SAMI Experience: Simulating Clouds in an Air Quality Model

Prepared by Stephen Mueller
Presented by Qi Mao
Tennessee Valley Authority
Muscle Shoals, AL

What is SAMI?

- SAMI: Southern Appalachian Mountains Initiative
- Purpose: To determine strategies for reducing air quality impacts (ozone, acid deposition & visibility) in Class I areas of the southern Appalachian Mountains
- Final report: To be issued August 2002

Atmospheric Modeling

- Meteorology: RAMS (version 3b)
- Air Quality: URM-1ATM (developed at Georgia Institute of Technology under the direction of Ted Russell)

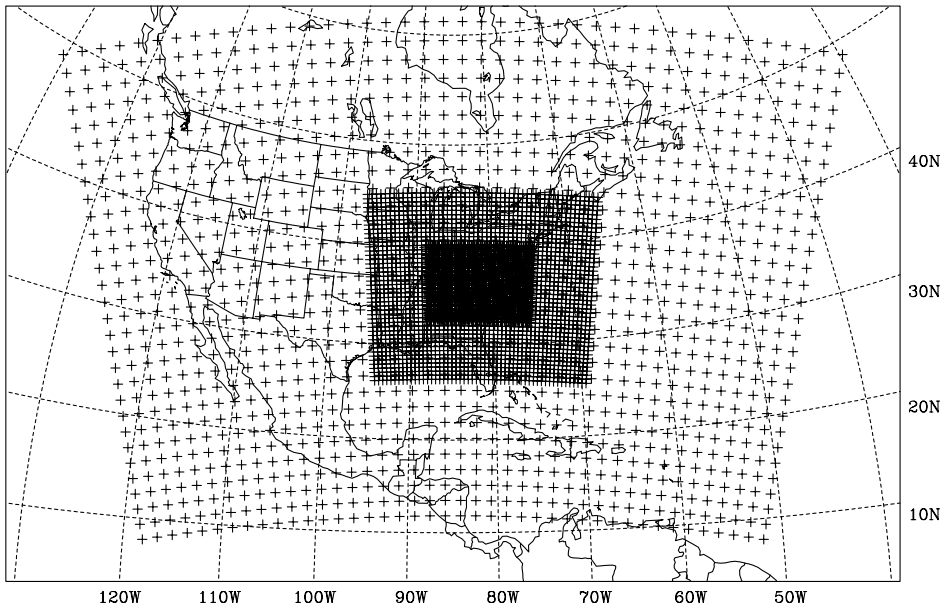
Modeling Approach

- Nine multi-day episodes were selected to represent air quality for 1991-1995.
- A total of 69 days were modeled (one winter episode, four spring episodes & four summer episodes).
- Meteorology ranged from cool and wet (February 1994), to warm and wet (August 1993), and hot and dry (July 1995).

Horizontal RAMS Modeling Grids

SAMI RAMS Domain : Oblique Stereographic Projection

Grid 1 CLAT=37.000 CLON= −85.000 DX= 96.00 km DY= 96.00 km NX= 83 NY= 60
Grid 2 CLAT=36.077 CLON= −81.259 DX= 24.00 km DY= 24.00 km NX=106 NY= 90
Grid 3 CLAT=36.521 CLON= −81.641 DX= 12.00 km DY= 12.00 km NX=100 NY= 74



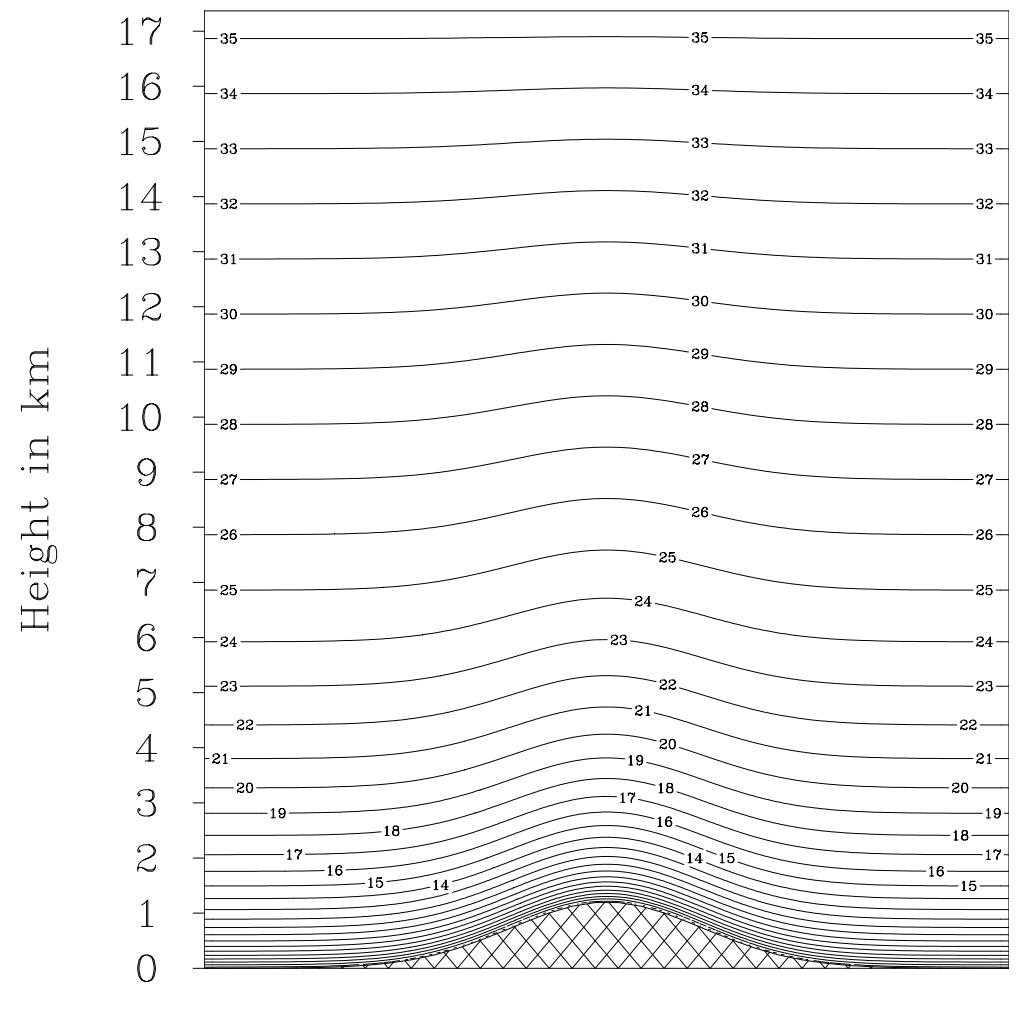
Grids used for all but July 1995 episode for which somewhat smaller grid dimensions were used.

<u>Grid cell sizes</u>

Parent grid: 96 km
1st nested grid: 24 km
2nd nested grid: 12 km

Vertical RAMS Modeling Grid

A 35-layer vertical structure was used for all simulations. Bottom layer depth was 20 m. Height at top of model was 17.4 km.



Meteorological Modeling

Approach designed by Kevin Doty (UAH)

Dr. Doty made several modifications to RAMS to overcome deficiencies in model performance. Ice microphysics were not simulated due to computer resource limitations. Changes included:

1) Making droplet fall velocities and collection efficiencies functions of temperature to mimic effects of frozen cloud particles.
2) Changes made to Kuo convection scheme to correct problems with overly deep convection or convection in areas where none was observed.

Meteorological Modeling (cont.)

3) Changes in the radiation scheme were introduced to correct biases in surface temperatures under cloudy conditions.
4) Nudging scheme was changed so nudging intensity could vary by nested grid, by variable being nudged (e.g, low-level wind & temperature nudging could be set to zero while mixing ratio nudging remained active), and by grid cell characteristic (e.g., nudging could be turned off when grid terrain slopes exceeded some threshold).
5) Nudging was adjusted, with iterative procedure, to ensure vertical heat & moisture fluxes agreed with similarity theory.

Meteorological Modeling (cont.)

6) Surface energy radiation budget modified over vegetation to minimize strong cool bias over vegetated areas. Approach was to substitute for standard RAMS approach using other published schemes.

Note: RAMS simulations were made by Kevin Doty (UAH) & Dennis McNally (Alpine Geophysics).

Meteorological Modeling (cont.)

Modeling Protocol

1) Boundary/nudging fields defined using NCAR Reanalysis data sets.
2) SSTs & soil moisture derived from NCAR Reanalysis as well.
3) Bi-weekly leaf area index & vegetation fraction fields provided by Penn State.
4) Detailed STATSGO soil type data base used.
5) Two “ramp-up” days run for each episode.
6) Model results were compared with observations & performance statistics computed. Emphasis for performance evaluation was on wind, temperature, mixing ratio & precipitation amount.

Treatment of Clouds

- Air quality model (URM-1ATM) uses convective and stratiform cloud height & fractional coverage information, along with relative humidity, to determine cloud presence for each model layer.
- URM-1ATM treats precipitating & non-precipitating clouds separately.
- Precipitating clouds are defined from RAMS information on convective & stratiform clouds.
- The presence of non-precipitating clouds is diagnosed from relative humidity when RH>90%.

Evaluation of Cloud Representation in Air Quality Model

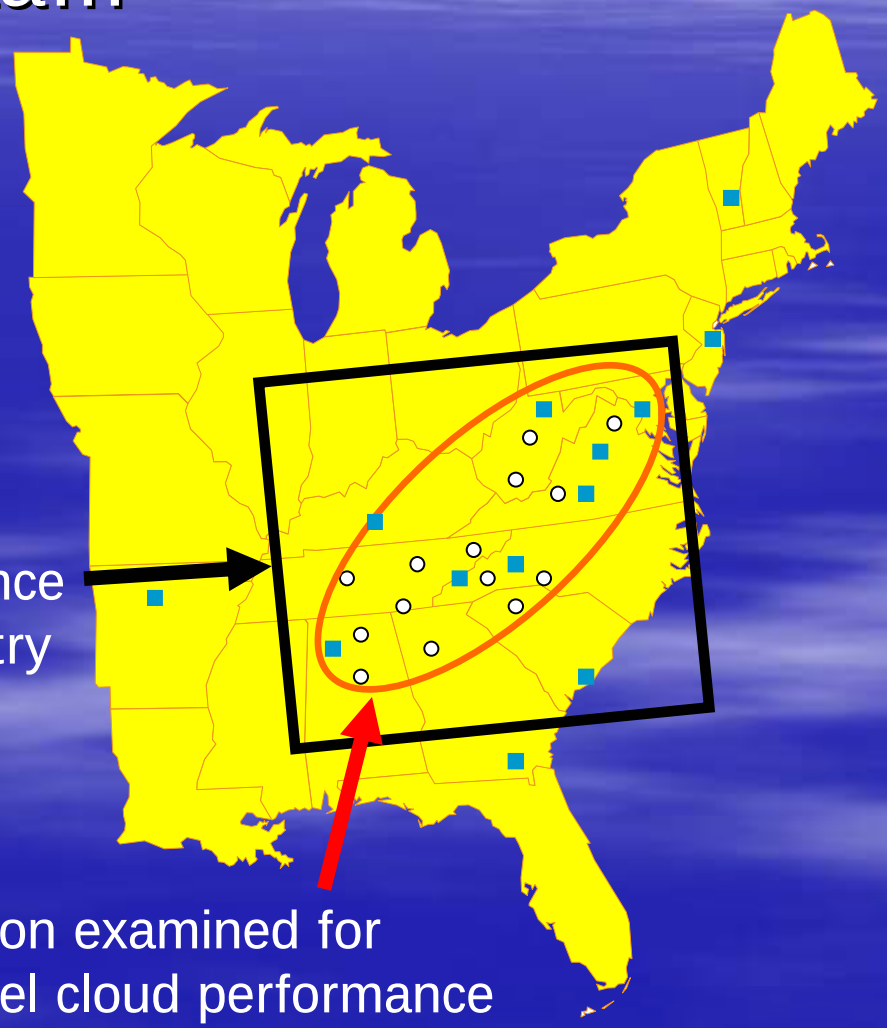
Cloud presence & influence were examined for 12-km portion of URM-1ATM grid. Four SAMI episodes were examined:

- April 26-May 3, 1995 (a couple cold fronts but little precipitation)
- June 24-29, 1992 (stationary front, moderate precipitation)
- July 11-19, 1995 (hot and dry)
- August 3-11, 1993 (stationary front, warm and quite wet)

Observations Used in Evaluations

NWS surface station data…

- Fractional cloud cover (FCC)
- Cloud ceiling height



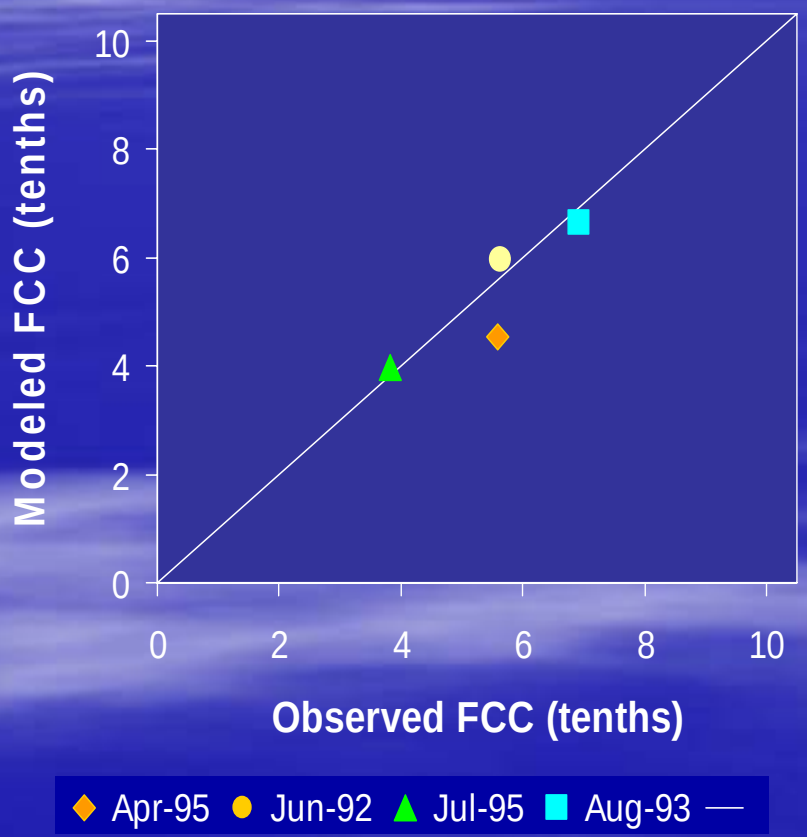
- NWS station (14)
- IMPROVE site (8)

Comparison with Observed FCC

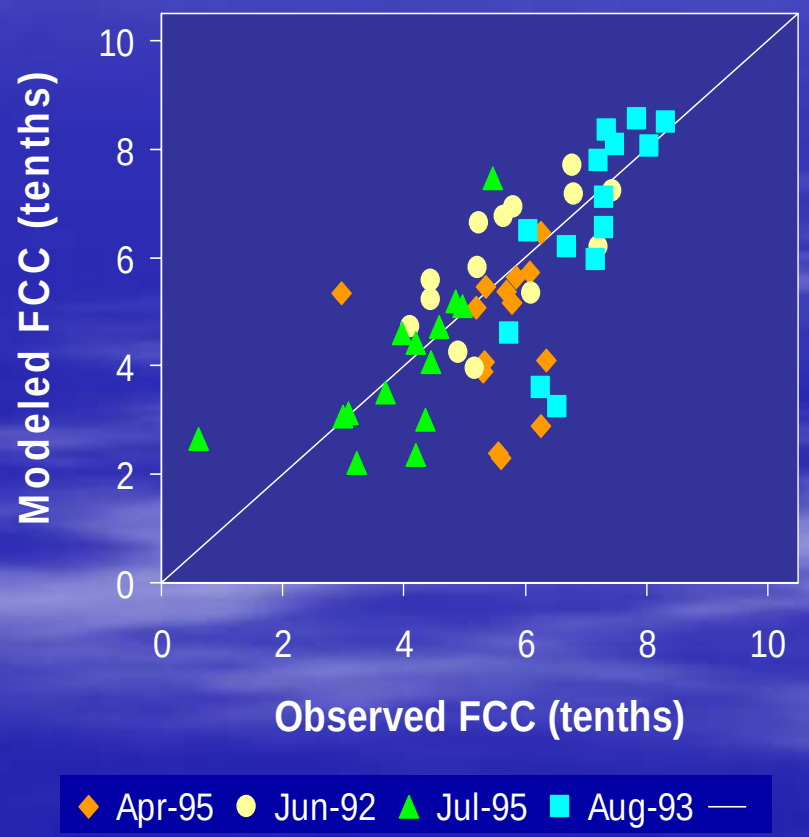
- URM-1ATM was configured with 7 vertical layers.
- FCC derived from URM-1ATM by counting number of cloudy 12-km grid cells in 3x3 cell matrix centered on observation point. Only layers above model surface layer were included when determining cloud presence.
- Comparisons were made for every third hour (00, 03, 06, …, 21 UTC).

FCC averaged by …

…episode, across all sites.

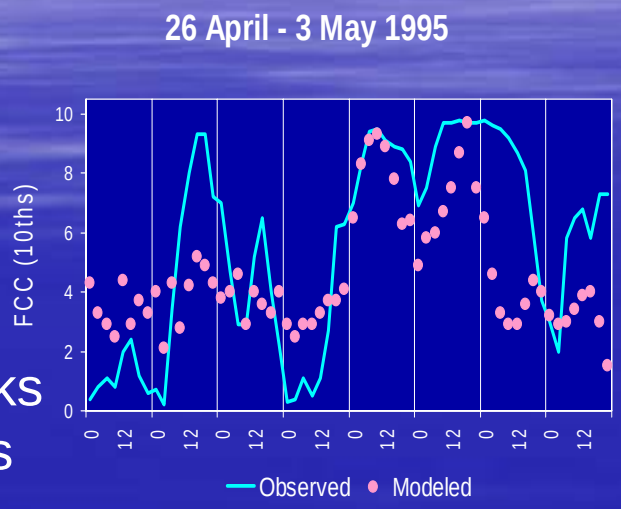


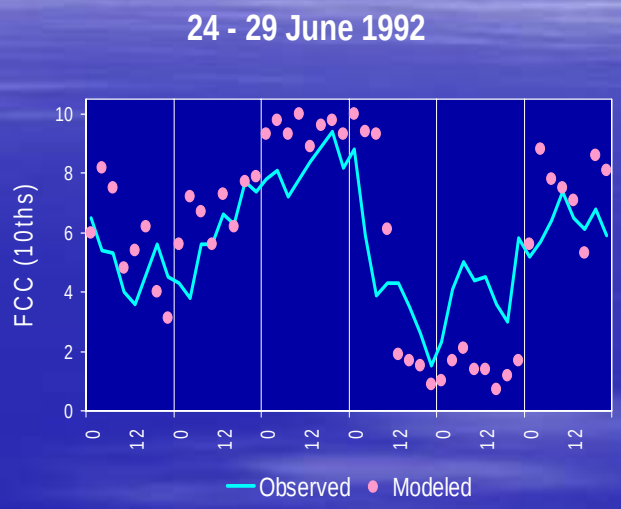
…episode & site.



Spatially-averaged Hourly FCC

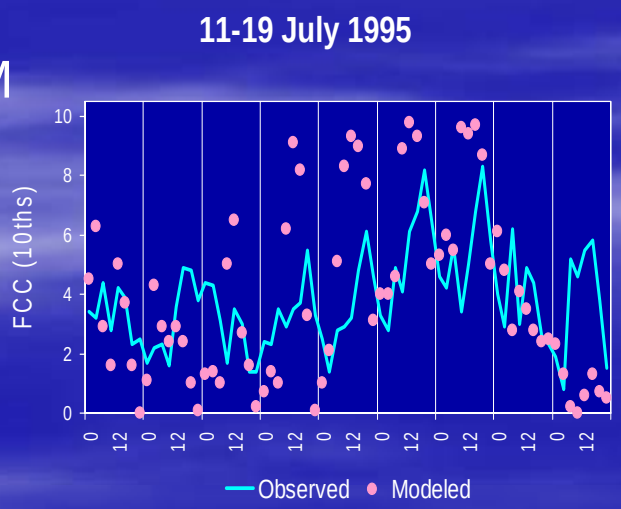
Missed peaks and valleys

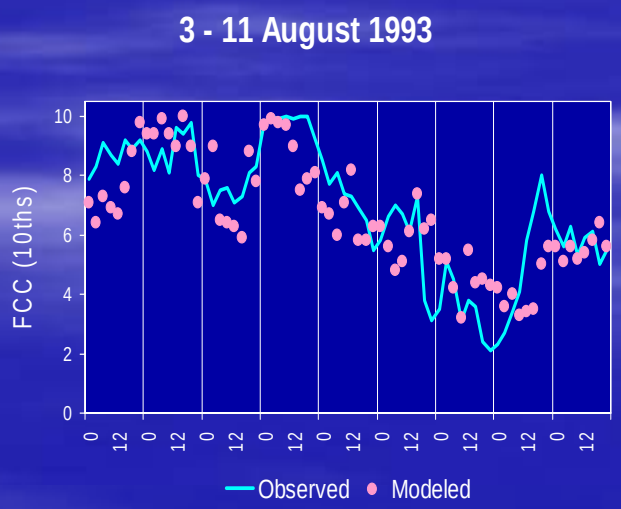




Good job

Over did PM convection



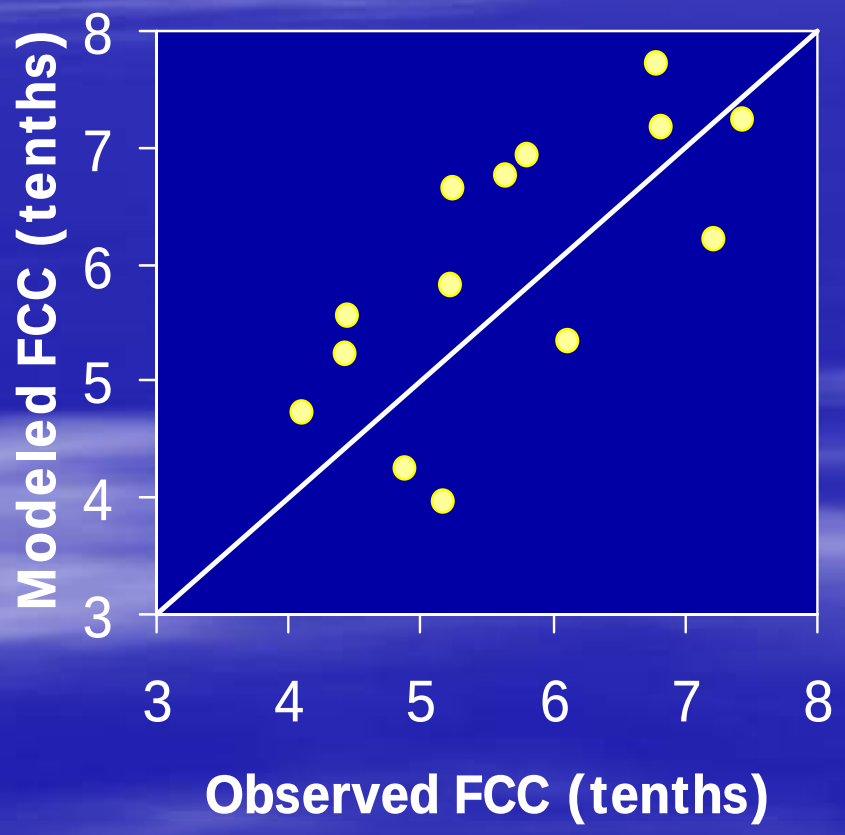


Excellent

Episode-averaged FCC by Site

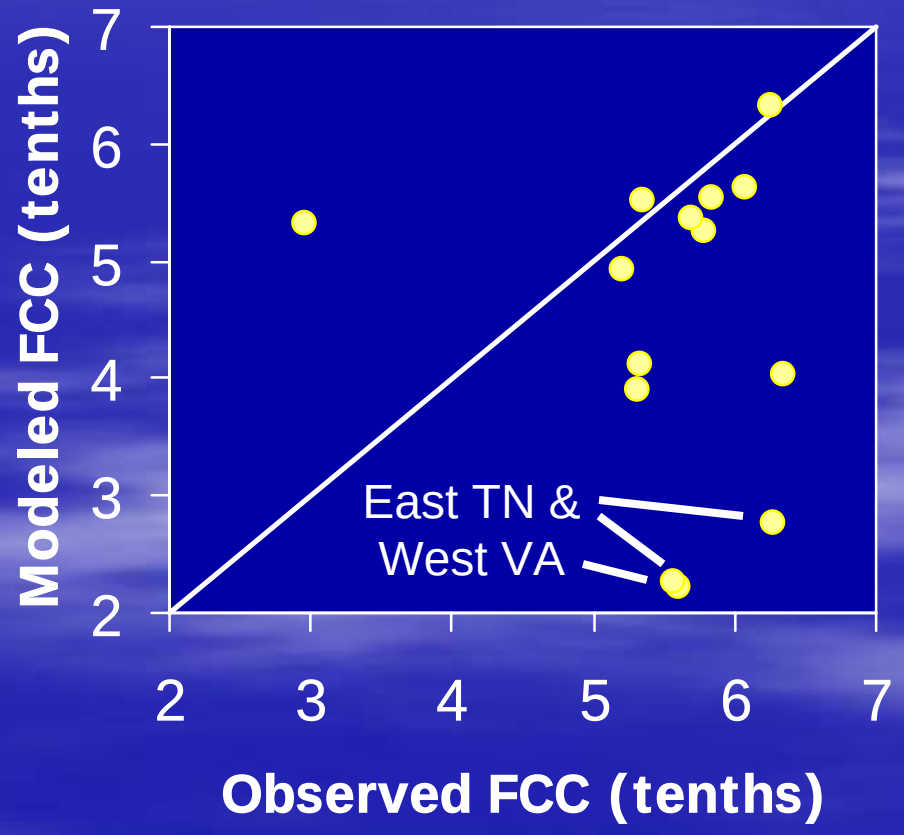
Good performance

24-29 June 1992

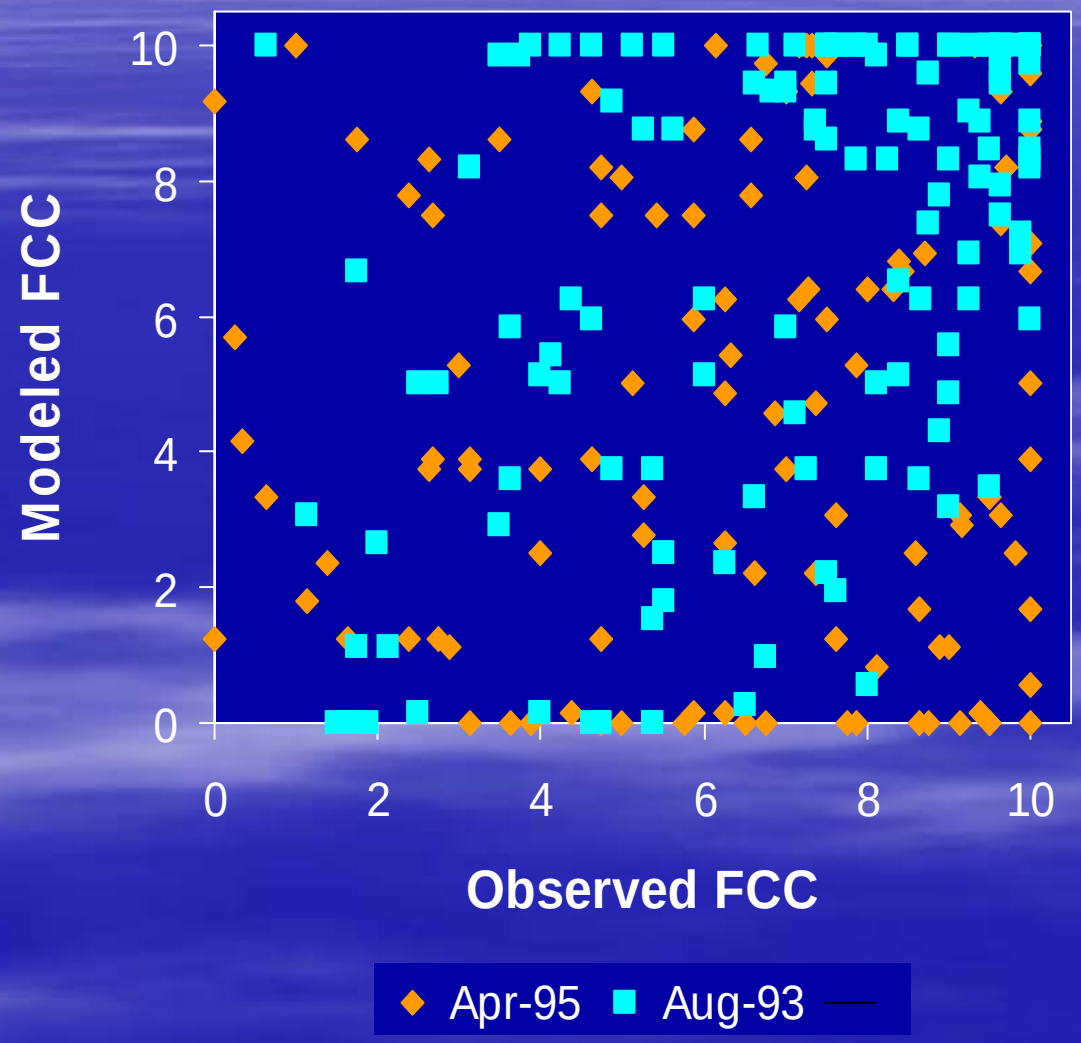


Poor performance

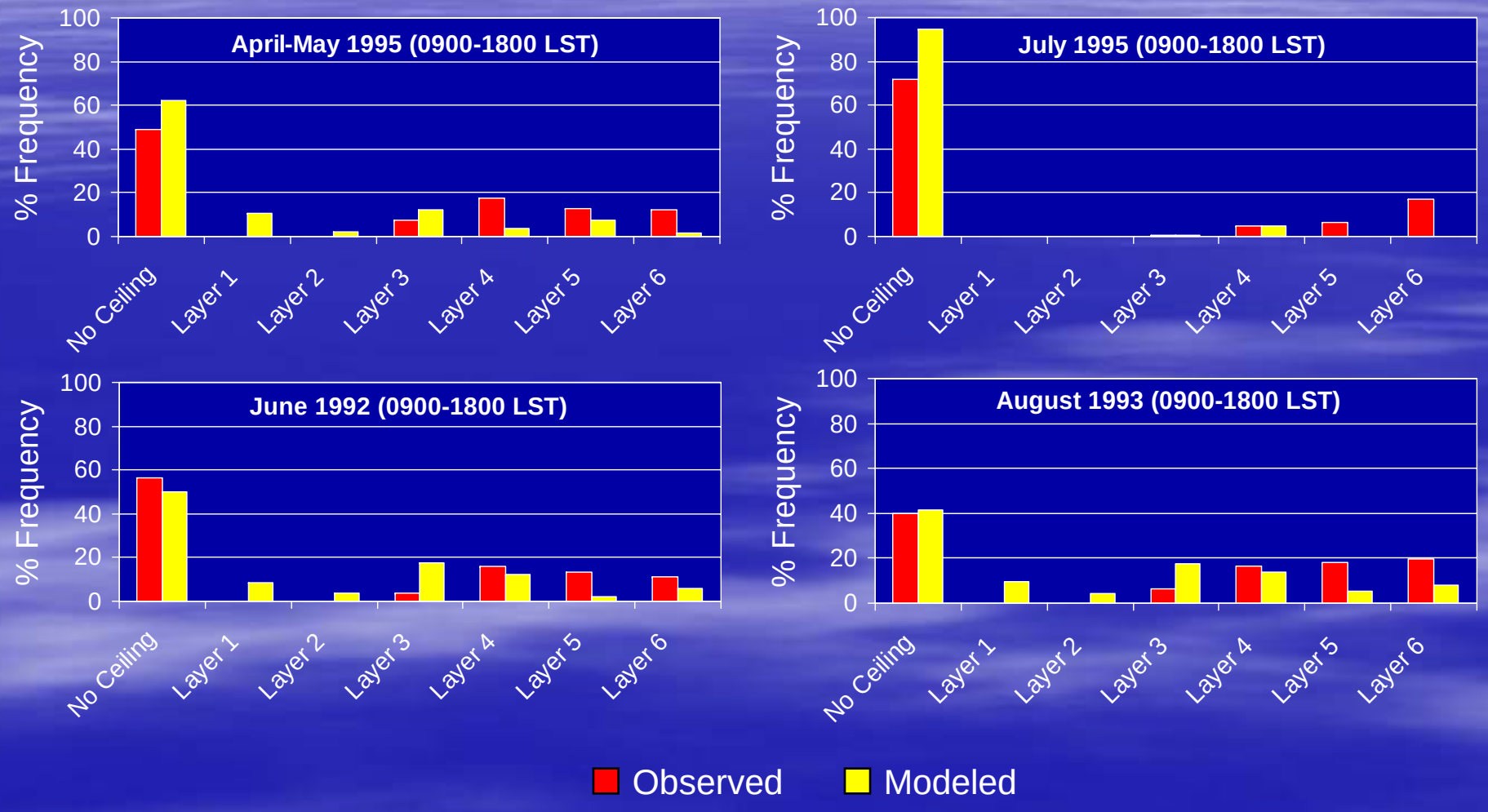
26 April - 3 May 1995



Daily-average FCC, by Site, Paired in Space & Time



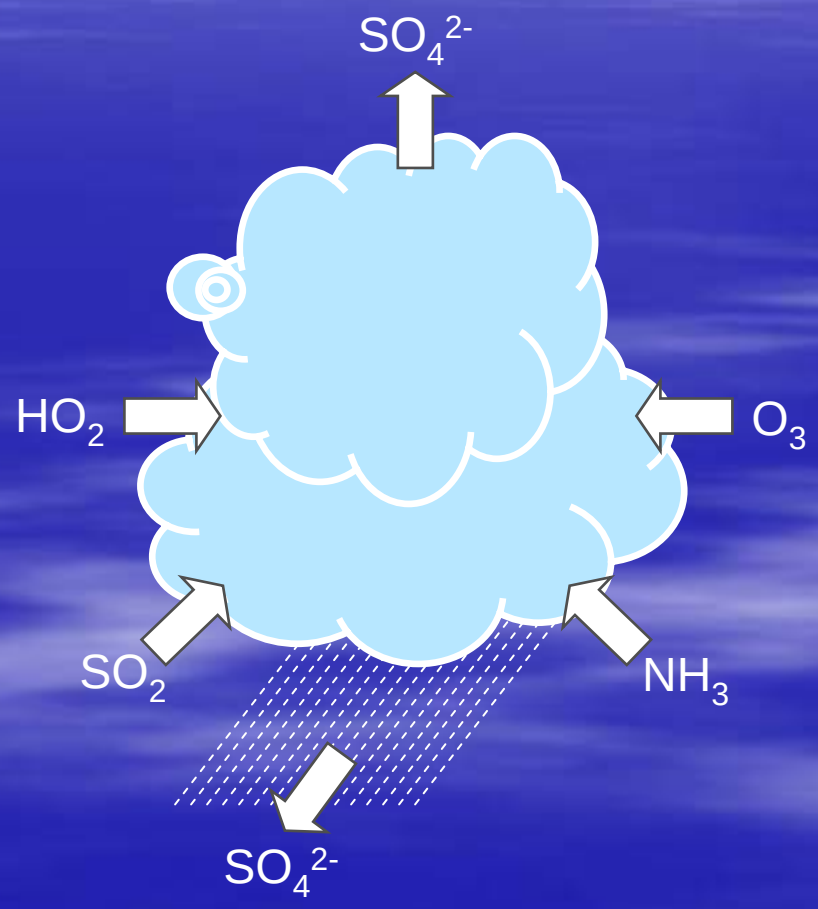
Comparisons of Daytime Cloud Ceiling Frequency Distributions by Episode



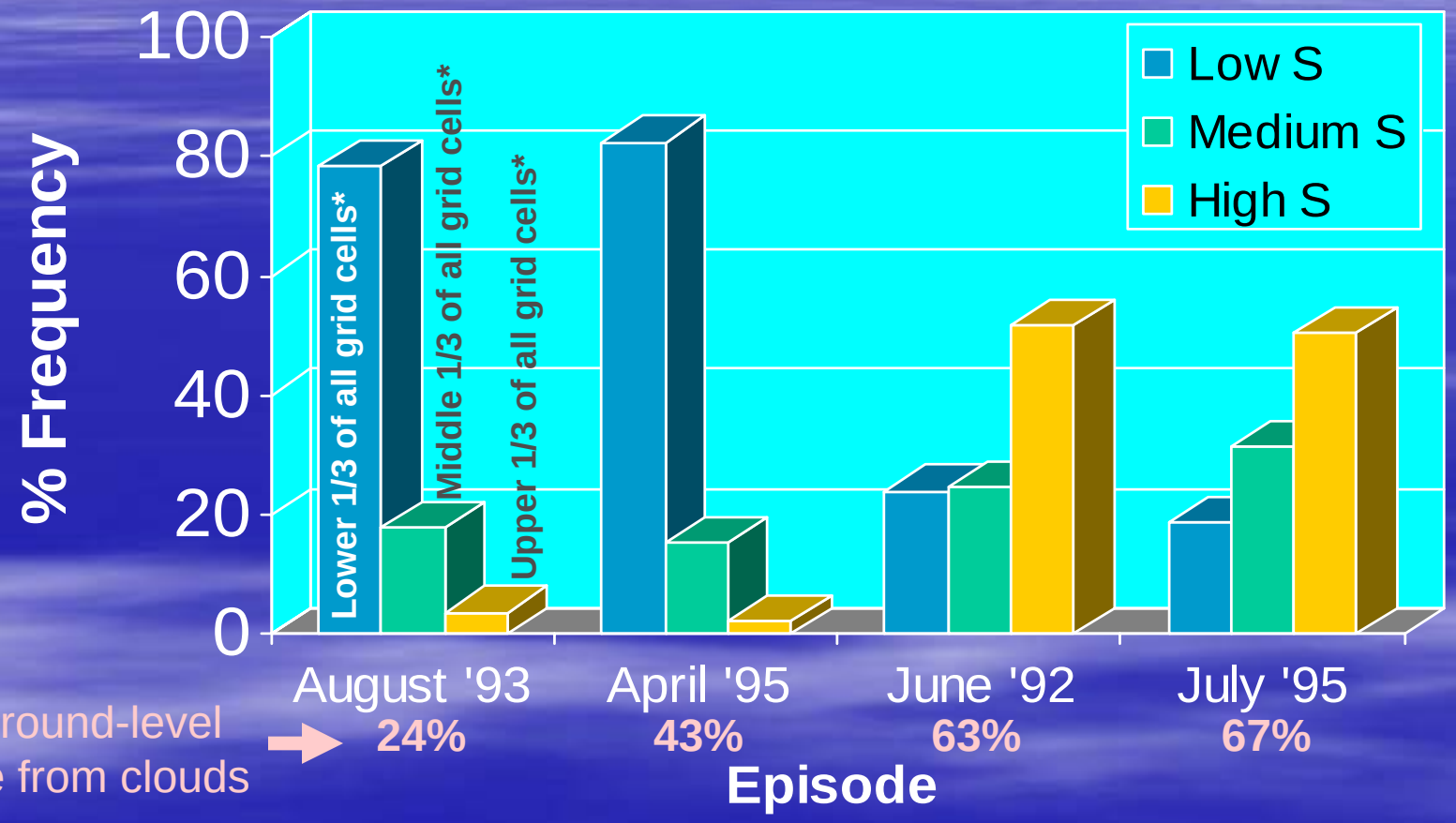
No significant amount of cloud ceilings occurred in layer 7.

Role of Clouds (Heterogeneous Chemistry) in Sulfate Aerosol Formation

- Clouds accelerate SO_2 oxidation/sulfate formation.
- Experiments with URM-1ATM revealed that precipitating clouds usually result in the net removal of sulfate.
- Therefore, sulfate aerosol formation can be dominated by non-precipitating clouds given an optimal level of cloudiness.
- Too many clouds will result in levels of peroxides (HO_2) & ozone (O_3) that are insufficient to accelerate SO_2 oxidation in clouds.



Modeled Contributions of Clouds to Sulfate Aerosol

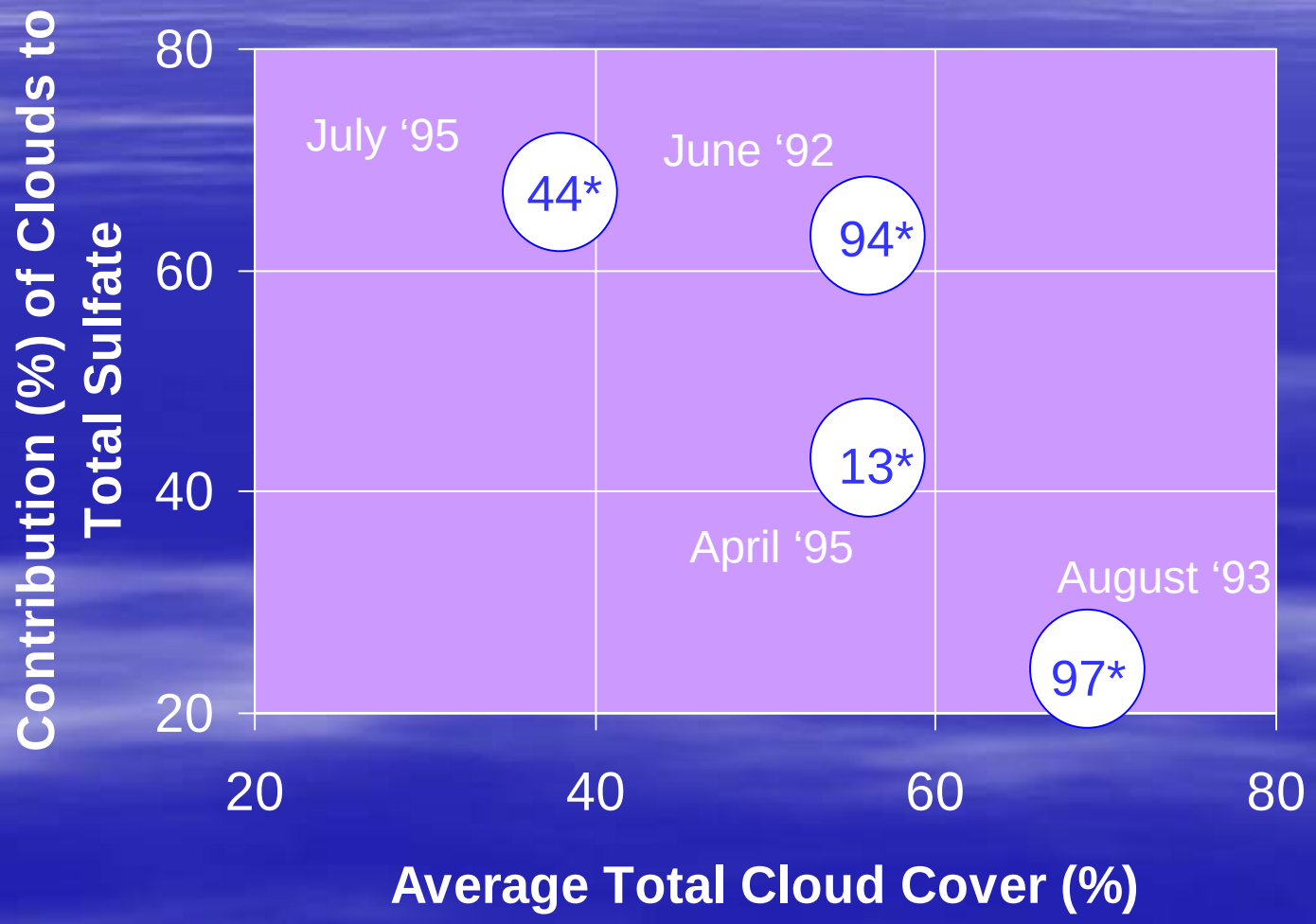


% of ground-level sulfate from clouds → 24% 43% 63% 67%

Increasing Contribution of Heterogeneous Mechanism →

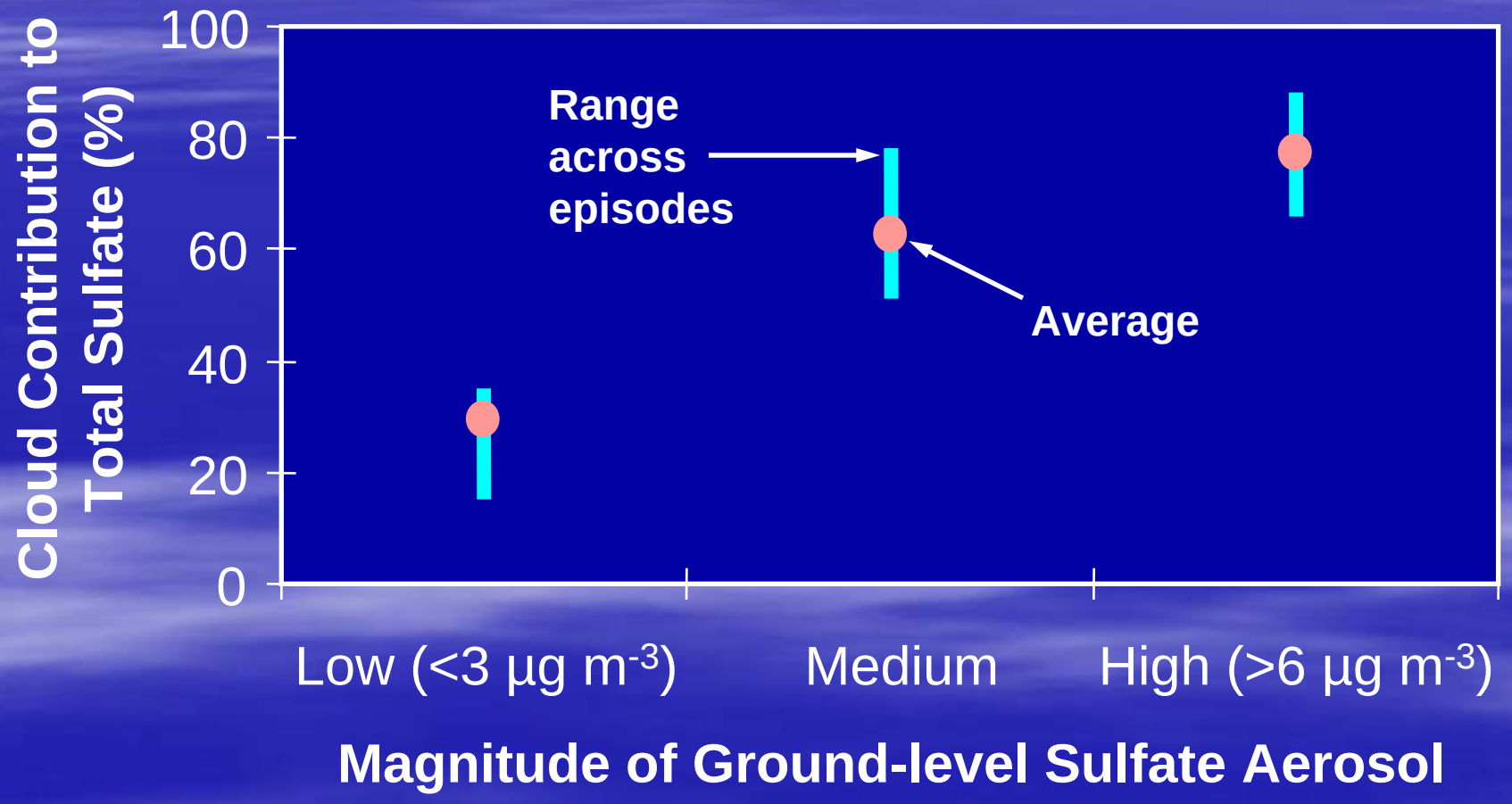
*Distribution of grid cell sulfate compiled across all four modeled episodes.

Characterization of Modeled Episodes



*% of model study region significantly influenced by precipitating clouds.

Cloud Contribution to Ground-level Sulfate Modeled for Four Episodes



Conclusions about Modeled Clouds

- Accuracy of simulated clouds varied greatly across four different episodes.
- Systematic biases (by time of day or location) in FCC were sometimes observed.
- The model had no skill with clouds for 24-h periods, implying little or no skill simulating sulfate source-receptor relationships for 24-h periods.
- The model had no skill simulating cloud ceiling height, and tended to under estimate heights.

Conclusions on the Role of Clouds

- Non-precipitating clouds, as represented by a model, are net sources of sulfate whereas precipitating clouds are usually net sinks.
- There is a strong positive association between high modeled sulfate concentrations and the relative contribution of cloud chemistry to sulfate.
- The episode with the largest simulated cloud contribution to total sulfate was the episode with the lowest overall level of cloud cover. The opposite was true for the most cloudy episode.
- Nearly 80% of computed sulfate >6 $\mu g\ m^{-3}$ was found to be derived from clouds.