MODELING HYDROLOGIC VARIABILITY

Efi Foufoula-Georgiou

University of Minnesota

NASA-GPM wtg

May 15-17, 2001

Qu: What is the main breakthrough in earth sciences in the last decade?

Demonstration of the interconnectivity of "earth system processes" at all scales

"earth system processes" ≡ land, ocean, atmosphere

- local phenomena ⟶ global scale effects
- global phenomena ⟶ local scale effects

Pressure is on to:

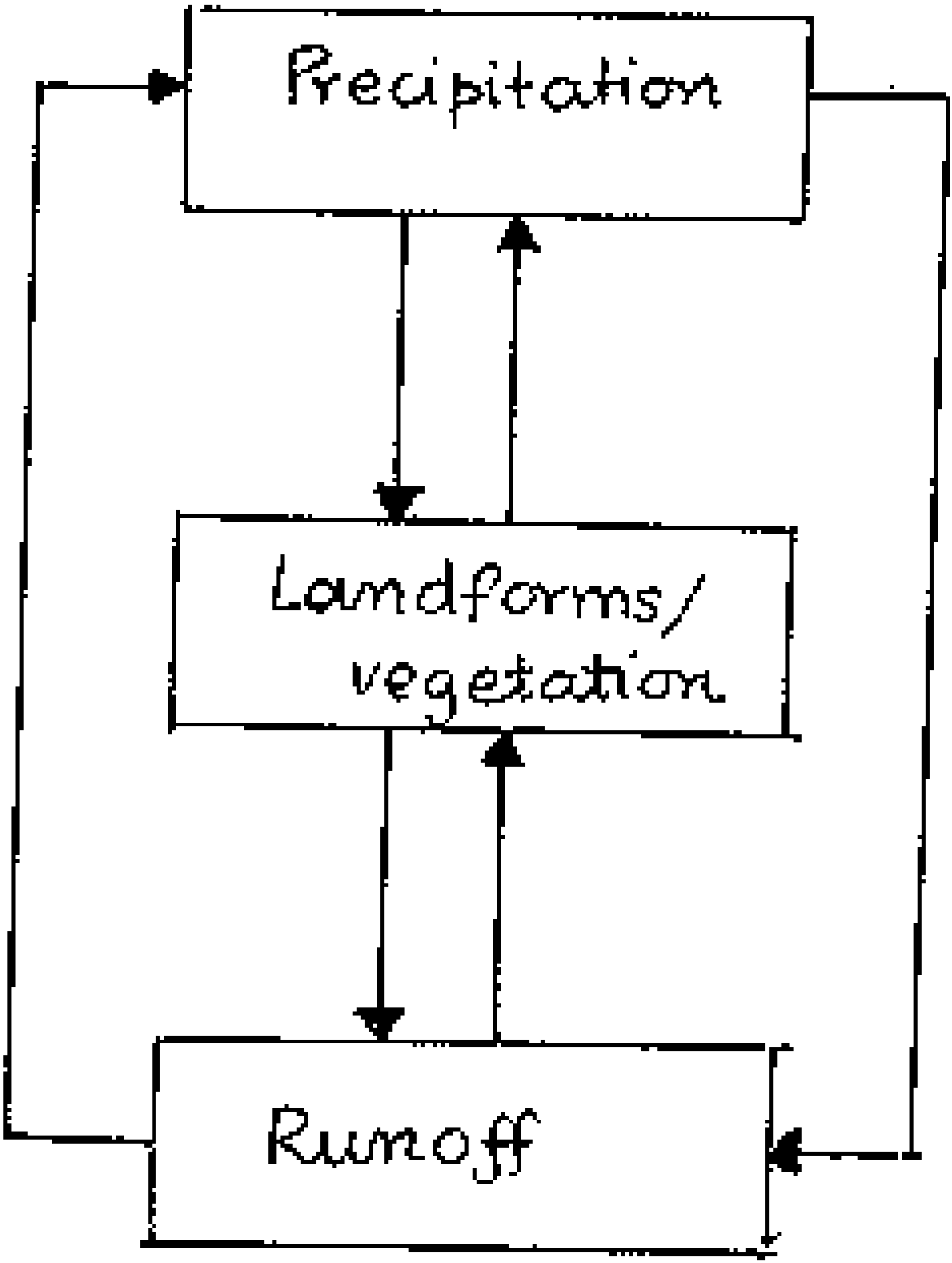
① Understand and quantify the dynamics of the whole system and its individual components at all scales

(water, energy and carbon cycles)

② Build models that can explain these dynamics and give ability for prediction

⇑

Need high resolution observations over the globe


Precipitation
Landforms/
vegetation
Runoff

ISSUES

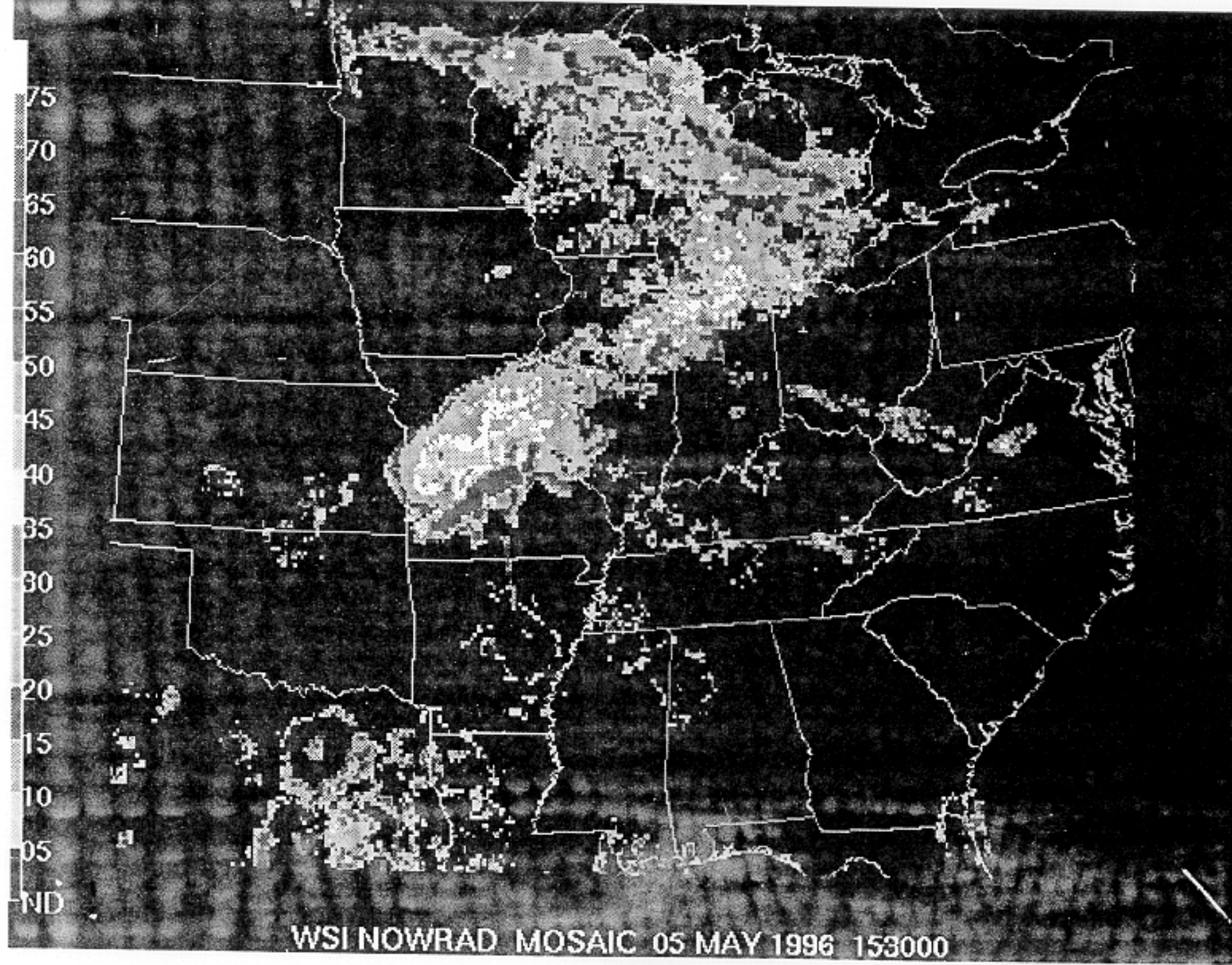
- Hydrologic processes exhibit variability over a large range of spatio-temporal scales

- Interactions and feedbacks take place at a wide range of scales

- Difficult to explain and model this observed variability from first principles → need observations to develop model parameterizations, validate models and for data assimilation

- Relate statistical characterizations of variability to physical observables

- Interest in estimation, modeling and prediction of water and energy fluxes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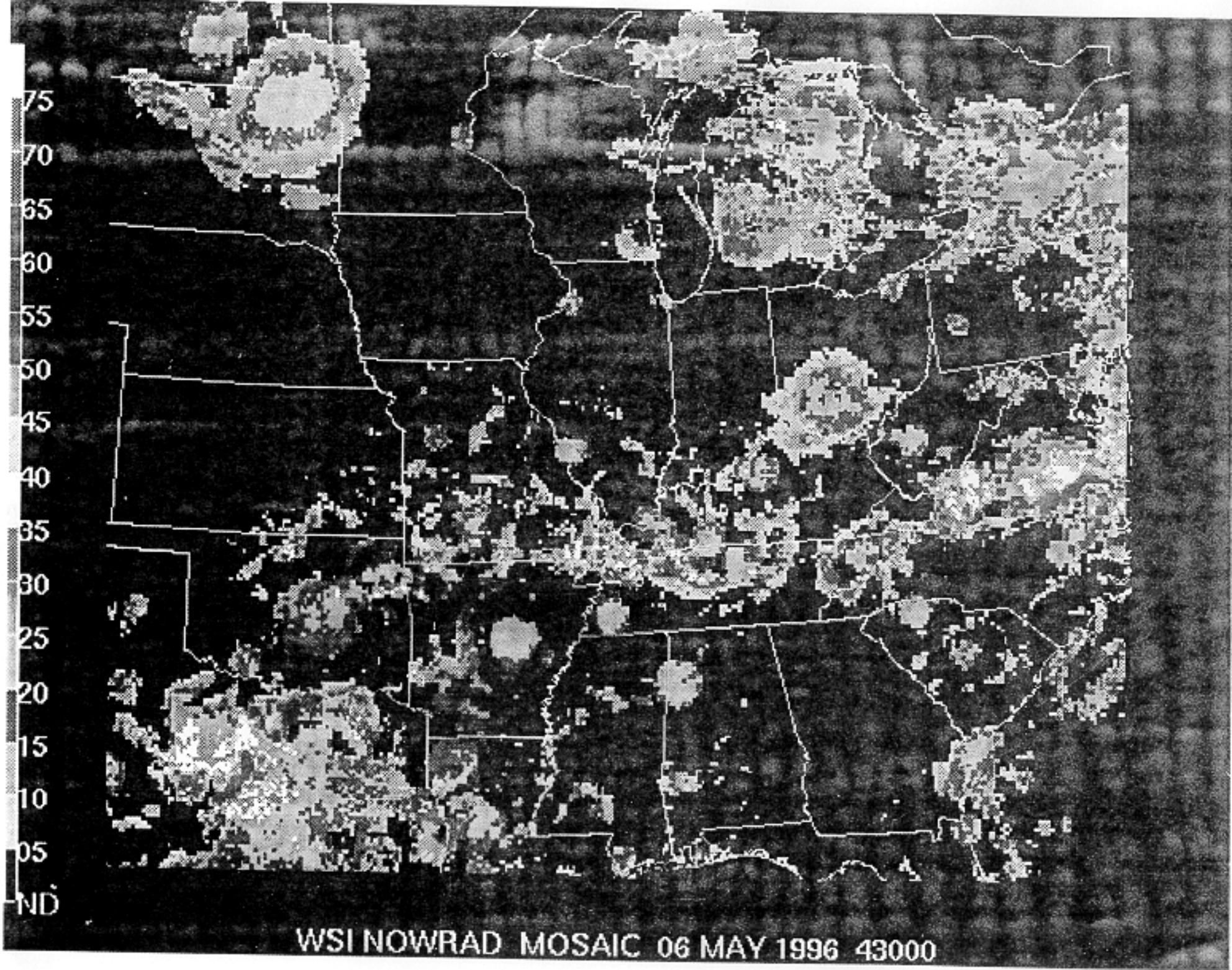
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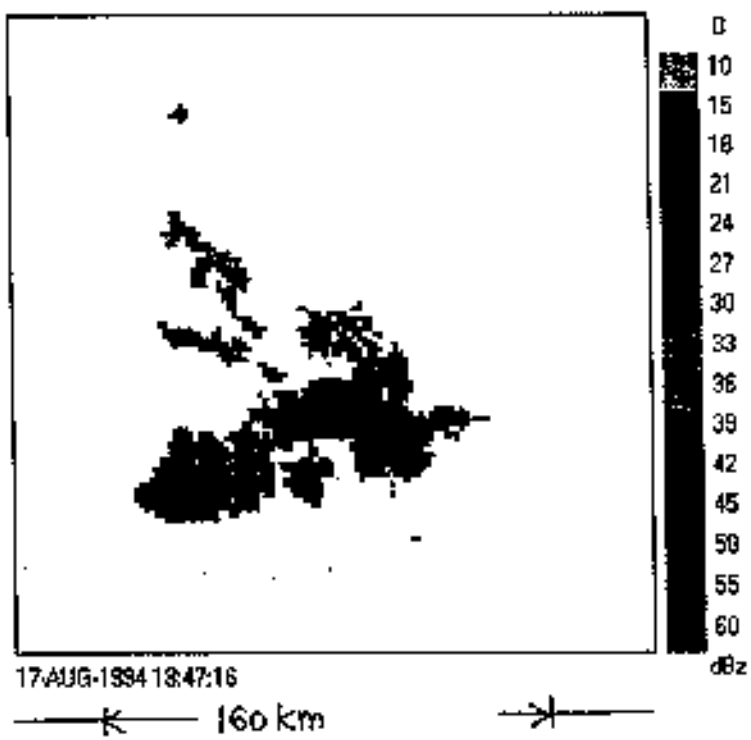
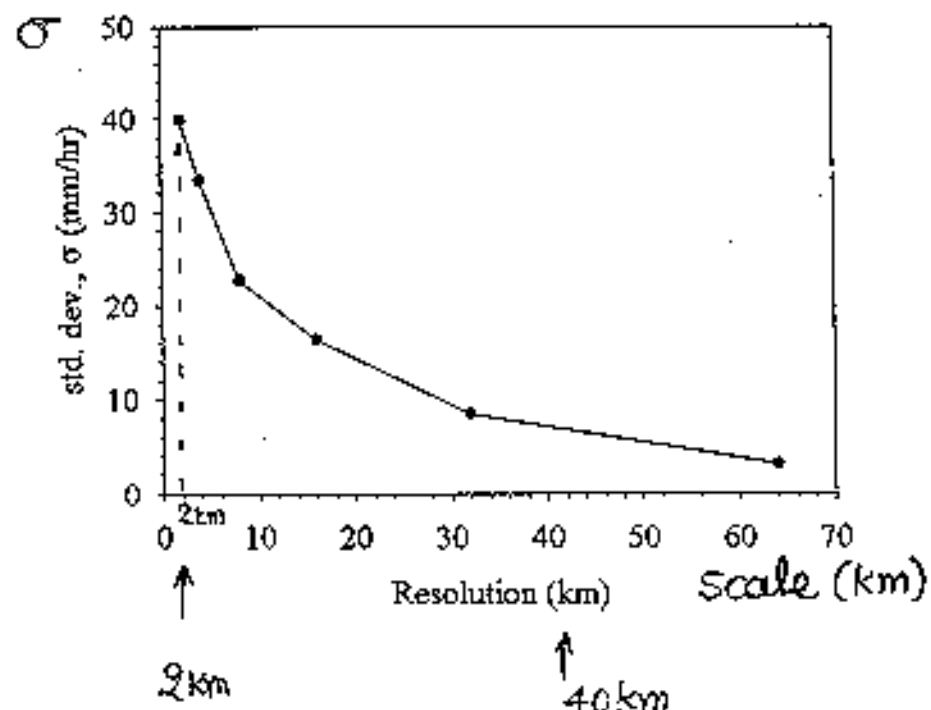
• Variability of precipitation is a function of the scale at which the process is examined

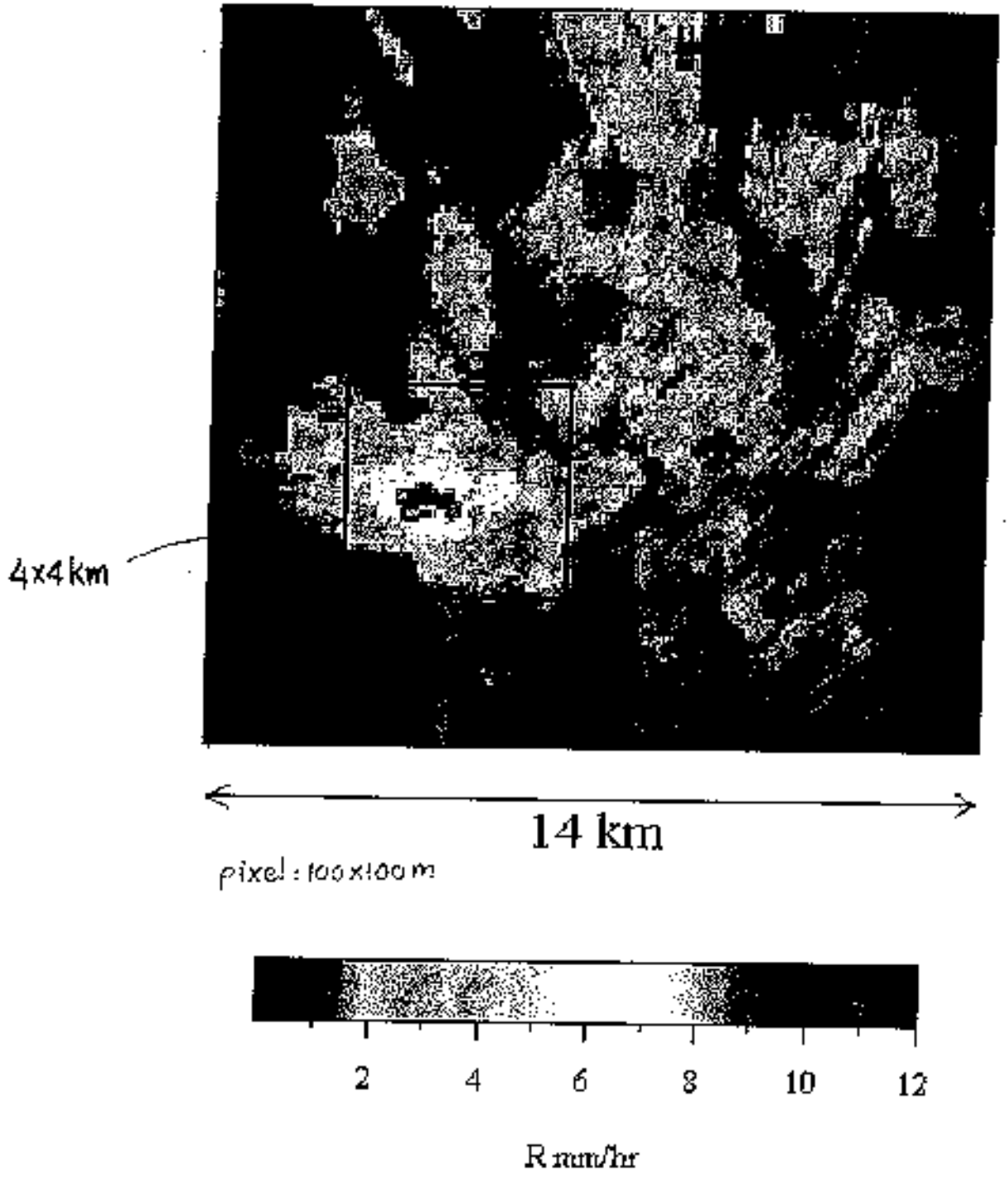
i.e. the larger the area over which we average, the smaller the variability of the field



pixel : 2×2 km

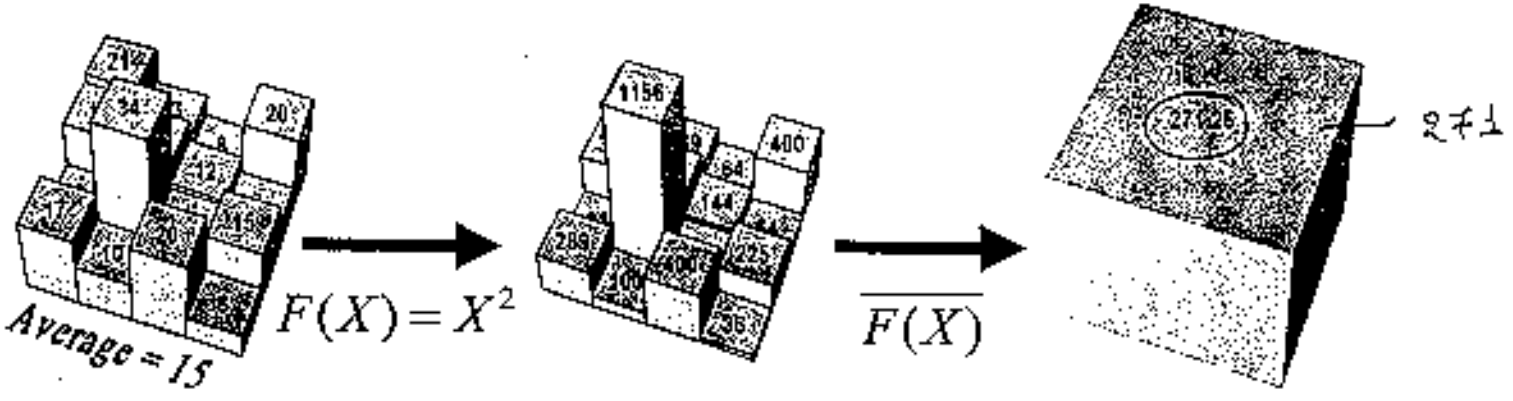


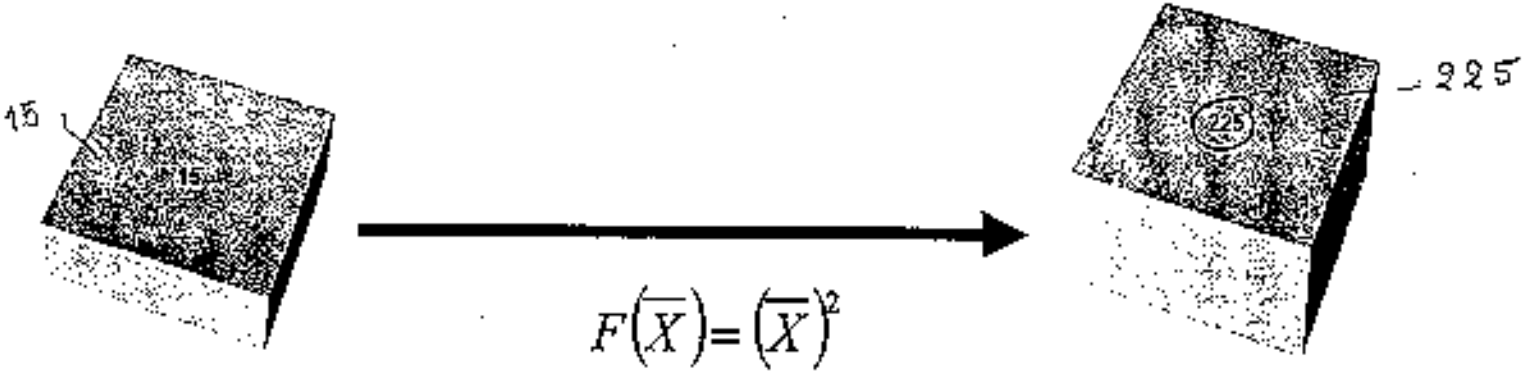
Moana 11:51



Data courtesy of Geoff Austin,
University of Auckland Physics Department

Nonlinear evolution of a variable





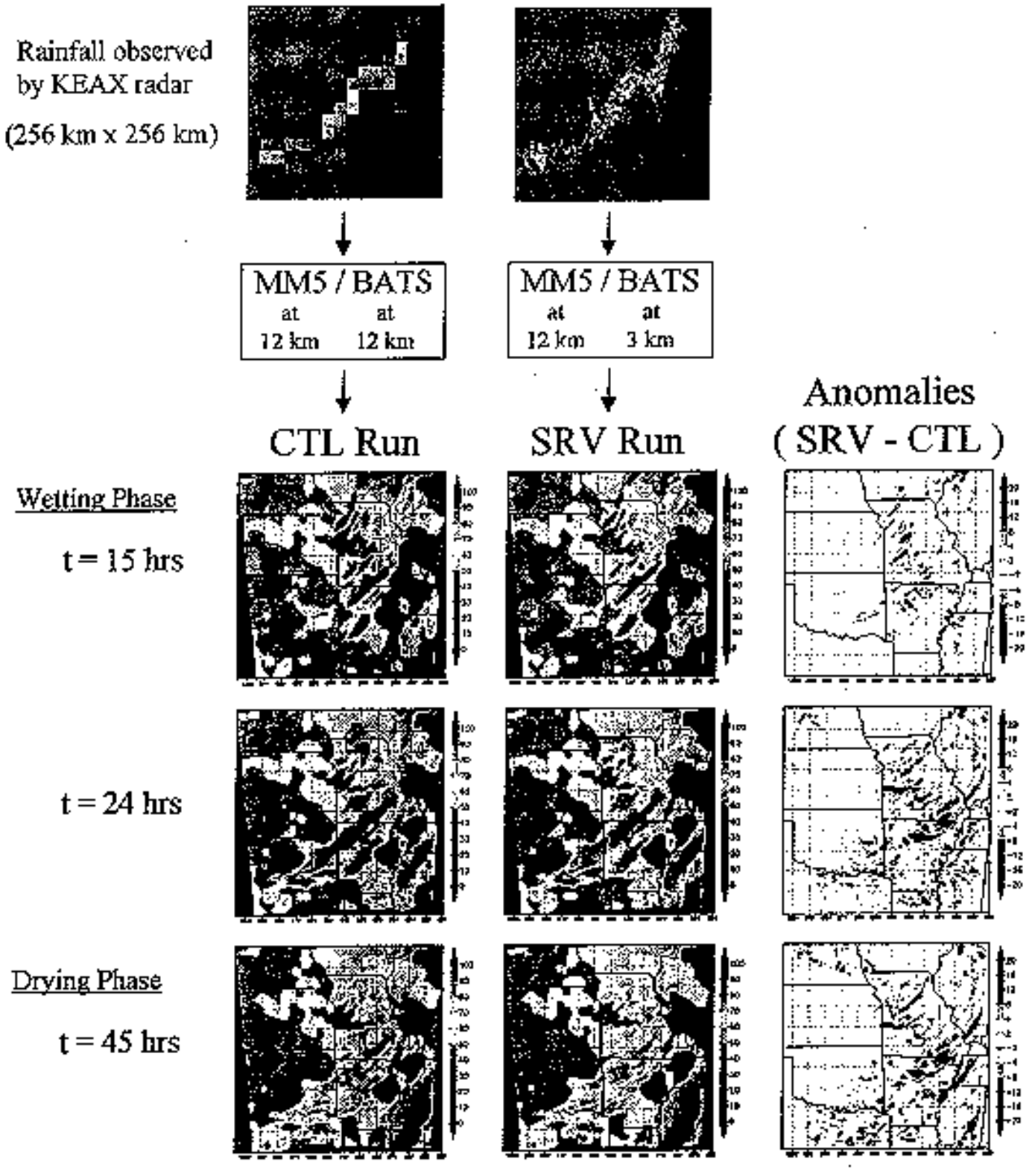
$$\overline{F(X)} = \frac{1}{N}\sum_{i=1}^{N} F(X_i) \neq F(\overline{X})$$

PROBLEMS TO DISCUSS

1. Effect of small-scale precipitation variability on predicted water and energy fluxes

2. Issues in NWP model validation : scales, dynamics

3. Effect of small-scale precipitation variability on estimation of rain from microwave sensors



Soil moisture as % saturation (in top 10 cm) shown at 12 km grid-scale

(1116 km x 1044 km)

E. Foufoula-Georgiou and D. Nykanen, University of Minnesota

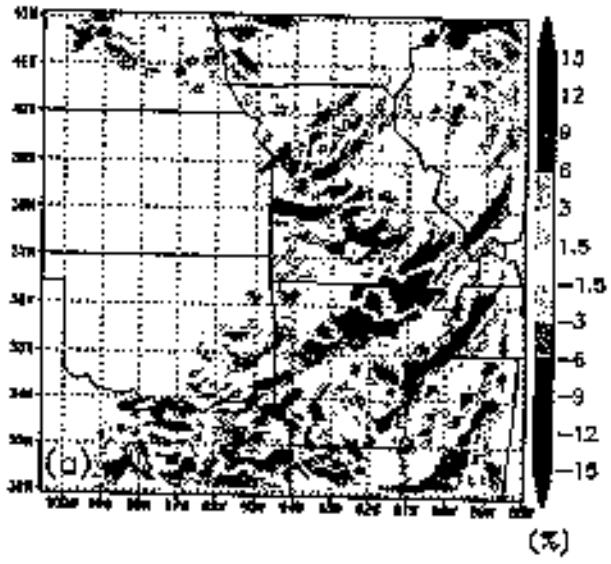
t = 32 hrs

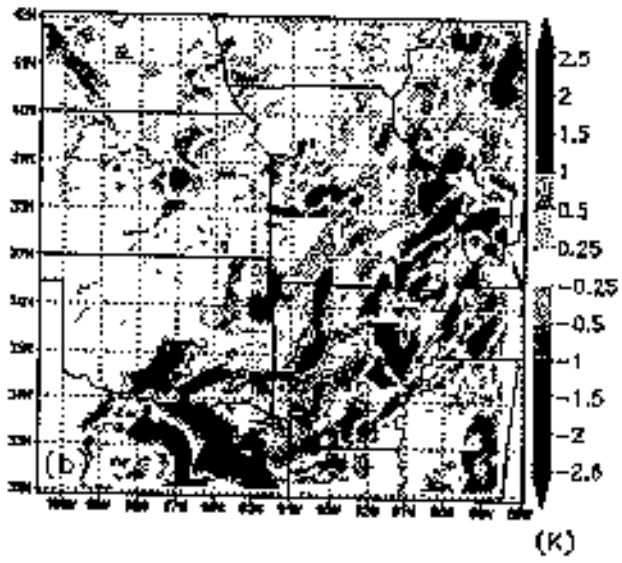
at 12 km grid-scale

Anomalies = SRV - CTL

Relative Soil Moisture in top 10 cm

(Su)



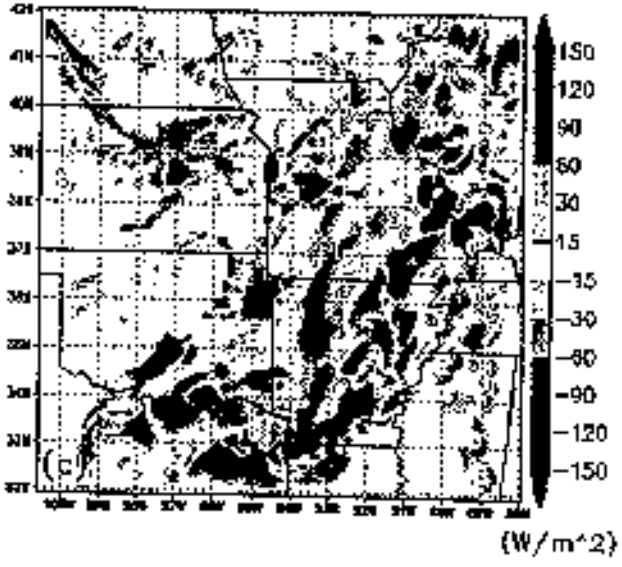


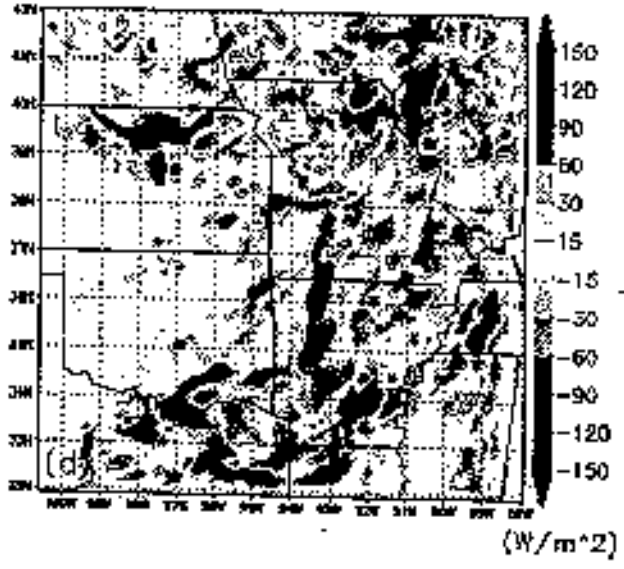
Surface Temperature

(TG)

Sensible Heat Flux from the surface

(HFX)

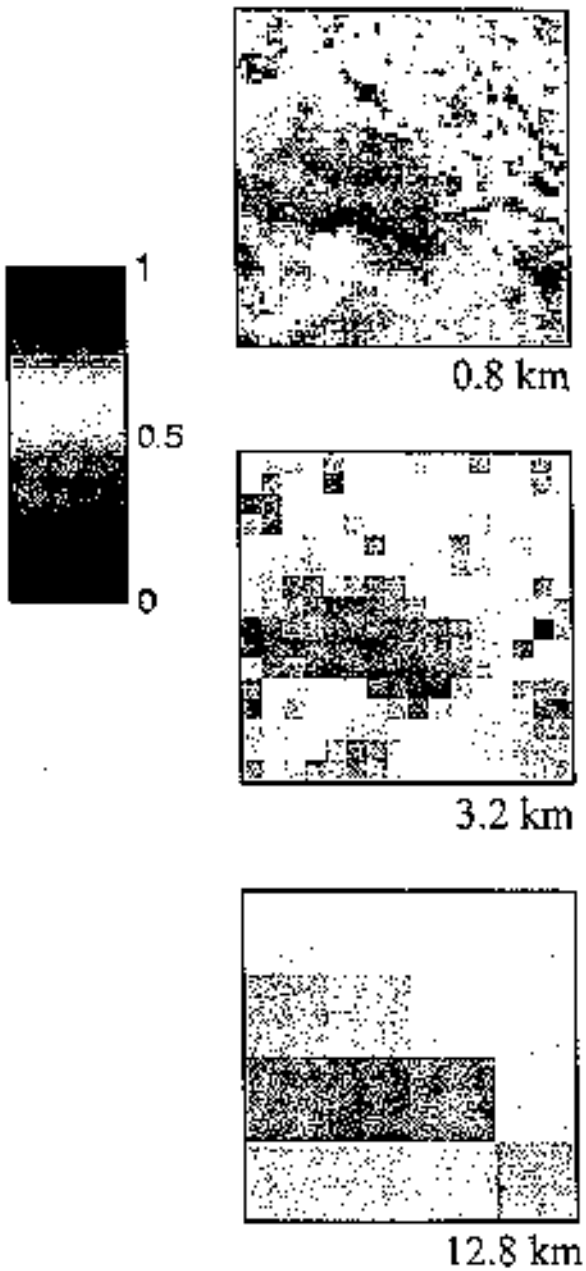


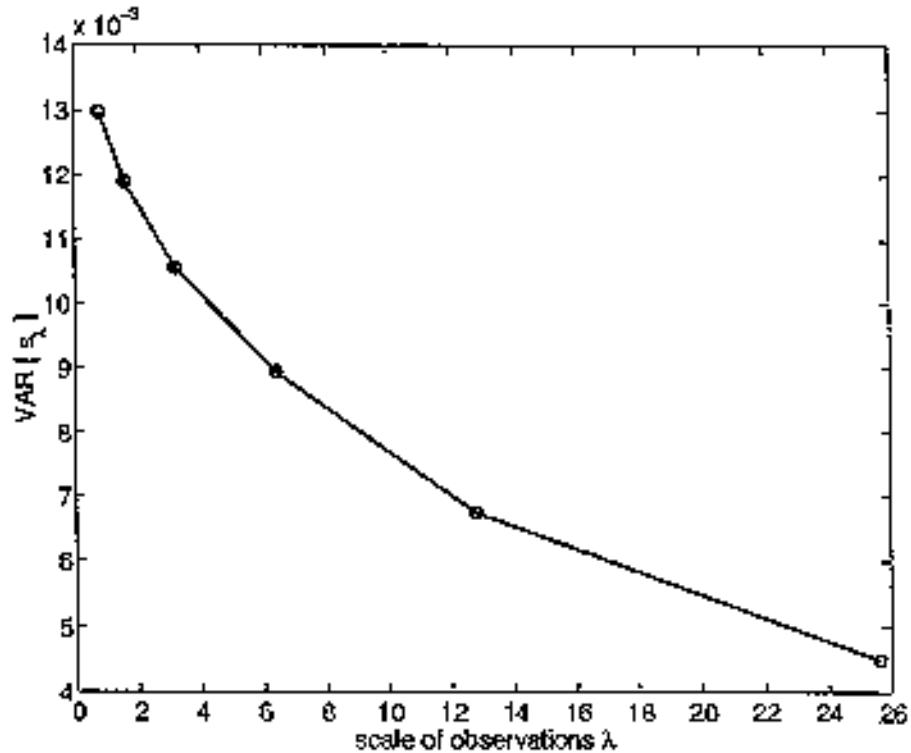


Latent Heat Flux from the surface

(QFX)

Scale-Dependency of Soil Moisture Variability





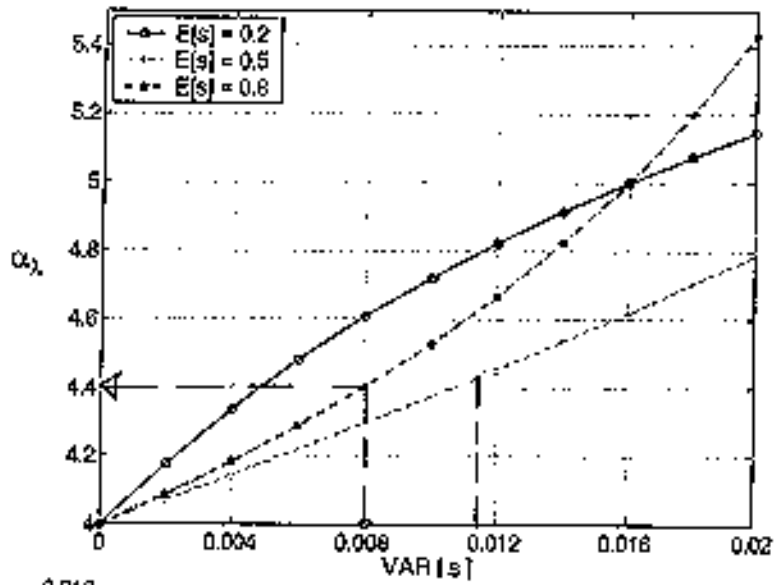
Scale-Dependency of Nonlinear Parameterizations

$$R_s = s^{\alpha} G \quad (1)$$ Surface Runoff Parameterization used in BATS

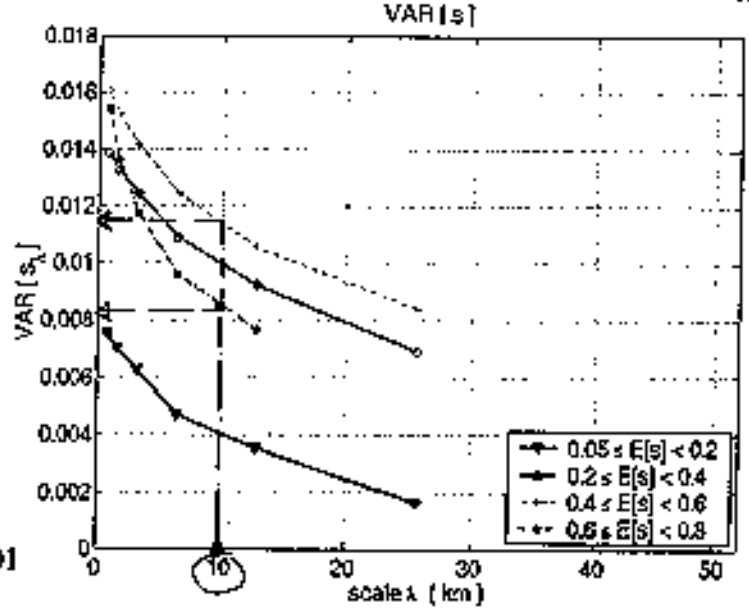
R_s = surface runoff
G = net input of water to the soil surface
s = average of relative soil moisture in upper layer and root zone layer
α = 4 for unfrozen soil

Assume: $\alpha = 4$ for scale $\lambda = 50$ km
Question: $\alpha = ?$ for scale $\lambda = 10$ km
(such that fluxes are preserved and VAR[s] vs. λ are respected)

- From second order analysis of (1) and preservation of flux R_s



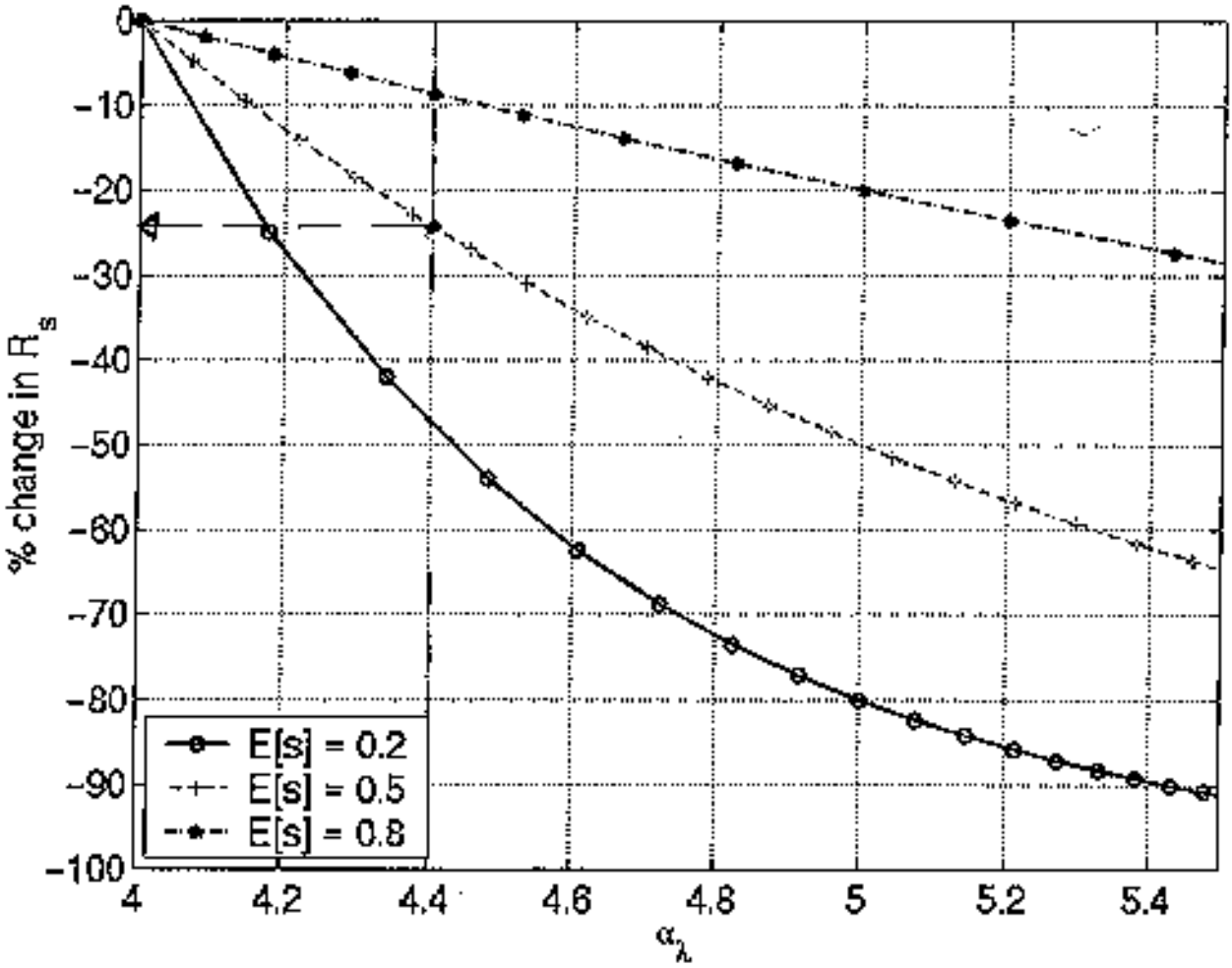
- From analysis of SGP97



Nykanen and Foufoula-Georgiou, AWR 2001

If did not change α from 4 to 4.4

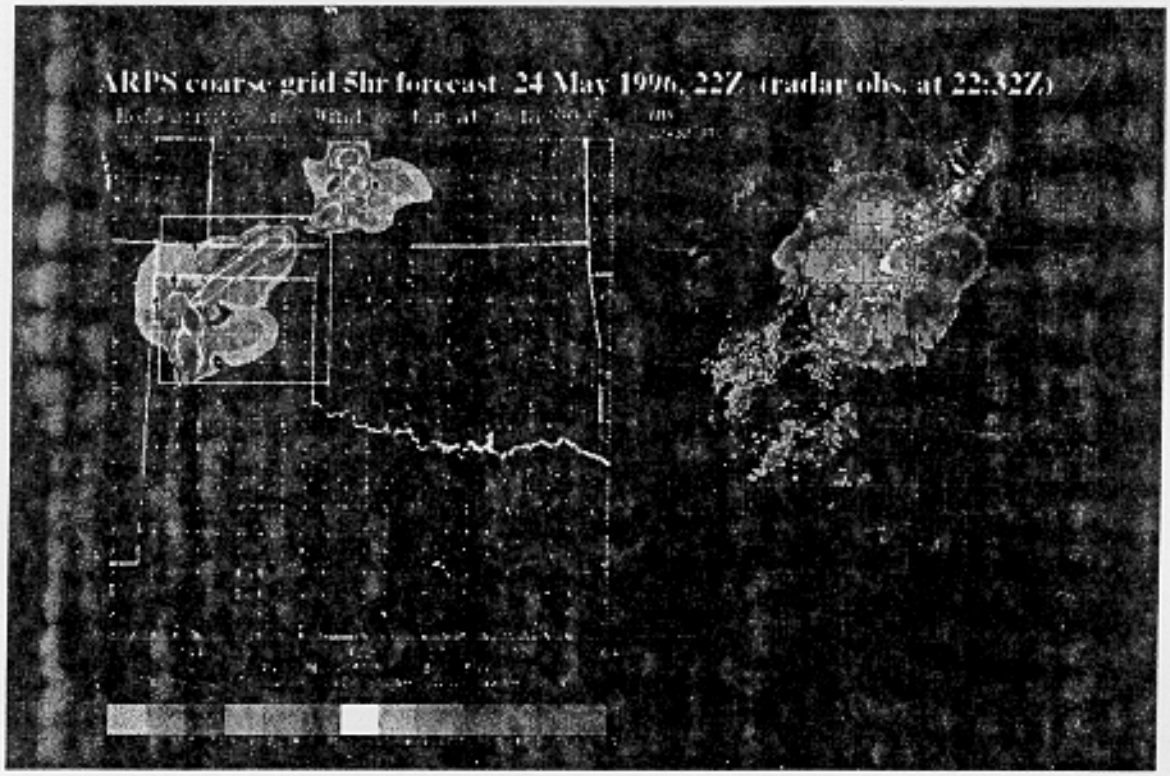
⇒ 20 - 40 % overestimation of R_s



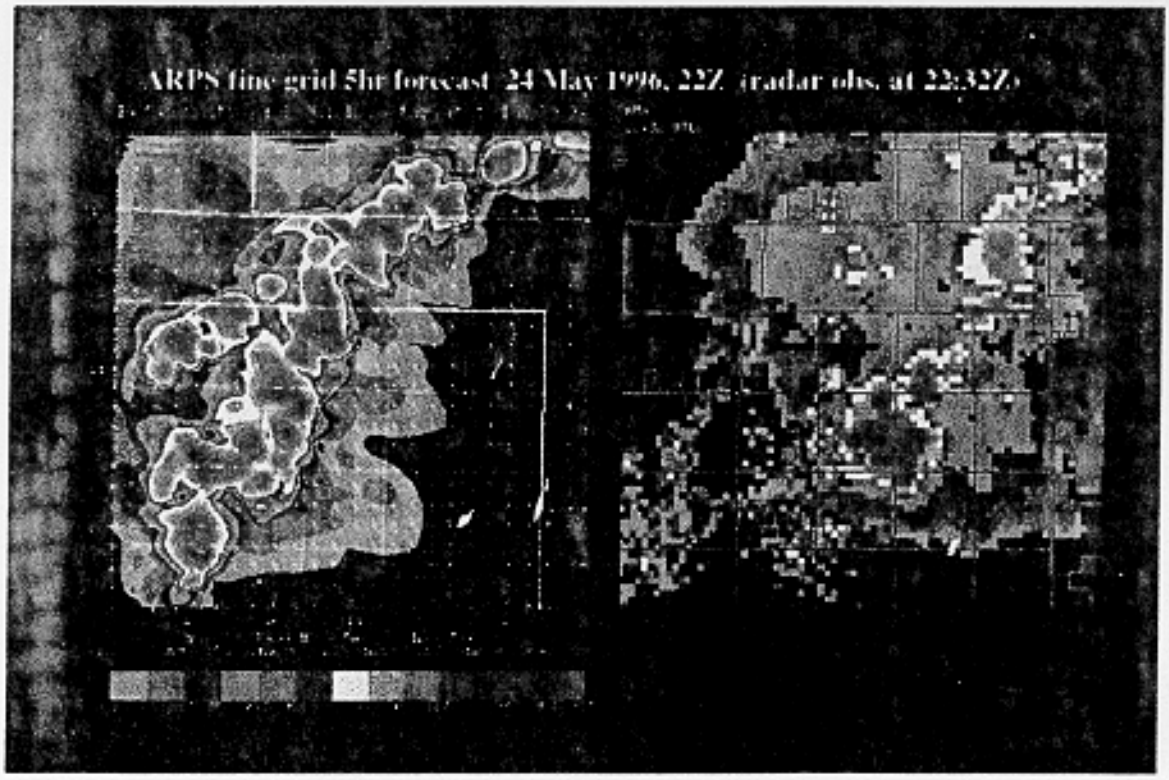
e.g., % change in R_s = 100 * [$R_s(\alpha=4.4)$ - $R_s(\alpha=4)$] / $R_s(\alpha=4)$

Nykanen and Foufoula-Georgiou, AWR 2001

Model ⇓ Observations ⇓



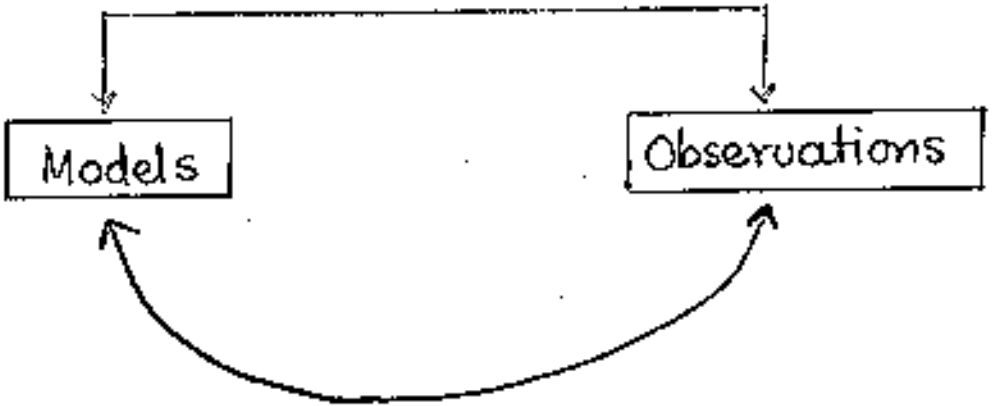
9km x 9km



3km x 3km

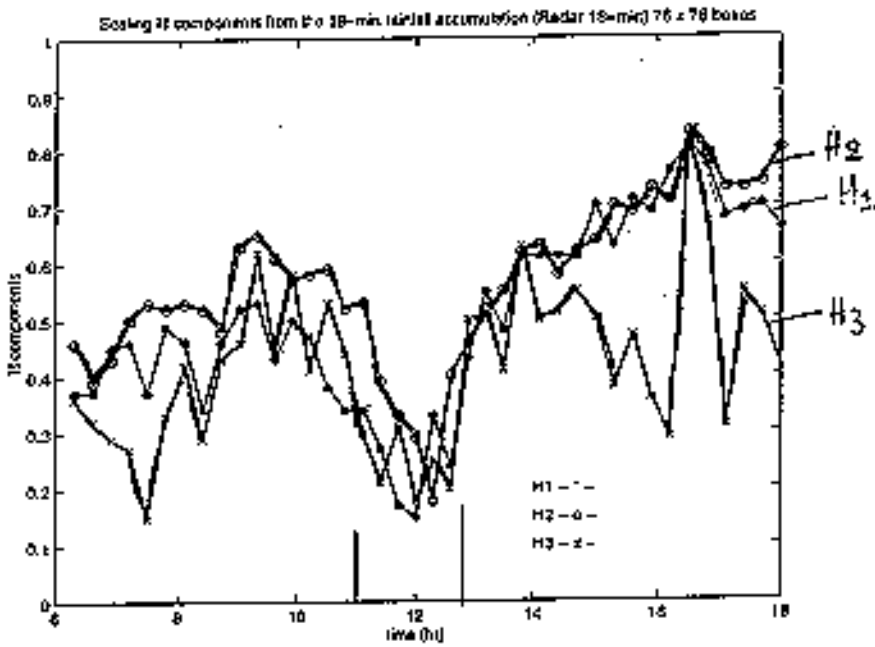
Figure 3: (a) 5-hour, 9 km grid ARPS prediction at 22Z on 24 May 1996. The model equivalent reflectivity is shown on the left and the corresponding radar image on the right. (b) 5-hour, 3 km grid ARPS prediction at 22Z on 24 May 1996. The model equivalent reflectivity is shown on the left and the corresponding radar image on the right.

"static" validation (RMSE, TS, BIAS, ...)



"Dynamic" validation (space-time dynamics measures)

OBSERVED – 18 min accum.



PREDICTED – 15 min accum.

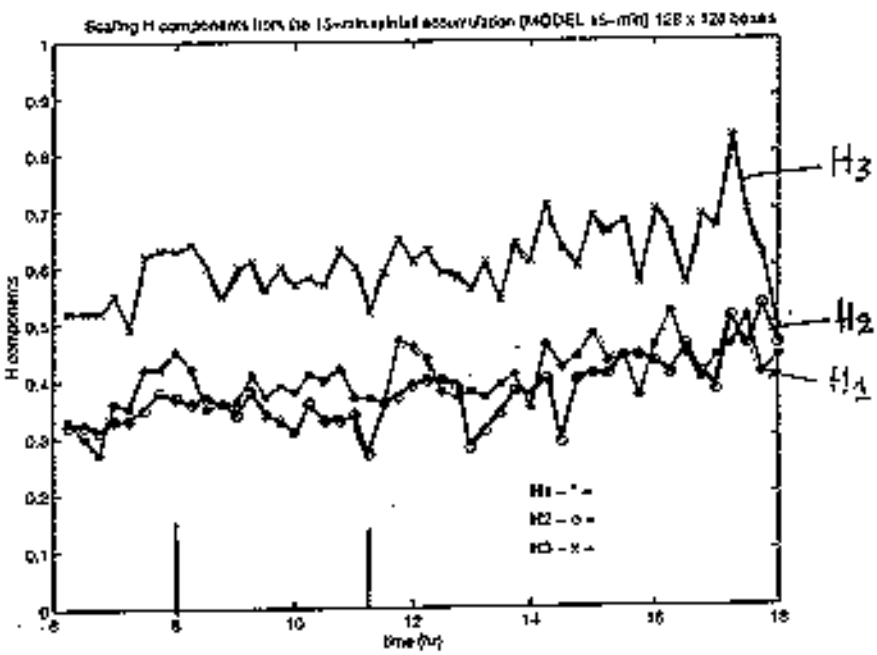
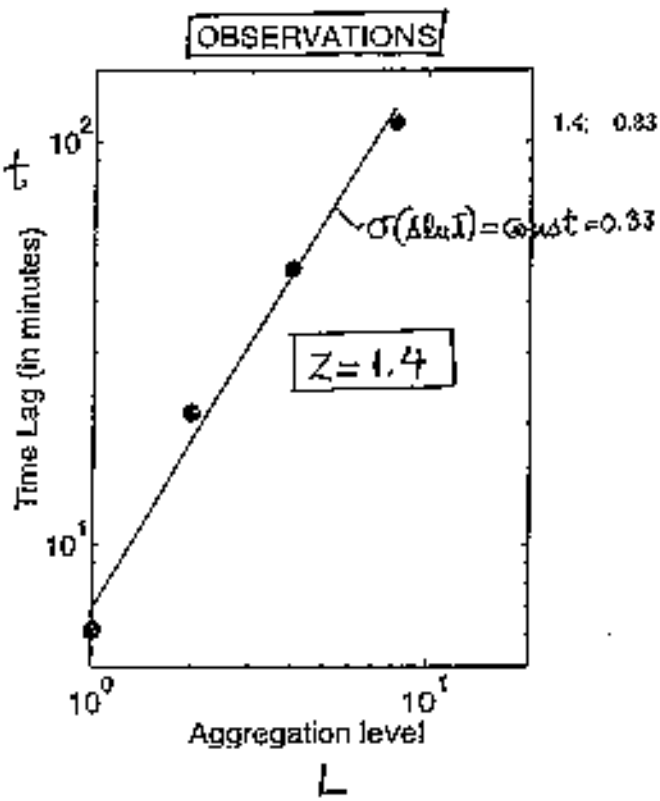


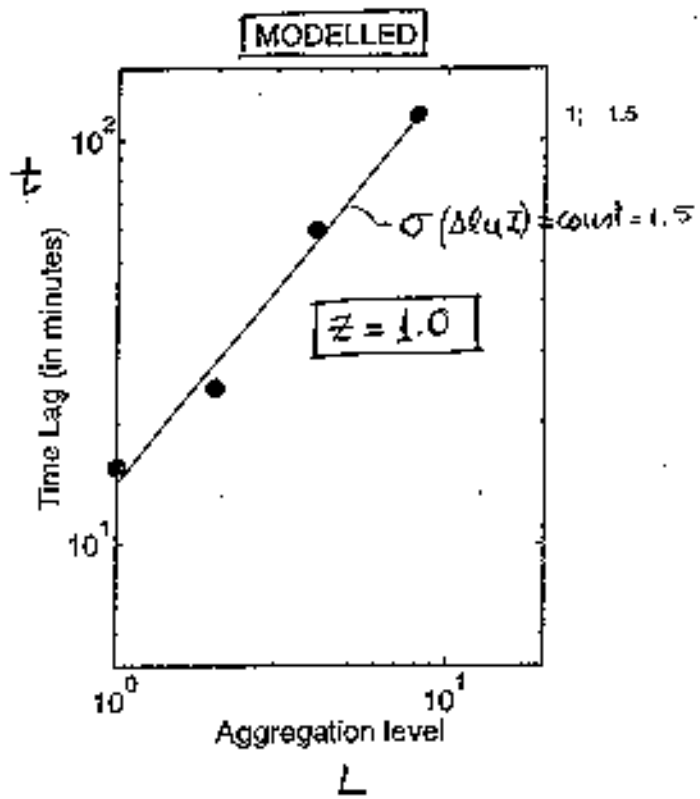
Figure 6.8: Scaling parameters H_1, H_2 and H_3 vs time from the 18-min observed (top) and 15-min predicted (bottom) accumulation precipitation fields.

Ref: Zepeda-Arce and Foufoula-Georgiou, JGR, 2000

Region 1

Iso-Stdev (Δ LnI) Lines





Ref: Zepeda-Arce and Foufoula-Georgiou, JGR, 2000.

Under $\frac{t_1}{t_2} = \left(\frac{L_1}{L_2}\right)^z$ pdfs of $\Delta \ln I(L,t)$ remain invariant

▷ <u>Model</u> :

<u>$z = 1.0$</u> $L_2 = 2L_1 \Rightarrow t_2 = 2t_1 \rightsquigarrow$

A feature twice as large will evolve 2 times slower

▷ <u>Observations</u> :

<u>$z = 1.4$</u> $L_2 = 2L_1 \Rightarrow t_2 = 2^{1.4} t_1 \simeq 3.4\, t_1 \rightsquigarrow$

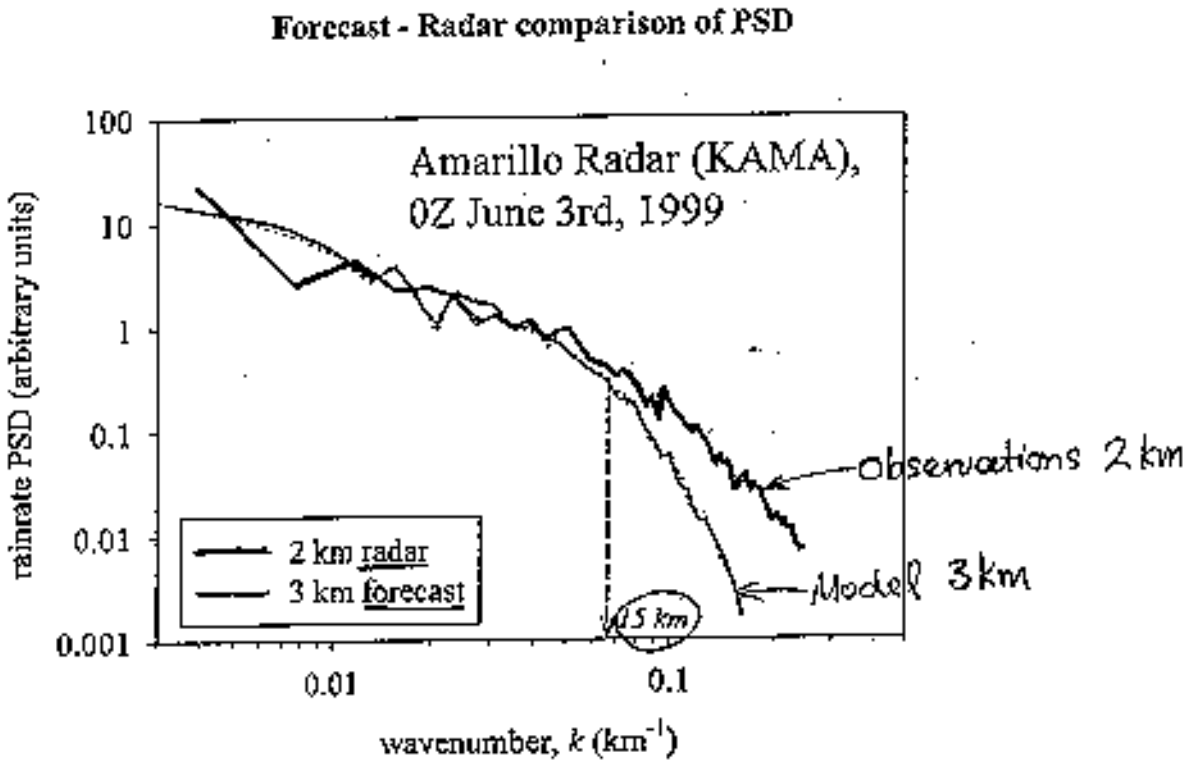
A feature twice as large will evolve $\simeq 3.4$ times slower.

<u>Ref</u> : Dynamic scaling in rainfall & Downscaling model.

→ Venugopal, Foufoula-Georgiou & Sapozhnikov, <u>JGR</u>, 1999a, b.

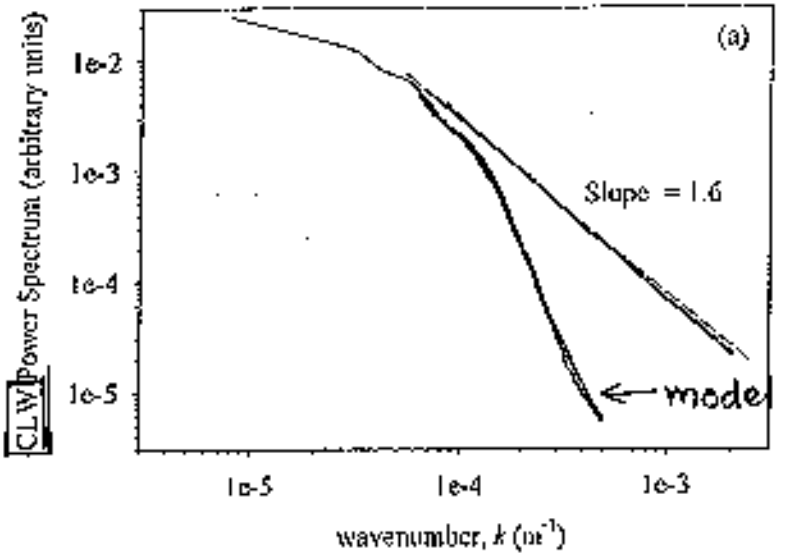
Multiple-scale Structure of Model Precipitation

- Fourier power spectrum of radar observed rain and forecast modeled rain show lack of variability at small scales.



- Lack of small-scale variability is attributed to computational smoothing

Harris & Foufoula-Georgiou, JGR, under review, 2000


(a)
CLW Power Spectrum (arbitrary units)
1e-2
1e-3
1e-4
1e-5
Slope = 1.6
← model
1e-5
1e-4
1e-3
wavenumber, k (m⁻¹)

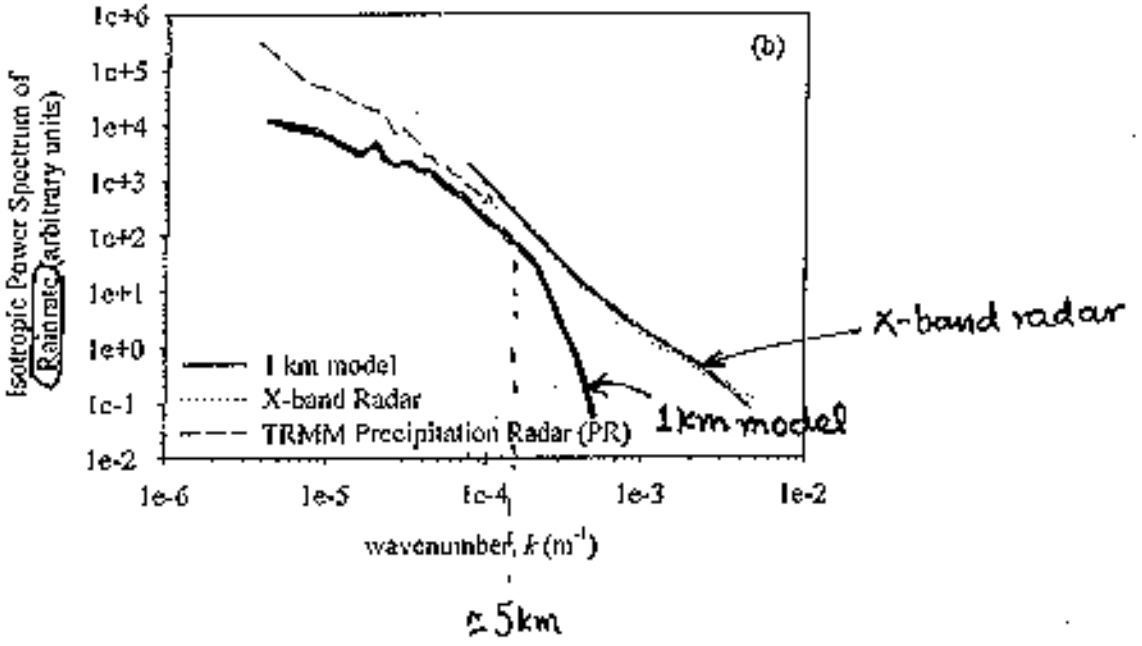

(b)
Isotropic Power Spectrum of Rainrate (arbitrary units)
1e+6
1e+5
1e+4
1e+3
1e+2
1e+1
1e+0
1e-1
1e-2
1 km model
X-band Radar
TRMM Precipitation Radar (PR)
X-band radar
1km model
1e-6
1e-5
1e-4
1e-3
1e-2
wavenumber, k (m⁻¹)
≃5km

Figure 3.

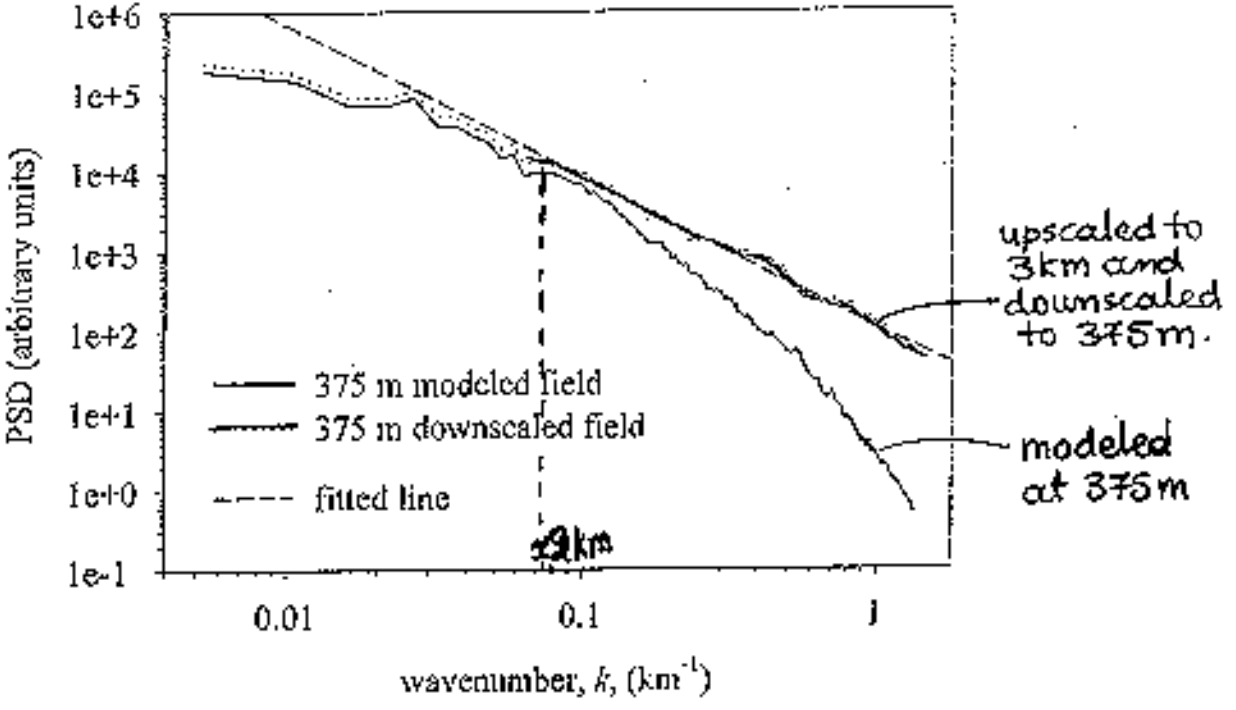

1e+6
1e+5
1e+4
1e+3
1e+2
1e+1
1e+0
1e-1
PSD (arbitrary units)
375 m modeled field
375 m downscaled field
fitted line
9km
0.01
0.1
1
wavenumber, k, (km⁻¹)
upscaled to 3km and downscaled to 375m.
modeled at 375m

Figure 9.

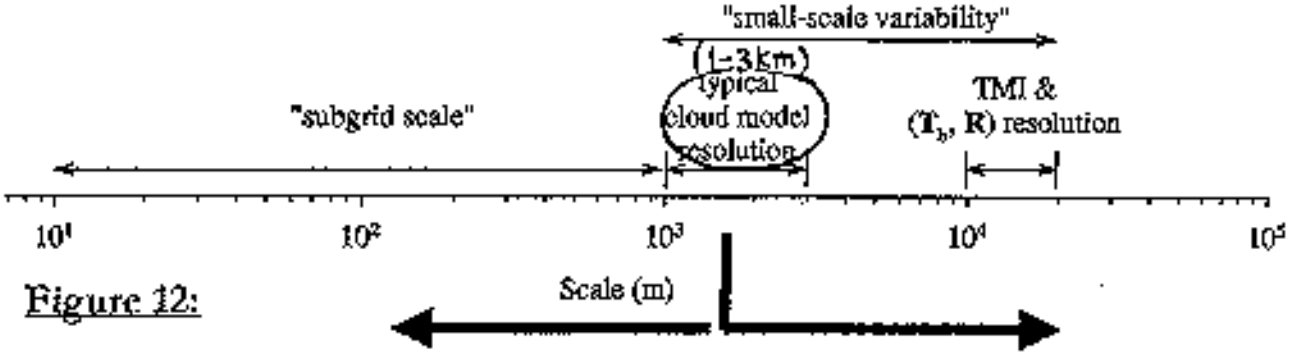
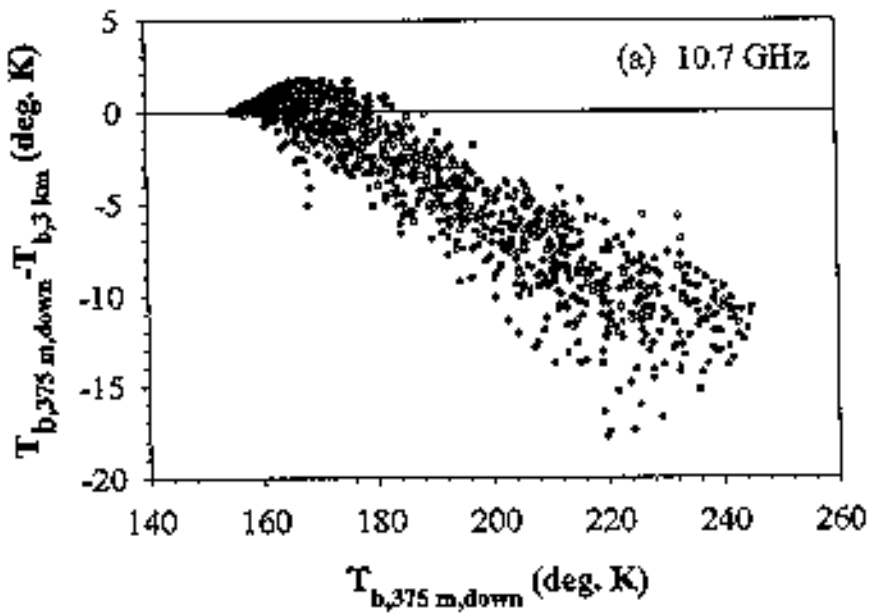


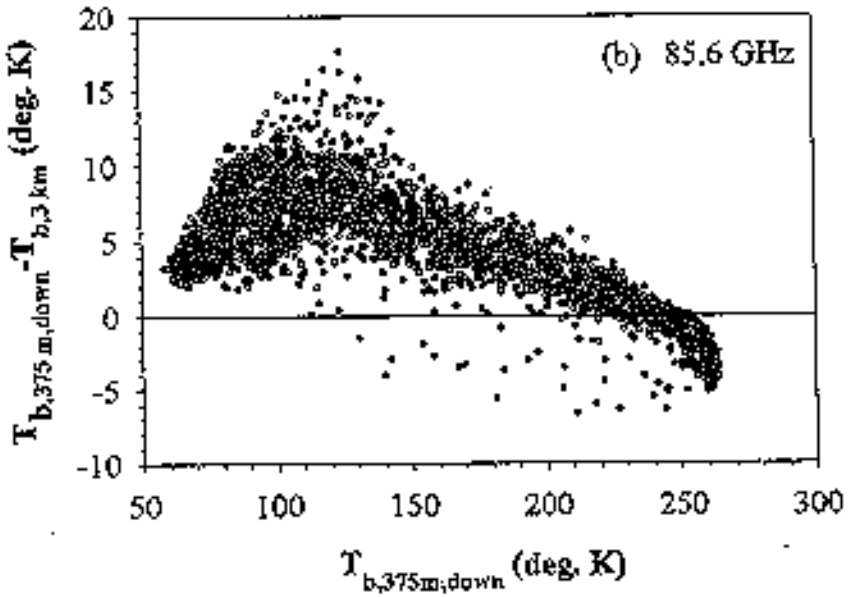
Figure 12:

Significant biases in T_b were found by ignoring subgrid variability (see Ref. 2). Note: Plane-parallel radiative transfer and wavelet-based downscaling were used in that study.

Significant differences in T_b were found due to mis-specified variability and structure in hydrometeor concentration between 3 km and 15 km (see Figure 11). Note: 3D radiative transfer as well as cascade-based downscaling were used in that study.

TRMM - Biases in T_b due to Lack of Small-scale Variability in Modeled Clouds





$T_{b,375m,down}$ = Simulated T_b from R.T. through 375 m downscaled fields (closer to reality)

$T_{b,3\ km}$ = Simulated T_b from R.T. through clouds aggregated to 3 km (what databases use)

Illustration of biases that result from ignoring the subgrid scale variability of hydrometeors in modeled clouds. Comparisons are made at a scale of 12 km.

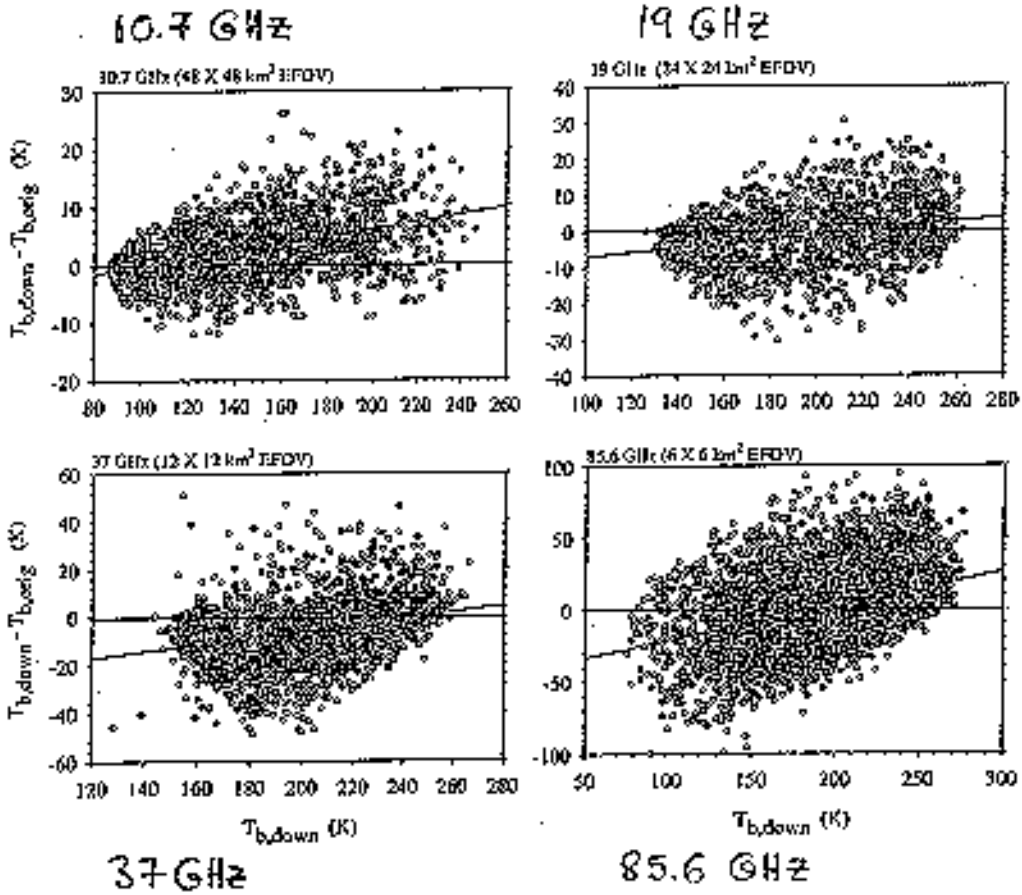
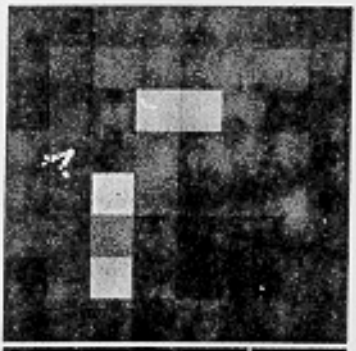


Figure 9. T_b scatterplots. $T_{b,down}$ are brightness temperatures of the ARPS forecasted fields upscaled to12 km and downscaled back down to 3 km. $T_{b,orig}$ are brightness temperatures of the original ARPS forecast fields. The linear regressions illustrate the general trend in bias with brightness temperature.

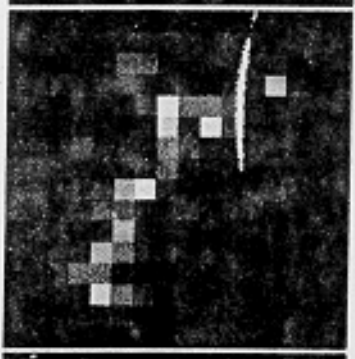
→ 3km–12km variability

Original

64x64 km



32x32 km



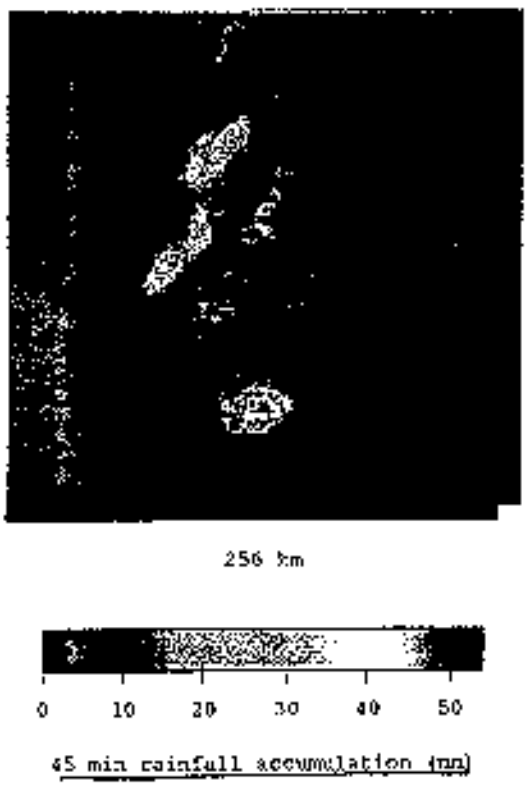
16x16 km

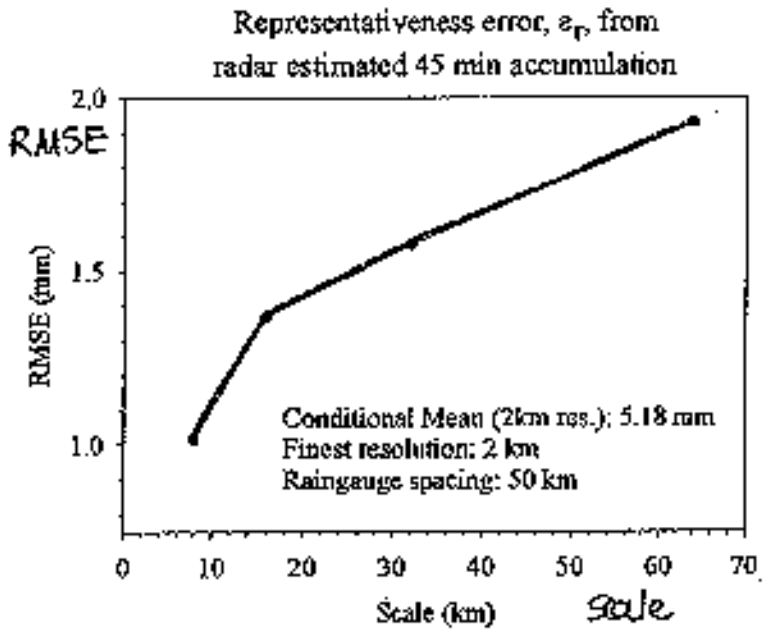
UPSCALING

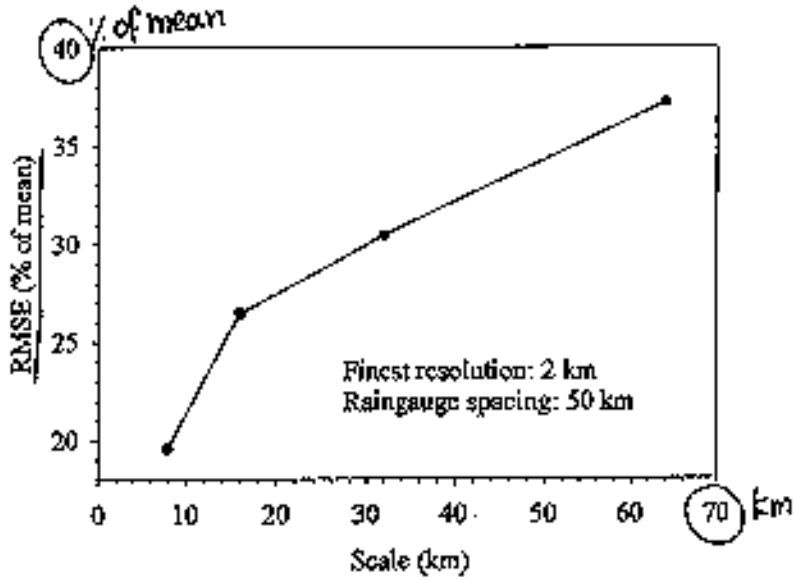
8x8 km

4x4 km

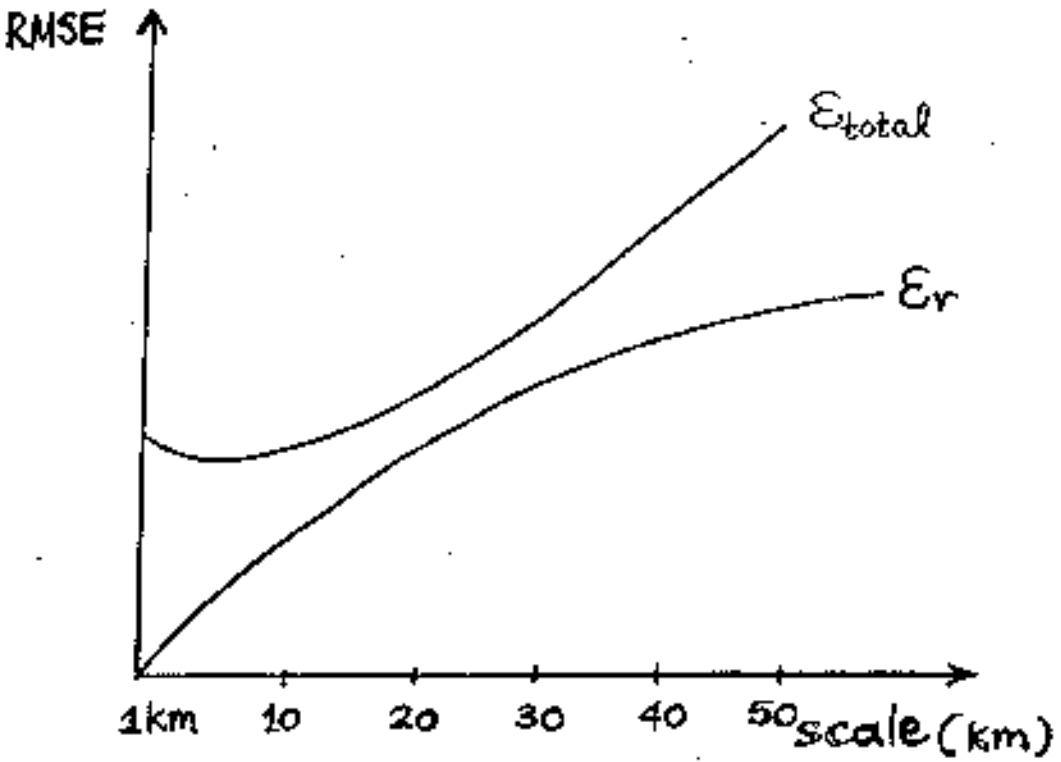
Representativeness Error (areal to point)

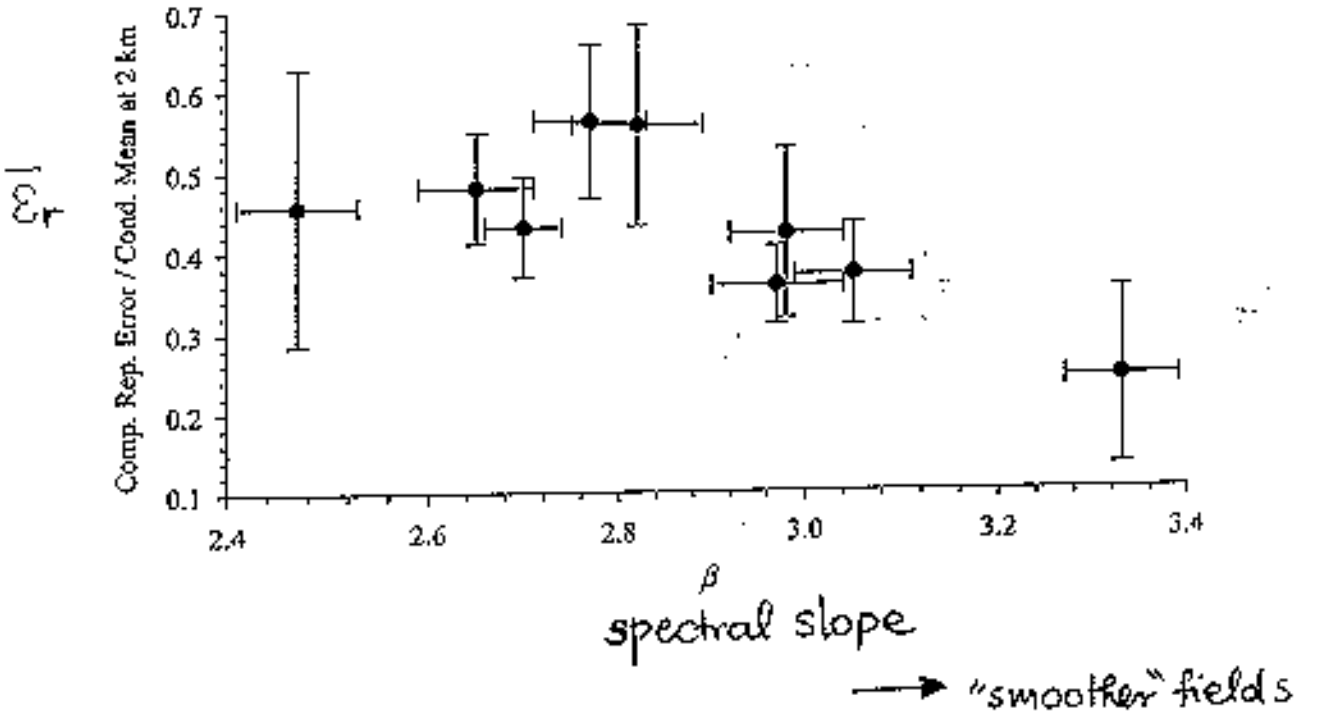






A→P


RMSE
ε_{total}
ε_r
1km
10
20
30
40
50
scale (km)



$\overline{\varepsilon_r}$
Comp. Rep. Error / Cond. Mean at 2 km
0.7
0.6
0.5
0.4
0.3
0.2
0.1
2.4
2.6
2.8
3.0
3.2
3.4
β
spectral slope
"smoother" fields

PROMISING DIRECTIONS

1. Optimal merging of multisensor observations to a consistent product at any desired scale plus its uncertainty
   - model verification
   - data assimilation
   - sensor validation

2. Understand how the observed statistical organization in many hydro-meteoro-geological processes relates to the underlying physics of the process
   - controlled physical experiments
   - controlled numerical simulations

3. Understand the limitations of physically-based models for prediction (limits to predictability)
   - based on observations
   - IC, BC, small-scale variability
   - merge physical/statistical models at appropriate scales

4. Nonlinear prediction based on spatial dynamics of forcing and the nonlinear response function of the "medium".
   - e.g. streamflow dynamics + spatial dynamics of precipitation appropriately combined via basin response for nonlinear prediction

References

1) Nykanen, D. K., E. Foufoula-Georgiou, W. M. Lapenta, "Impact of small-scale rainfall variability on larger-scale spatial organization of land-atmosphere fluxes", *J. Hydrometeorology*, 2(2), 105-121, 2001.

2) Nykanen, D. K., E. Foufoula-Georgiou, "Soil moisture variability and its effect on scale-dependency of nonlinear parameterizations in coupled land-atmosphere models", *Advances in Water Resources*, accepted for publication, in press, 2001.

3) Tustison, B., D. Harris and E. Foufoula-Georgiou, "Scale issues in verification of precipitation forecasts," *J. Geophys. Res.*, accepted for publication, in press, 2001.

4) Harris, D. and E. Foufoula-Georgiou, "Subgrid variability and stochastic downscaling of modeled clouds: effect on radiative transfer computations for rainfall retrieval," *J. Geophys. Res.*, accepted for publication, in press, 2001.

5) Harris, D., E. Foufoula-Georgiou, K. Droegemeier, and T. T. Levit, "Multi-scale statistical properties of a high resolution precipitation forecast," *J. Hydrometeorology*, accepted for publication, in press, 2001.