Scaling properties of aerosol optical thickness from sun-photometric and satellite data

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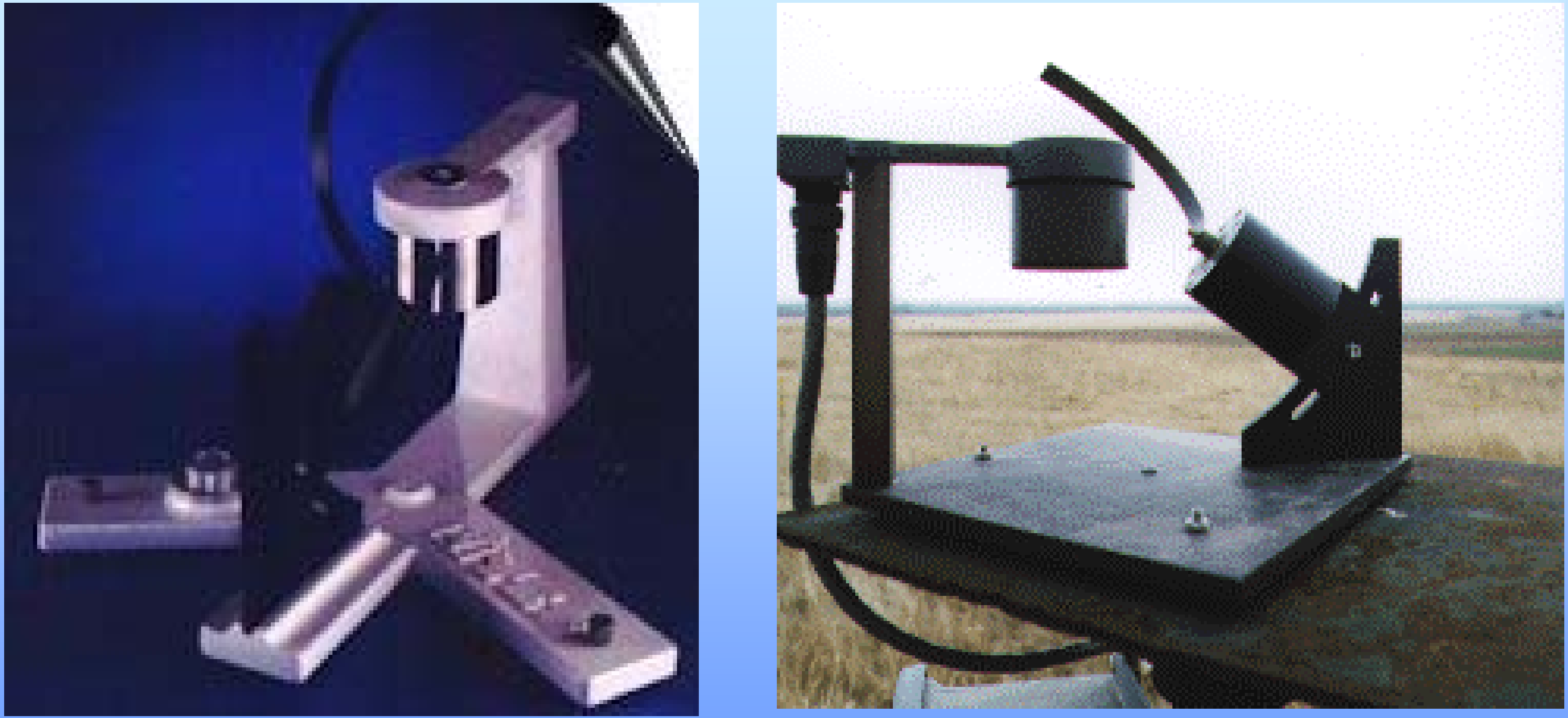
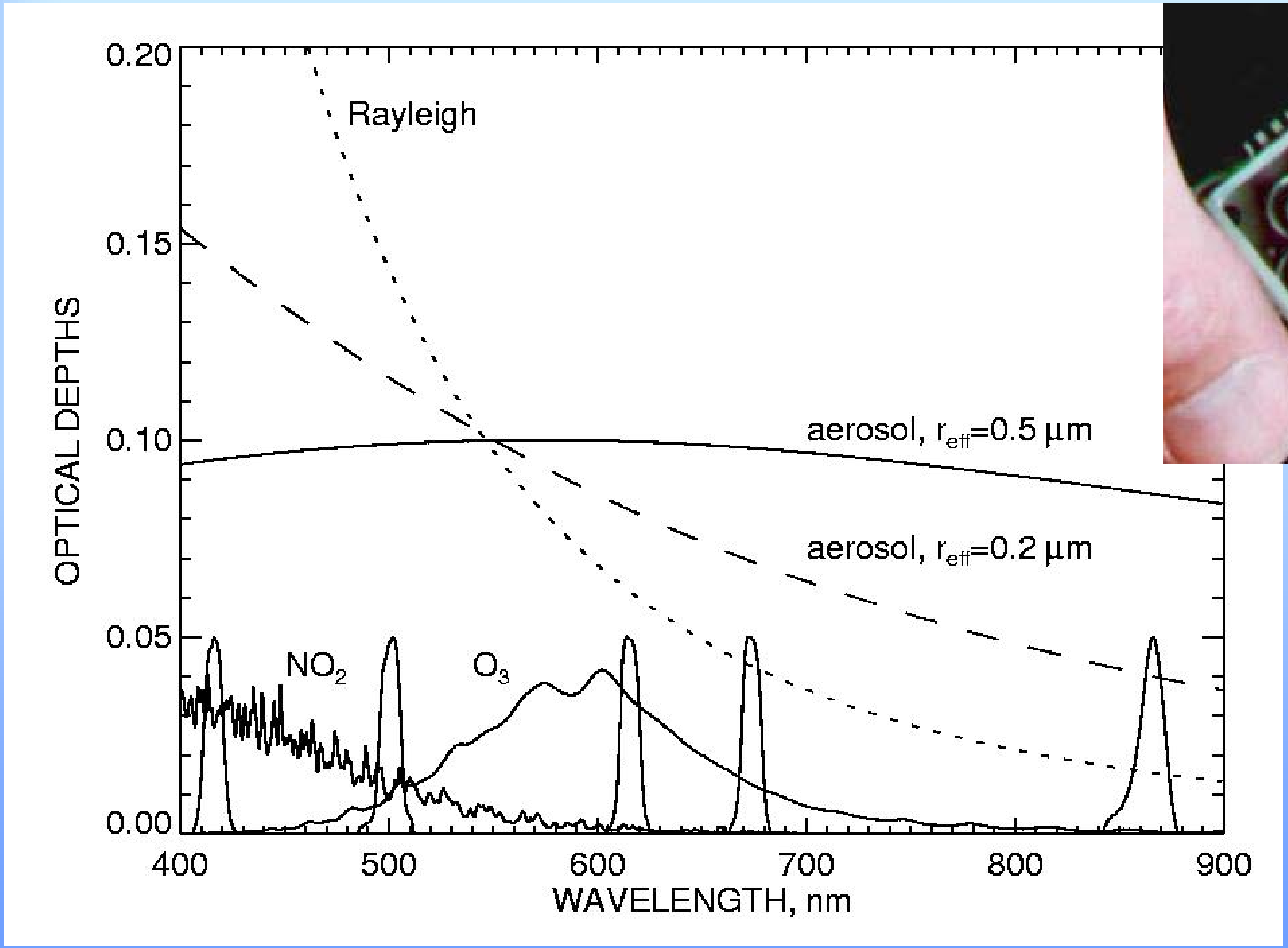
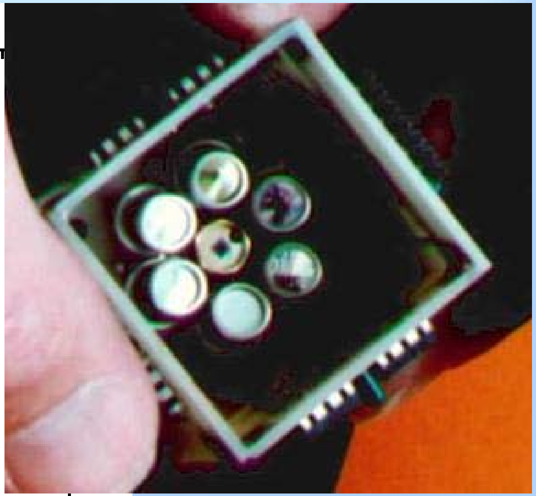
MFRSR instrument

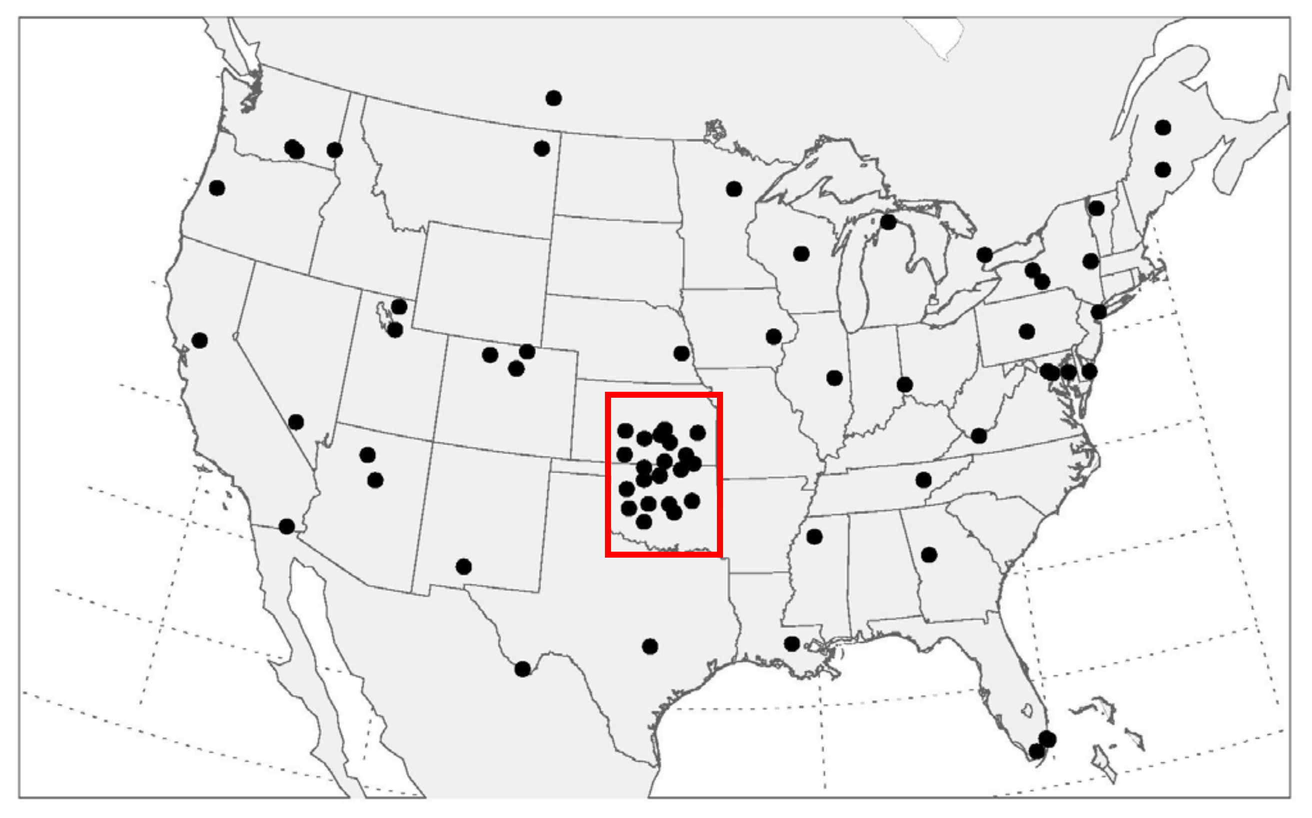


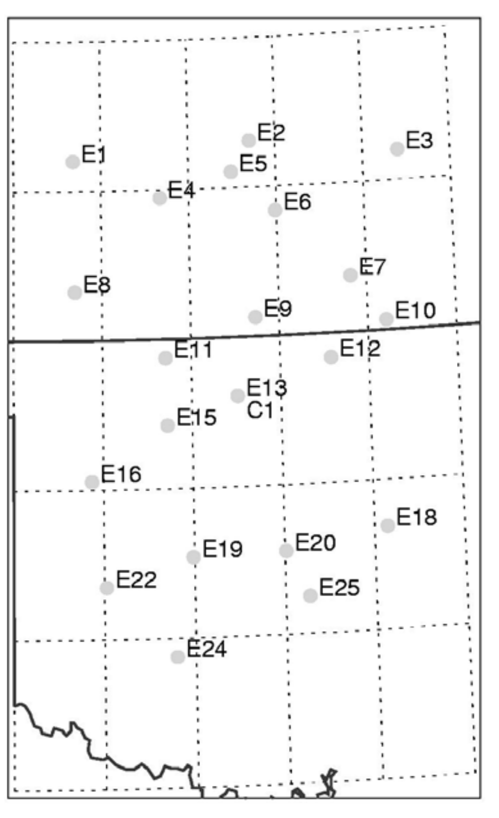
MFRSR spectral sensitivity





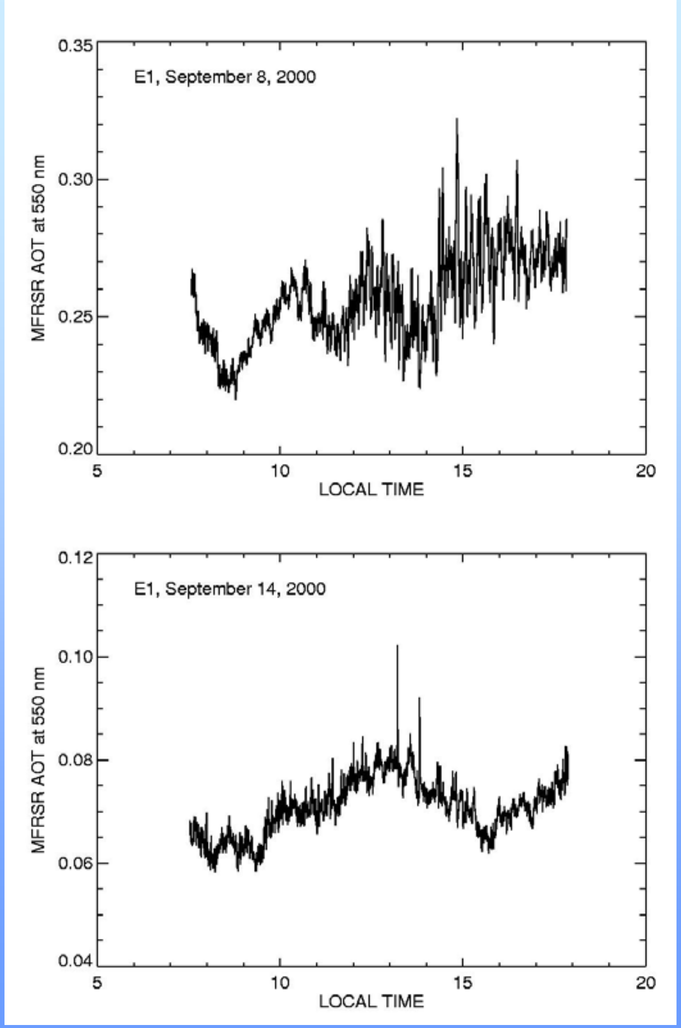
MFRSR networks

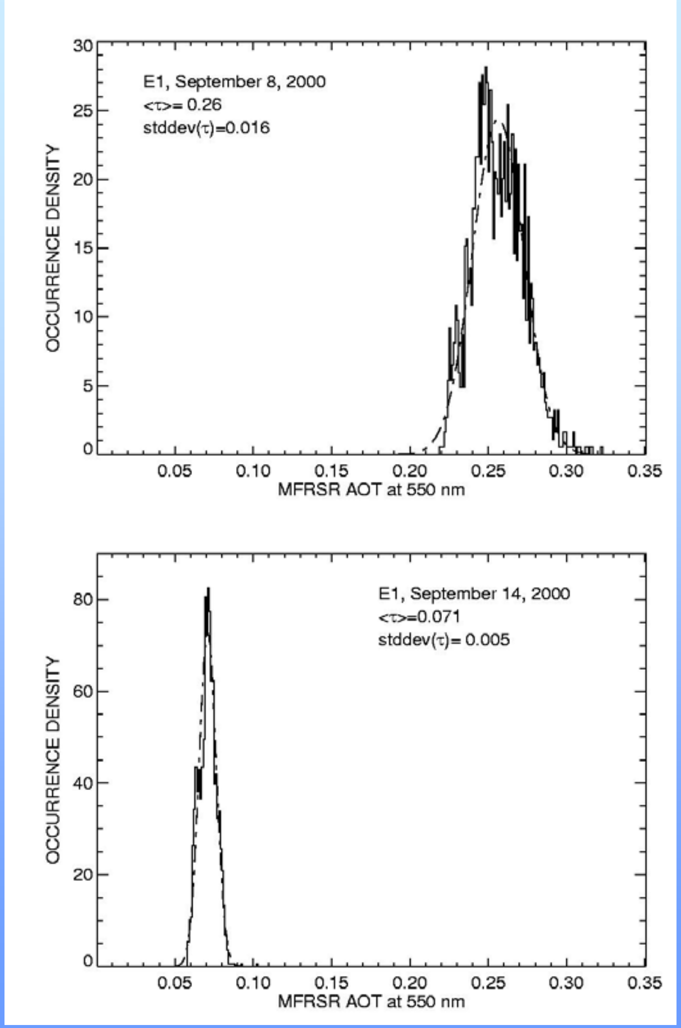




Southern Great Plains Network (DOE ARM)

Gaussian statistics of aerosol optical thickness





Two-point statistics, scale invariance

$\tau(x)$ is a stochastic AOT field, $\hat{\tau}(k)$ - its Fourier transform

Power Spectrum:

$$E(k) = \frac{2}{L} | \hat{\tau}(k) |^2 \propto k^{-\beta}$$

Structure functions:

$$S_q(r) = \overline{| \tau(x+r) - \tau(x) |^q} \propto r^{\zeta(q)}$$

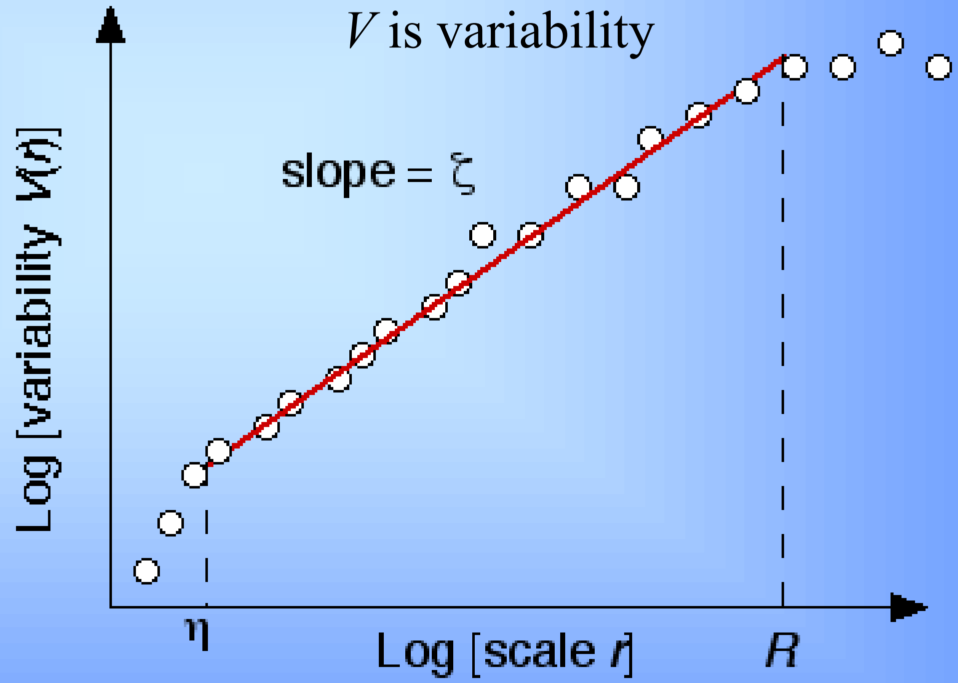
$$\beta = \zeta(2) + 1 \approx 2H_2 + 1 \qquad H_q = \zeta(q) / q$$

Scale-Invariance

Scale-Invariance
—a powerful
unifying concept

$$V(r) \propto r^{\zeta}$$

V is variability



$$\eta \leq r \leq R$$

Scale-invariance (scaling):

- statist. invariance under change in scale *r*
- power-law in *r* over large range of scales

$$V(\lambda r) \propto \lambda^{\zeta} V(r)$$

Example for atmospheric wind

2D turbulence
β=3

3D turbulence
β=5/3

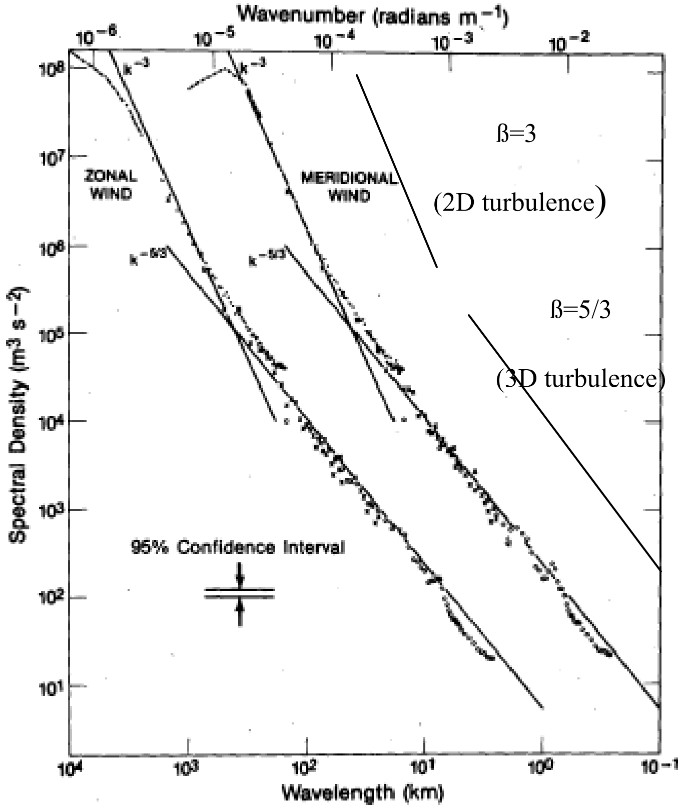
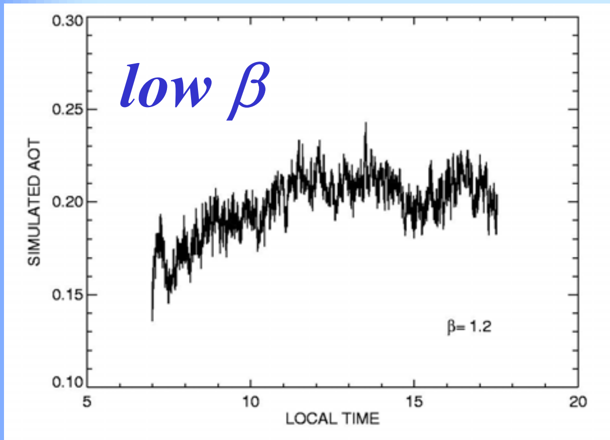


FIG. 2. Wavenumber spectra of zonal and meridional velocity composited from 3 groups of flight segments of different lengths. The 3 types of symbols show results from each group. The straight lines indicate slopes of −3 and −5/3. The meridional wind spectra are shifted one decade to the right (after Nastrom et al., 1984).

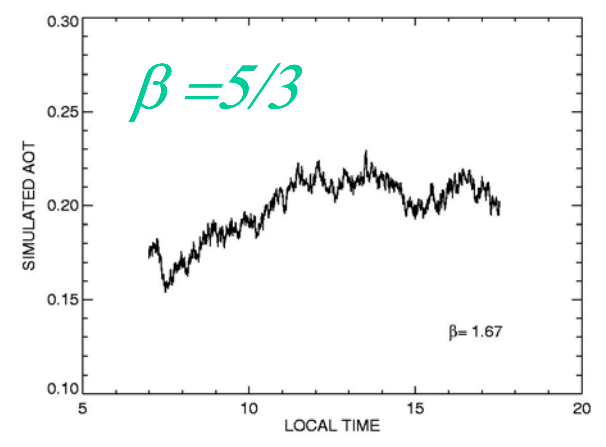
Wind fluctuations in the free troposphere at 9-14 km altitude

From Gage and Nastrom, 1989

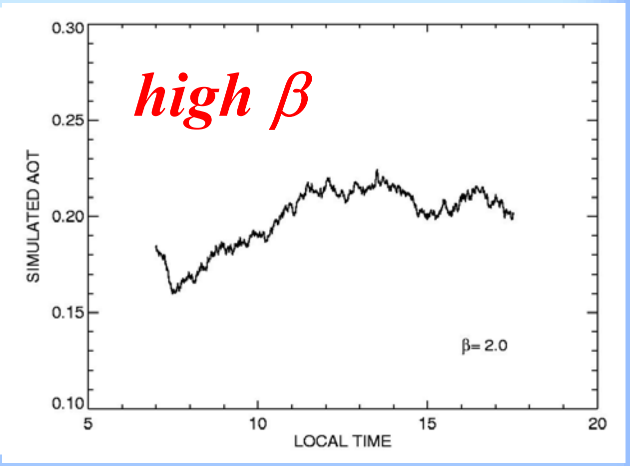
Simulated examples of scale-invariant AOT



β = 1.2



β = 1.67

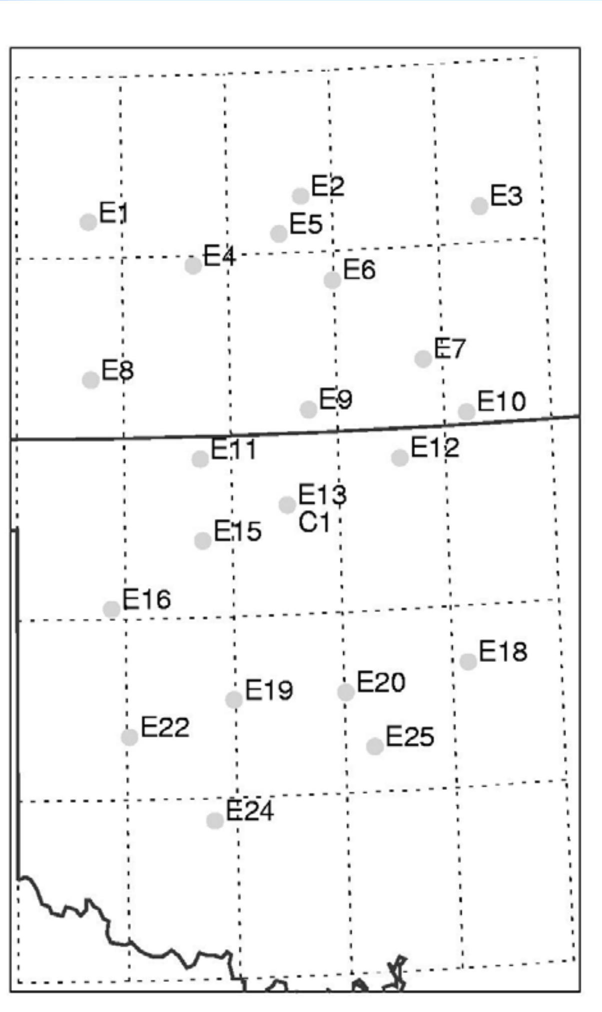


β = 2.0

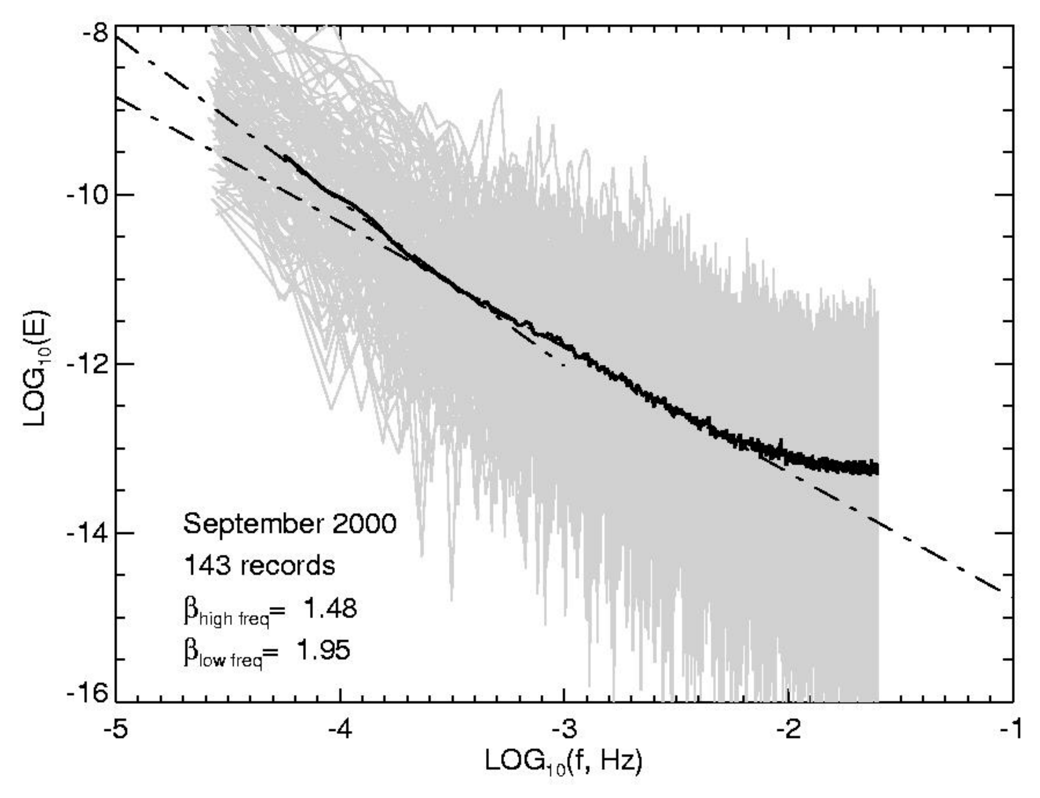
$$E(k) \sim k^{-\beta}$$

All three curves have the same mean and standard deviation

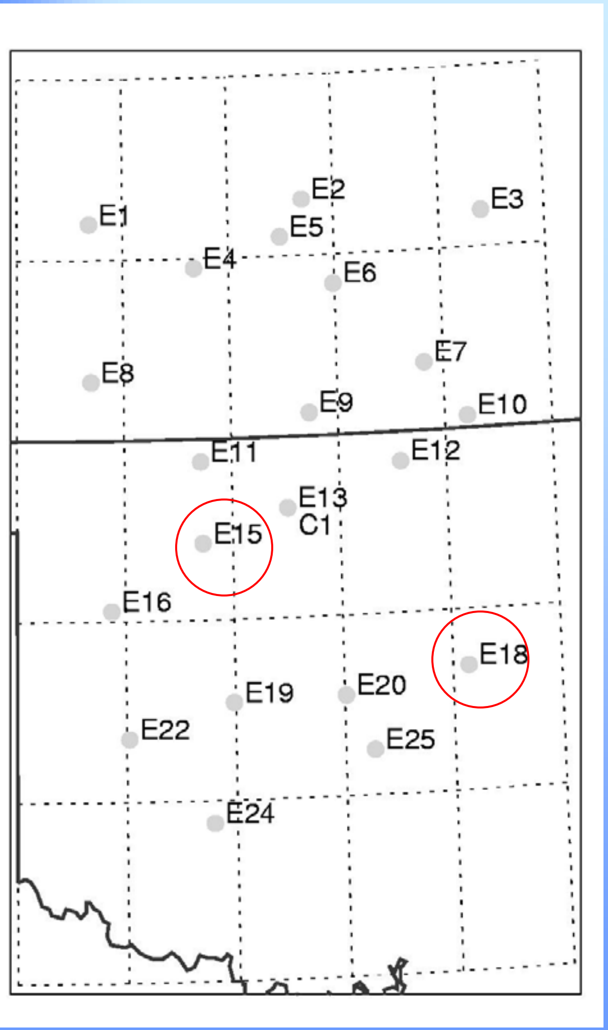
AOT from MFRSR network



Power spectrum

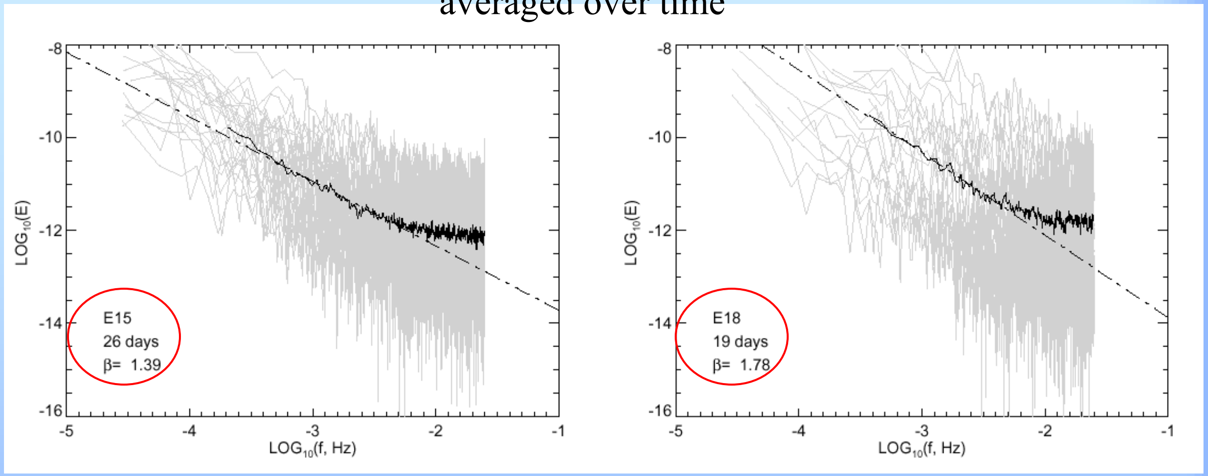


AOT from MFRSR network

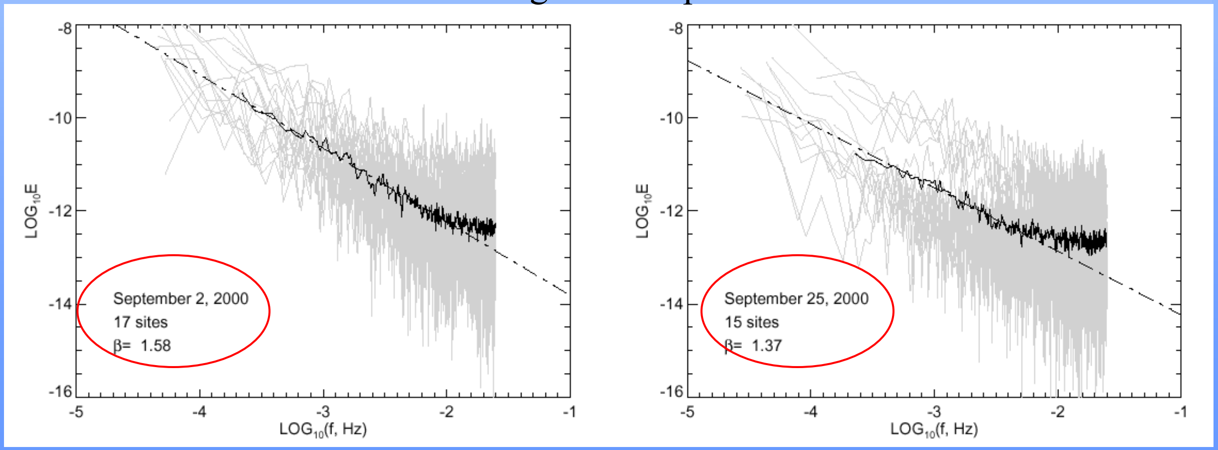


Power spectrum

averaged over time

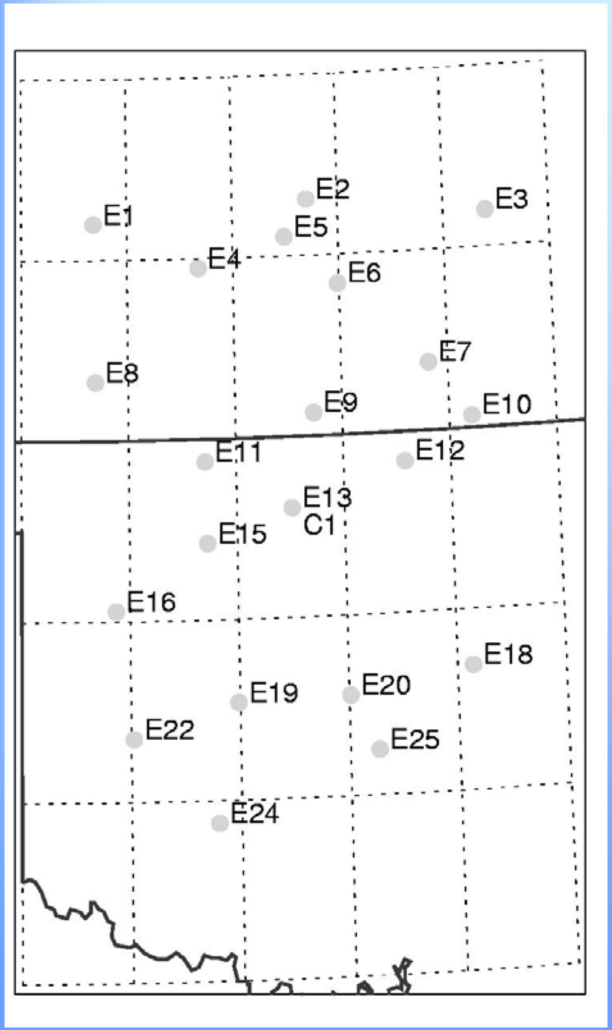


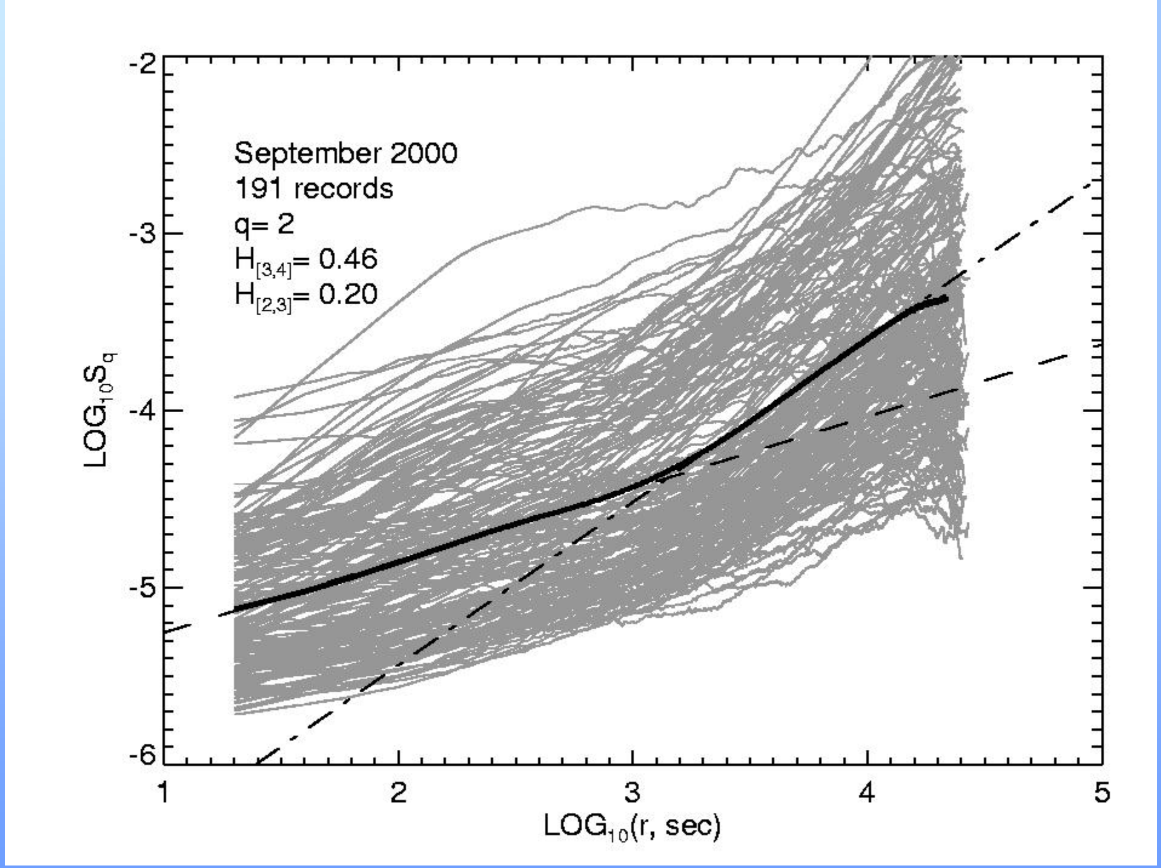
averaged over space



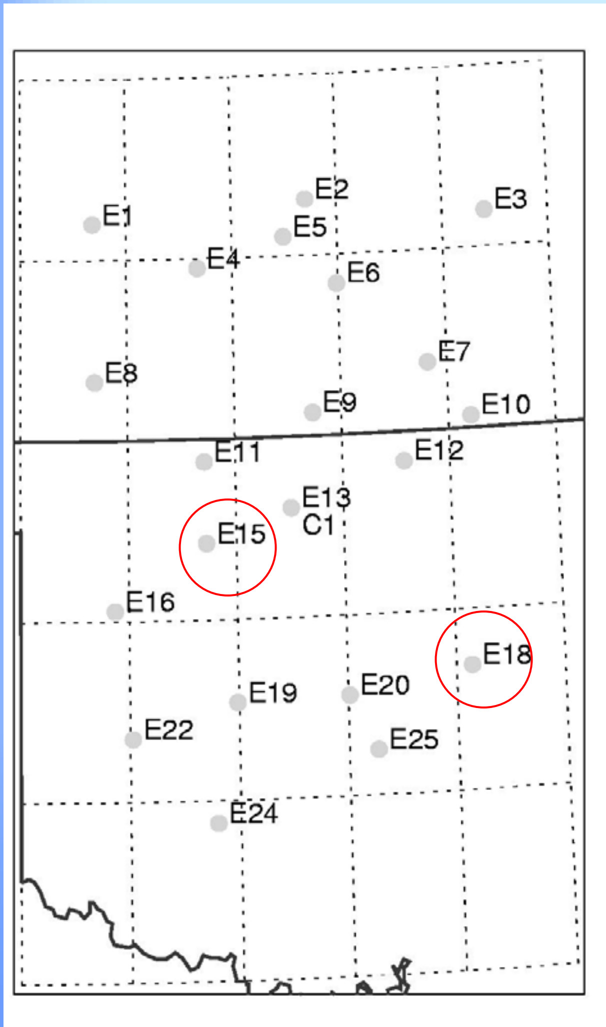
AOT from MFRSR network

Structure functions (2nd order)



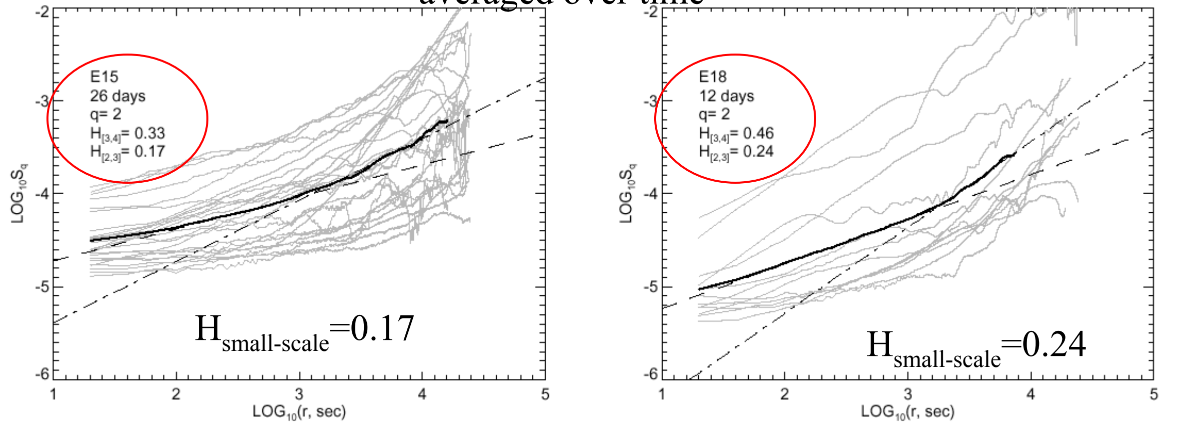


AOT from MFRSR network

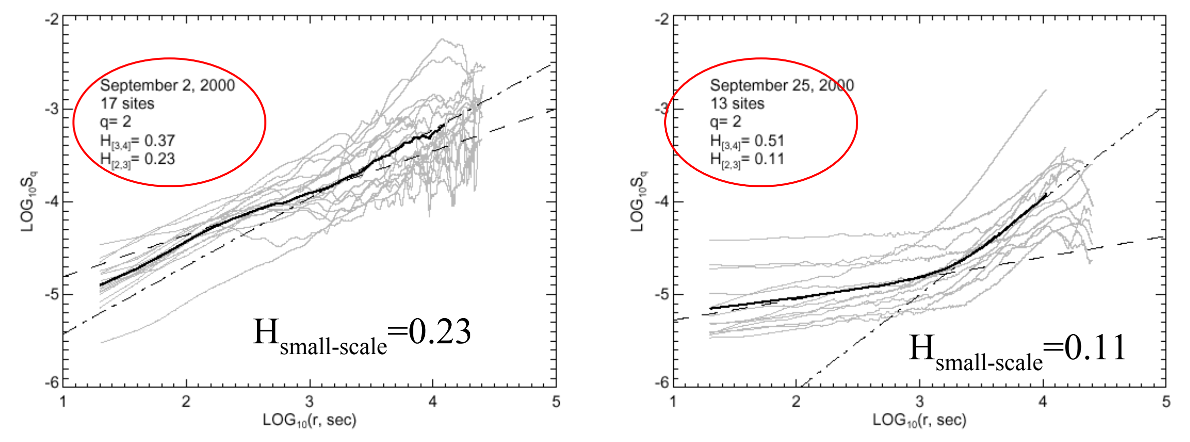


Structure functions

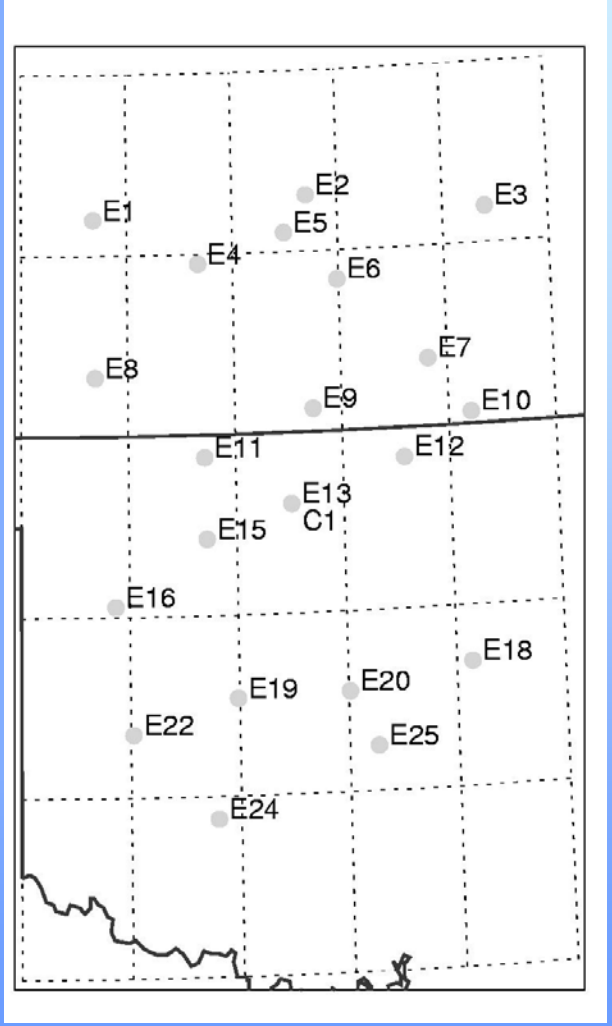
averaged over time



averaged over space



AOT from MFRSR network

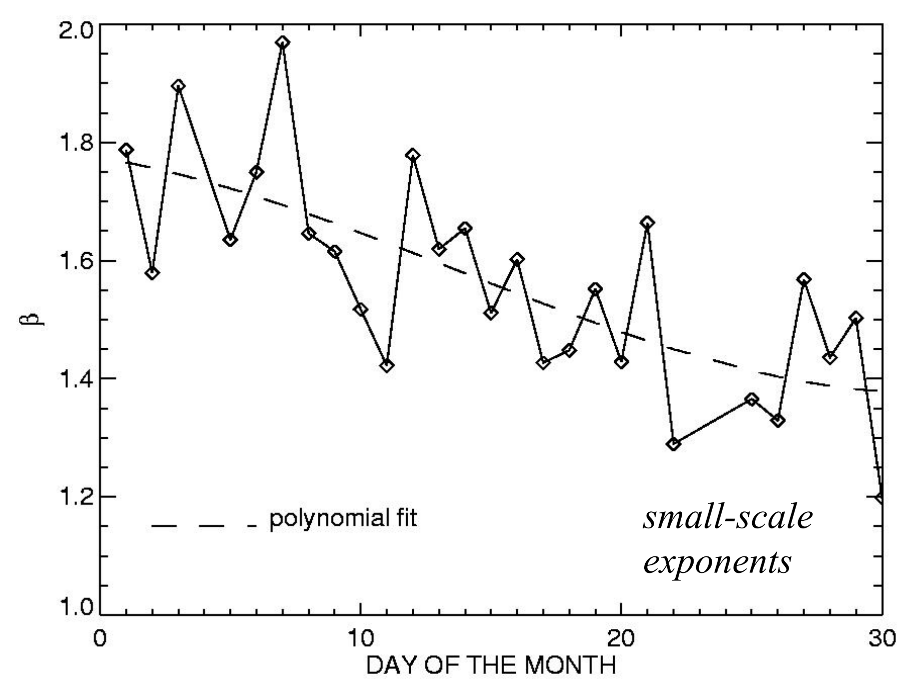


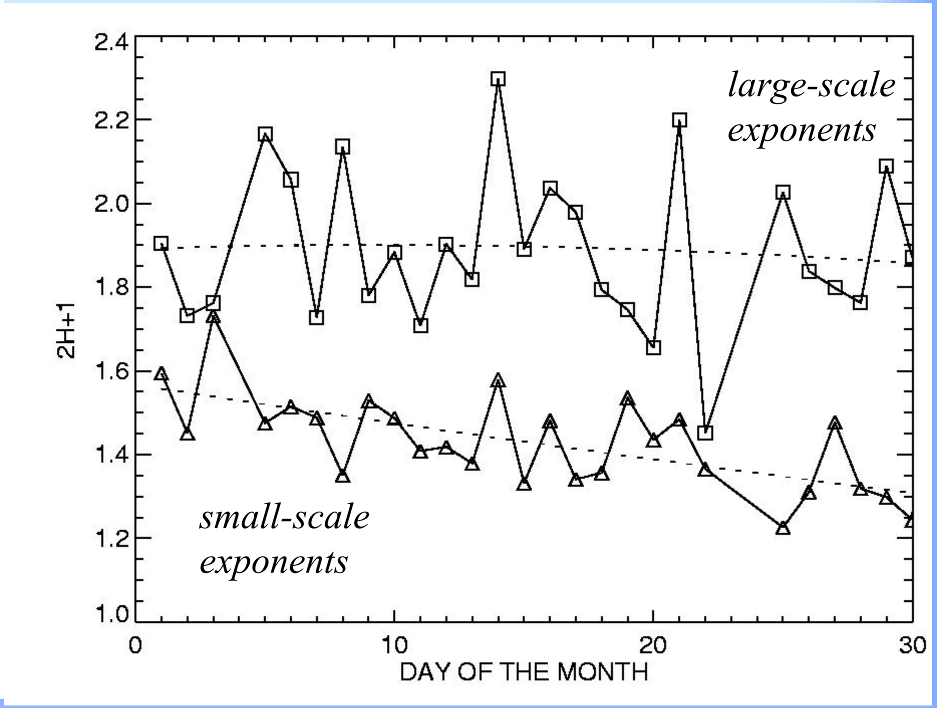
Questions to ask:

- What the small-scale spectral exponents are driven by? Or what fluctuations of the AOT (in time and space) depend on?

- What physics is behind the scale break?

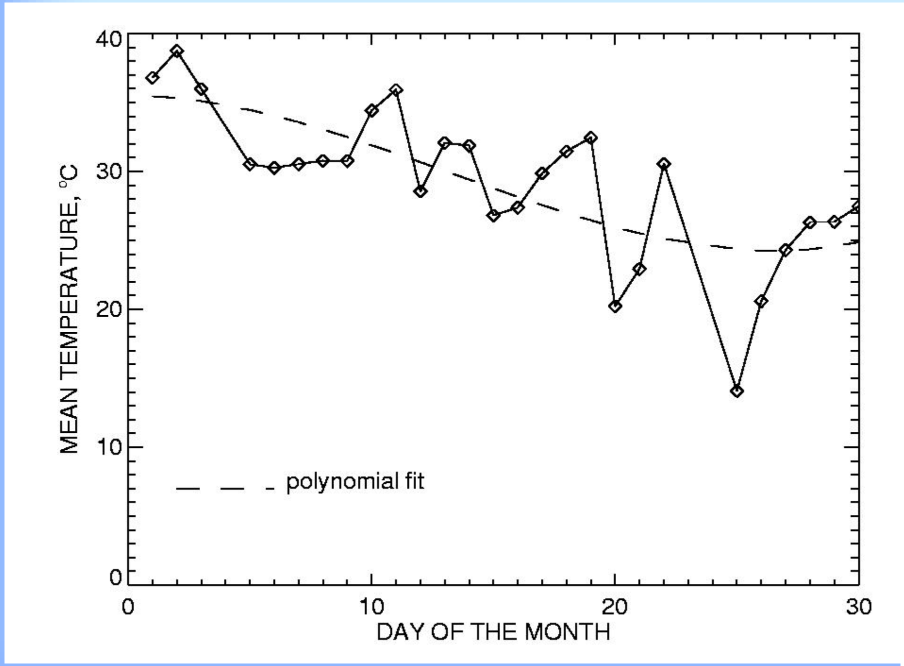
Time dependence of scaling exponents



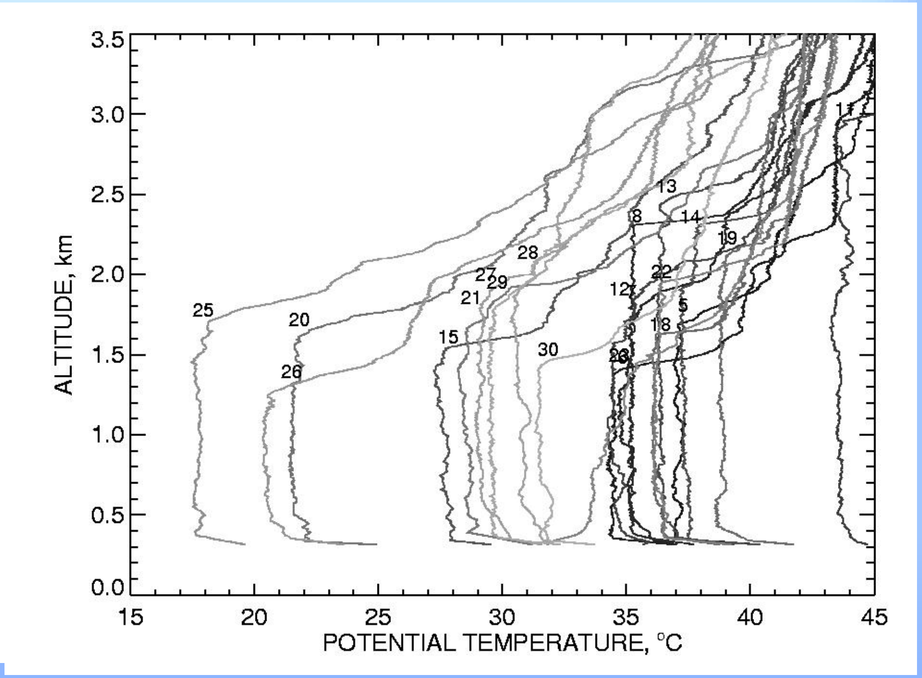


β $2H+1$

Temperature decrease

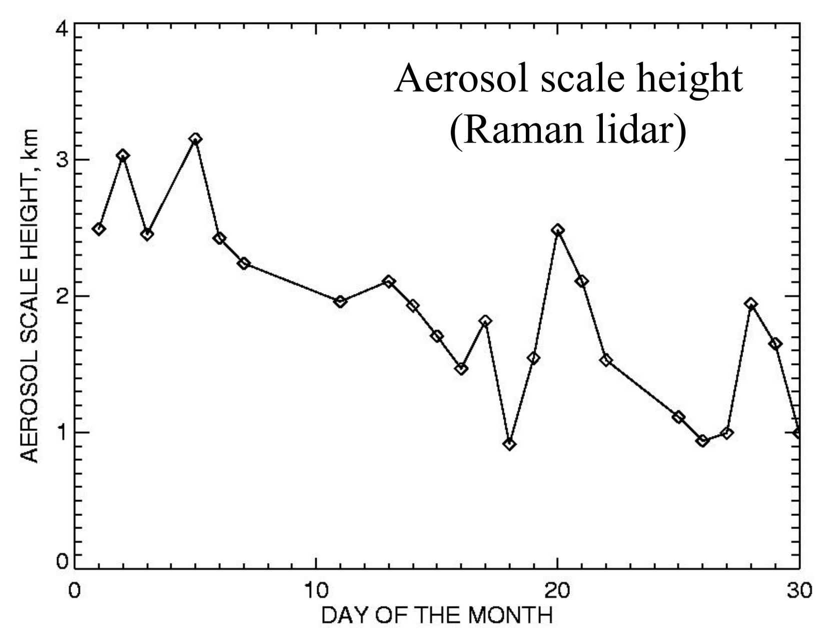


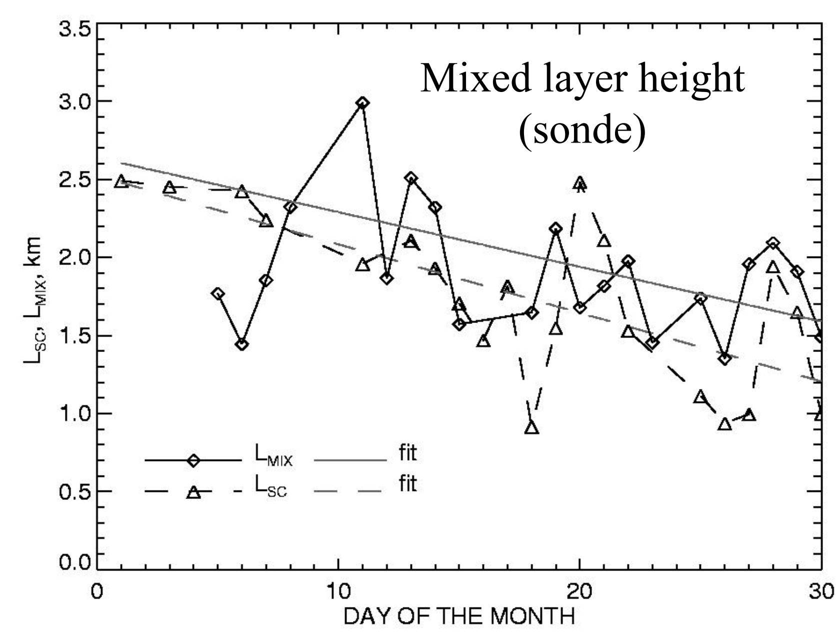
Ground temperature

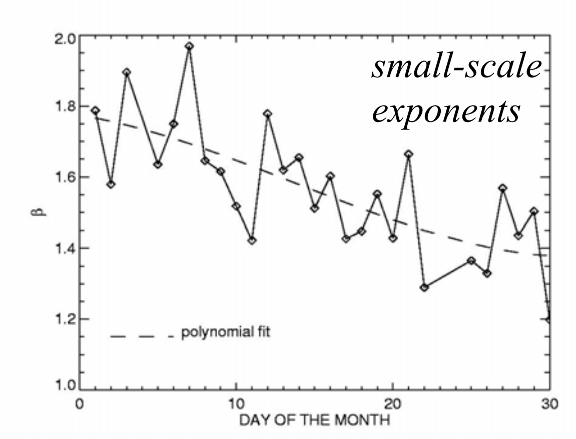


Potential temperature profiles (sonde)

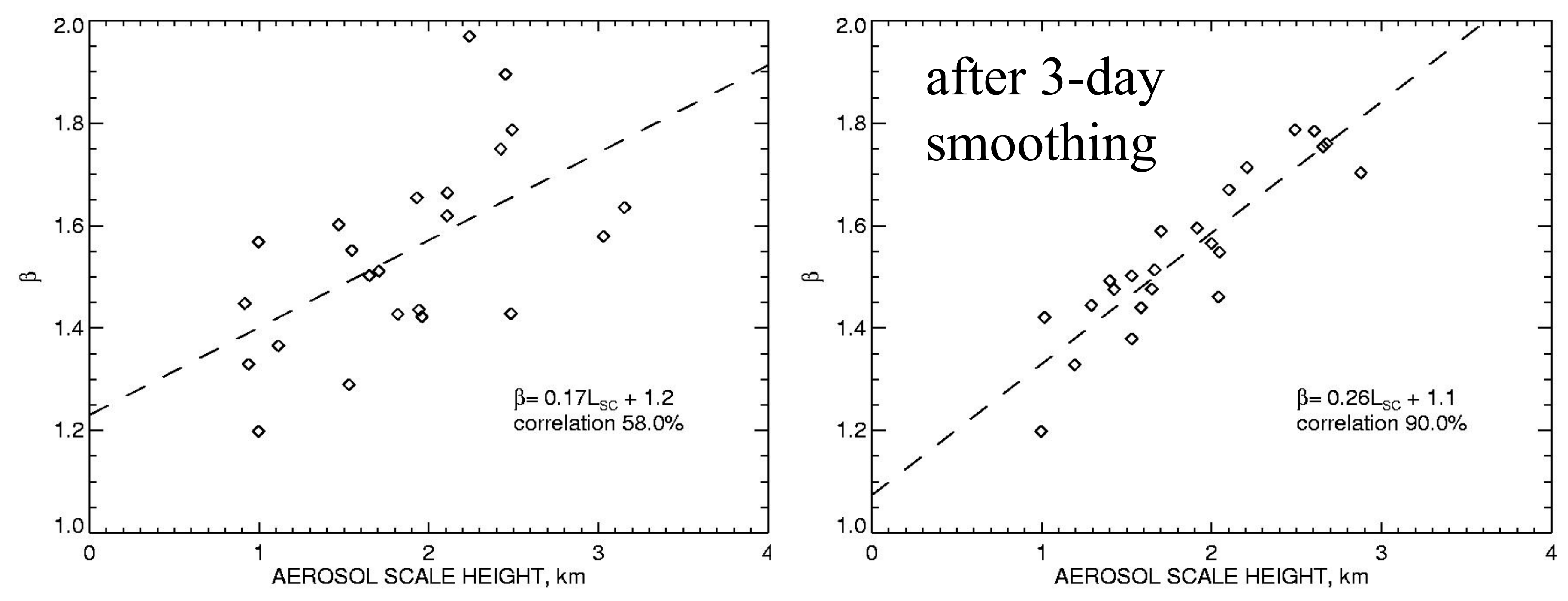
β vs. aerosol scale height





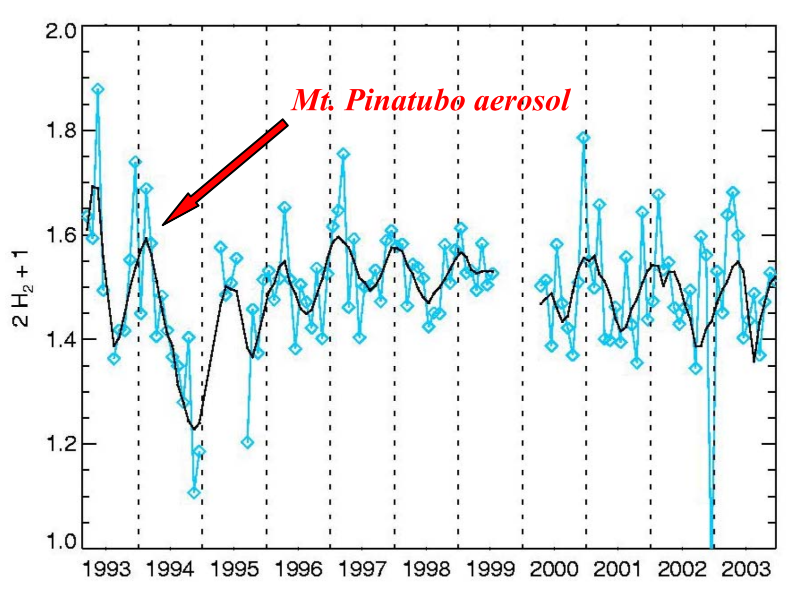


Correlation between daily values of β and aerosol scaling heights

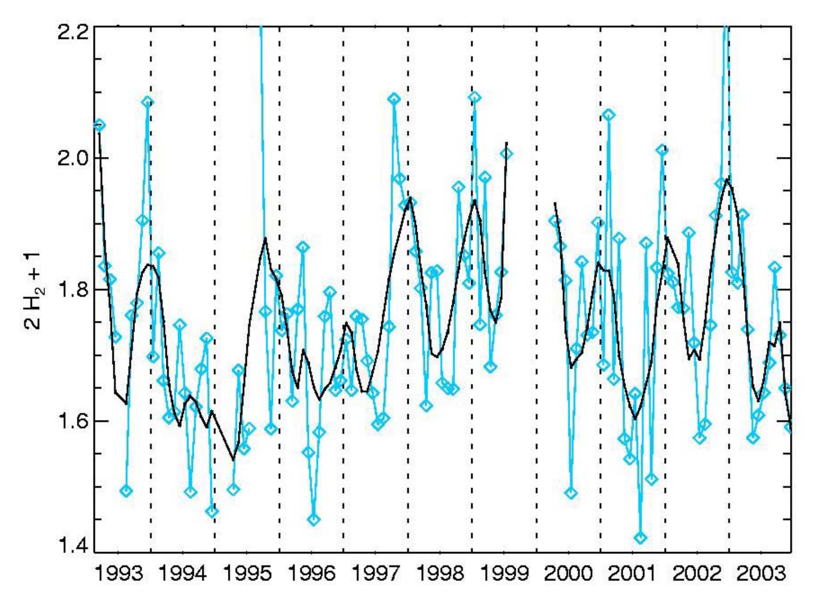


Variability in1993-2003

Monthly mean scaling exponents $2H_2+1$ for SGP CF (870 nm)



Mt. Pinatubo aerosol



Small-scale

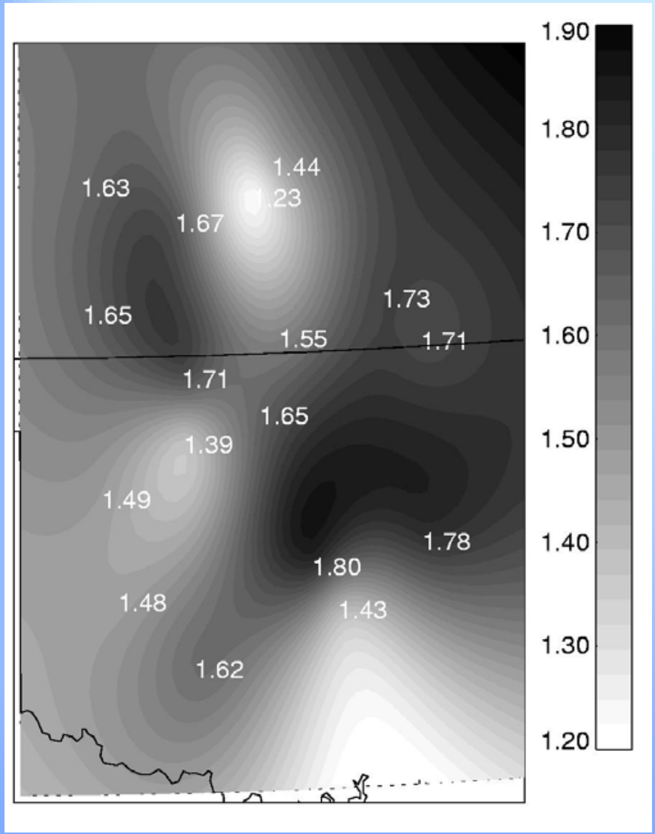
- strong trend in 1993-1994
- seasonal cycle with max in Spring

. or Winter

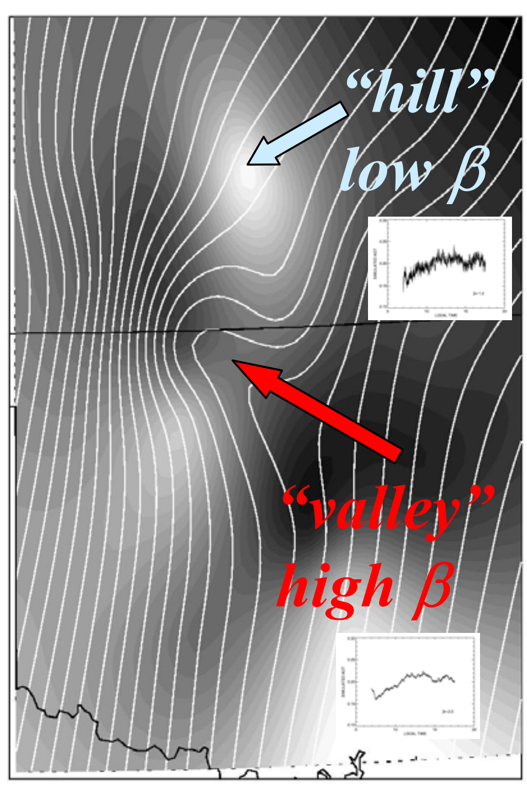
Large-scale

- smaller inter-annual trend

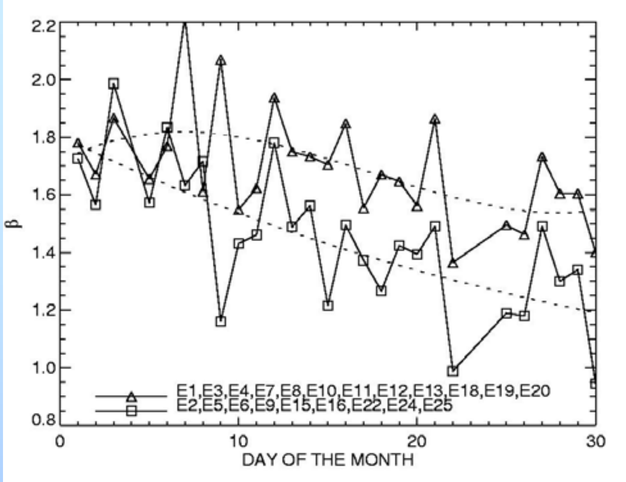
β v.s. topography



Mean values of β for SGP network sites in September 2000.

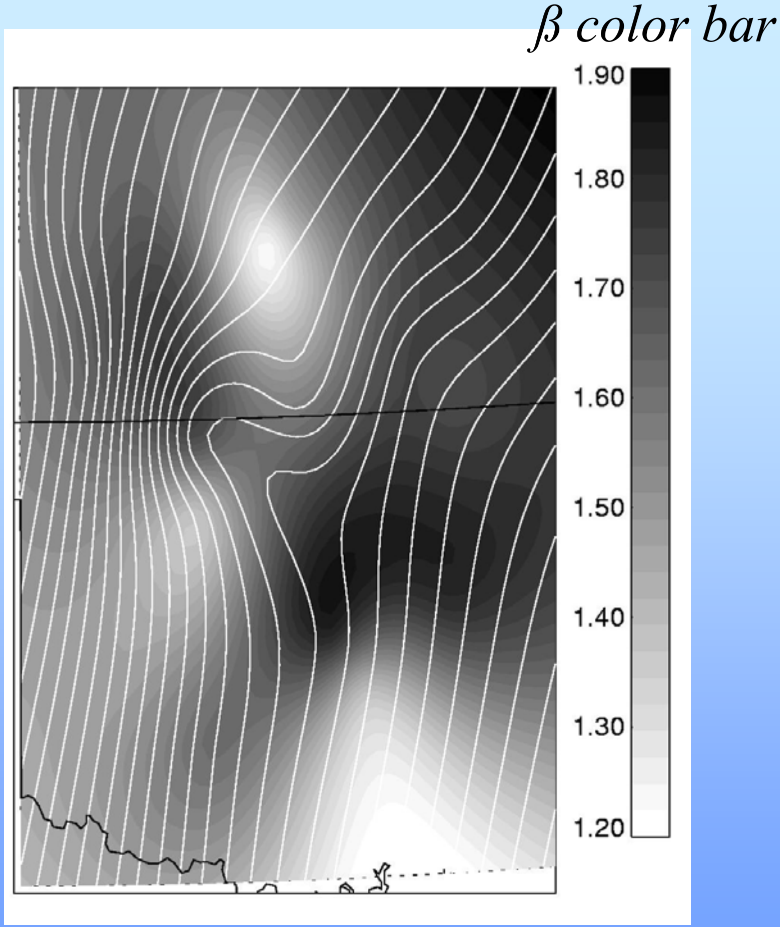


Same as left with altitude isolines over-plotted.

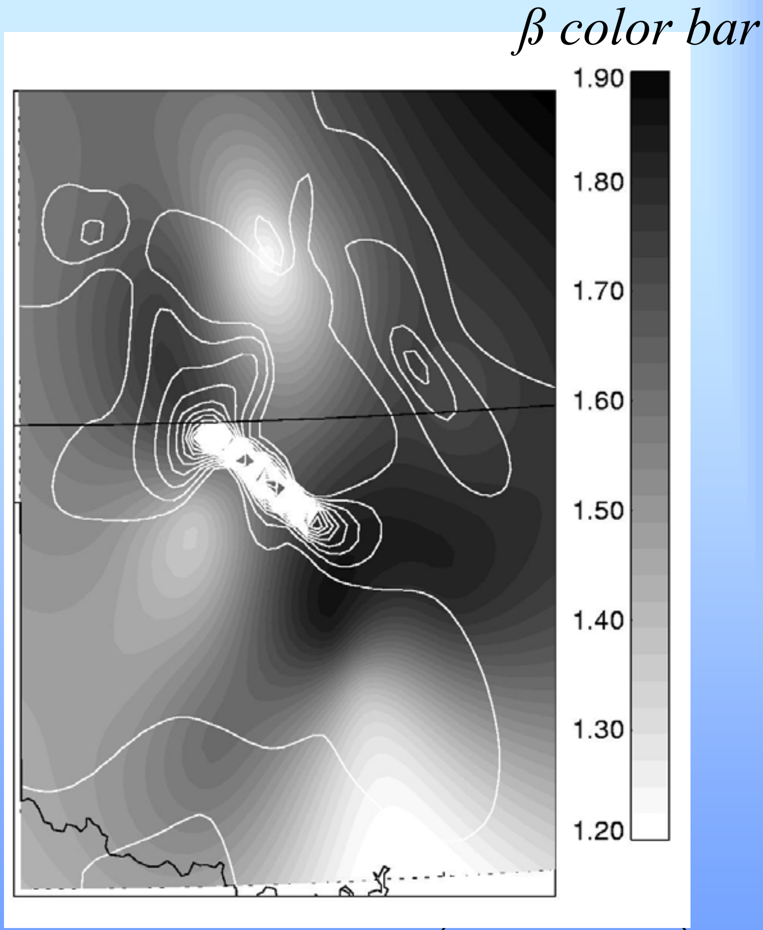


Temporal evolution of β in "β > 1.6" and "β < 1.6" groups during September 2000.

β v.s. topography



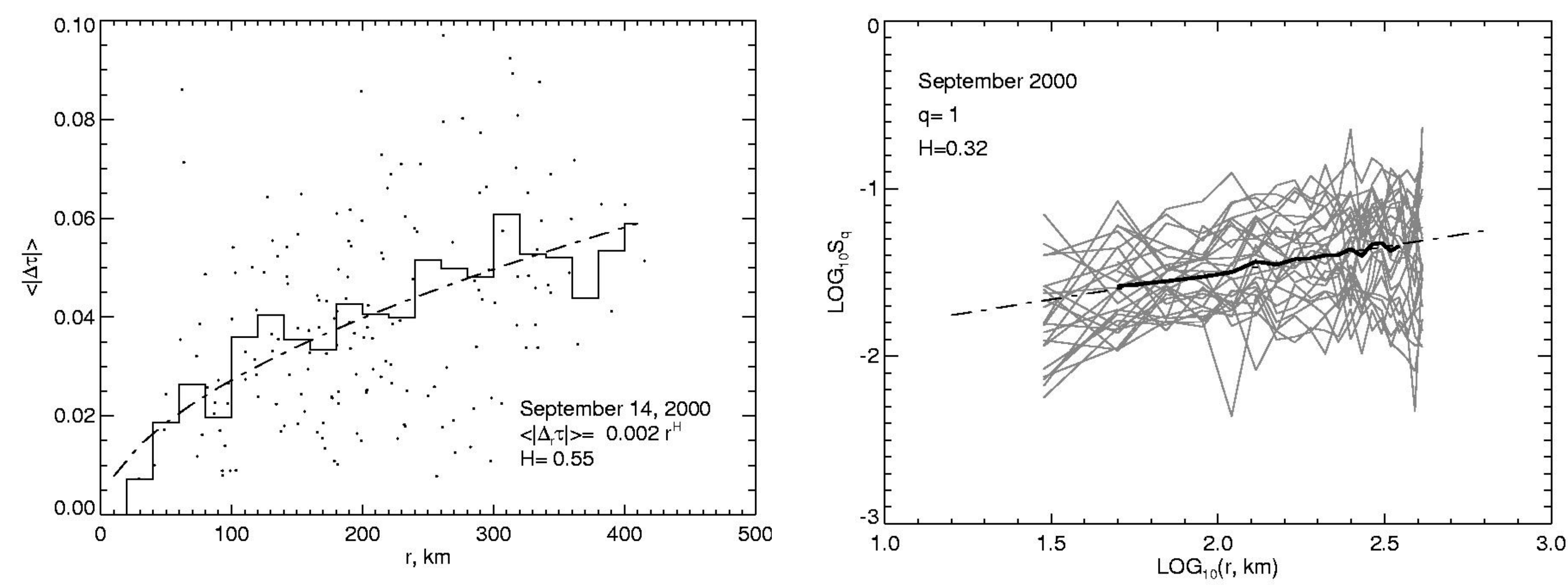
Altitude: h



Curvature: $K = div\left(\frac{\nabla h}{\sqrt{1+|\nabla h|^2}}\right)$

Spatial structure functions

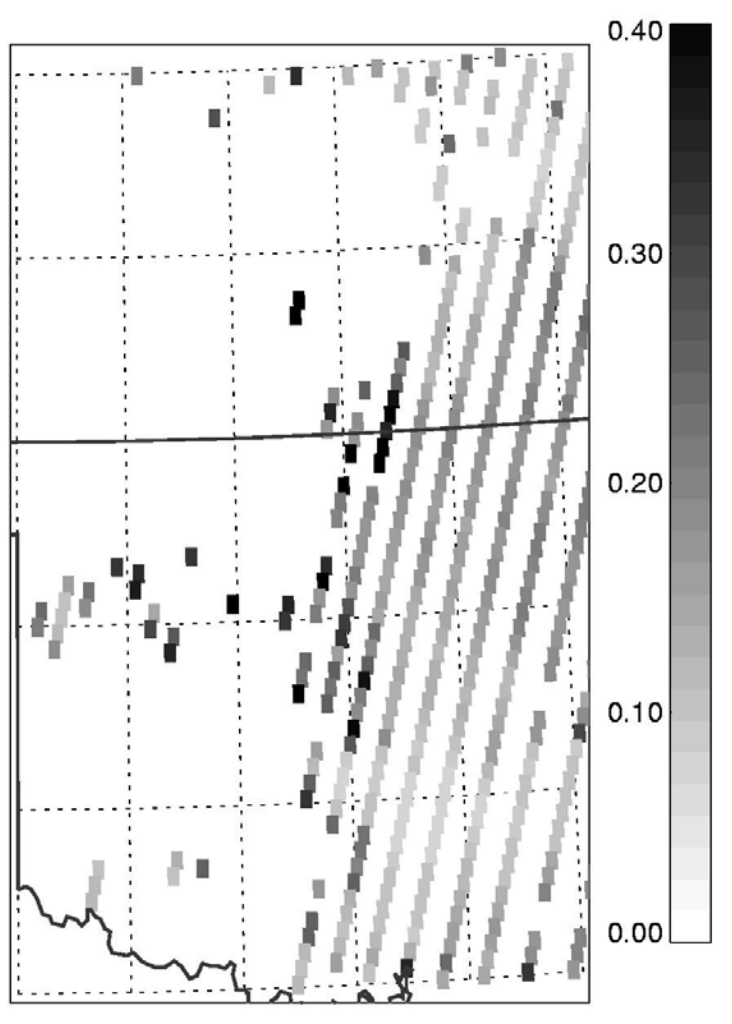
$$\Delta\tau = |\tau(r_1) - \tau(r_2)|, \quad r = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$$

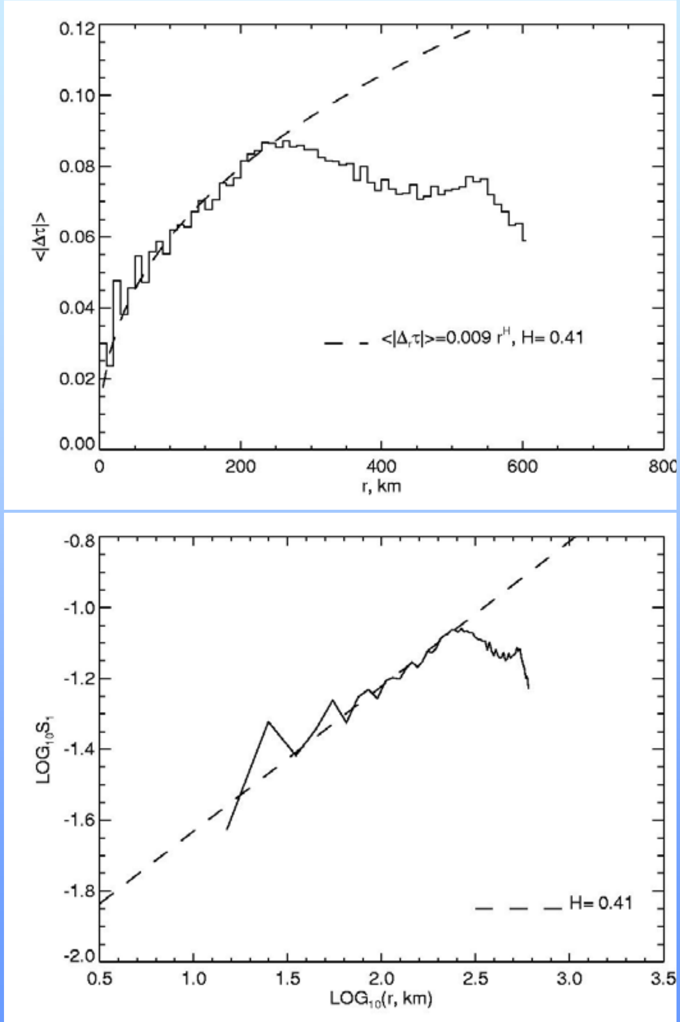


The first order spatial structure function for Sep. 14, (left: 19 sites, 171 pairs) and for all days in Sep. 2000 (right: 21 sites, 210 pairs, range: 30 – 415 km, spacing: 2.3 km mean, 18 km max).

MODIS SF: SGP

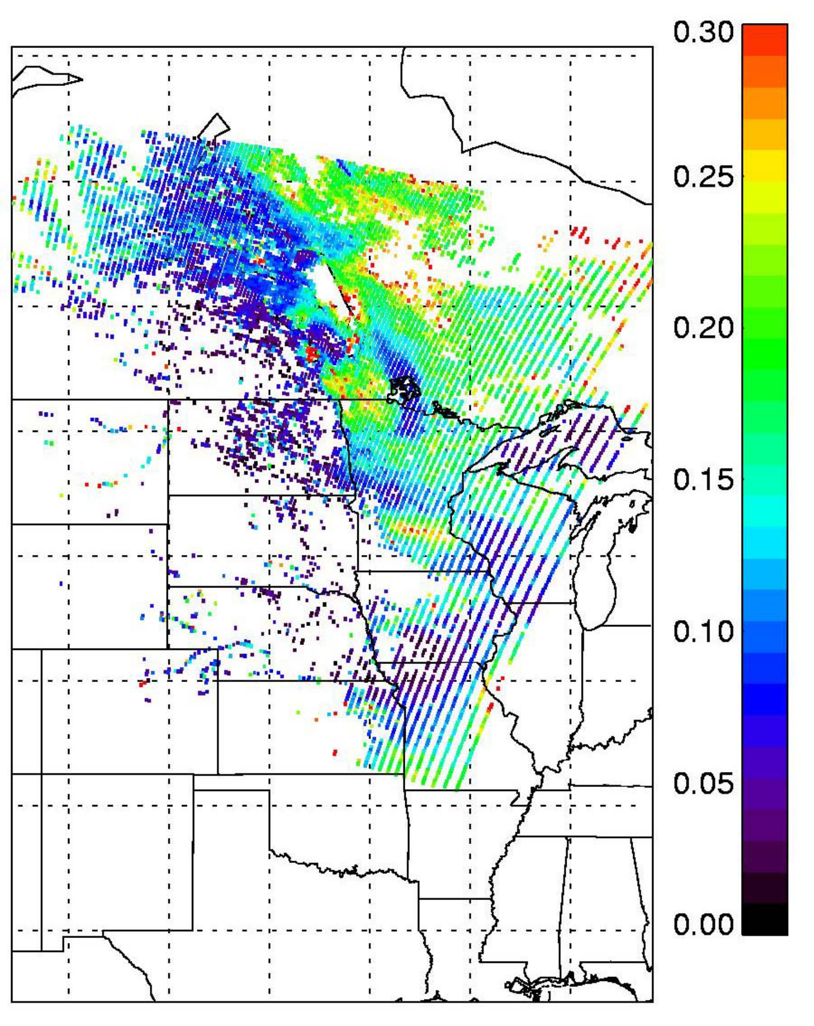
September 14, 2000, 508 pixels, 128,778 pairs

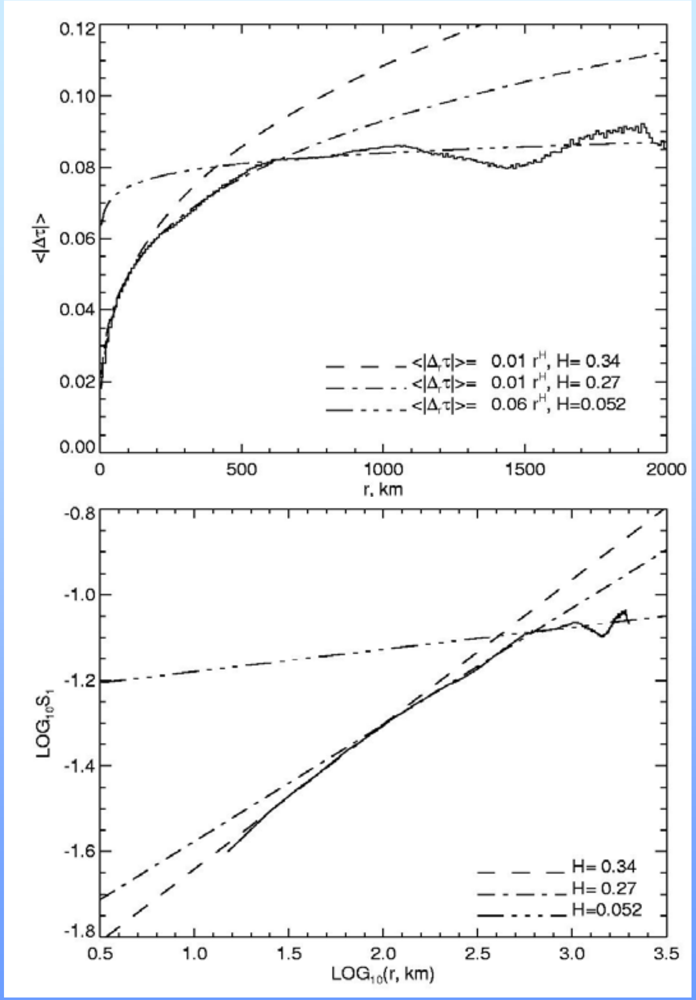




MODIS SF: NE USA

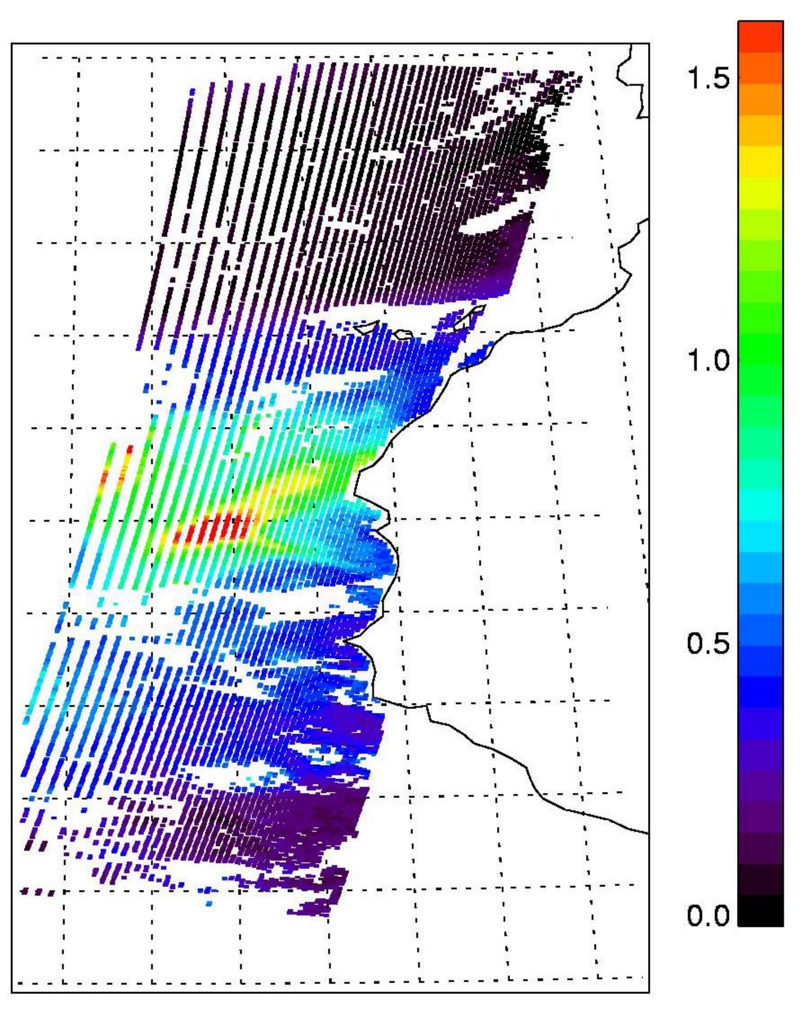
September 14, 2000; 9,292 pixels, 43,165,986 pairs

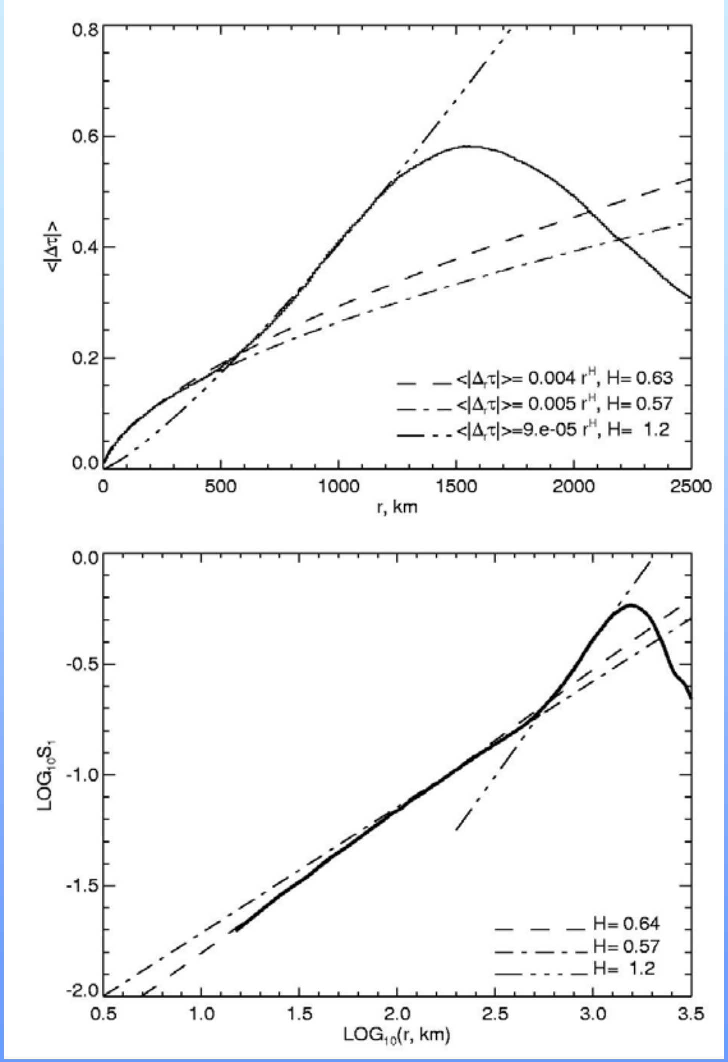




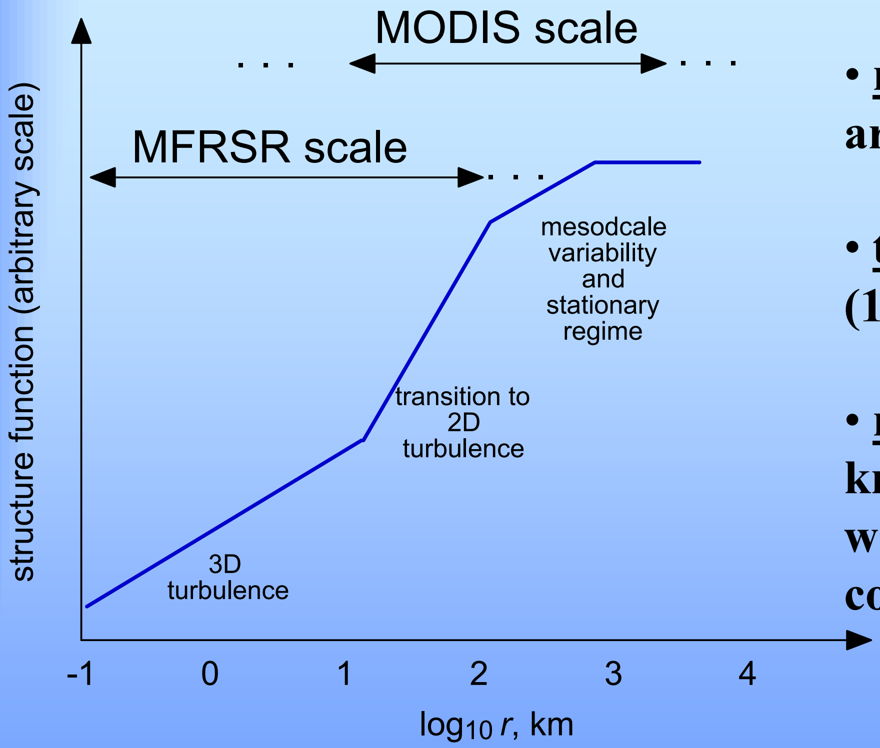
MODIS SF: Sahara dust plume

June 4, 2001; 12,295 pixels, 75.5 million pairs





AOT Scaling Regimes (preliminary results)

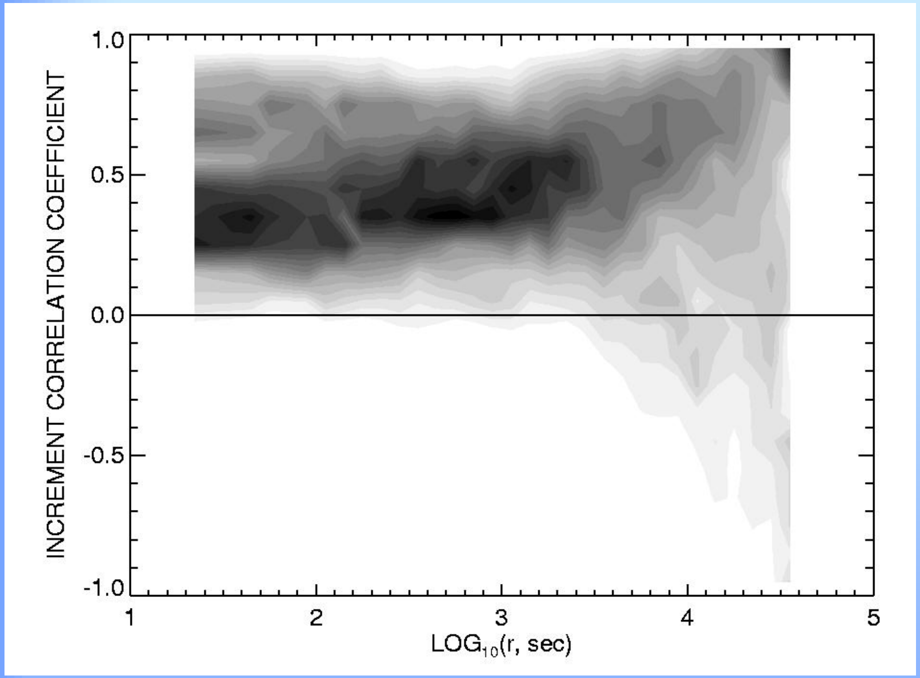


- **<u>microscale</u> (0.5--15 km) where fluctuations are governed by 3D turbulence;**

- **<u>transition</u> towards large-scale 2D turbulence (15--100 km);**

- **<u>mesoscale</u> variability (scales up to 100--600 km and <u>synoptic scales</u> (after 600--1000 km) where AOT fields become stationary and loose correlation.**

AOT correlation with aerosol size (preliminary results)



Statistical distribution of the correlation coef. C_{uv} values obtained by analysis of 294 clear sky daily MFRSR records from Sept. 2000.

A multivariate structure function S_{uv} and a scale-dependent correlation coef. C_{uv} of two fields *u(x)* and *v(x)* (*x* is time, or space):

$$S_{uv}(r) = \overline{[u(x+r) - u(x)][v(x+r) - v(x)]}$$

$$C_{uv}(r) = \frac{S_{uv}(r)}{\sqrt{S_{uu}(r) S_{vv}(r)}}$$

Scales up to 6 hours (~ 100 km): positive correlation - AOT variation is dominated by **hygroscopic growth.**

Larger scales: correlation starts to change sign - AOT variation is influenced by fine mode **aerosol concentrations**.

Conclusions

- ***Scale invariance is a fundamental property of atmospheric aerosol datasets.***

- ***Variability in a large scale range is characterized by 1 or 2 parameters complementary to Gaussian statistics.***

- ***AOT scaling reflects mixed layer meteorology and aerosol processes (transport, hygroscopic growth)***