DETERMINING AEROSOL RADIATIVE FORCING AT ARM SITES

A CHALLENGE FOR

ASP AND ARM

Stephen E. Schwartz, ASP Chief Scientist (and ARM PI)

Joint Meeting
ARM Aerosol and Cloud Properties Working Groups

Lansdowne VA, November 11-13, 2008

OVERVIEW

Aerosol radiative forcings: magnitudes and uncertainties

CCSP - SAP 2.3 – Path forward: Traditional approach

CCSP - SAP 2.3 – Definition of aerosol radiative forcing

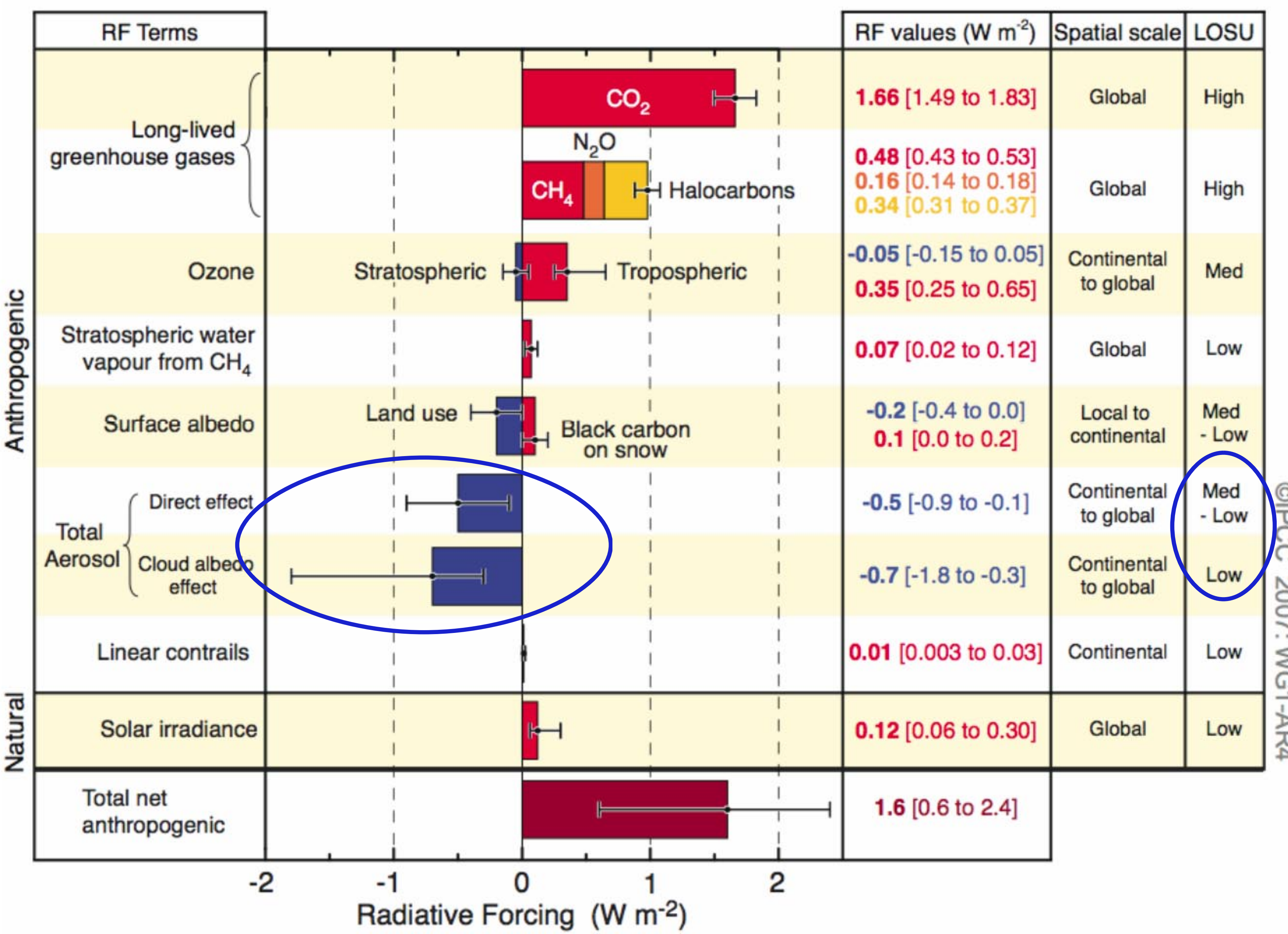
Dimensions of aerosol radiative forcing

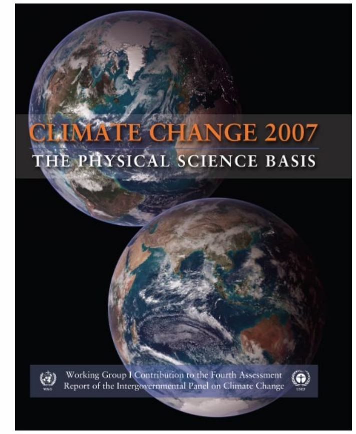
Measurement based determination of aerosol radiative forcing at ARM site(s) – A new approach

Concluding remarks

GLOBAL-MEAN RADIATIVE FORCINGS (RF)

Pre-industrial to present (Intergovernmental Panel on Climate Change, 2007)

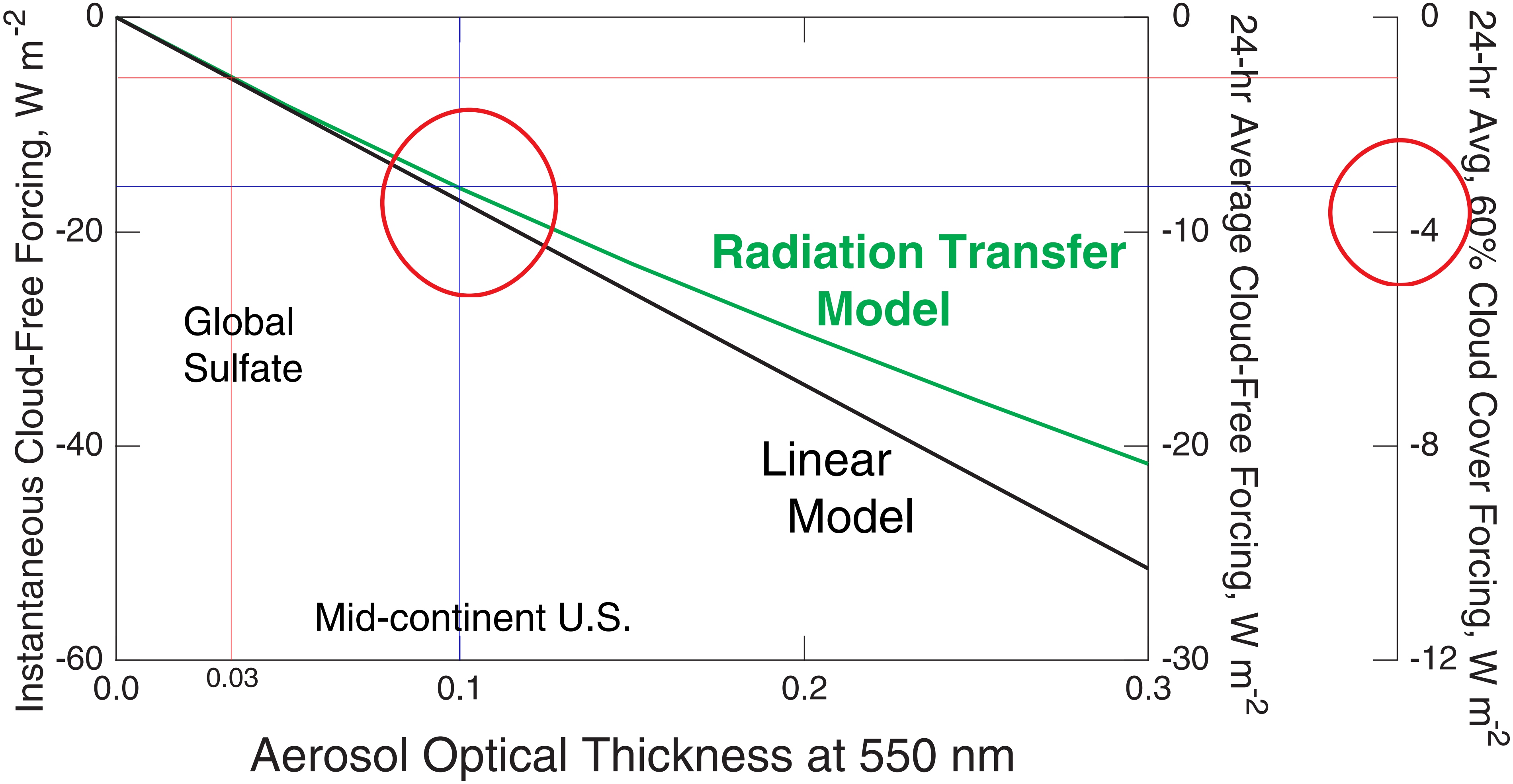




LOSU denotes level of scientific understanding.

ESTIMATES OF AEROSOL DIRECT FORCING

By linear model and by radiation transfer modeling



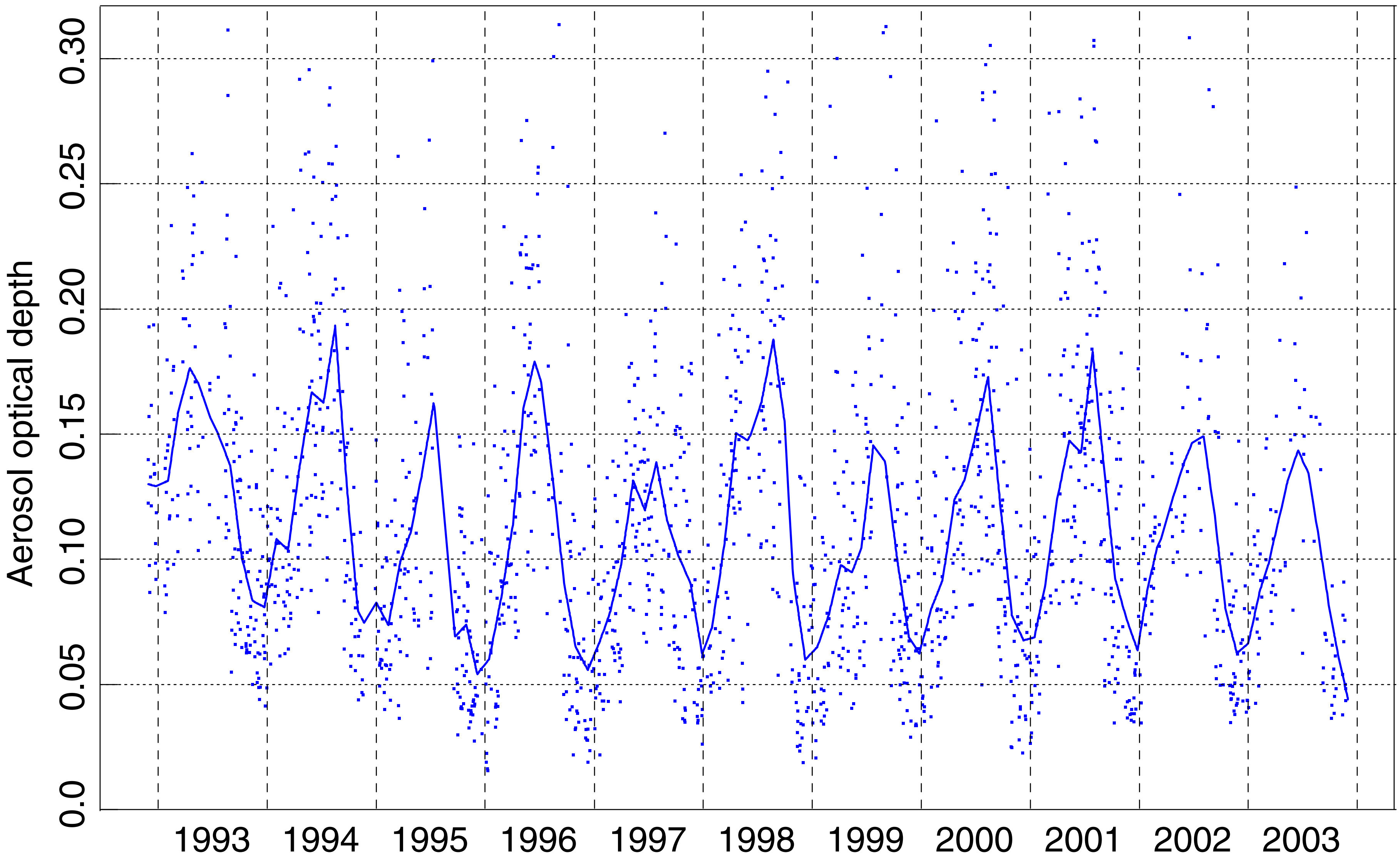
Global average sulfate optical thickness is 0.03: ***1 W m^{-2} cooling.***

In ***continental U. S.*** typical aerosol optical thickness is 0.1: ***3 W m^{-2} cooling.***

AEROSOL OPTICAL DEPTH

Determined by sunphotometry

North central Oklahoma - Daily average at 500 nm



J. Michalsky et al., JGR, 2001

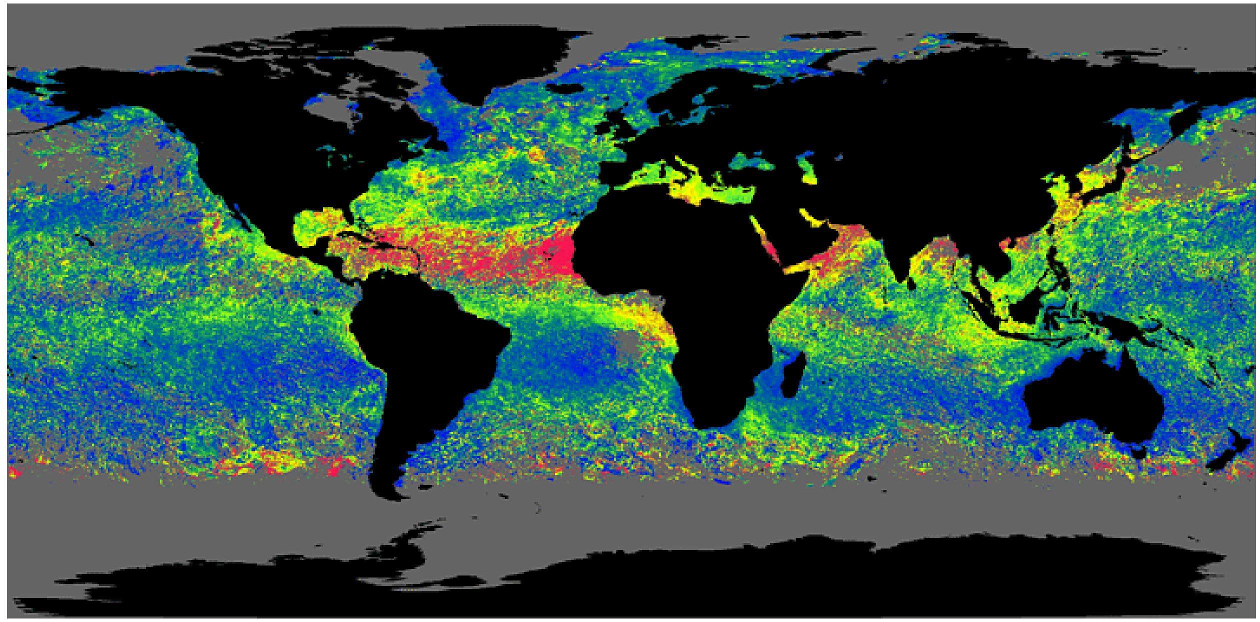
MONTHLY AVERAGE AEROSOL JUNE 1997

Polder radiometer on Adeos satellite

Optical Thickness τ

$\lambda = 865$ nm

0 — 0.5

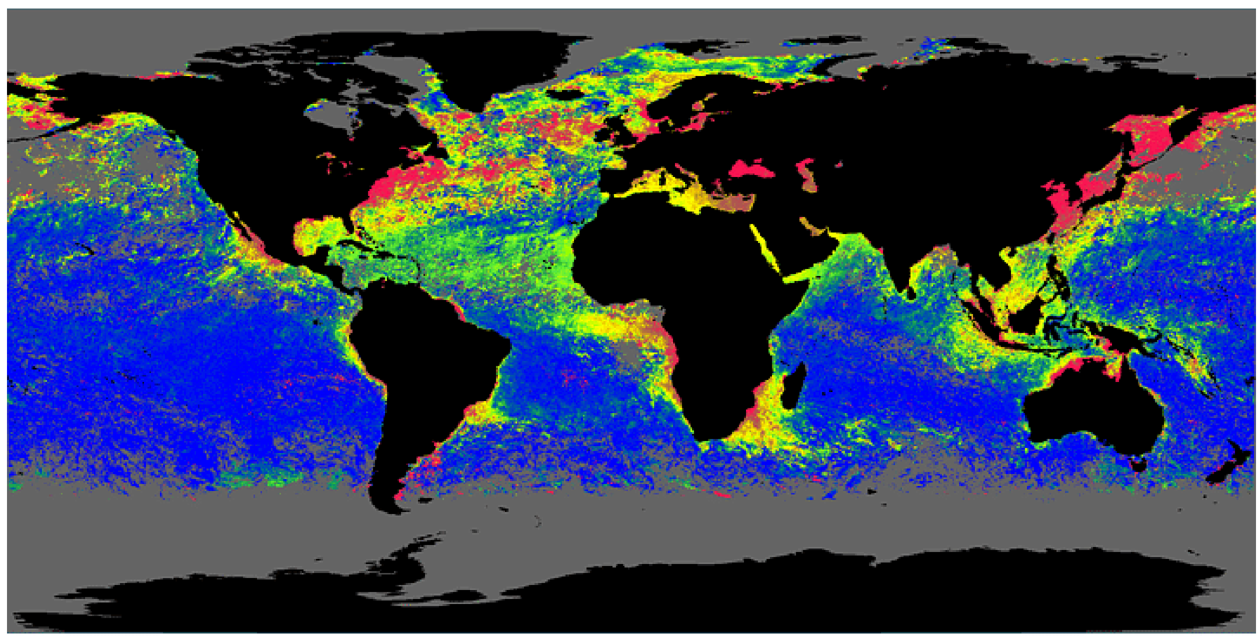


Ångström Exponent α

$$\alpha = -d \ln \tau / d \ln \lambda$$

-0.2 — 1.2

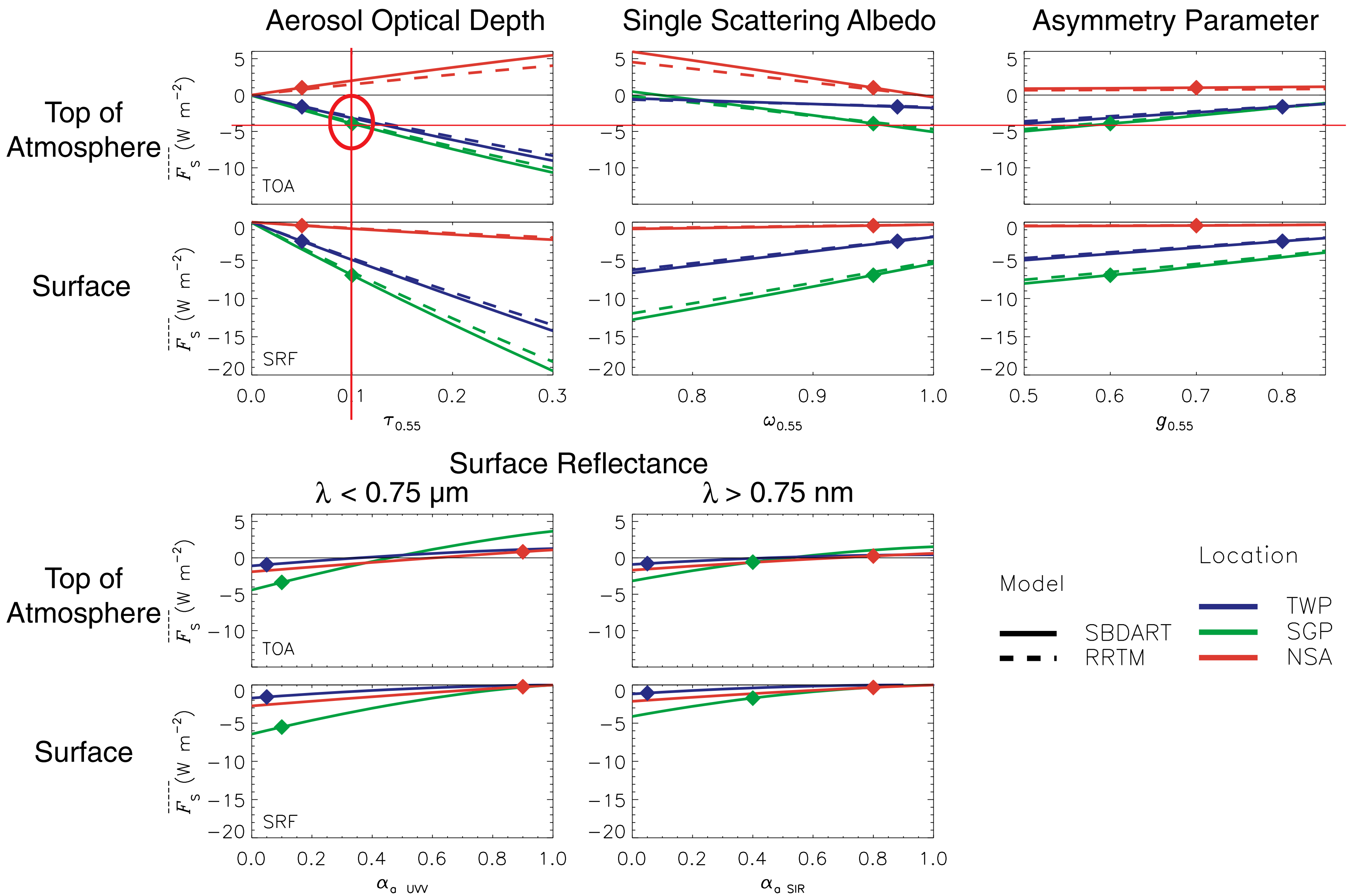
Large Particles — Small Particles



Small particles are from gas-to-particle conversion.

AEROSOL DIRECT CLOUD-FREE FORCING

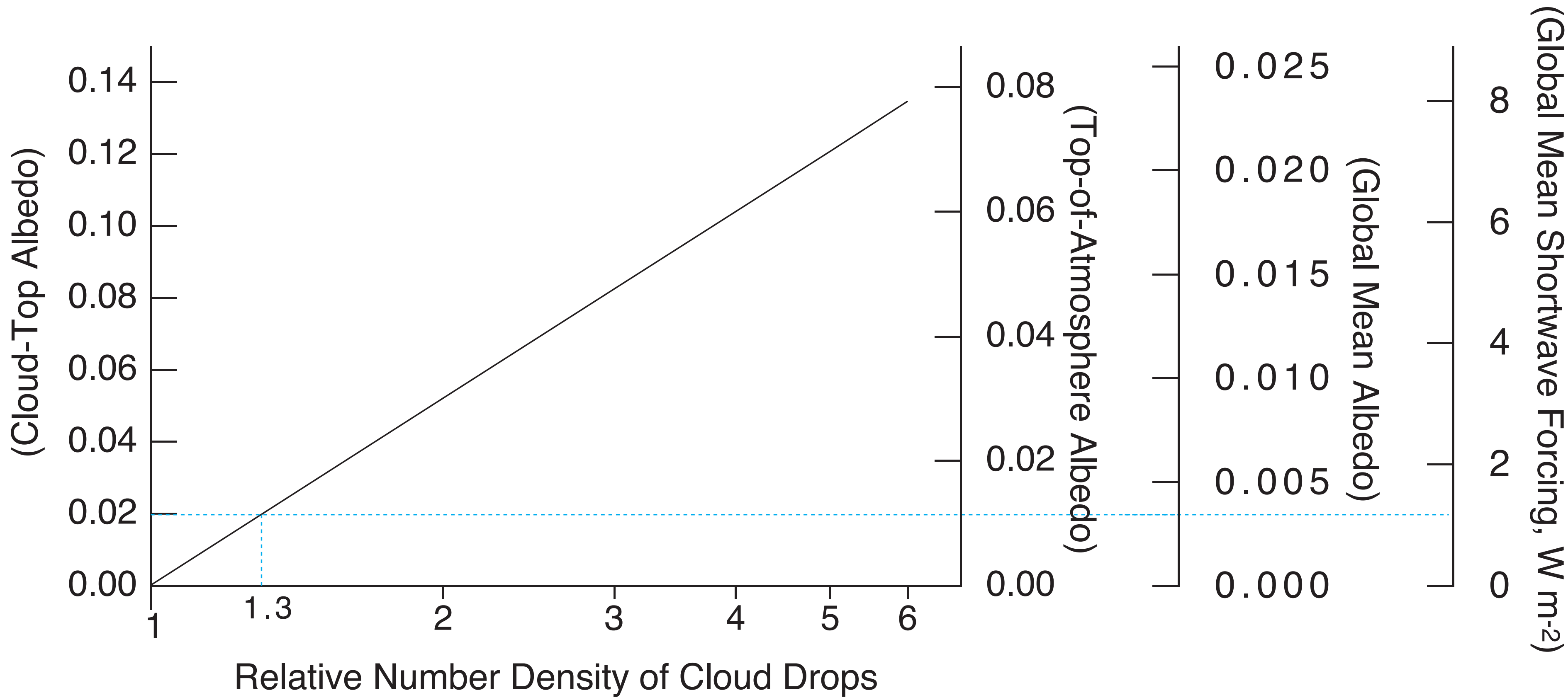
Sensitivity to aerosol and surface properties – 24 hr average at equinox



McComiskey, Schwartz, Schmid, Guan, Lewis, Ricchiazi, Ogren, JGR, 2008

Points denote default values of variables.

SENSITIVITY OF ALBEDO AND FORCING TO CLOUD DROP CONCENTRATION



Schwartz and Slingo (1996)

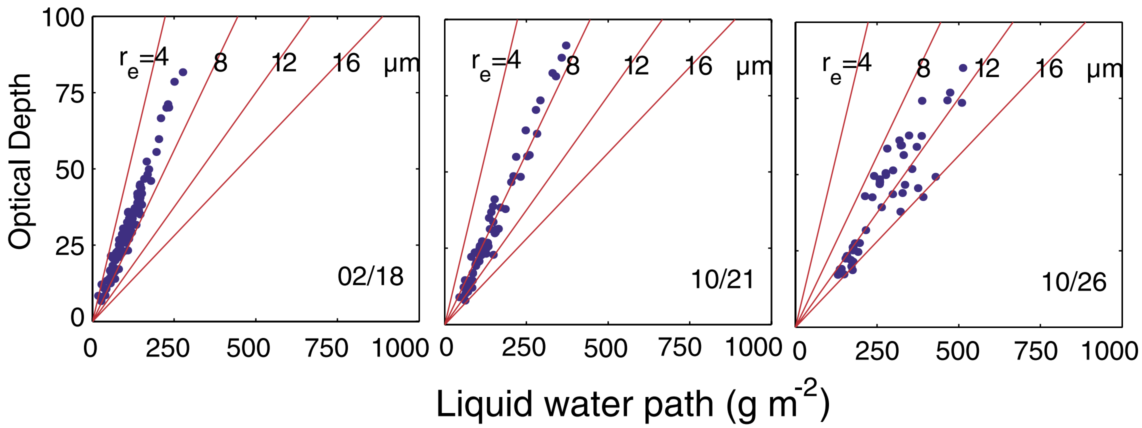
Indirect forcing is highly sensitive to perturbations in cloud drop concentration.

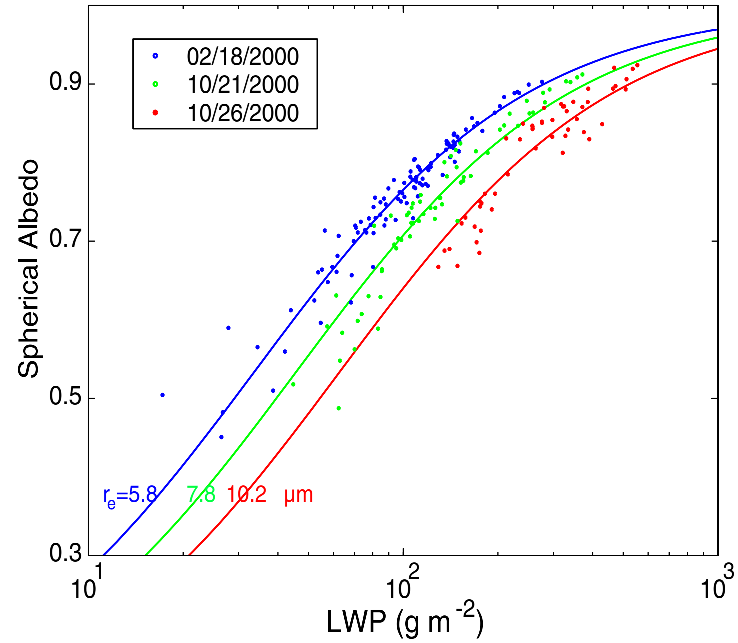
A 30% increase in cloud drop concentration results in a forcing of ~1 W m^{-2}.

CLOUD ALBEDO AND FORCING CALCULATED FROM MEASURED EFFECTIVE RADIUS AND LIQUID WATER PATH

North Central Oklahoma

Effective radius determined from slope of Optical depth vs. Liquid water path





Cloud albedo is calculated for observed data and for average effective radius for each day.
Forcing is calculated for indicated conditions relative to October 26.

Radiative forcing for solar zenith angle 60° and liquid water path 100 g m^{-2}

Date, 2000	Effective radius r_e, µm	Optical Depth	Net flux at TOA W m^{-2}	Forcing relative to 10/26, W m^{-2}
10/26	10.2	15.1	293	—
10/21	7.8	20.8	266	27
02/18	5.8	28.3	240	53

Kim, Schwartz, Miller, and Min, JGR, 2003

Aerosol Properties and Their Impacts on Climate

Synthesis and Assessment Product 2.3

U.S. Climate Change Science Program

Coordinating Lead Author:

Mian Chin, NASA Goddard Space Flight Center

Lead and Contributing Authors:

Ralph Kahn, Lorraine Remer, Hongbin Yu, NASA GSFC;
David Rind, NASA GISS;
Graham Feingold, NOAA ESRL; Patricia Quinn, NOAA PMEL;
Stephen Schwartz, DOE BNL; David Streets, DOE ANL:
Rangasayi Halthore, Philip DeCola, NASA HQ

October 2008

THE WAY FORWARD – CCSP SAP 2.3

Observational tasks

Maintain current and enhance future ***satellite aerosol monitoring*** capabilities.

Maintain, enhance, and expand the ***surface observation networks***.

Execute a continuing series of ***coordinated field campaigns***.

Measure ***aerosol, clouds, and precipitation variables jointly***.

Fully ***exploit the existing information in satellite observations*** of AOD and particle type.

Measure aerosol chemical, physical, and optical properties in ***laboratory studies***.

Improve ***measurement-based techniques for distinguishing anthropogenic from natural aerosols***.

THE WAY FORWARD – CCSP SAP 2.3 *cont'd*

Modeling tasks

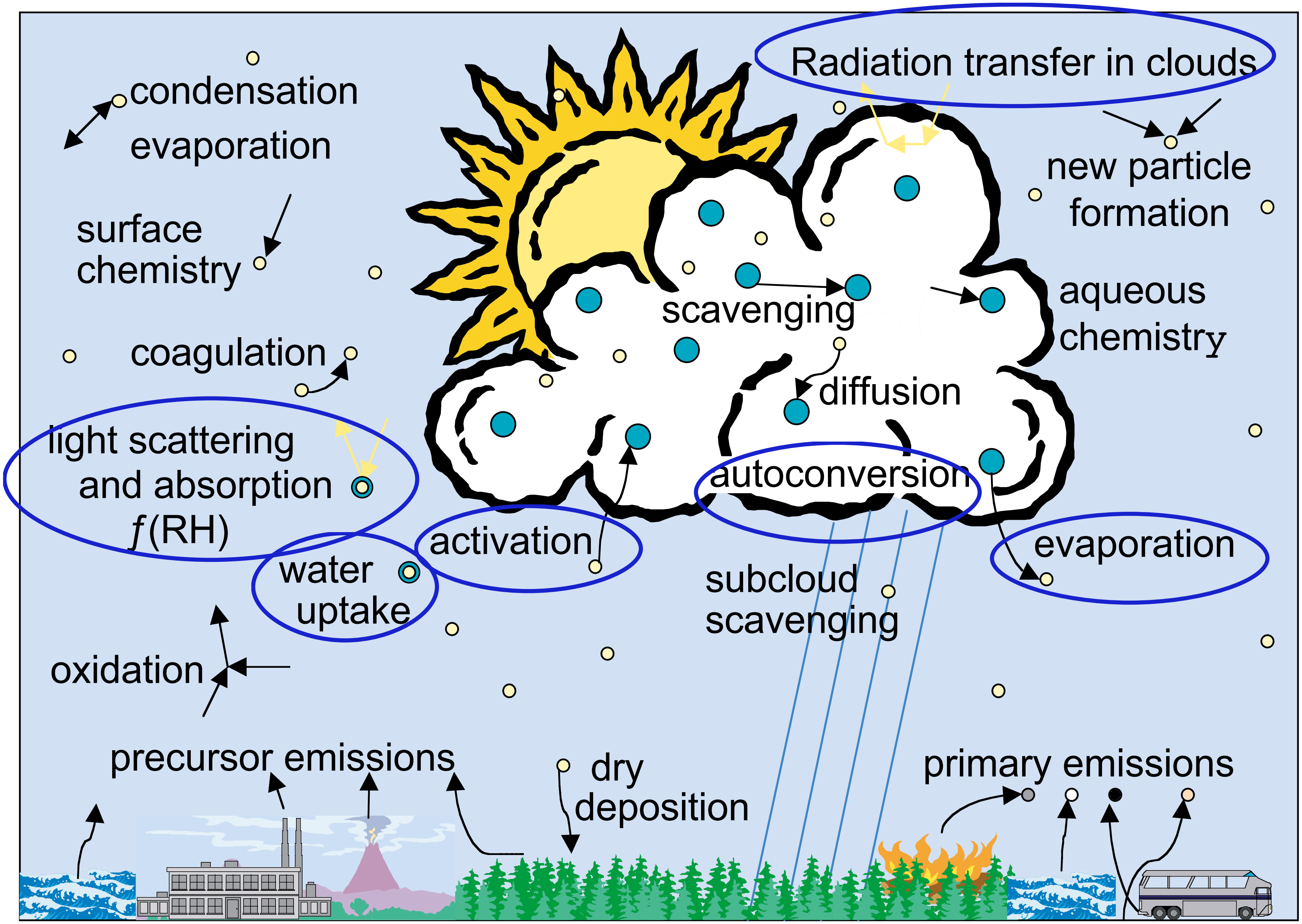
Improve model simulation of aerosols (including components and atmospheric processes) and aerosol direct radiative forcing.

Advance the ability to ***model aerosol-cloud-precipitation interaction***.

Refine ***emissions inventories***.

Simulate climate change with ***coupled aerosol-climate system models***.

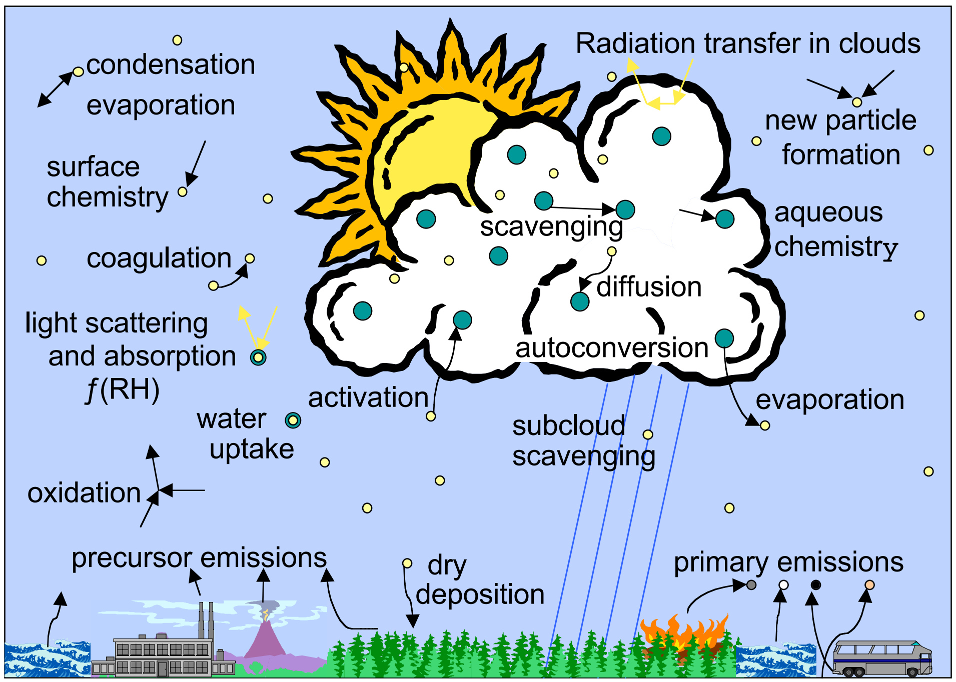
AEROSOL PROCESSES THAT MUST BE UNDERSTOOD AND REPRESENTED IN MODELS



Modified from Ghan and Schwartz, Bull. Amer. Meterol. Soc., 2007

APPROACH TO DETERMINE AEROSOL FORCING

Numerical simulation of physical processes



Isomorphism of processes to computer code

Modeling aerosol processes requires understanding these processes, developing and testing their numerical representations, and incorporating these representations in global scale models.

AEROSOL RADIATIVE FORCING DEFINITION

From CCSP SAP 2.3

Net energy flux (downwelling minus upwelling) ***difference*** between an ***initial*** and a ***perturbed*** aerosol loading state, at a specified level in the atmosphere.

There are a number of ***subtleties*** associated with this definition:

(1) The ***initial state*** against which aerosol forcing is assessed must be specified.

(2) A distinction must be made between

Total aerosol RF – Initial state is complete absence of aerosols; and

Anthropogenic aerosol RF - Initial state is natural (preindustrial) aerosol.

(3) In general, total aerosol RF and anthropogenic aerosol RF include energy associated with both the ***shortwave*** (solar) and the ***longwave*** (primarily planetary thermal infrared) radiative components.

. . .

AEROSOL RADIATIVE FORCING DEFINITION *cont'd*

(5) Aerosol RF can be evaluated at the ***surface***, within the atmosphere, or at ***top-of-atmosphere*** (TOA).

(6) Differences between TOA forcing and surface forcing represent ***heating within the atmosphere***.

Atmospheric heating can affect vertical stability, circulation on many scales, cloud formation, and precipitation.

In this document these additional climate effects are ***not included*** in aerosol RF.

(7) Aerosol direct RF can be evaluated under ***cloud-free conditions*** or ***"all-sky"*** conditions.

Cloud-free direct aerosol forcing is ***more easily and more accurately measured or calculated***.

Cloud-free direct aerosol forcing generally exceeds all-sky forcing because clouds mask the aerosol contribution to the scattered light.

Indirect aerosol RF must be evaluated for all-sky conditions.

In this document ***aerosol RF is assessed for all-sky conditions***.

AEROSOL RADIATIVE FORCING DEFINITION *cont'd*

(8) Aerosol RF can be evaluated ***instantaneously***, or ***daily averaged*** (24-hour), or some other time period.

Measurements generally provide instantaneous values.

Models usually consider aerosol RF as a daily average quantity.

In this document ***daily averaged aerosol RF is reported***.

(9) Another subtlety is the ***distinction between forcing and feedback***.

The concept of aerosol effects on clouds is complicated by the impact clouds have on aerosols.

In this report, ***feedbacks are taken as the consequences of changes in surface or atmospheric temperature***.

DIMENSIONS OF AEROSOL RADIATIVE FORCING

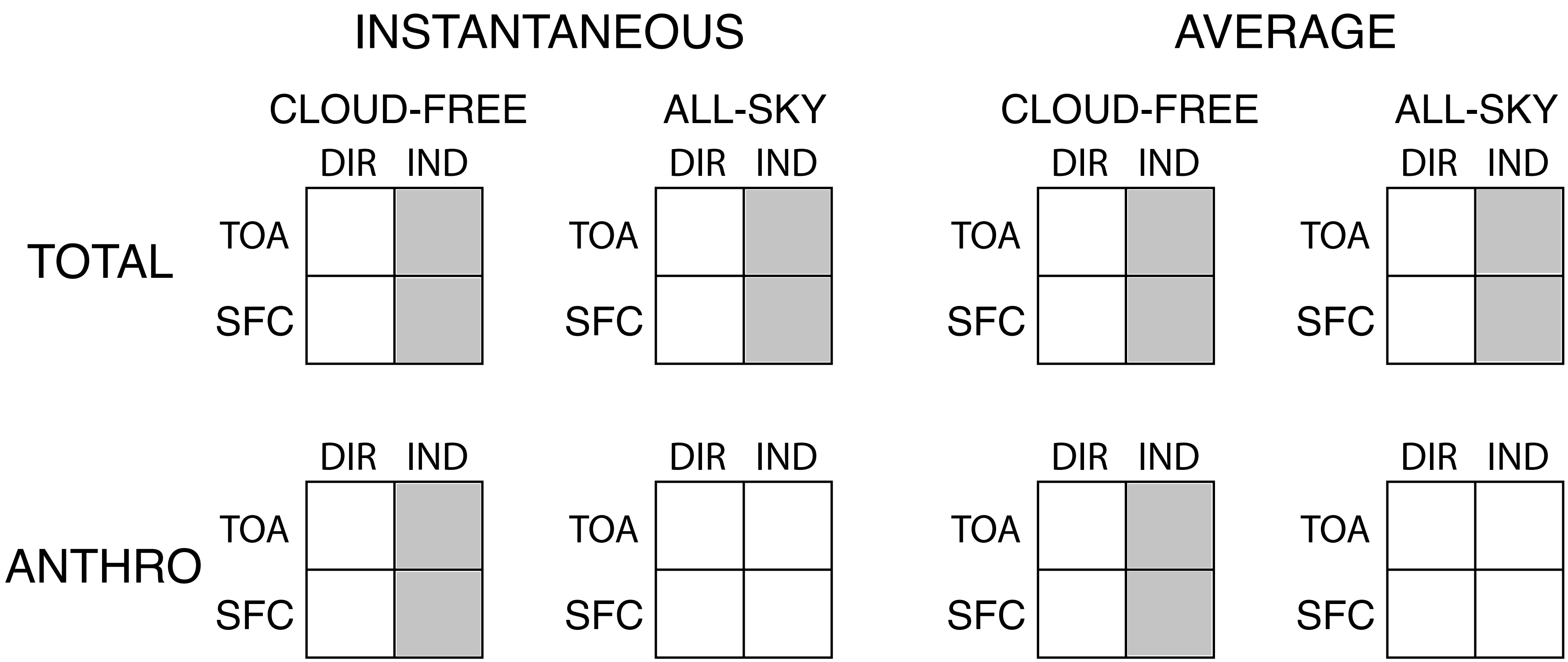
At least ***six dimensions*** to definition of aerosol RF:

Direct	Indirect
Cloud-free	All-sky
Top-of-Atmosphere	Surface
Total aerosol RF	Anthropogenic aerosol RF
Shortwave	Longwave
Instantaneous	24-hr to annual average

At least ***64*** aerosol radiative forcing quantities.

Each aerosol RF is a ***difference*** between two fluxes: perturbed aerosol minus initial aerosol.

AEROSOL FORCINGS TO BE DETERMINED



No indirect forcing in cloud-free sky.

Indirect forcing must be referred to natural aerosol, not zero aerosol.

Ten forcings to be determined, instantaneous and average.

Twenty, if shortwave and longwave are determined separately.

CHALLENGE TO ARM AND ASP

Determine aerosol radiative forcings at ARM site(s).

. . . with well specified definitions.

. . . with "known and reasonable uncertainties".

Deliver these radiative forcings regularly and systematically as an ARM VAP.

This is a necessary (not sufficient) element of determining anthropogenic aerosol forcing pertinent to climate change over the industrial period.

Developing these forcing products would be an enormous challenge to ARM and ASP requiring substantial resources.

CHALLENGES IN DETERMINING AEROSOL RADIATIVE FORCINGS

Determining ***anthropogenic contribution*** to aerosol.

Aerosol mass spectrometer

Modeling

Aerosol ***optical properties*** (σ_{ep}, ω_0, g) including RH dependence as $f(x, y, z)$.

$\boldsymbol{N_{ccn}(s)}$ ***and*** $\boldsymbol{N_{cd}}$ for actual and natural aerosol as $f(x, y, z)$. s is supersaturation.

Determination of ***3-D cloud morphology***.

3-D Radiative transfer calculation of direct and indirect forcing.

Accuracy sufficient to lend confidence to modeling of difference due to anthropogenic aerosol

Consistency and error estimation from radiation measurements.

CONCLUDING REMARKS

The traditional approach to determining aerosol forcing seems ***unlikely to converge*** very quickly.

There are ***multiple aerosol radiative forcings***. Distinguishing them is essential to progress.

Direct determination of aerosol radiative forcings at ARM sites would be a ***stringent test of ability to determine these forcings***.

Determining aerosol radiative forcings at ARM sites would ***lend confidence to extending this process globally***, from remote sensing and in-situ measurements.

Confident determination of aerosol radiative forcings at ARM sites would require ***substantial new effort and commitment***.