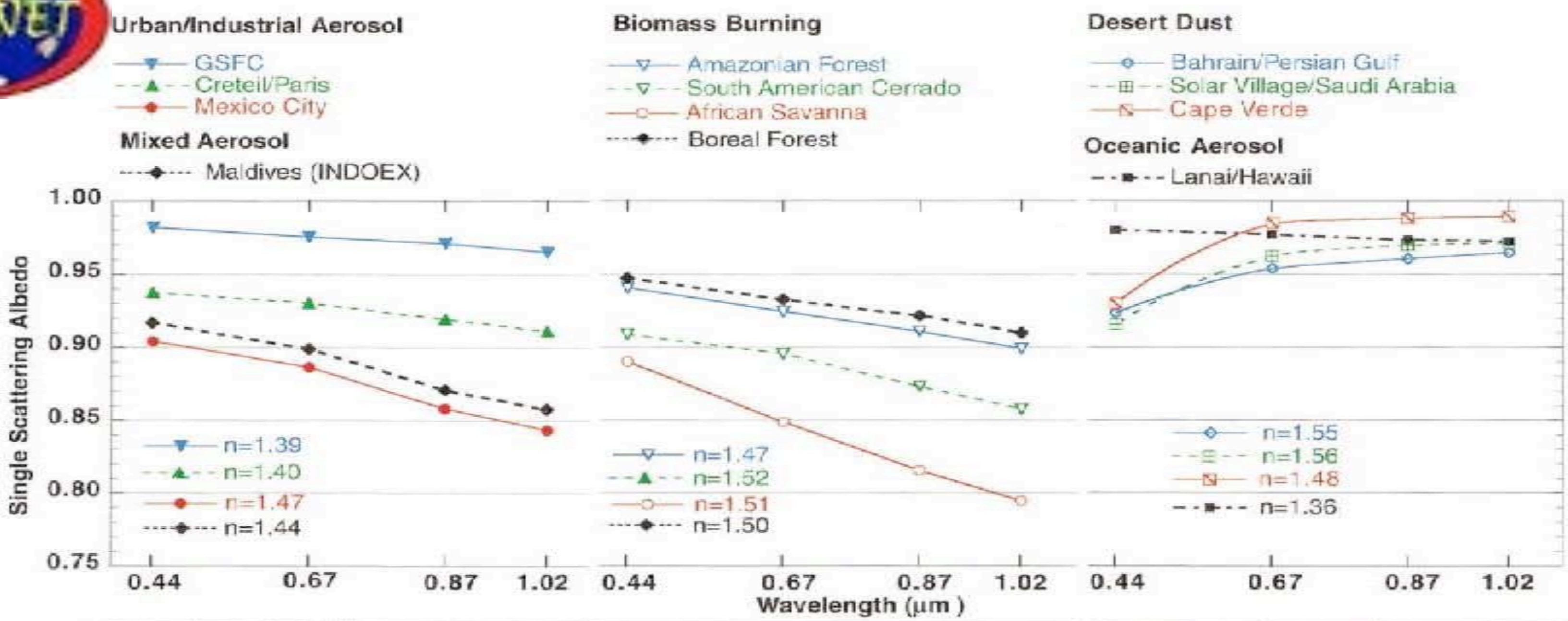
♦ **Dedicated satellite sensors & retrieval algorithms**

♦ **Sophisticated aerosol models**

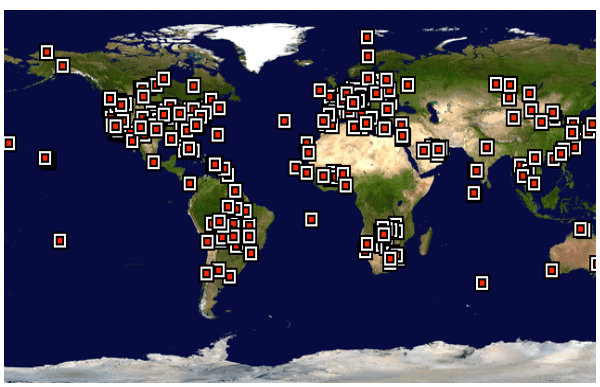
♦ **Integrated satellite-model characterization**

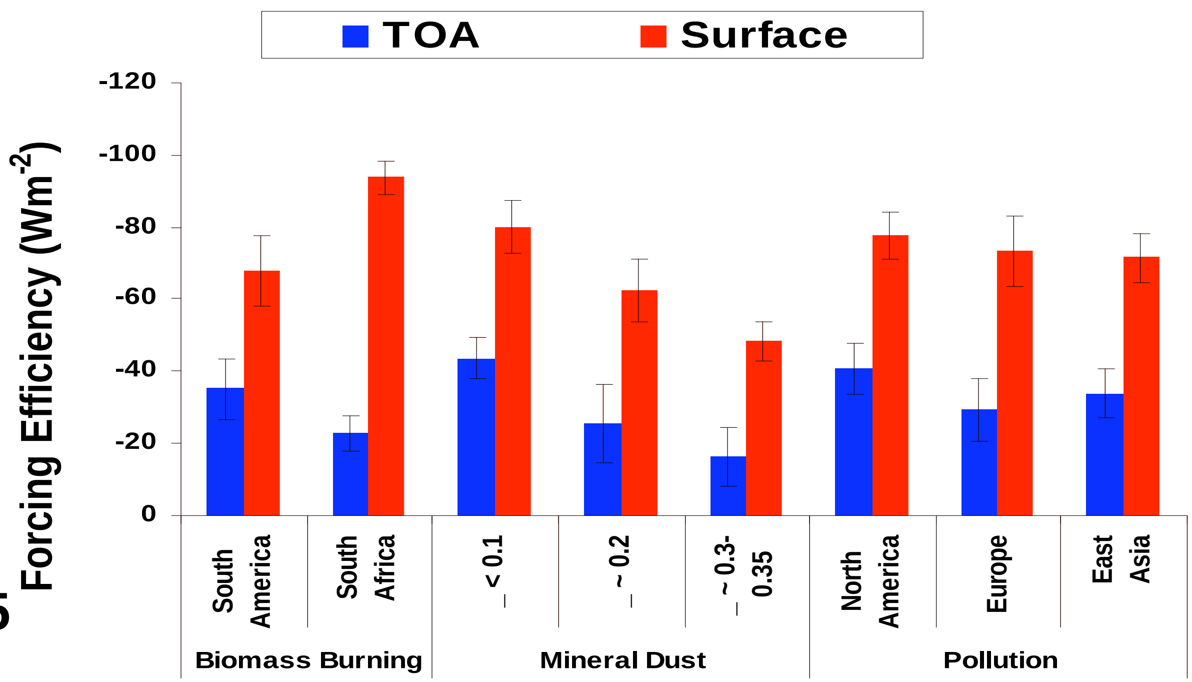
♦ **Global aerosol network & intensive field experiments**





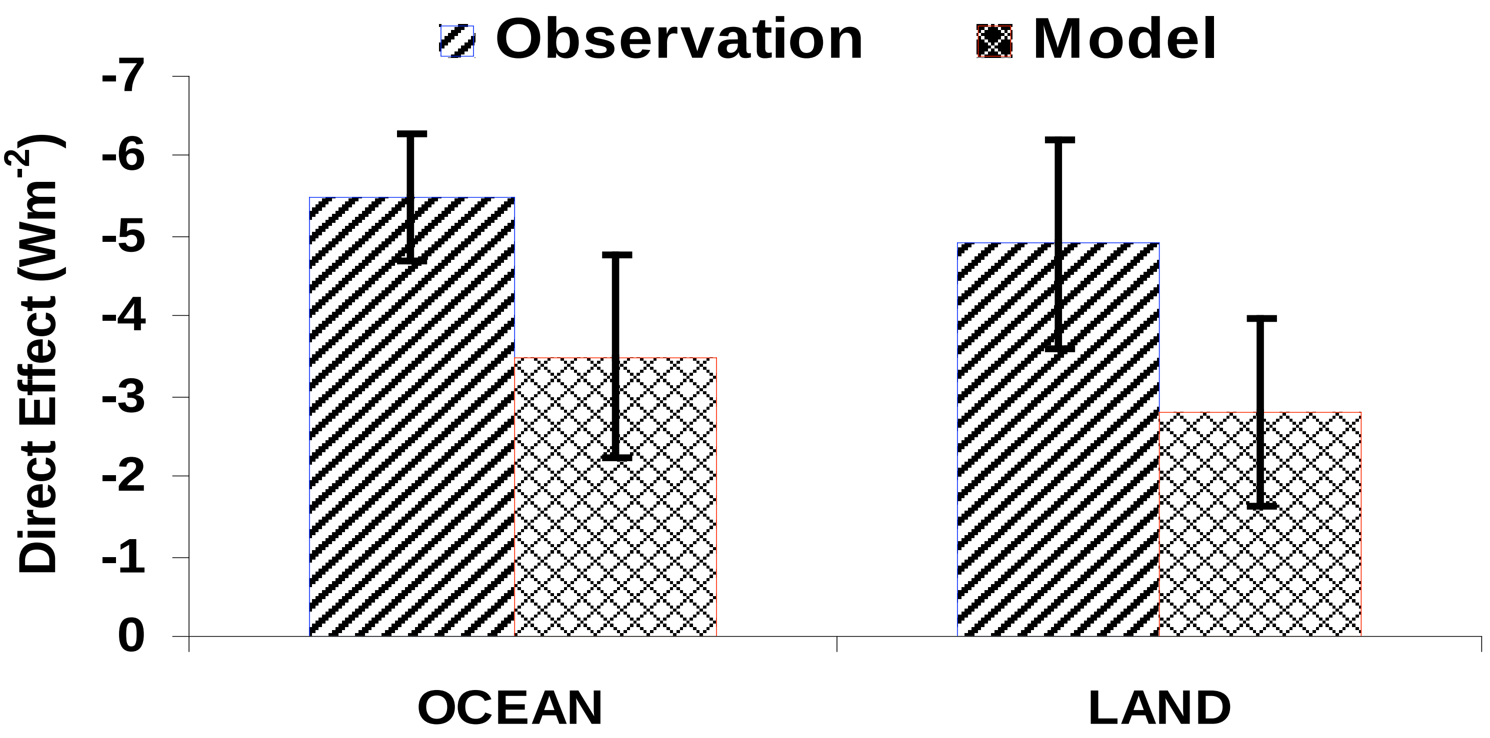
Dubovik et al., 2002





Zhou et al., 2005

Clear-sky Aerosol Direct Effect at TOA



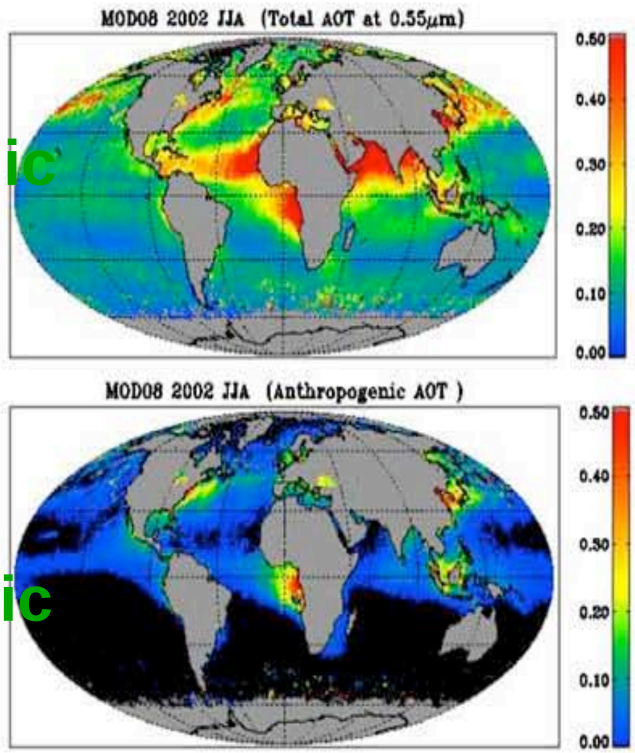
♦ 11 satellite-based (MODIS, MISR, CERES, POLDER, SeaWiFS, ……)

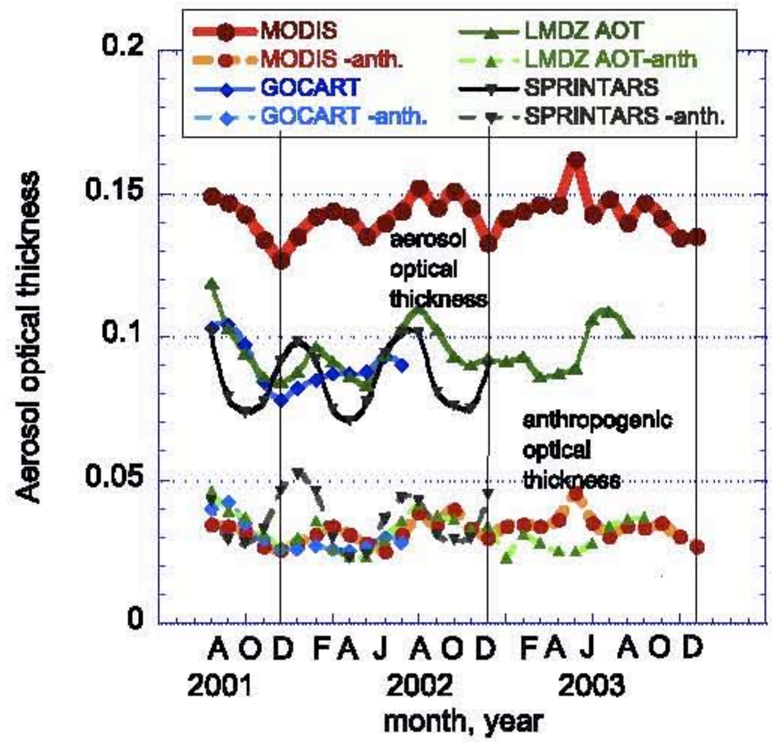
♦ 5 model-based (GOCART, GISS, 2 French & 1 Japan models)

MODIS measured aerosol size parameters can be used to distinguish anthropogenic aerosols from natural aerosols

Natural + Anthropogenic

Anthropogenic





Over ocean, the anthropogenic contribution to MODIS AOT is about 21%. MODIS and models are consistent in anthropogenic AOT. ***(Kaufman et al., JGR, 2005)***

The clear-sky aerosol direct forcing at the top of the atmosphere is -1.4 ± 0.4 W/m2 over ocean.

Outstanding Issues ……

- The reason for satellite-model discrepancies is not clear;
- The aerosol direct effect/forcing over land is poorly constrained;
- Cloud impacts on aerosol direct forcing are uncertain; CALIPSO+CLOUDSAT will address the profile issue and hopefully resolve it;
- A coordinated research strategy needs to be developed for assimilation of satellite measurements into models.

Model Intercomparison of Indirect Aerosol Effects

Joyce E. Penner, Johannes Quaas, Toshihiko Takemura, Trude Storelvmo, Karl Taylor, and Huan Guo

Submitted to Atmospheric Chemistry and Physics

Bottom line:

Modeling aerosol indirect effects on clouds remains poorly quantified in part because better measurements are needed.

A set of controlled experiments was used to compare models and to define which aspects of models need better quantification

- Each experiment allows more and more flexibility to choose the model group’s own methods

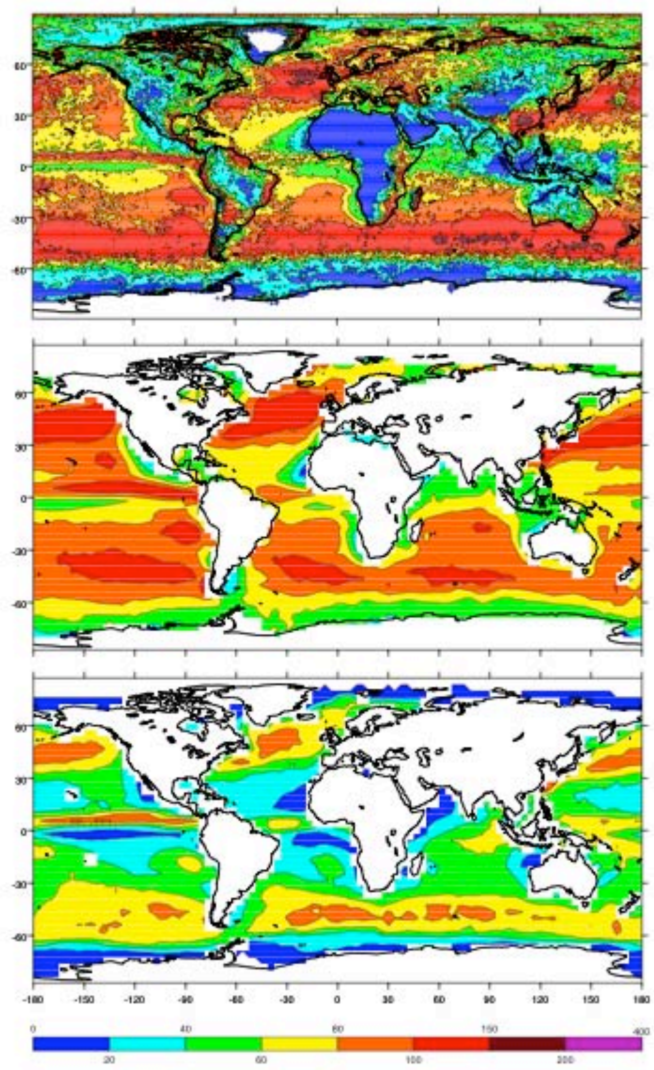
  - First model runs are with specified aerosol fields; specified aerosol affect on production of cloud droplets; and no effect of aerosols on precipitation efficiency

  - Final model runs are with common aerosol sources, but each group chooses their own preferred method for aerosol/cloud interactions including precipitation efficiency

Why is the aerosol/cloud problem difficult?
Satellite observations are not accurate enough to constrain clouds in climate models:

Observed cloud liquid water path (g/m^2) is poorly known so it is difficult to improve the models.

Clouds reflect 54 W/m^2, so a small change from aerosols can have a large forcing impact

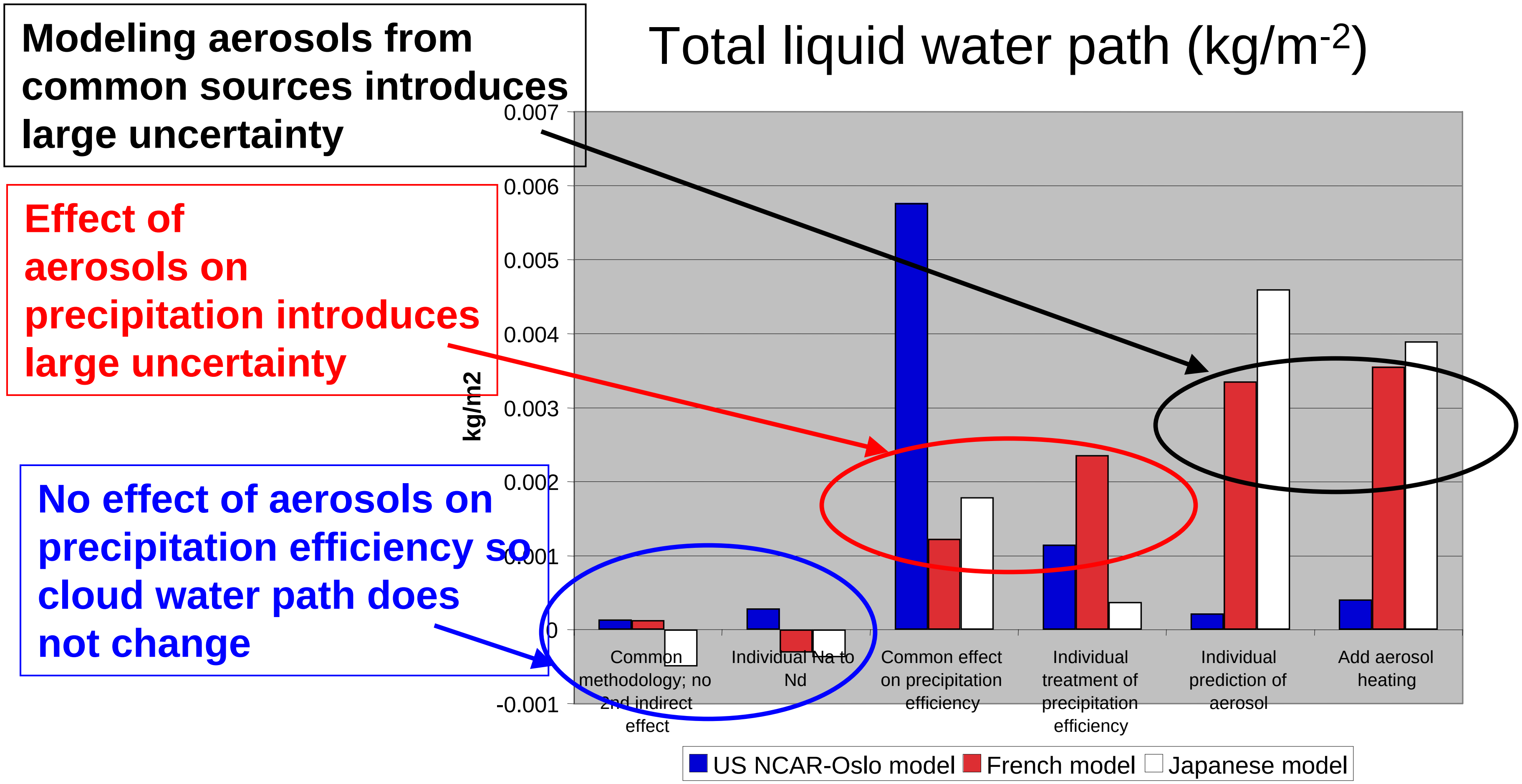


MODIS:
Mean LWP = 66.8 g/m2

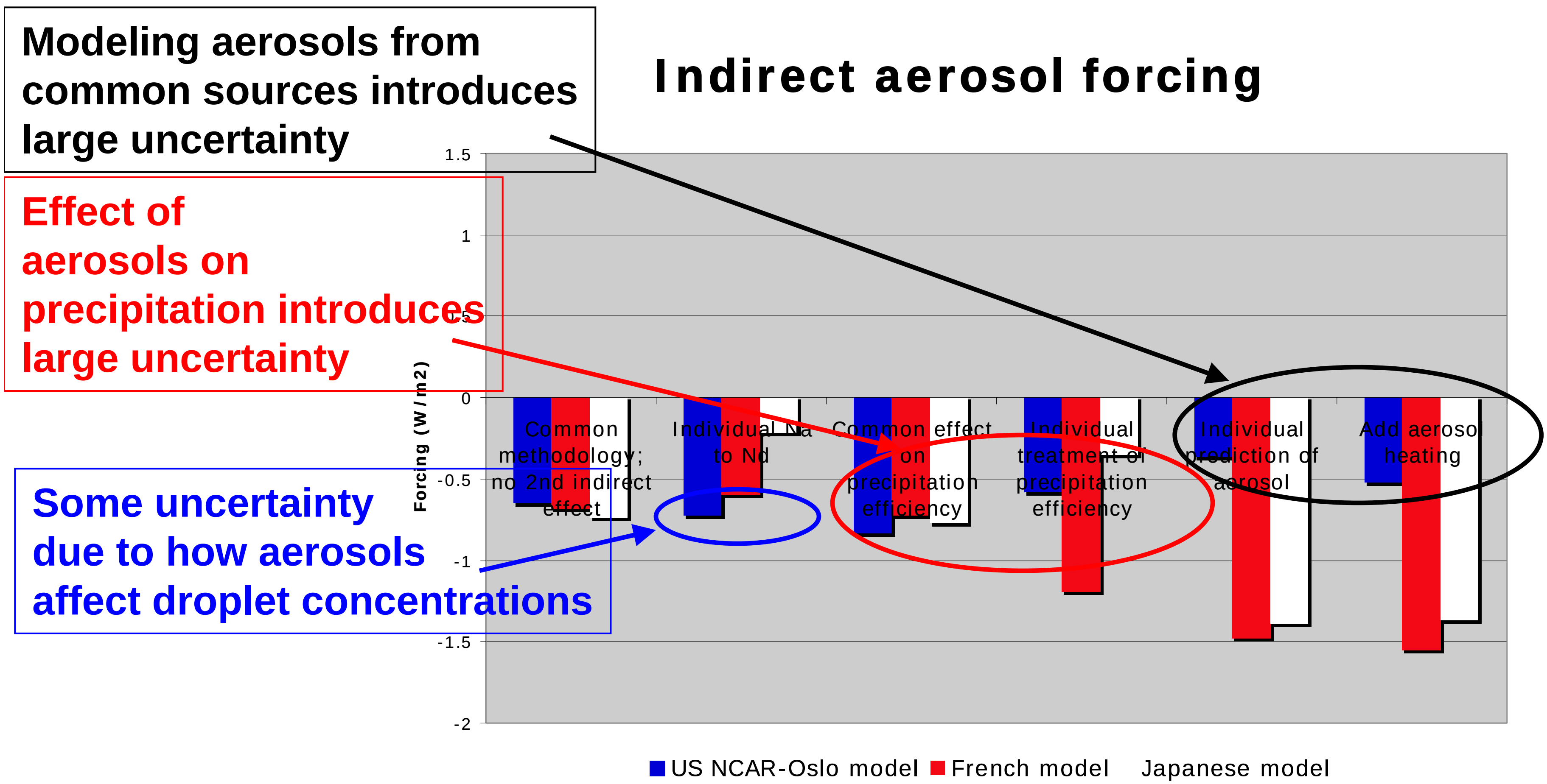
SSMI:
Greenwald et al.
Mean LWP = 78.7 g/m2

SSMI:
Weng and Grody,
Mean LWP = 47.9 g/m2

The change in total cloud water path from pre-industrial to present day varies significantly among the models when the effect of aerosols on precipitation efficiency is introduced and when models attempt to predict aerosols:



These uncertainties translate into large uncertainties in indirect forcing



Next steps

- We need to develop the right observations and use these to improve and constrain the models.

- Better quantification of the vertical aerosol distribution (Calypso) and cloud distribution and water path (Cloud Sat) will be used to improve the models

- Field experiments can also be used to improve the model treatment of precipitation efficiency, though better model resolution may ultimately be needed

Approach For Synthesis and Assessment Product

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❖Use broader-community-assessment information to craft *explicit* CCSP decision-support information and tools.

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Phase II: CCSP Aerosol – Climate Decision-Support Synthesis and Assessment Product

Examples :

Inflow-outflow aerosol budgets for North America

Industrial sectors' policy-useful foci
(e.g., such as transportation, diesel and particulate matter vis-a'-vis gasoline, choices for power generation)

Quantitative links between AQ changes and corresponding aerosol-radiation changes.

North American Decision-Support: Information and Impacts

Process.
Follow CCSP Guidelines for Producing Synthesis and Assessment Products

Involve users and stakeholders: Policy Agencies, Resource Managers, Industry and Non-Governmental Organizations, the U.S. Climate Change Technology Program

Schedule.
Prepare Prospectus and make available for review late-2005 - early-2006

Preliminary scientific information base will be available
-NRC report and the Expert Review draft of IPCC
-Complete after the acceptance of the IPCC FAR (2007).

BACK UP SLIDES

The Assessment Products: The Important Role of This Workshop

- **The relation: International and national information products**

  Several modes of constructive interface:

  > 2.1 Some experts are in common

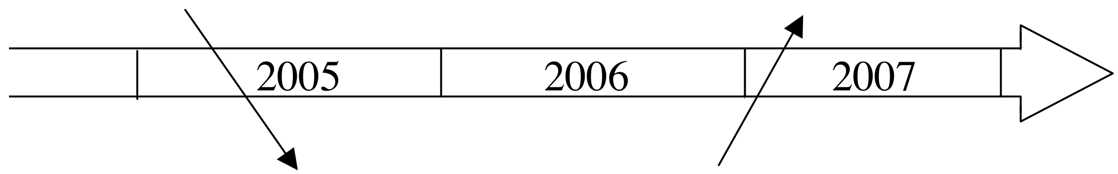
  > 2.2 CCSP product often can be viewed as input to international endeavor

  > 2.3 International product often can serve as the science basis for CCSP to focus on national issues.

- **Two examples**

  ☑ **CCSP-stimulated review papers(2005/6)**

  ❑ **CCSP decision-support products related to U.S. (2007)**



  ❑ **IPCC Fourth Assessment Report (2007)**

  ❑ **U.N. Montreal Protocol Ozone Depletion Report (2006)**

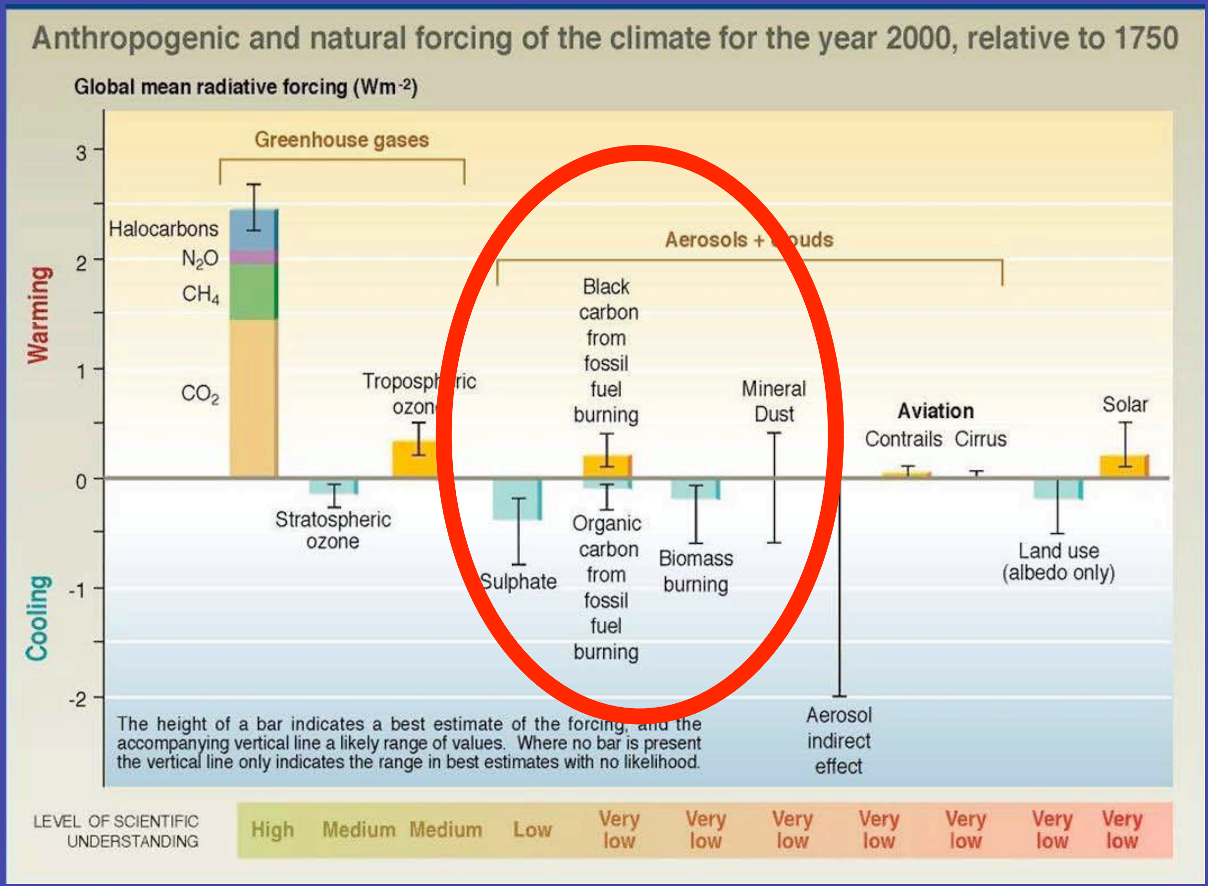
- **This workshop**

  We seek your comment and input to the types of decision support information upon which we could focus.

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 (ω_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.

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.

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

A.R. Ravishankara (NOAA), T.S. Bates (NOAA), T.L. Anderson (University of Washington), G. Carmichael (University of Iowa), A. Clarke (University of Hawaii), C. Erlick (The Hebrew University of Jerusalem), L. Horowitz (NOAA), P.K. Quinn (NOAA), S.E. Schwartz (Brookhaven National Laboratory), and H. Maring (NASA).

Summary
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 Phase 1 product and was funded by the NOAA Climate Program and the NASA Radiation Science Program.