The effects of organization on convective and large-scale interactions using cloud resolving simulations with parameterized large-scale dynamics

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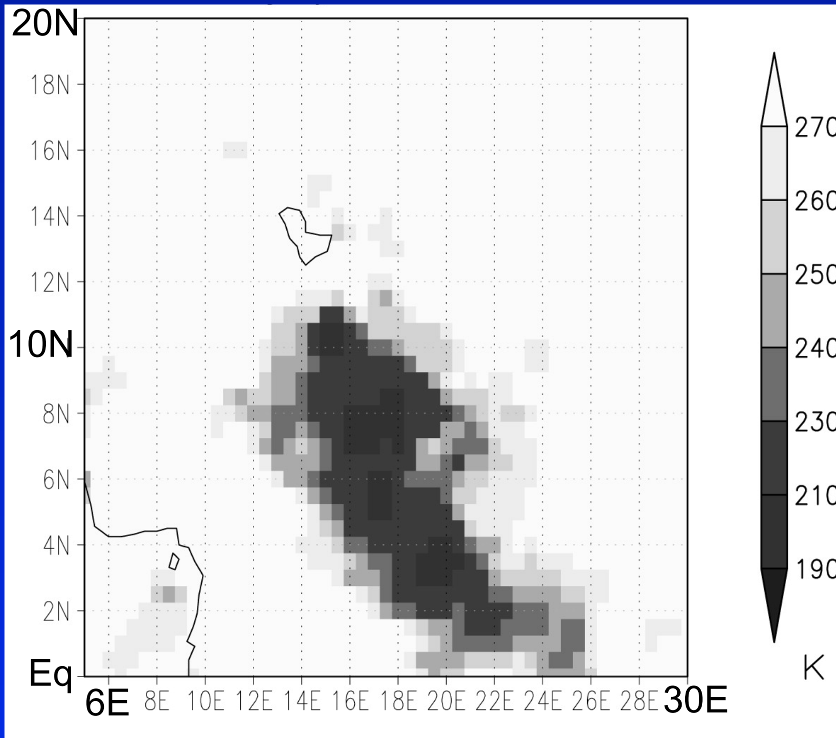
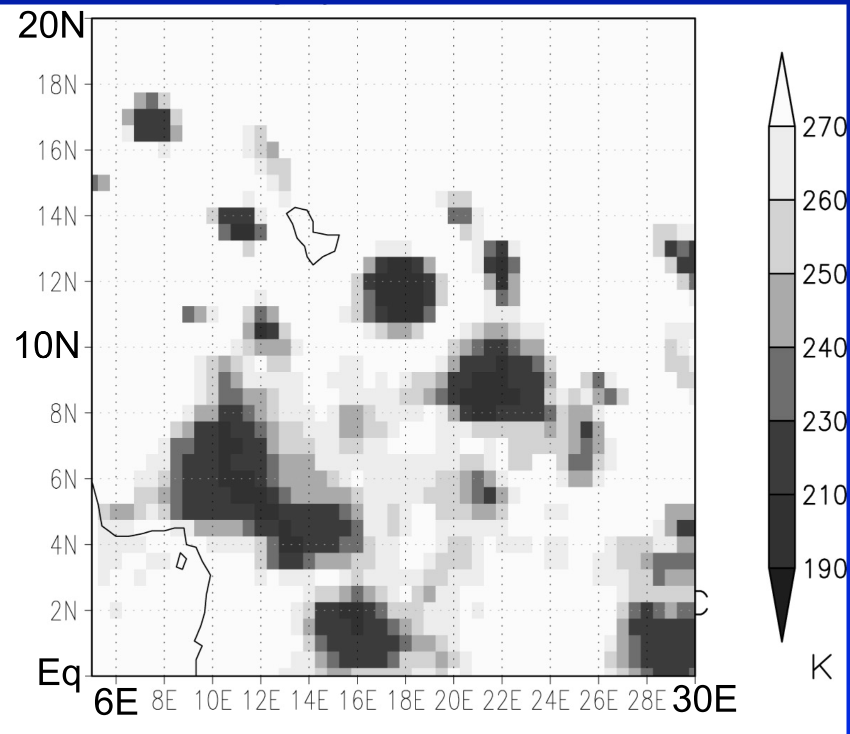
Forms of convective organization



One Coherent Clump



Scattered Blobs

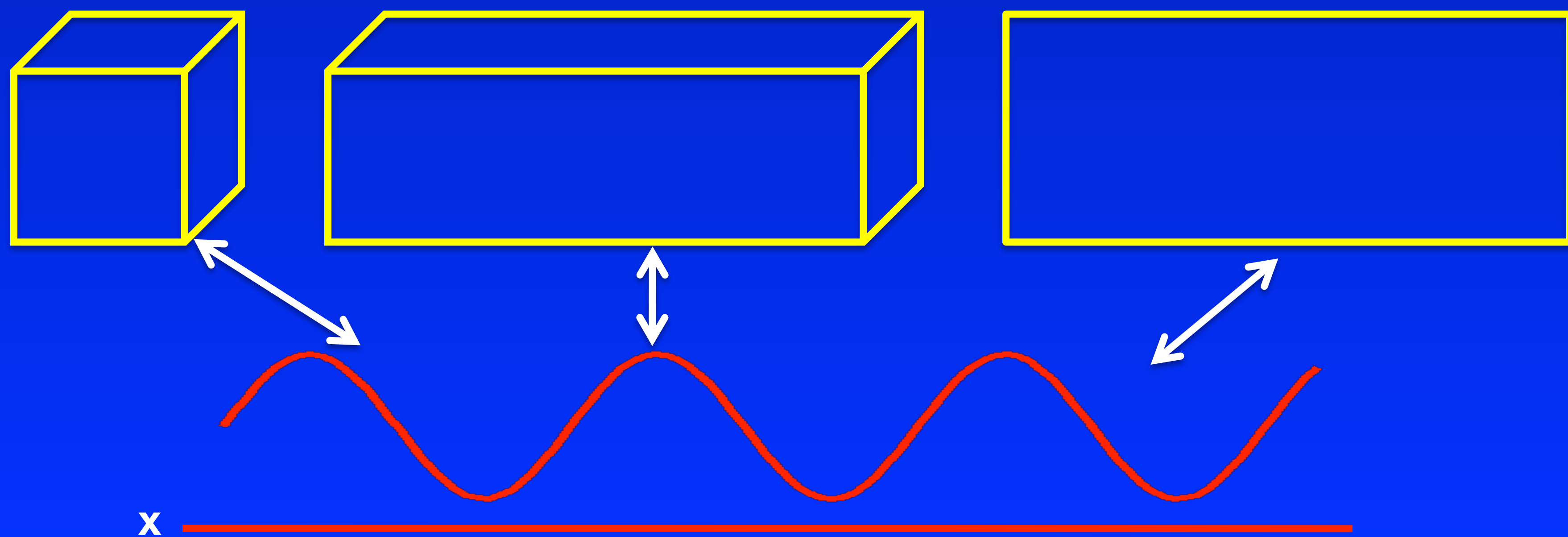
Are these differences important?

Tobin et al. (2012)

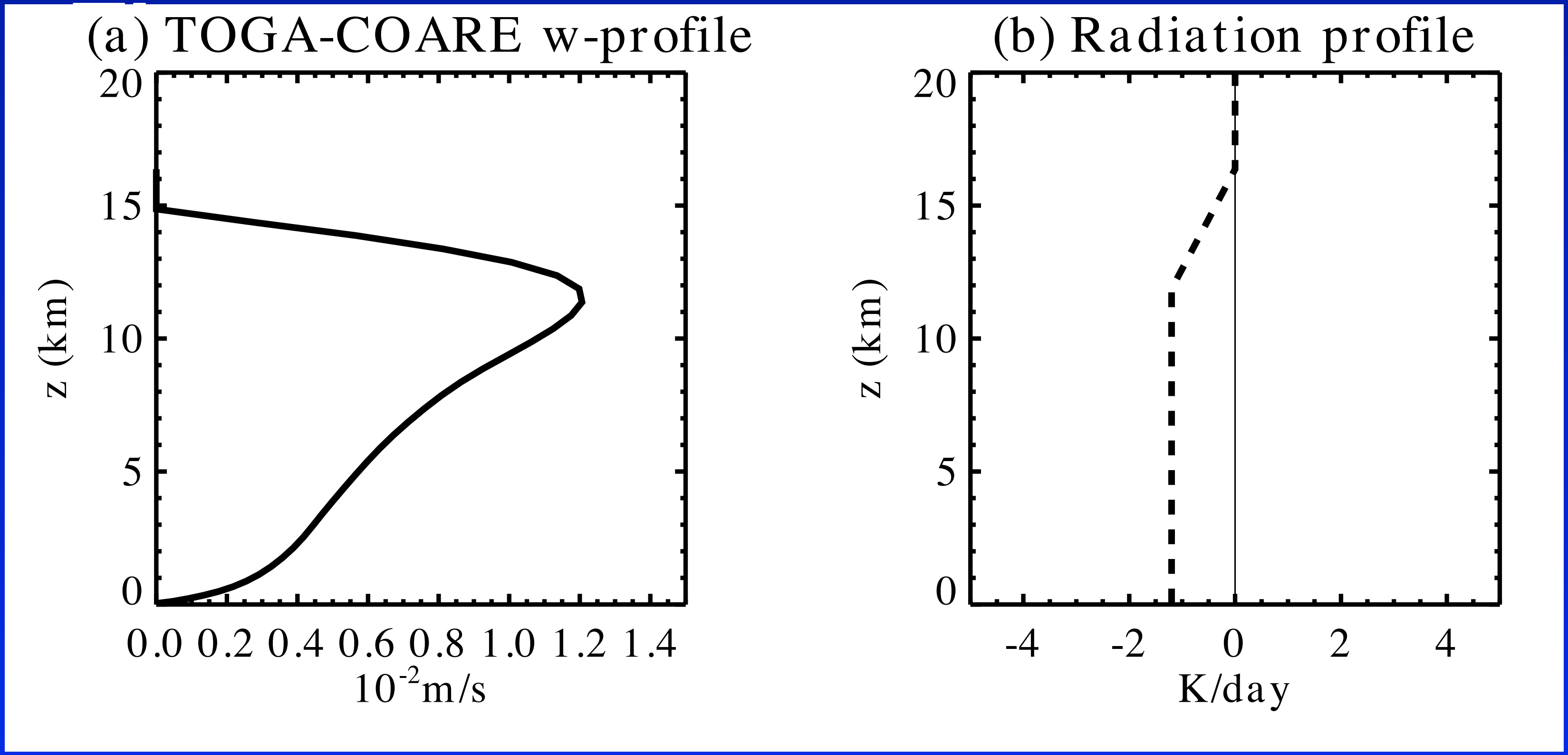
Approach: SAM + PLSD (Kuang 2008)

More or less *organized* convection via altering domain geometry, or adding shear

Double x-dimension, halve y-dimension

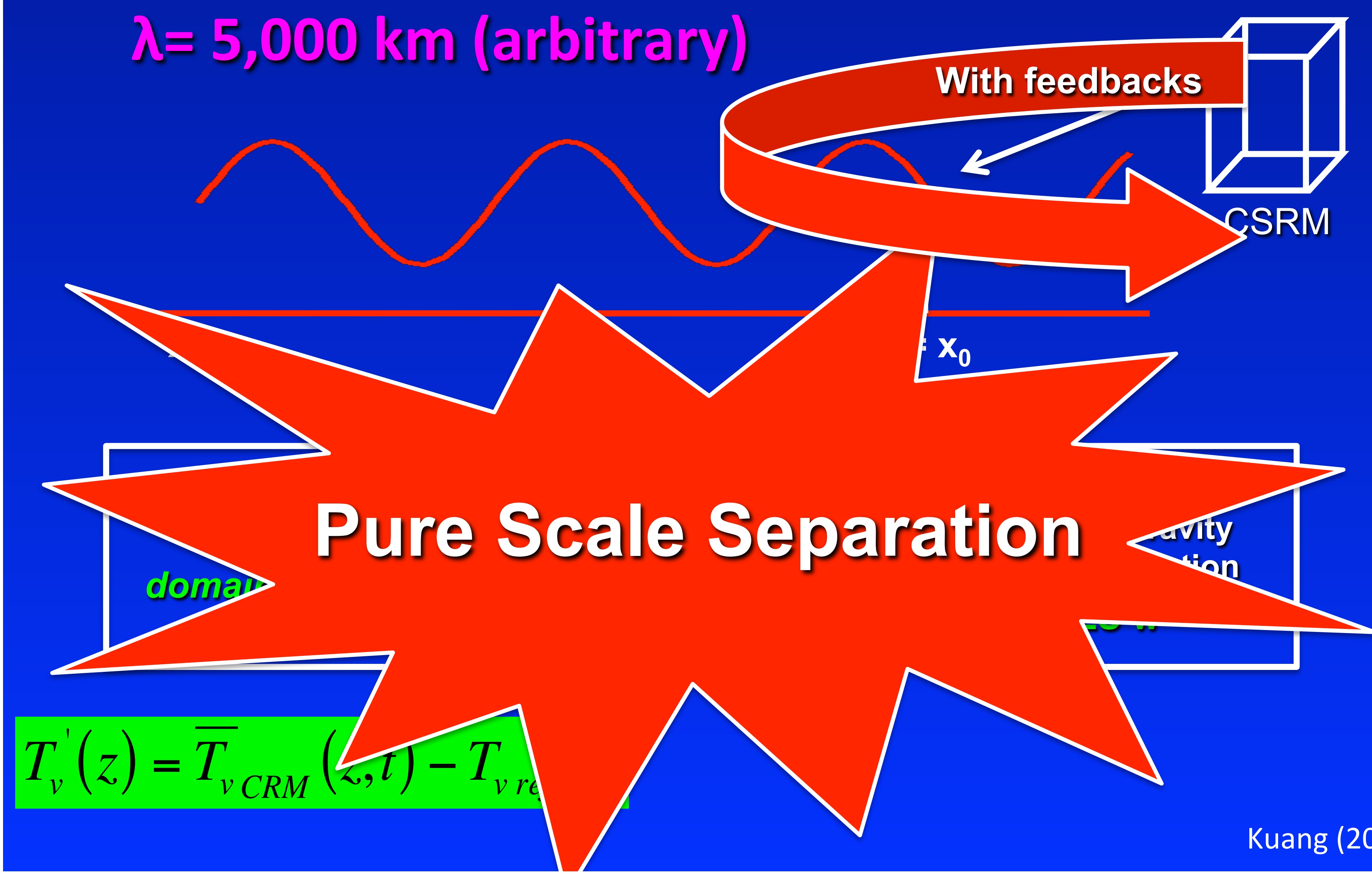


CSRM: System for Atmospheric Modeling (SAM)

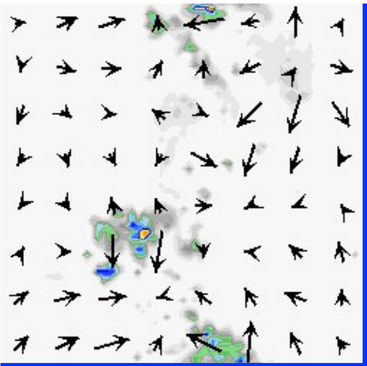


- Prescribed radiation profile
- Prescribed background vertical velocity profile

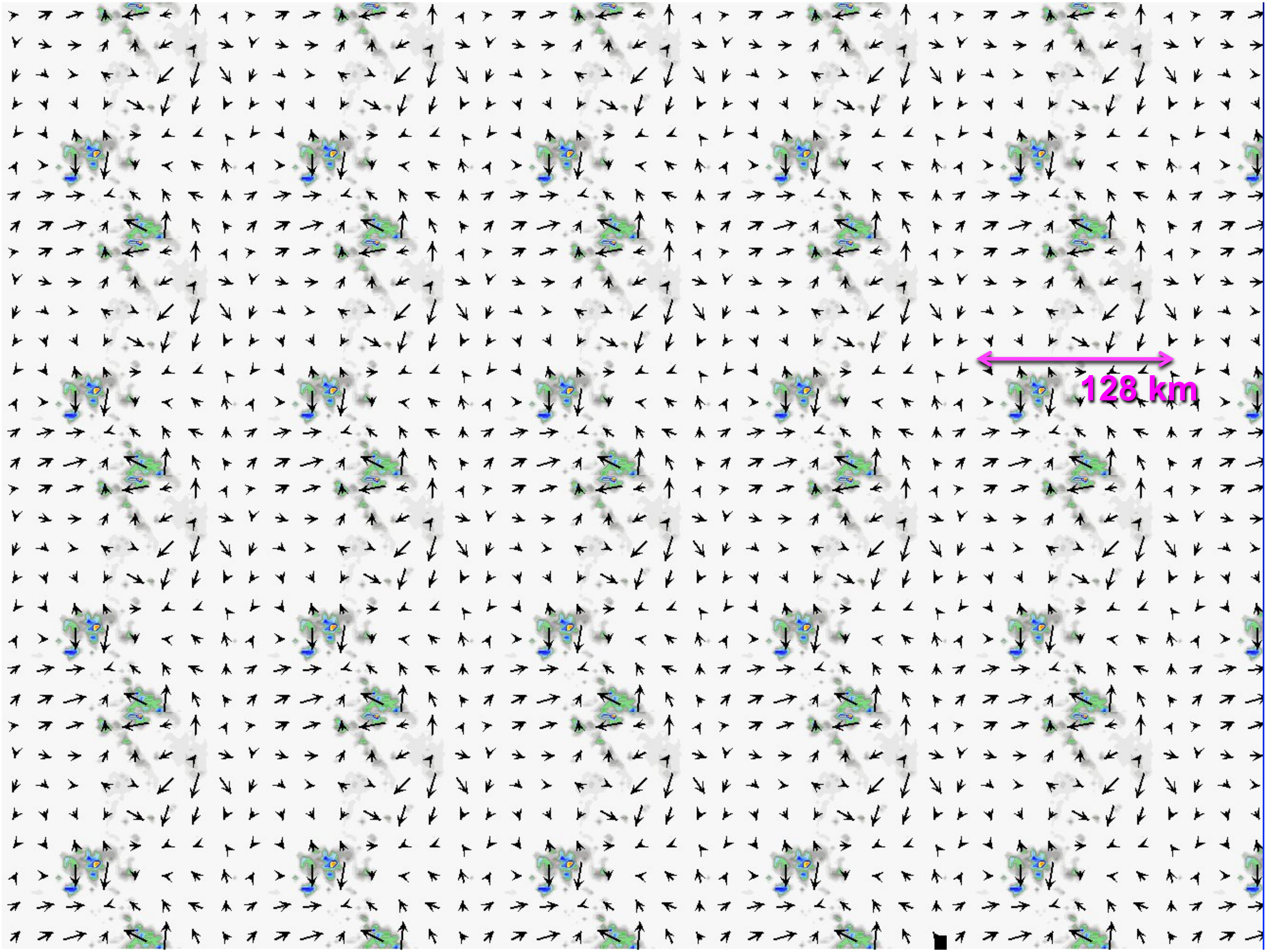
SAM with parameterized large-scale dynamics

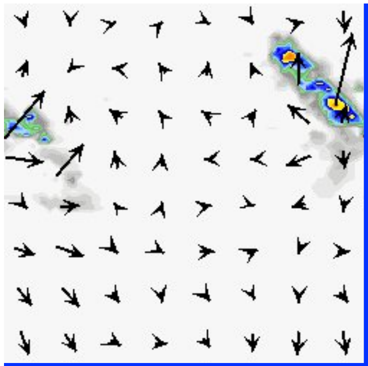


Kuang (2008)

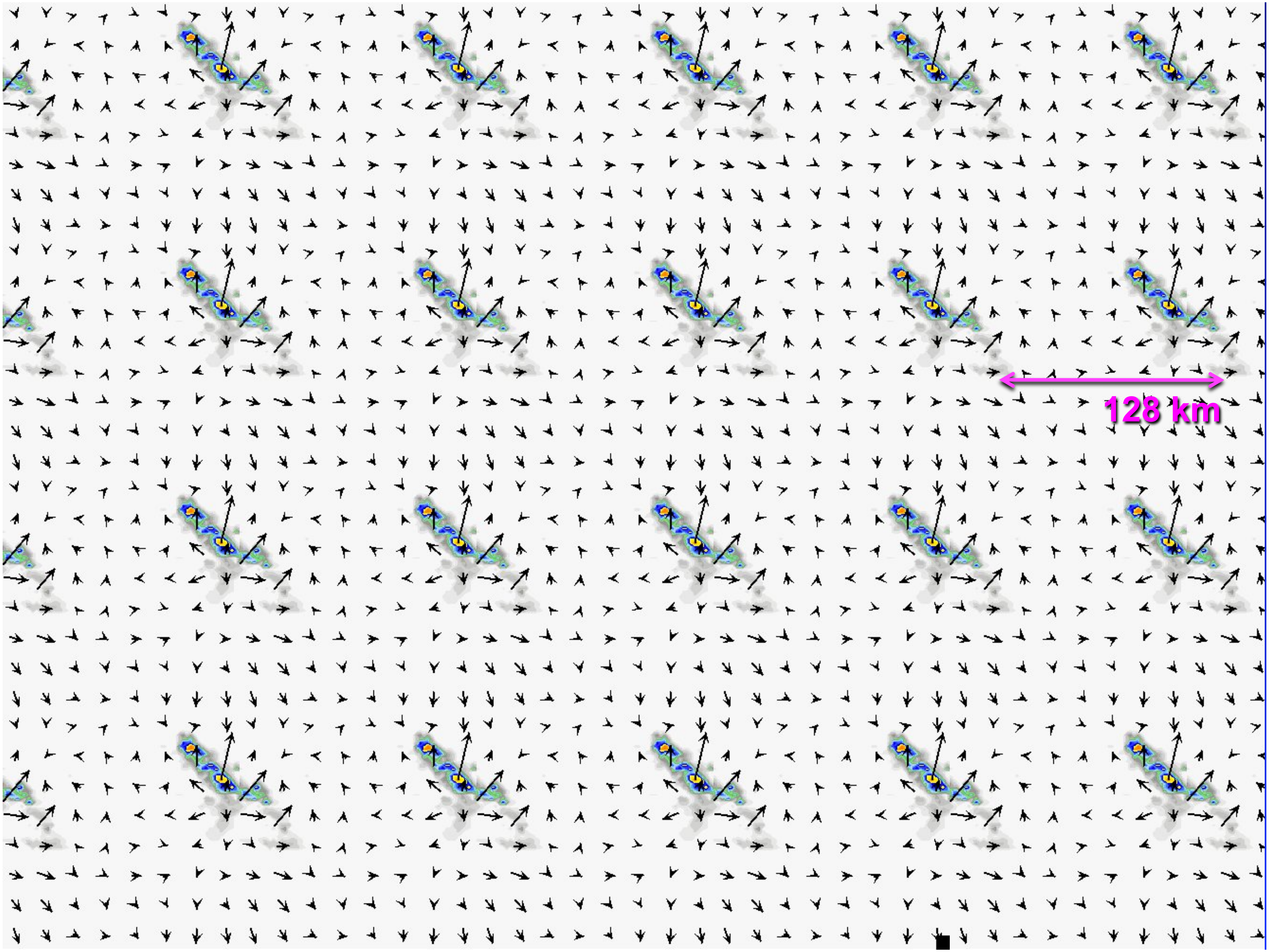


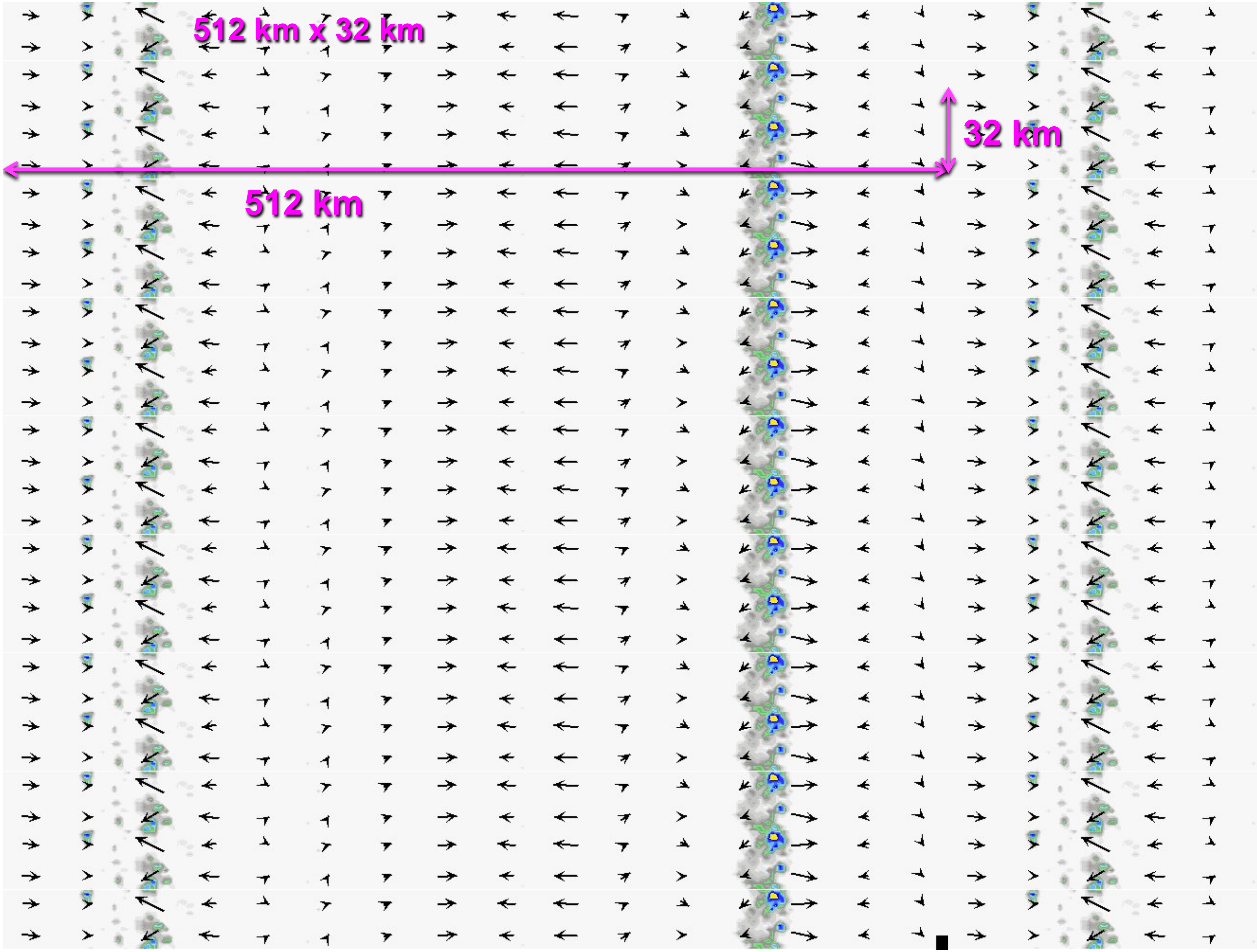
- Snapshots of 15 min avg. rainfall

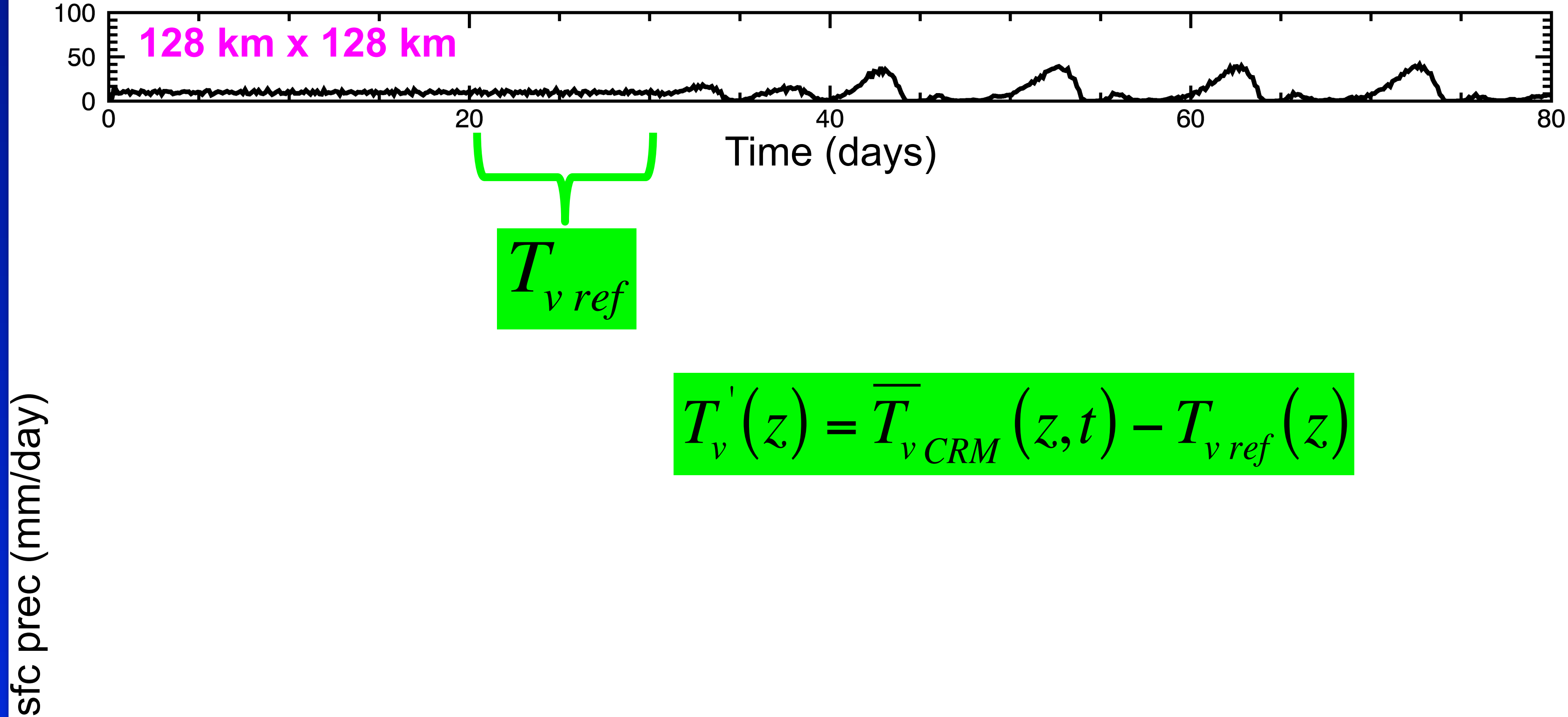

128 km



128 km x 128 km +Shear

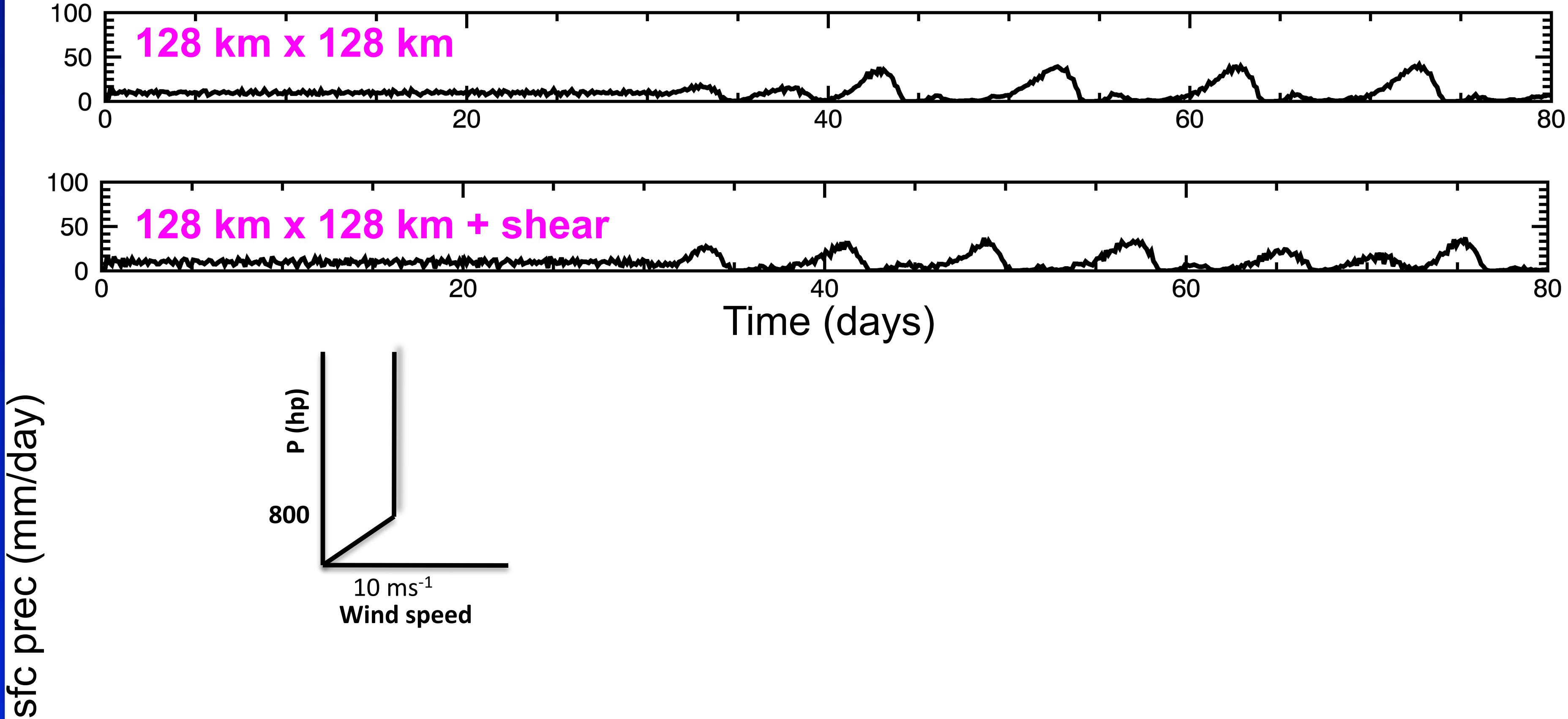

128 km

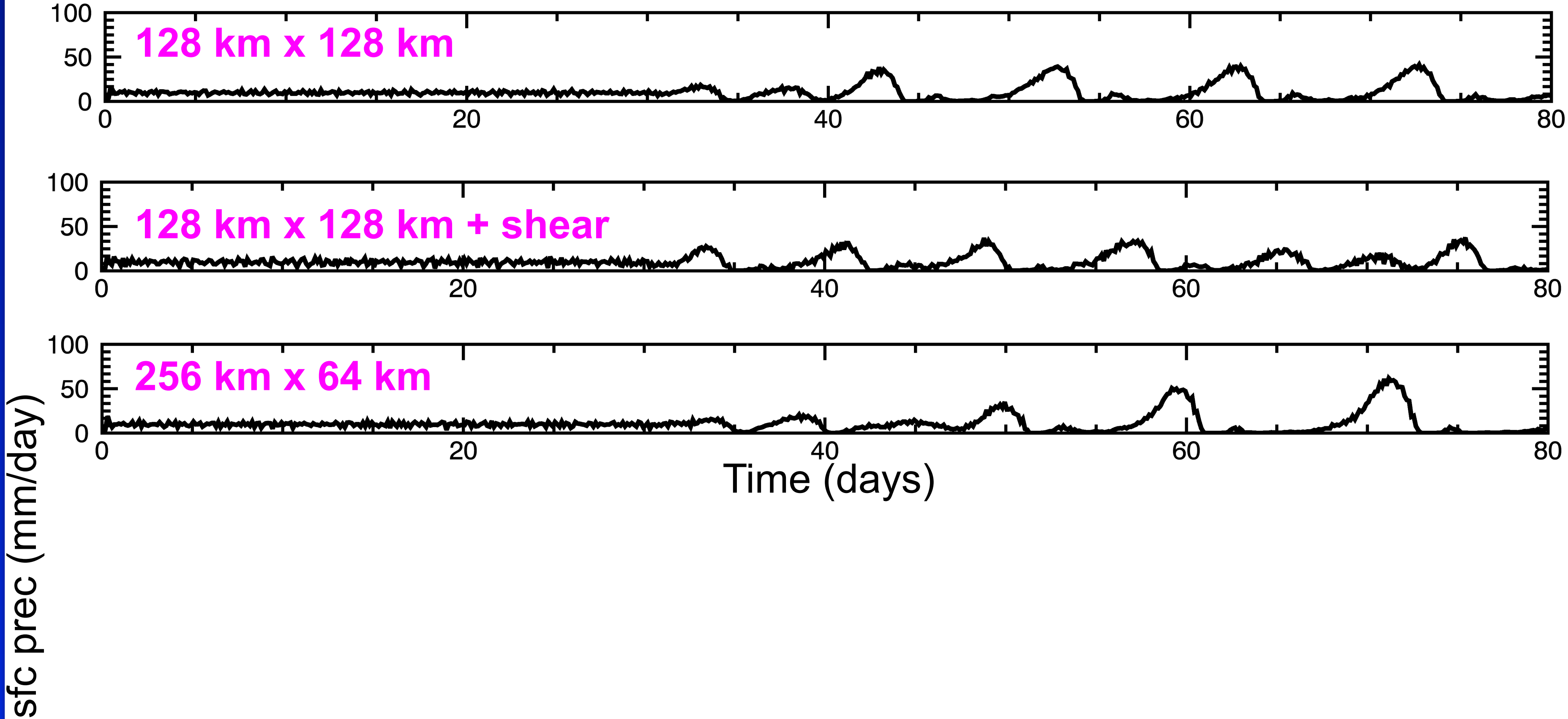

512 km x 32 km
32 km
512 km



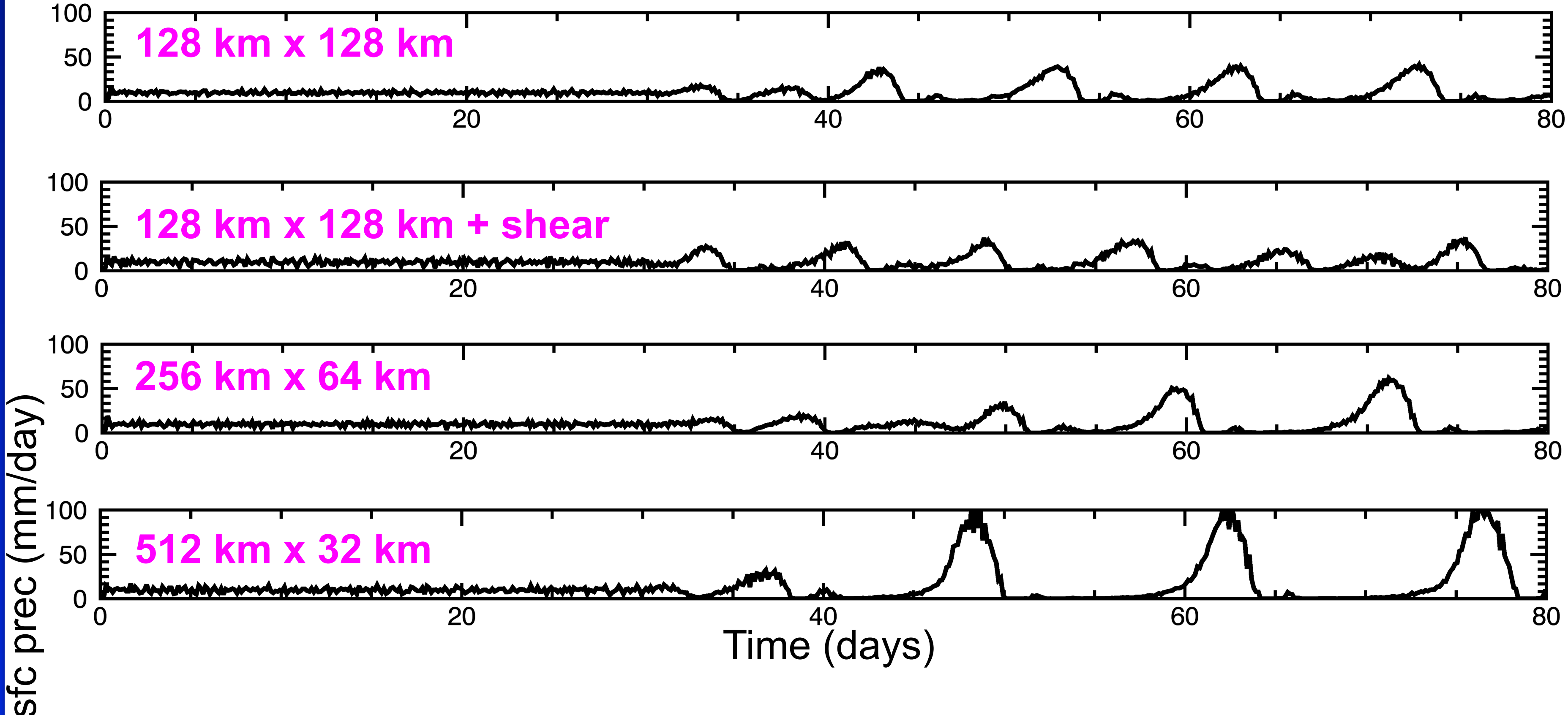
$$T_{v\,ref}$$

$$T_v^{'}(z) = \overline{T}_{v\,CRM}(z,t) - T_{v\,ref}(z)$$

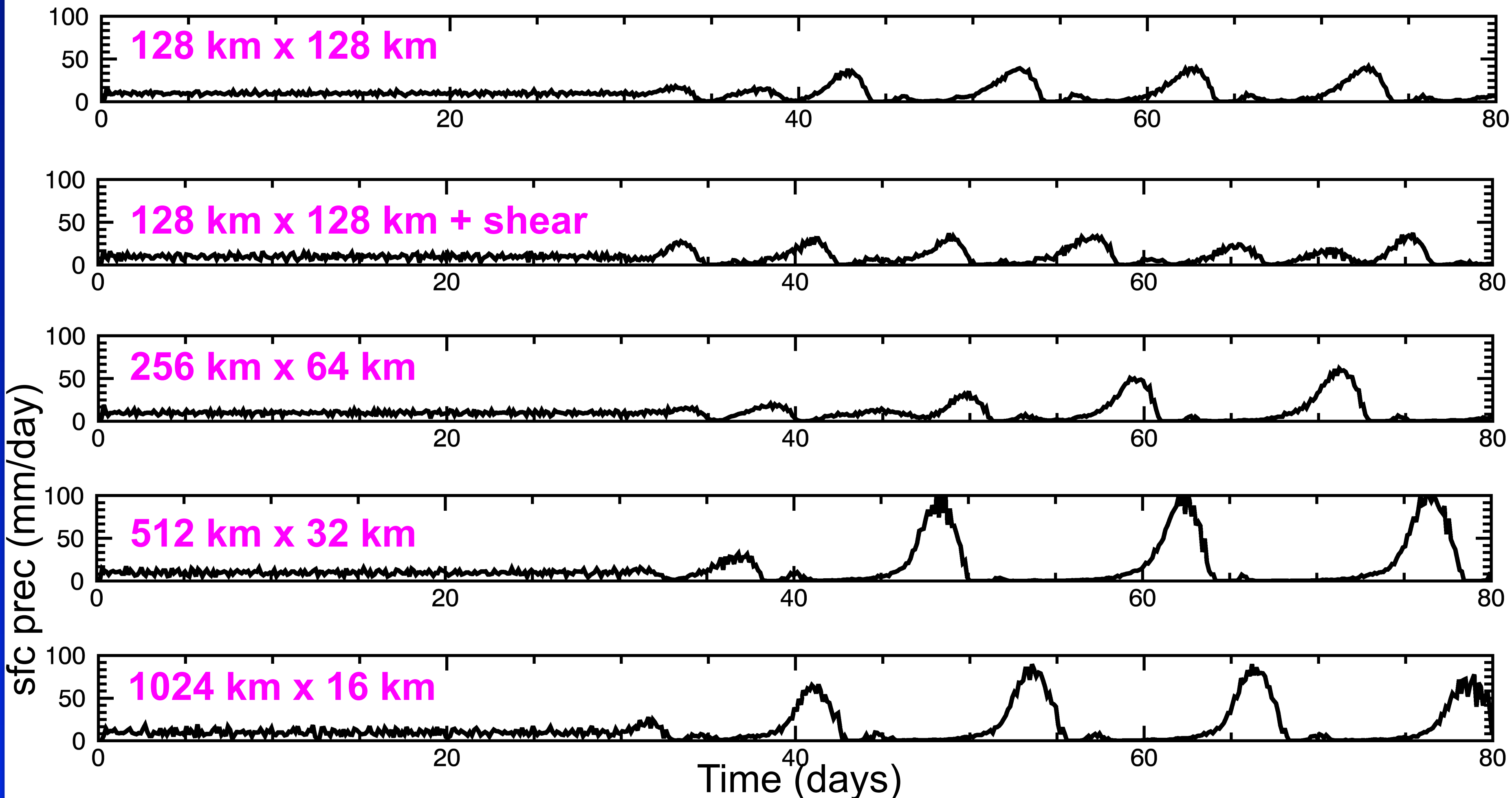

100
50
0
128 km x 128 km
0
20
40
60
80
100
50
0
128 km x 128 km + shear
0
20
40
60
80
Time (days)
sfc prec (mm/day)
P (hp)
800
10 ms-1
Wind speed



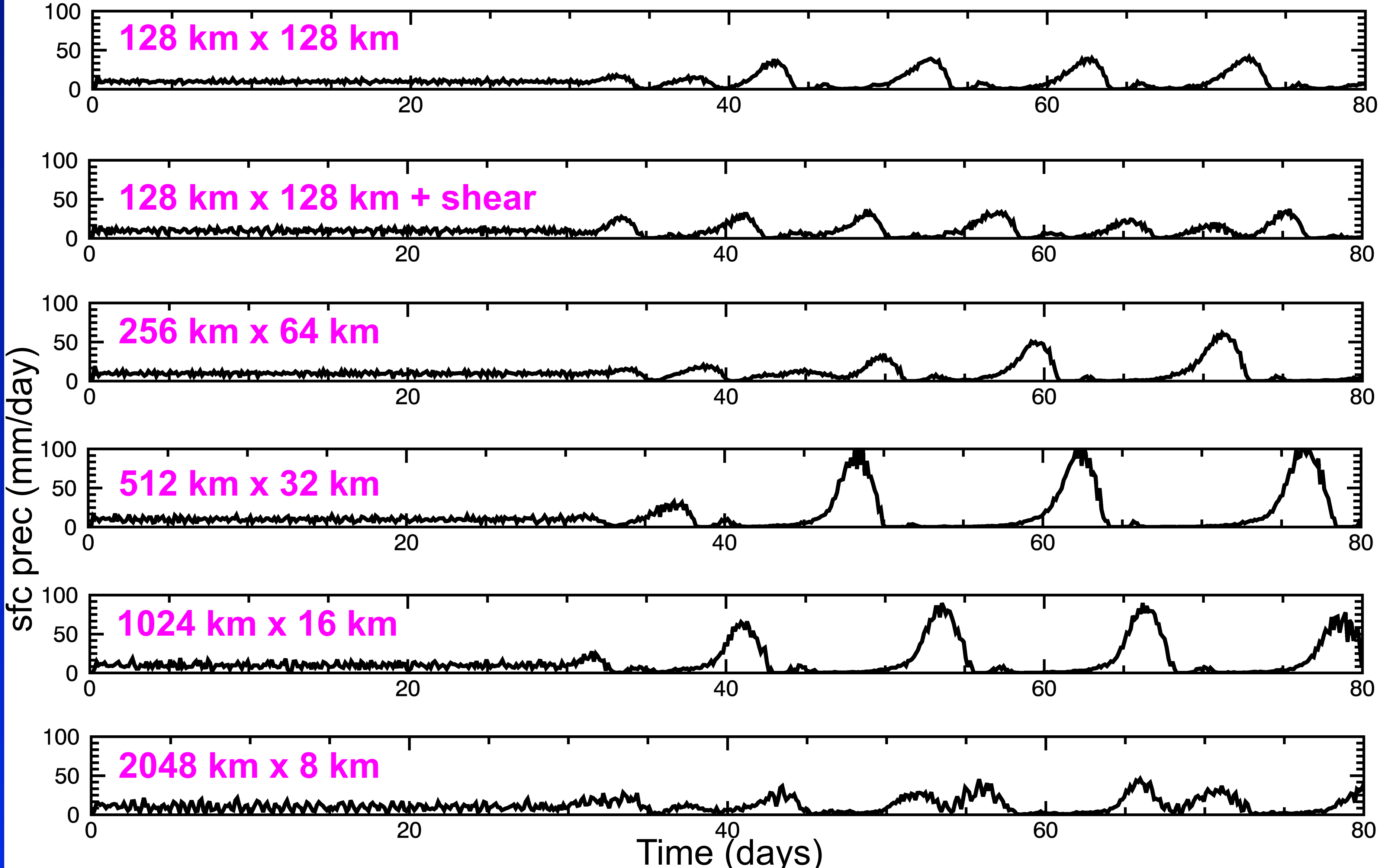
128 km x 128 km
128 km x 128 km + shear
256 km x 64 km
100
50
0
0
20
40
60
80
Time (days)
sfc prec (mm/day)

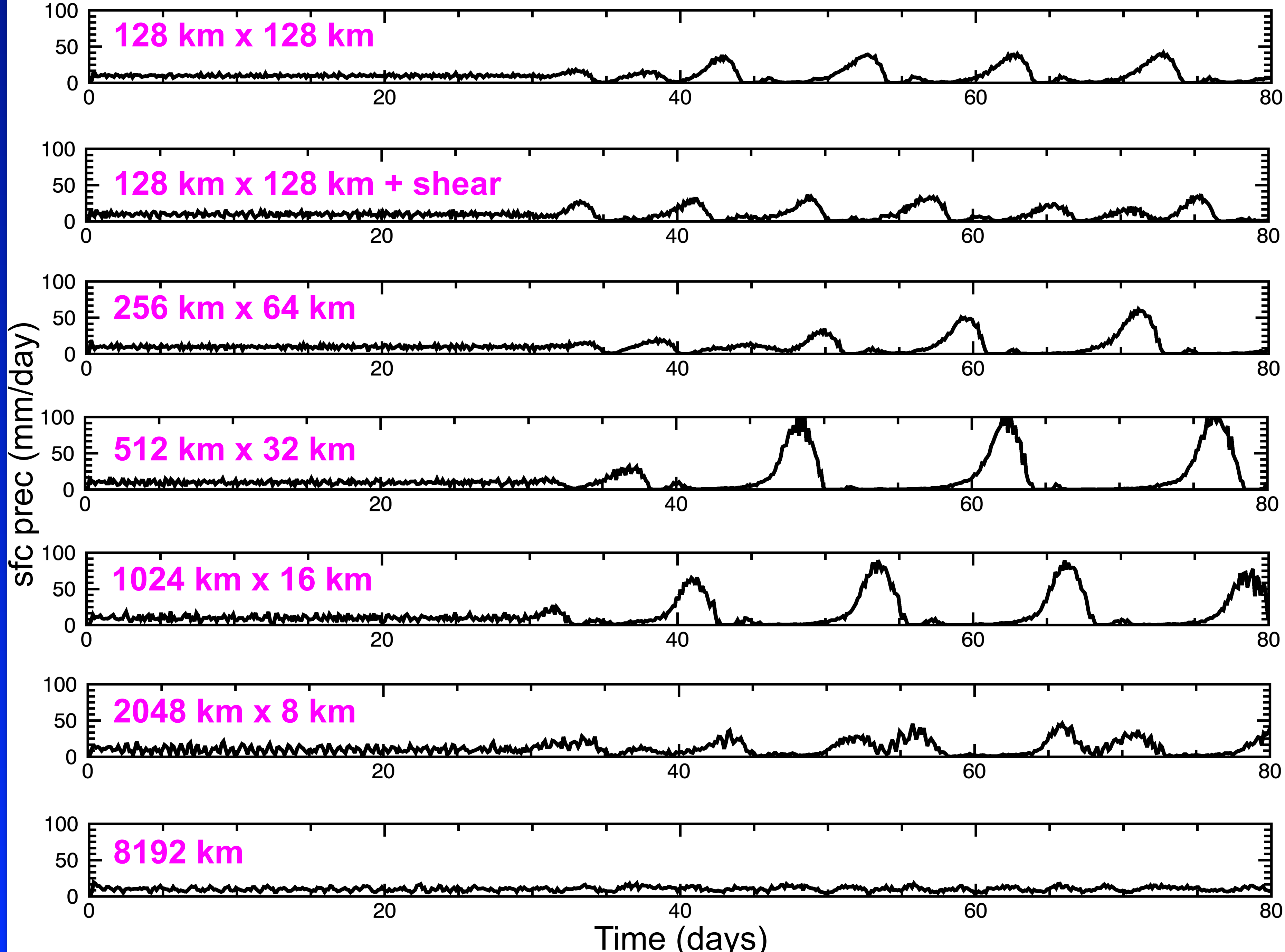


128 km x 128 km
128 km x 128 km + shear
256 km x 64 km
512 km x 32 km
sfc prec (mm/day)
Time (days)
100
50
0
0
20
40
60
80

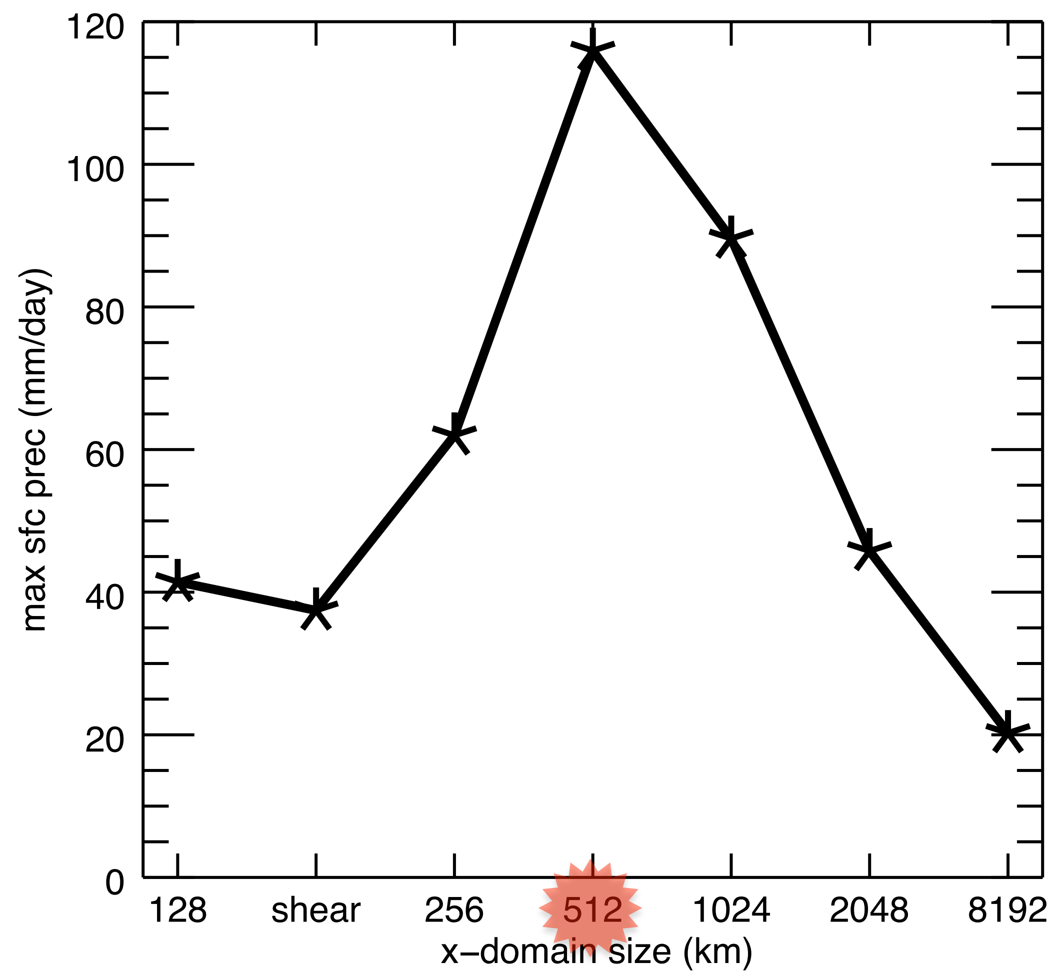


128 km x 128 km
128 km x 128 km + shear
256 km x 64 km
512 km x 32 km
1024 km x 16 km
sfc prec (mm/day)
Time (days)
0
20
40
60
80
100
50


128 km x 128 km
128 km x 128 km + shear
256 km x 64 km
512 km x 32 km
1024 km x 16 km
2048 km x 8 km
sfc prec (mm/day)
Time (days)
0
50
100
0
20
40
60
80


128 km x 128 km
128 km x 128 km + shear
256 km x 64 km
512 km x 32 km
1024 km x 16 km
2048 km x 8 km
8192 km
sfc prec (mm/day)
Time (days)

Domain Shape vs. Max Precip



Can we understand the 512 km x 32 km optimum?

Can changes in precipitation oscillation magnitude be explained by sensitivity differences to a prescribed perturbation?

- e.g. Tulich and Mapes (2010), Jones and Randall (2012)

Prescribe large-scale vertical velocity

CSRM

domain avg. T'_v

T'_v (density) →

← advection of T and q by LS w

Large Scale 2D Linear Gravity Wave Equation

LS w

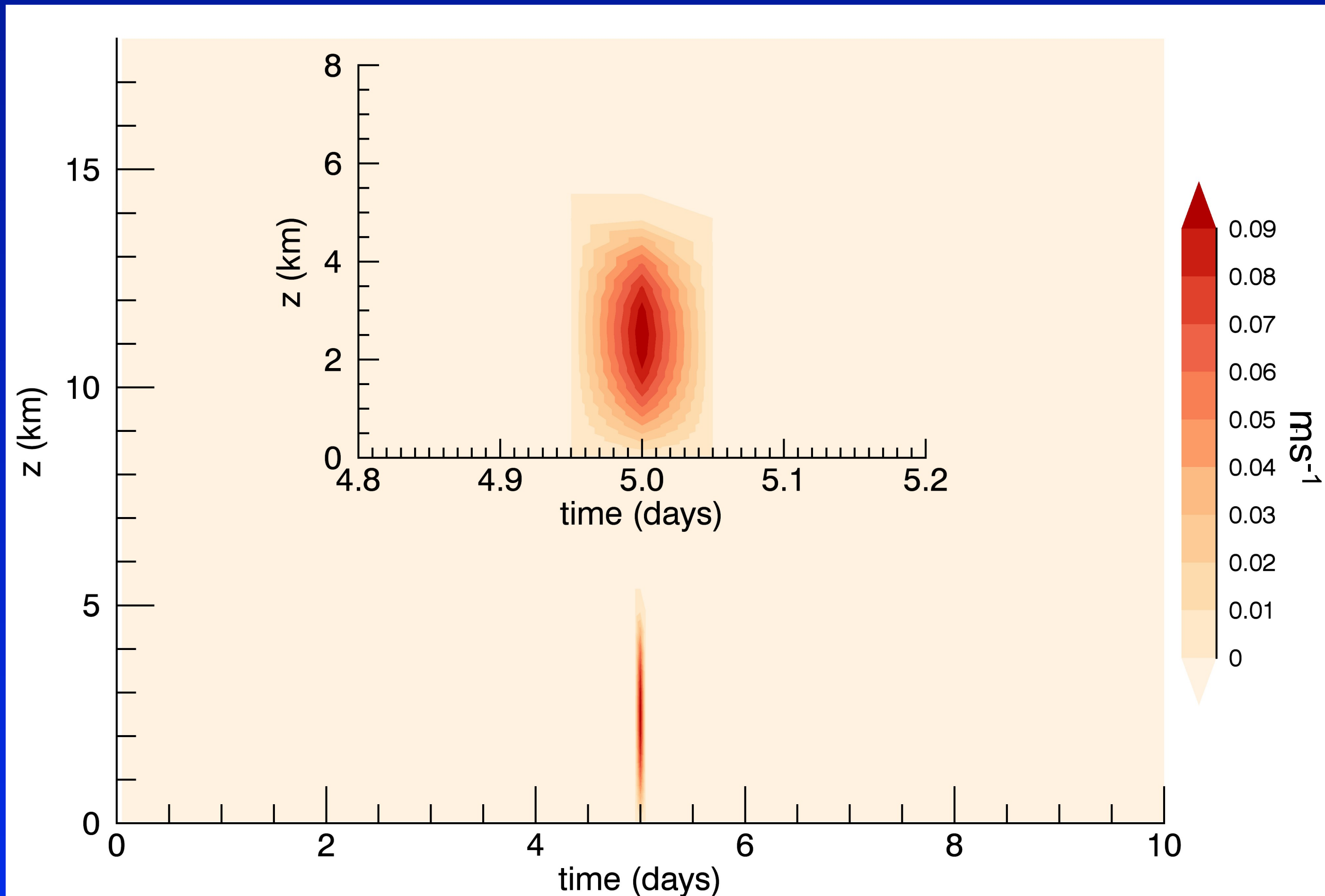
Specify w & T_{ref}, q_{ref}

CSRM given same large-scale forcing across domain setups

$$\frac{\partial T}{\partial t} = w\left(\frac{\partial T_{ref_{128}}}{\partial z} - \frac{g}{c_p}\right) + \left(\frac{\partial T_{conv}}{\partial t}\right) - \varepsilon_T$$

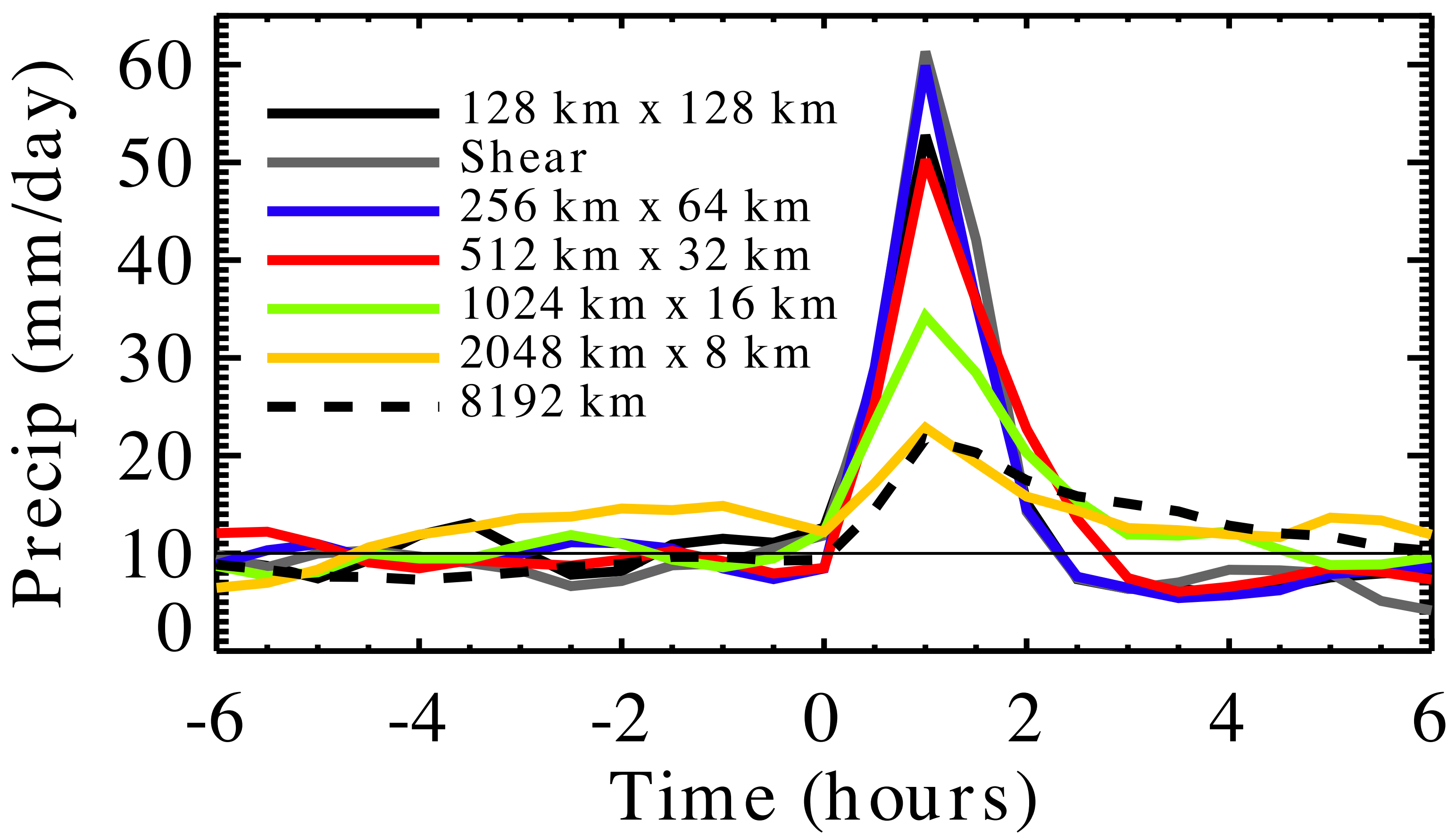
$$\frac{\partial q}{\partial t} = w\left(\frac{\partial q_{ref_{128}}}{\partial z}\right) + \left(\frac{\partial q_{conv}}{\partial t}\right) - \varepsilon_q$$

Specified large-scale w profile



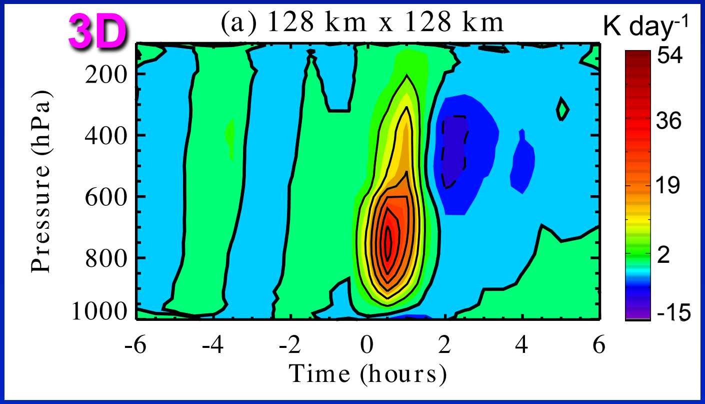
- **Vertical velocity chirp**
- **1-hr positive burst balanced by subsidence spread evenly over remaining time of 10-day period**
- **7 ensemble members**

Ensemble avg. precipitation response to specified large-scale vertical velocity



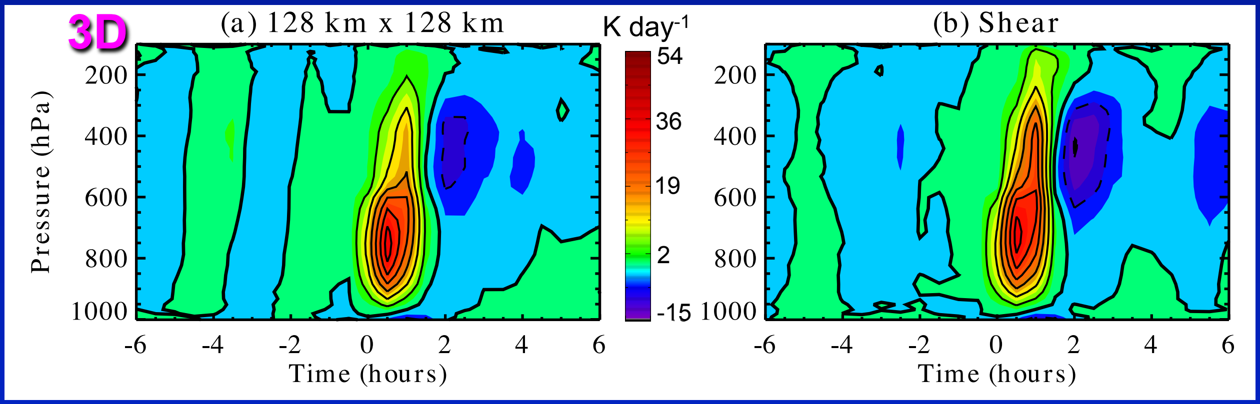
- **Systematic decrease in prec max beyond 256 km x 64 km domain**

Ensemble avg. convective heating anomalies to specified large-scale vertical velocity



- Each contour 6 K day^{-1}
- Thick line is zero contour
- Integral over 10-day period is zero

Ensemble avg. convective heating anomalies to specified large-scale vertical velocity



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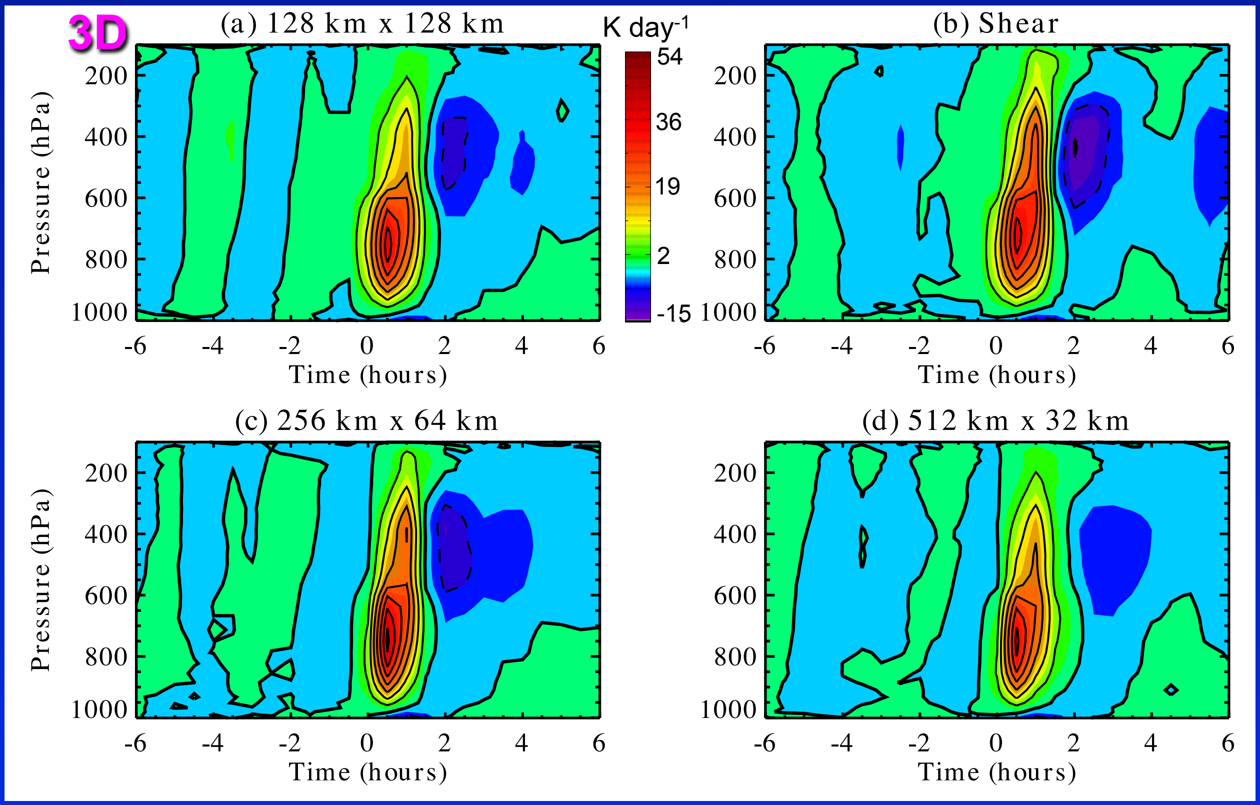
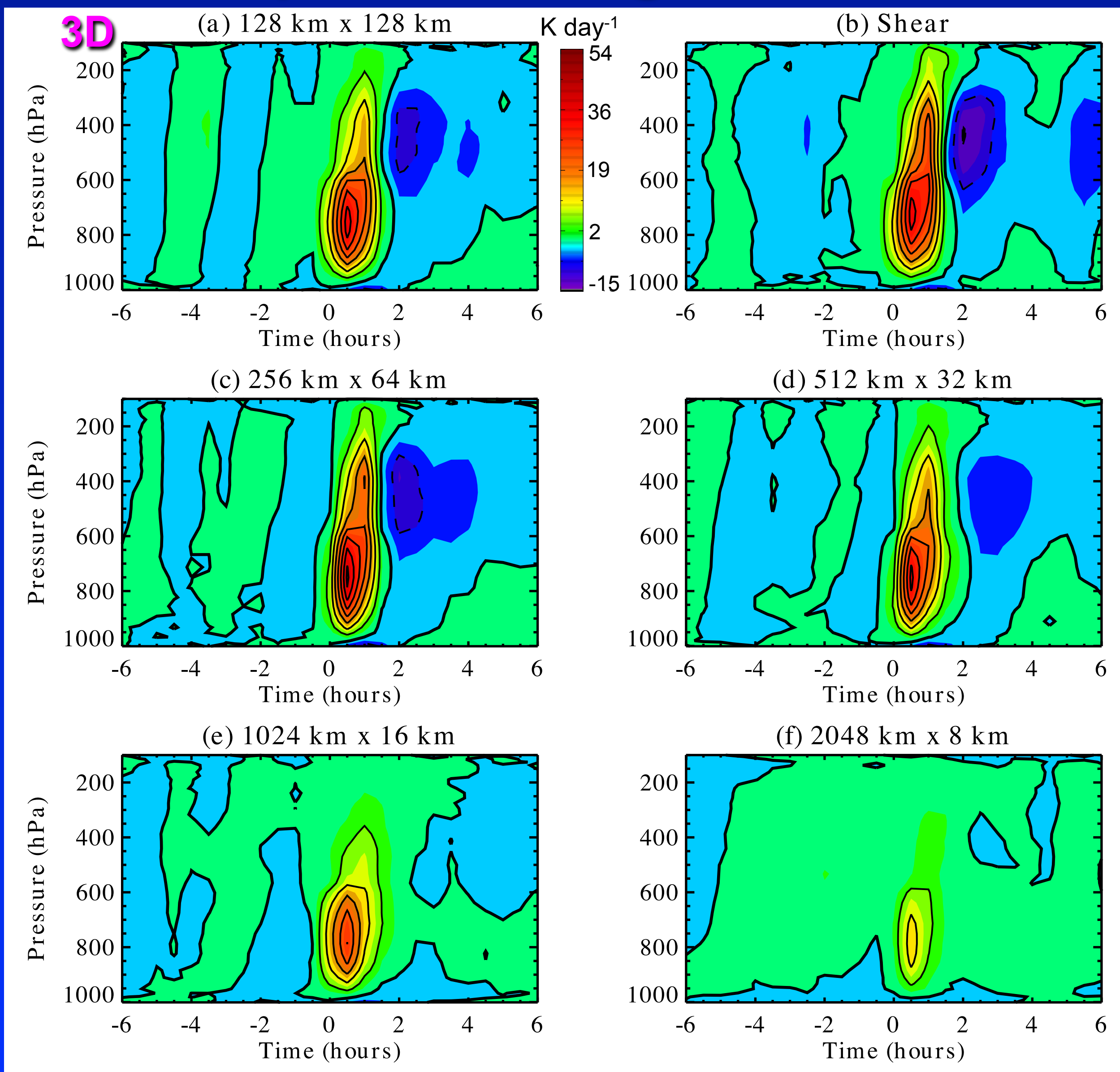
Ensemble avg. convective heating anomalies to specified large-scale vertical velocity



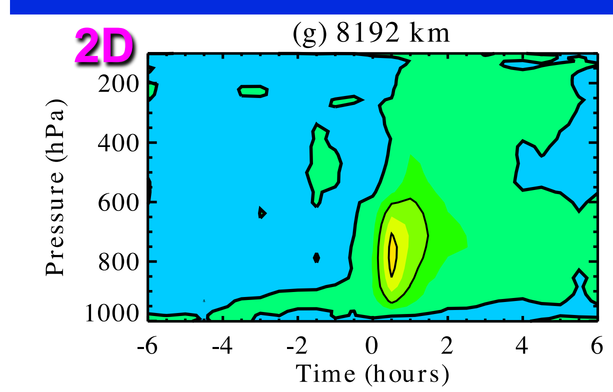
- Each contour 6 K day^{-1}
- Thick line is zero contour
- Integral over 10-day period is zero

Ensemble avg. convective heating anomalies to specified large-scale vertical velocity

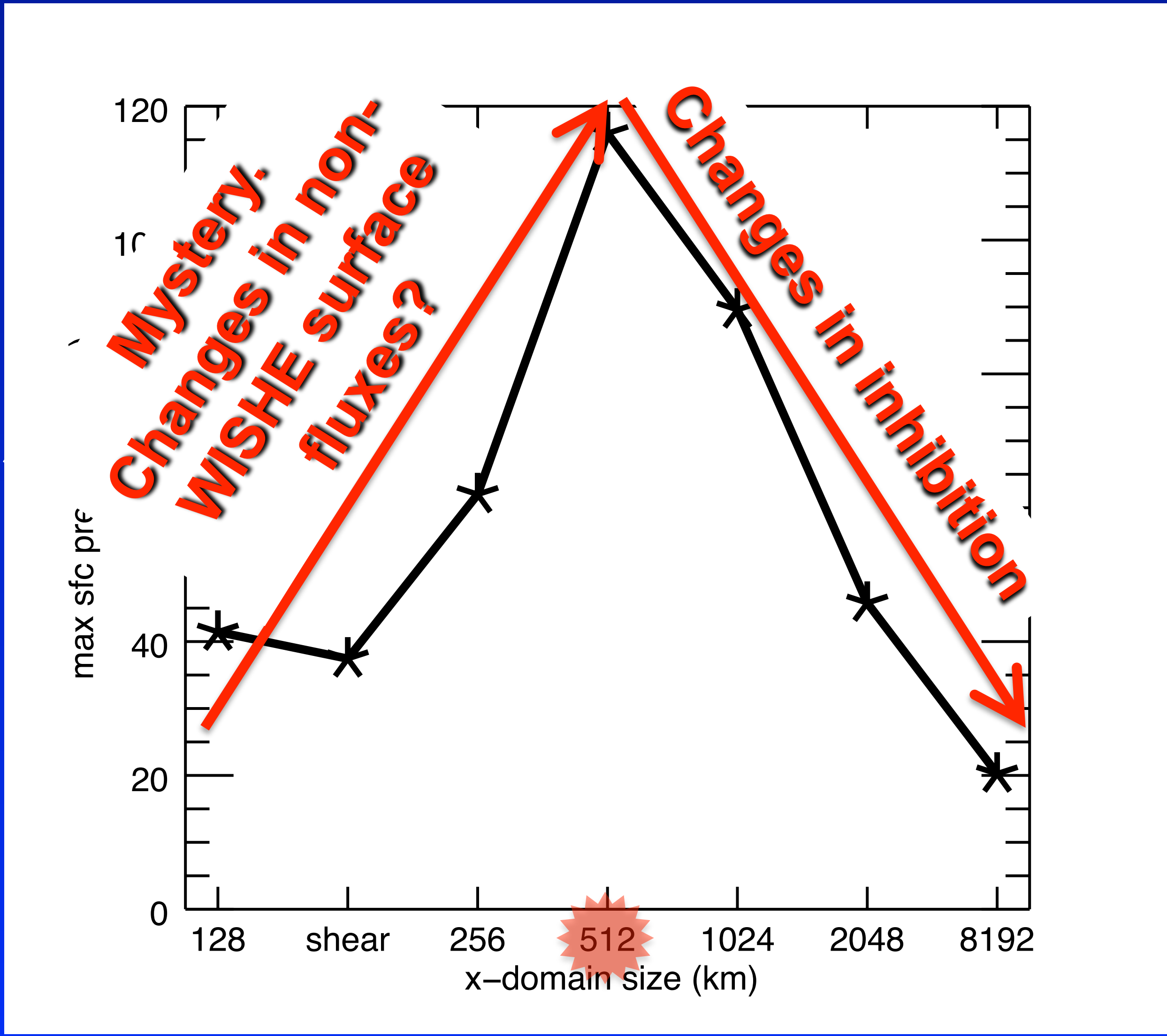


- **Q1 weakens and localizes from 3D -> 2D**
- **3D more inhibited**

- Each contour 6 K day^{-1}
- Thick line is zero contour
- Integral over 10-day period is zero



Domain Shape vs. Max Precip



Can we understand the 512 km x 32 km optimum?

Summary & Conclusions

- **Shear simulations results:**
  - Convective squall lines
  - Shear and non-shear runs similar in 3D isotropic domain
- **Change in domain shape results:**
  - Infinite line of convective blobs spaced increasingly farther apart
  - 512 km x 32 km optimum (i.e. largest post-coupled precip.)
- **Mean state sensitivity experiments:**
  - Coupled system indifferent to changes in background mean state
- **Prescribed large-scale w experiments:**
  - 3D more inhibited than 2D – more intense, both local & non-local convective heating response
- **Organization via *shear* and *degree of "2D-ness"* give *different* convective oscillations for the coupled system.**

Ways Forward...

- SST forcing experiments like Wang and Sobel (2011)
- Larger 3D domains
- Different shear profiles
- Apply multiple k's in LS wave equation
- Superparameterization – full physics of large scale

Results robust to:

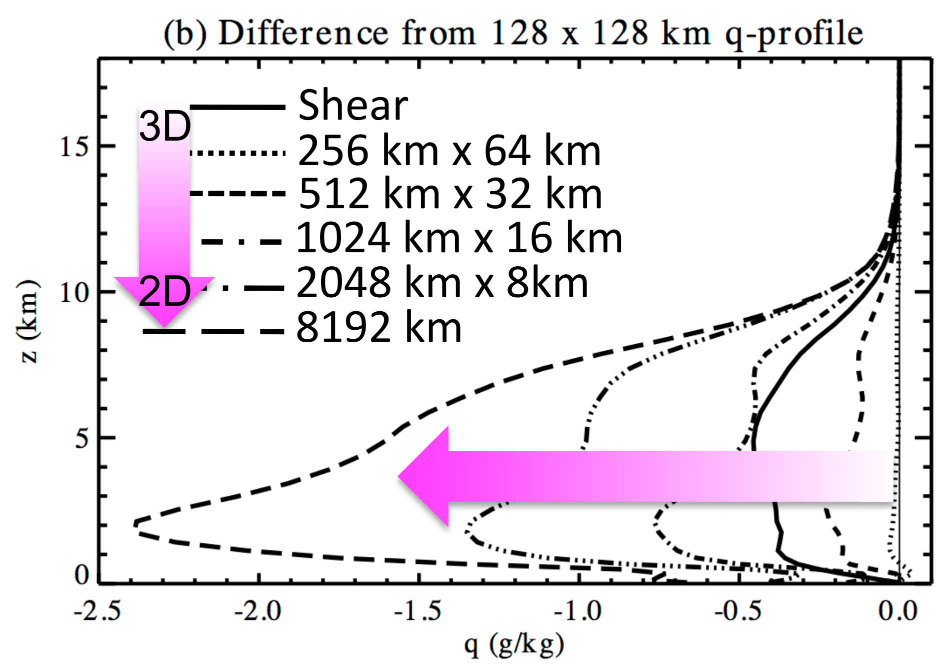
- 2,500 & 10,000 vs. 5,000 km large-scale λ
- 2- and 4-day vs. 10-day damping
- Different combos of u-, T-, and q-damping
- Large-scale w advecting $\overline{T}(z, t)$ & $\overline{q}(z, t)$
- Fixe… …change coef… …las
- Fixed rad profile from uncoupled intera… …alized rad profil…
- Backg… …OGA w- profil… …s domain- avera…

$$\frac{\partial^2}{\partial z^2}\left(\frac{\partial(\rho w)}{\partial t}\right) = -k^2 \rho g \left(\frac{T_v'}{T_{v\,ref}}\right) - \varepsilon \frac{\partial^2(\rho w)}{\partial z^2}$$

$$\frac{\partial T}{\partial t} = w\left(\frac{\partial T_{ref}}{\partial z} - \frac{g}{c_p}\right) + \left(\frac{\partial T_{conv}}{\partial t}\right) - \varepsilon_T$$

$$\frac{\partial q}{\partial t} = w\left(\frac{\partial q_{ref}}{\partial z}\right) + \left(\frac{\partial q_{conv}}{\partial t}\right) - \varepsilon_q$$

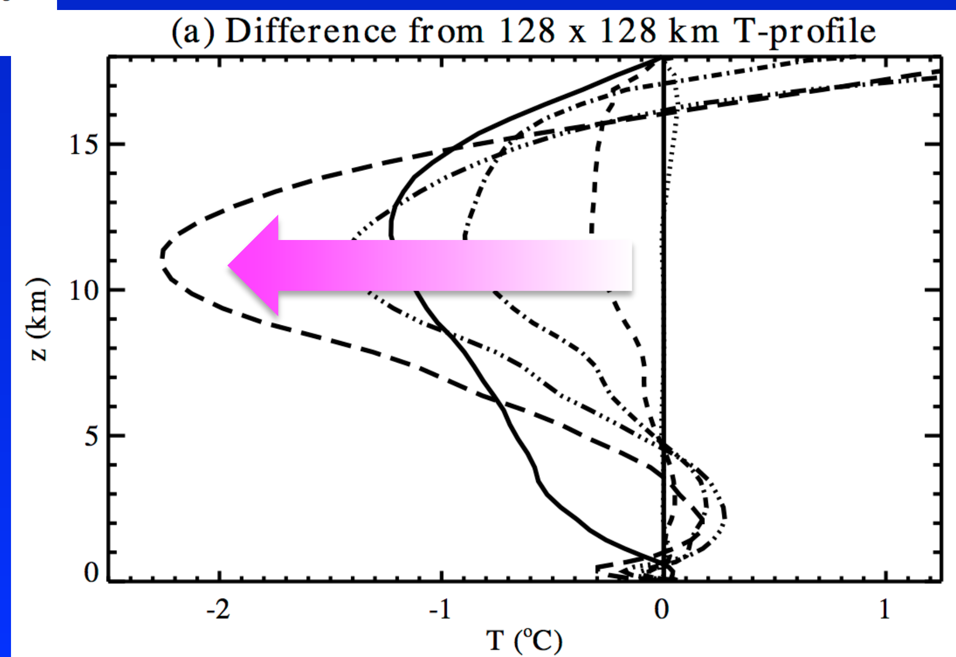
Mean State Sensitivity



- Comparing the average over the last 50 days of a 100 day *uncoupled* run in indicated domain set-up to 128 km x 128 km uncoupled average.

- Longer, narrower domains – drier, yet more unstable (in vertically averaged sense)

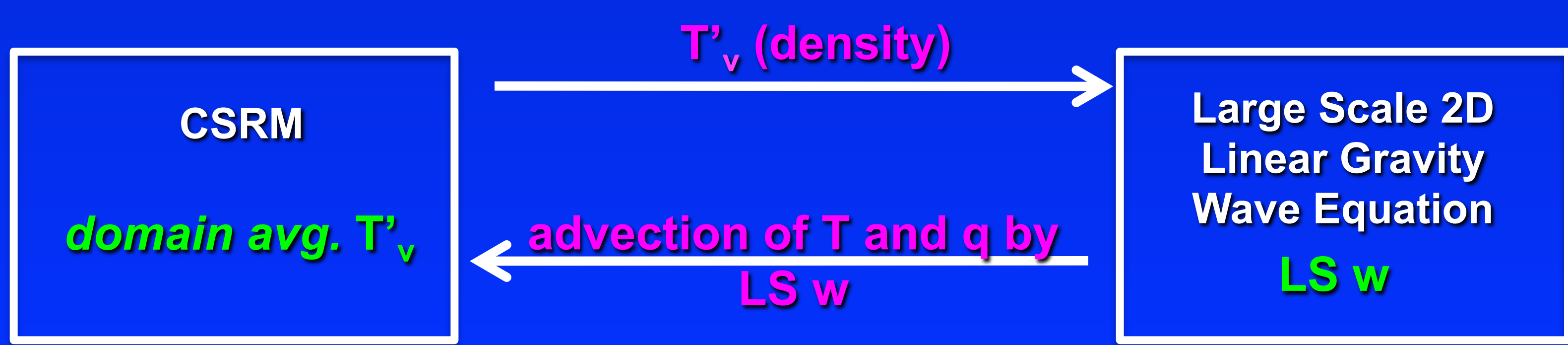
- **Perhaps stretched domains too dry to support convectively coupled waves.**



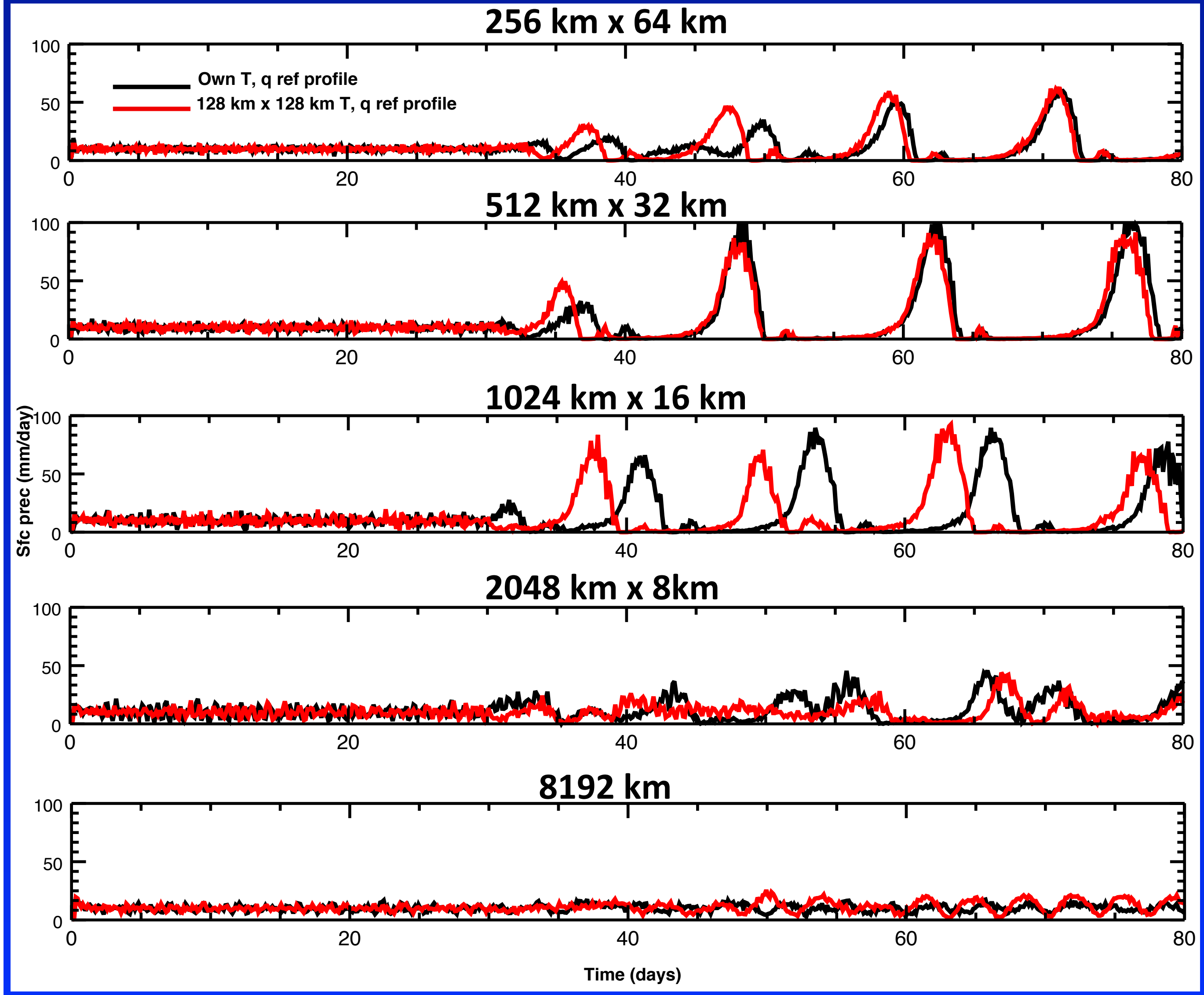
Are changes in precipitation oscillation magnitude due to mean state differences vs. form of convection?

$$\frac{\partial^2}{\partial z^2}\left(\frac{\partial(\rho w)}{\partial t}\right) = -k^2 \rho g\left(\frac{T_v'}{T_{v\,ref_{128}}}\right) - \varepsilon \frac{\partial^2(\rho w)}{\partial z^2}$$

$$T_v'(z) = \overline{T}_{v\,CRM}(z,t) - T_{v\,ref_{128}}(z)$$



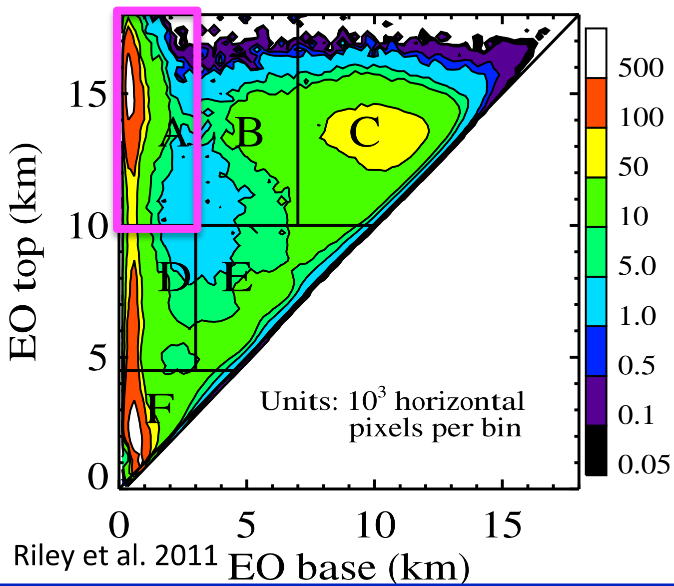
128 km x 128 km uncoupled sounding in each domain setup



- Domains got moister sounding than they would otherwise compute
- Indifferent to specified $T_{v\ ref}$ profile
- *Coupled system adjusts to foreign snd.*

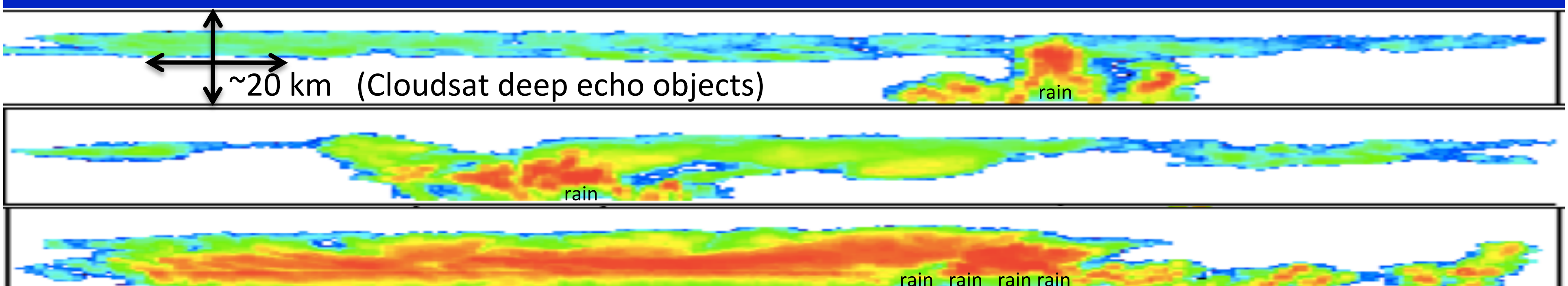
Glimpse form-function relationship with CloudSat

Organized vs. Unorganized (Wide vs. Narrow)

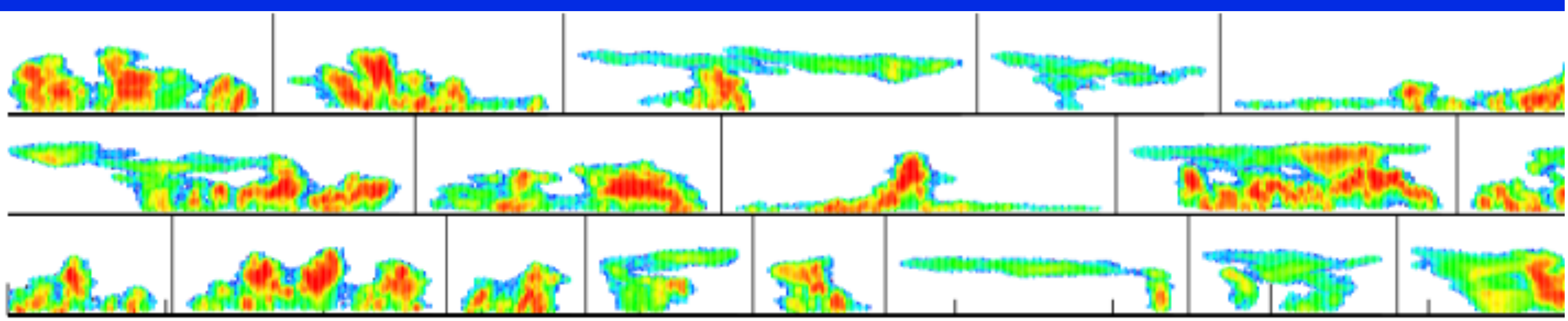


Riley et al. 2011

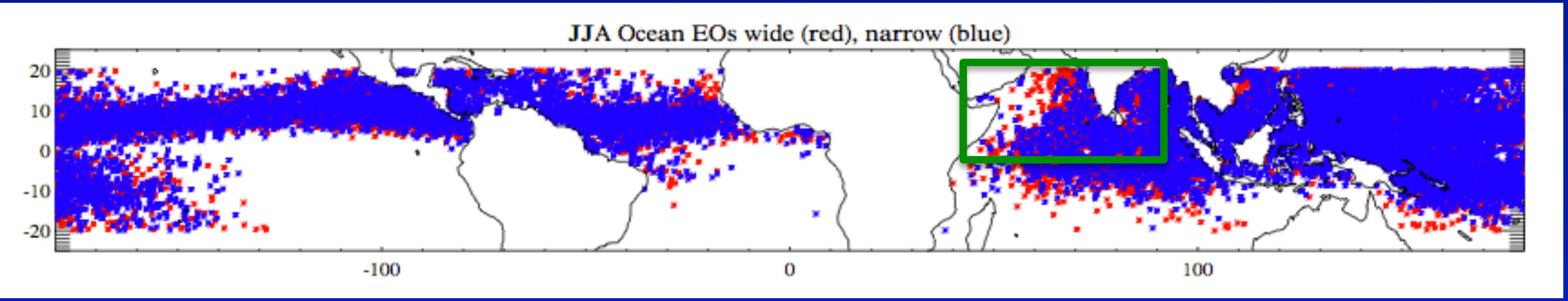
Width > 200 km

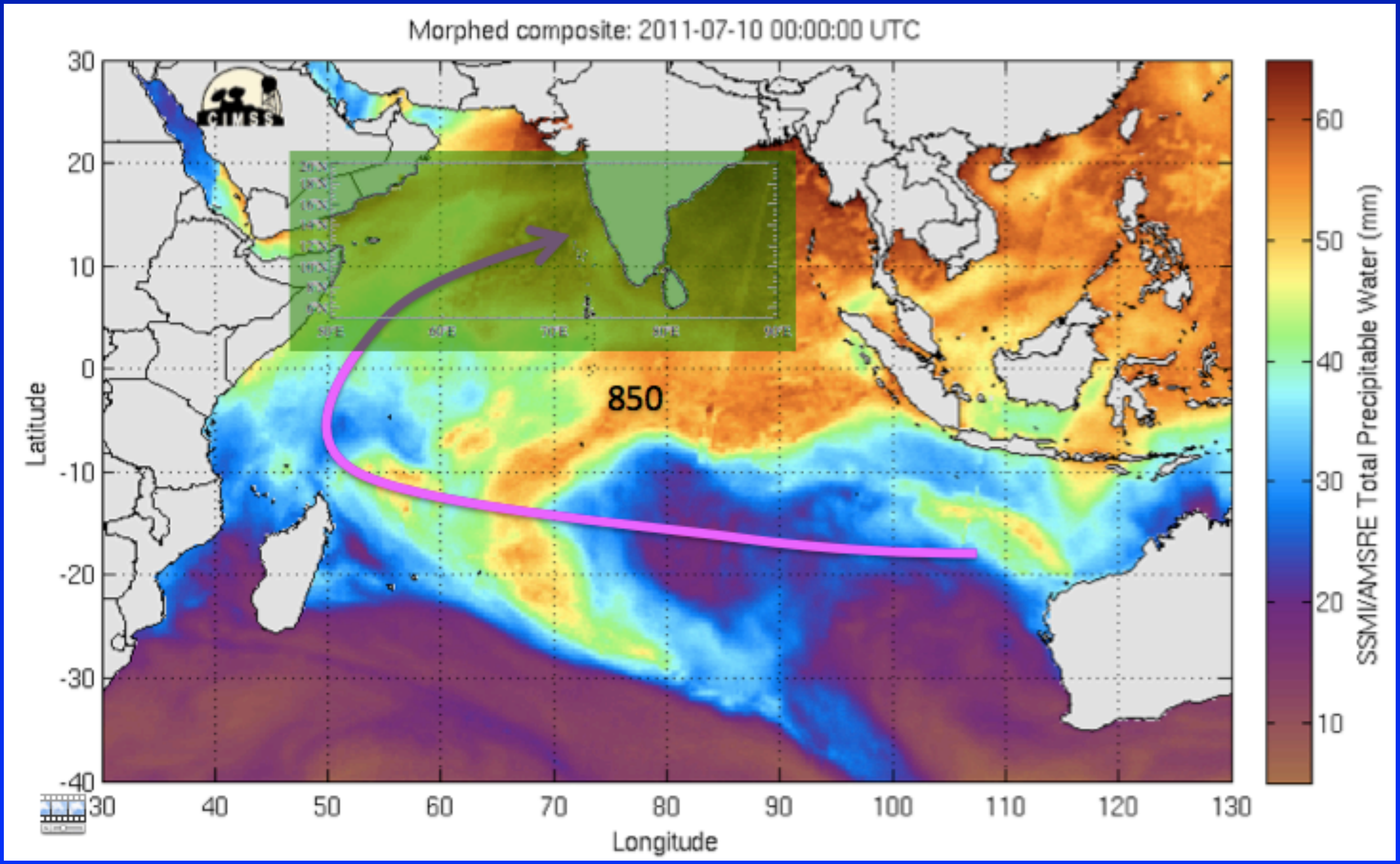


Width ≤ 200 km



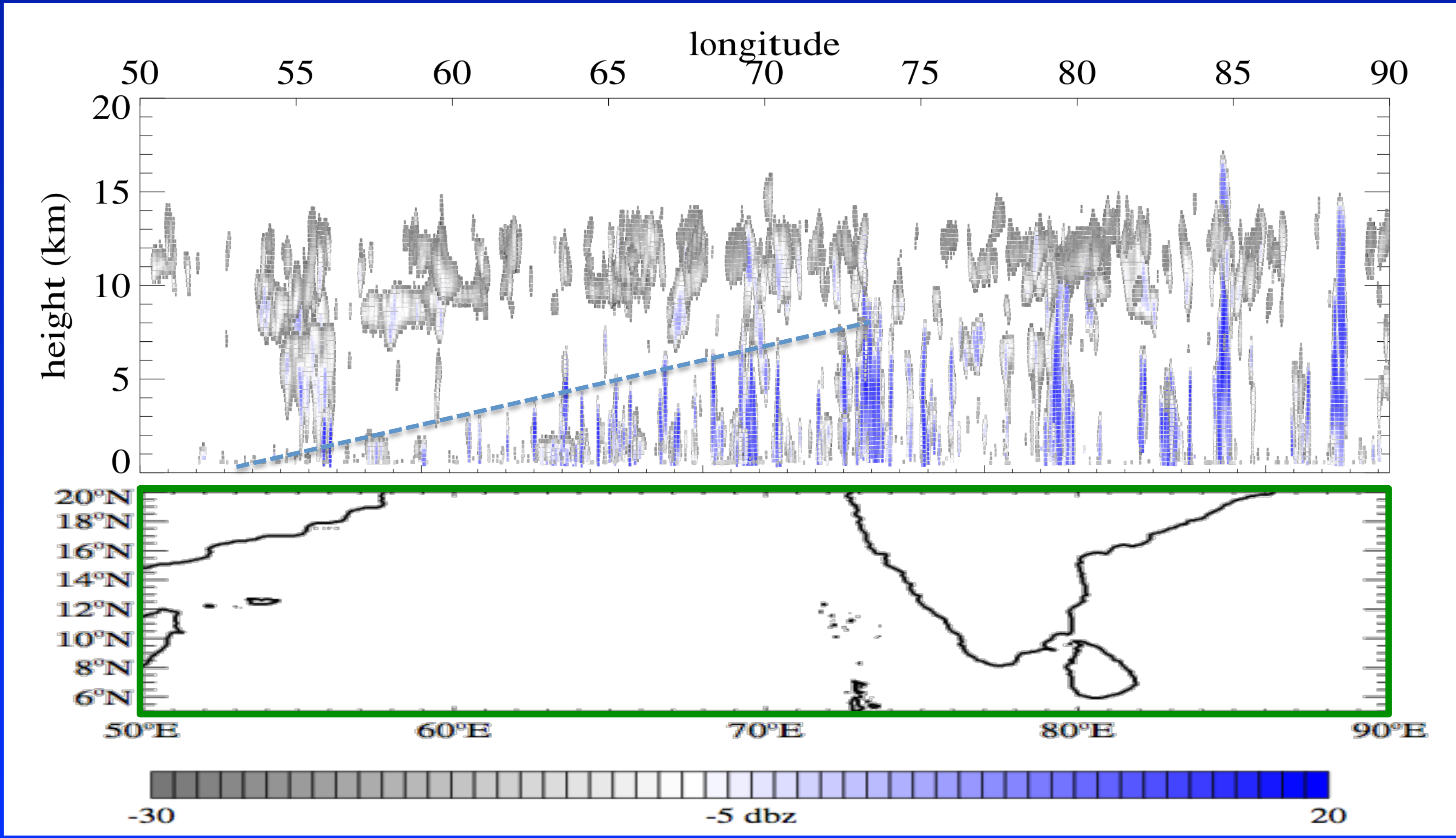
Mean lat, lon of wide (red) and narrow (blue) EOs





- Column water vapor (MIMIC) shows summertime low-level flow

Representative summer 2006-9 cloudsat radar echo objects <200km in horizontal width



now with >200km ones in red

Organization (wide cbs) prevails in environment that generally favors suppressed convection