AEROSOL DIRECT FORCING

OBSERVATIONAL PERSPECTIVE

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WORKSHOP ON
MONITORING GLOBAL AEROSOL FORCING OF CLIMATE:
EVALUATING REQUIREMENTS FOR SATELLITE MONITORING, GROUND-BASED MONITORING, IN-SITU MEASUREMENTS AND GLOBAL MODELING

GFDL-NOAA
PRINCETON NJ

SEPTEMBER 13-14, 2000

WORKSHOP OBJECTIVES

(From Charge to Workshop)

Define what is needed to evaluate the anthropogenic aerosol climate forcing, its uncertainty, and its temporal change on decadal time scales.

- ***Define a strategy for obtaining the time-dependent aerosol climate forcing from a combination of satellite monitoring, ground-based monitoring, in-situ measurements, and global modeling.***

- *Evaluate the contribution that the NPOESS program could make to determination of the aerosol climate forcing.*

REQUIREMENTS

What is needed in order to succeed?

Represent aerosol forcing in climate models with known and reasonable uncertainty.

- *Provide a secular representation of aerosol forcing over the industrial period.*
- *Quantitatively attribute aerosol forcing to aerosol type (natural, anthropogenic; by source category).*
- *Provide the capability of representing aerosol forcing in climate models for a range of assumed future scenarios.*

These requirements can be met only with evaluated aerosol models.

(*Models are the only means to describe aerosol forcing for past time and for future scenarios.*)

MODEL EVALUATION REQUIREMENTS

4-D distribution of aerosol loading properties and properties that may be compared with observation for highly diverse conditions of aerosol properties.

- *Model must be driven by observationally-derived meteorological fields.*
- *Model requires realistic source strengths of aerosols and aerosol precursors.*

4-D observational data set suitable for model evaluation.

OBSERVATIONAL REQUIREMENTS

Provide the understanding *necessary to represent aerosol forcing in climate models.*

Provide an ***observational basis for present aerosol direct forcing****.*

Provide an observational data base to permit ***evaluation of models****:*

- *Loading (mass concentration, column burden)*
- *Composition (as a function of size; homogeneity vs. heterogeneity)*
- *Physical properties (size distribution and its RH-dependence, non-sphericity...)*
- *Optical properties (extinction coefficient, single scattering albedo, phase function or asymmetry parameter...) including wavelength dependence*
- *Vertical and geographical distribution of all the above*

Not at all places and times, but at sufficient, and sufficiently diverse, locations and times as to provide required confidence in models.

AEROSOL DIRECT SHORTWAVE FORCING

Global Average for ***Nonabsorbing*** Aerosol

$$\Delta F = -\frac{1}{2} F_0 T^2 (1 - A_c)(1 - R)^2 \bar{\beta}\tau \qquad \tau = \int \alpha C dz = \int \sigma_{ep} dz$$

Light Extinction Coefficient
Mass Concentration
Mass Extinction Efficiency
Aerosol Optical Depth
Mean Upscatter Fraction
Surface Reflectance
Cloud Fraction
Atmospheric Transmittance
Solar Constant
Change in Net TOA Flux

Global Average for ***Absorbing*** Aerosol

$$\Delta F = -\frac{1}{2} F_0 T^2 (1 - A_c)(1 - R)^2 \bar{\beta}\tau\omega \left\{ 1 - \frac{2R}{(1-R)^2} \frac{(1-\omega)}{\bar{\beta}\omega} \right\}$$

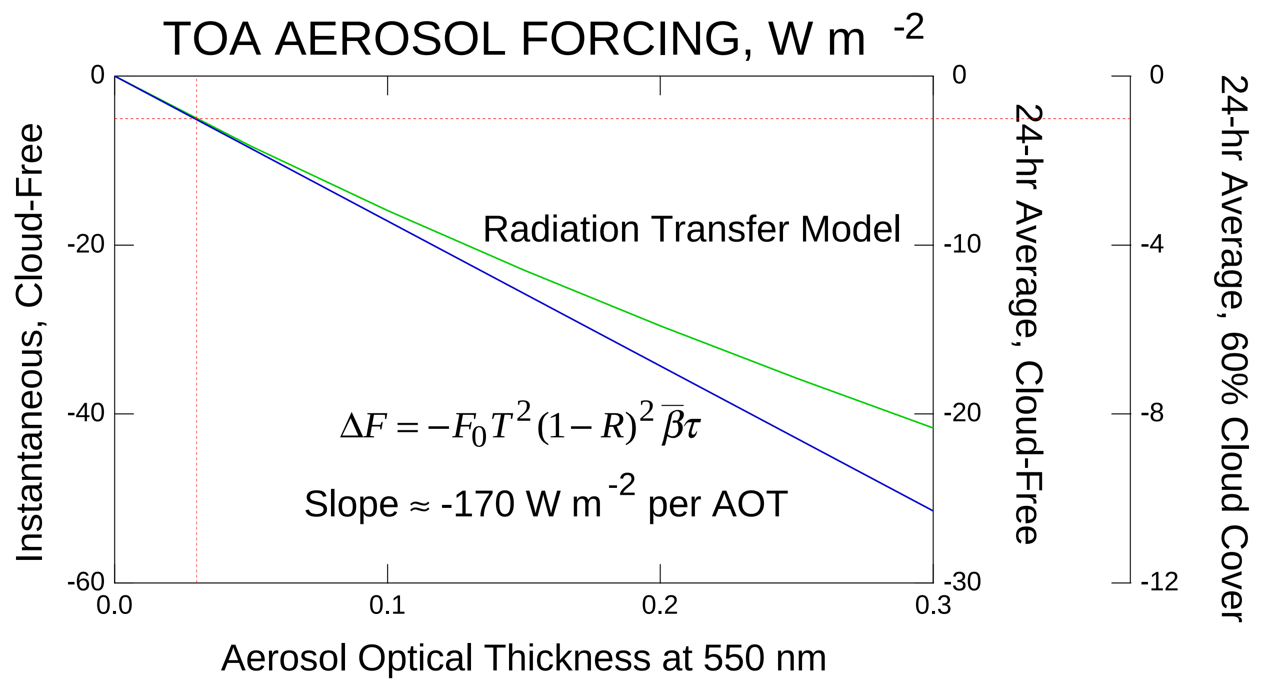
Single Scattering Albedo

DIRECT AEROSOL FORCING AT TOP OF ATMOSPHERE

Dependence on Aerosol Optical Thickness

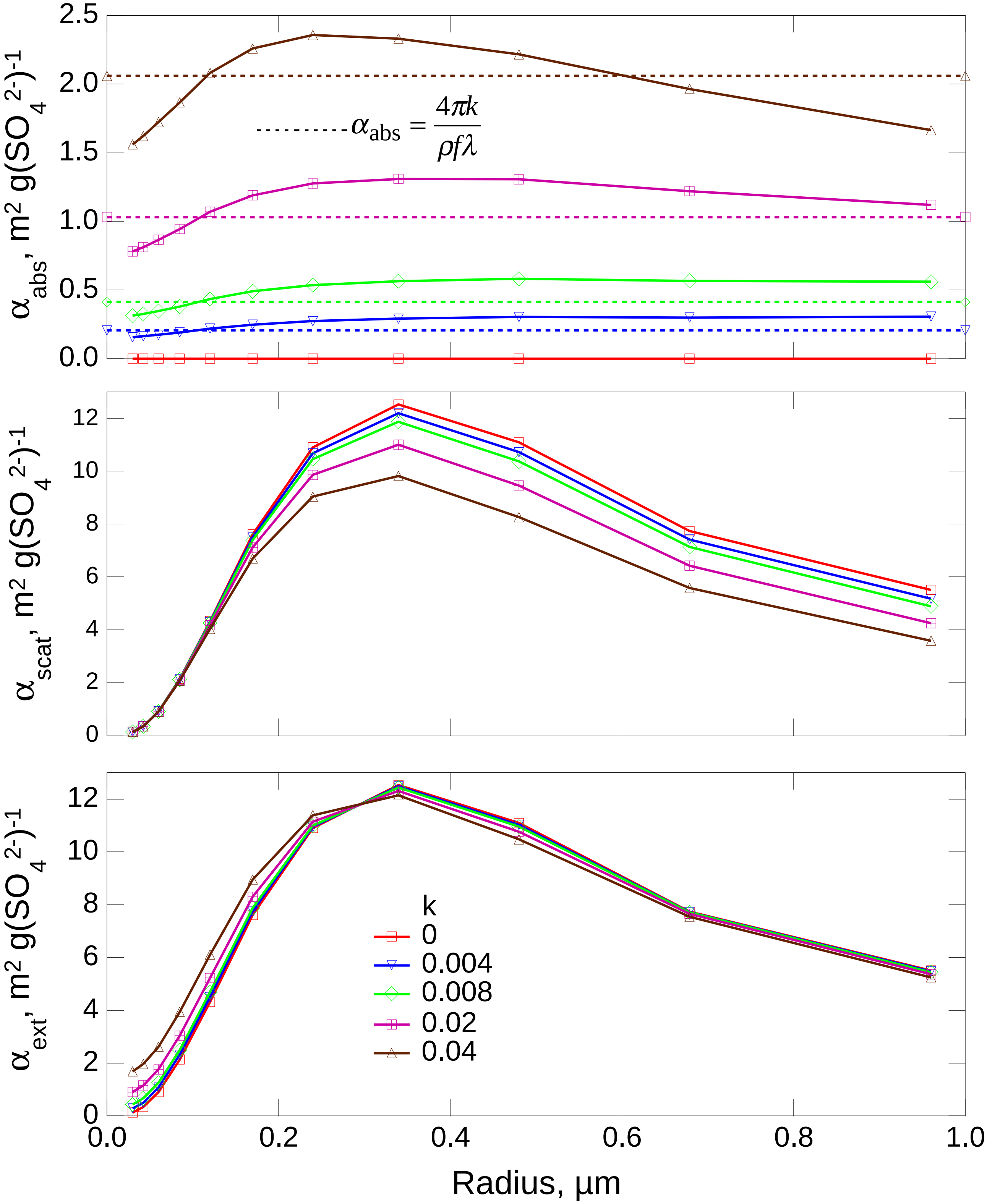
Comparison of Linear Formula and Radiation Transfer Model

Particle Radius r = 85 nm. Surface Reflectance R = 0.15

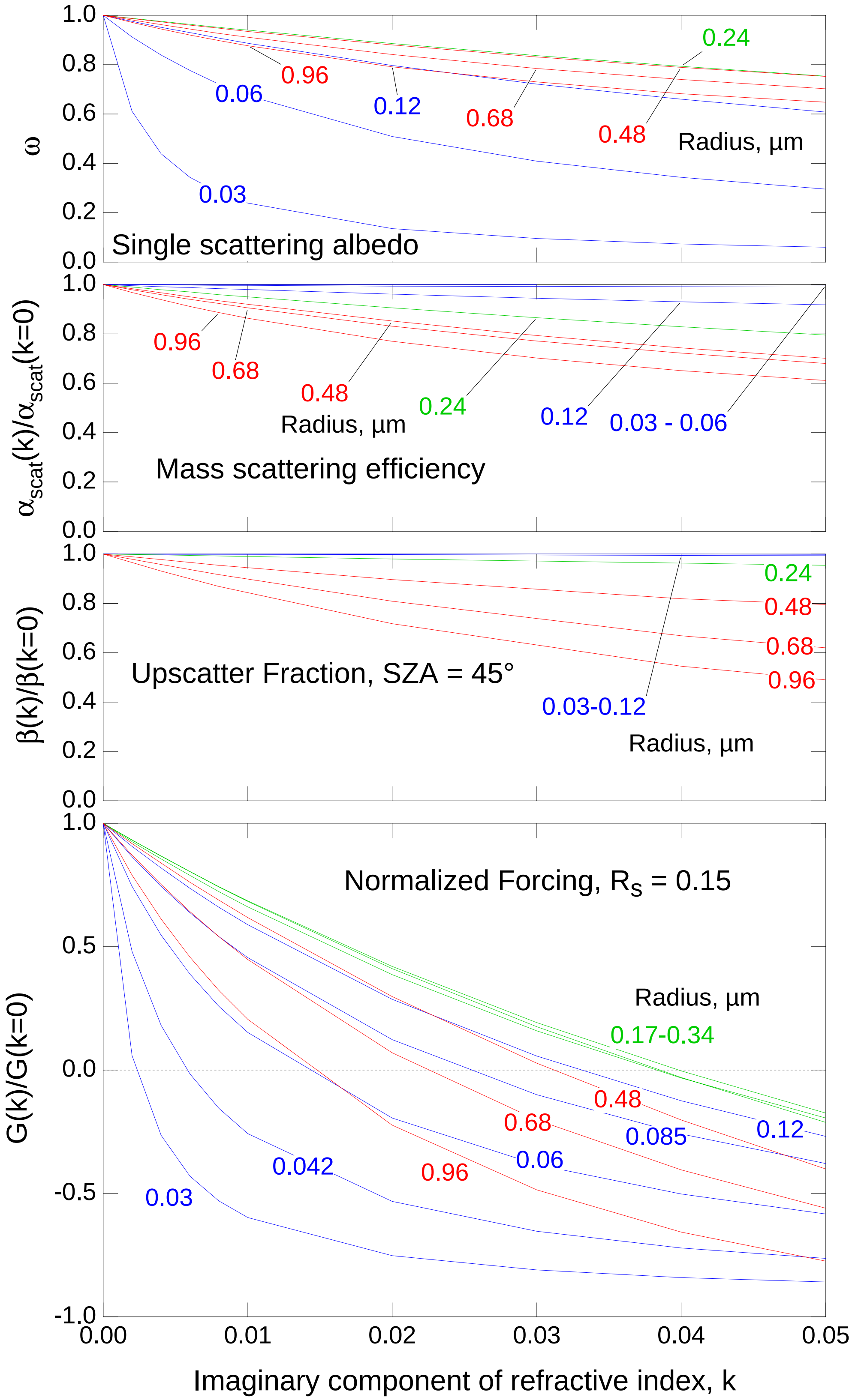


Global-average AOT 0.03 corresponds to global-average forcing -1 W m^{-2}.

INFLUENCE OF ABSORPTION ON AEROSOL OPTICAL PROPERTIES

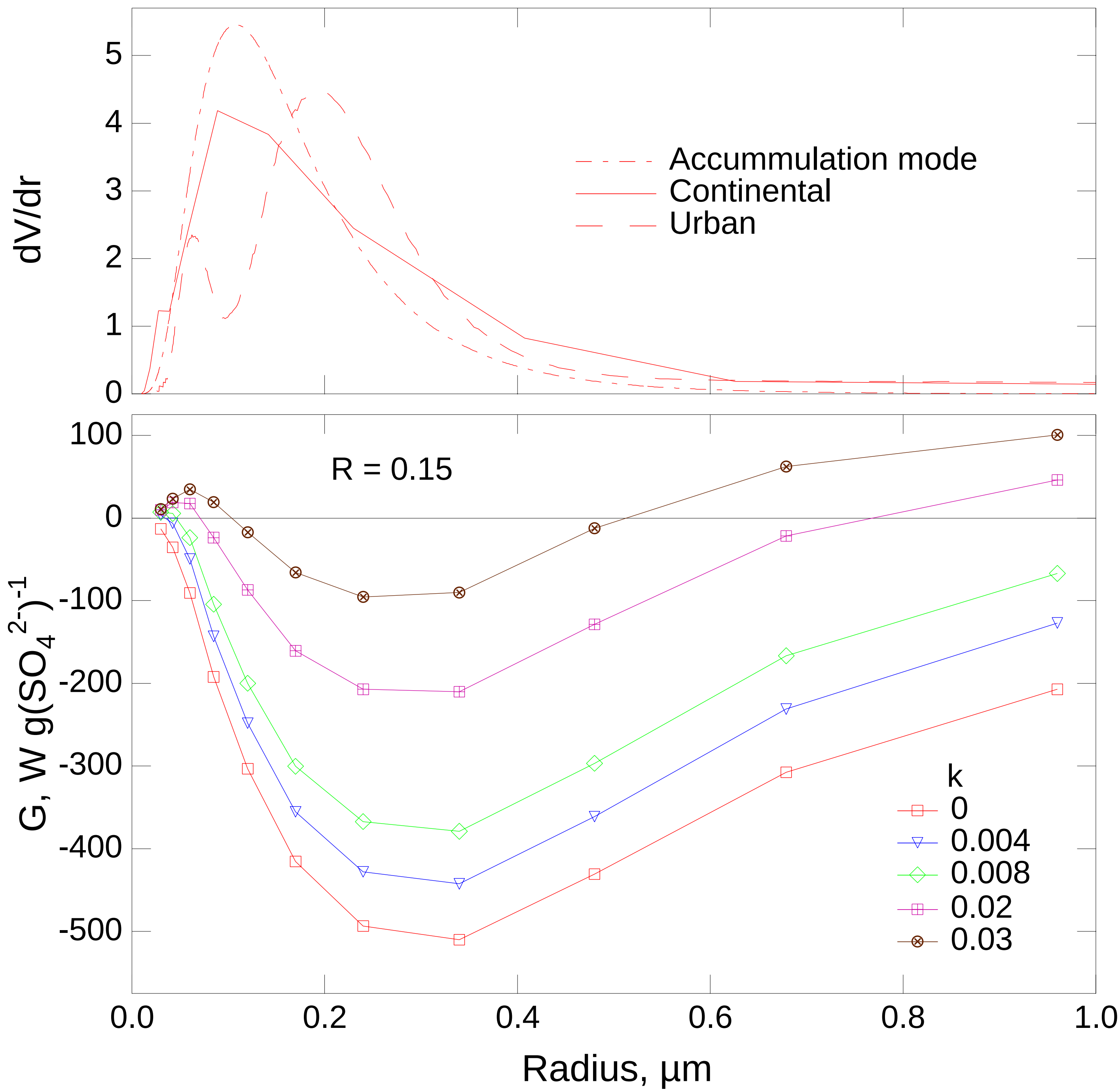


FRACTIONAL INFLUENCE OF ABSORPTION ON AEROSOL OPTICAL PROPERTIES AND NORMALIZED FORCING



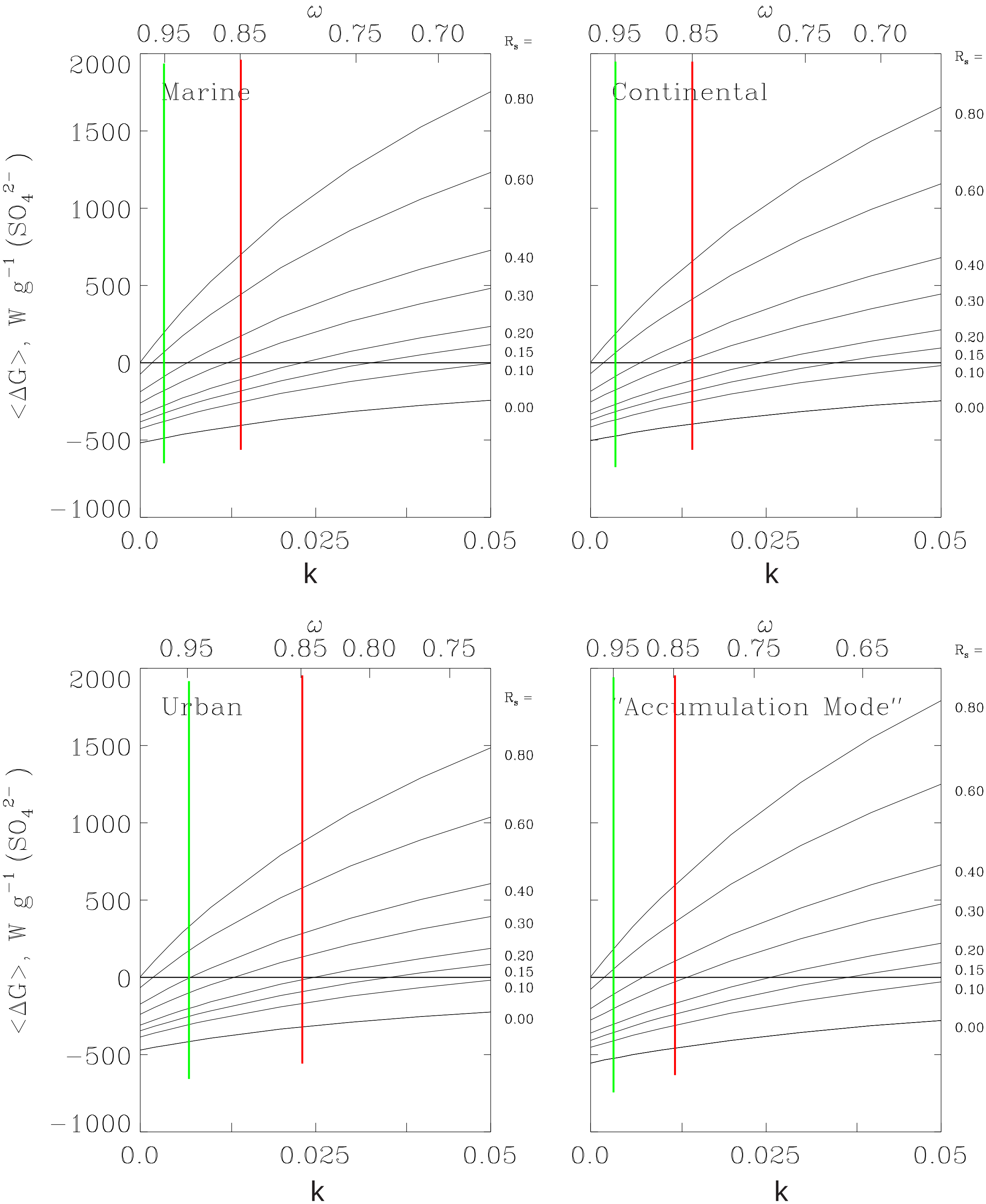
GLOBAL AVERAGE NORMALIZED FORCING

Radius dependence compared to typical aerosol volume distributions



GLOBAL AVERAGE NORMALIZED FORCING

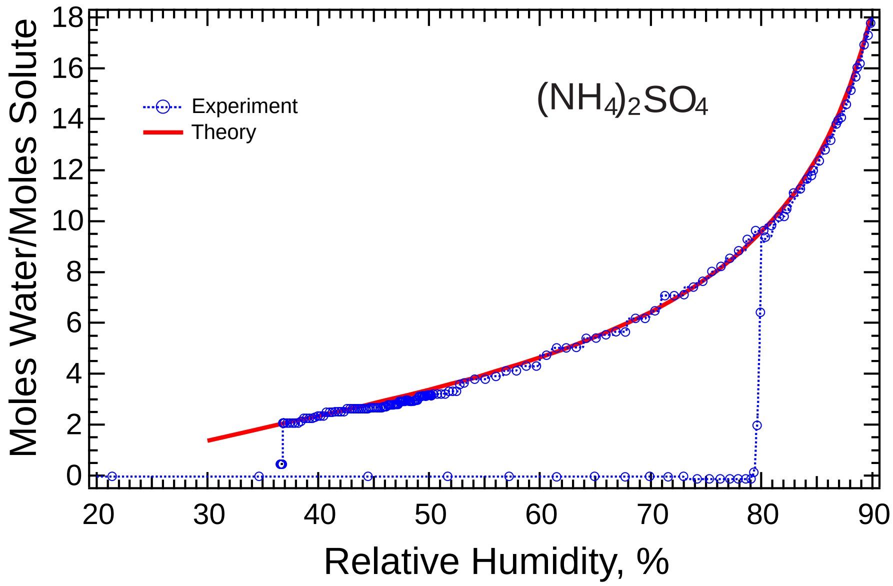
Dependence on absorption and surface reflectance for typical aerosol distributions



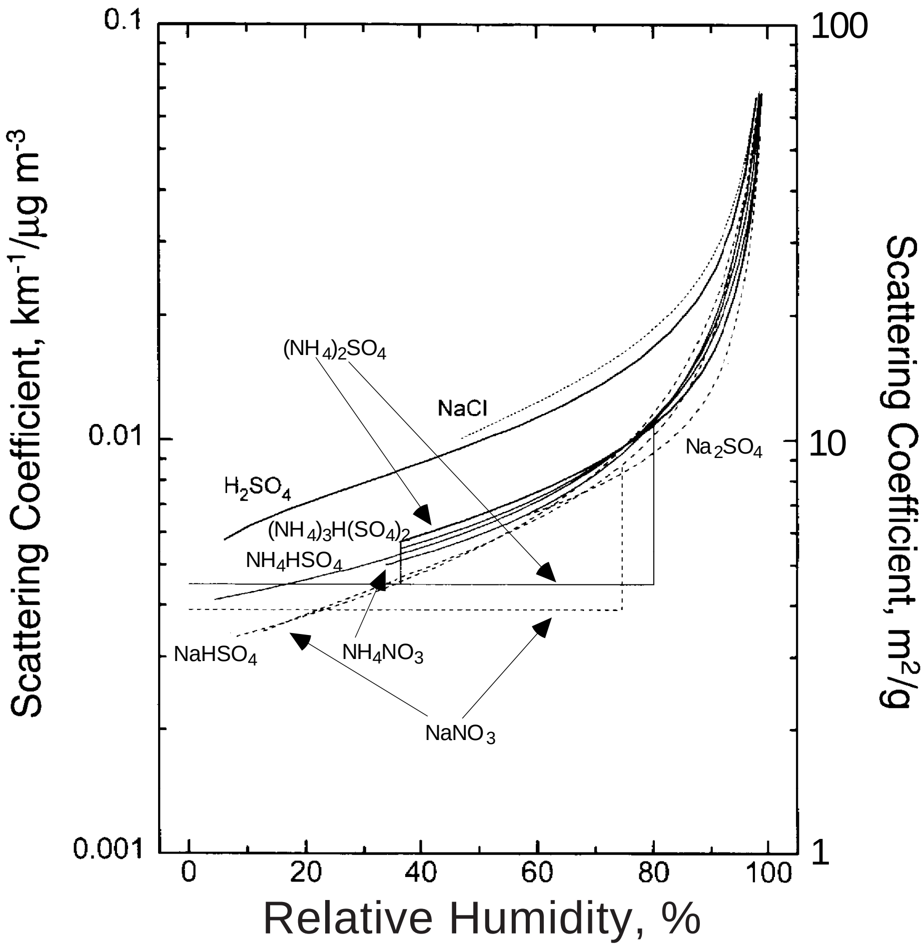
Compare to single scattering albedo w at SGP 0.92 ± 0.06 (one s.d.; 10,000 2-hour averages of 1-minute data).

WATER UPTAKE AND LIGHT SCATTERING COEFFICIENT

Dependence on Relative Humidity



D. Imre, T. Onasch, BNL



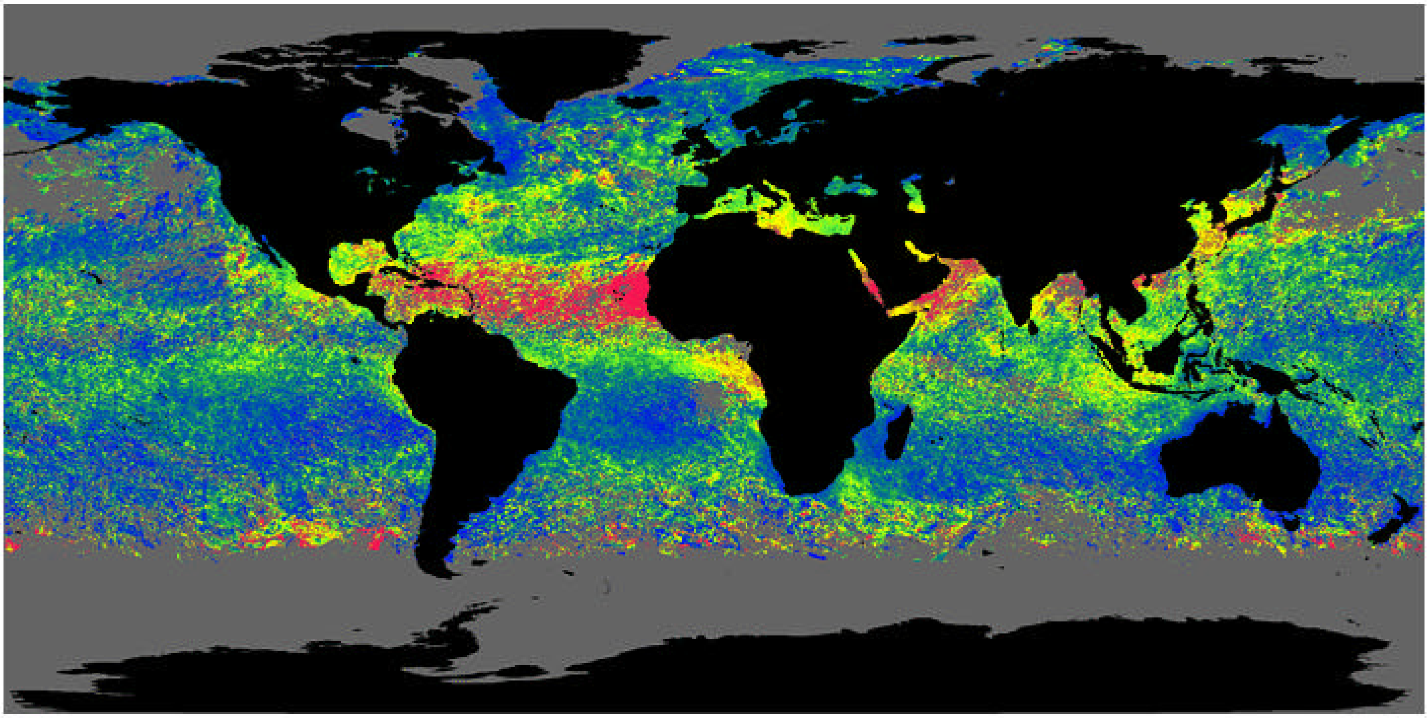
Lognormal, D_g = 0.3 µm; σ_g = 1.5; Tang, JGR, 1996

MEASUREMENT STRATEGIES

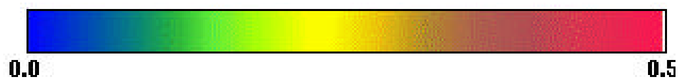
Approach	*LongTerm vs. Campaign*	*Global vs. Local*	*Aggregate vs. Detailed*
Satellite remote sensing	LT	G	A
Ground-based remote sensing	LT	L -> G	A
Ground-based in-situ composition, physical, optical properties	C -> LT	L	D
Aircraft remote sensing	C	L	A
Aircraft in-situ composition, physical, optical properties	C	L	D

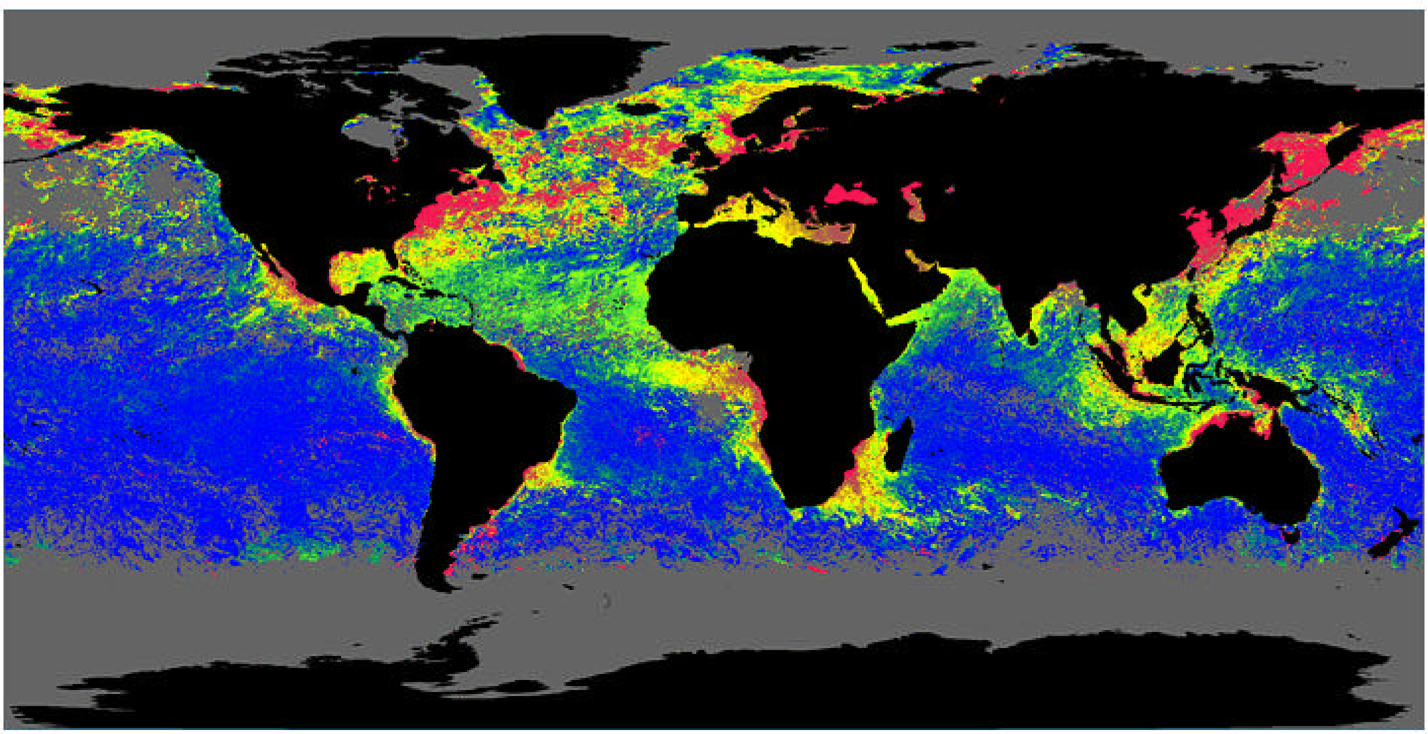
Local measurements can be extended to quasi-global by network of measurements.
Campaign measurements can be extended to LongTerm.

MONTHLY AVERAGE AEROSOL JUNE 1997



Optical Thickness at 865 nm



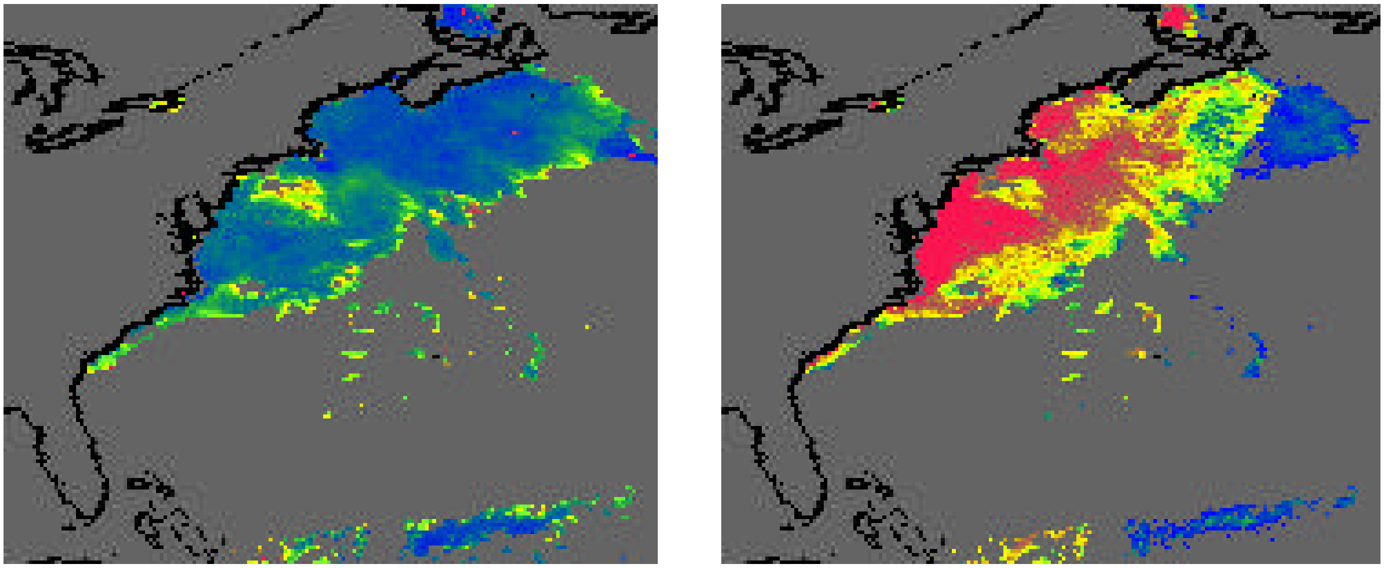


Ångström Exponent

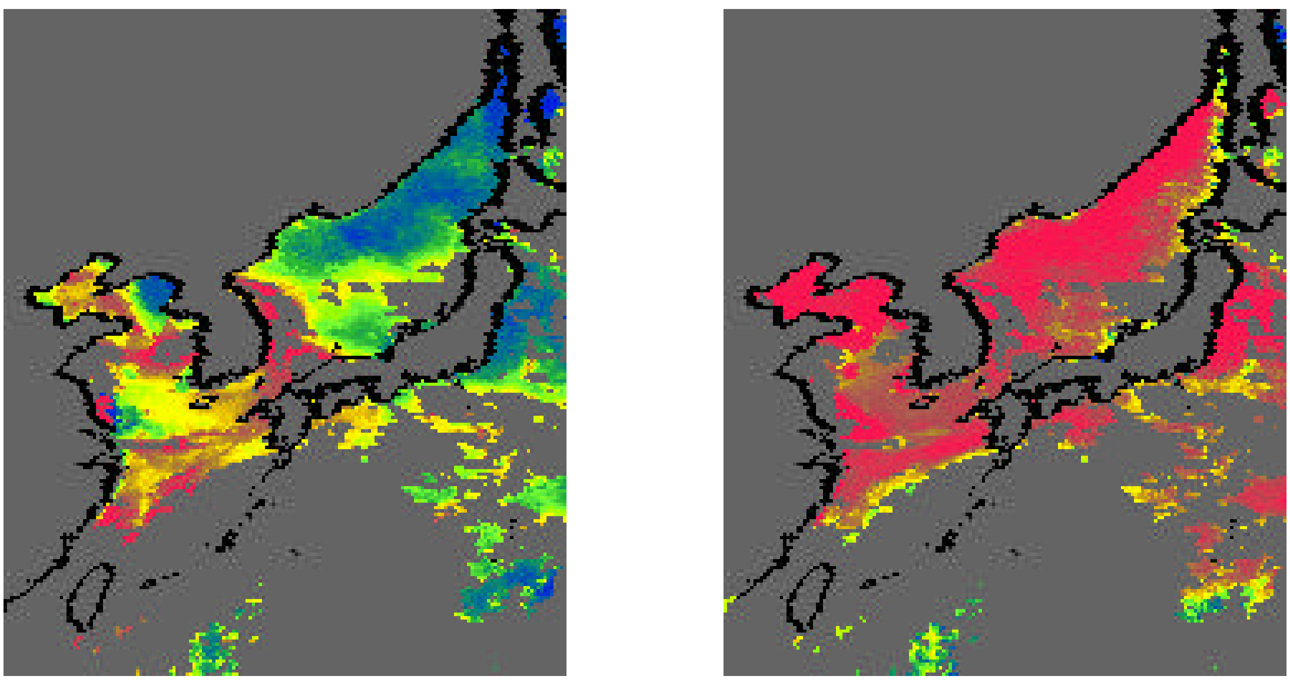
Polder/Adeos CNES/NASDA LOA/LSCE

INSTANTANEOUS AEROSOL

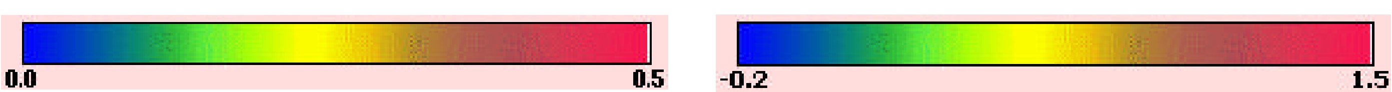
Optical Thickness at 865 nm | Ångström Exponent



April 16, 1997

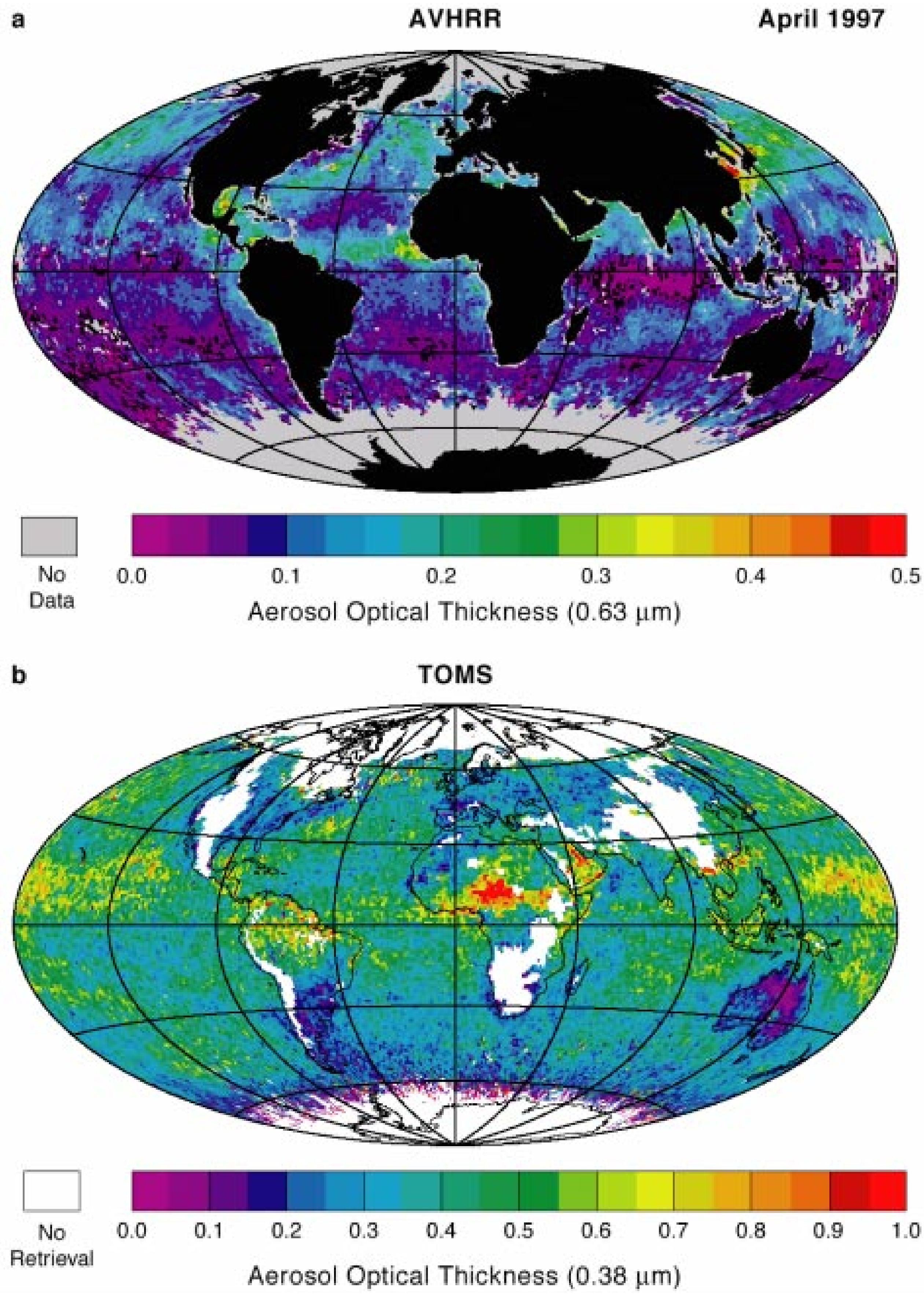


March 25, 1997



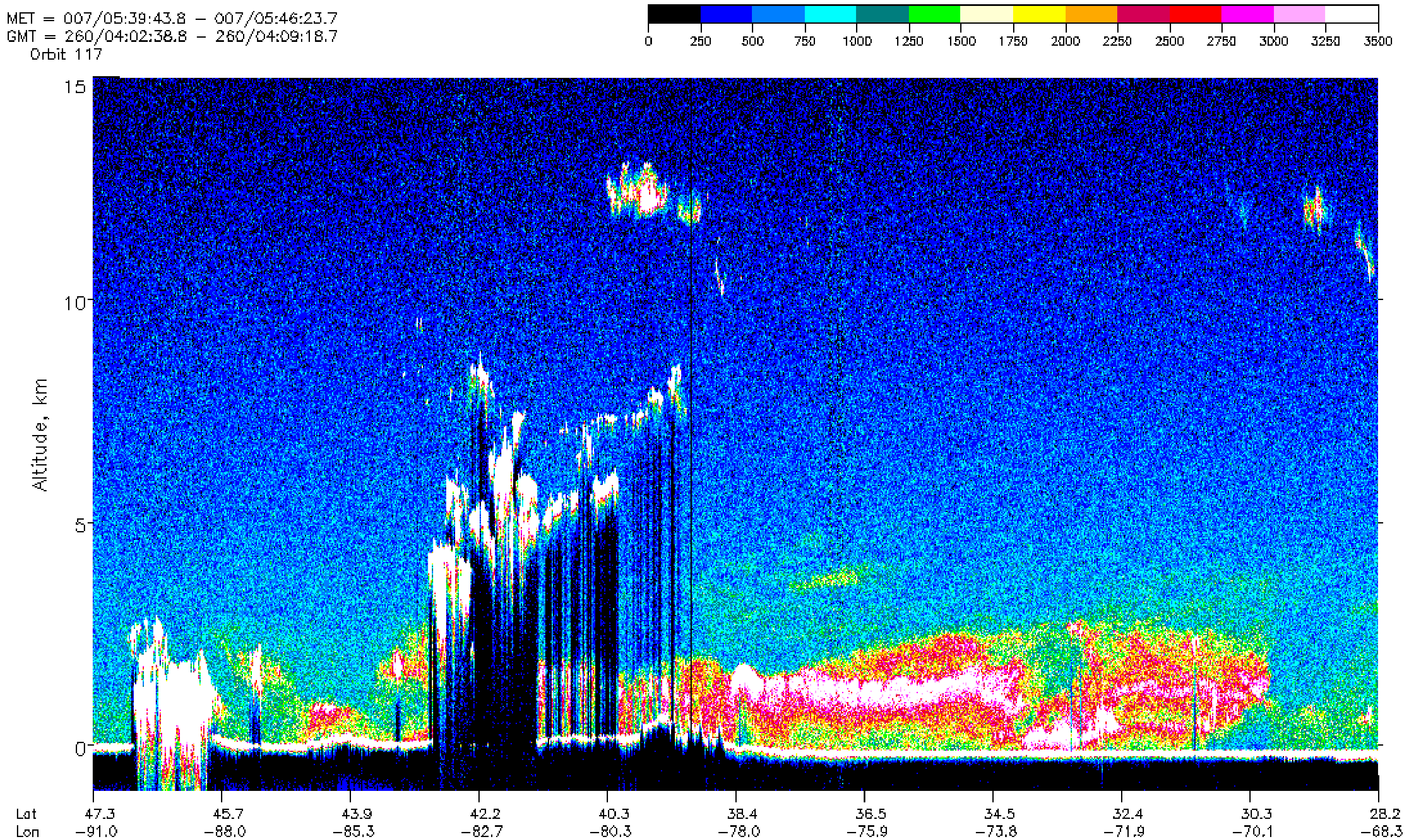
Polder/Adeos CNES/NASDA LOA/LSCE

AEROSOL OPTICAL DEPTH FROM AVHRR AND TOMS



King et al. (BAMS, 1999

"SULFATE" PLUME EXTENDING EAST OF NORTH AMERICA
180˚ BACKSCATTER RETURN
LITE (Lidar In-Space Technology Experiment)



Superior WI

Steubenville OH

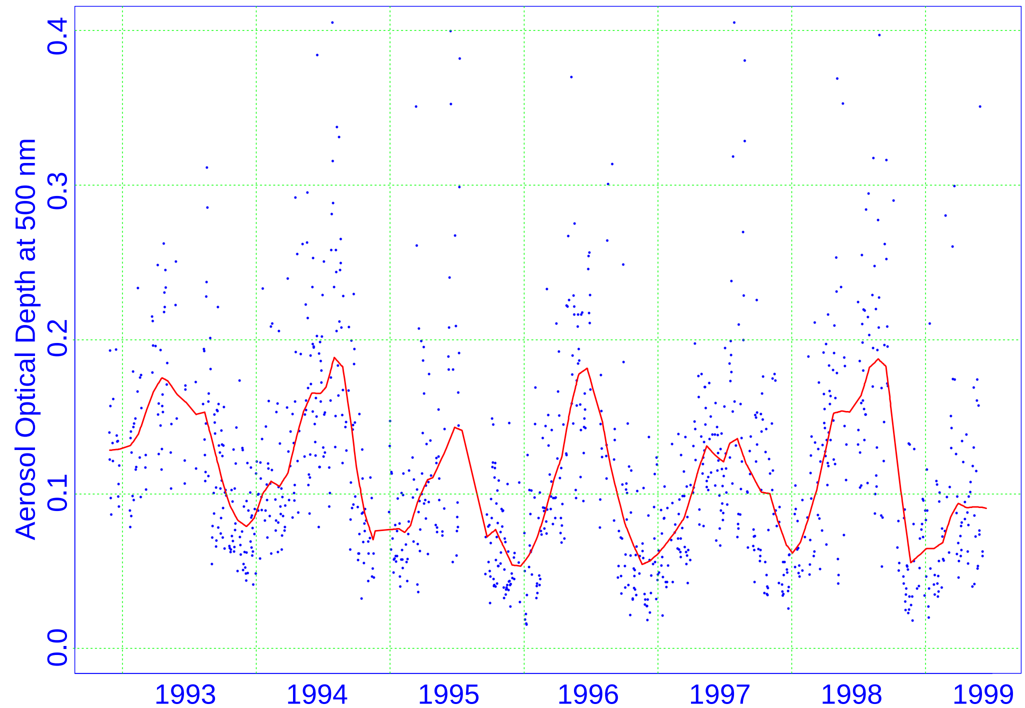
Virginia Beach VA

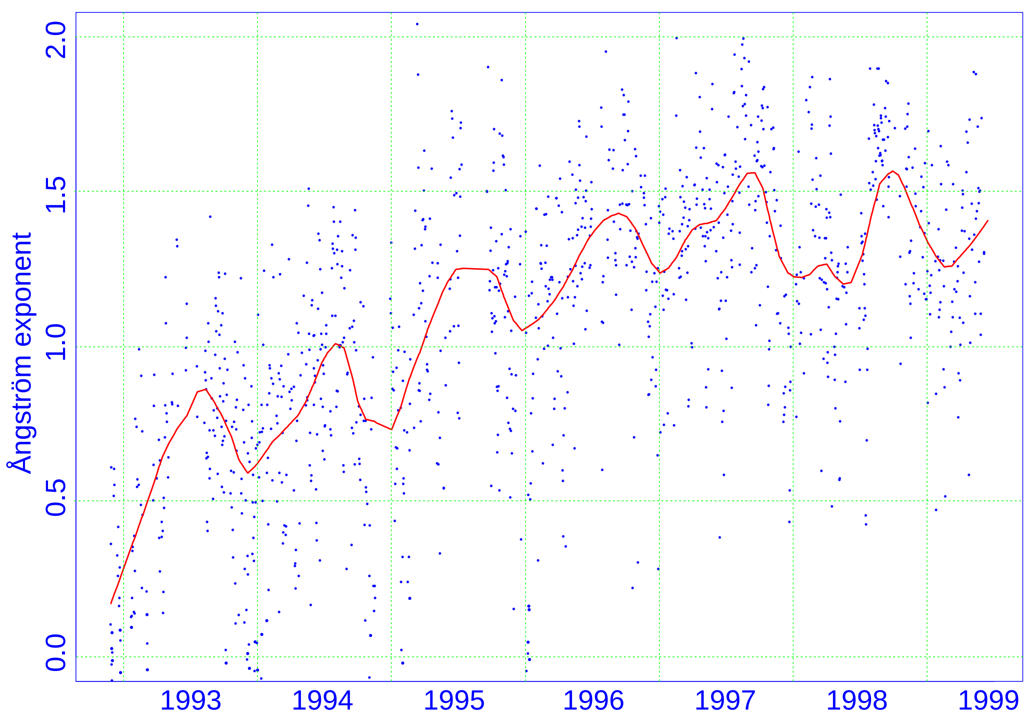
1200 km E of Cape Canaveral

AEROSOL OPTICAL DEPTH AND ÅNGSTRÖM EXPONENT

Determined by Sunphotometry

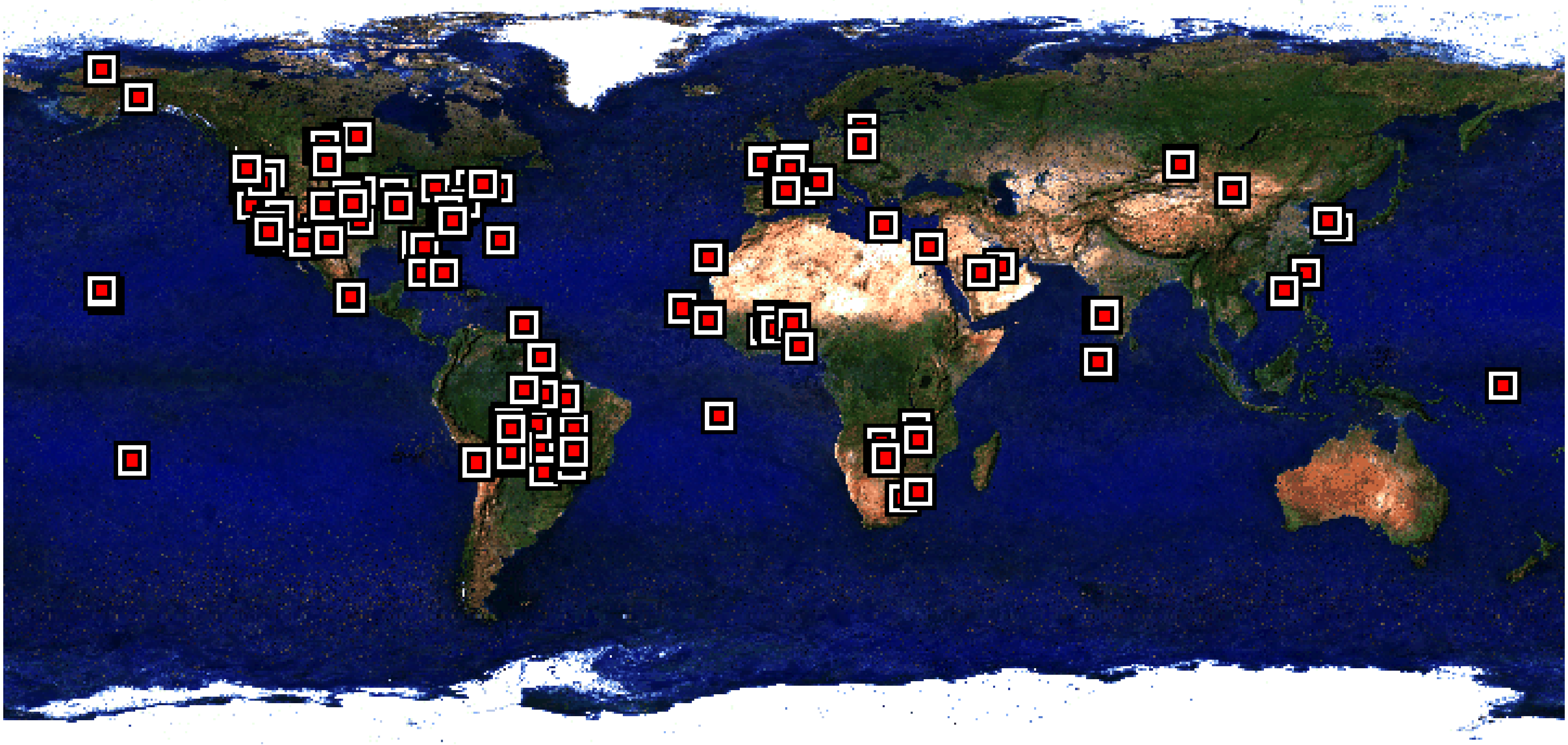
North Central Oklahoma





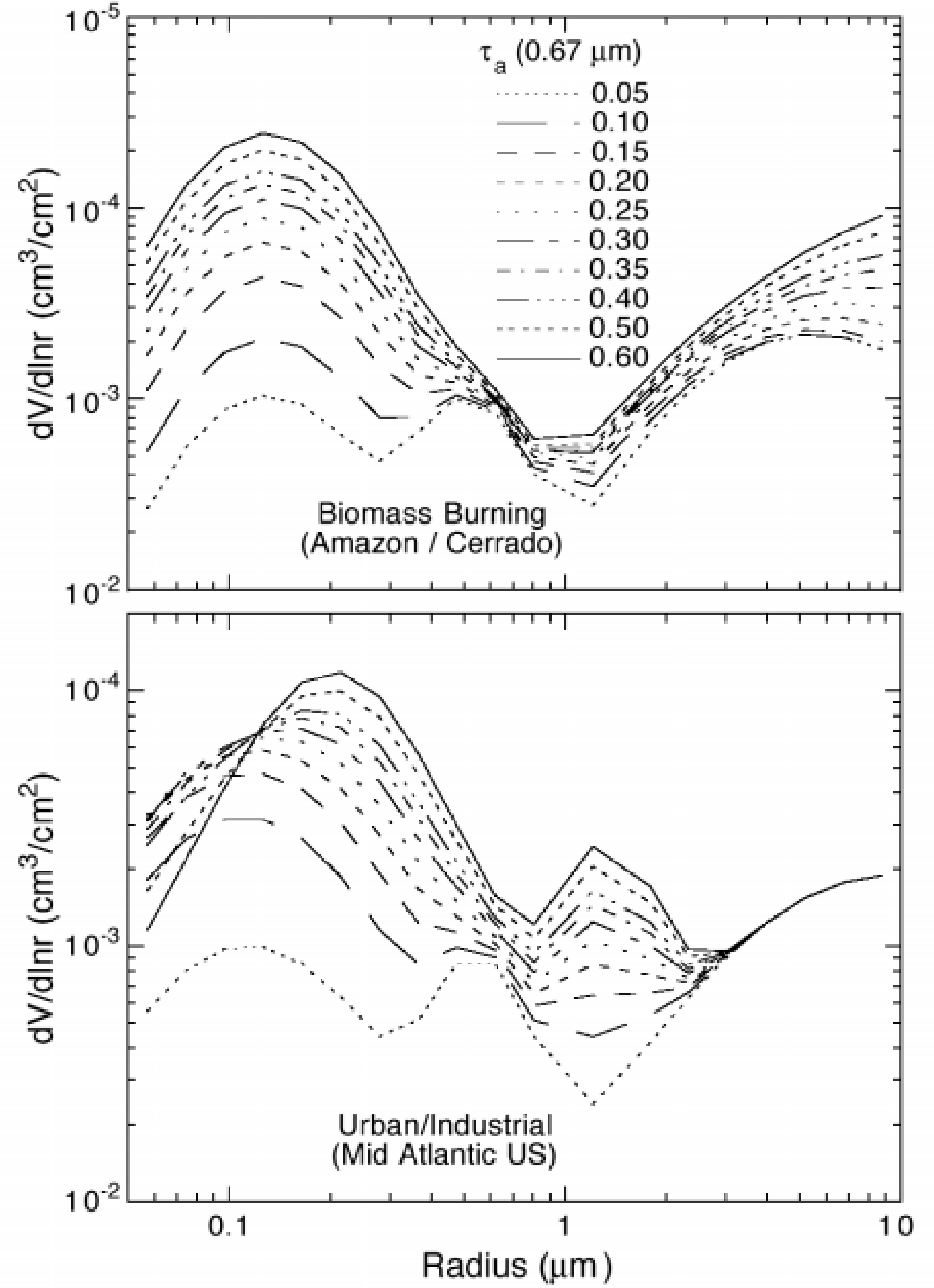
J. Michalsky, PNNL

AERONET (AErosol RObotic NETwork)



Holben et al., NASA GSFC, **http://aeronet.gsfc.nasa.gov:8080/**

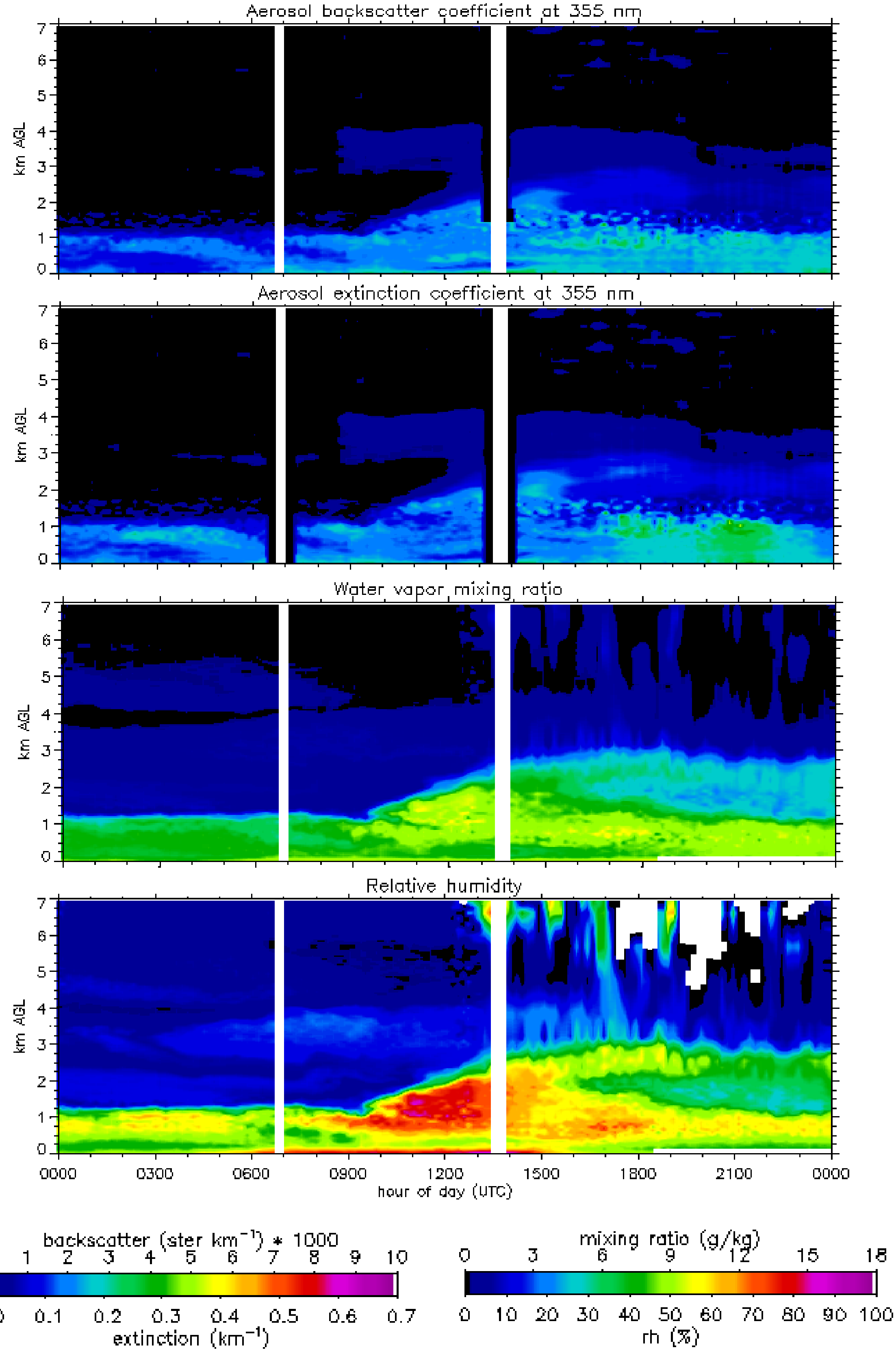
AEROSOL SIZE DISTRIBUTION FROM AERONET SPECTRAL OPTICAL DEPTH AND SKY RADIANCE



King et al. (BAMS, 1999) after Remer et al. (1996)

RAMAN LIDAR AEROSOL AND WATER VAPOR

North Central Oklahoma, October 6, 1999

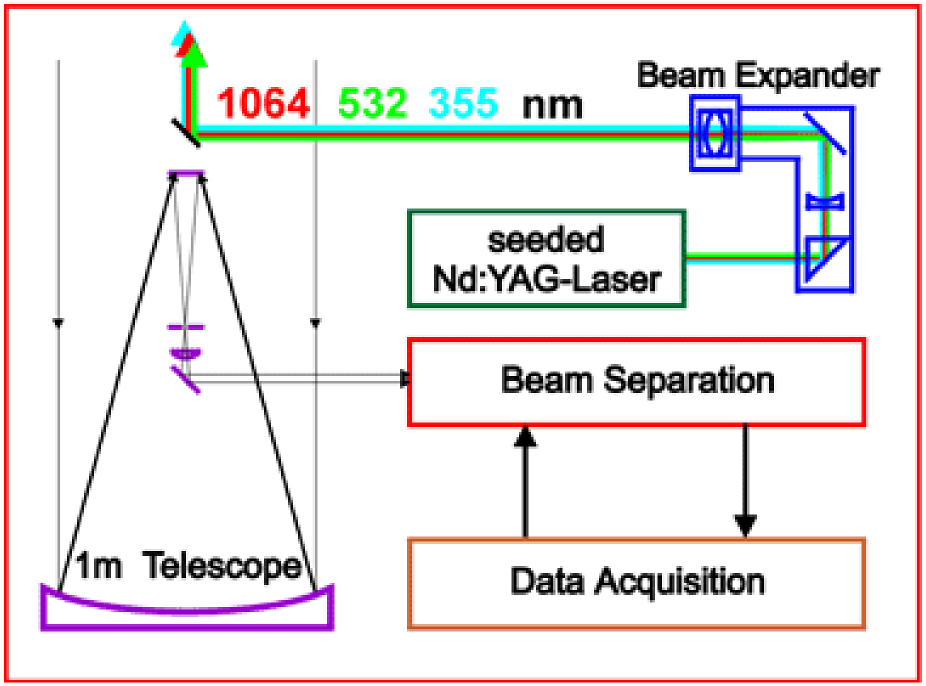


DOE ARM Program; D. Turner, PNNL

http://yard.arm.gov/~turner/raman_lidar_quicklooks.html

MULTIPLE-WAVELENGTH LIDAR - RAMAN-LIDAR

Aerosol Raman Lidar



Extinction

387 α_{aer}

607 α_{aer}

Temperature

529.0

530.3

533.7 T

535.0

Backscatter

355

387 β_{aer}

532 ⊥

532 ∥ β_{aer}

607

1064 β_{aer}

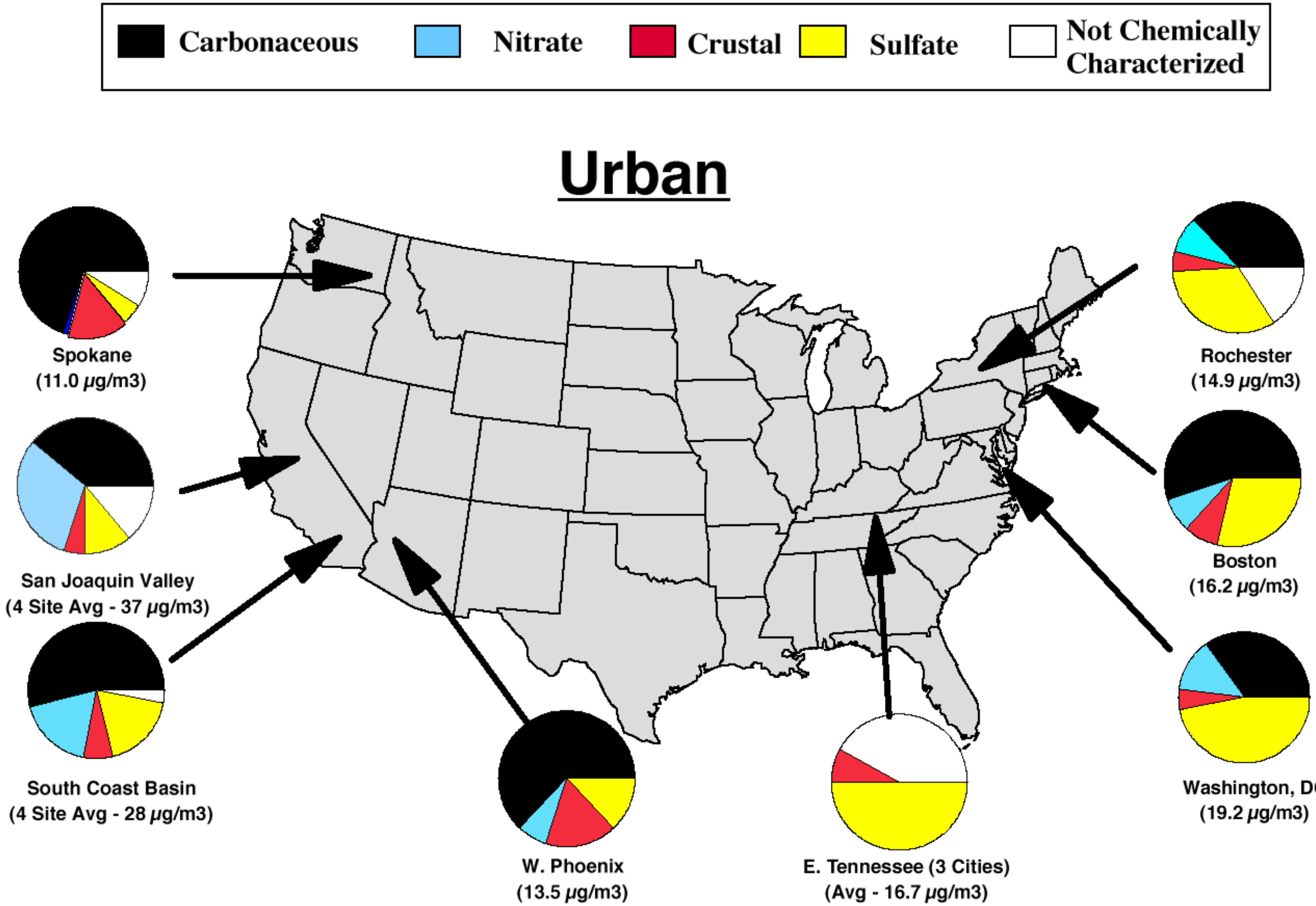
Humidity

387 m_{H_2O}

407

Institut für Troposphärenforschung, Leipzig

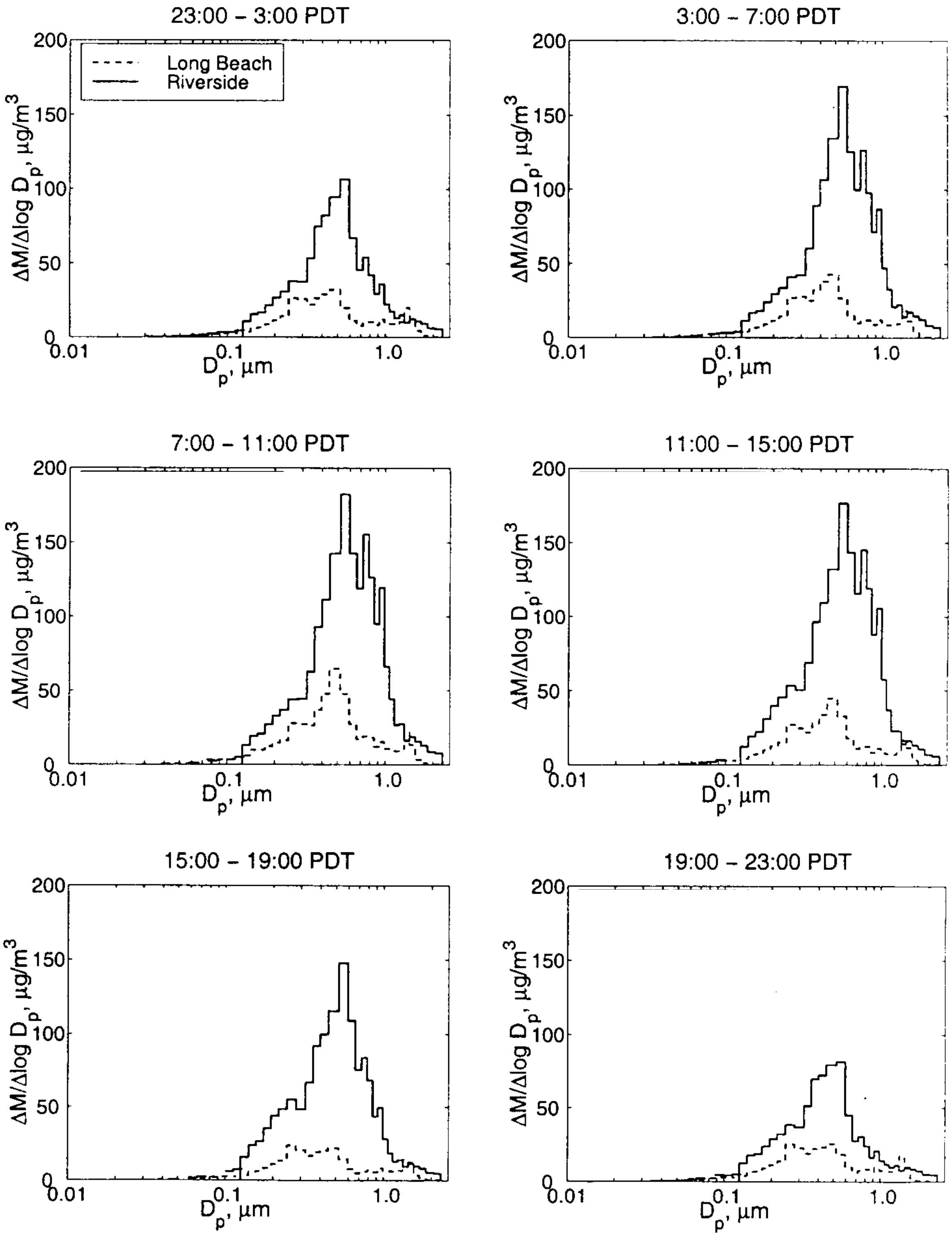
DEPENDENCE OF AEROSOL COMPOSITION ON LOCATION



EPA, *National Air Quality and Emissions Trends Report, 1997*, 1998

REGIONAL AND DIURNAL DIFFERENCES IN AEROSOL LOADING AND SIZE

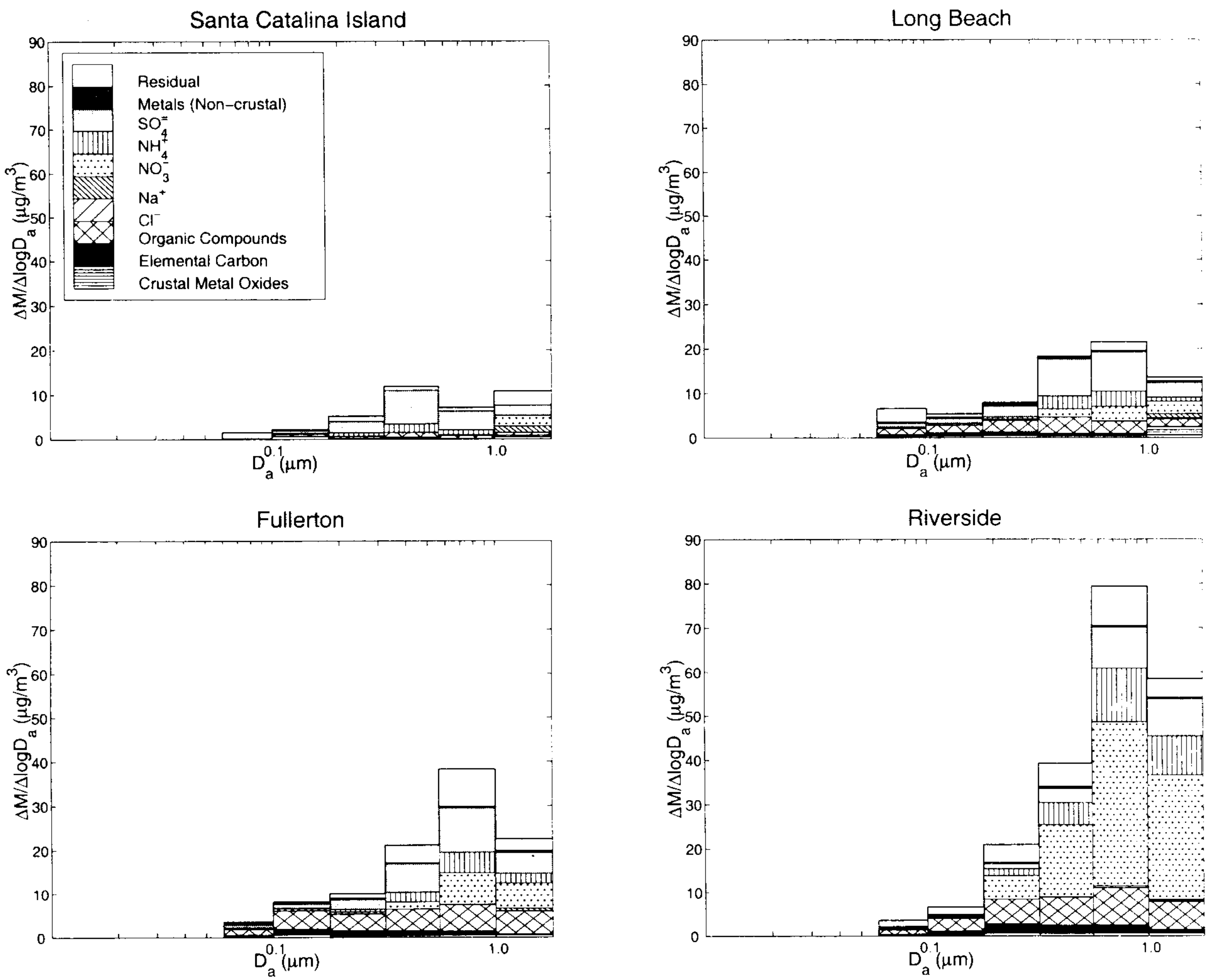
Composite of 4-hr samples over 9 days, September-October, 1996



Hughes, Cass, Prather et al. (1999)

REGIONAL DIFFERENCES IN AEROSOL LOADING, COMPOSITION, AND SIZE

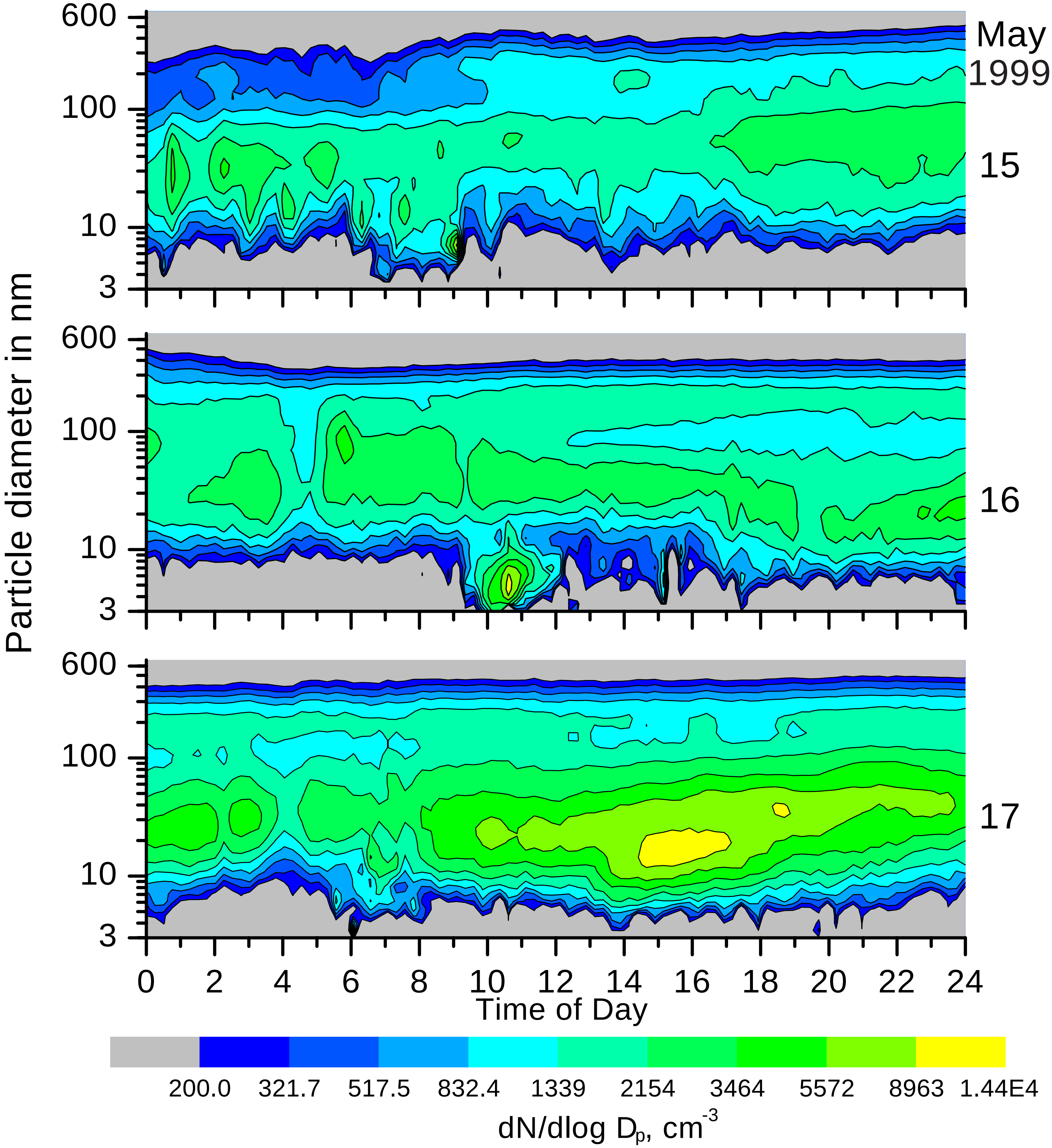
Composite of 4-hr samples on several days, September-October, 1996



Hughes, Cass, Prather et al. (1999)

TIME DEPENDENT PARTICLE SIZE DISTRIBUTION

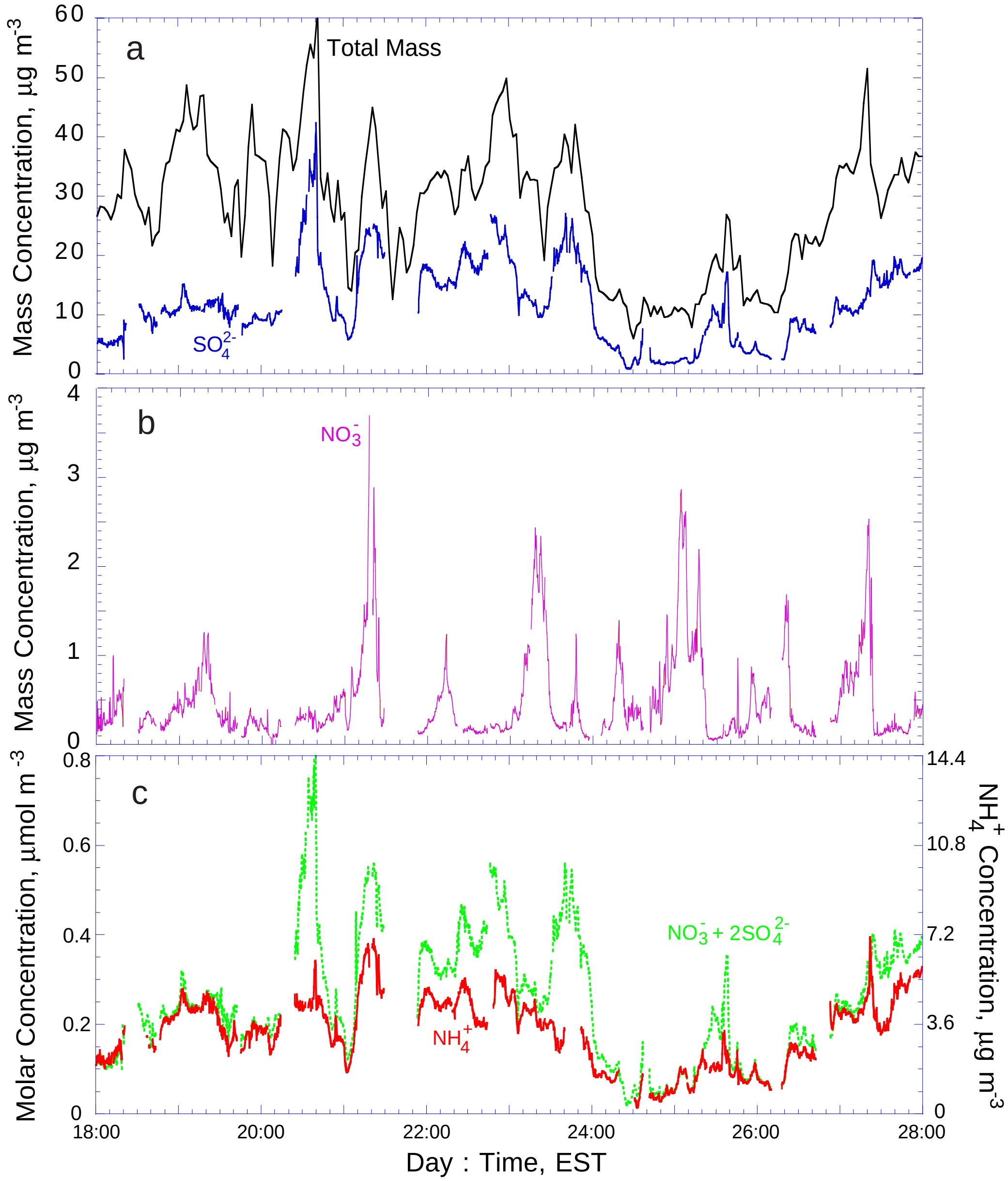
Differential Mobility Analyzer, Low Relative Humidity
Rural Germany, May, 1999. Time Resolution 10 min



W. Birmili (IFT, Leipzig)

TIME-DEPENDENT PARTICLE COMPOSITION

Atlanta GA, Summer 1999



Y.-N. Lee, BNL; R. Weber, GaTech

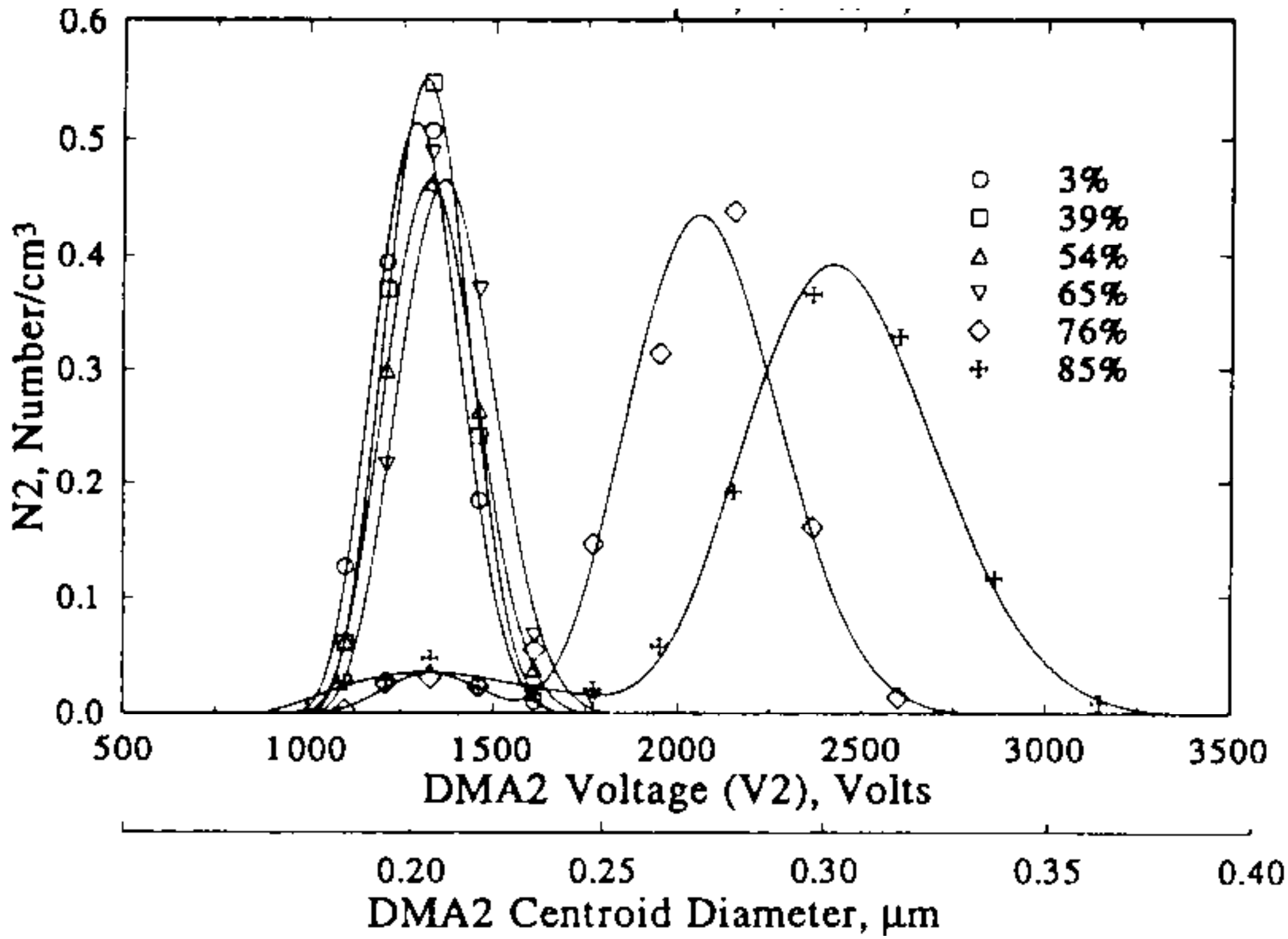
- Rapid (sub-daily) variation of aerosol components.
- Lack of correlation of several aerosol components.
- Varying extent of neutralization of acid by ammonia.
- Correlation of sulfate concentration with total aerosol mass.

Such information is not available with conventional filter sampling.

DIFFERENTIAL HUMIDITY RESPONSE WITHIN AEROSOL

First analyzer, low RH; Second analyzer variable RH

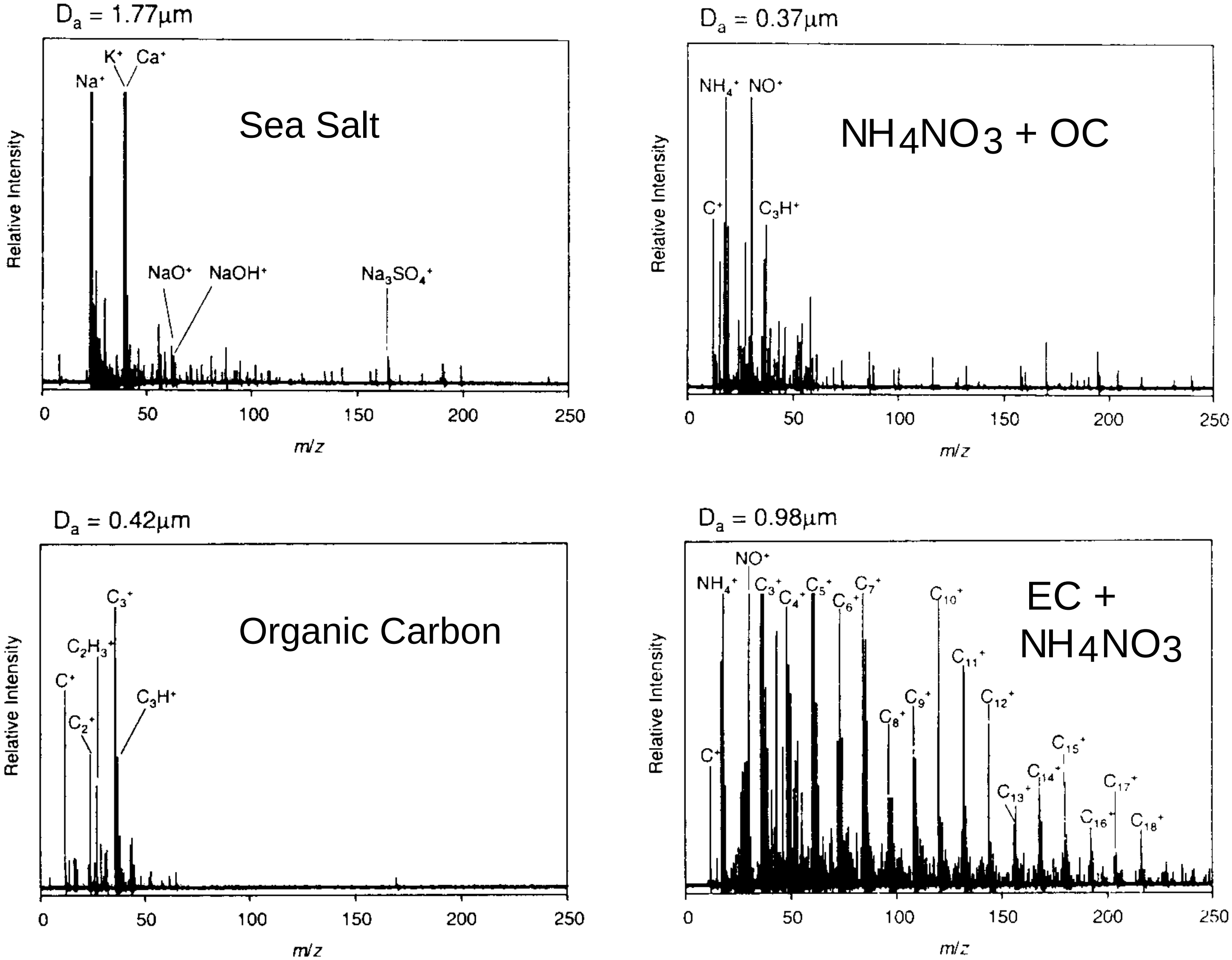
Hopi Point, Grand Canyon, Arizona, March 1, 1990, 14:15



Zhang, McMurry et al. (1993)

PARTICLE-TO-PARTICLE COMPOSITION DIFFERENCES

Time-of flight mass spectra of individual particles, South Coast, CA, September-October, 1996

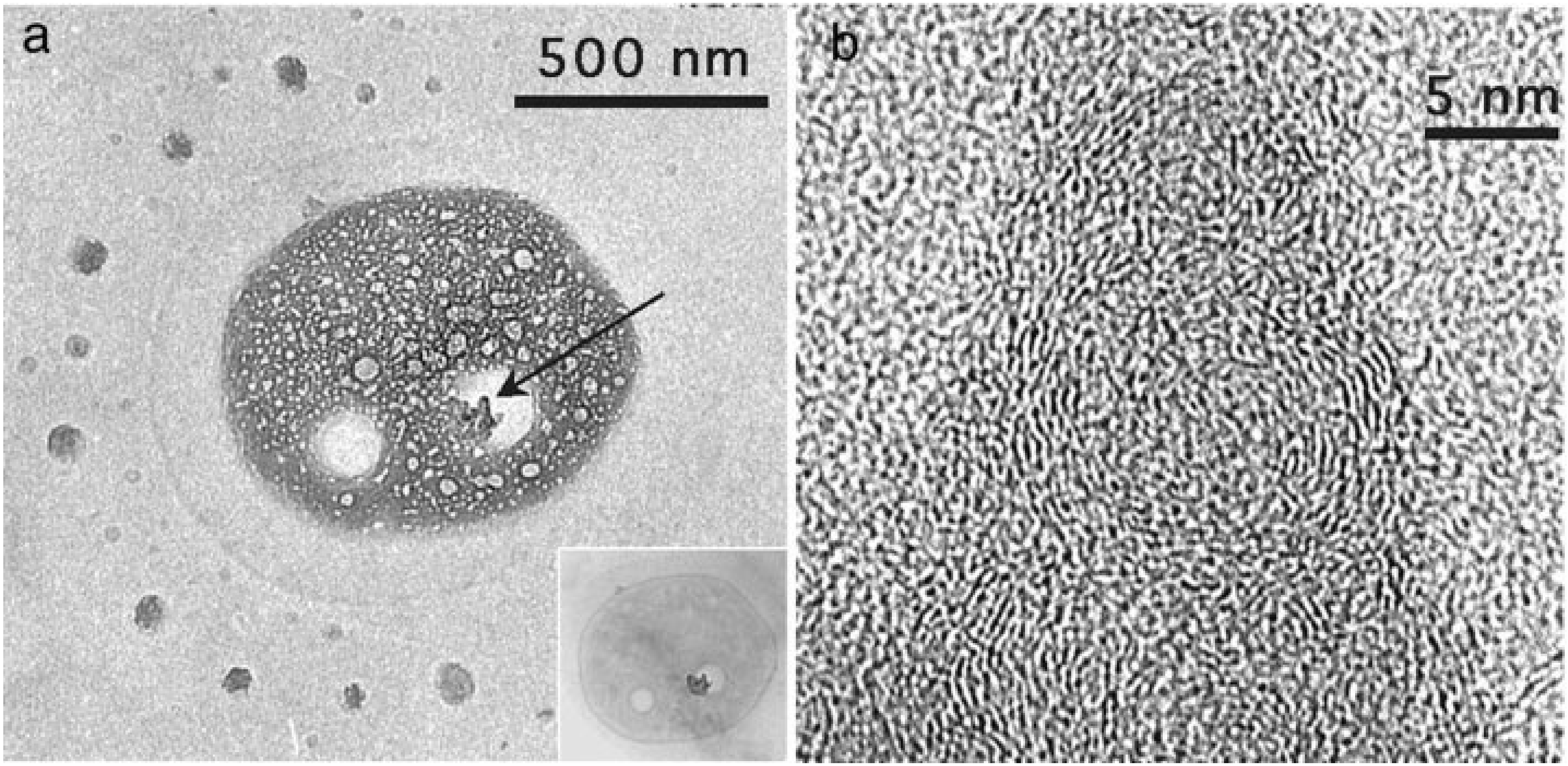


Hughes, Cass, Prather et al. (1999)

TRANSMISSION ELECTRON MICROGRAPH OF INDIVIDUAL PARTICLE

Soot inclusion in single particle consisting mainly of $(NH_4)_2SO_4$

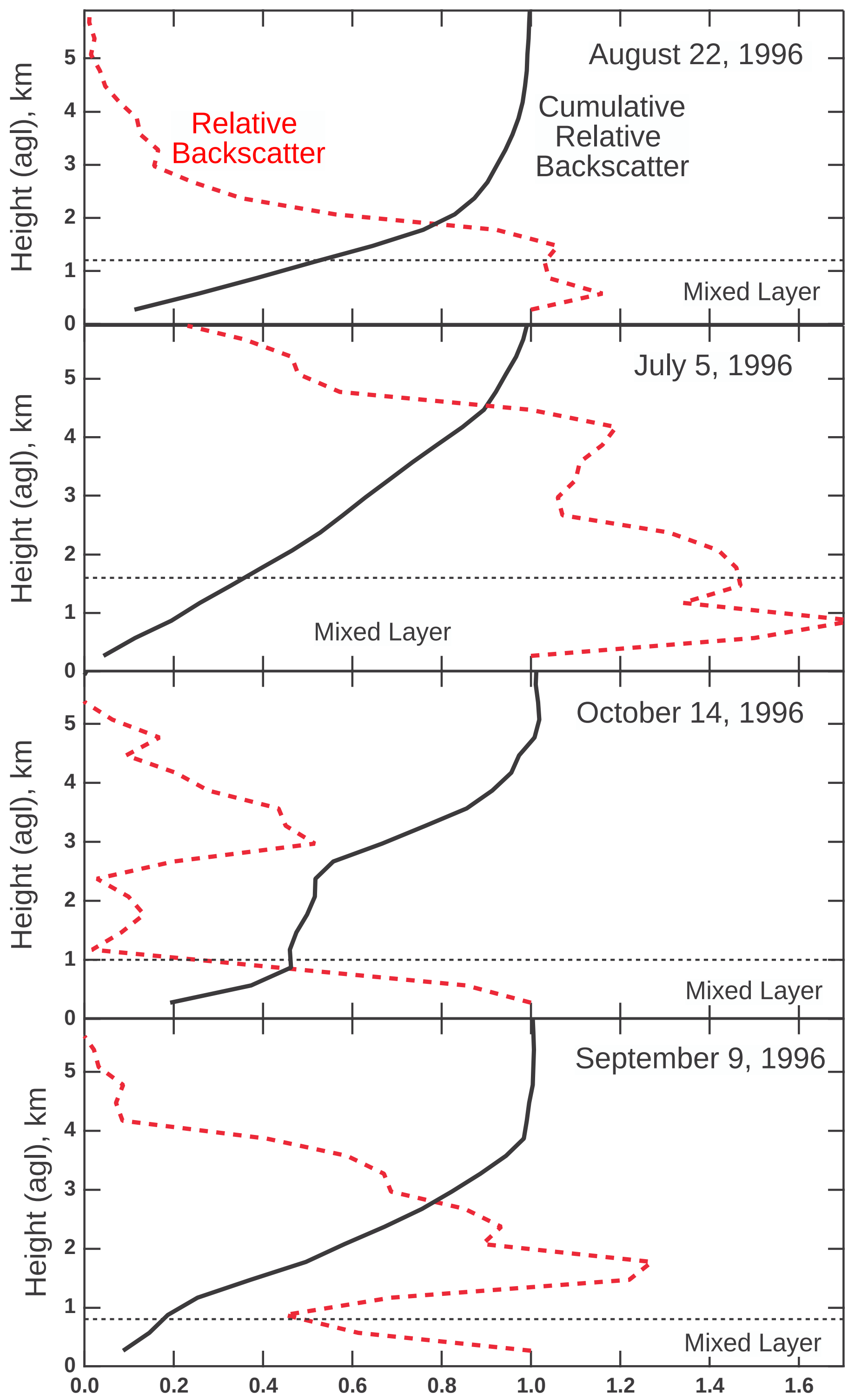
Unpolluted air near Tasmania.



Buseck and Pósfai (1999)

AEROSOL VERTICAL DISTRIBUTION

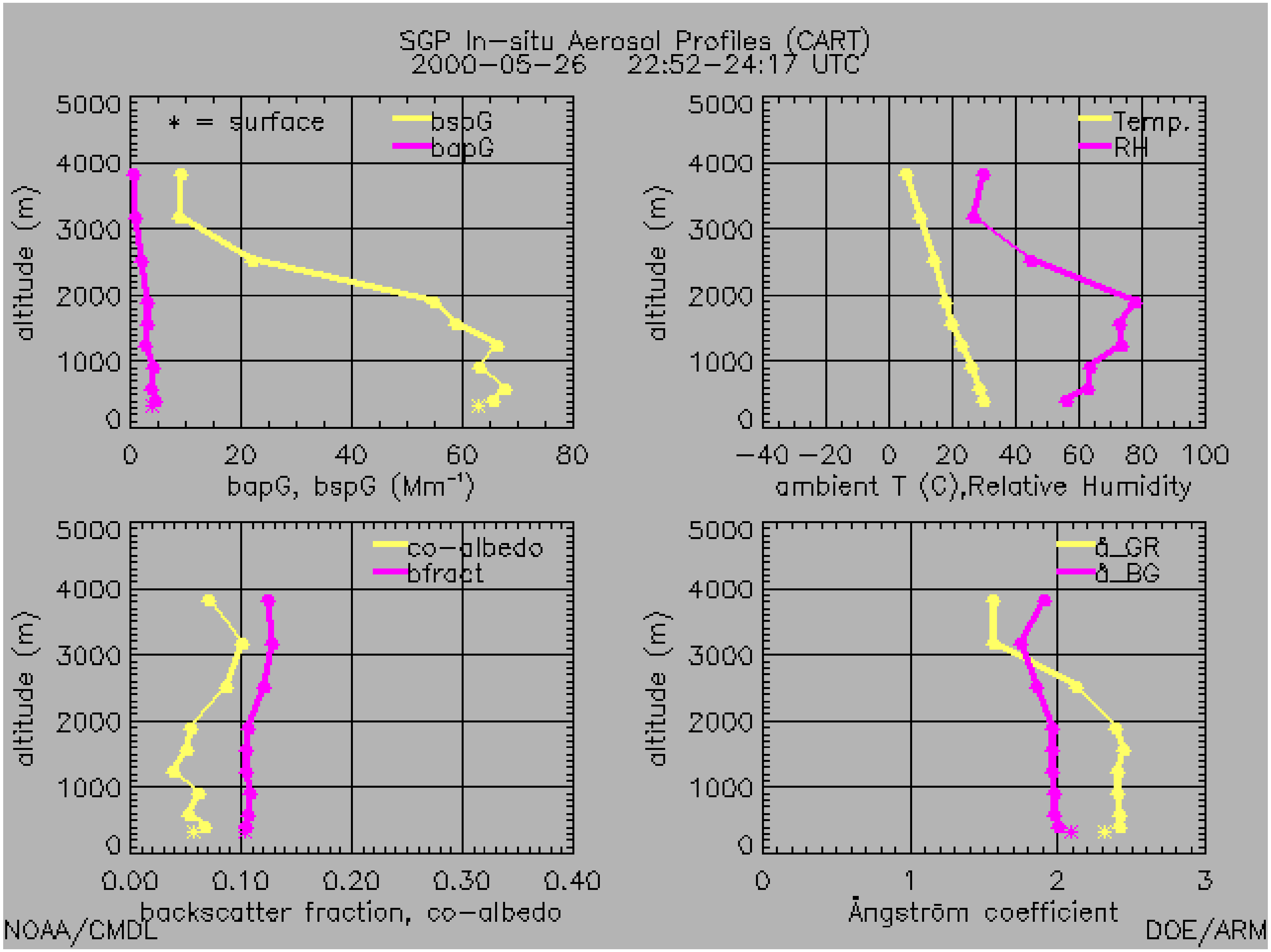
Aerosol Lidar Backscatter on Cloud-Free Days
North Central Oklahoma



Bergin, Schwartz, Halthore, Ogren & Hlavka (2000)

VERTICAL DISTRIBUTION OF AEROSOL PROPERTIES

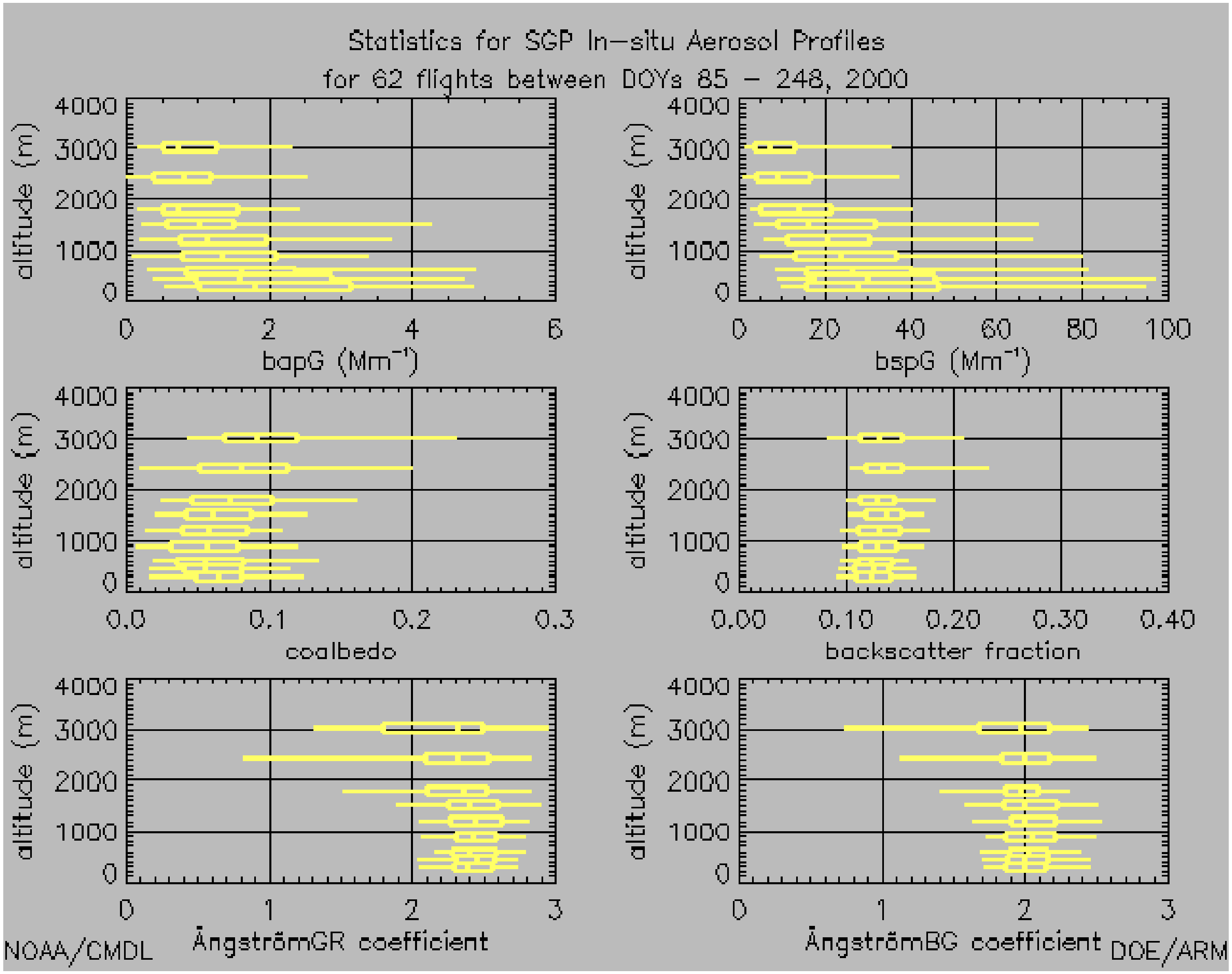
North Central Oklahoma



J. Ogren, NOAA CMDL

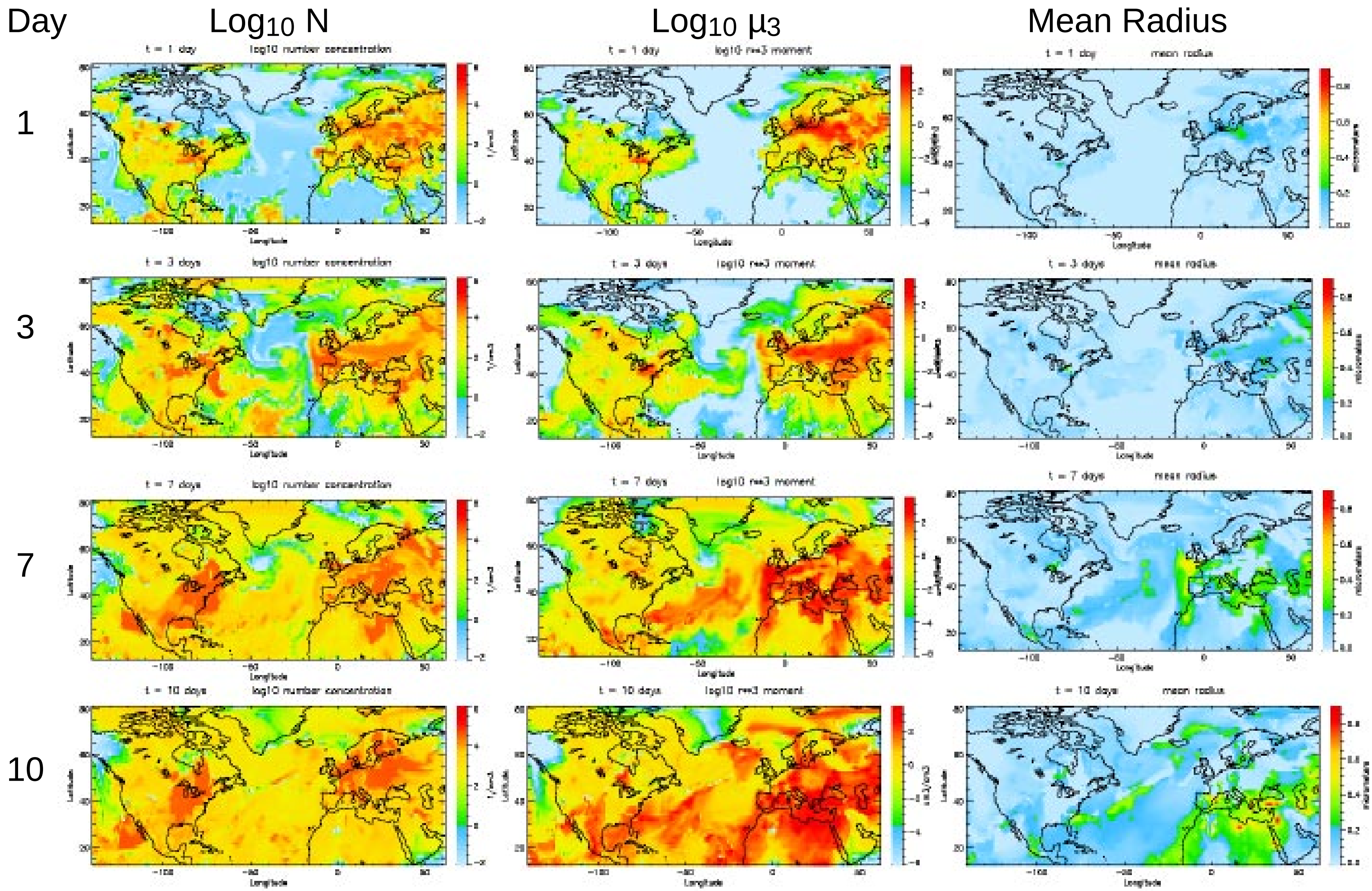
STATISTICS OF VERTICAL DISTRIBUTIONS OF AEROSOL PROPERTIES

North Central Oklahoma



J. Ogren, NOAA CMDL

MODELING EVOLUTION OF AEROSOL LOADING AND PROPERTIES
Moment-based representation of aerosol microphysics



Wright, McGraw, Benkovitz & Schwartz (2000)

MODEL EVALUATION

Comparison of measured and modeled sulfate concentrations
Model is driven by observation-derived meteorological data

Benkovitz, Schwartz et al. (1994)

MEASUREMENT STRATEGIES

Approach	*LongTerm vs. Campaign*	*Global vs. Local*	*Aggregate vs. Detailed*
Satellite remote sensing	LT	G	A
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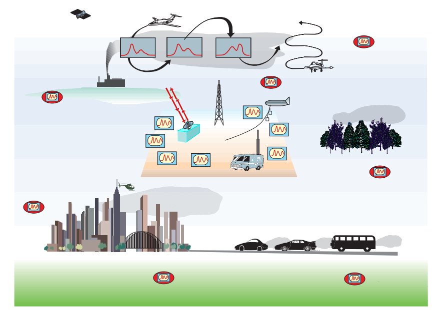
Local measurements can be extended to quasi-global by network of measurements.
Campaign measurements can be extended to LongTerm.

Looking to the Future...

DOE-SC-XXXX

Tropospheric Aerosol Program



Preliminary Program Plan

June 1999

U. S. Department of Energy
Office of Science
Office of Biological and Environmental Research
Environmental Sciences Division

Our quest for progress must be sustainable. We have no right to destroy the earth.

Ecological damage, including global warming, must be curbed.

All low-lying countries must be saved: When the United Nations meets to usher in yet another century, will the Maldives and other low-lying island nations still be represented here?

MAUMOON ABDUL GAYOOM, President of Maldives

United Nations Millennium Summit, September, 2000