Vertical Distribution of Aerosols over the ARM SGP: Measured vs. Modeled

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Fourth AEROCOM Workshop, 15-17 June, 2005

ARM Climate Research Facility

ARM Atmospheric Radiation Measurement Program

NASA

Outline

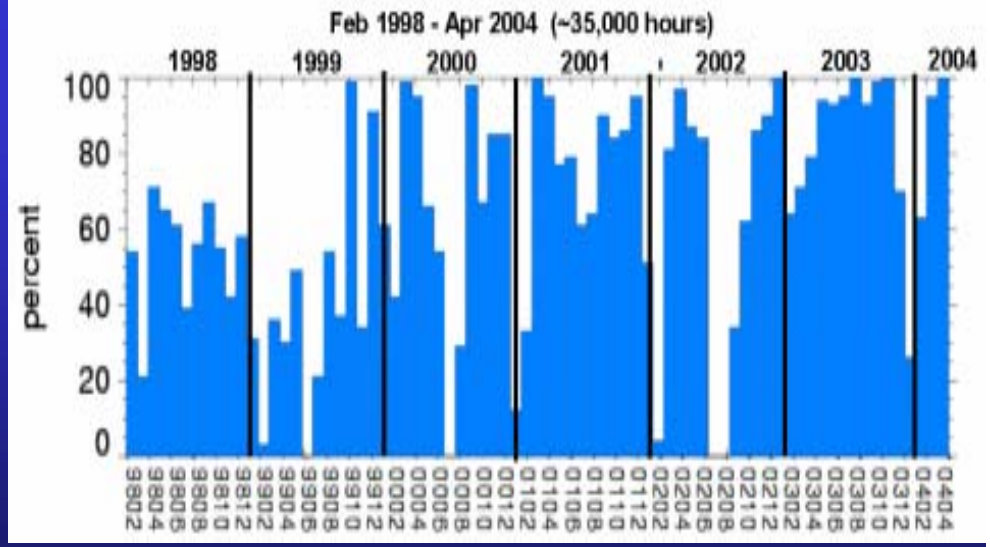
- DOE ARM SGP CRF Raman Lidar System
- Aerosol and Water Vapor Measurements
- AEROCOM comparisons of aerosol extinction, RH
- In Situ Aerosol Profiling (IAP) comparisons
- Airborne lidar comparisons

Acronyms

DOE = Department of Energy
ARM = Atmospheric Radiation Measurement
SGP = Southern Great Plains
CRF = Climate Research Facility
CARL = CRF Raman Lidar

CART Raman Lidar (CARL)

- DOE ARM SGP CF site (Lamont , Oklahoma) (36° 37 ' N, 97° 30 ' W)
- Nd:YAG (355 nm) (day/night)
- Wavelengths
  - Rayleigh/Mie (355 nm)
  - Depolarization (355 nm)
  - Raman water vapor (408 nm)
  - Raman nitrogen (387 nm)
- 39 meter range resolution
- water vapor and aerosol profiles
- precipitable water vapor and aerosol optical thickness
- aerosol and cloud depolarization
- designed for continuous, autonomous operation



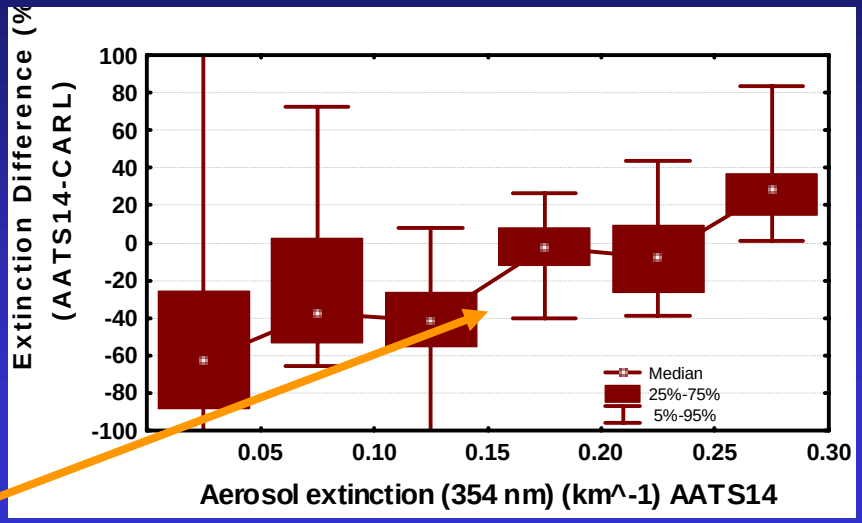
Data: available via ftp from ARM (http://www.arm.gov)

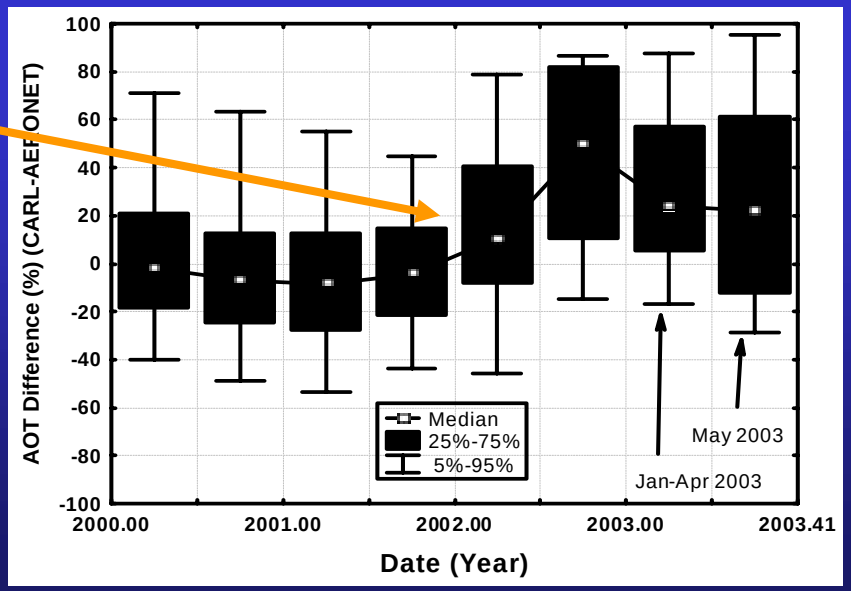
Additional information: http://www.arm.gov/docs/instruments/static/rl.html

(Turner et al., JAOT, 2002)

CARL Aerosol Extinction Profile Evaluation

- CARL extinction profiles were evaluated using airborne remote sensing and in situ measurements acquired during May 2003 Aerosol IOP
- CARL extinction values generally larger (20-30 Mm^{-1}) than values from other sensors
- Largest differences were found for low (<50 Mm^{-1}) aerosol extinction values and were significantly less (~10%) for higher (150-300 km^{-1}) values of aerosol extinction.
- Larger differences were due to impacts of loss of sensitivity of CARL since early 2002
- Absolute differences (~30 Mm^{-1}) between the CARL aerosol extinction values and values from the other instruments are within the range deemed acceptable (larger of 50 Mm^{-1} or 20%) when evaluating the lidars within the EARLINET project [*Pappalardo et al.*, 2004]
- Water vapor measurements in low-mid troposphere are within 5% of other measurements





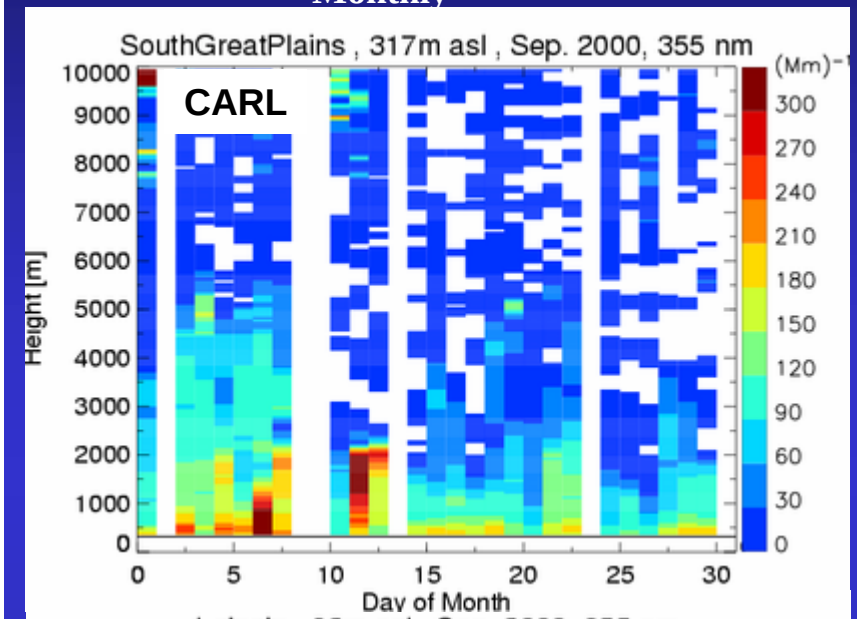
Ferrare et al., JGR in press, 2005

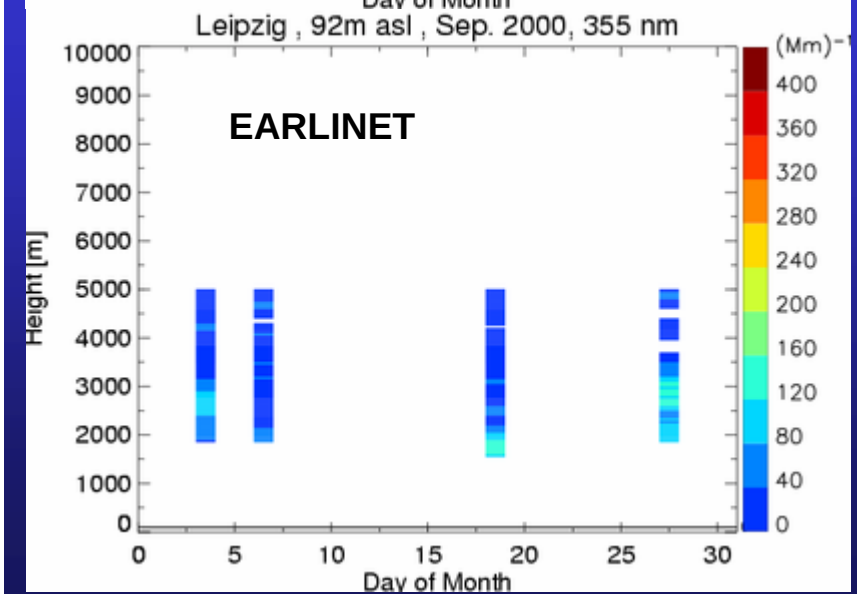
Continuous vs. Periodic Measurements

CARL – continuous

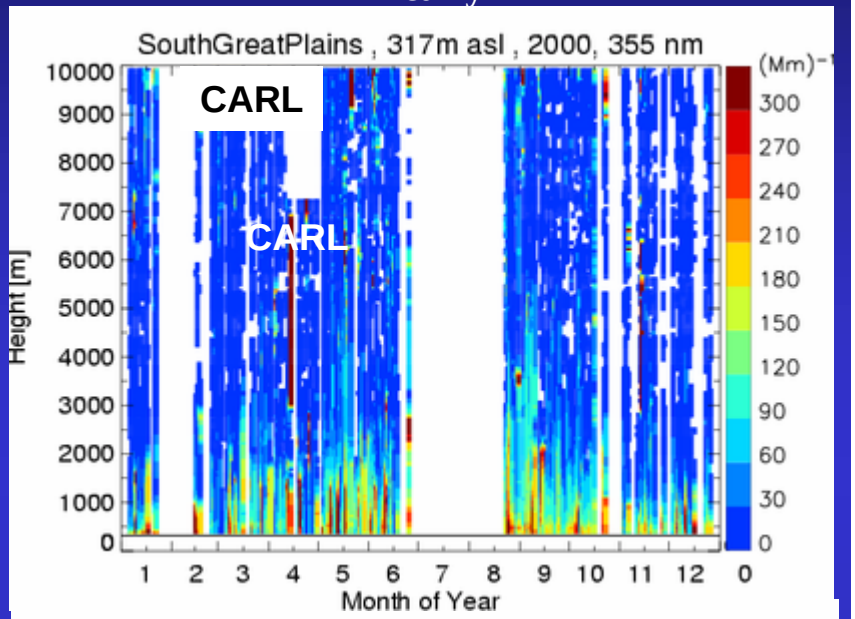
EARLINET – periodic 3 times/week (Monday 13:00 UT; Monday, Thursday 1 hour after sunset)

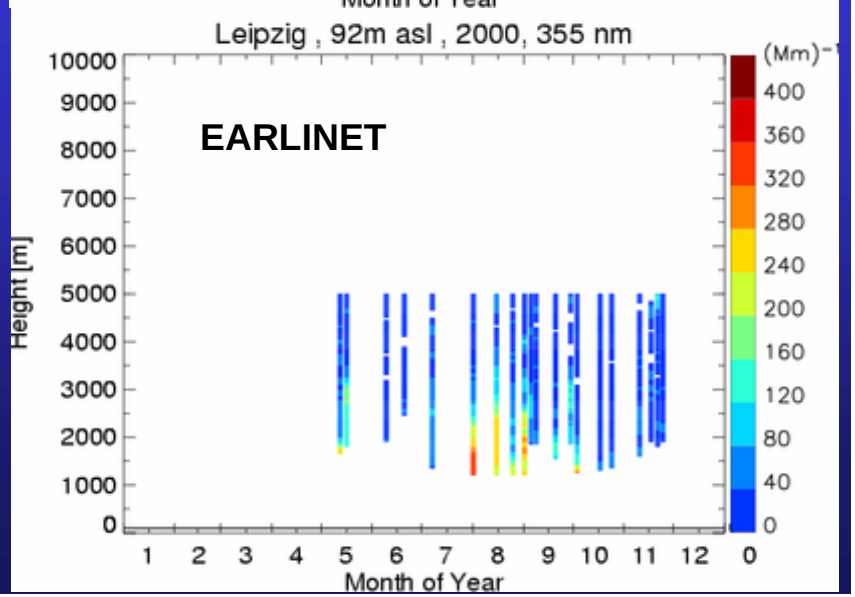
Monthly



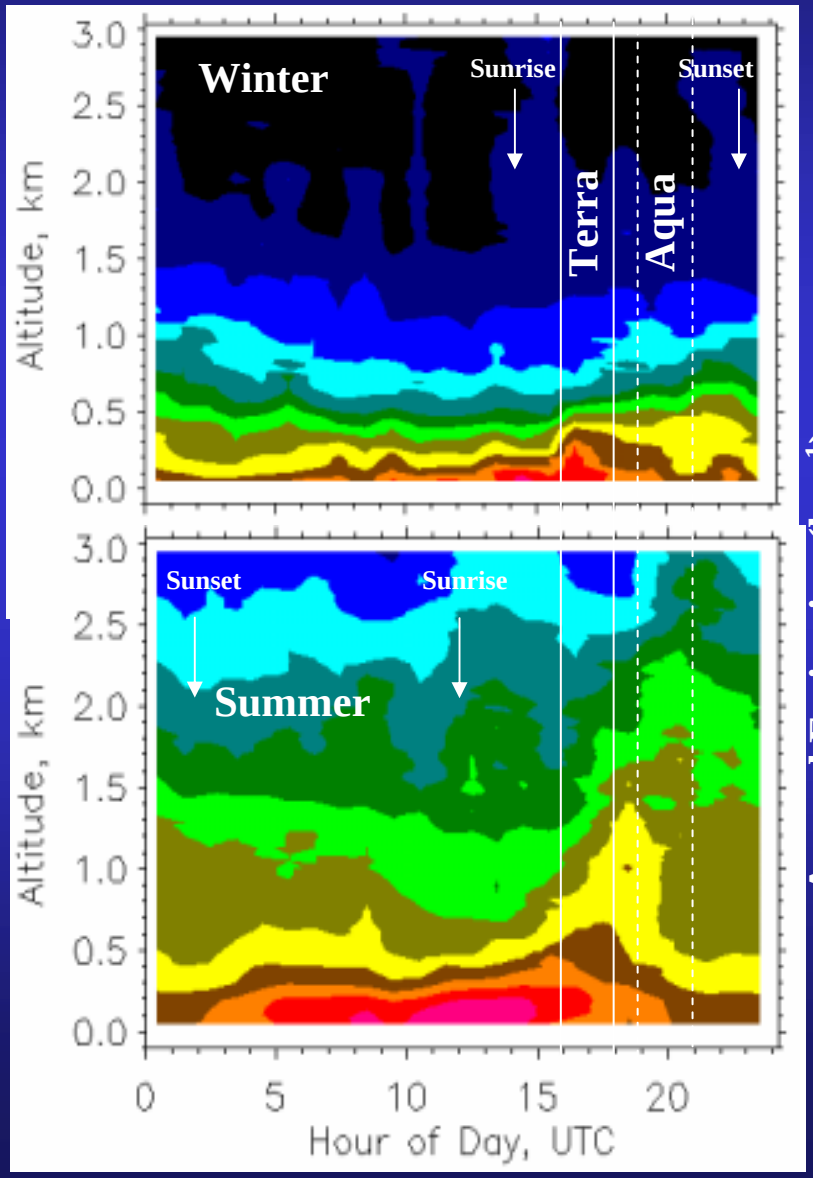


Yearly



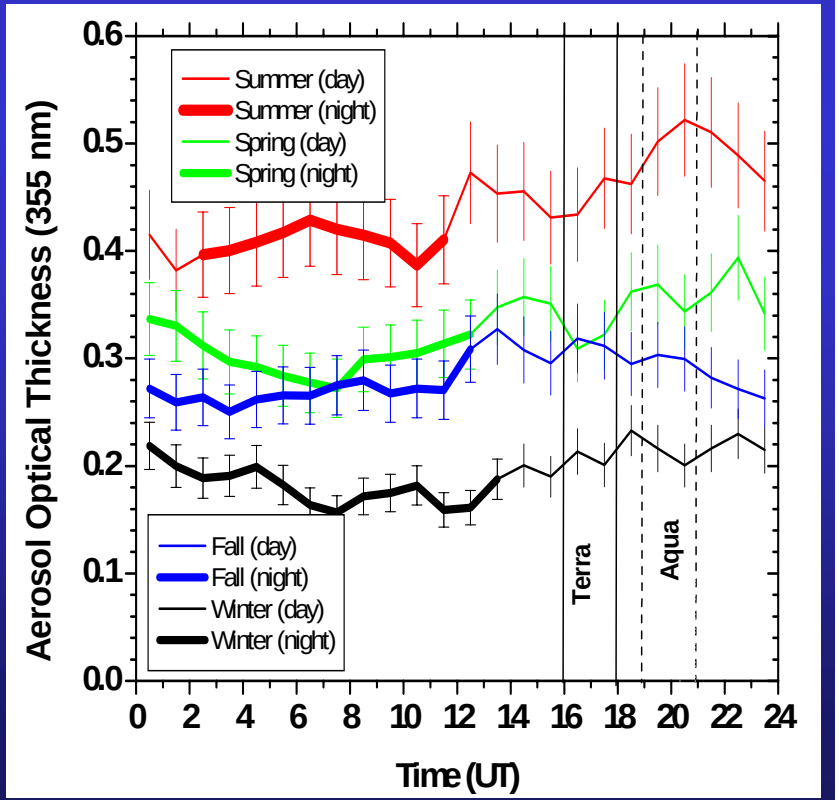


Average Diurnal Variation of Aerosol Extinction Profiles and AOT



- Large changes in vertical profile
- Smaller changes in AOT (st. dev ~ 10%)

AOT



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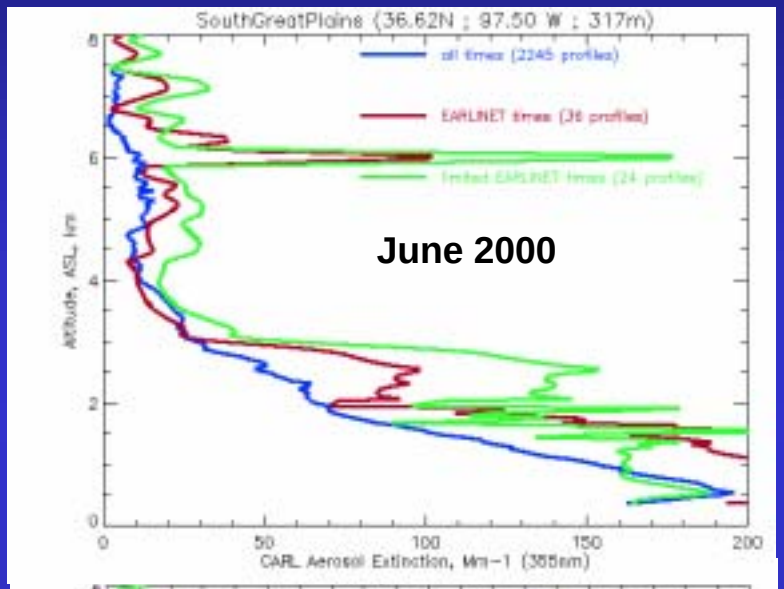
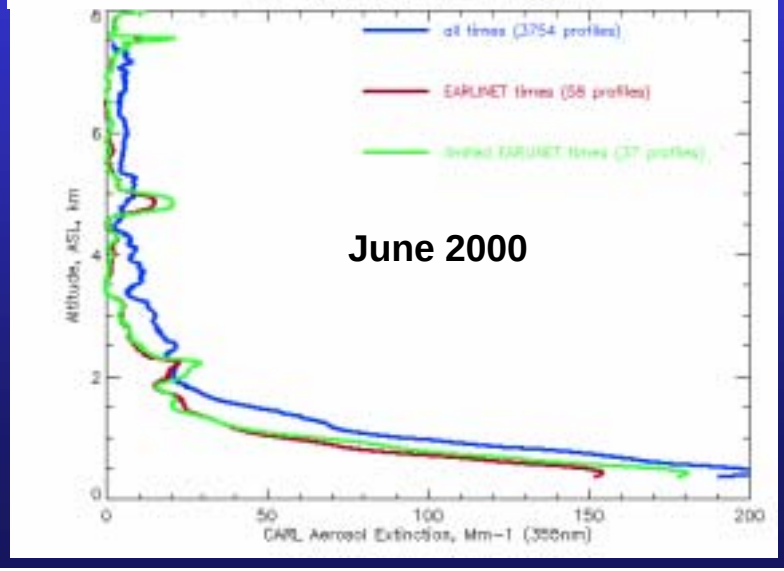
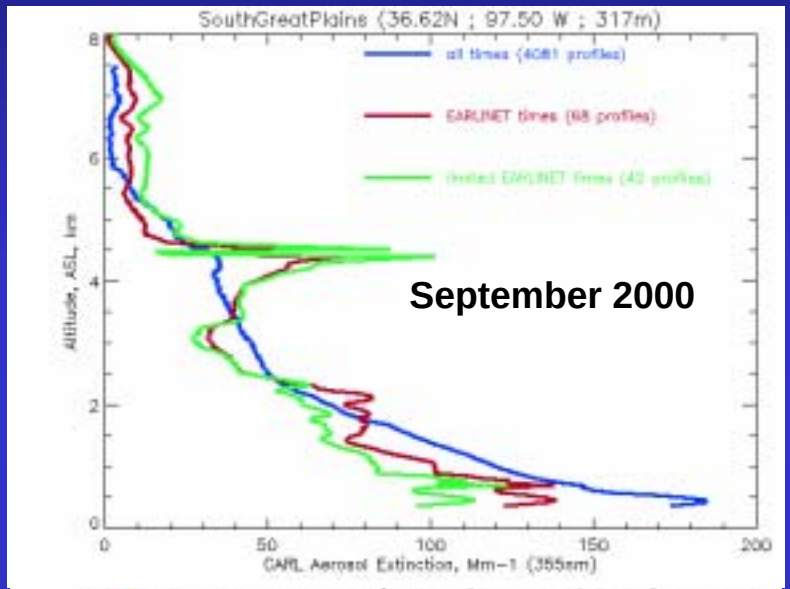
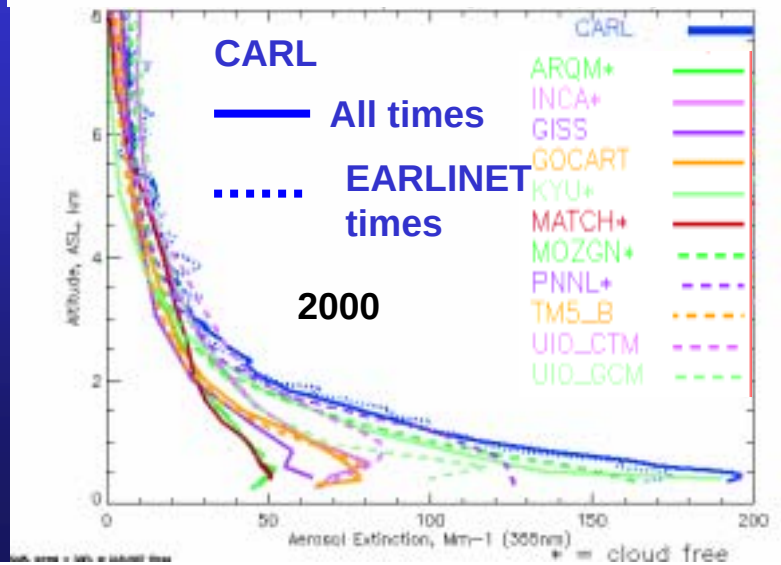
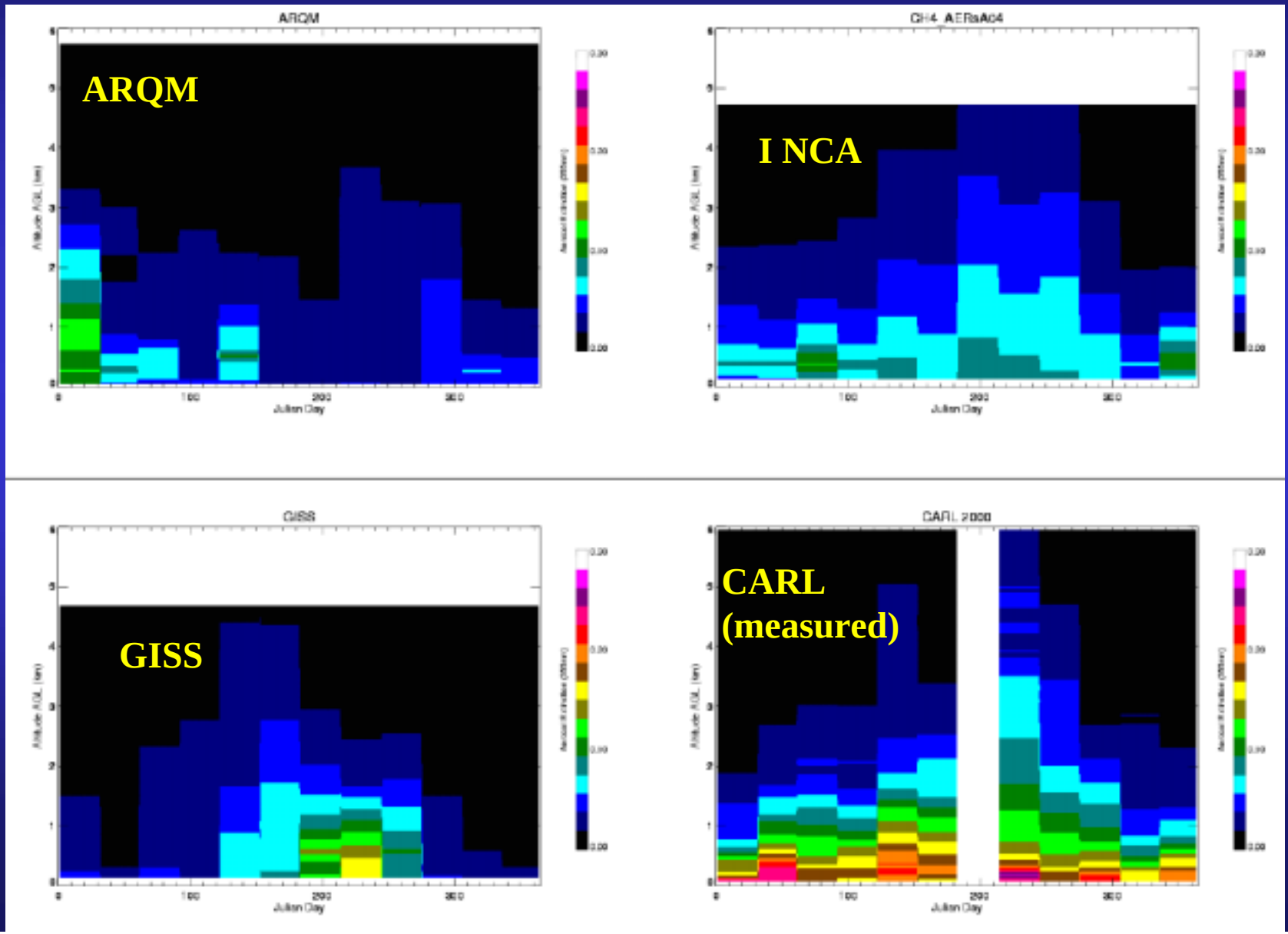






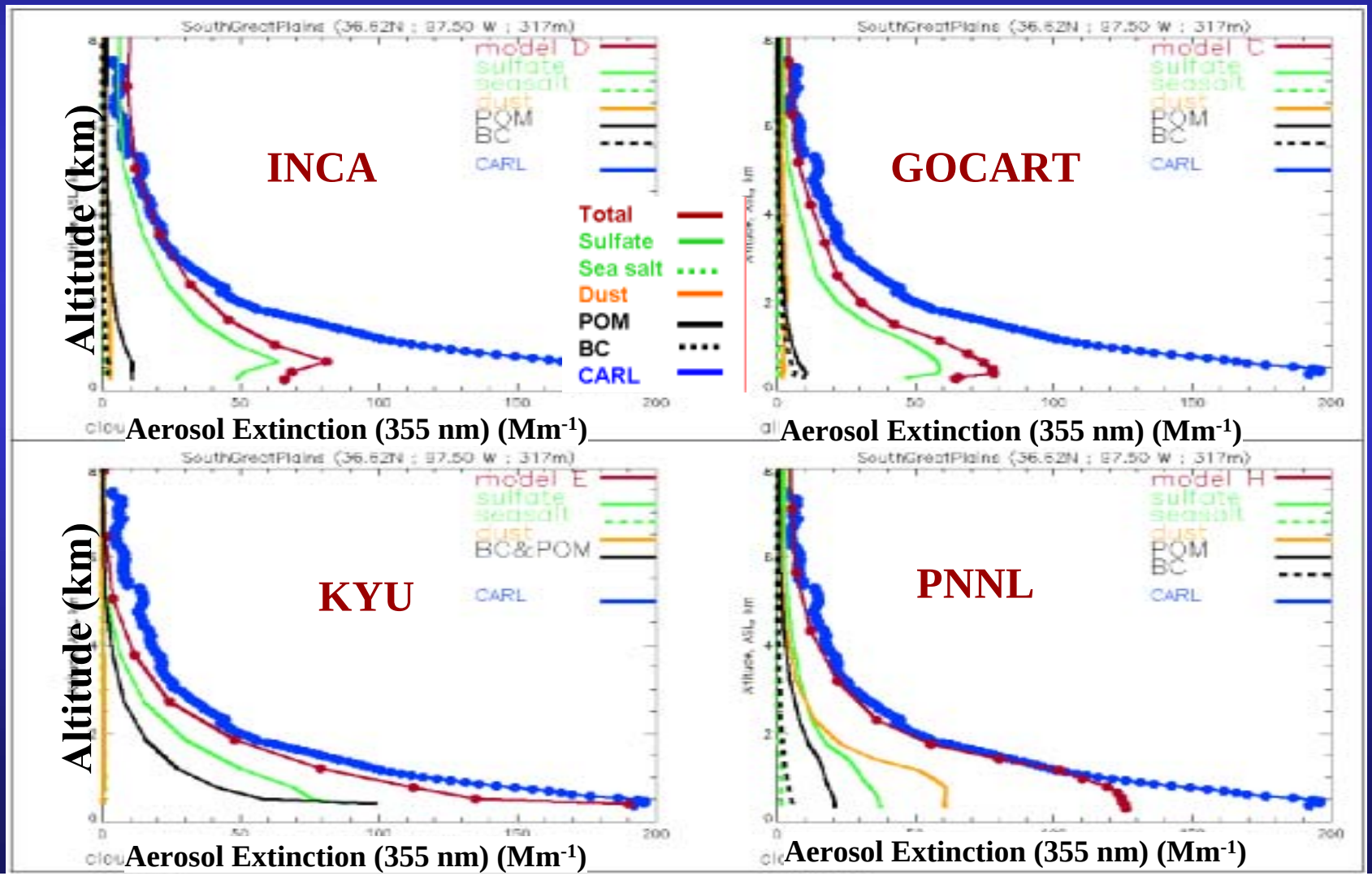


Measured vs. Modeled Monthly Average Aerosol Extinction Profiles



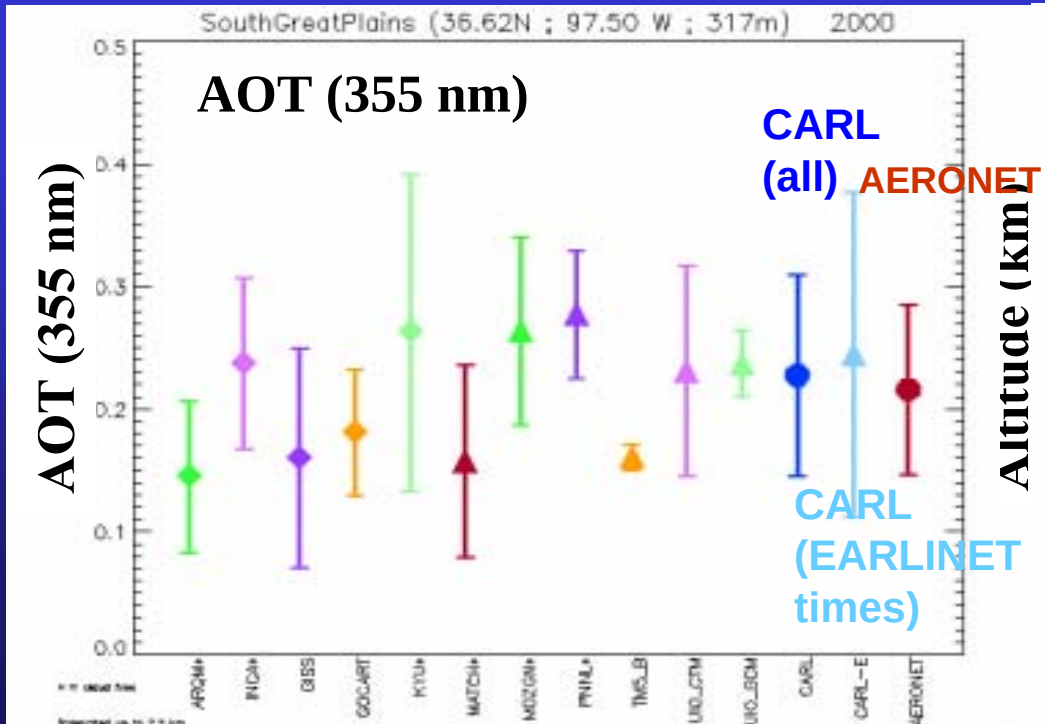
Measured versus Modeled Yearly Average Aerosol Extinction Profiles

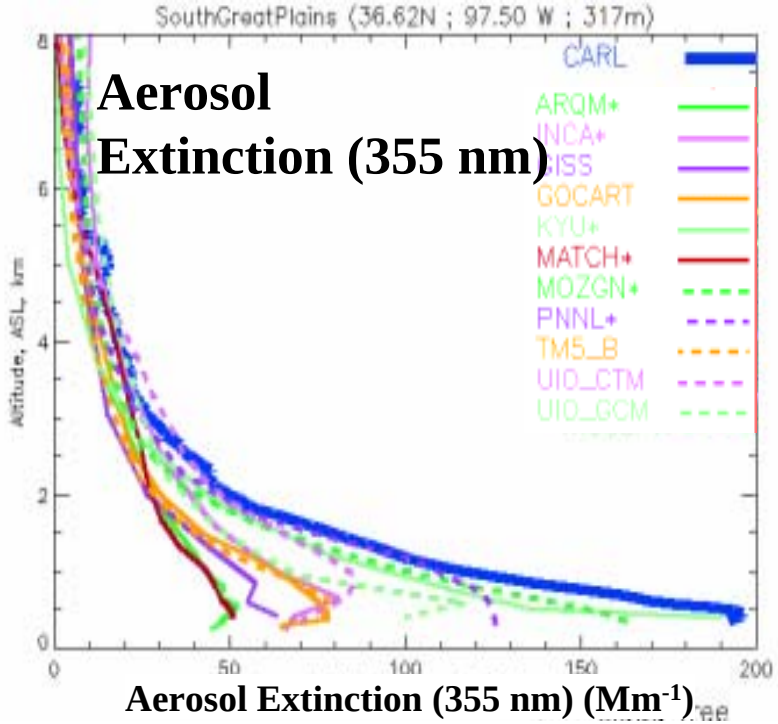
- Large variability in modeled vertical distributions and aerosol components
- Profile behavior of various aerosol constituents may give indication of model strengths and weaknesses



Measured versus Modeled Aerosol Optical Thickness

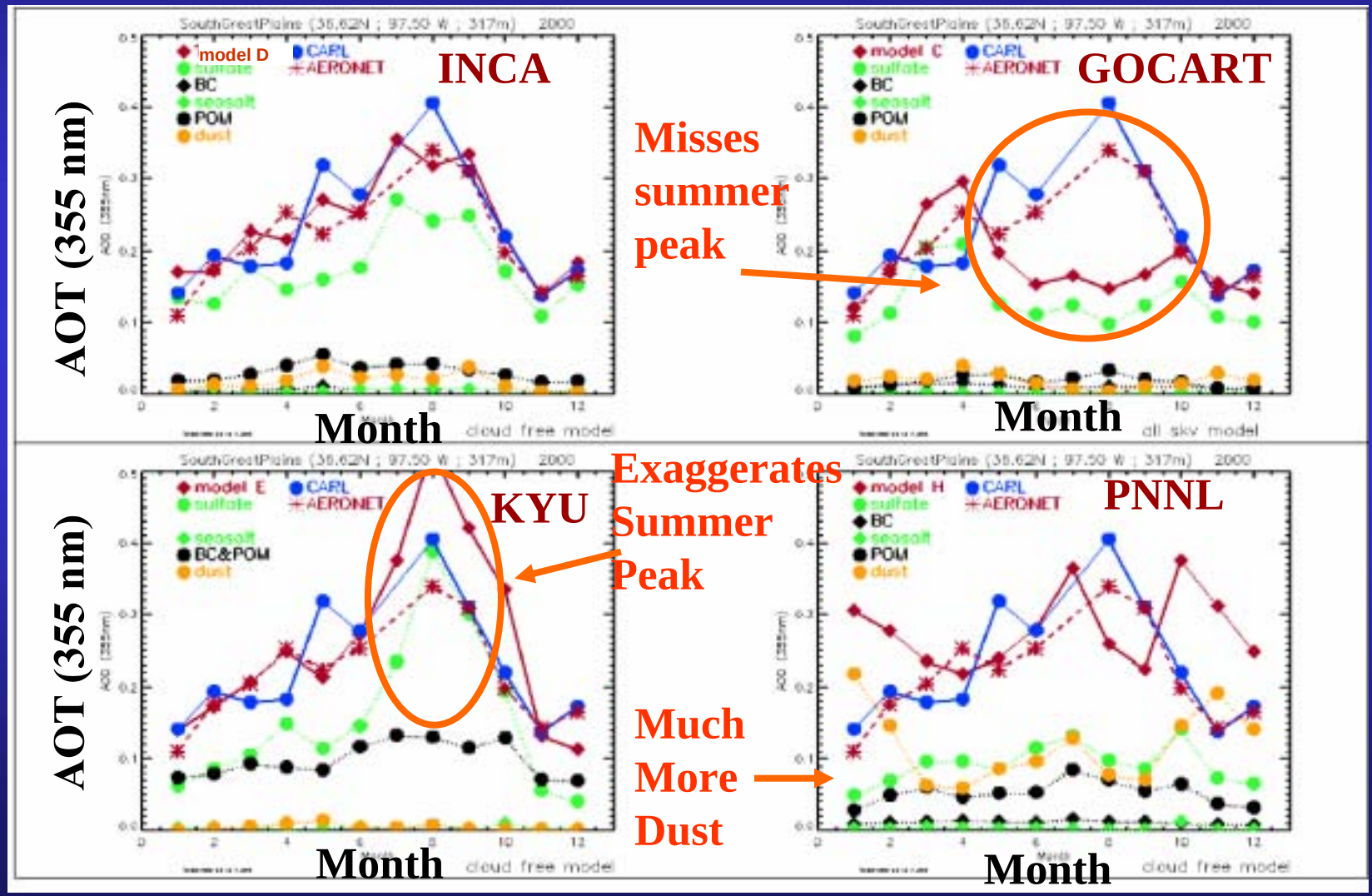
- Although models may agree in total AOT, significant differences can exist in vertical distributions and contributions to AOT from various aerosol components
- Averaging on larger temporal and/or spatial scales gives better agreement
- Deviations between mean aerosol extinction profiles are generally small (~20-30%) for altitudes above 2 km, and grow considerably larger below 2 km
- Models generally have lower aerosol extinction near the surface; perhaps due to
  - too little vertical mixing
  - not enough humidification of aerosol
  - potential high bias of lidar measurements near surface





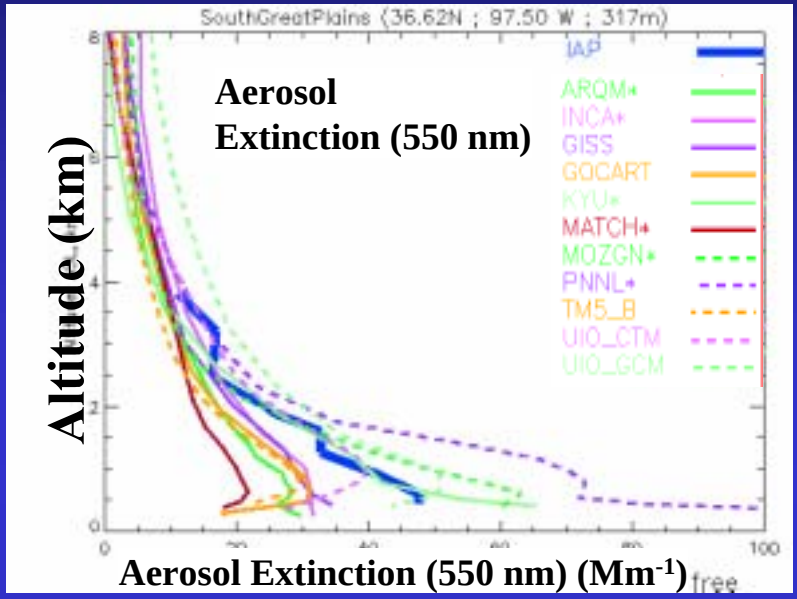
Measured versus Modeled Aerosol Optical Thickness

- Seasonal variation of total AOT varies among the models
- Proportion of AOT due to various aerosol components varies among the models

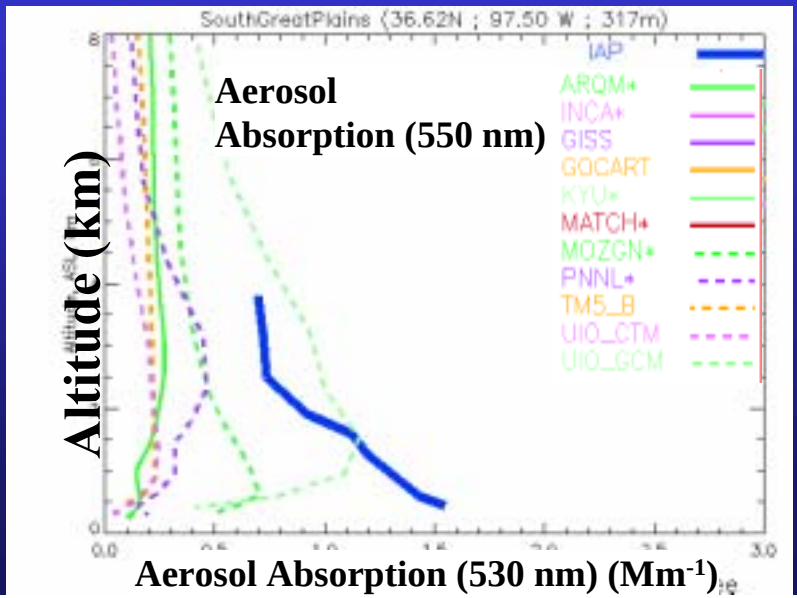


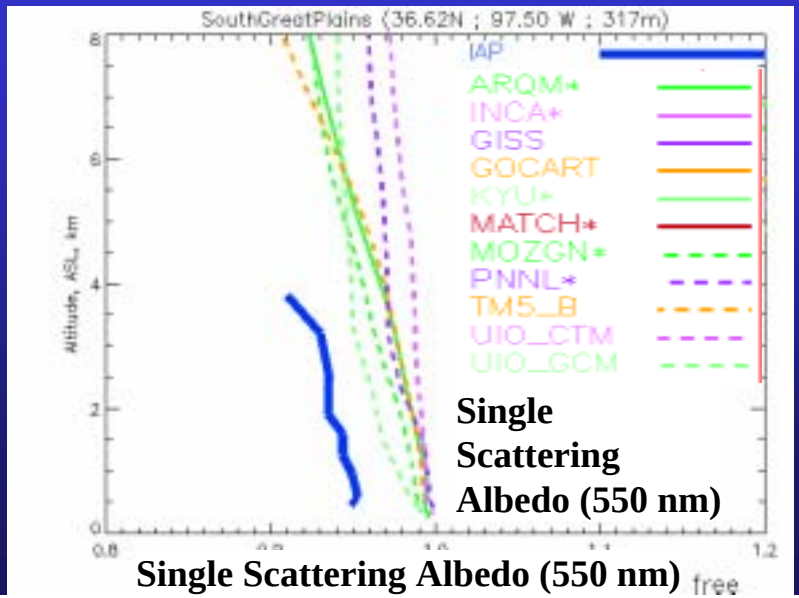
In Situ Aerosol Profiling (IAP) - 2000

(Andrews et al., JGR, 2004)

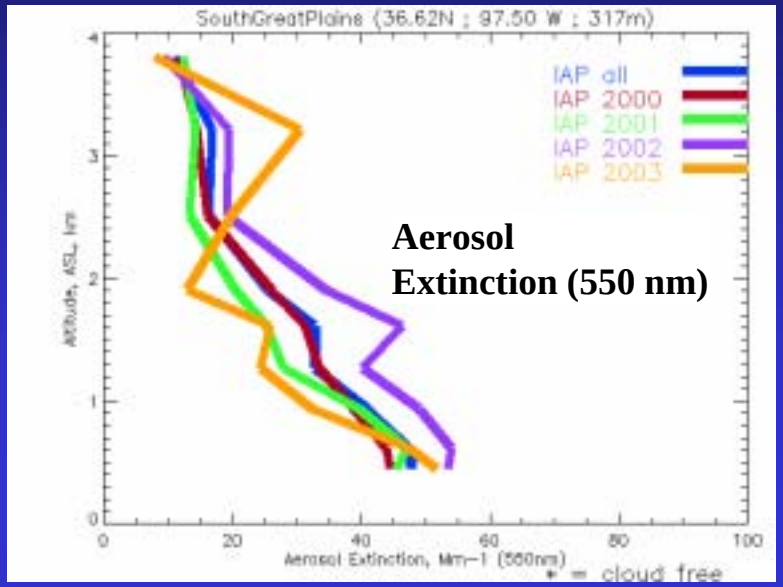


- Daytime measurements 2-3 times/week
- Primary Measurements
  - Aerosol scattering (3 λ) (dry)
  - Aerosol absorption (1 λ) (dry)
  - Hemispheric backscatter fraction (dry)
- Derived Parameters
  - Aerosol single scatter albedo
  - Aerosol optical thickness
  - Angstrom exponents
- Converted to ambient humidity using f(RH) measured at surface
- Applied supermicron scattering correction derived from surface

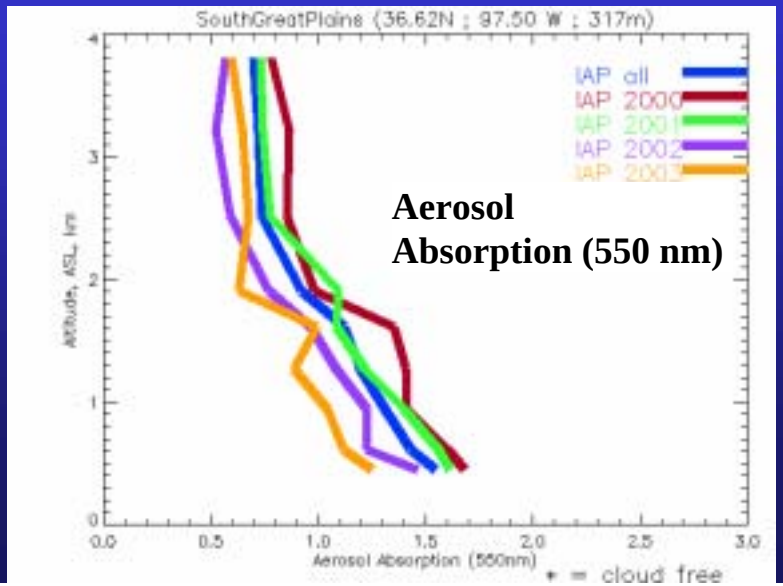


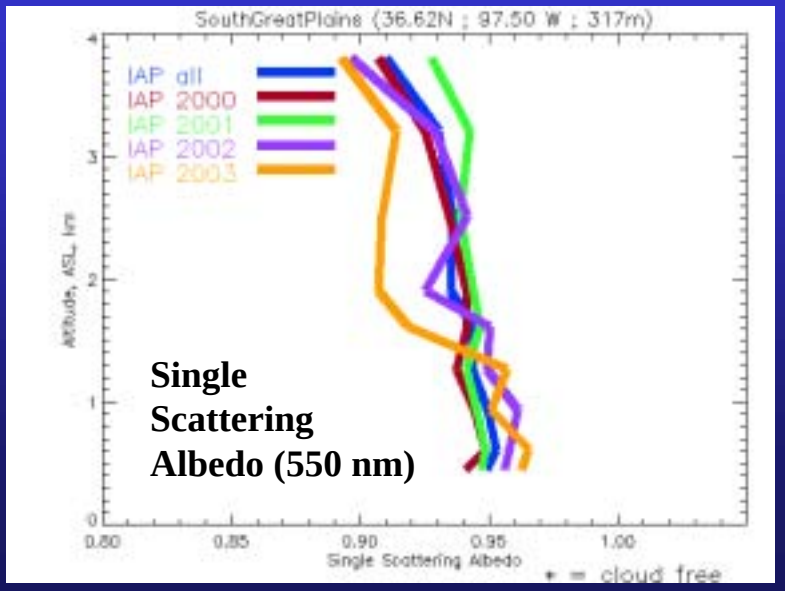


In Situ Aerosol Profiling (IAP) – 2000-2003



- **Measurements suggest small decrease in absorption and increase in single scatter albedo with time**
- **Measurements show decrease in single scatter albedo with altitude**

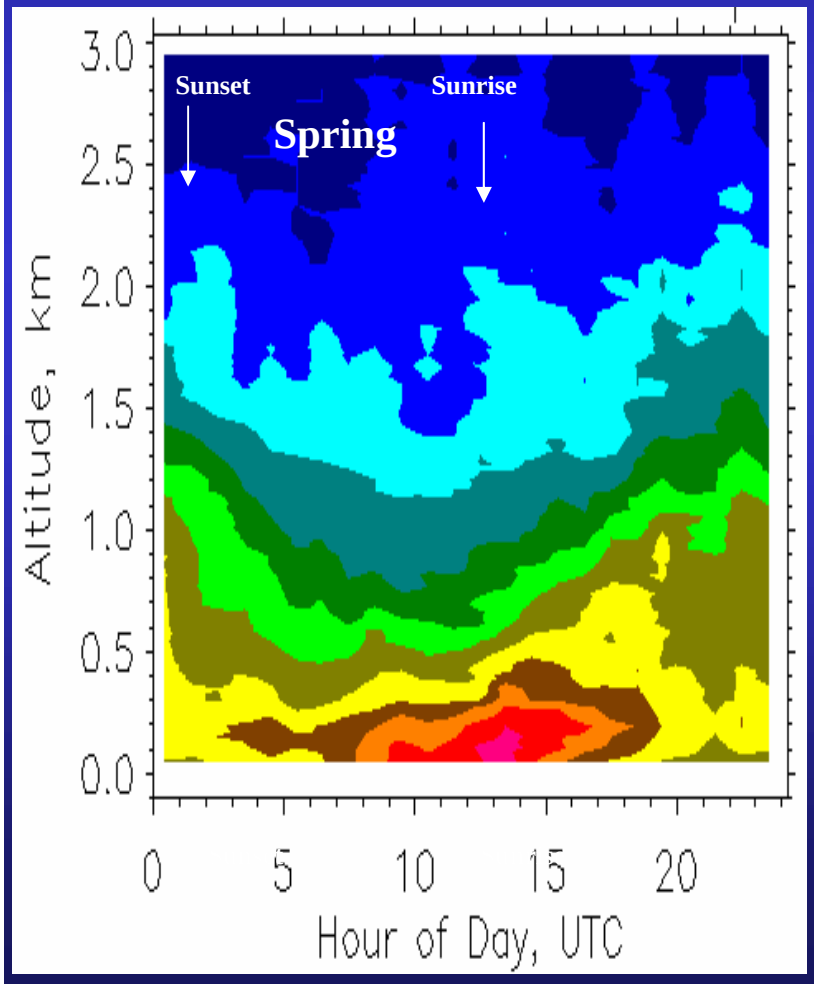


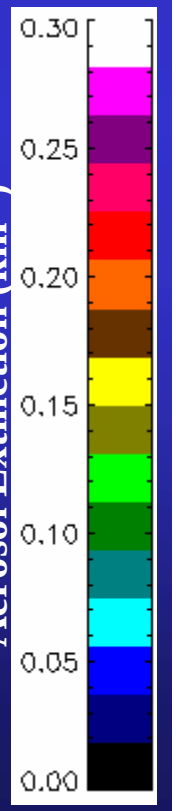


Correlation between Aerosol Extinction and Relative Humidity

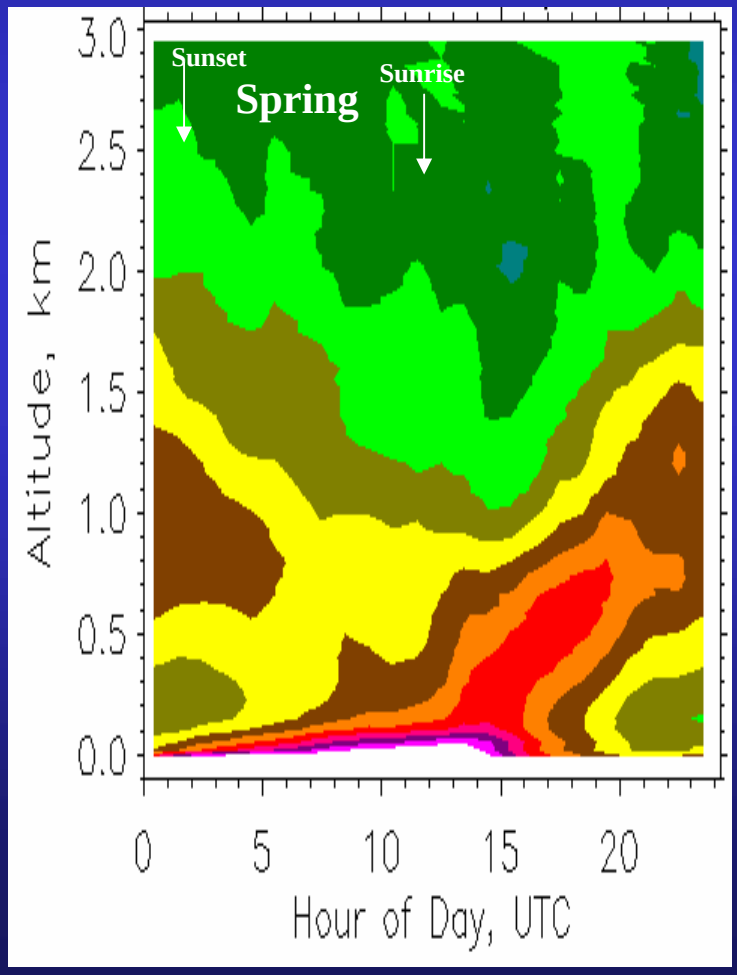
- CARL aerosol extinction profiles averaged over 946 days (Mar. 1, 1998 – Dec. 31, 2001)
- Higher extinction concentrated over smaller vertical extent at night
- Highest aerosol extinction and RH found near surface at night

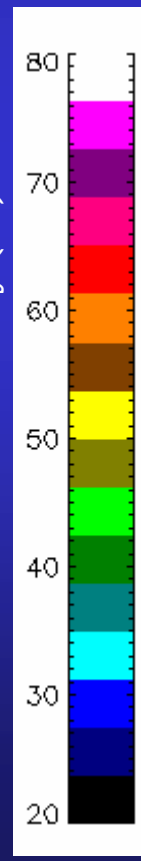
Aerosol Extinction





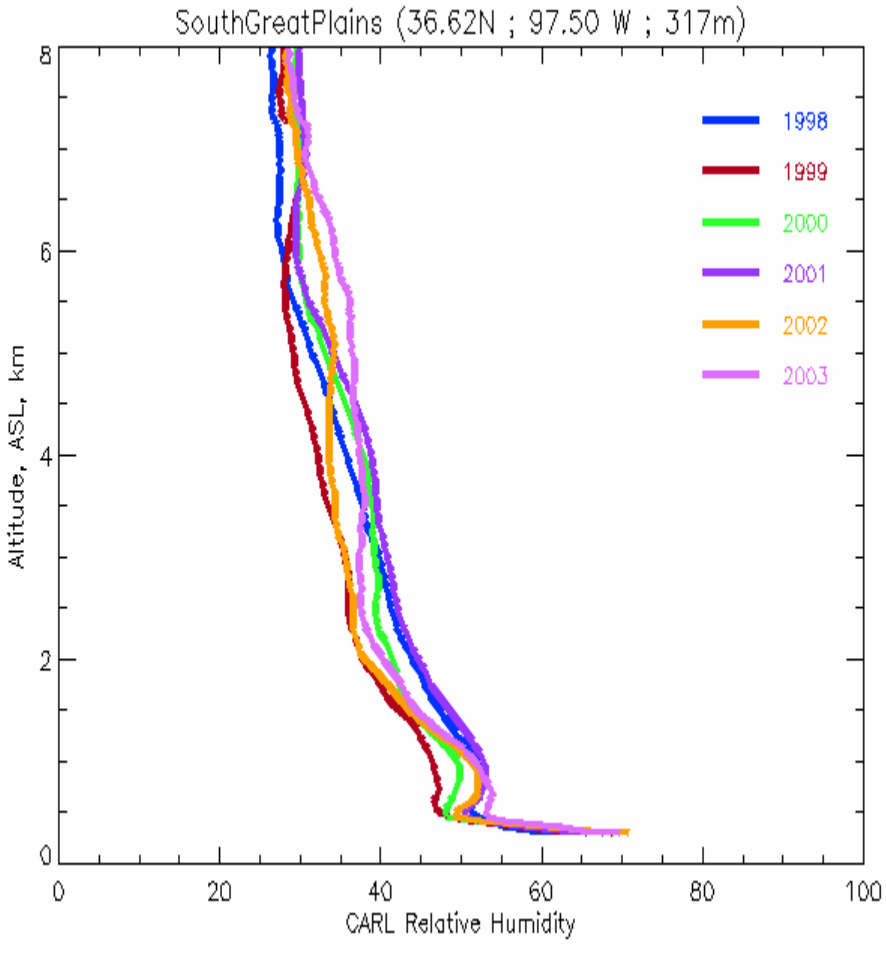
Relative Humidity

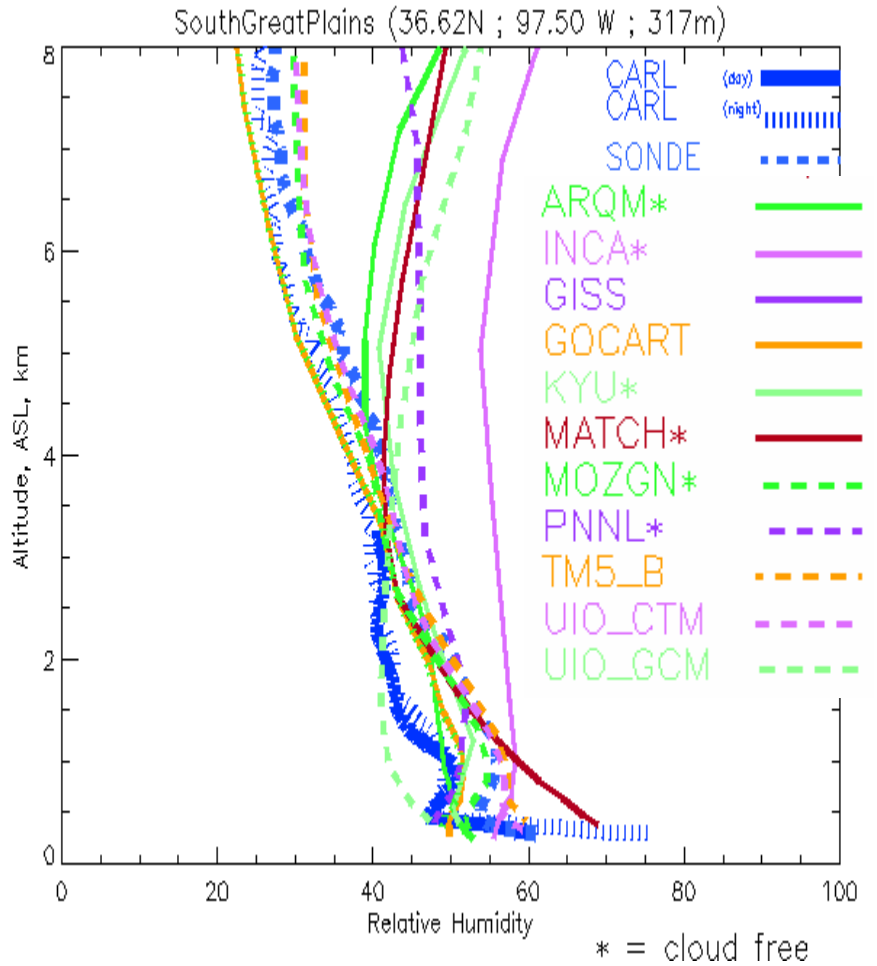




Relative Humidity Profile Comparisons

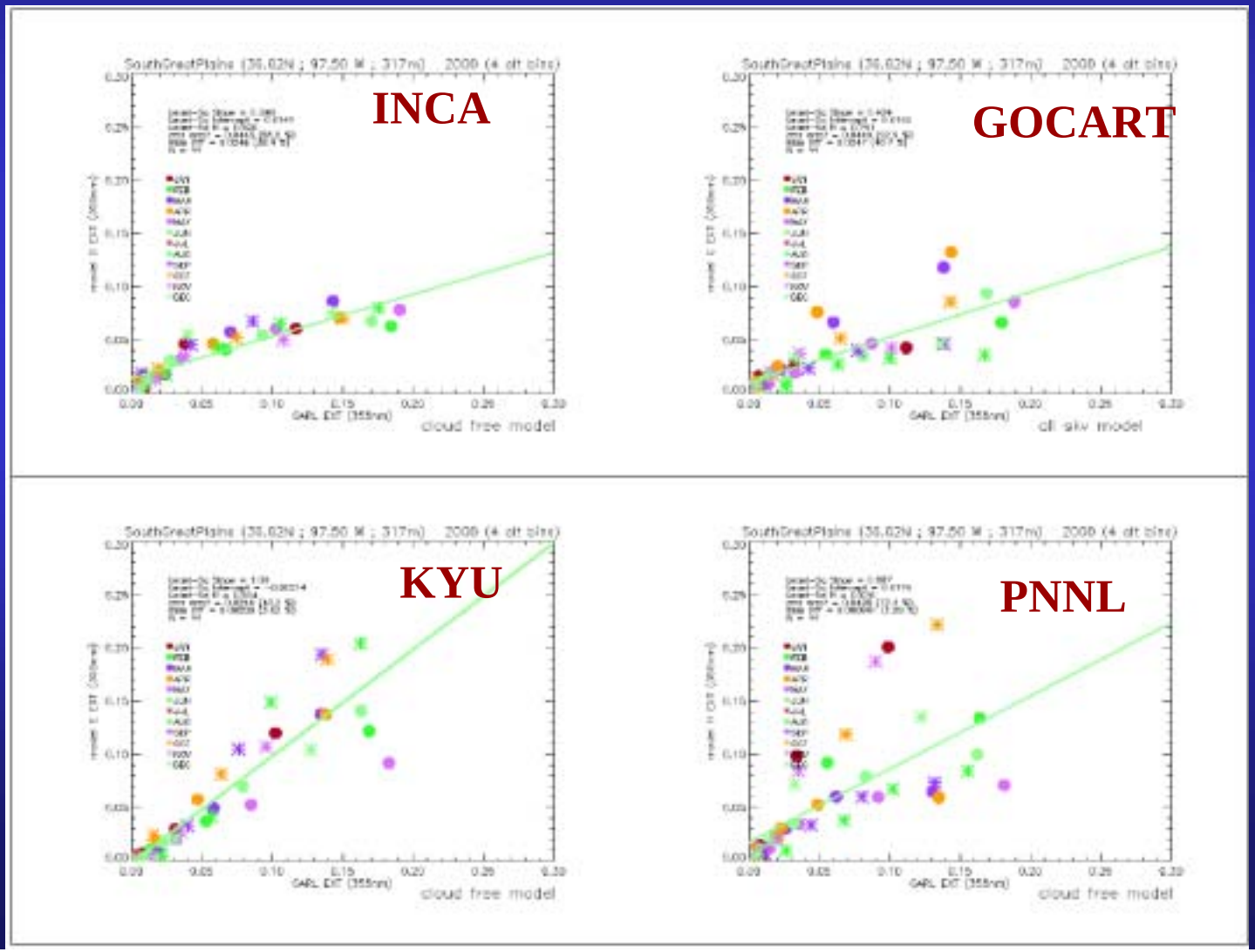
- CARL integrated water vapor measurements calibrated to match microwave radiometer total column water
- CARL water vapor measurements acquired during clear skies and so annual average slightly drier than radiosonde average





Aerosol Extinction Regression Results

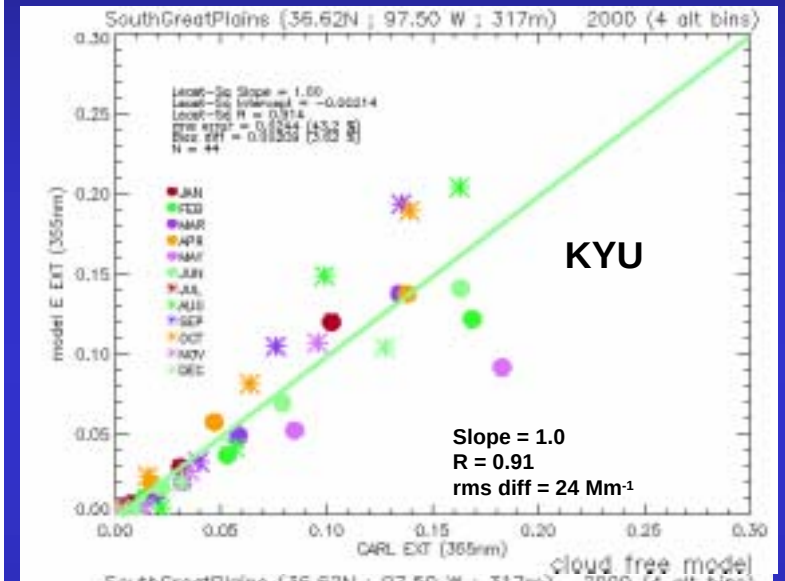
- Regressions computed using monthly averages from 0-8 km
- Slopes 0.4-1.0, indicative of differences in the lowest few km
- Correlation coefficients 0.7-0.9; Bias differences 0-30 Mm^{-1}

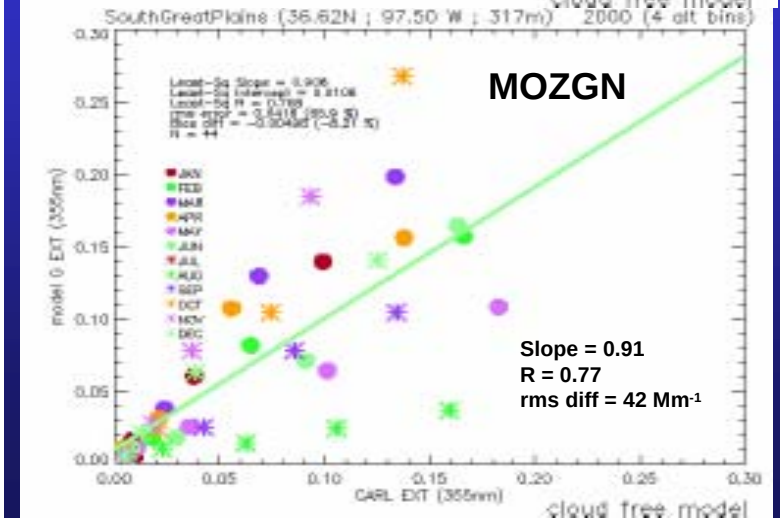


Aerosol Extinction Regression Results

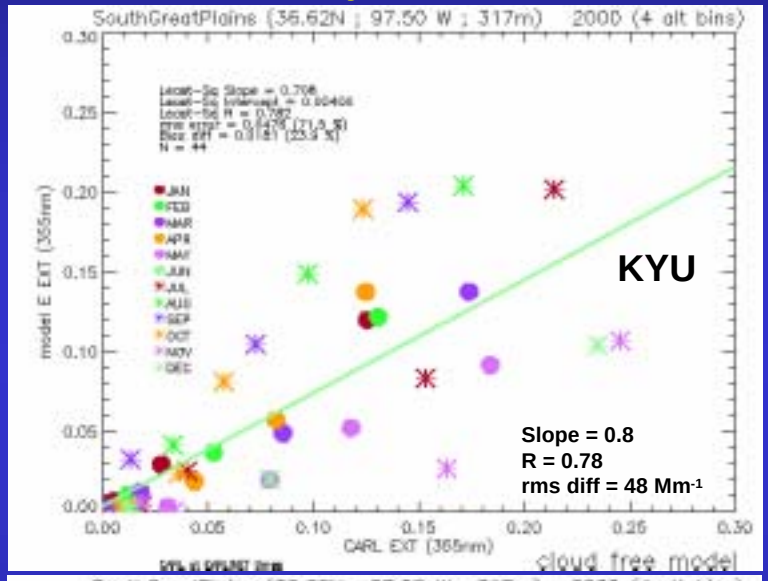
- Regressions computed using monthly averages from 0-8 km
- Using data at all times and not just at EARLINET times, reduces bias errors, increases correlation, and increases slopes

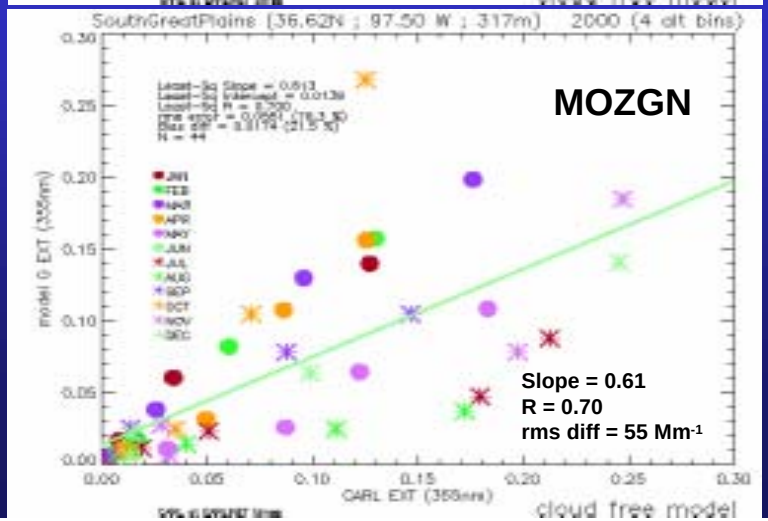
CARL data at all times





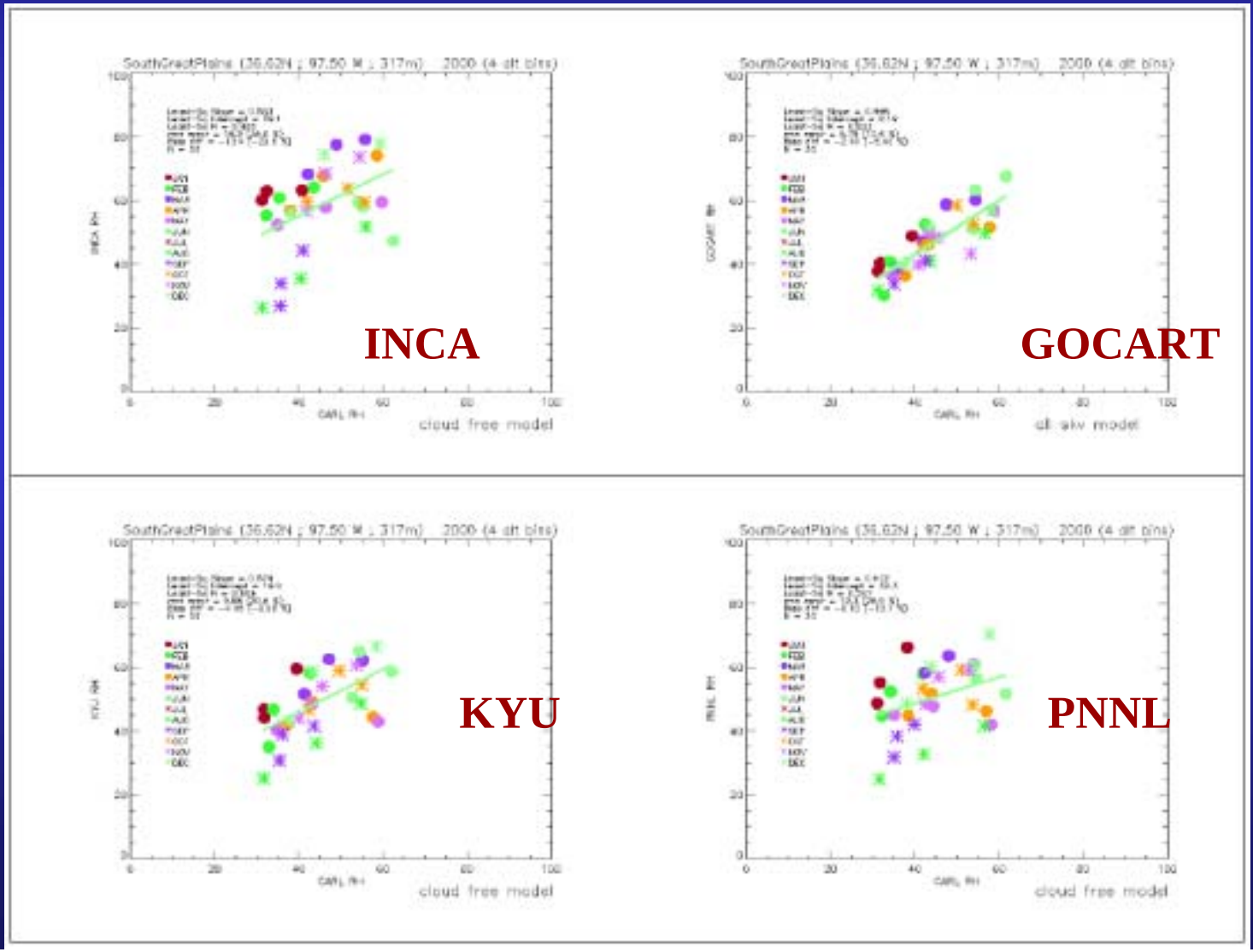
CARL data only at EARLINET times





Relative Humidity Regression Results

- Regressions computed using monthly averages from 0-3 km
- Slopes 0.6-1.0; Correlation coefficients 0.4-0.8; Bias differences 4-8 %

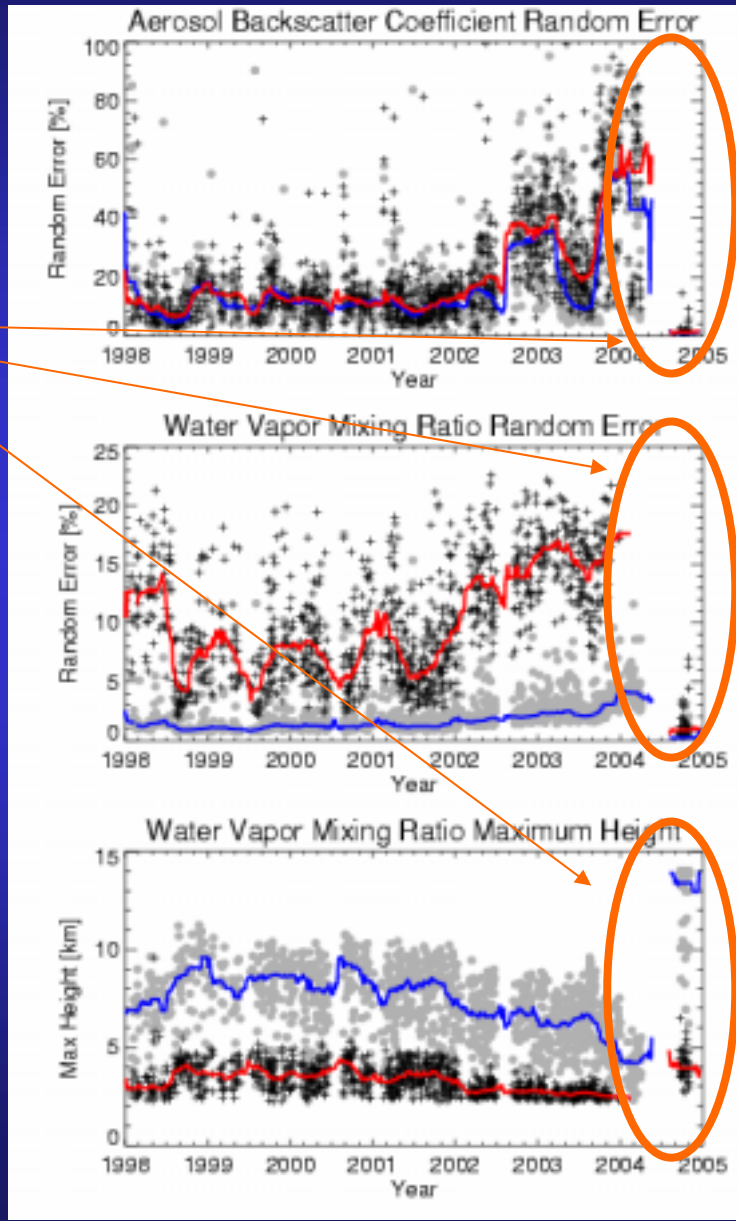


New and Improved CARL

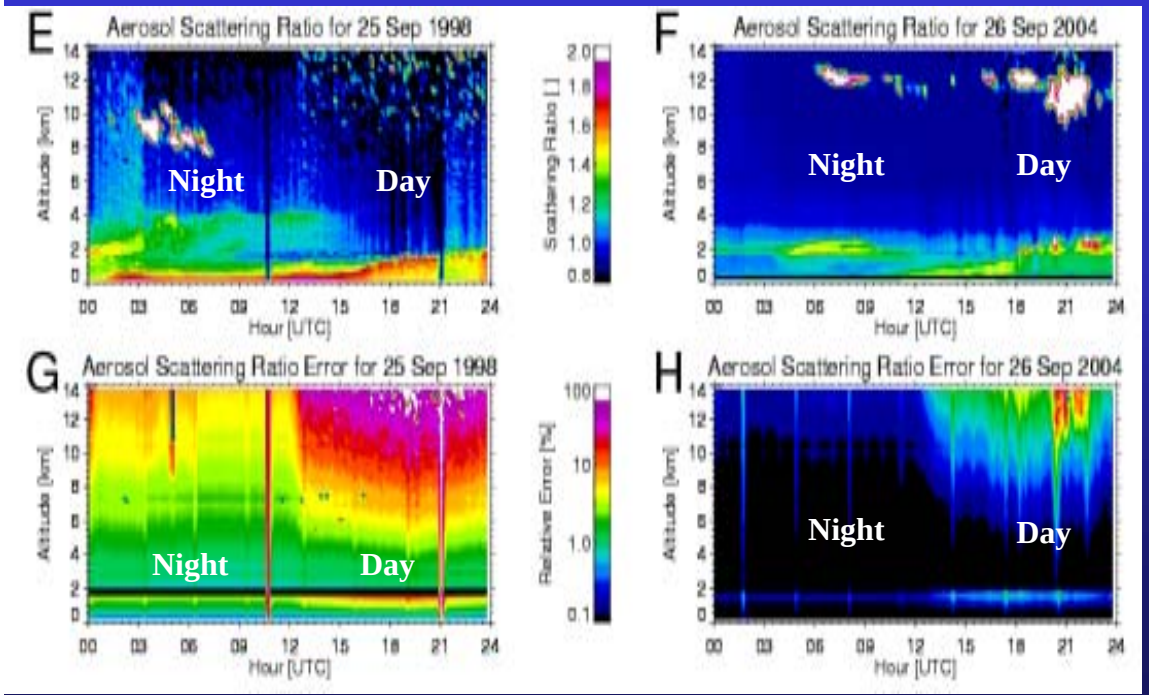
- Since late 2001, CARL signal strengths had decreased
- Impacts:
  - Occasional misalignments – bias errors
  - Reduction in max range
  - Larger random error

Major modifications/upgrades implemented in 2004 dramatically improved CARL measurements

- ➢ Random errors reduced by factor of 10-20
- ➢ Significantly increased max retrieval altitudes

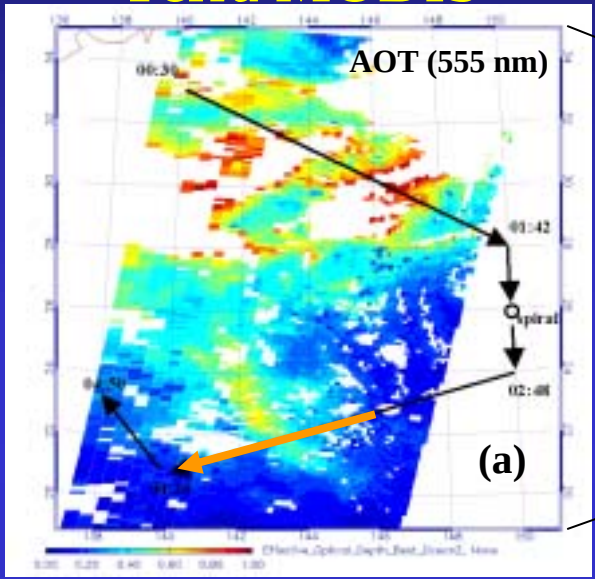


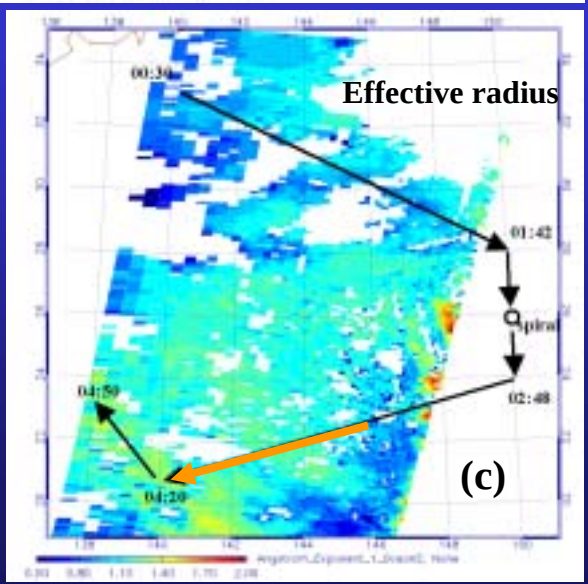
Original **New and Improved**



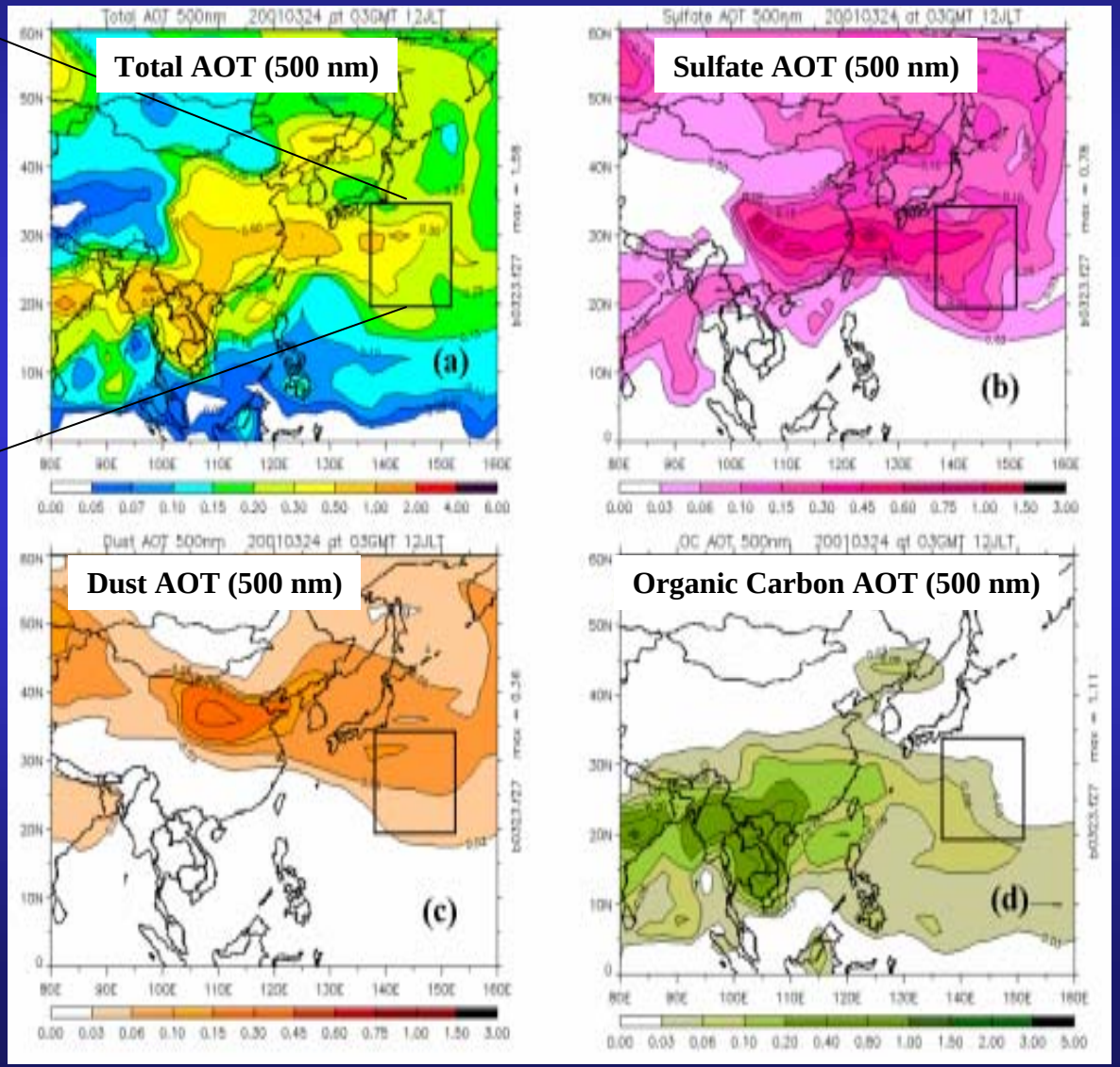
March 24, 2001 Airborne Lidar Measurements

Terra MODIS





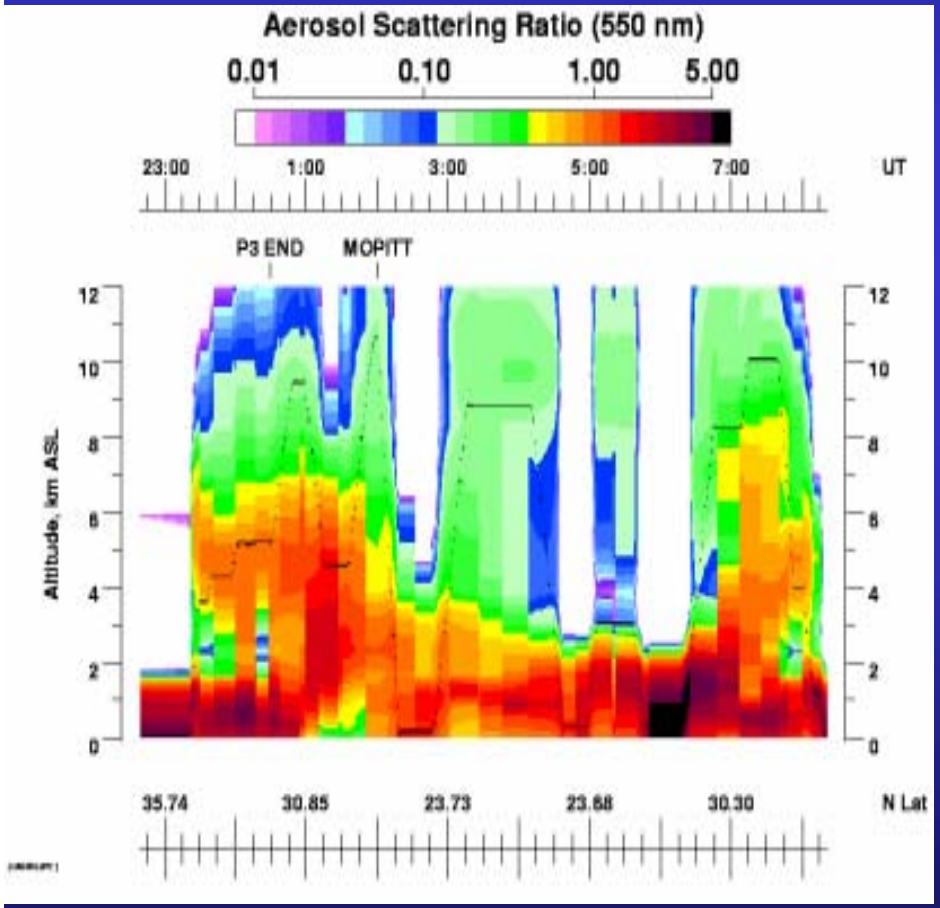
GOCART



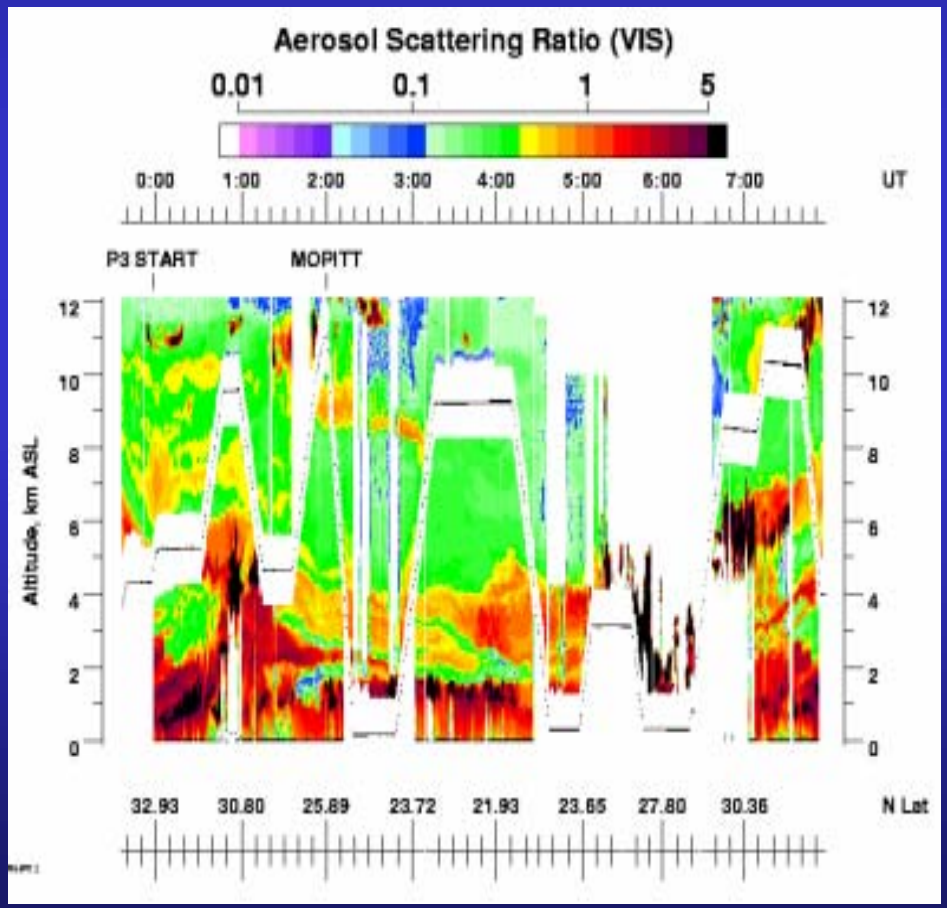
Airborne Lidar Comparison with GOCART

- TRACE-P NASA DC-8 Flight 14 March 23-24, 2001
- Attenuated aerosol scattering ratio from UV DIAL System

GOCART



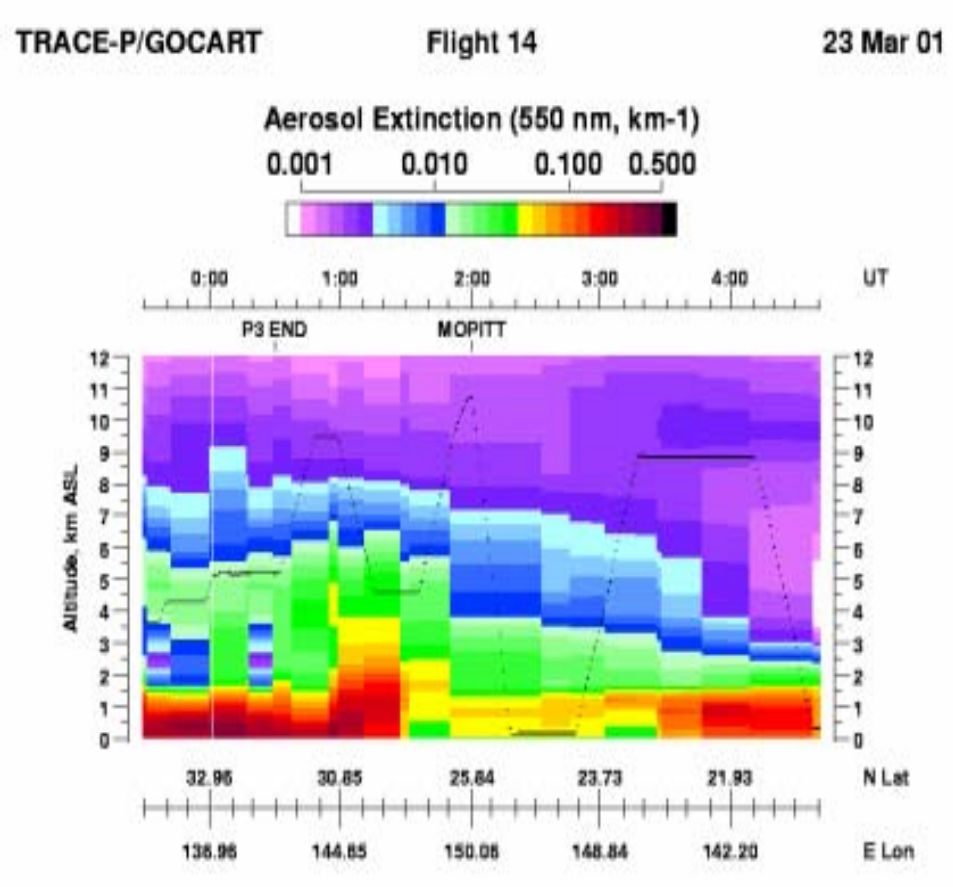
UV DIAL



Airborne Lidar Comparison with GOCART

- TRACE-P NASA DC-8 Flight 14 March 23-24, 2001
- Lidar aerosol retrievals constrained using MODIS AOT
- Aerosol Extinction Coefficient

GOCART



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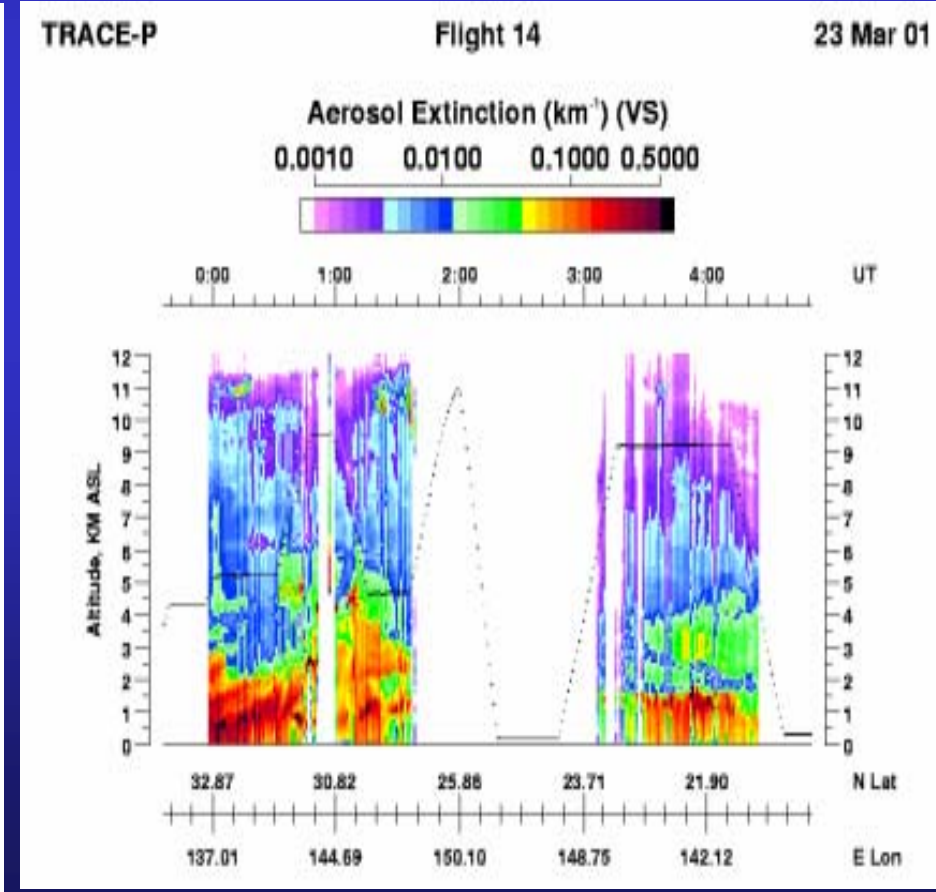
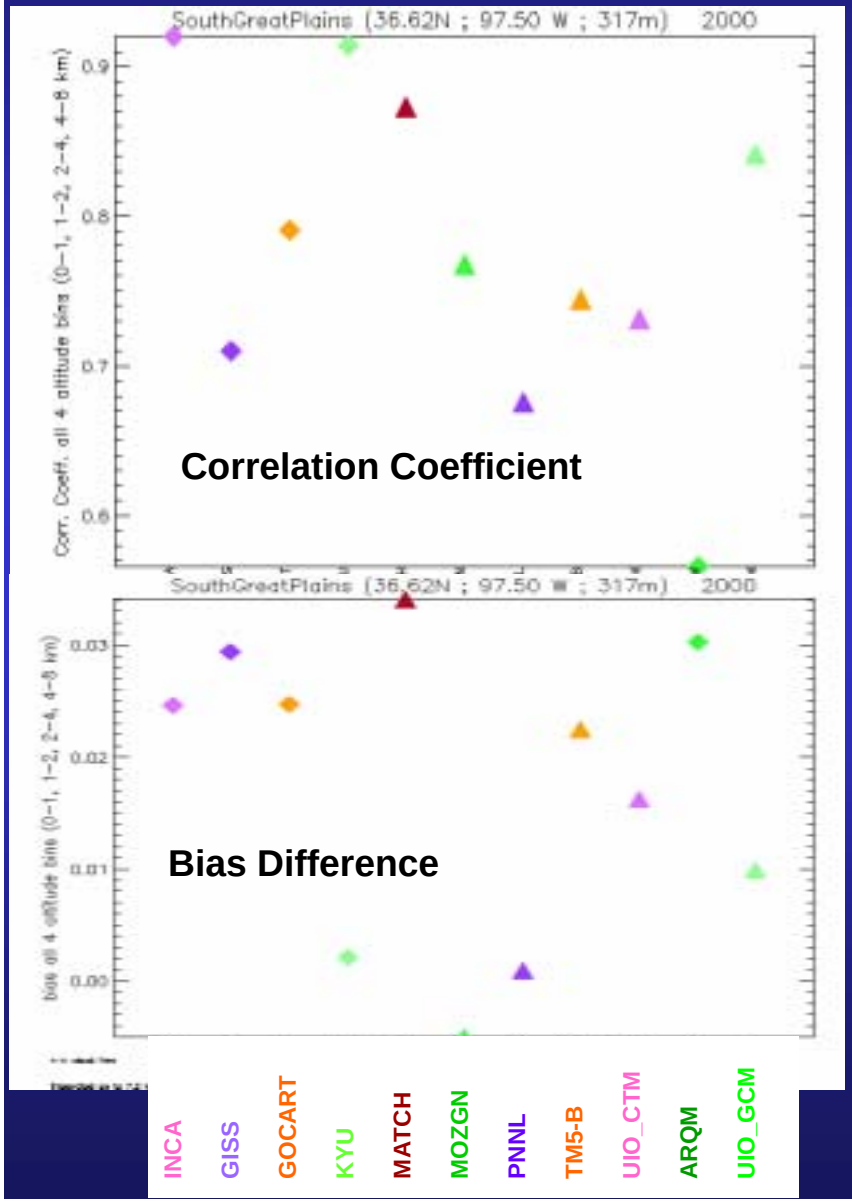


Summary

- CARL routinely provides continuous profiles of aerosol backscattering and extinction, depolarization, RH
- Diurnal variability
  - Large changes in vertical profile, smaller changes in integrated values
  - Correlations in aerosol extinction, relative humidity
- Model mean aerosol profiles typically show smaller vertical variability than the mean CARL observations
- Average model profiles of aerosol extinction are generally smaller than CARL measurements, especially in lower levels
- Average model profiles of relative humidity are in better agreement with CARL measurements than aerosol extinction
- In situ aerosol measurements on periodic small aircraft flights suggest that models underestimate aerosol absorption
- Airborne profiles provide additional, periodic dataset to evaluate model performance over a wide range of locations and aerosol types

Aerosol Extinction Regression Results



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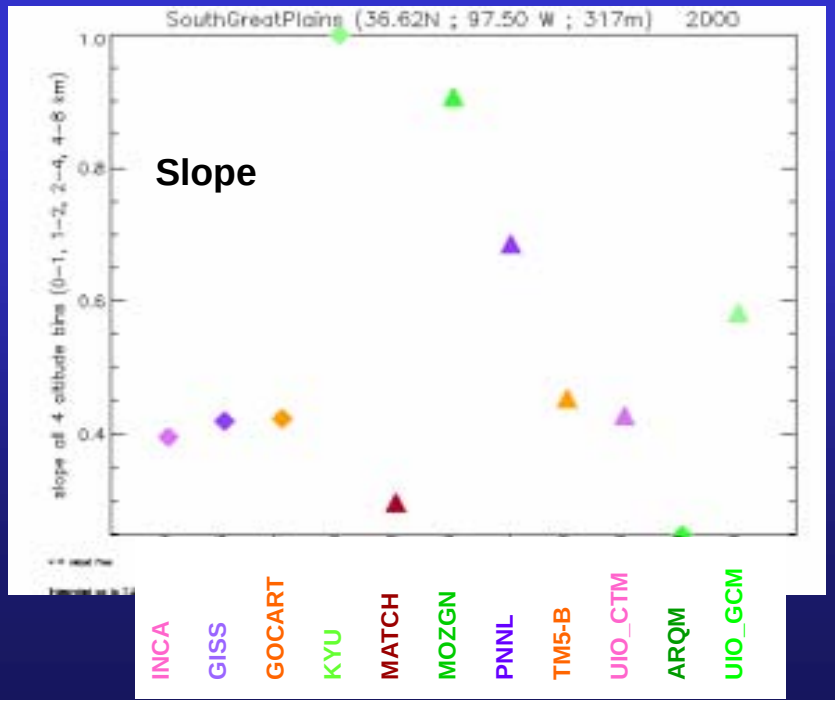
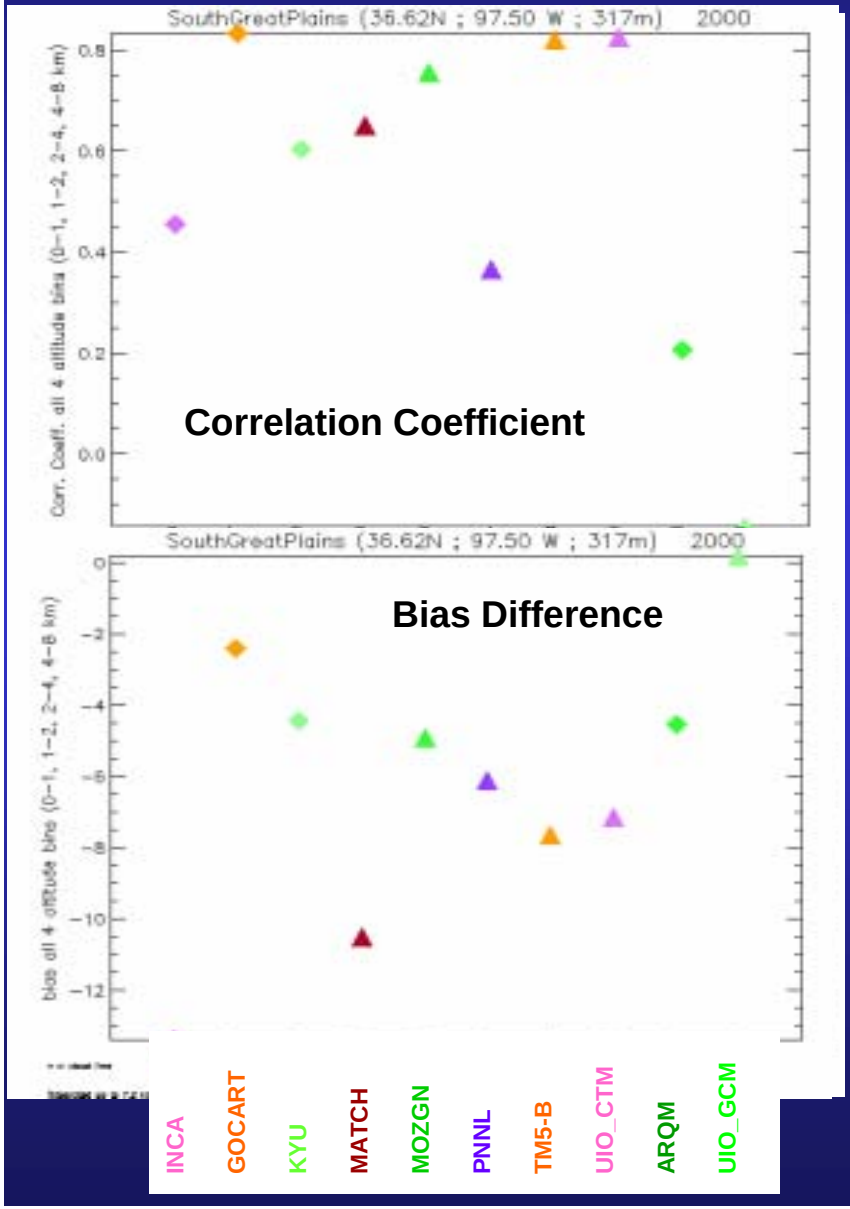
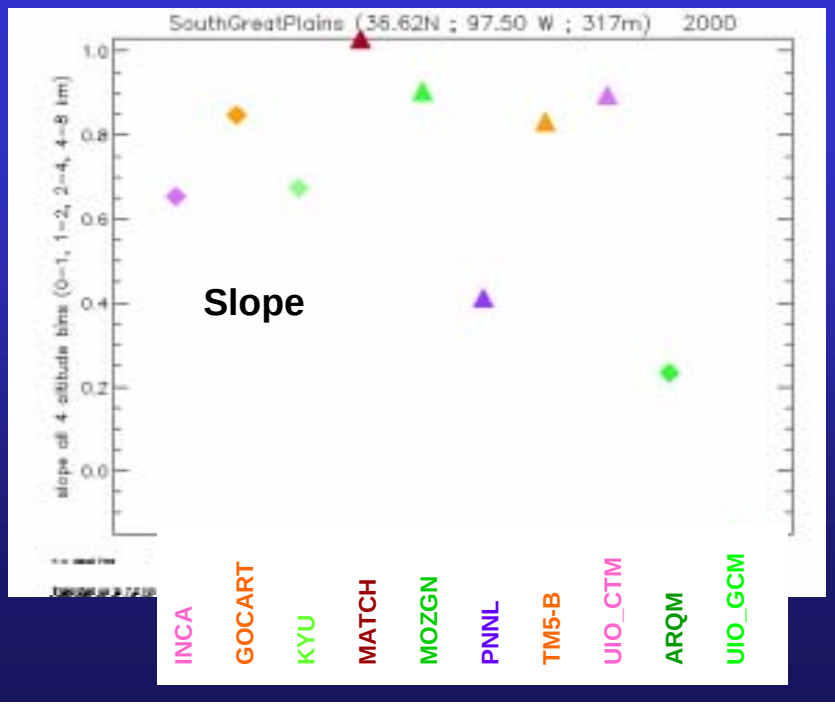
- Correlation coefficients 0.7-0.9
- Bias differences 0-30 Mm^{-1}



Relative Humidity Regression Results

- Regressions computed using monthly averages from 0-3 km
- Slopes 0.6-1.0
- Correlation coefficients 0.4-0.8
- Bias differences 4-8 %



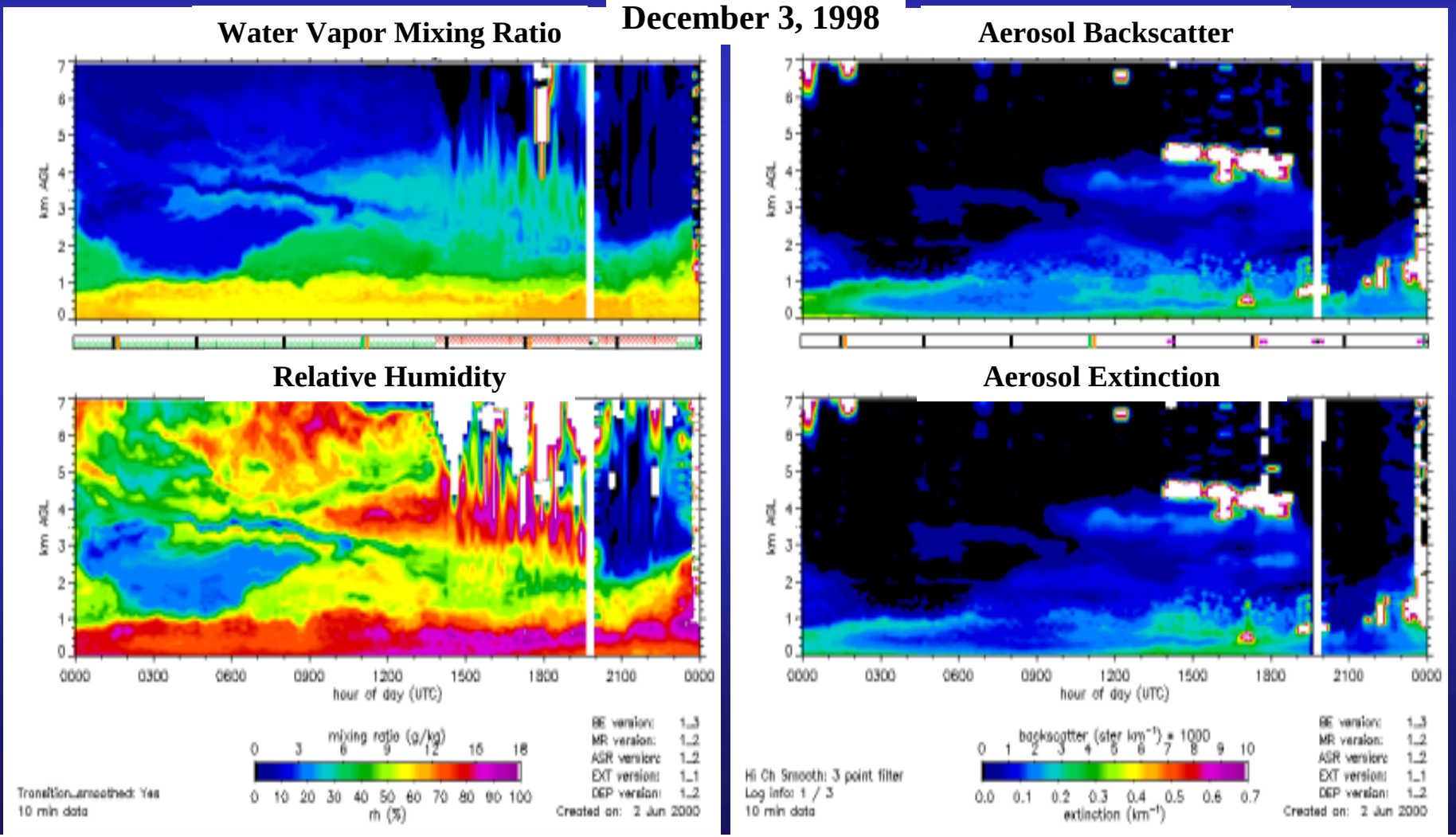


CARL Aerosol and Water Vapor Profiles

Automated algorithms for routine retrievals of water vapor and aerosol profiles
(Turner et al., *J. Atmos. Oceanic Tech.*, 19, 2002)

Data: available via ftp from ARM Experiment Center (http://www.arm.gov)

Color images at: http://playground.arm.gov/~turner/raman_lidar_quicklooks.html



Models

Sprintars, Kyushu University, Kyushu (KYU) Toshihiko Takemura et al.

LMDzT-INCA, Lab Science Climat et de l'Enivonnement, Paris (LSCE) Michael Schulz, Yves Balkanski, Christiane Textor, Sylvia Generoso, Sarah Guibert, Didier Hauglustaine

GCM/ CAM, ARQM Met Service Canda, Toronto (ARQM) Sunling Gong et al.

MIRAGE, Battelle, Pacific Northwest National Laboratory, Richland (PNNL) Steve Ghan and Richard Easter

CTM2,Univ. of Oslo, Oslo (UIO- CTM) Gunnar Myhre et al.

ULAQ- CCM, Universita degli Studi L'Aquila (ULAQ) Giovanni Pitari, Eva Mancini and Veronica Montanaro

CCM- Oslo, Univ. of Oslo, Oslo(UIO- GCM) Trond Yversen, Oyvind Seland, J. E. Kristjansson

MATCH, NCAR, Boulder (MATCH) David Fillmore, Phil Rasch, Bill Collins

IMPACT/ DAO, Univ Michigan, Ann Arbor (UMI) Joyce Penner et al.

GISS, Dorothy Koch und Susanne Bauer

TM5 (IMAU) Maarten Krol, Frank Dentener

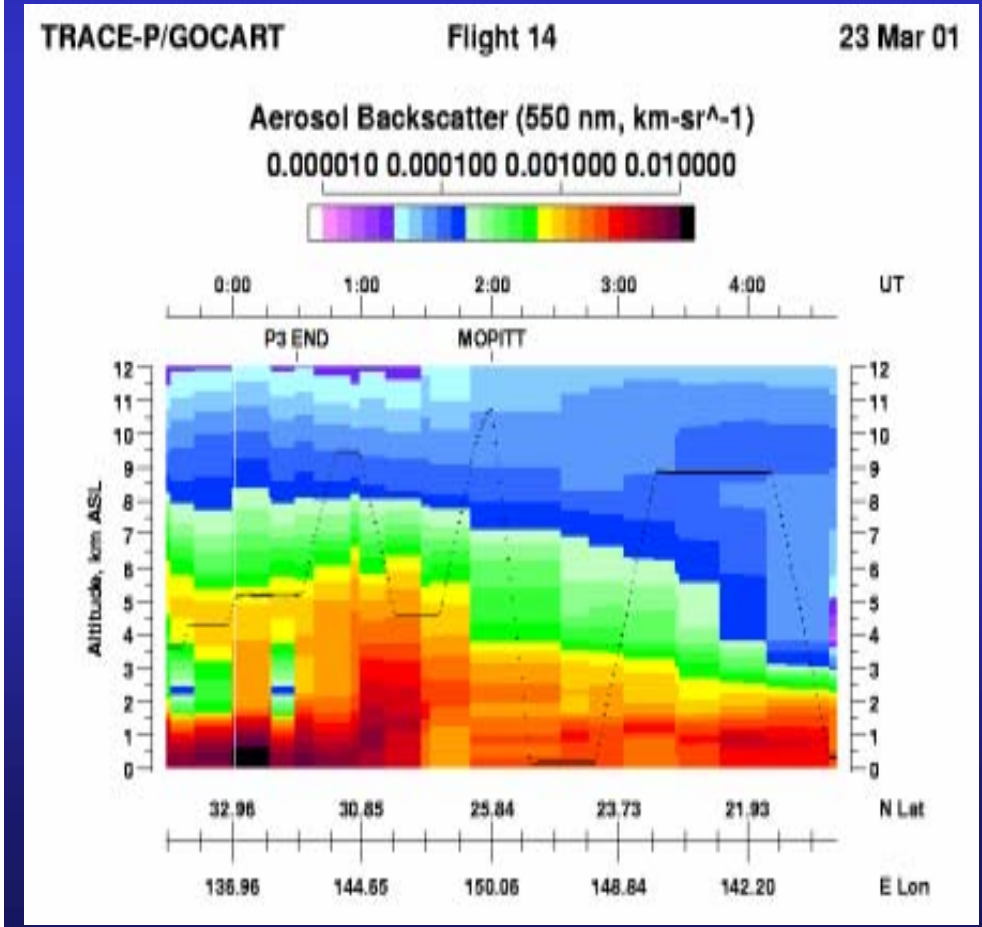
GOCART, Mian Chin, Paul Ginoux

MOZART- GFDL- NCAR (MOZGN) (NOAA- GFDL& NCAR) Larry Horowitz, Xuexi Tie, Jean-Francois Lamarque, Paul Ginoux

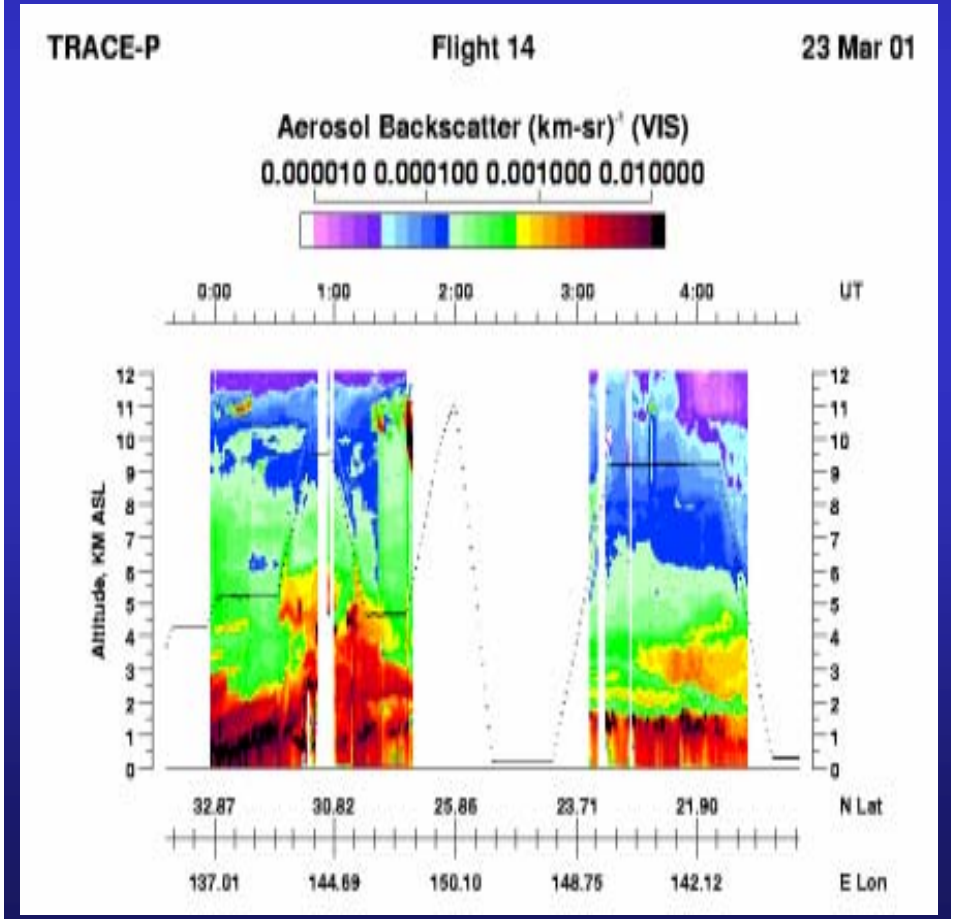
Airborne Lidar Comparison with GOCART

- TRACE-P NASA DC-8 Flight 14 March 23-24, 2001
- Lidar aerosol retrievals constrained using MODIS AOT
- Aerosol Backscatter Coefficient

GOCART

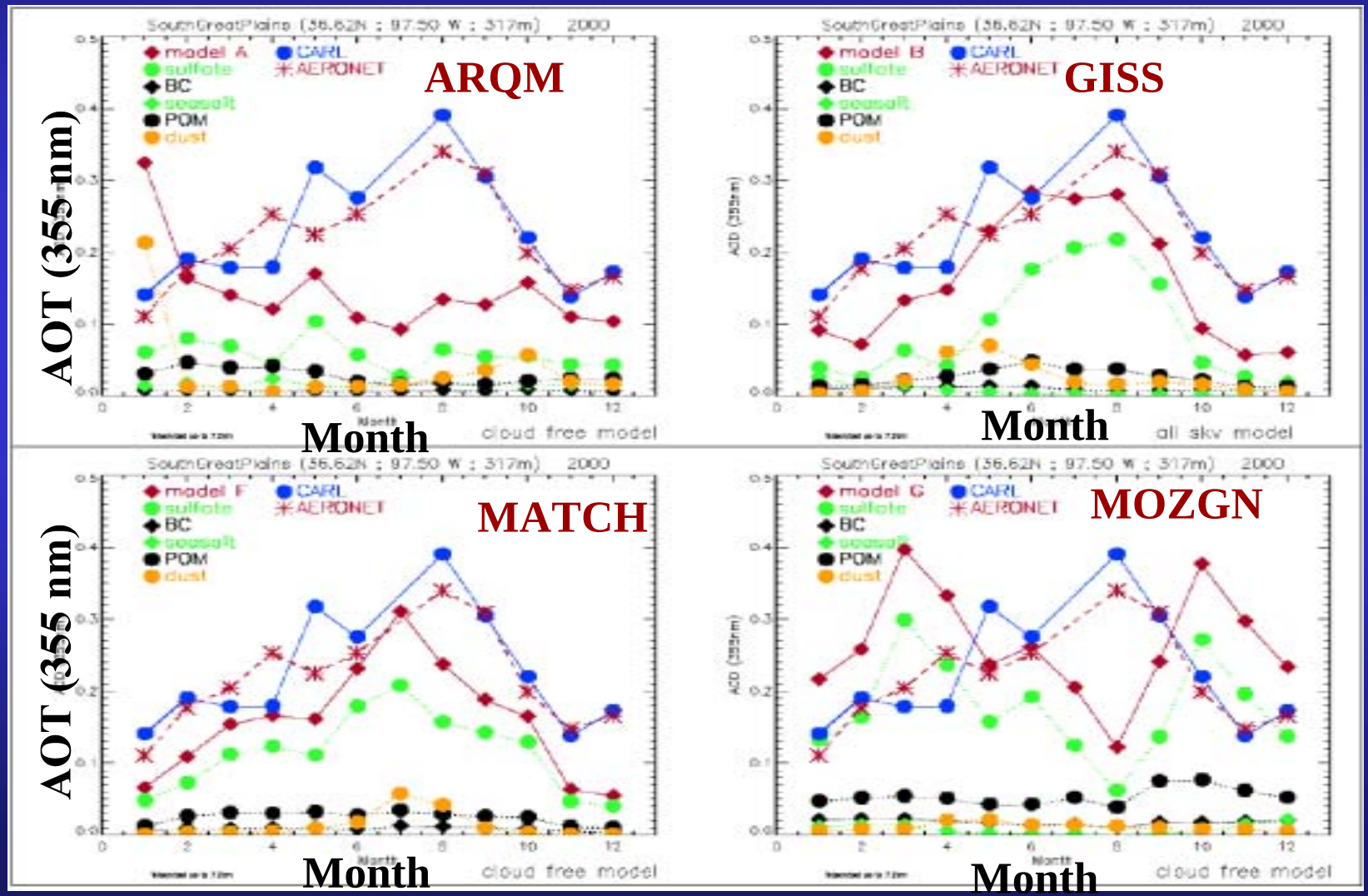


UV DIAL

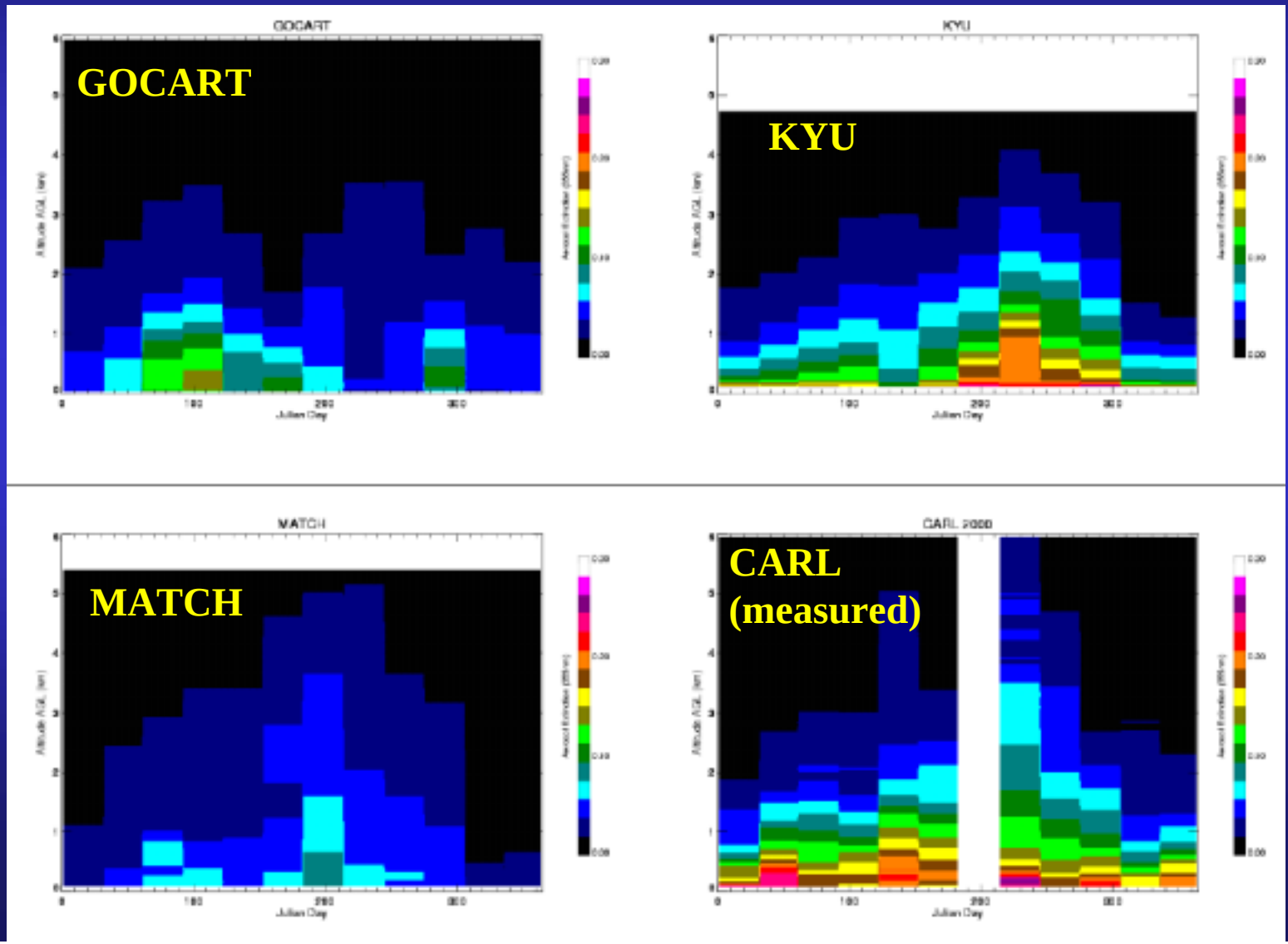


Measured versus Modeled Aerosol Optical Thickness

- Seasonal variation of total AOT varies among the models
- Proportion of AOT due to various aerosol components varies among the models

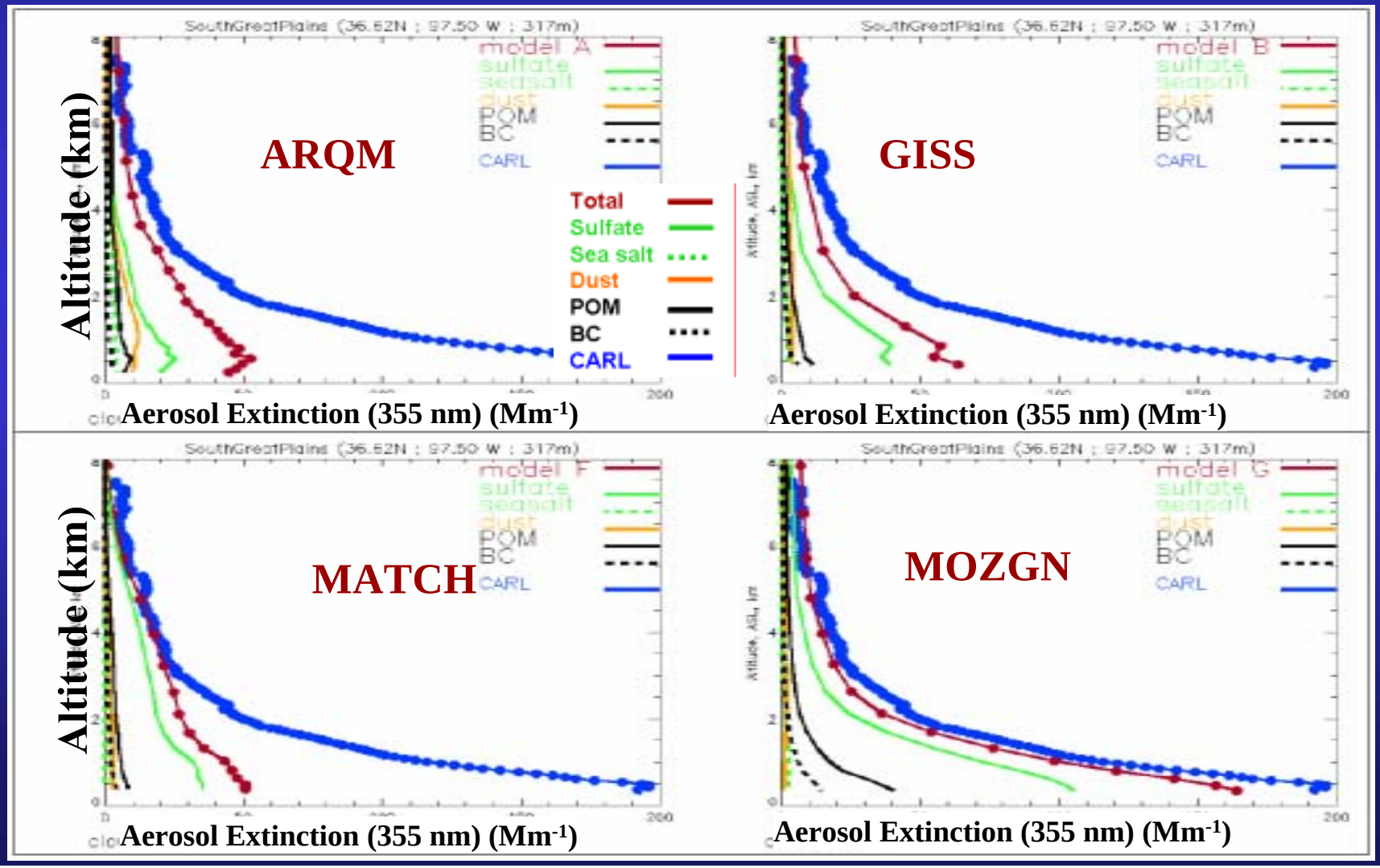


Measured vs. Modeled Monthly Average Aerosol Extinction Profiles

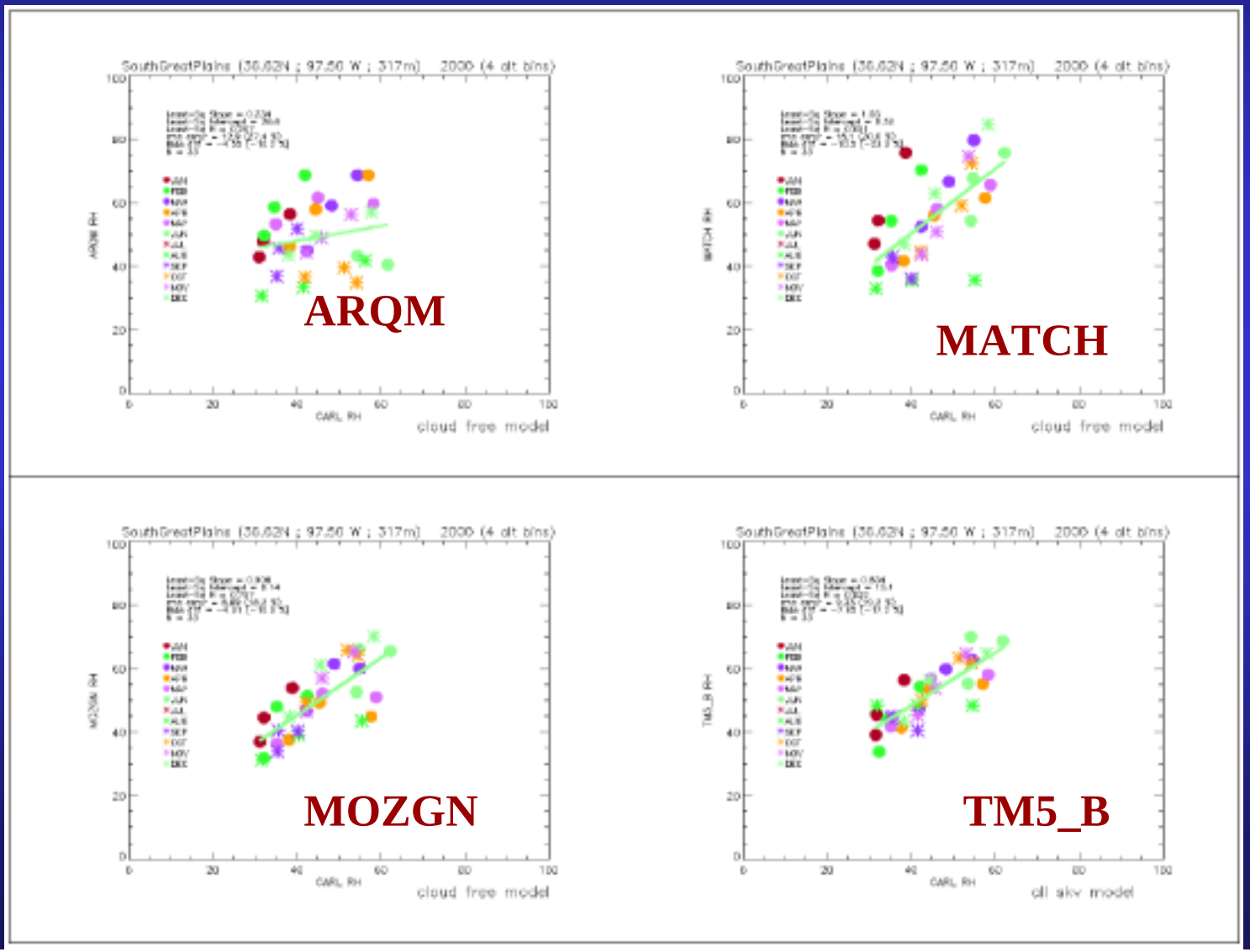


Measured versus Modeled Yearly Average Aerosol Extinction Profiles

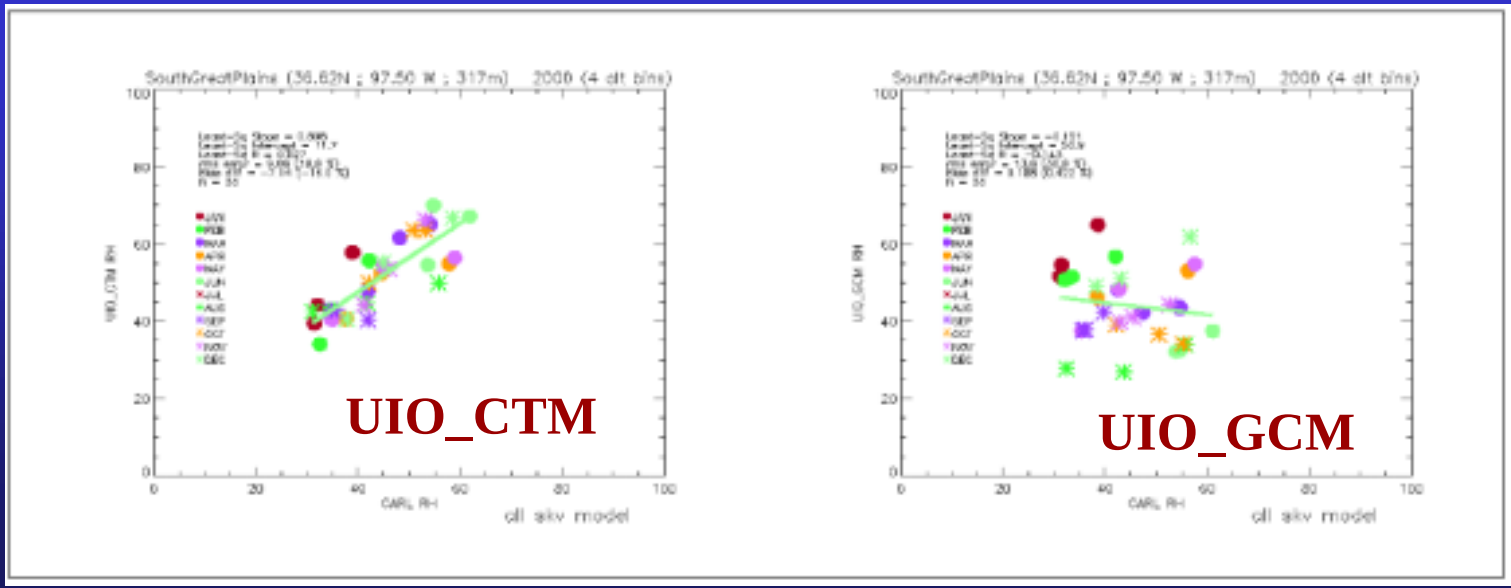
- Large variability in modeled vertical distributions and aerosol components
- Profile behavior of various aerosol constituents may give indication of model strengths and weaknesses



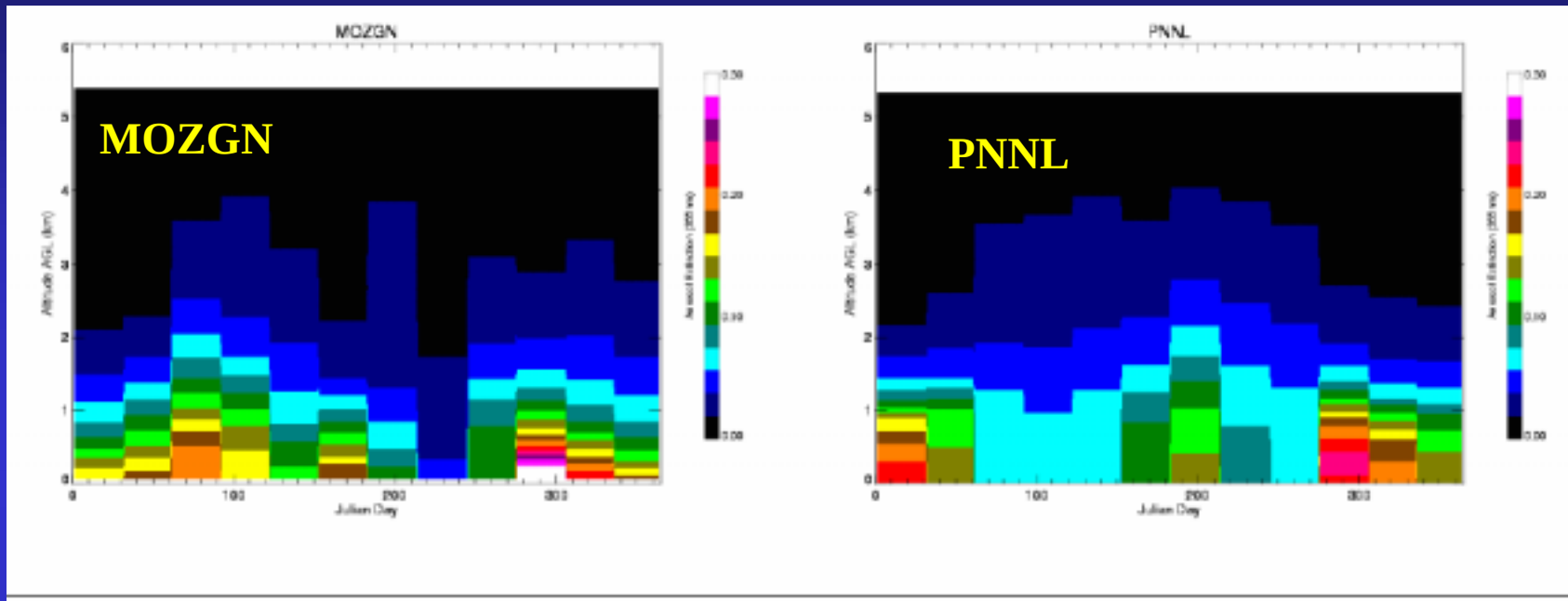
Relative Humidity Regression Results

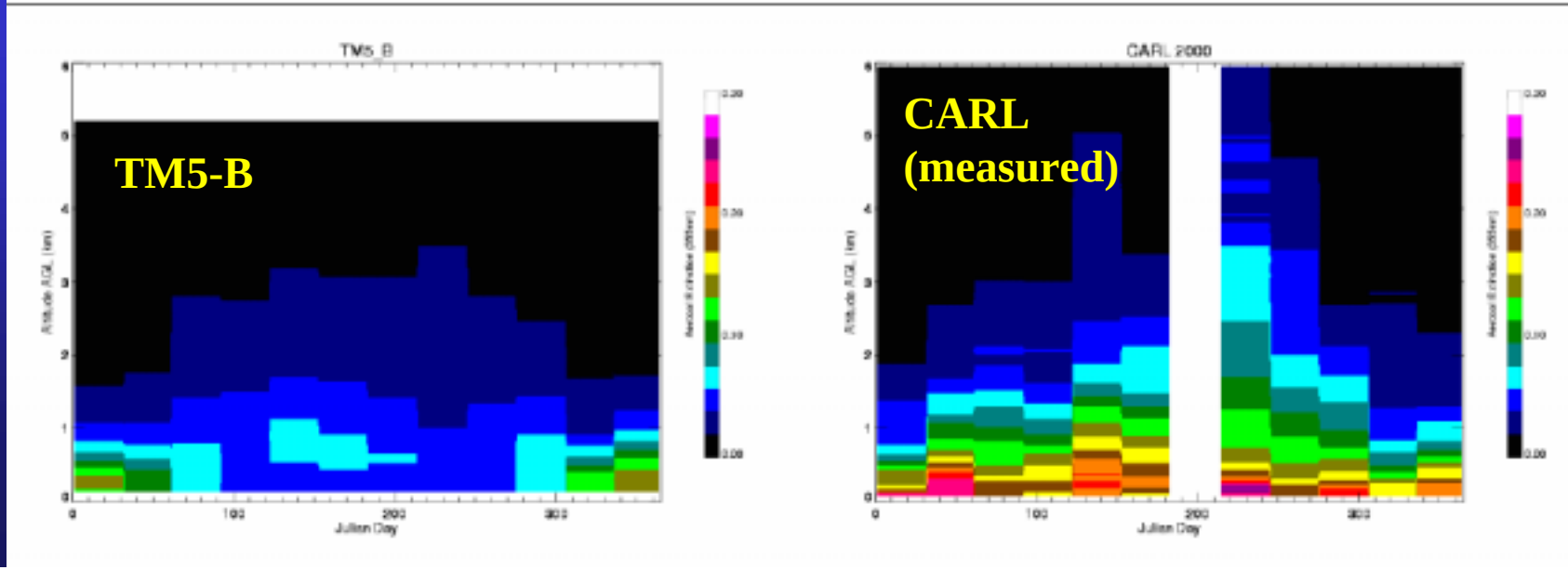


Relative Humidity Regression Results

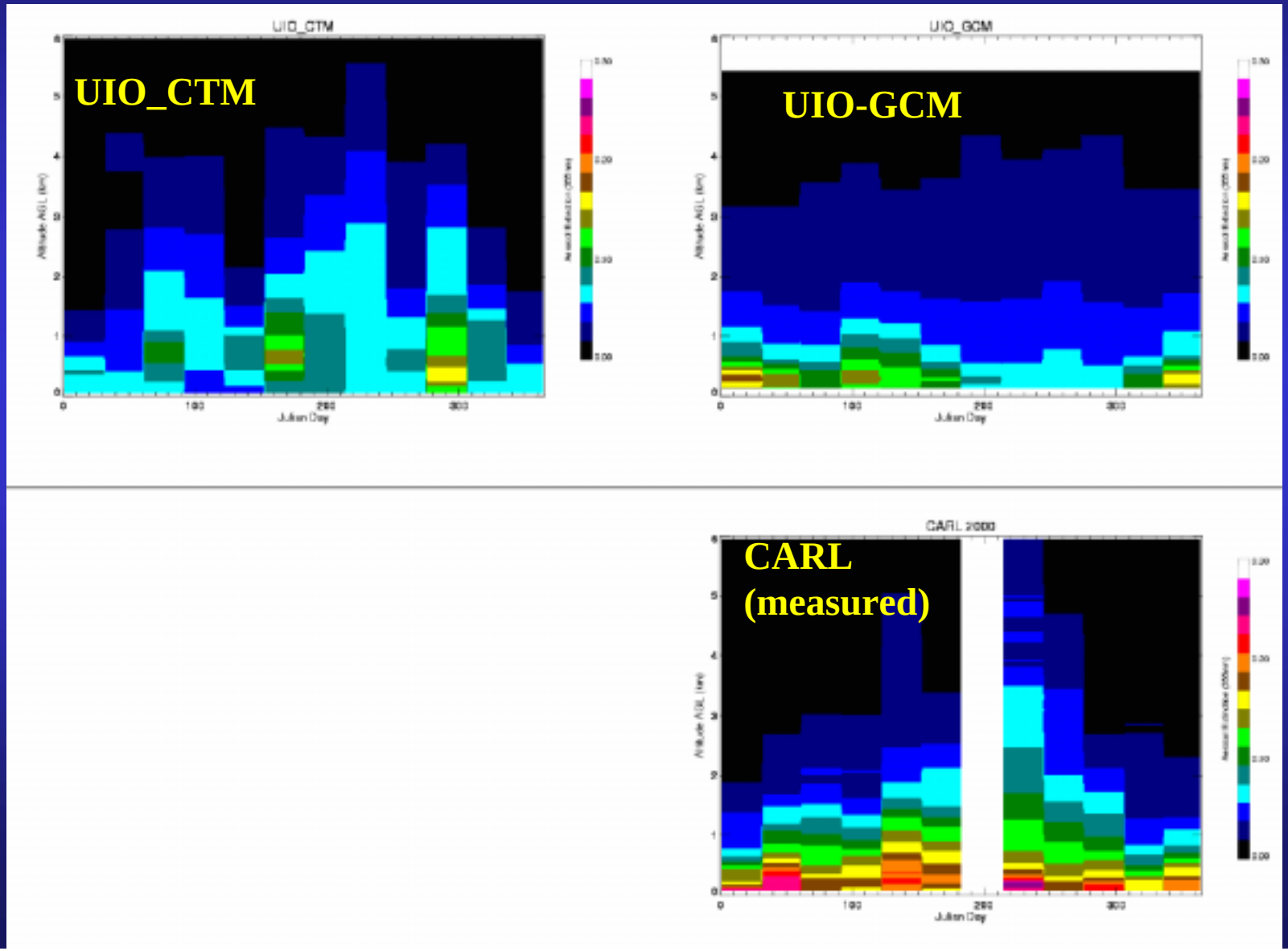


Measured vs. Modeled Monthly Average Aerosol Extinction Profiles





Measured vs. Modeled Monthly Average Aerosol Extinction Profiles



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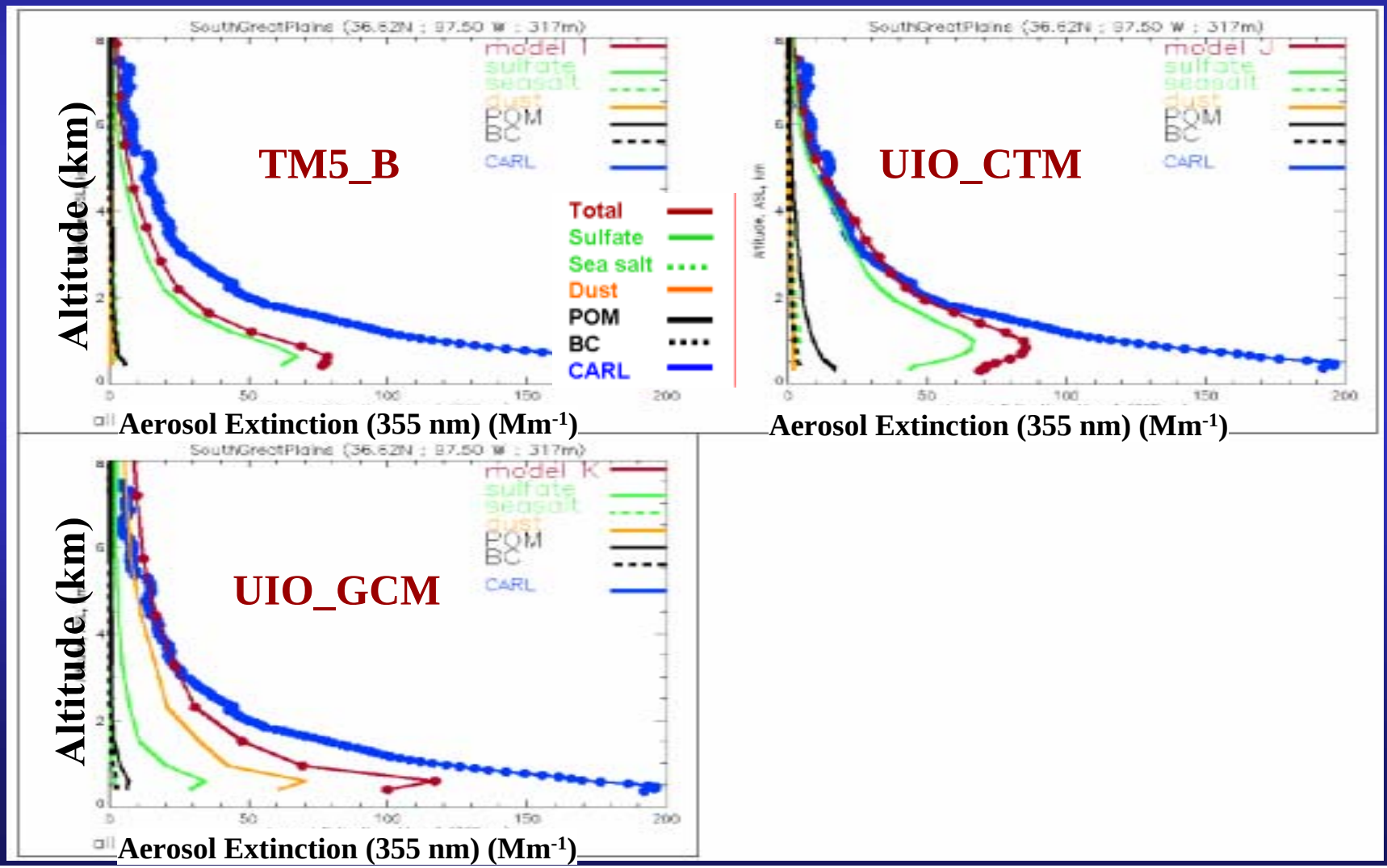

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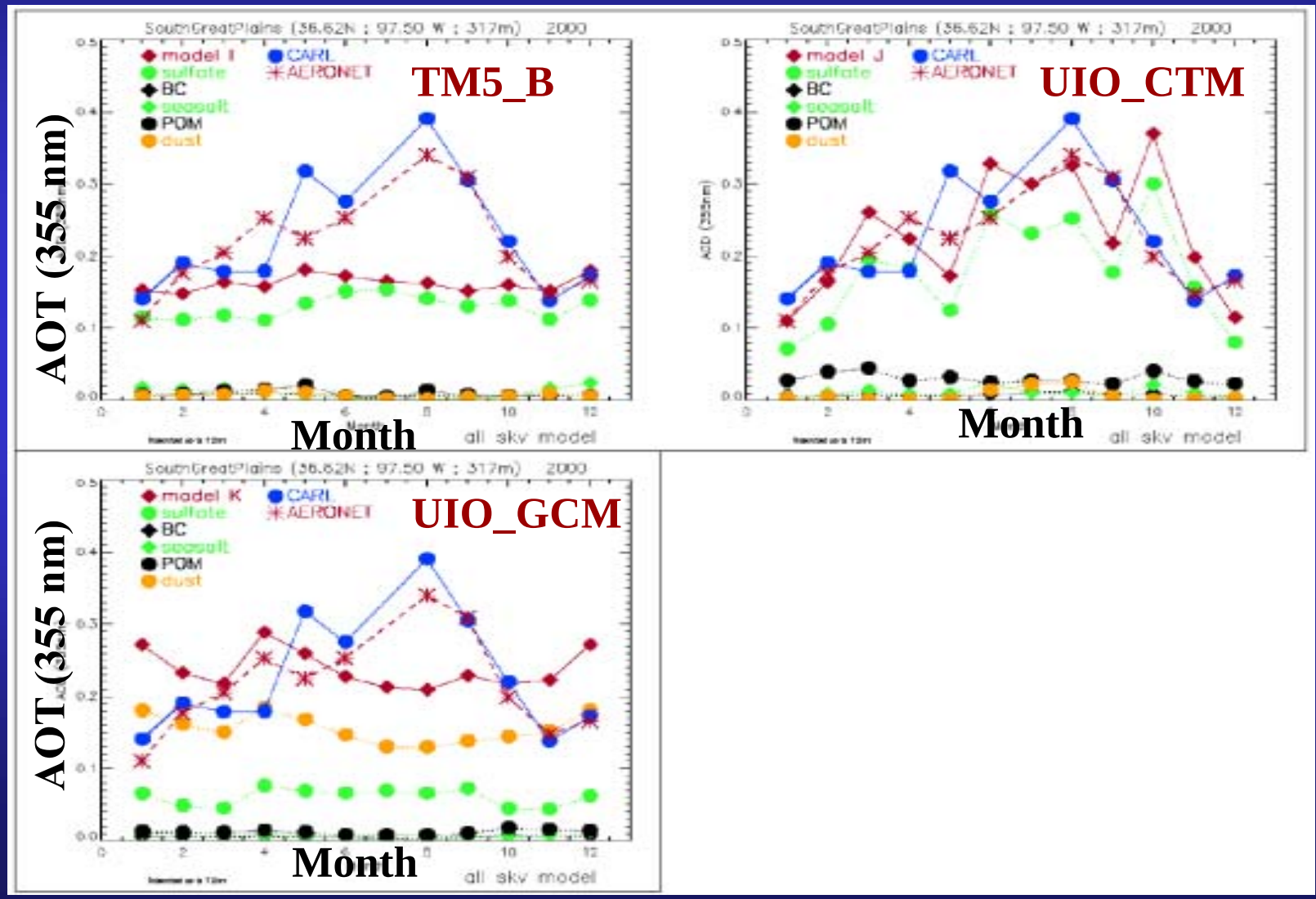
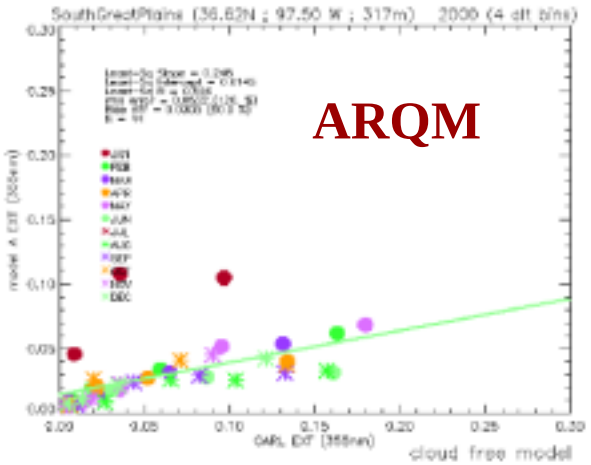
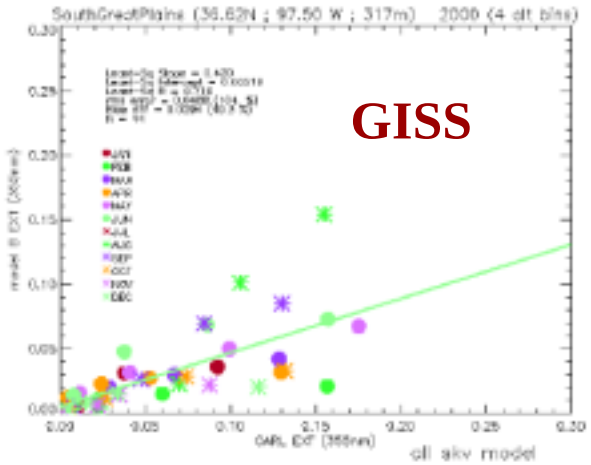
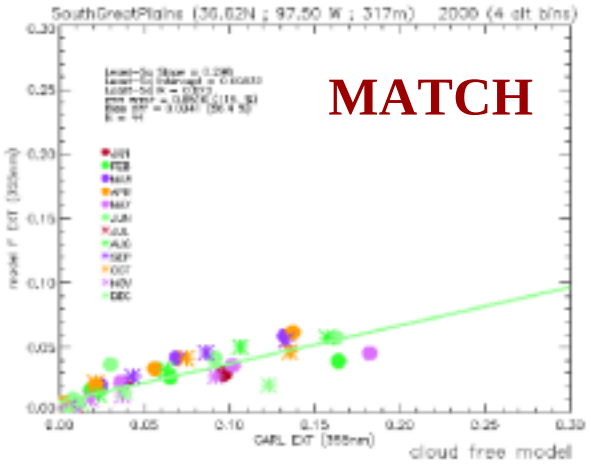
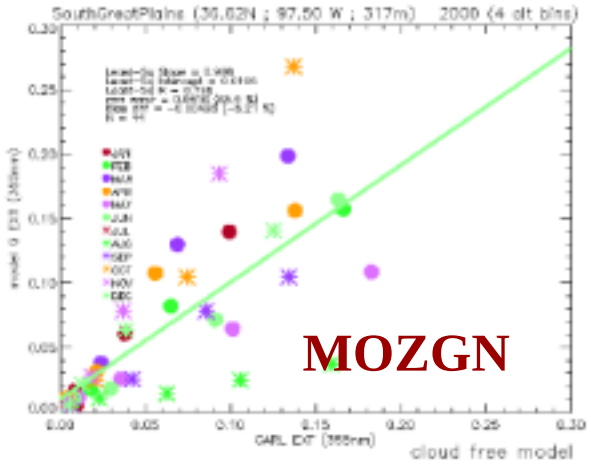


Aerosol Extinction Regression Results

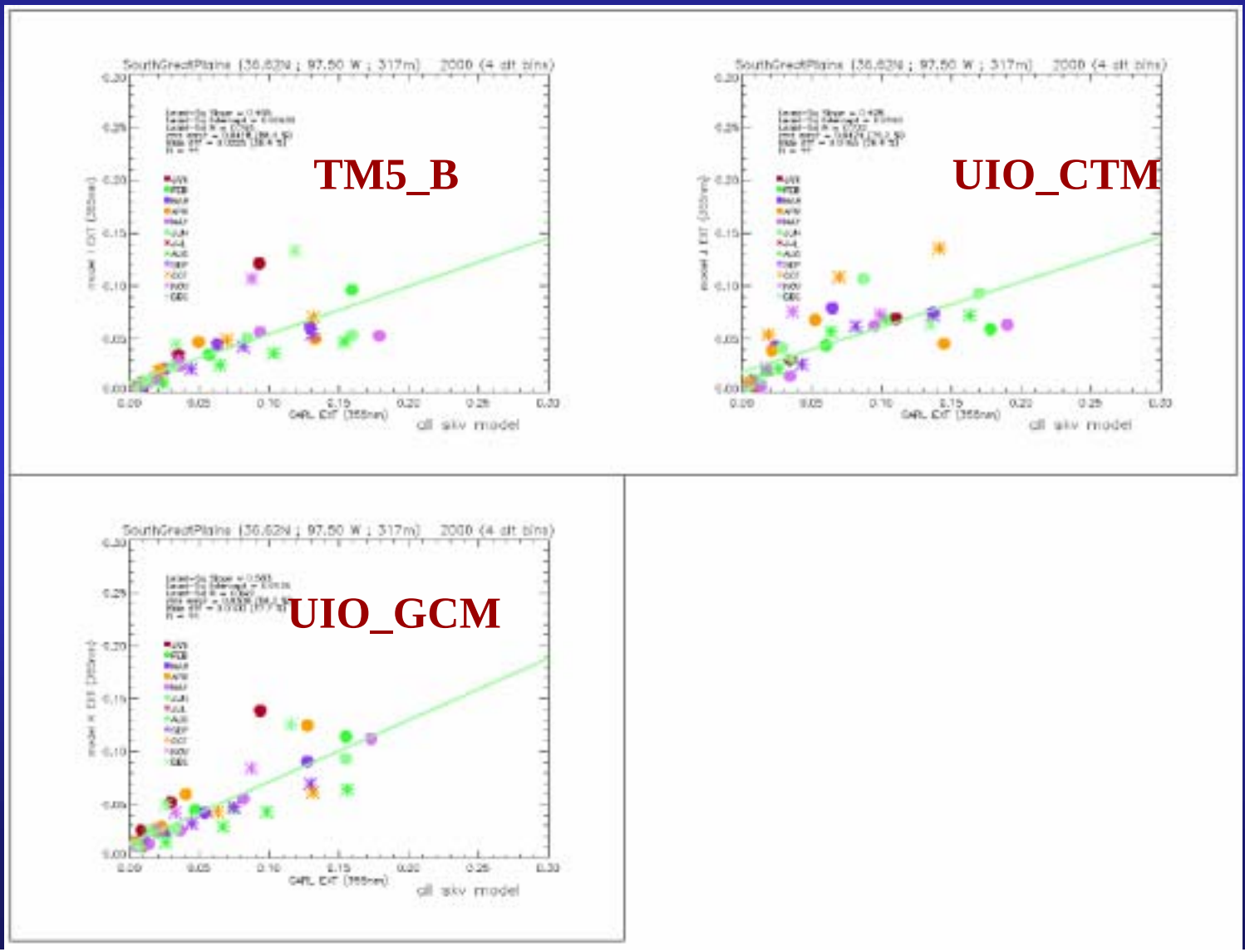


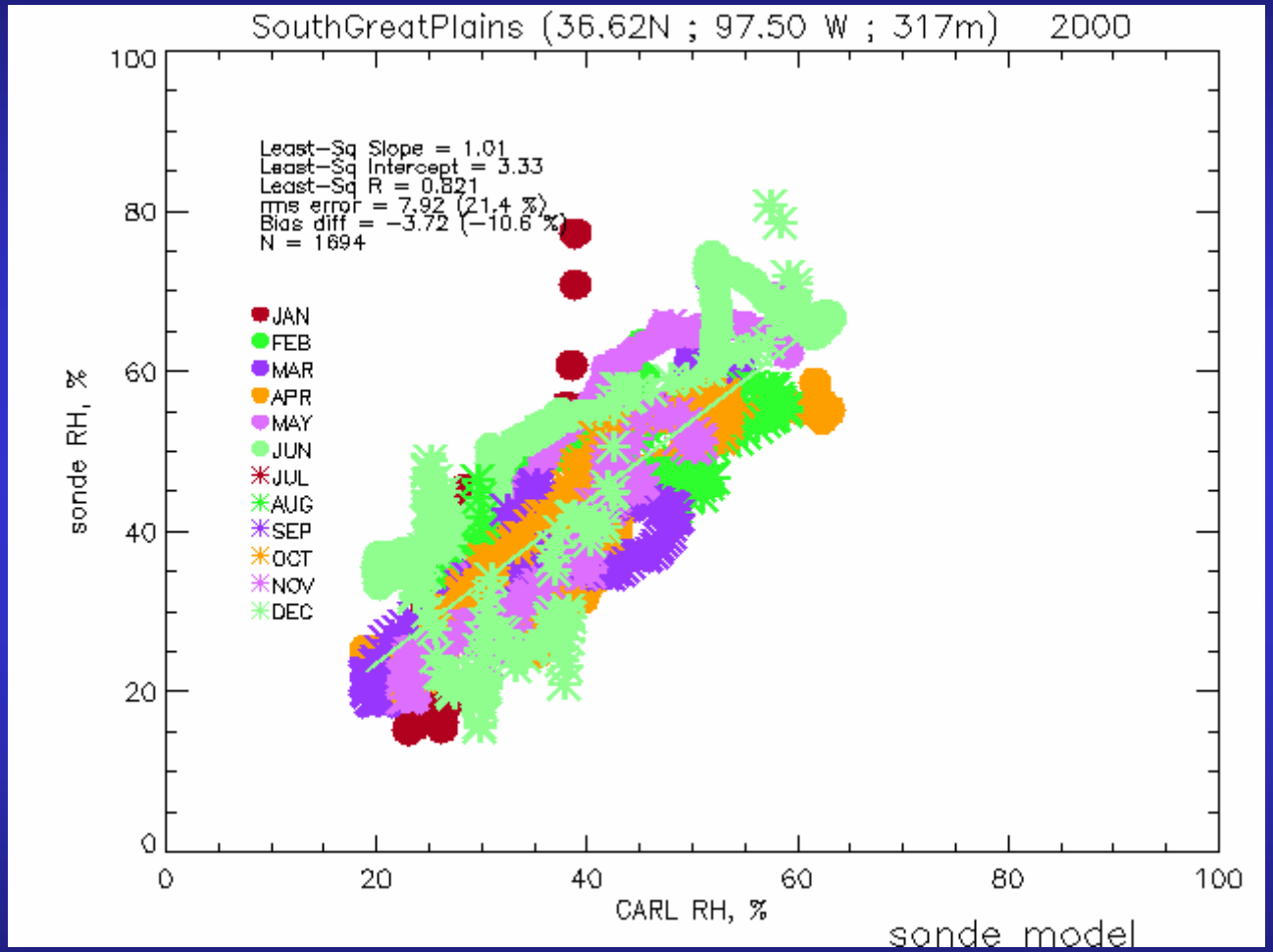






Aerosol Extinction Regression Results




SouthGreatPlains (36.62N ; 97.50 W ; 317m) 2000
Least-Sq Slope = 1.01
Least-Sq Intercept = 3.33
Least-Sq R = 0.821
rms error = 7.92 (21.4 %)
Bias diff = -3.72 (-10.6 %)
N = 1694
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
sonde RH, %
CARL RH, %
sonde model
0
20
40
60
80
100