THE DOE 'GRAND CHALLENGE' REQUIREMENTS FOR AEROSOL RESEARCH

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Workshop on

Identifying Outstanding Grand Challenges in Climate Change Research: Guiding DOE's Strategic Planning

Arlington VA

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OVERVIEW

Grand challenges in climate research: ***Determining climate system sensitivity and response to forcings***.

The importance of aerosols to understanding climate change and projecting future climate change.

The grand challenge in atmospheric aerosol research: ***Determining aerosol forcing***.

Aerosol processes that must be understood and represented in climate models.

Representing aerosols in global chemical transport models and global climate models.

Major new developments in understanding aerosol forcing.

Essential research to narrow uncertainty in aerosol forcing.

Summary.

GRAND CHALLENGES IN CLIMATE SCIENCE

Charge to this committee

Under Secretary for Science
Washington, DC 20585
October 1, 2007

1. What are the grand challenges in ***understanding Earth's past and present climate variability and forcing?***

   What key research, observational and computational capabilities are necessary to ***understand the past and present climate and the forcing responsible for past and present changes in climate?***

2. What are the grand challenges in reducing uncertainty and improving confidence in ***projecting how the Earth's climate at regional to global scales may change in the future*** in response to natural an/or human-induced forcing?

   What key basic research, observational and computational capabilities are necessary to ***reduce uncertainty and improve confidence in projecting future climate response to such forcing?***

DOE GRAND CHALLENGE IN CLIMATE CHANGE RESEARCH

Develop confident capability to ***project climate change that would result from alternative emissions scenarios***.

The zero-order challenge:

Determine Earth's climate sensitivity with sufficient accuracy to permit informed decision making on energy policy.

Climate sensitivity:

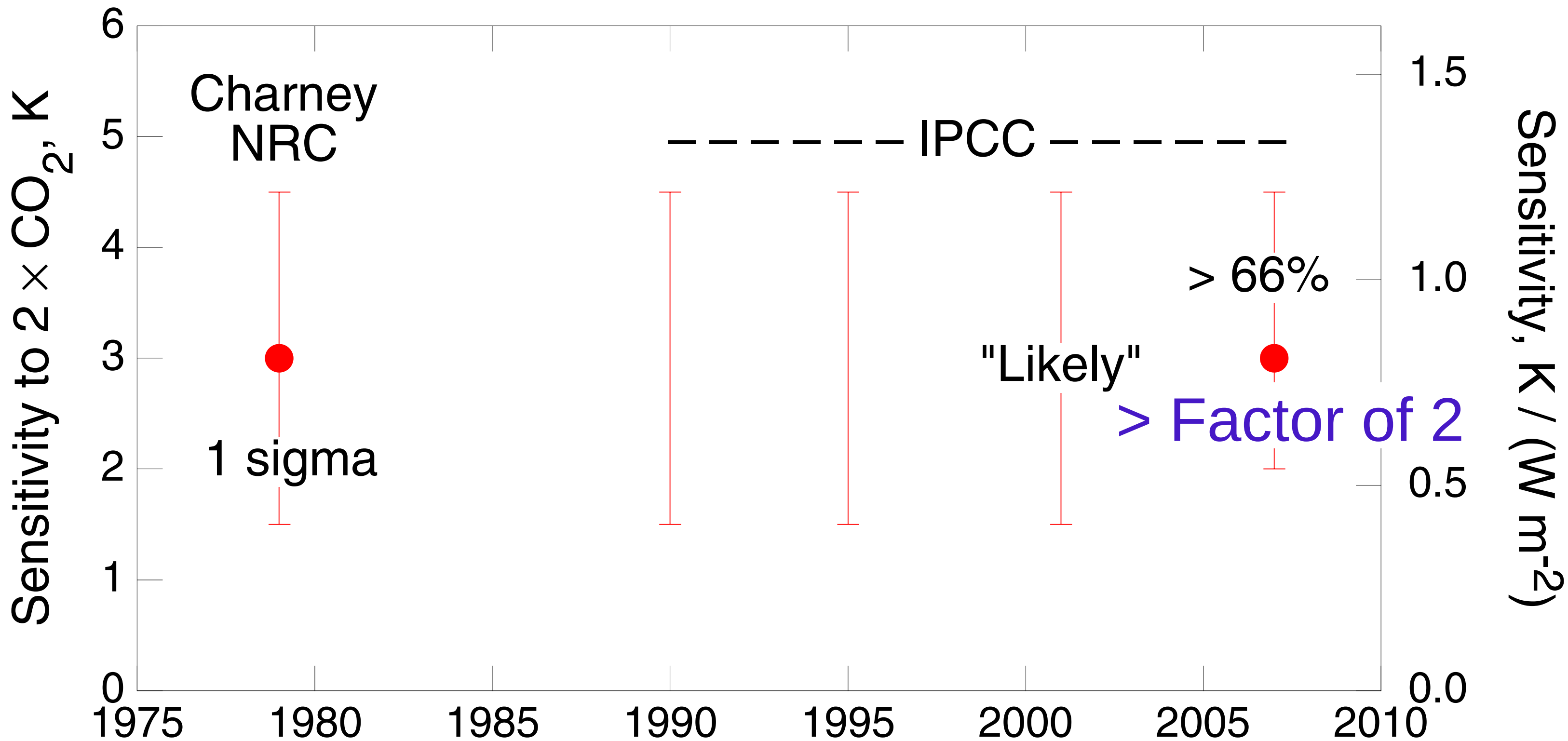
$$S = \Delta T / F$$

ΔT = change in global mean temperature.

F = forcing = change in radiative flux component.

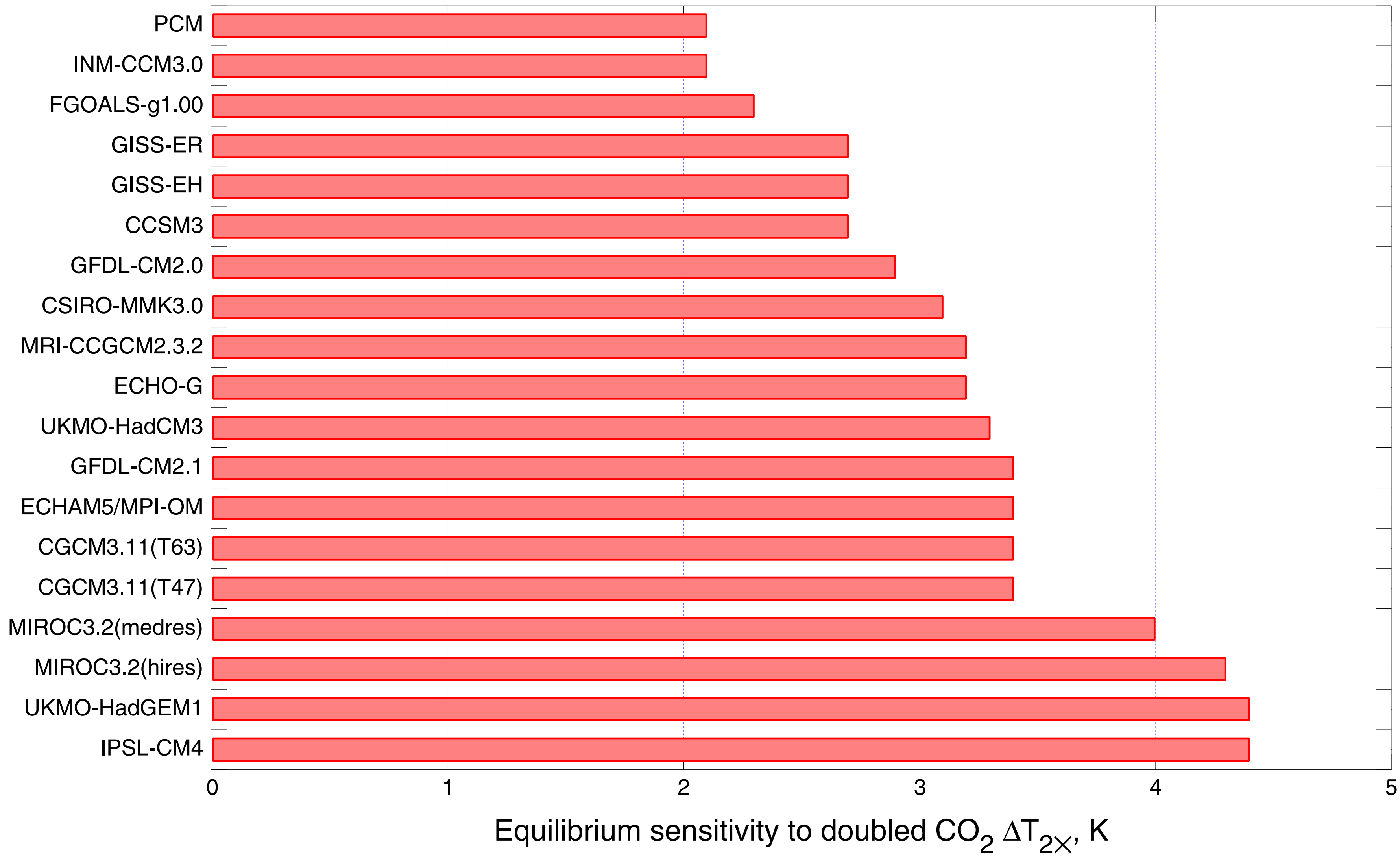
CLIMATE SENSITIVITY ESTIMATES THROUGH THE AGES

Estimates of central value and uncertainty range from major national and international assessments



EQUILIBRIUM SENSITIVITIES IN CURRENT CLIMATE MODELS

20 Models employed in IPCC AR4 simulations



Sensitivity varies by more than a factor of 2.

IMPLICATIONS OF UNCERTAINTY IN CLIMATE SENSITIVITY

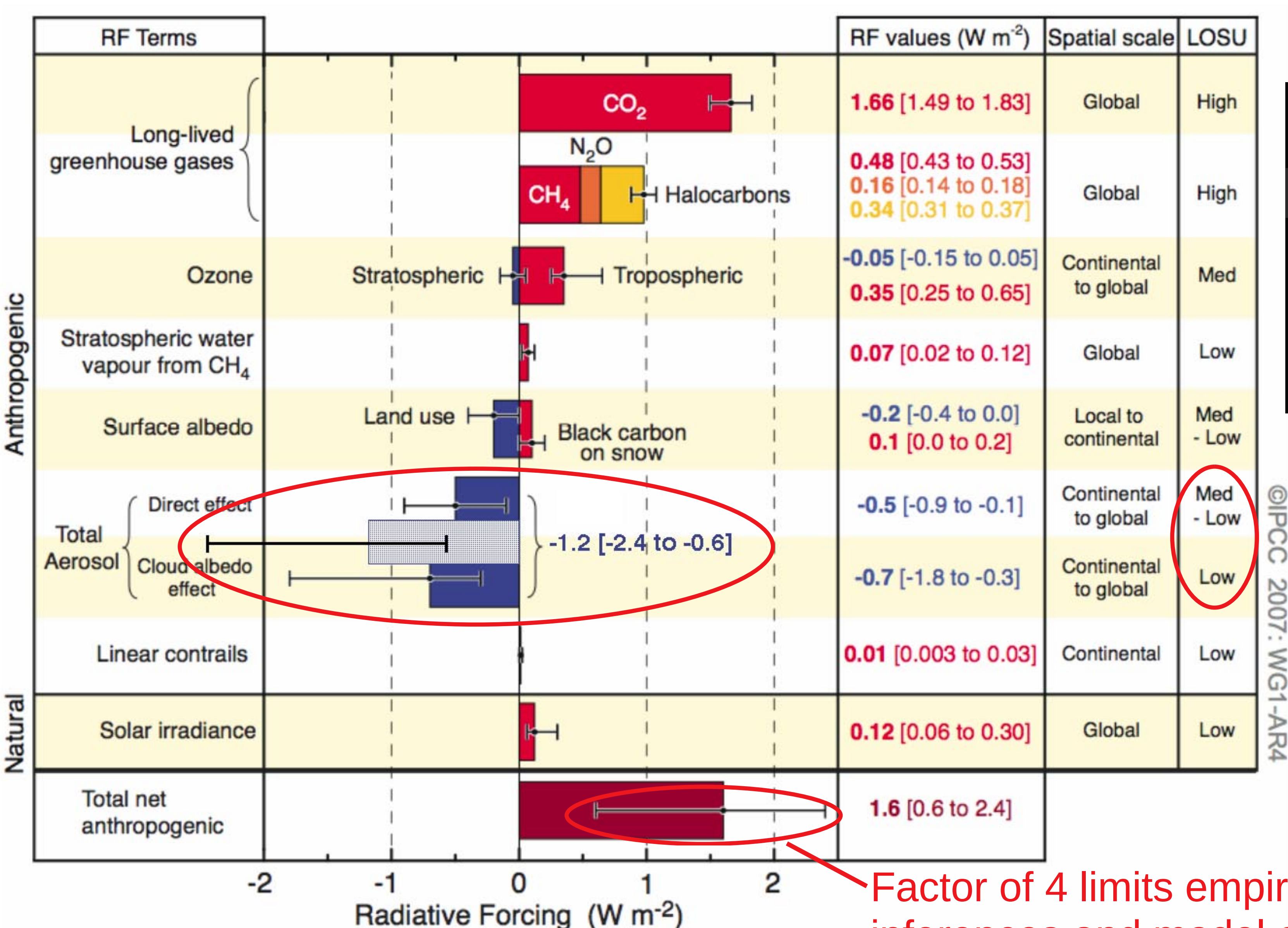
Uncertainty in climate sensitivity translates directly into . . .

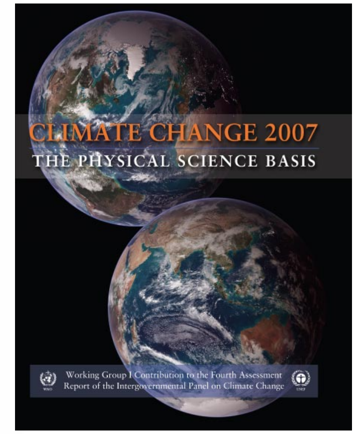
- Uncertainty in the amount of ***incremental atmospheric*** **CO_2** that would result in a given increase in global mean surface temperature.
- Uncertainty in the amount of ***fossil fuel carbon*** that can be combusted consonant with a given climate effect.

At present this uncertainty is more than a factor of 2.

GLOBAL-MEAN RADIATIVE FORCINGS (RF)

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





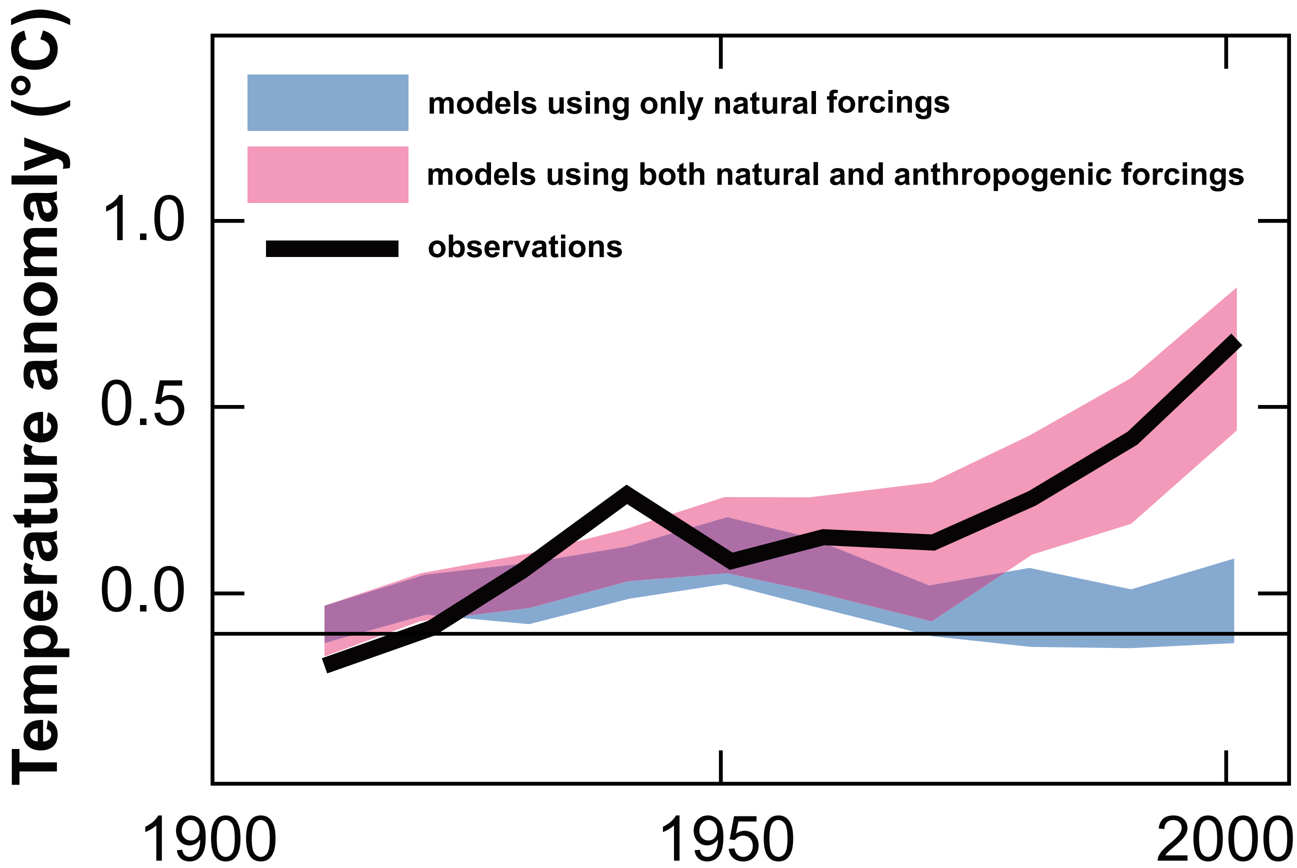
Factor of 4 limits empirical inferences and model evaluation.

LOSU denotes level of scientific understanding.

Uncertainty range: 5 - 95%.

GLOBAL MEAN TEMPERATURE CHANGE

Ensemble of 58 model runs with 14 global climate models

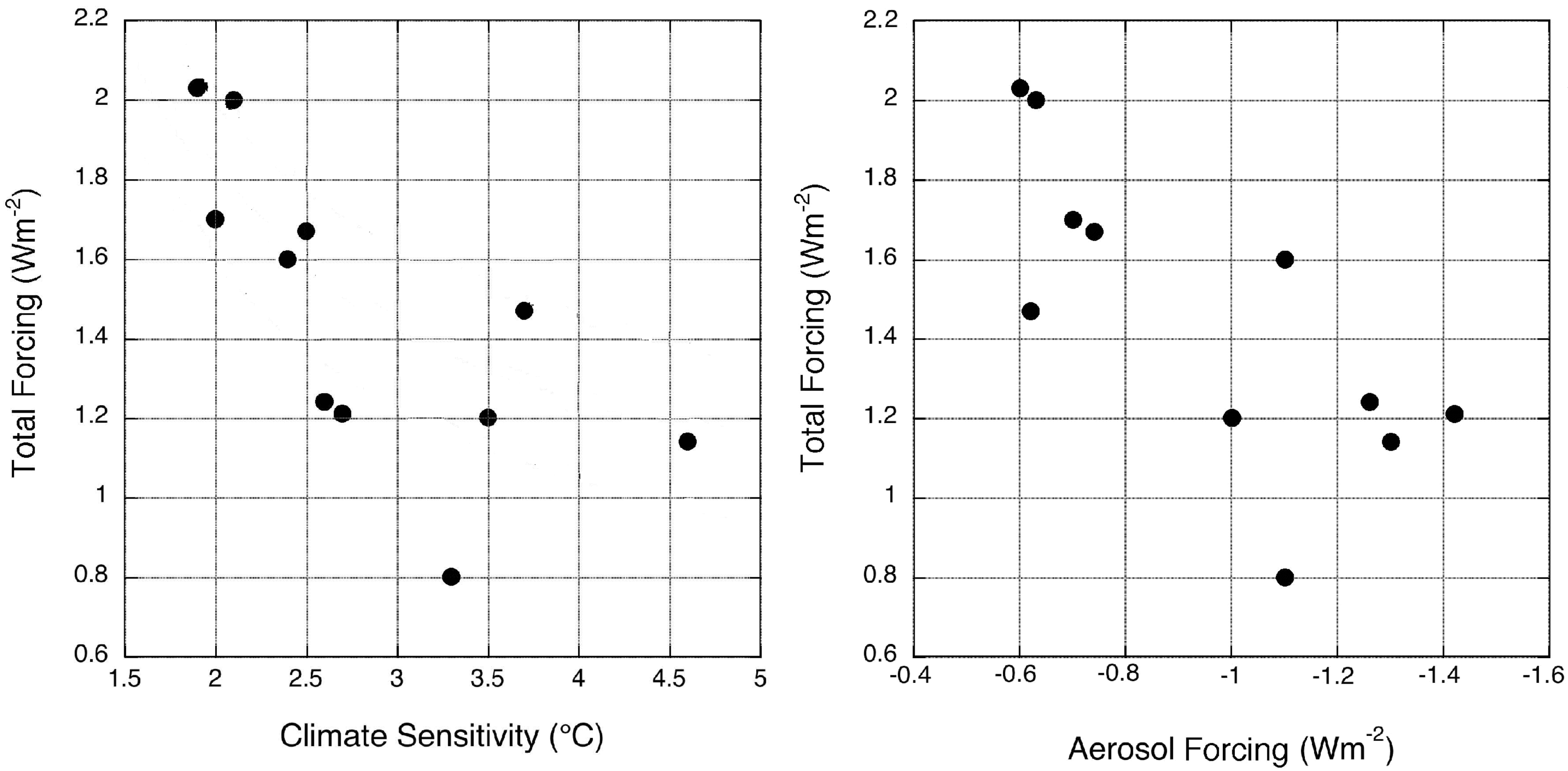


“ Models can … simulate many observed aspects of climate change over the instrumental record. One example is that the ***global temperature trend over the past century … can be modelled with high skill when both human and natural factors that influence climate are included***.

IPCC AR4, 2007

CORRELATION OF AEROSOL FORCING, TOTAL FORCING, AND SENSITIVITY IN CLIMATE MODELS

Eleven models used in 2007 IPCC analysis



Modified from Kiehl, GRL, 2007

Climate models with higher sensitivity have lower total forcing.

Total forcing decreases with increasing (negative) aerosol forcing.

AEROSOLS
THE “MONKEY WRENCH” OF FORCING

THE GRAND CHALLENGE IN ATMOSPHERIC AEROSOL RESEARCH

Develop the scientific understanding and model based estimates of ***aerosol forcing*** to usefully bound uncertainty in ***total forcing*** at present, over the industrial period, and for prospective future emissions.

BERAC RECOMMENDATIONS FOR ASP – 2004

- “ Reconfiguring the ASP to a program emphasizing ***radiative forcing of climate from aerosols*** has great merit in contributing to the CCSP goals and as such should be implemented as soon as practical.
- “ The reconfigured ASP should have as its goal the reduction of uncertainties in two specific gap areas. These are (1) the ***indirect effects of aerosols on clouds*** and (2) the role of ***black carbon and organic carbon aerosols*** on climate forcing.
- “ A well-balanced program consisting of ***field*** measurements, ***laboratory*** experiments, ***theoretical*** analysis with process ***modeling***, and development and application of new ***instrumentation*** will be required.
- “ The reconfigured ASP needs to be ***closely coordinated*** with the ***DOE Atmospheric Radiation Program (ARM)*** program and vice-versa as well as collaboration with other stakeholder programs in order to make most effective use of limited resources.
- “ The reconfigured ASP should look to the ***climate modeling program within DOE*** and the larger Climate Change Science Program (CCSP) as a test bed for ***applying knowledge and parameterizations*** gleaned both from the reconfigured ASP and the ARM programs.

-- *A Reconfigured Atmospheric Science Program*

DOE Biological and Environmental Research Advisory Committee, April 2004

AEROSOL PROCESSES THAT MUST BE UNDERSTOOD AND REPRESENTED IN CLIMATE MODELS

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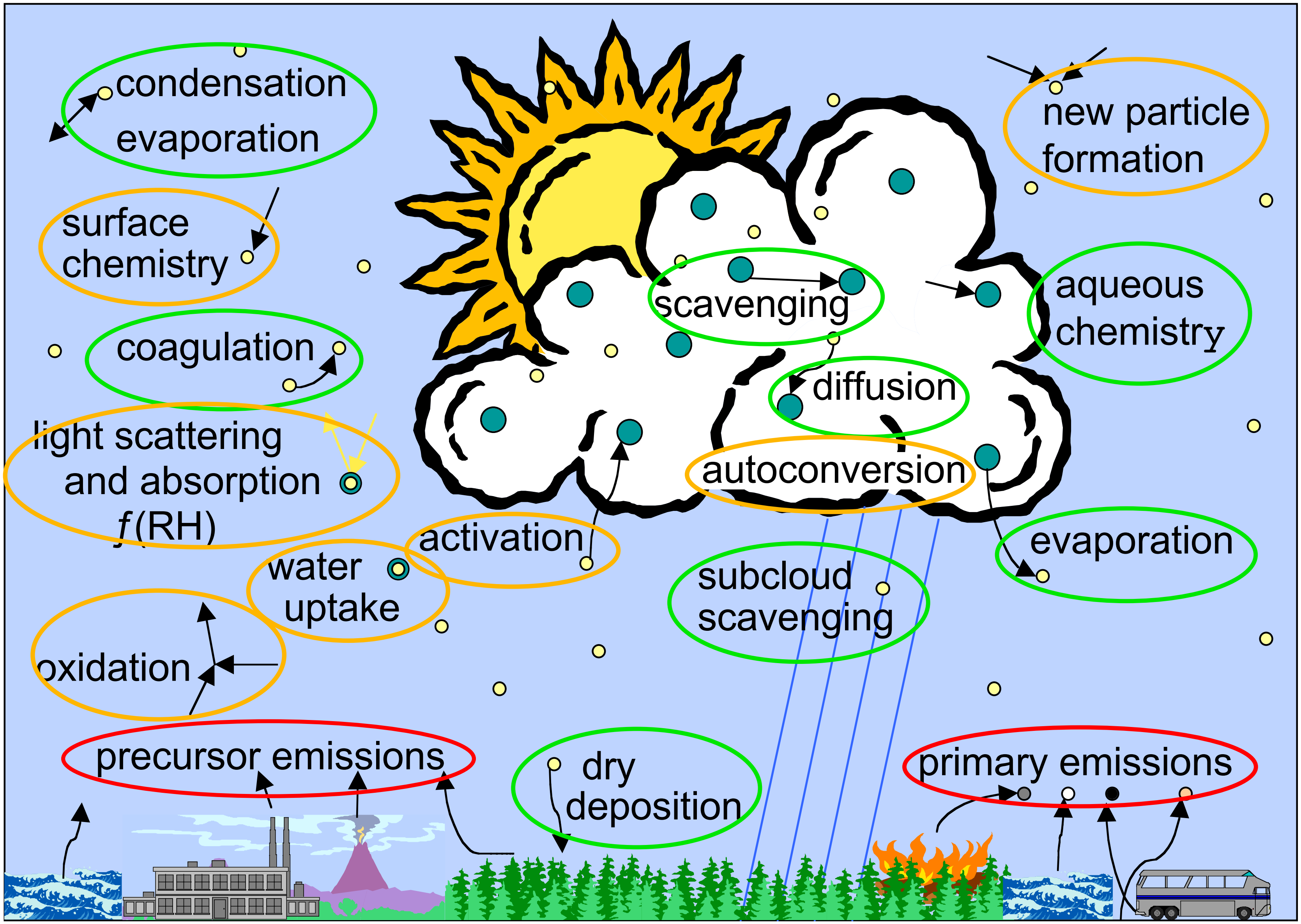
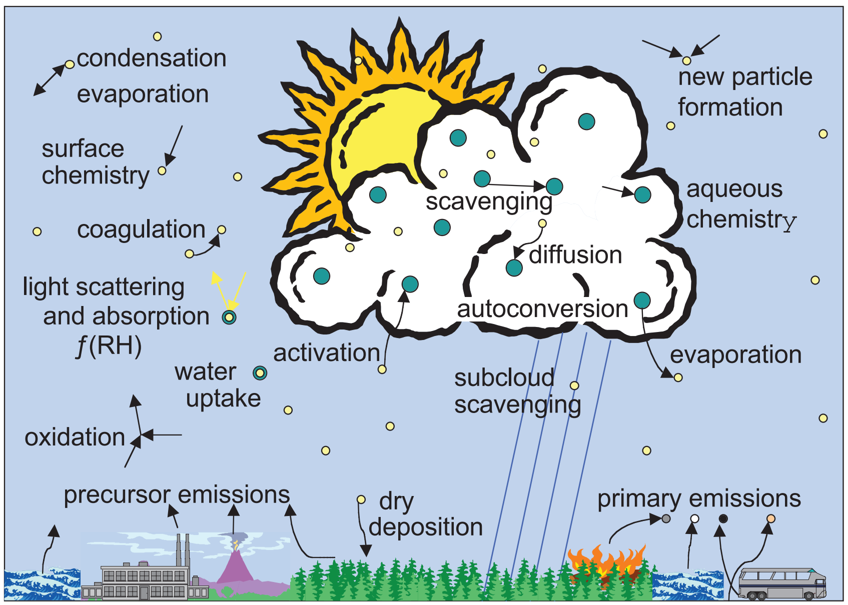


Ghan and Schwartz, Bull. Amer. Meterol. Soc., 2007

APPROACH TO DETERMINE AEROSOL FORCING

Numerical simulation of physical processes



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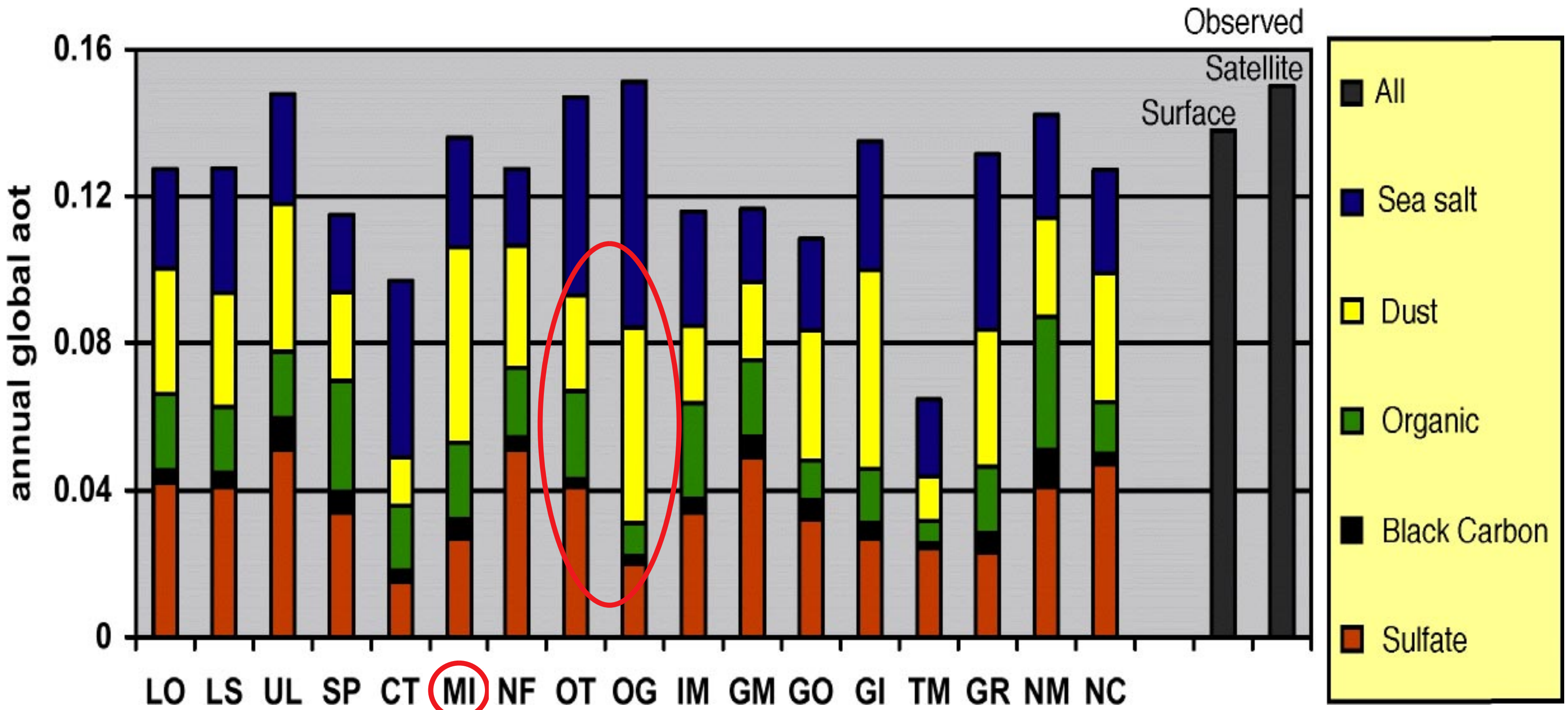
Isomorphism of processes to computer code

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

REPRESENTING AEROSOLS IN GLOBAL CHEMICAL TRANSPORT MODELS

AEROSOL OPTICAL DEPTH IN 17 MODELS (AEROCOM)

Comparison also with surface and satellite observations



Kinne et al., ACP, 2006

Surface measurements: AERONET network.

Satellite measurements: composite from multiple instruments/platforms.

Are the models getting the “right” answer for the wrong reason?

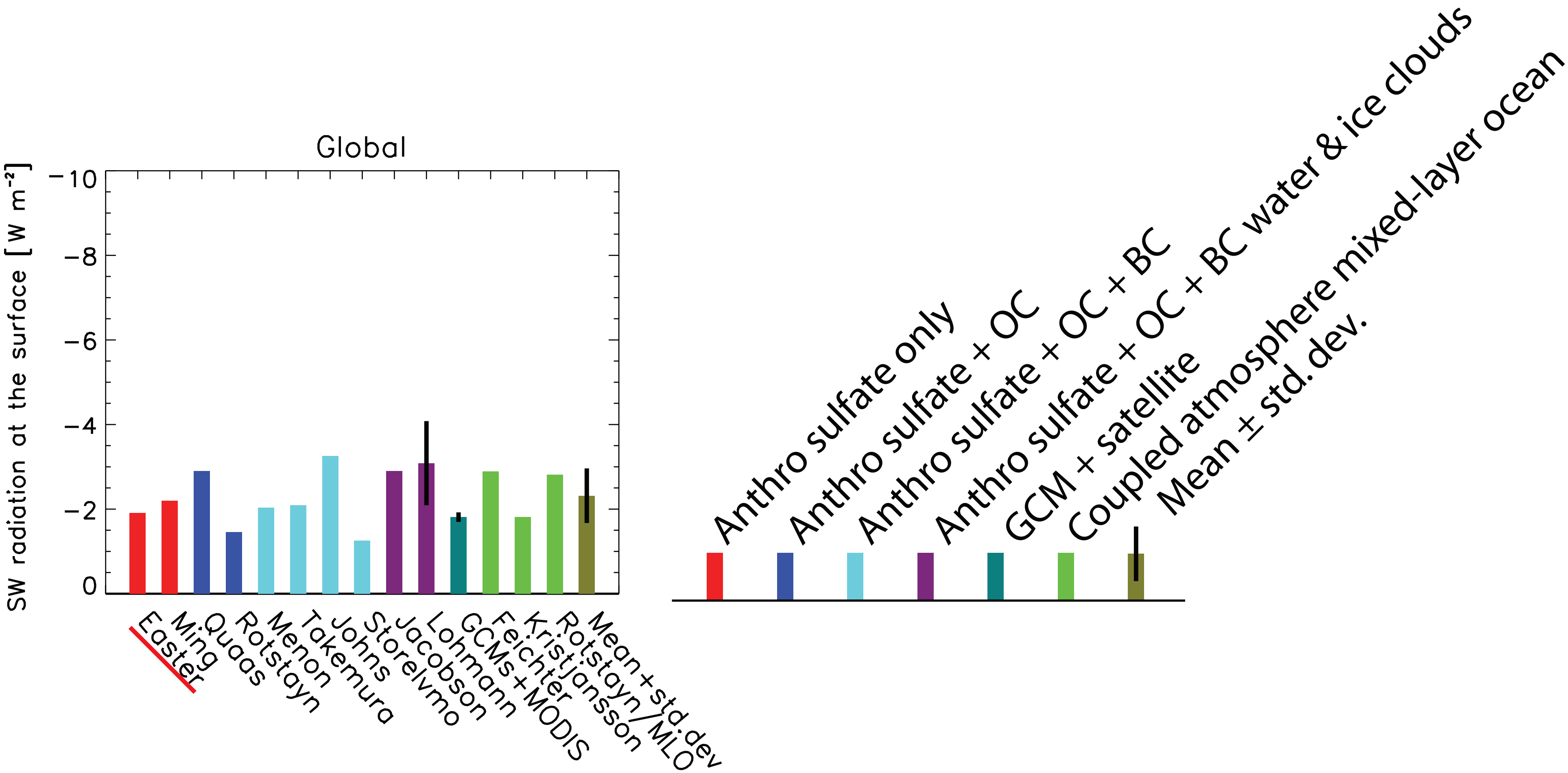
Are the models getting the “right” answer because the answer is known?

Are the satellites getting the “right” answer because the answer is known?

REPRESENTING AEROSOL FORCING IN GLOBAL CLIMATE MODELS

GLOBAL MEAN AEROSOL FORCING

Top of atmosphere forcing by direct, semi-direct, and indirect effects

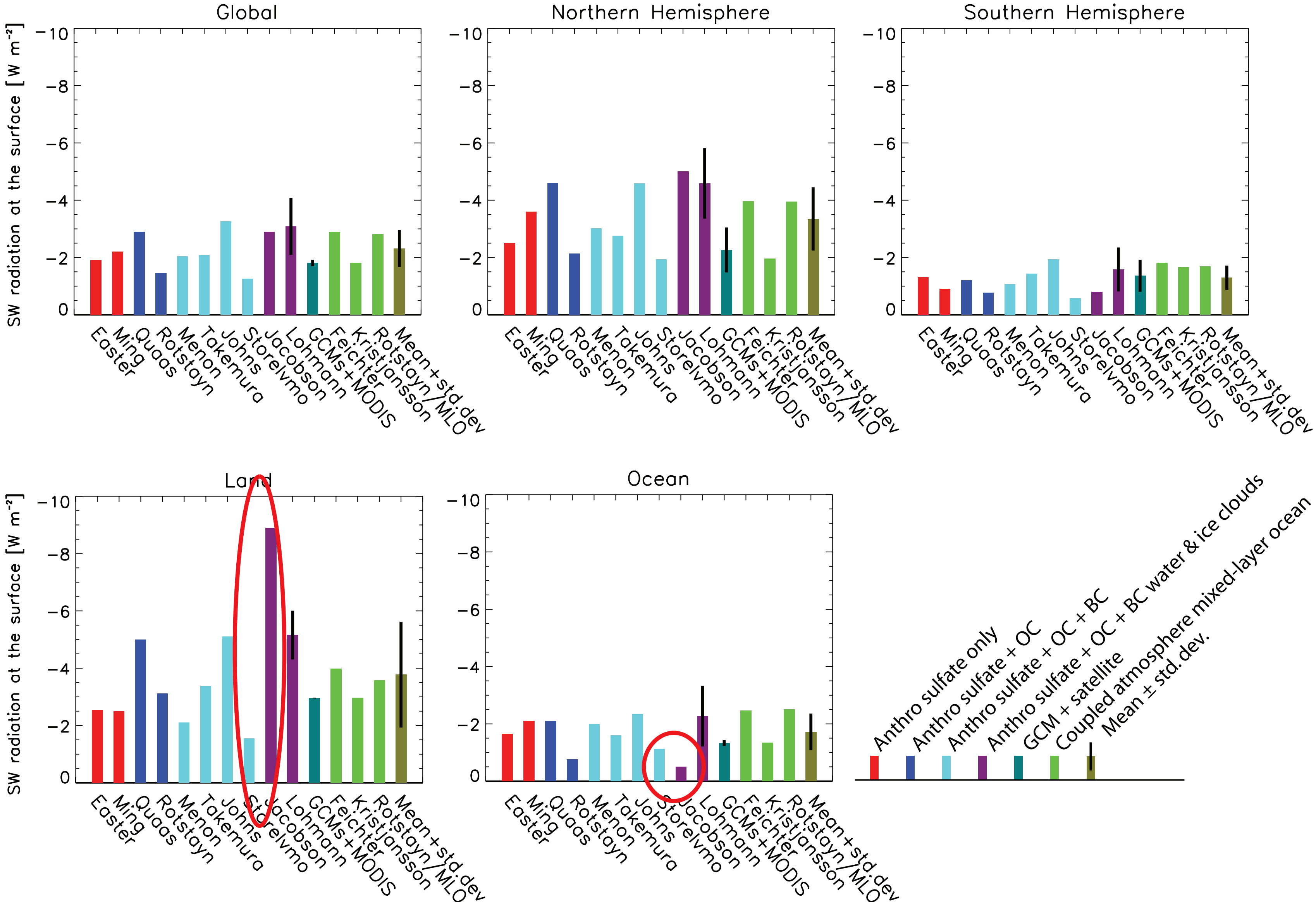


IPCC AR4, 2007

Forcings are comparable despite different aerosol components.

TOP OF ATMOSPHERE AEROSOL FORCING

Forcing by direct, semi-direct, and indirect effects



IPCC AR4, 2007

Global forcings are comparable . . . but many differences in detail.

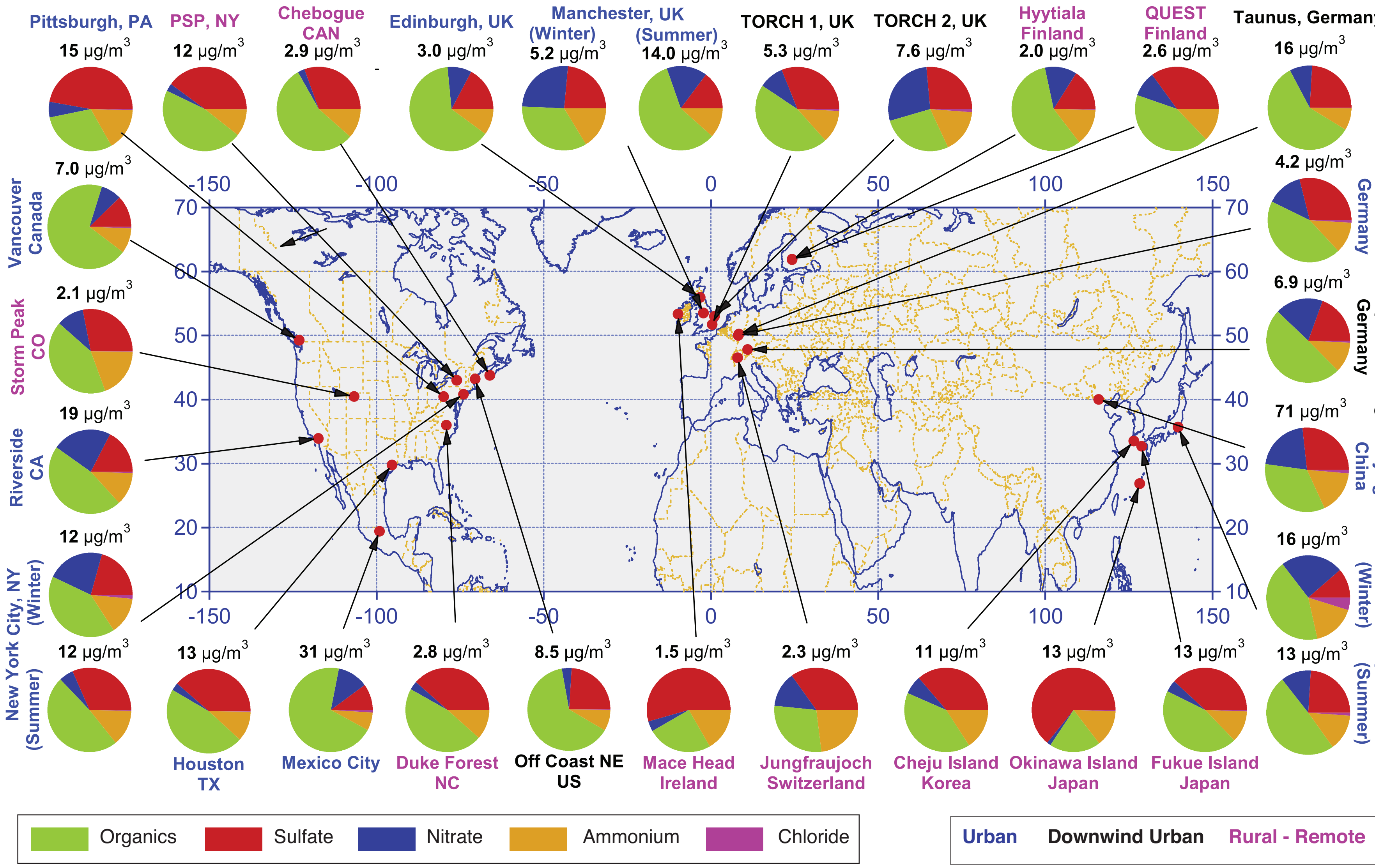
AEROSOL FORCING

WHAT'S NEW?

Organics

DOMINANCE OF ORGANIC AEROSOL

Measurements by aerosol mass spectrometer

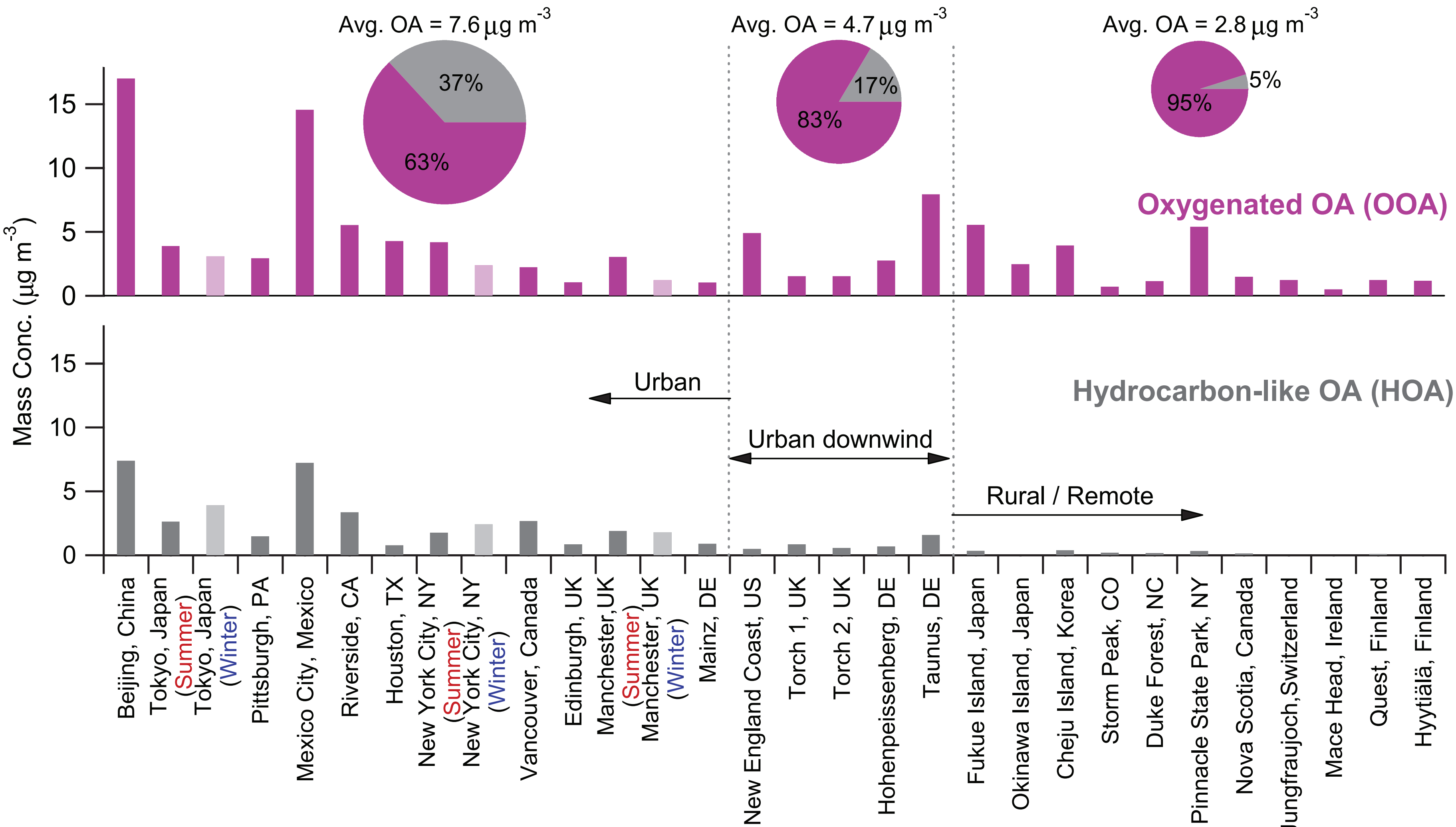


Zhang et al., GRL, 2007

Organic aerosol is major or dominant species throughout the anthropogenically influenced Northern Hemisphere.

PRIMARY AND SECONDARY ORGANIC AEROSOL BY LOCATION TYPE

Area of pie scaled to organic aerosol concentration



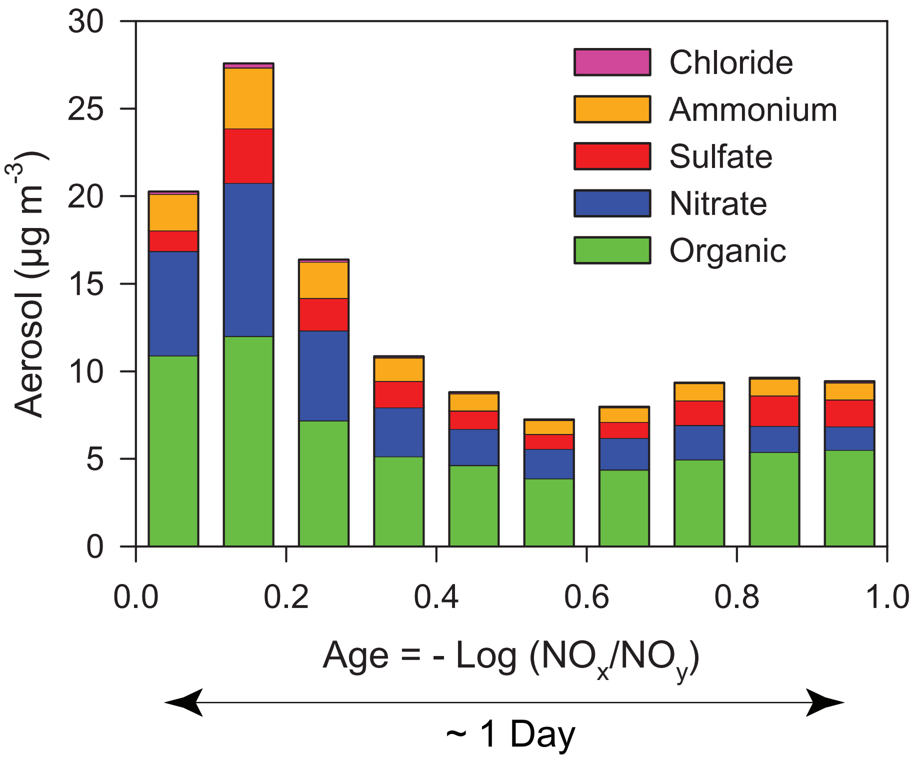
Zhang et al., GRL, 2007

Secondary fraction increases with increasing distance from urban sources.

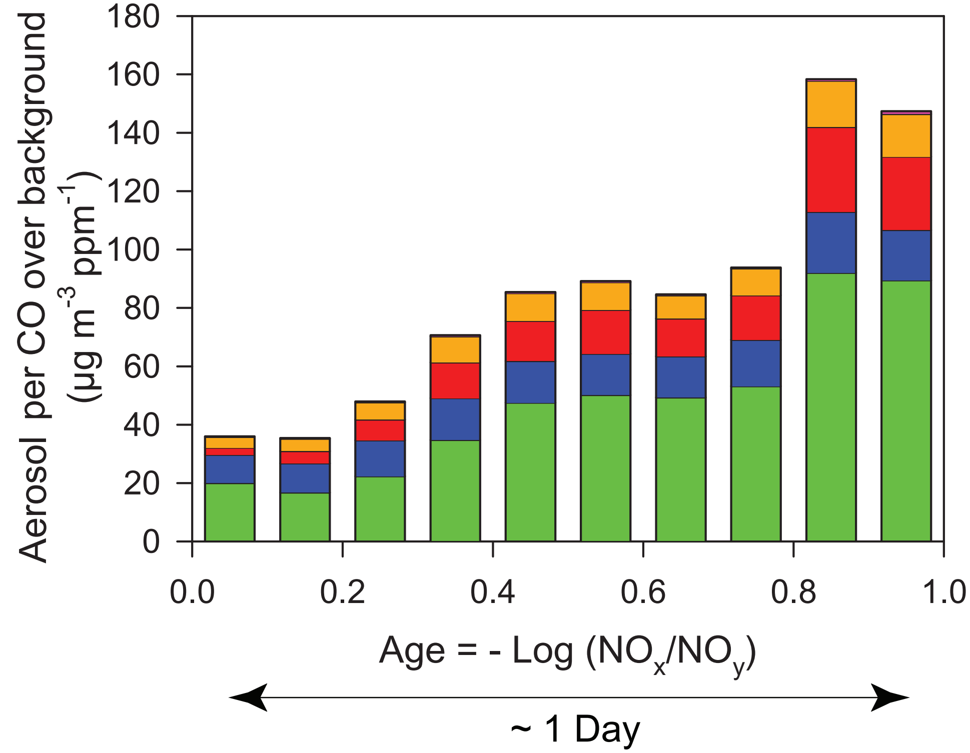
SECONDARY AEROSOL PRODUCTION

Parcel age measured using $-\mathrm{Log}(NO_x/NO_y)$ as clock

Concentration



Normalized concentration



Kleinman et al, ACP, 2008

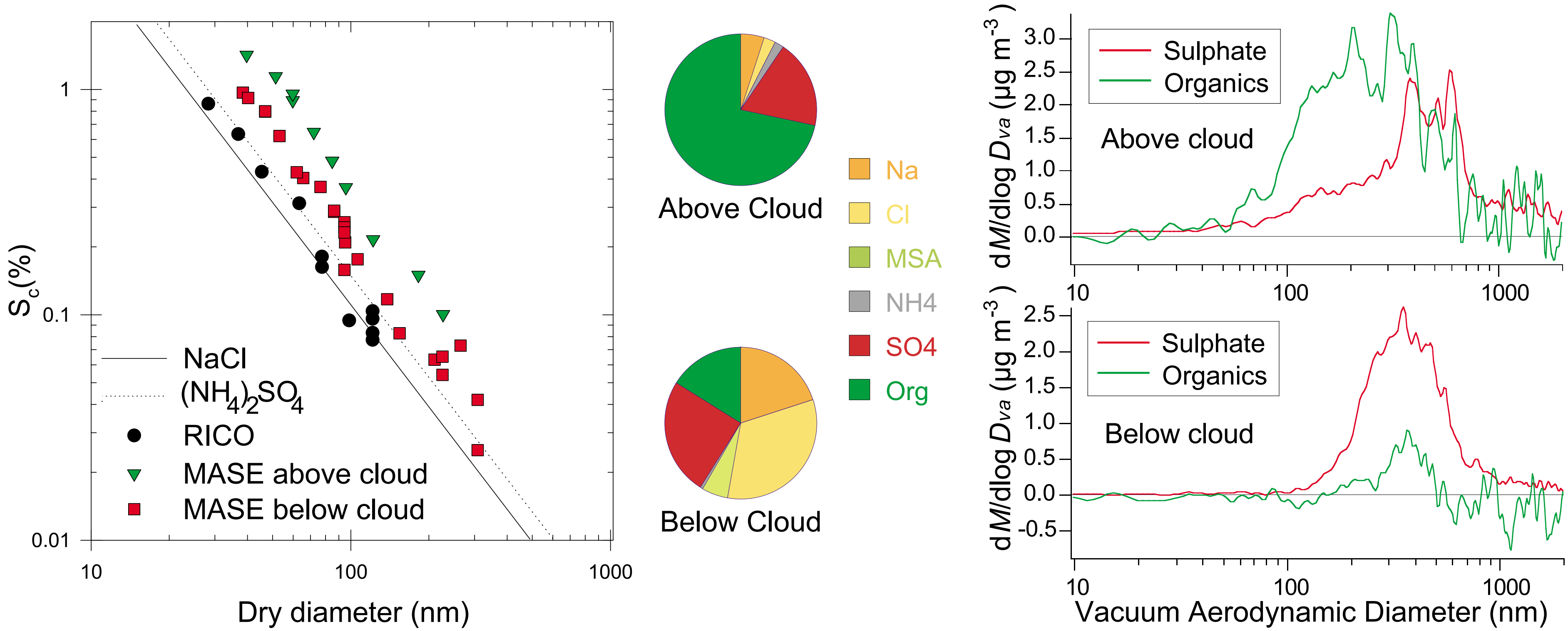
Dilution is accounted for by normalizing aerosol concentration to CO above background.

~5 × increase in organic aerosol.

Measured increase in organic aerosol exceeds modeled based on laboratory experiments and measured volatile organic carbon ***tenfold***.

COMPOSITION MATTERS

Size dependent critical supersaturation of aerosol particles



J. Hudson, Y.-N. Lee, M. Alexander

Measurements below (110-170 m) and above (400-470 m) clouds off the coast of California, north of San Francisco, on July 25, 2005.

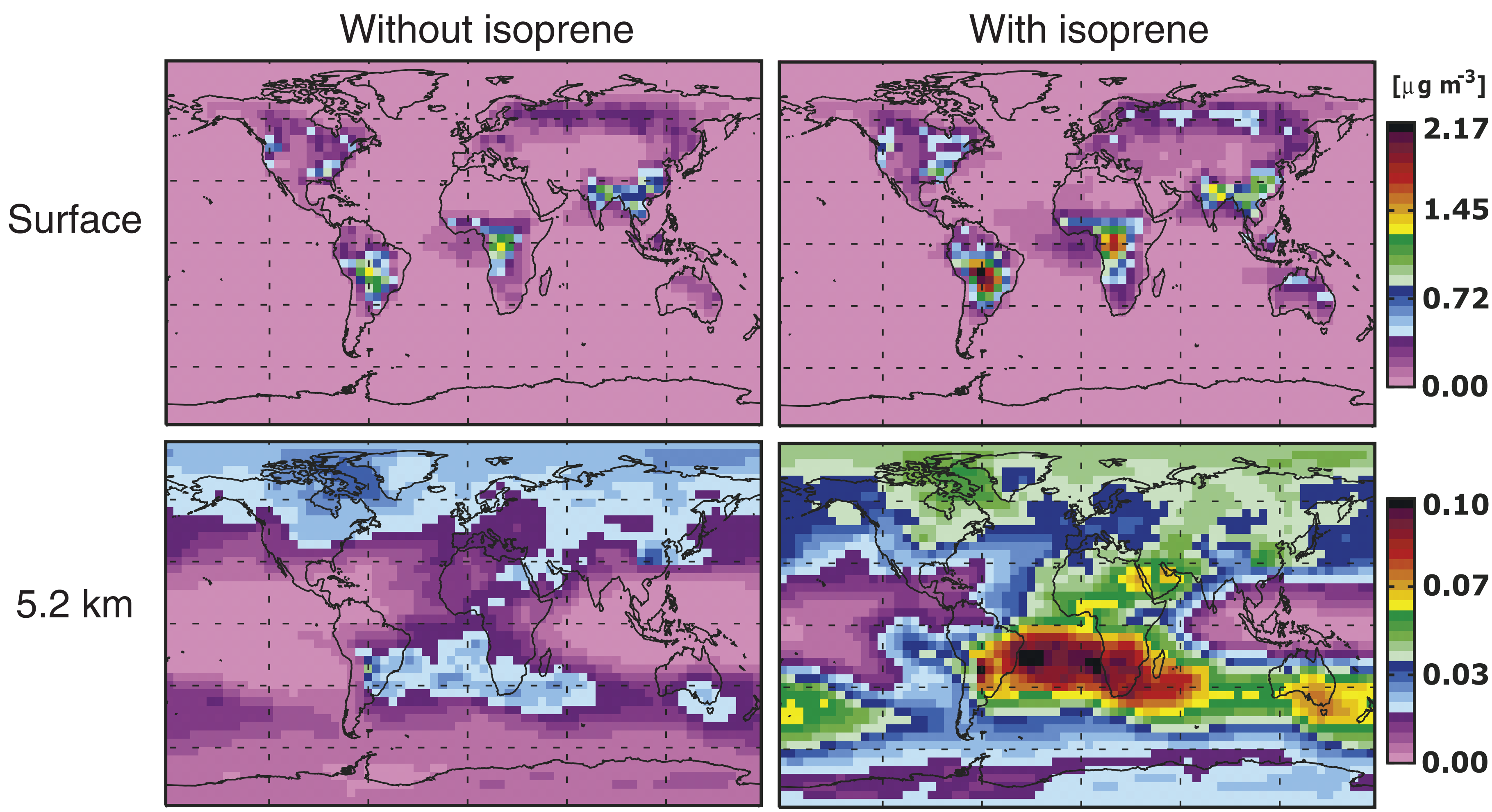
Higher supersaturation is required to activate particles with greater organic fraction.

Bulk composition determined by PILS (particle into liquid sampler).

Size-dependent composition determined by aerosol mass spectrometer.

ISOPRENE ENHANCEMENT TO SECONDARY ORGANIC AEROSOL

Modeled SOA without and with isoprene at surface and 5.2 km



Henze and Seinfeld, GRL, 2006

Isoprene increases global SOA by more than a factor of 2.

Relative enhancement is much greater in free troposphere (note different scales).

AEROSOL FORCING

ESSENTIAL RESEARCH

ESSENTIAL RESEARCH

Emissions measurements and databasing

Chemically speciated size distributed primary particle emissions.

Precursor gas emissions (natural and anthropogenic).

Activity based anthropogenic emissions – emission factors.

- At specific times and locations of field projects.
- Globally as input to chemical transport models.
- Temporal dependence: seasonal, time of day.

Databasing of present-day emissions suitable for modeling.

Development of historical emissions database.

Development of emissions for projected future activities.

DOE cannot do this alone. Must partner. But the activity is essential!

ESSENTIAL RESEARCH
(*cont'd*)

Field measurements

Supersites continuously characterizing aerosol composition and properties.

Closure experiments relating optical and cloud nucleating properties to size dependent composition.

Globally representative data base: evaluation of chemical transport models.

Surface based and satellite remote sensing (vertical profiling).

Mobile platforms: *e.g.*, containers on commercial ships, aircraft.

Intensive field projects – surface and airborne: evolution of aerosol properties; globally and seasonally representative.

Clear-air and cloud-aerosol interactions; water and ice clouds.

DOE cannot do this alone. Must partner. But the activity is essential!

ESSENTIAL RESEARCH
(*cont'd*)

Lab and theory

Quantify key reactions and processes in isolation.

Determine dependence on species concentrations and other controlling variables.

Reactions to be studied are informed by field measurements.

New particle formation rates; dependence on precursor concentrations.

Relate optical properties to composition, morphology; humidity dependence, effects of coatings, etc.

See to incorporation of findings into models.

DOE cannot do this alone. Must partner. But the activity is essential!

ESSENTIAL RESEARCH
(*cont'd*)

Modeling

Develop and test process models.

Local high-resolution models at time of field intensives.

Regional- to global-scale models, driven by analyzed observed meteorological fields.

Continuously evaluate by comparison to measurements.

Develop and test models suitable for global climate models.

Join with climate modelers to make sure this works.

Systematic and continual assessment of forcings and uncertainties.

DOE cannot do this alone. Must partner. But the activity is essential!

SUMMARY

Aerosol forcing is substantial in the context of greenhouse gas forcing.

Uncertainty in aerosol forcing is substantial in this context.

This uncertainty greatly ***limits ability to evaluate performance of climate models*** over the twentieth century.

This uncertainty ***limits informed decision making on energy policy***.

A path forward exists to quantify aerosol forcing much better than at present.

Quantifying aerosol forcing would require substantial effort by DOE and national and international partners.

Failure to reduce uncertainty in aerosol forcing would result in ***continued large uncertainty in Earth's climate sensitivity and projections of future climate change***.

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