



**Fine-scale Simulation of  
Summertime Convection over the  
U.S. Continent & Evaluation against  
NEXRAD data**

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**MMM & Water-Cycle Program**

**NCAR**

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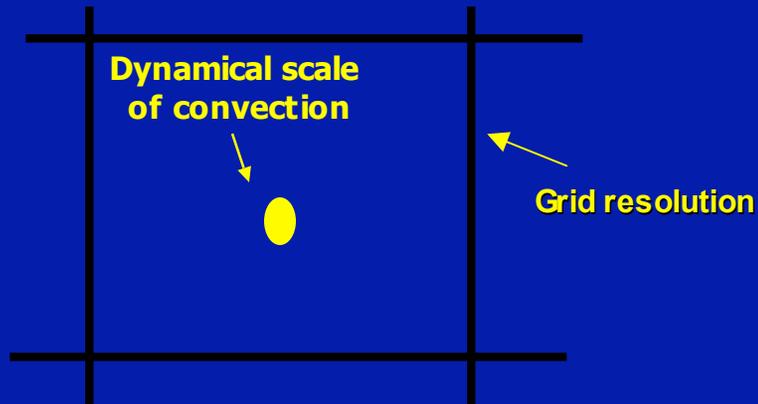
**Physical resolution  $\equiv$  10 x grid  
resolution**

**i.e., ~ 10 grid points needed to accurately represent the  
a physical entity**

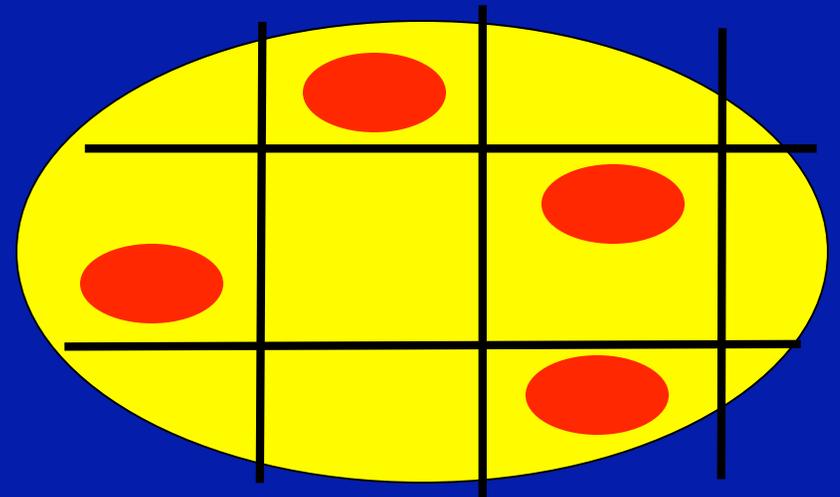
**... especially for precipitating convection where the  
fastest growth rates are on small scales**

**... but mesoscale organization of convection is resolved  
in preference to convection per se**

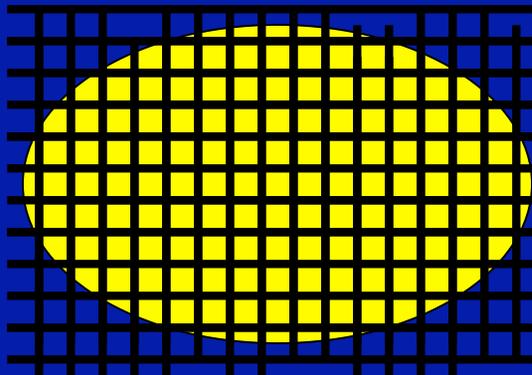
# Under-resolved explicit circulations



**Traditional convective parameterization based on scale separation**



**Under-resolved explicit dynamics + parameterized convection – problems but practical advantages too at  $\sim 10$ -km grid-resolution**

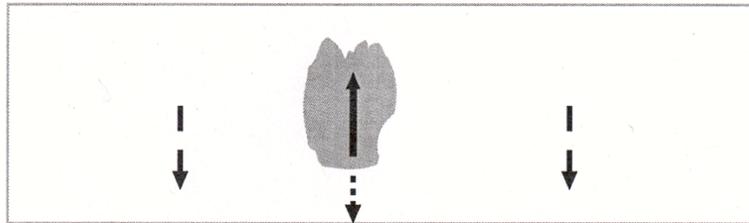


**Cloud-system-resolving models (CSRM): note  $\sim 100$  m grid-resolution**

# A dichotomy

**'ordinary convection' : traditional parameterization**

a)

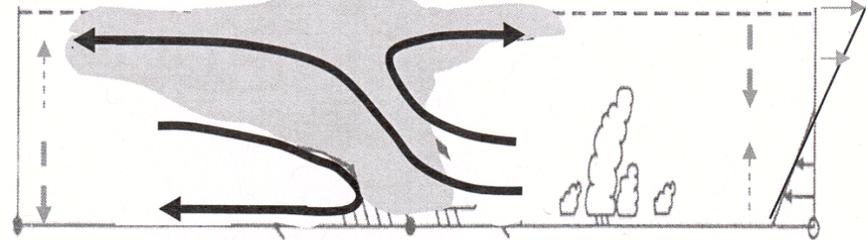


Isolated system, single grid volume

- Entraining plume (small-scale mixing)
- Environmental shear omitted
- Local response
- Closed system (confined subsidence)
- Weak scale-interaction
- Gravity waves not involved

**'mesoscale organization' : super-parameterization & global CSRМ**

b)



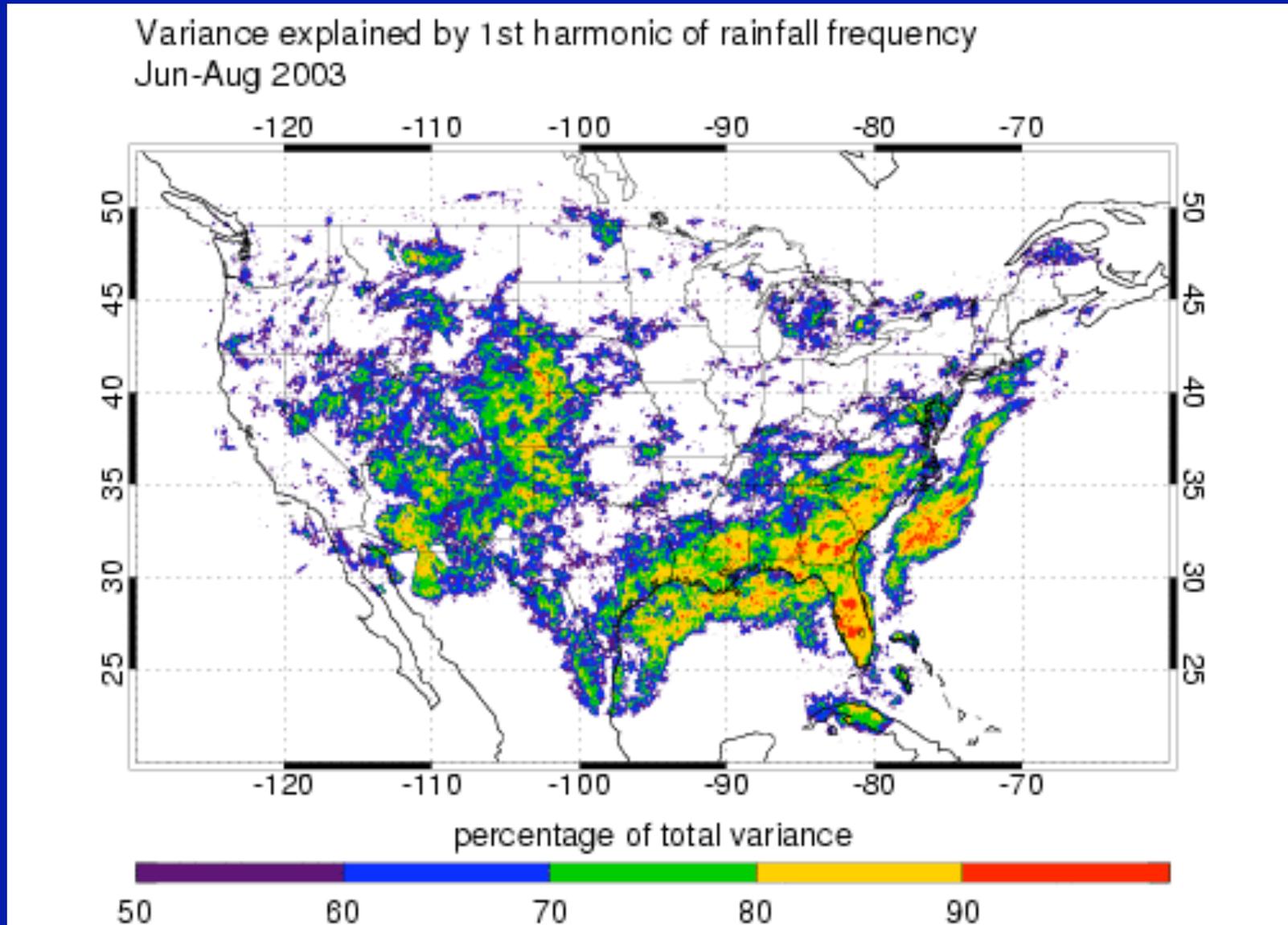
Propagating system, many grid volumes

- Organized flow (mesoscale dynamics)
- Environmental shear important
- Local and remote response
- Open system (wave response)
- Strong scale-interaction
- Convectively-generated gravity waves

## **At ~10-km grid-resolution (i.e., next - generation global NWP models) ...**

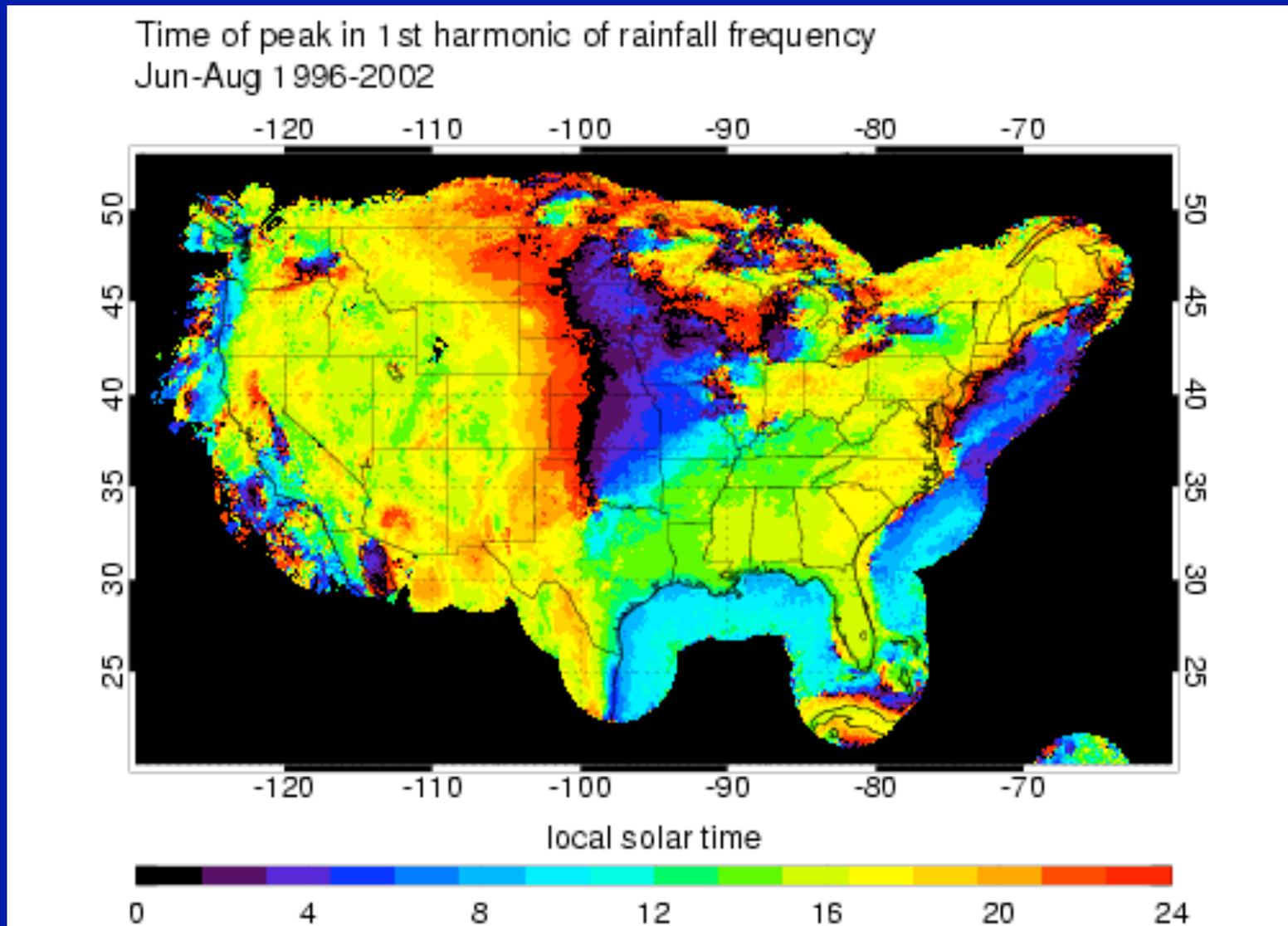
- Parameterized convection and explicit convection occur simultaneously**
- Parameterization is ill-conditioned, explicit convection is under-resolved**
- This affects dynamics ... scale-selection, transport, scale-interaction ...**
- Significant fraction of precipitation falls from organized convective systems**
- Positive attributes, and pitfalls too, for NWP models, and ultimately, for climate models**

# Amplitude of diurnal cycle:



Kniviel et al. (2004)

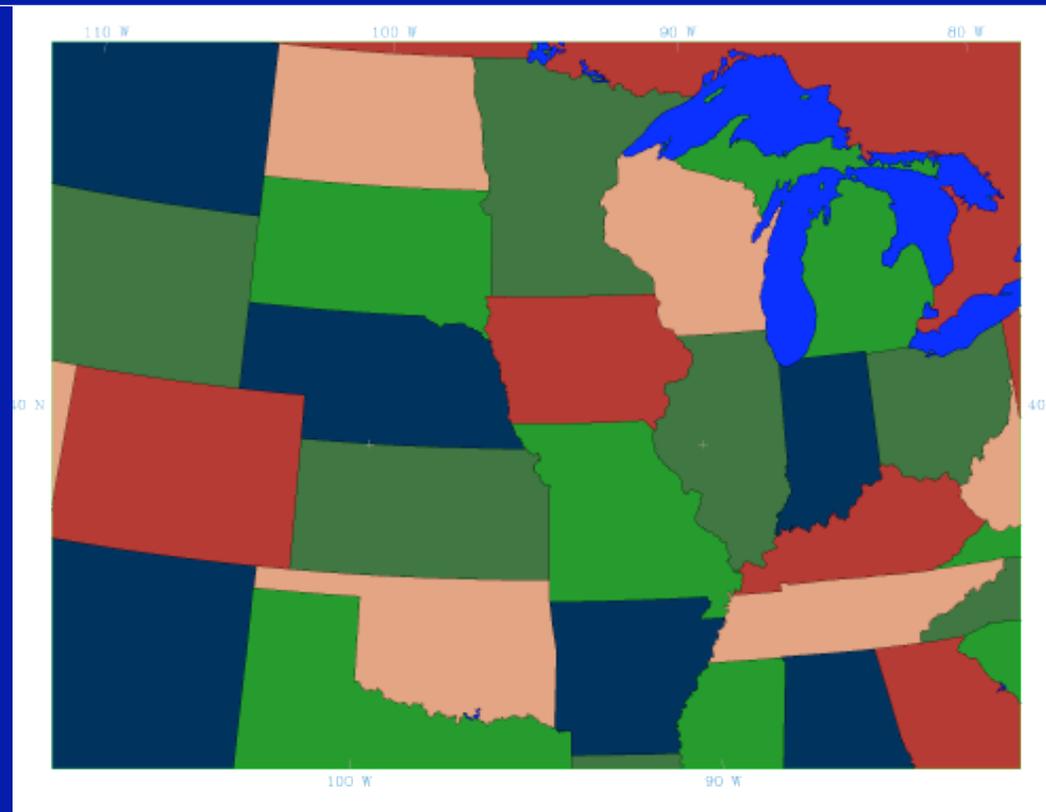
# Phase of diurnal cycle: getting it right means getting traveling convective systems right ...



Kniviel et al. (2004)

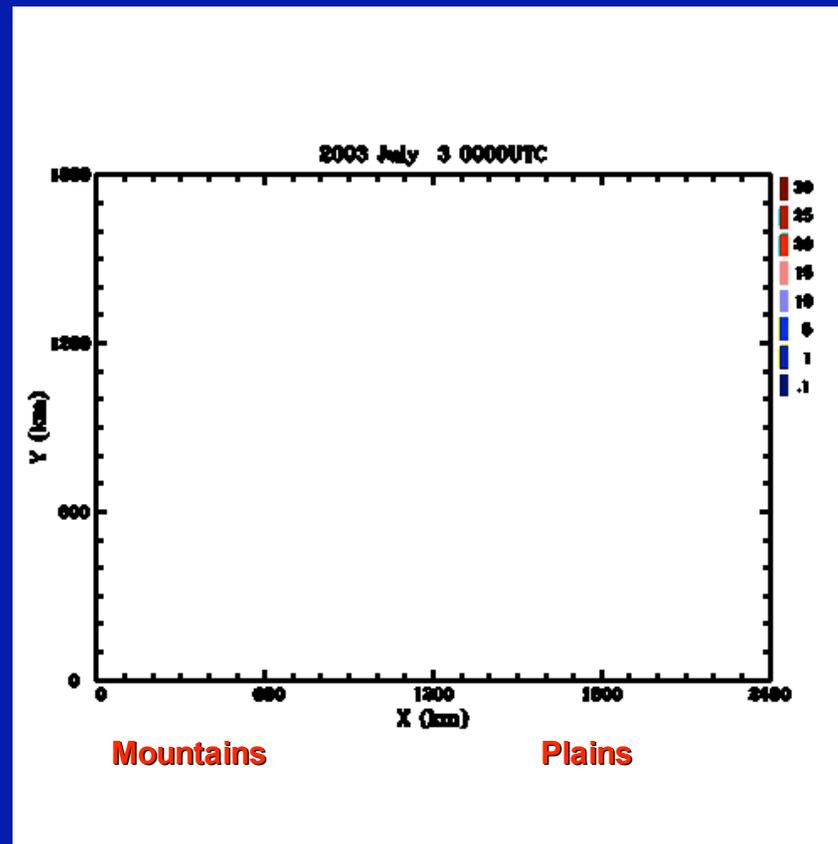
# **Hierarchical simulations: resolution dependence**

**MM5 incorporating NCEP MRF boundary layer & surface exchange schemes, Noah LSM, GSFC microphysics, Betts-Miller convective parameterization, 40-km ETA model analysis for lateral boundary conditions and large-scale forcing**



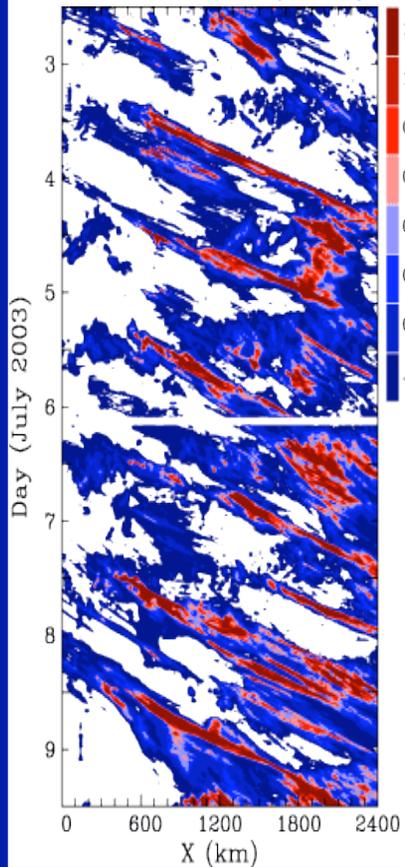
**Simulate 3-10 July 2003 at 3-km, 10-km, 30-km, 60-km grid-resolution**

# Precipitation: 3-km grid resolution

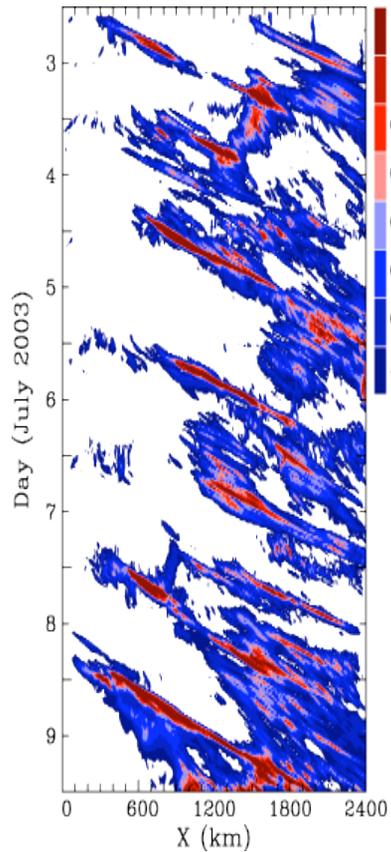


# Meridionally averaged rain-rate

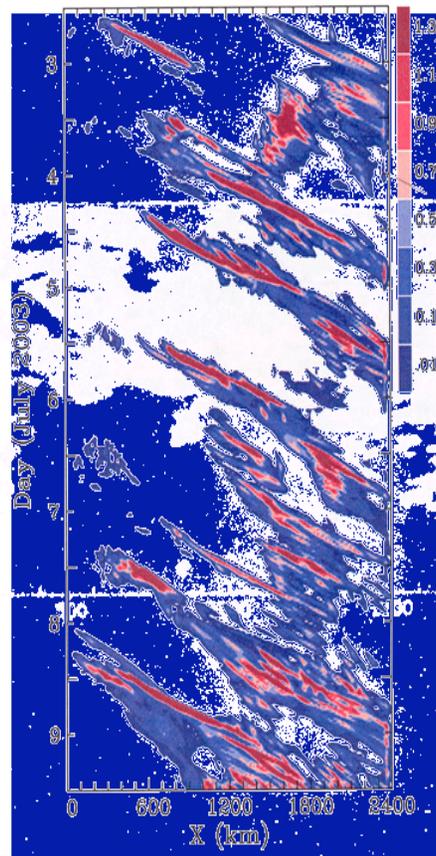
**NEXRAD analysis**  
Carbone et al. (2002)



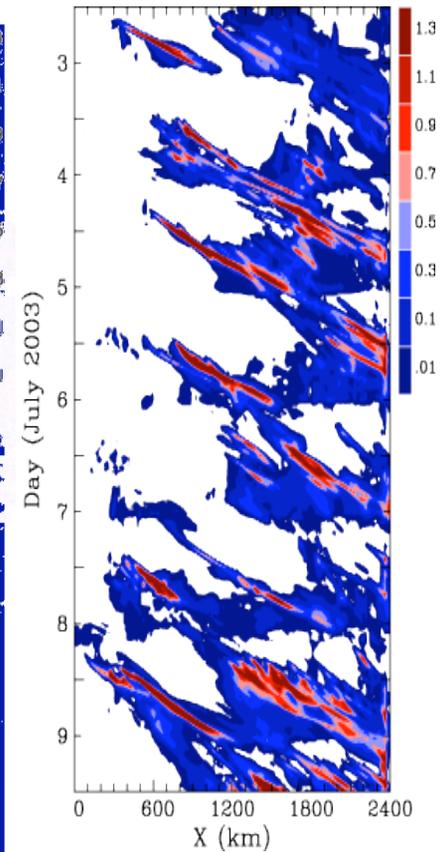
**3-km explicit**



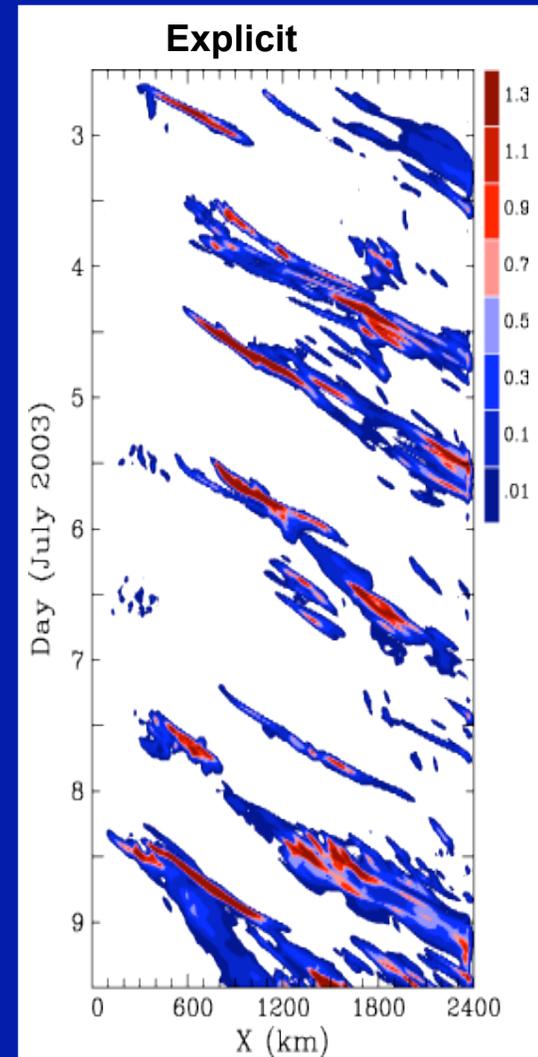
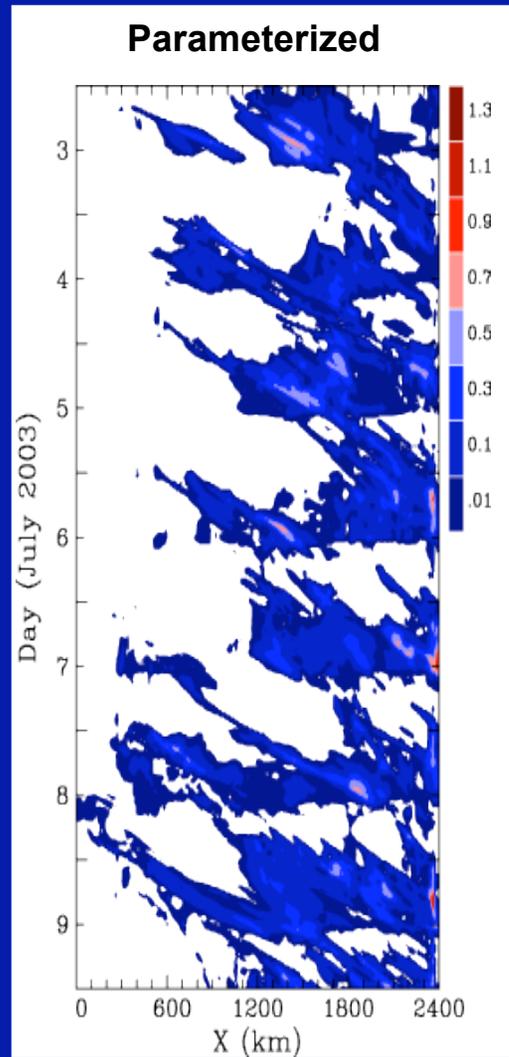
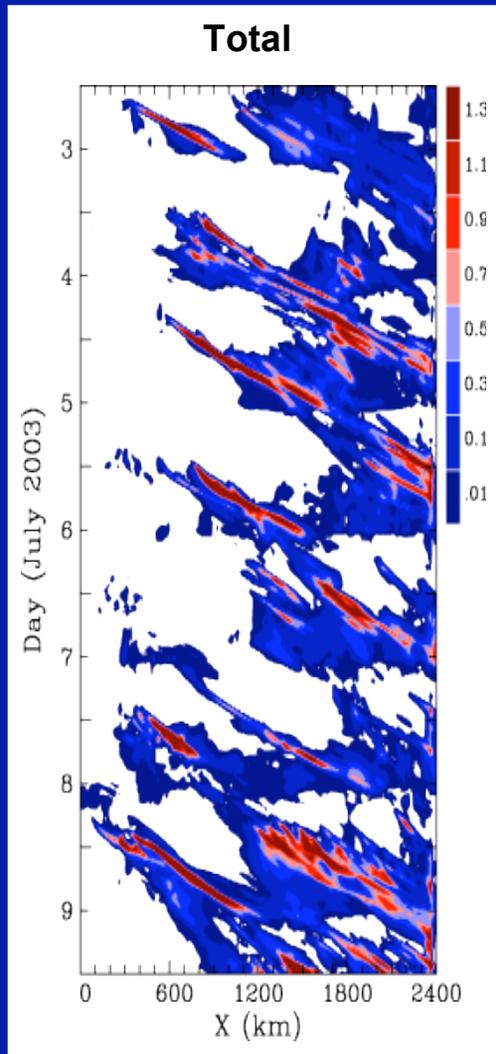
**10-km explicit**



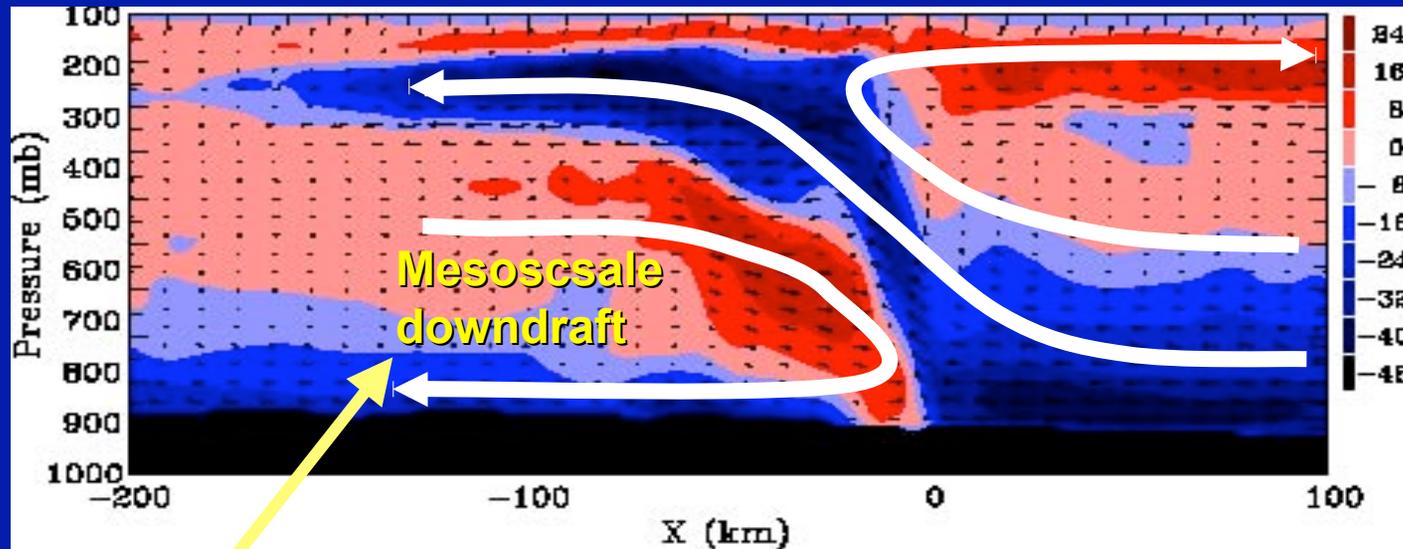
**10-km Betts-Miller**



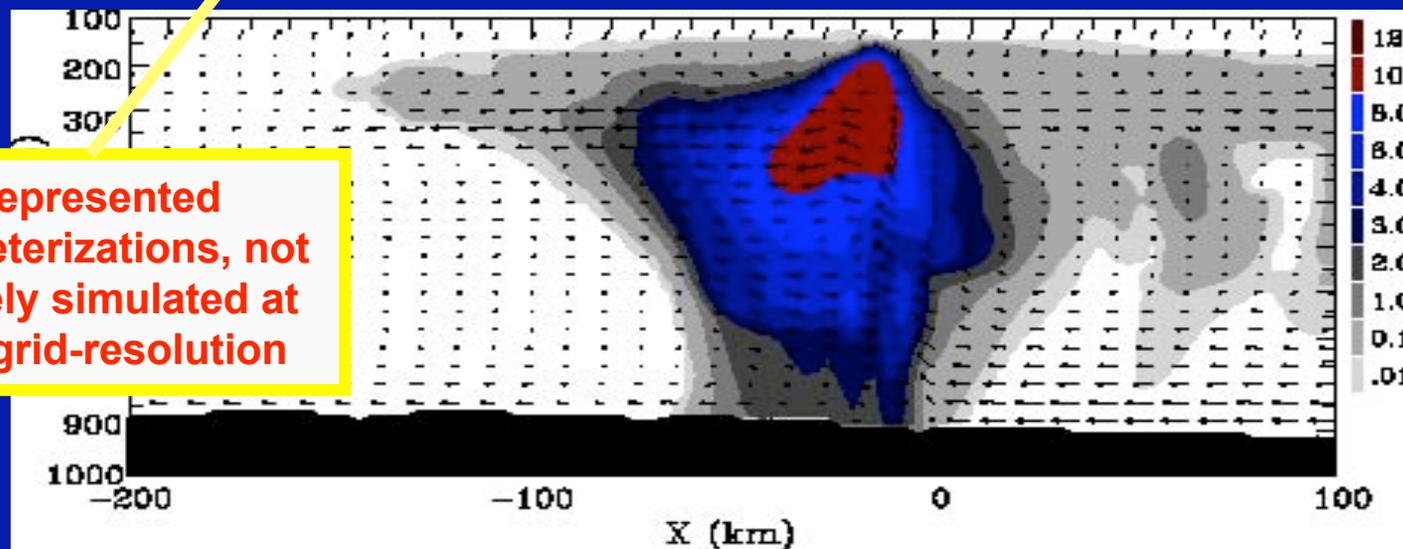
# Parameterized vs. explicit precipitation



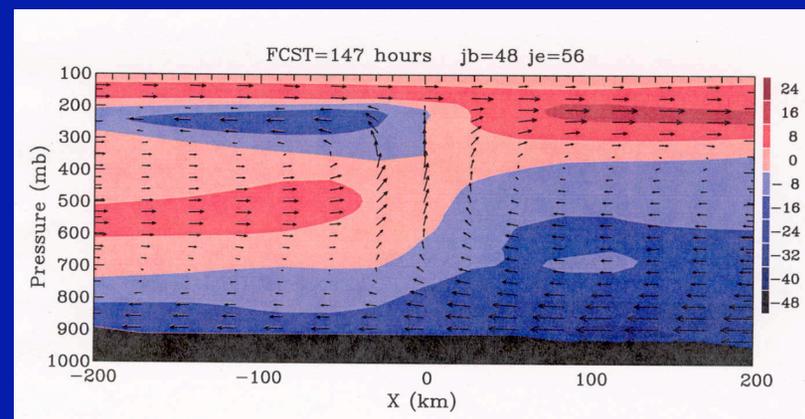
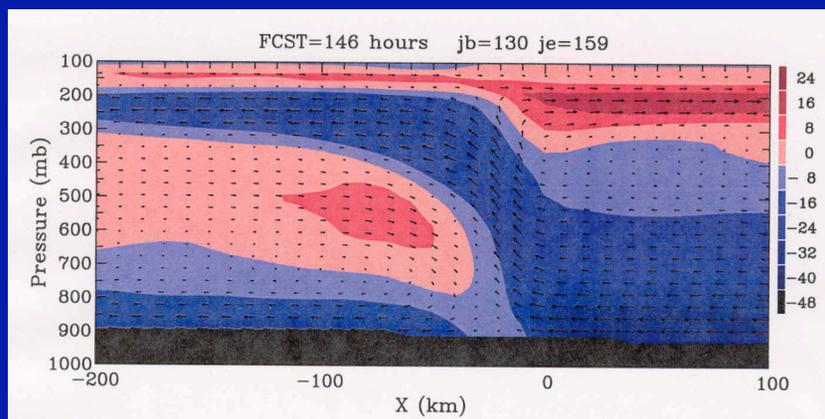
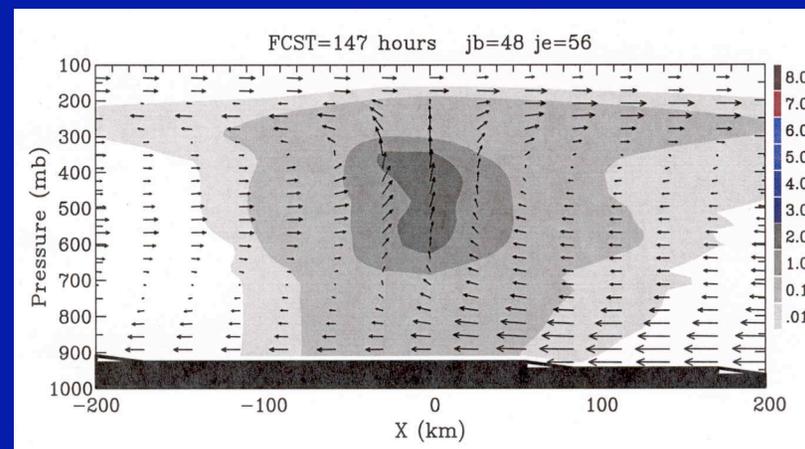
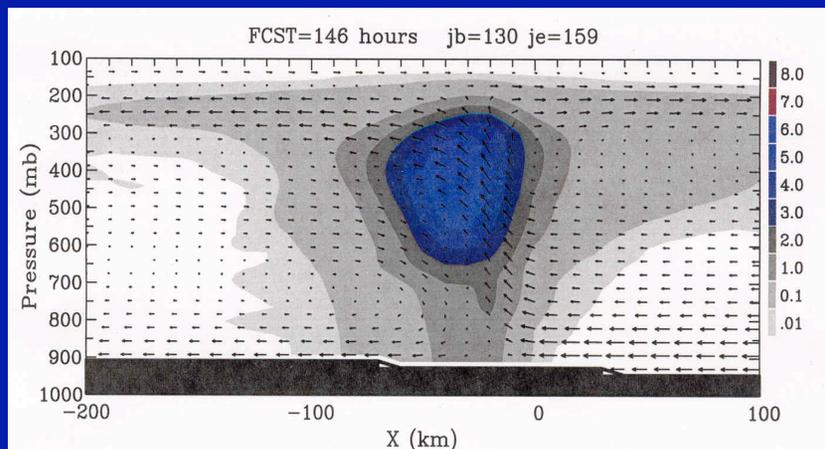
# 3-km grid resolution



**Not represented  
in parameterizations, not  
adequately simulated at  
~10-km grid-resolution**



# Under-resolution distorts airflow



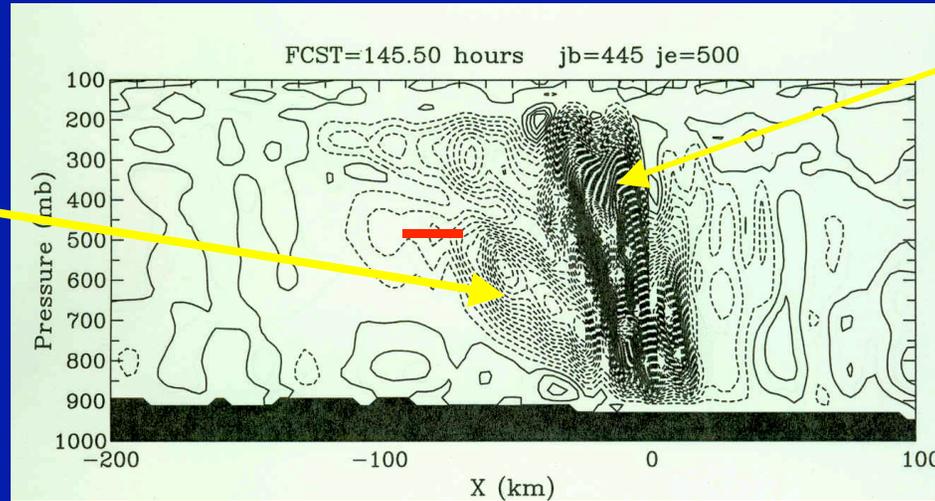
$\Delta = 10$  km

$\Delta = 30$  km

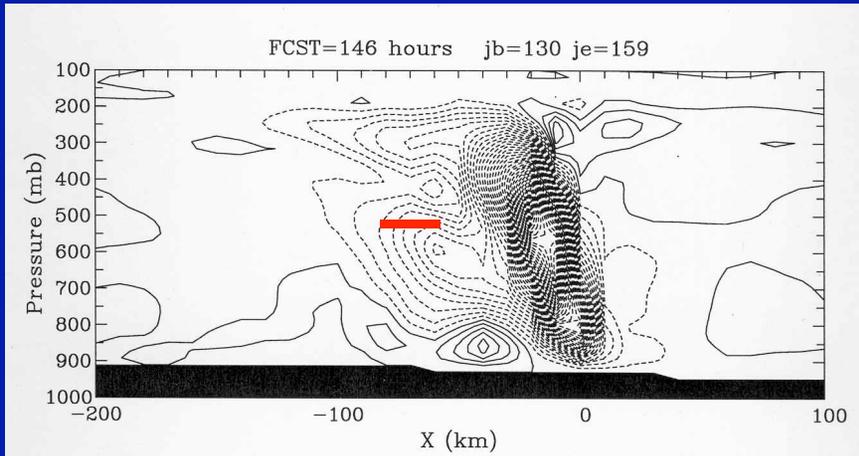
# Momentum transport:

convective

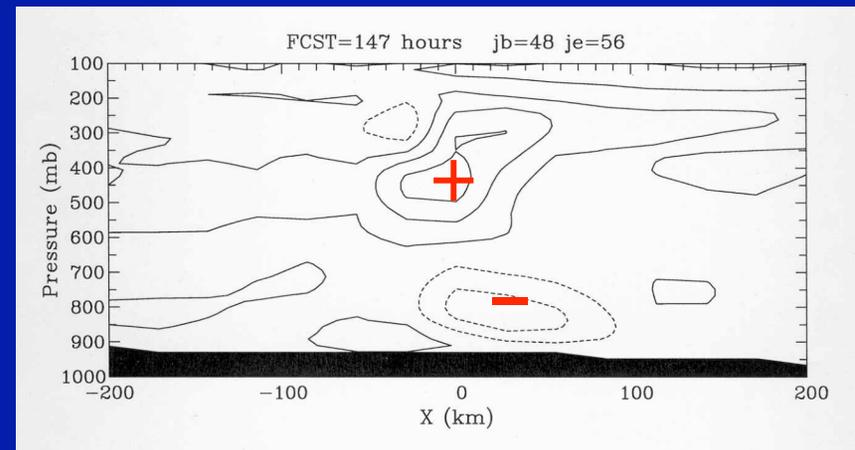
mesoscale



$\Delta = 3 \text{ km}$

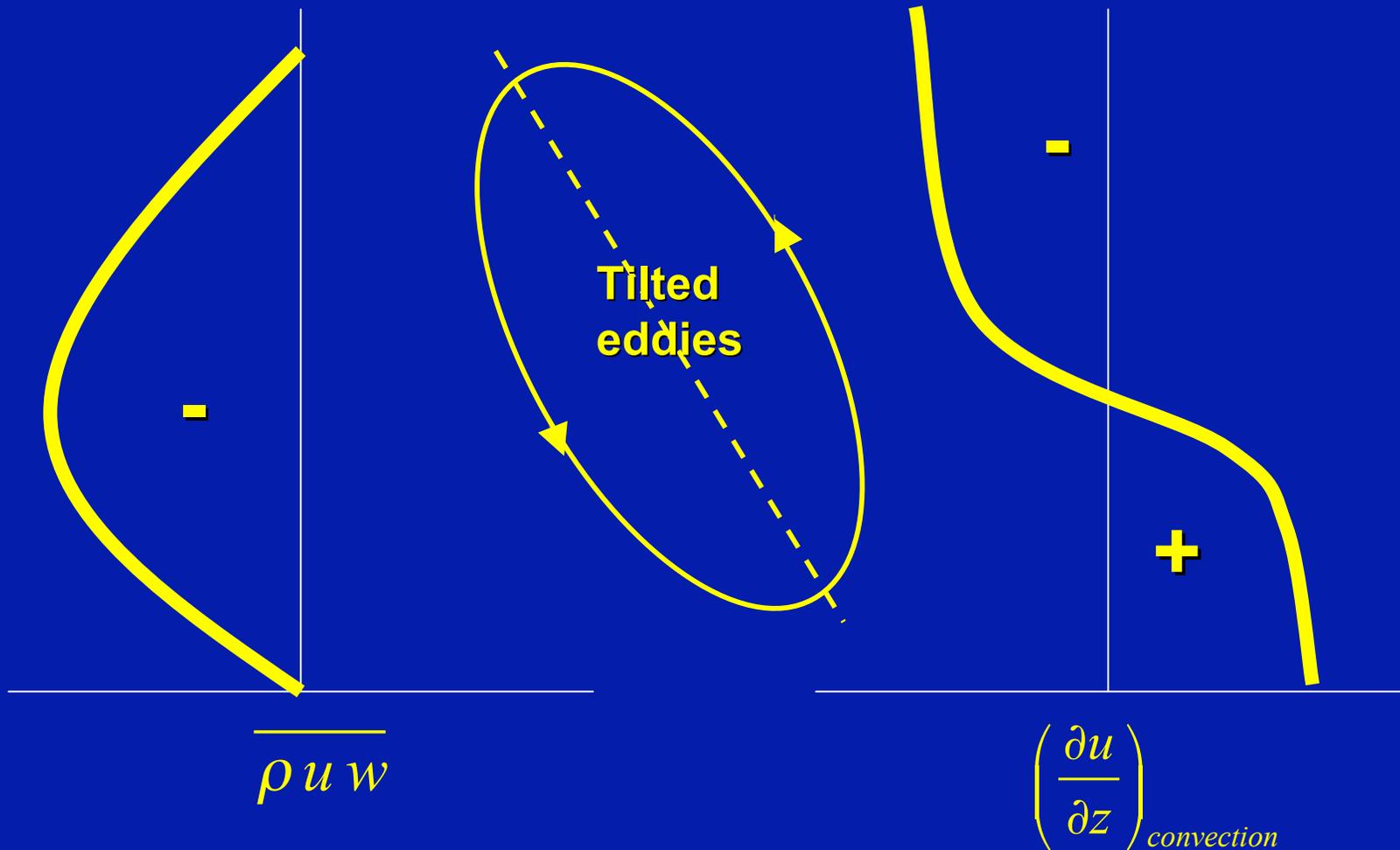


$\Delta = 10 \text{ km}$

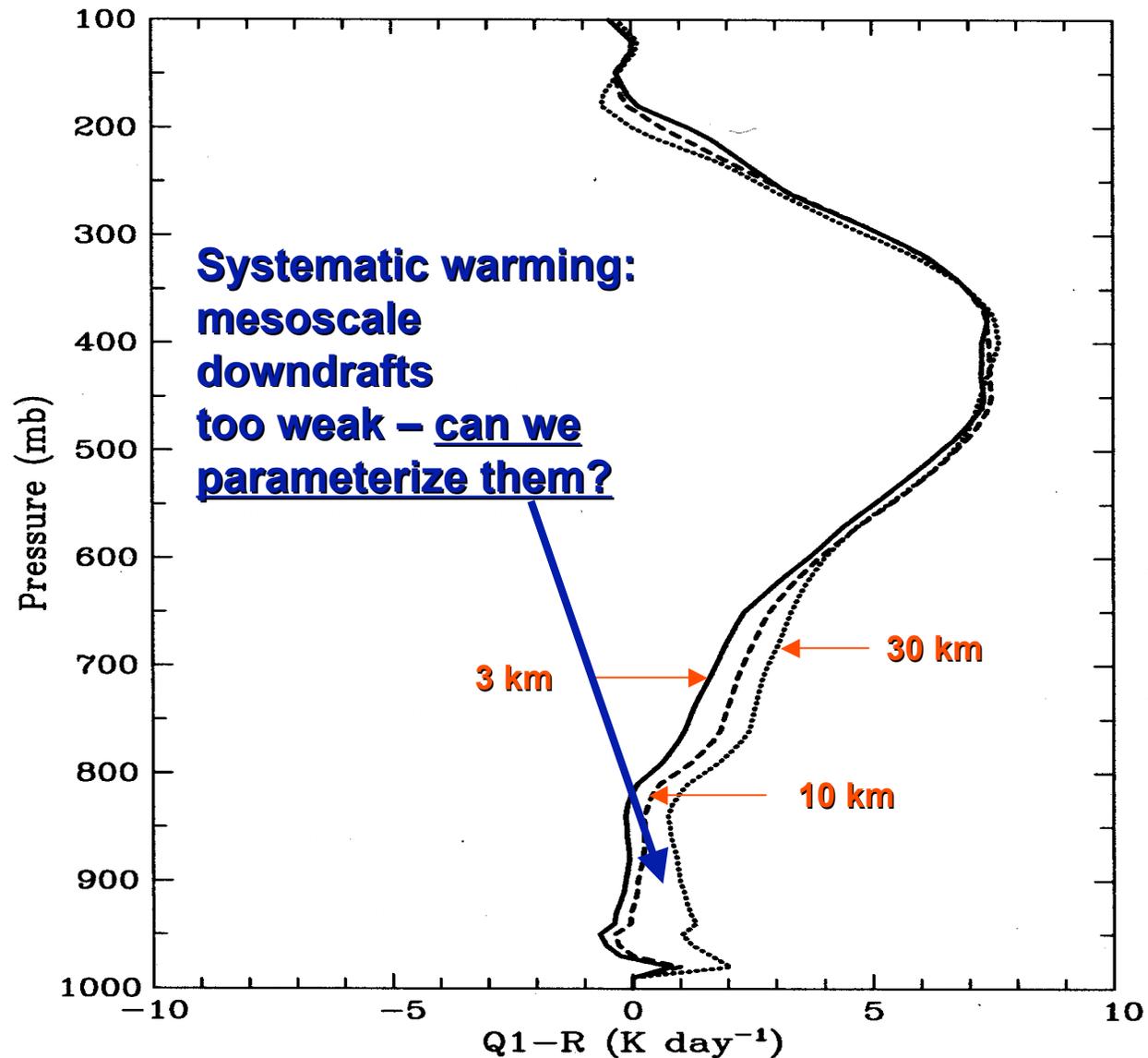


$\Delta = 30 \text{ km}$

# Momentum transport (eastward traveling system)



# Resolution dependence of convective heating

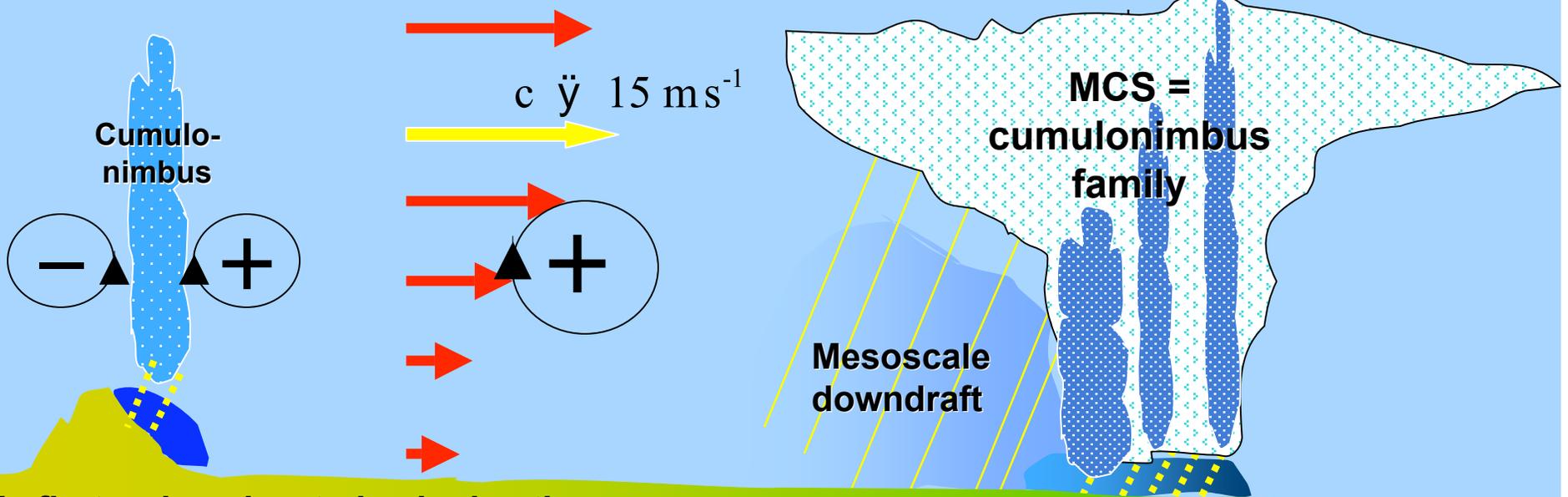


# **Parameterizing convective organization**

# A problem of interaction among elevated solar heating, environmental shear & traveling convection

Afternoon

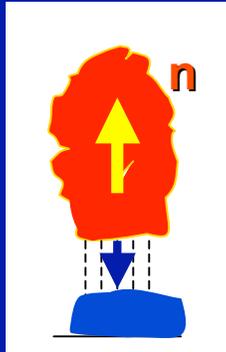
Next morning



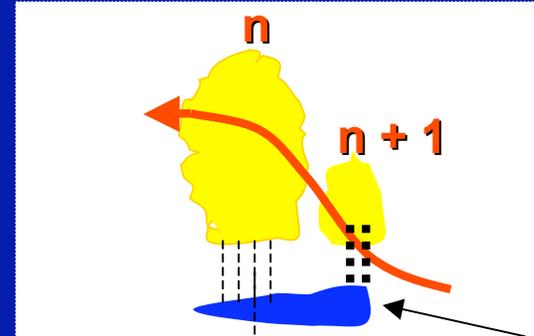
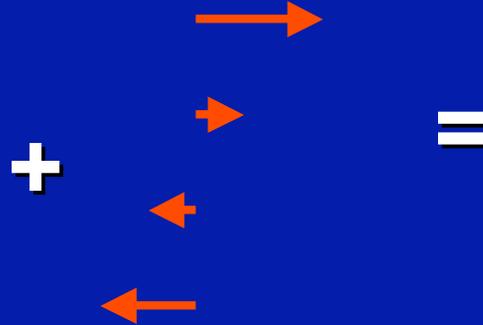
To first order, elevated solar heating  
determines start position & start  
time of traveling convection

~1000 km

# Upscale evolution

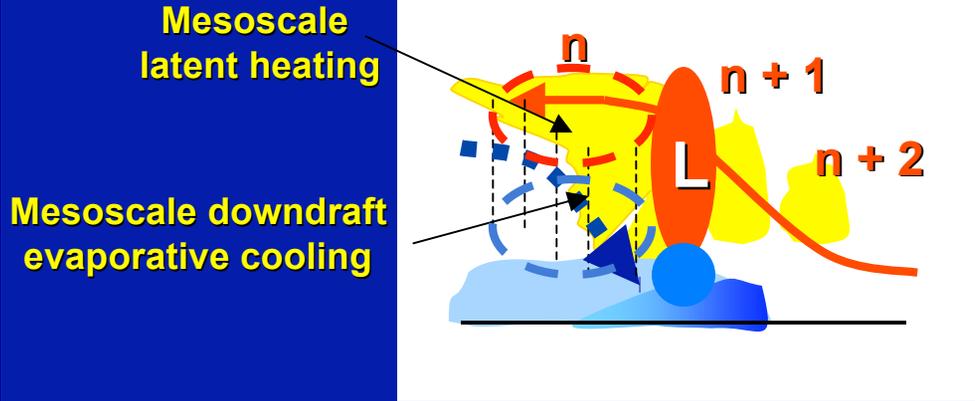


Stage 1: onset



Dynamic triggering

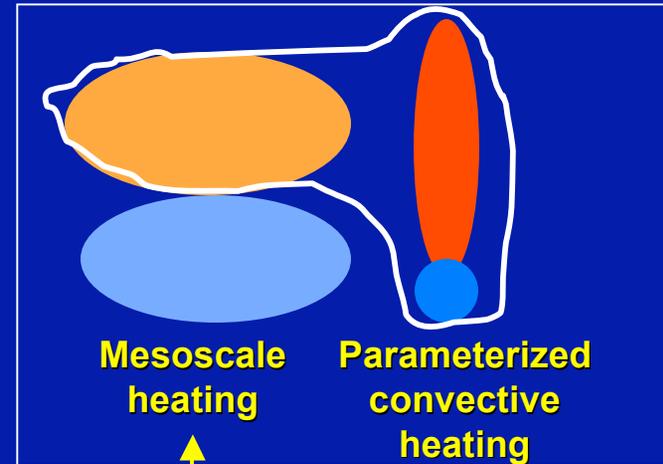
Stage 2: upscale development



Mesoscale latent heating

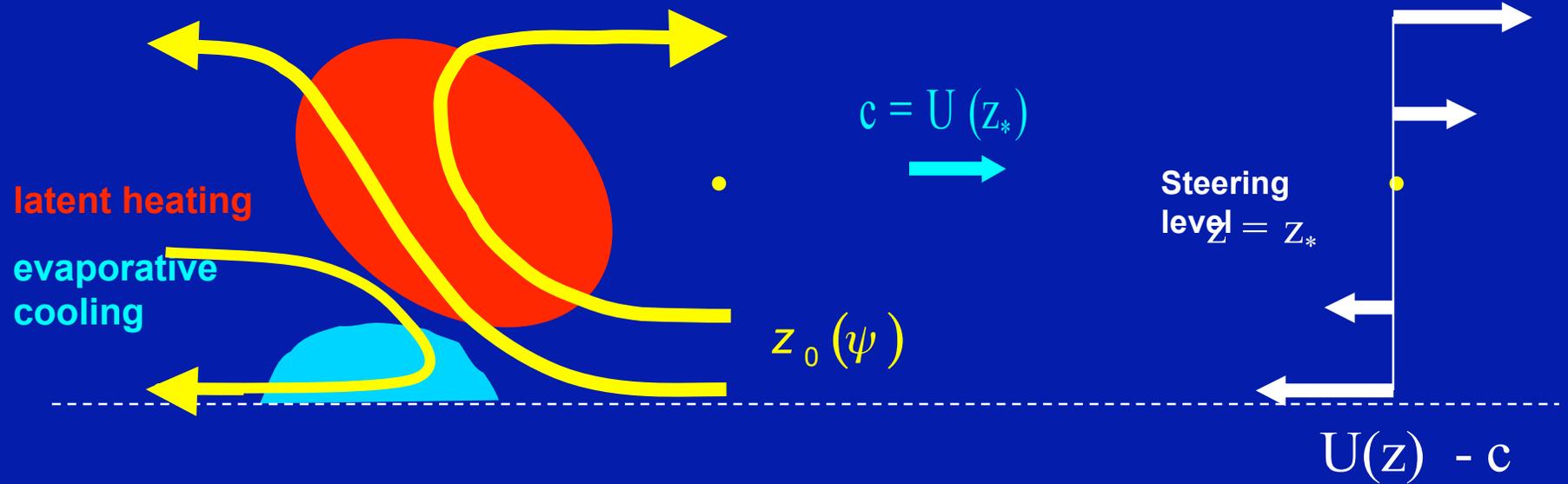
Mesoscale downdraft evaporative cooling

Stage 3: development of mesoscale circulation



Let's parameterize this upscale process

# A firm dynamical basis exists ...



Formally described by Moncrieff & Green (1972) equation:

$$\nabla^2 \psi = G(\psi) + \int_{z_0}^z \left( \frac{\partial F}{\partial \psi} \right) dz$$

vorticity along trajectories      inflow vorticity      vorticity generated by latent heating

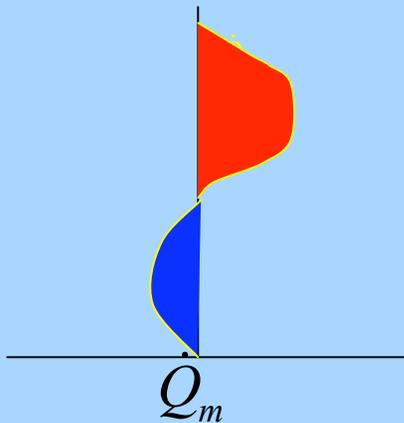
$F(\psi, z, c)$ : Lagrangian buoyancy

# A simple stratiform heating/mesoscale downdraft parameterization

$$\dot{Q}_m(p,t) = \alpha_1 \dot{Q}_c(t) \sin \partial \frac{p - p_s}{p_s - p_*} \quad p_* \leq p \leq p_s$$

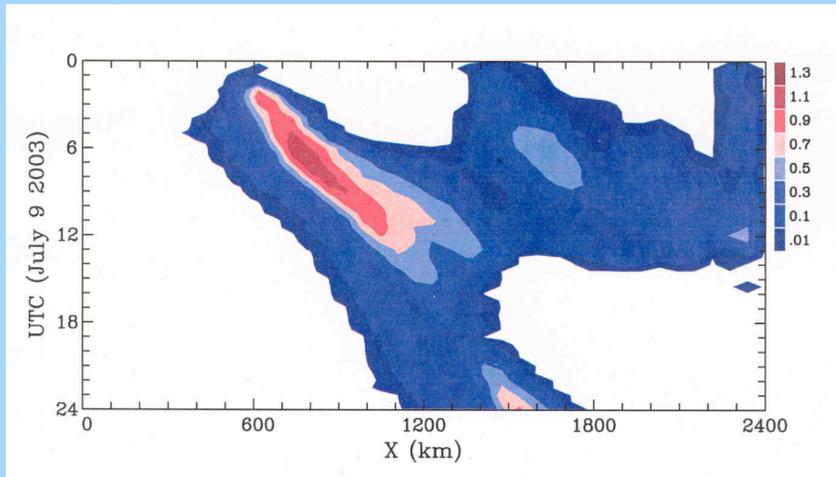
$$\dot{Q}_m(p,t) = \alpha_2 \dot{Q}_c(t) \sin \partial \frac{p_s - p}{p_* - p_t} \quad p_t \leq p \leq p_*$$

$Q_c$  = parameterized *convective* heating

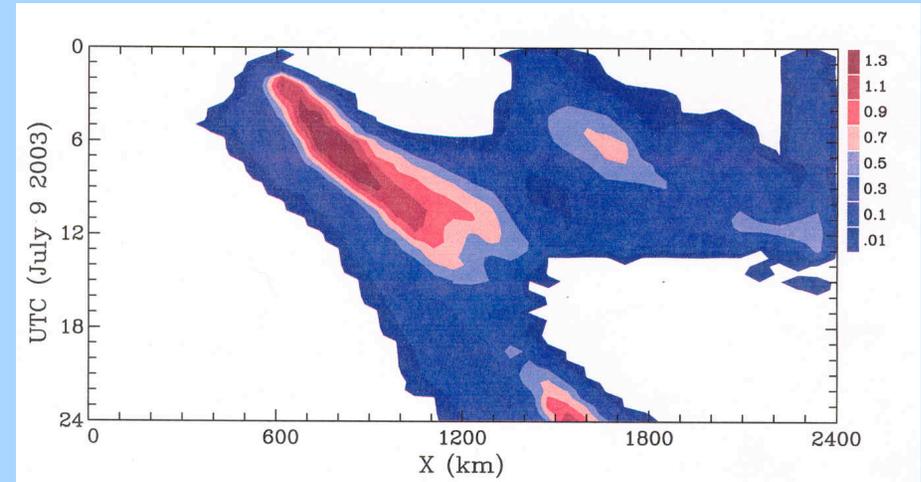


**Moncrieff (1992), Johnson (1993), Betts (1997)**

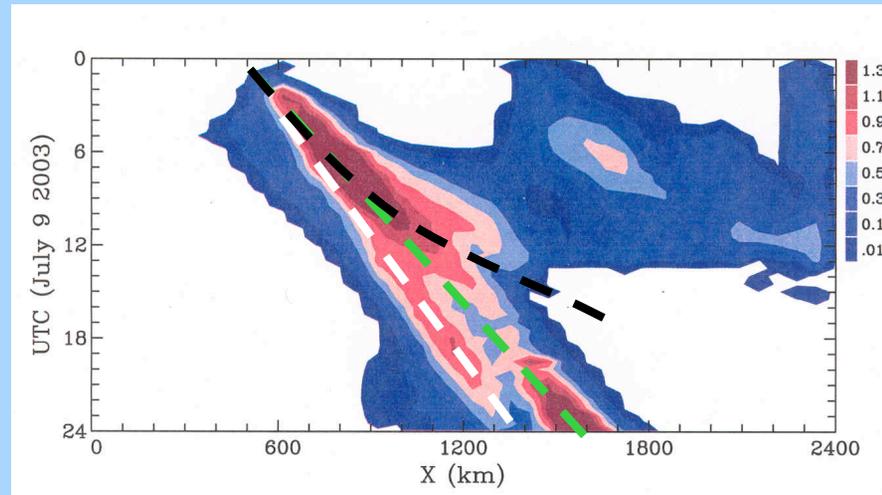
$\Delta = 60 \text{ km}$



**Parameterization**

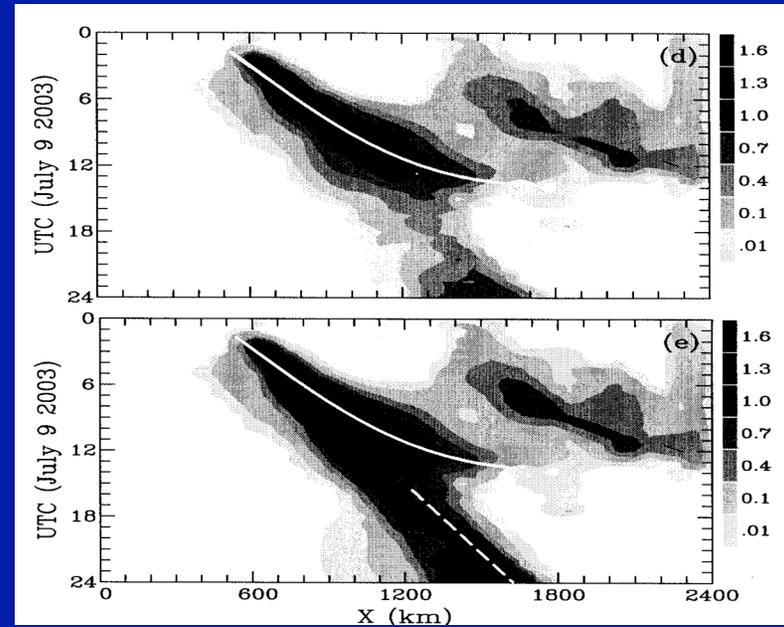
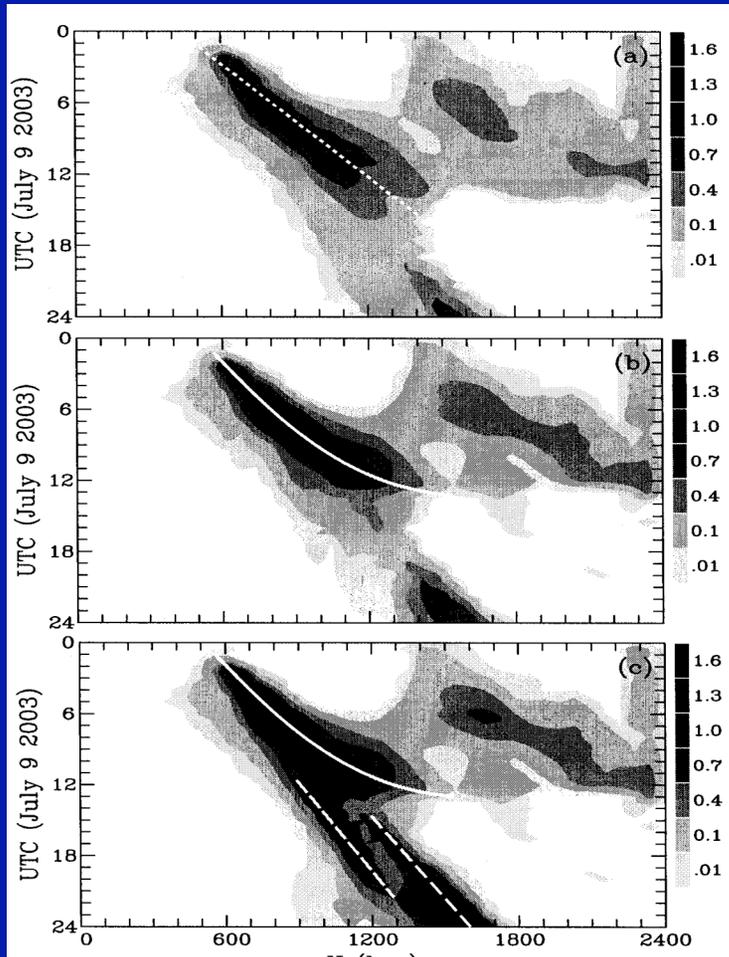


**Parameterization + mesoscale heating**

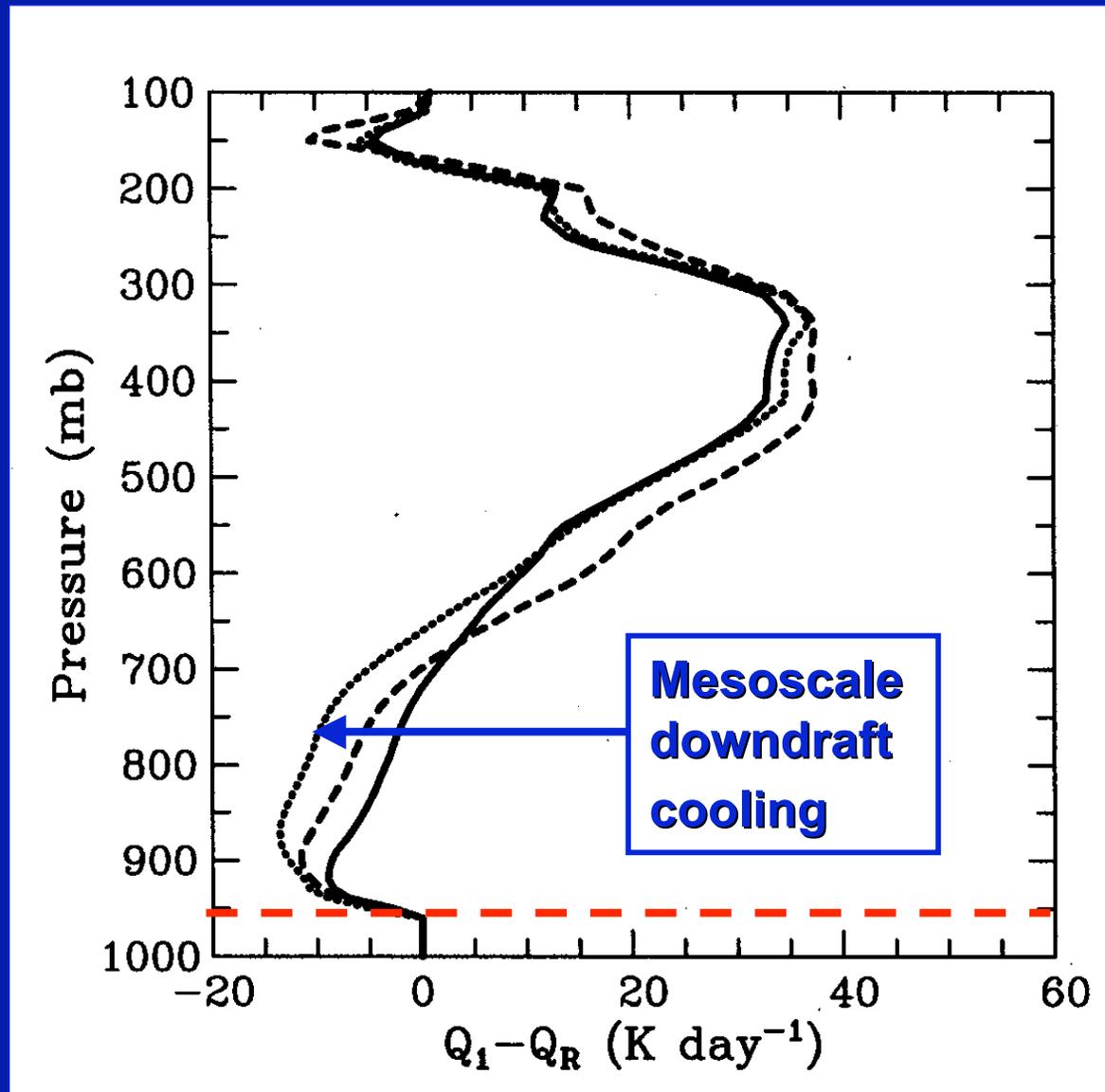


**Parameterization + mesoscale heating + grid-scale heating**

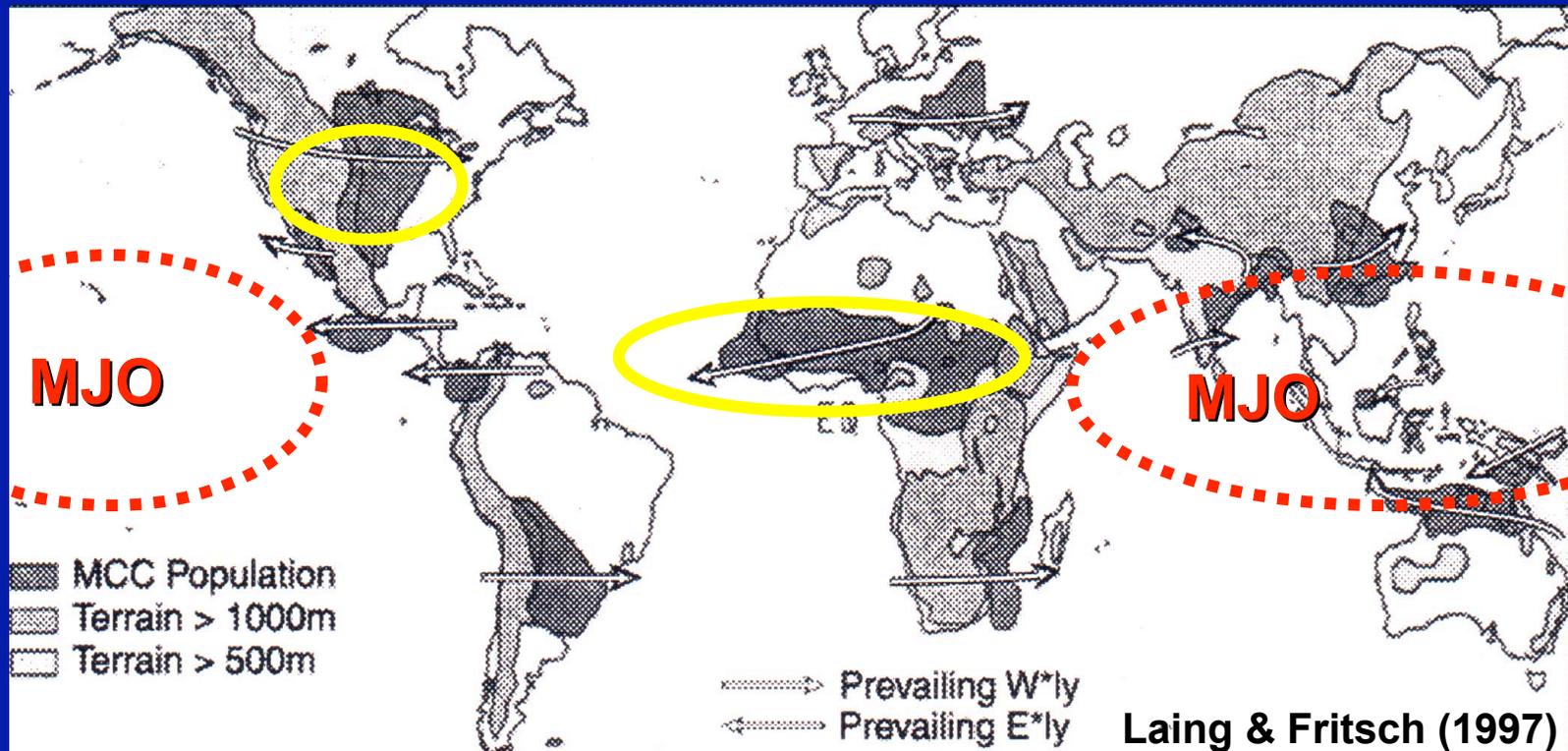
# Effect of mesoscale parameterization



# Effect of mesoscale parameterization on convective heating



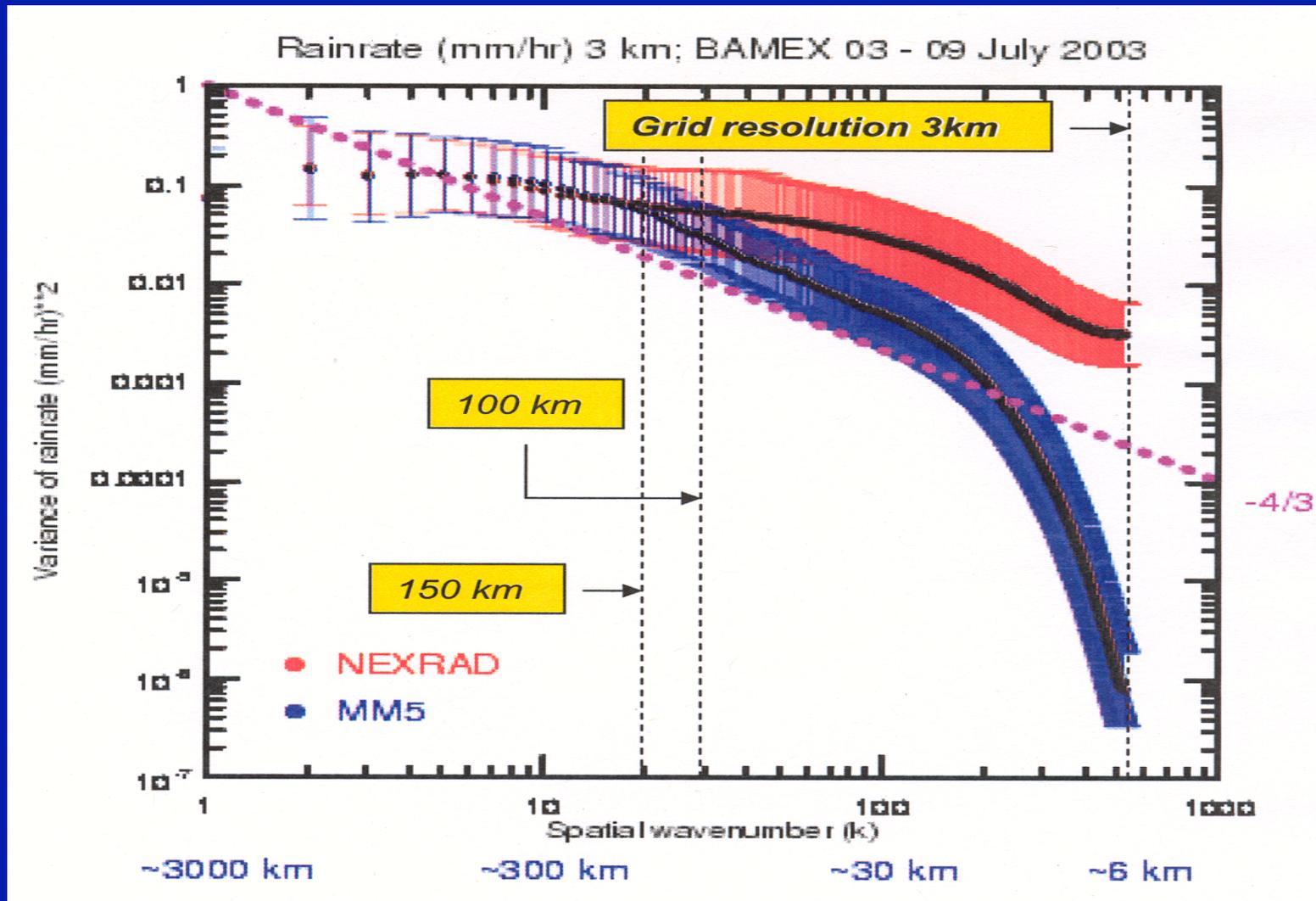
# Large-scale convective organization



... is correlated with shear zones & mountain ranges

# **Statistical comparison with NEXRAD data**

# Rain-rate spectra



# Summary

- **U.S. continent results should apply to other regions of the world**
- **In global CSRM / MMF approaches, mesoscale organization is a primary representation problem**
- **Global CSRM / MMF approaches redefines, but does not obviate, the parameterization problem: brings dynamics to the fore**

# Summary

- **At ~10-km grid-resolution, the representation of convection is markedly different from parameterization at coarse resolution -- under-resolved explicit circulations**
- **Cloud-system-resolving simulations verified by NEXRAD from observations**
- **Weak mesoscale downdrafts in ~10-km models alleviated by mesoscale downdraft parameterization, but the cloud-systems still travel too slowly**
- **Betts-Miller convective parameterization could be improved by calculating a thermodynamic reference profile for the continental U.S.**
- **Work continues on Betts-Miller and other convective parameterizations**

*Thanks!*