

Toward form-function relationships
for multicellular/ organized convection

or maybe

Toward a moist dynamics that takes
account of cloud systems

(review/ essay in prep. for JMSJ)

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Motivation

- **Disconnect** between detailed observations and large-scale desires that justify them
 - Observations are 4+ dimensional (xyzt +scales)
 - full of rich mesoscale texture (cloud systems)
 - How can observations of all this truly inform understanding and modeling?

Example: mixing in convection

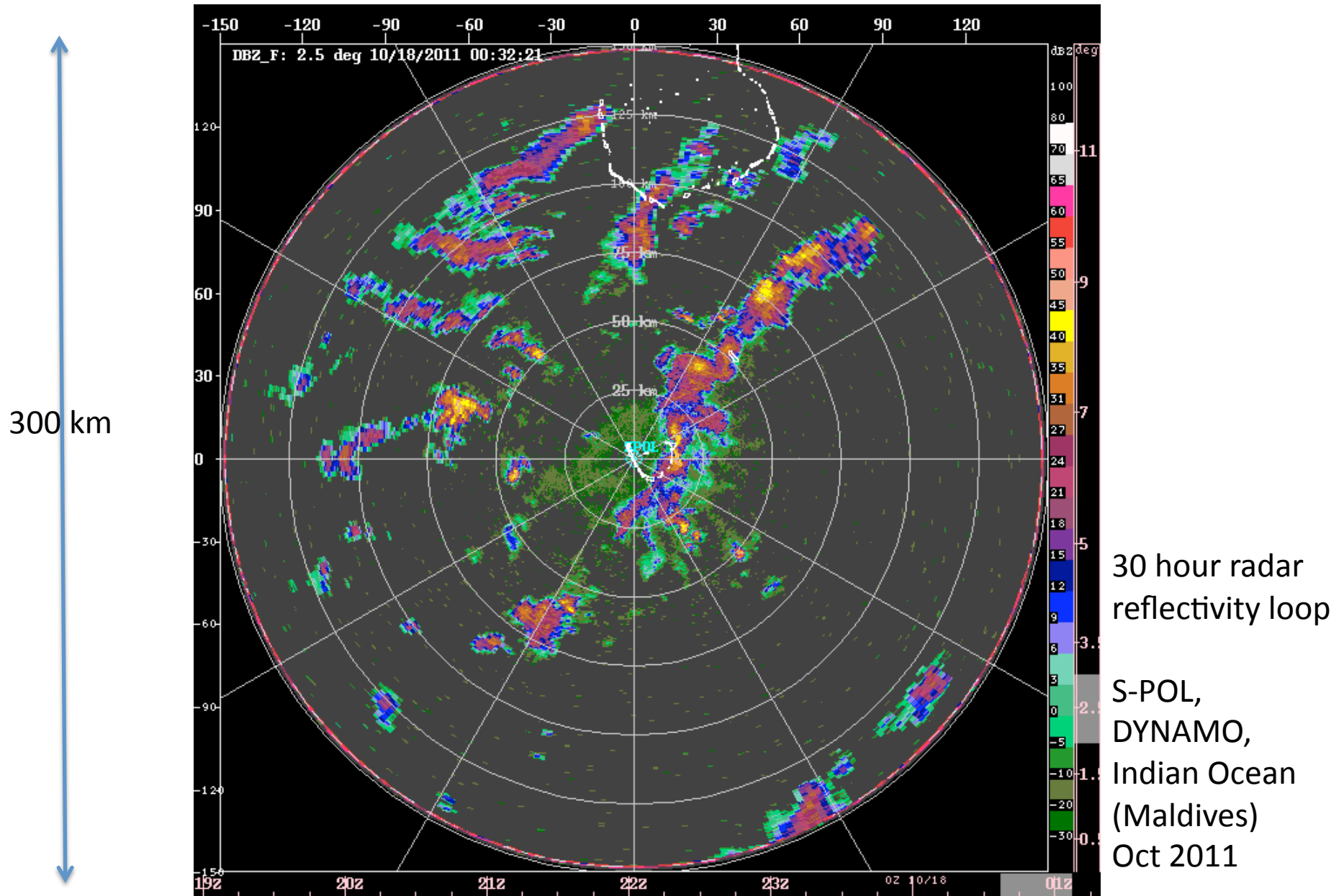


Brooks Salzwedel **Plume #1** 2009 12" x 8" Mixed Media

“The authors identify the entrainment rate coefficient of the convection scheme as the most important single parameter... [out of 31]...[for]... HadSM3 climate sensitivity”

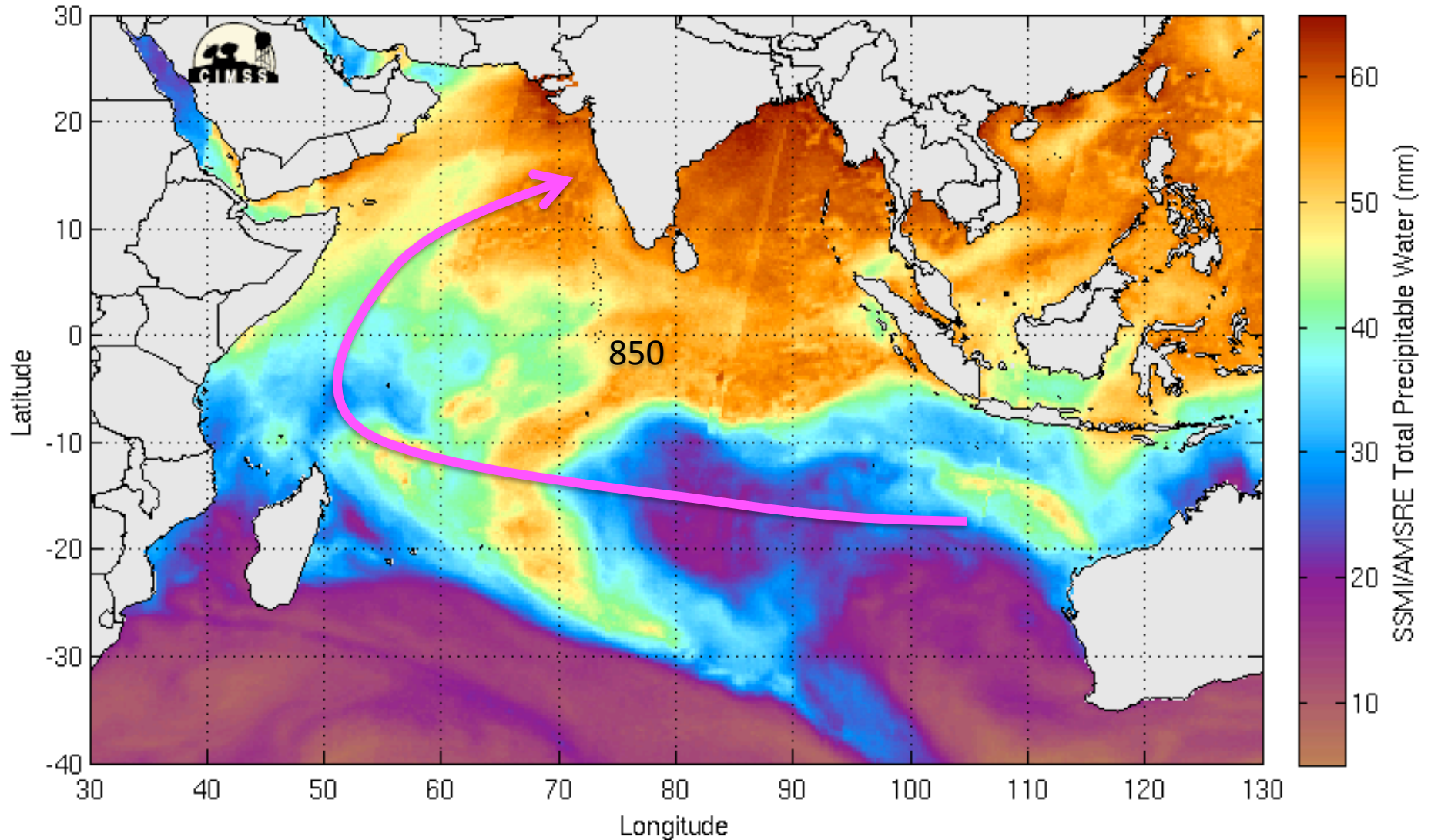
Rougier et al. 2009, *J.Clim.*
doi:10.1175/2008JCLI2533.1.

Find me the entrainment coefficient



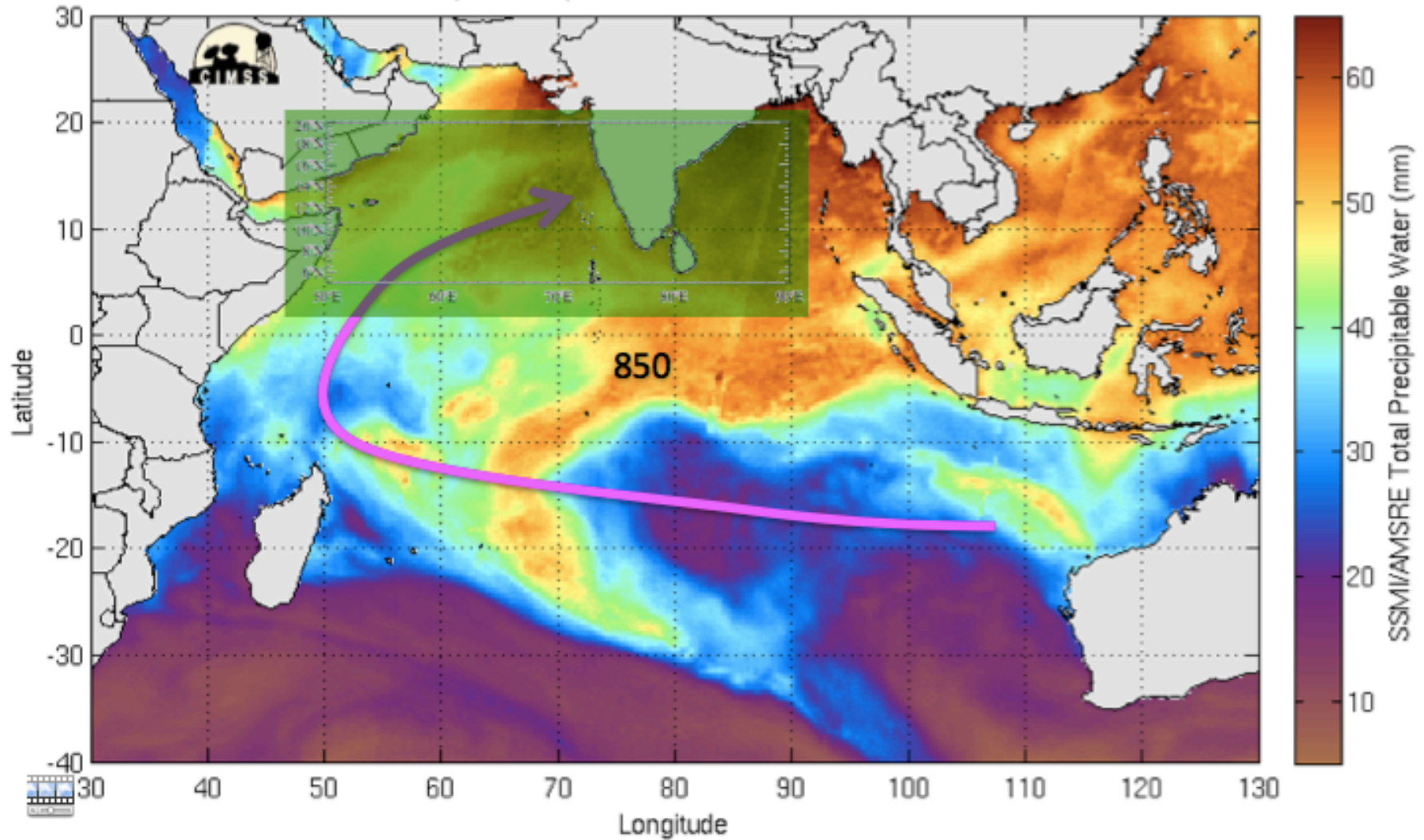
Column water vapor (MIMIC) shows summertime low-level flow

Morphed composite: 2011-07-10 00:00:00 UTC

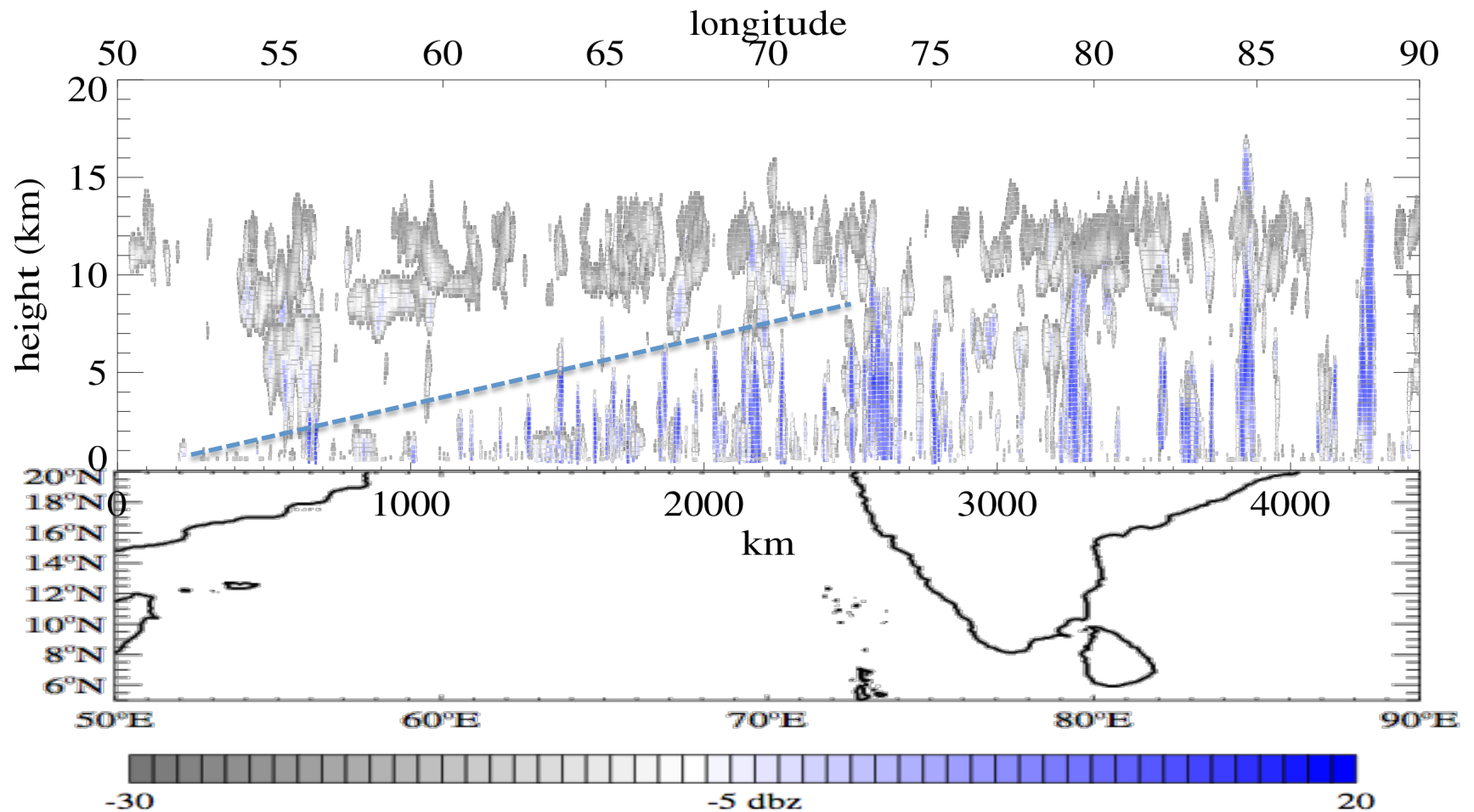


Column water vapor (MIMIC) shows summertime low-level flow

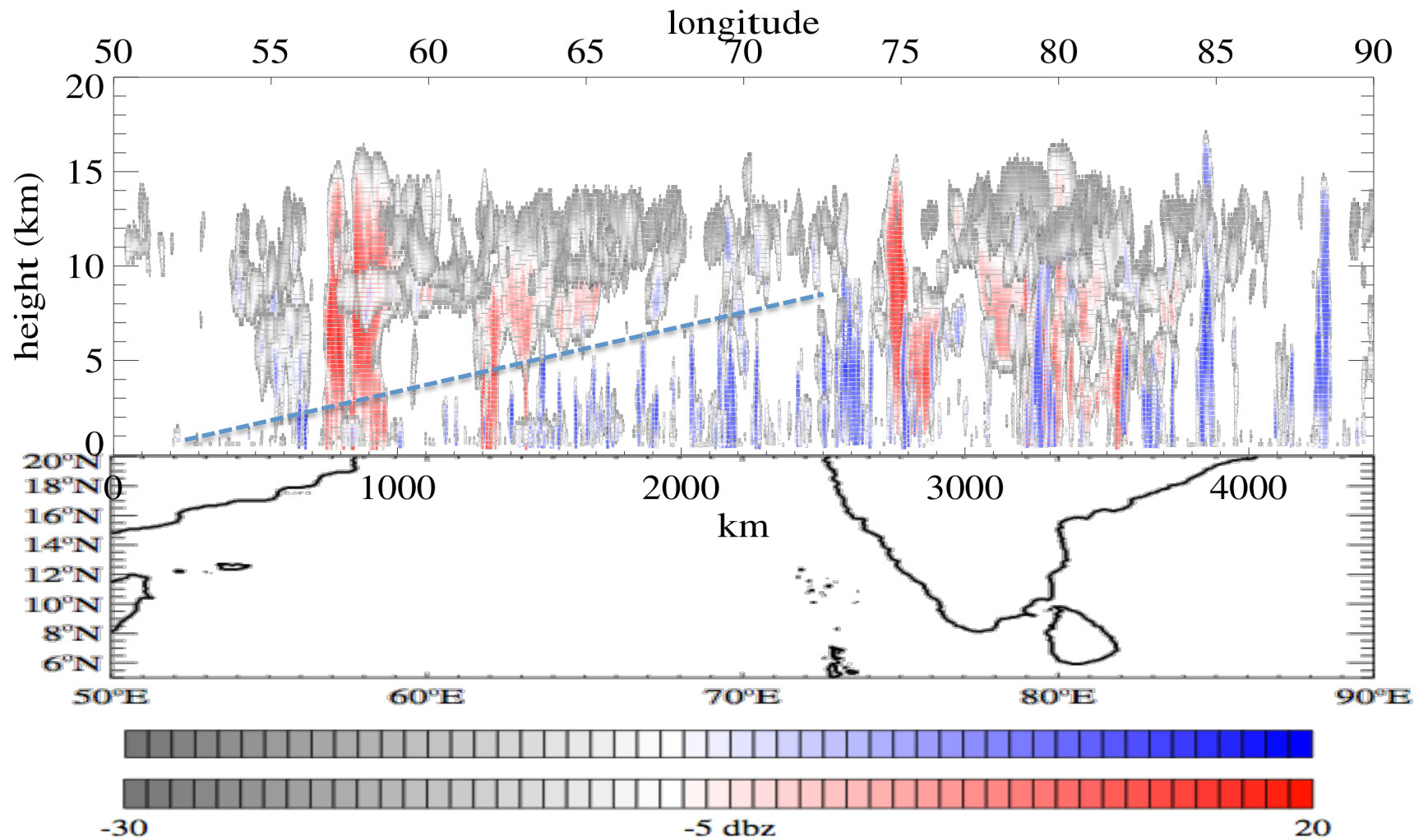
Morphed composite: 2011-07-10 00:00:00 UTC



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

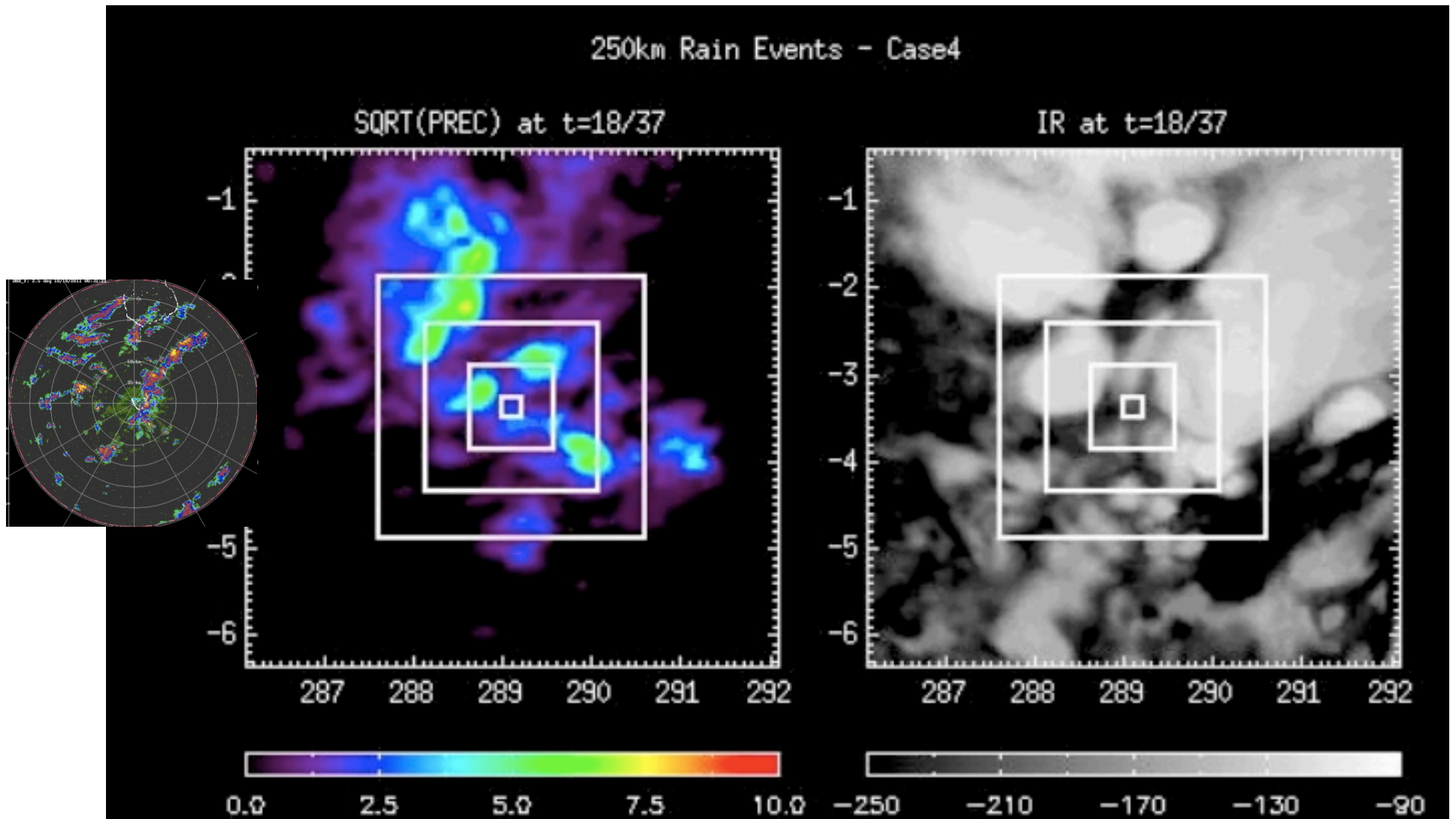


now with >200km ones in red



Models have mesoscales too. So what?

GEOS-5 5km mesh (!) global model



Runs: Putman & Suarez (2011), NASA GSFC / Figs: Mapes, Song & Putman, in prep.

An organ-ized set of cells

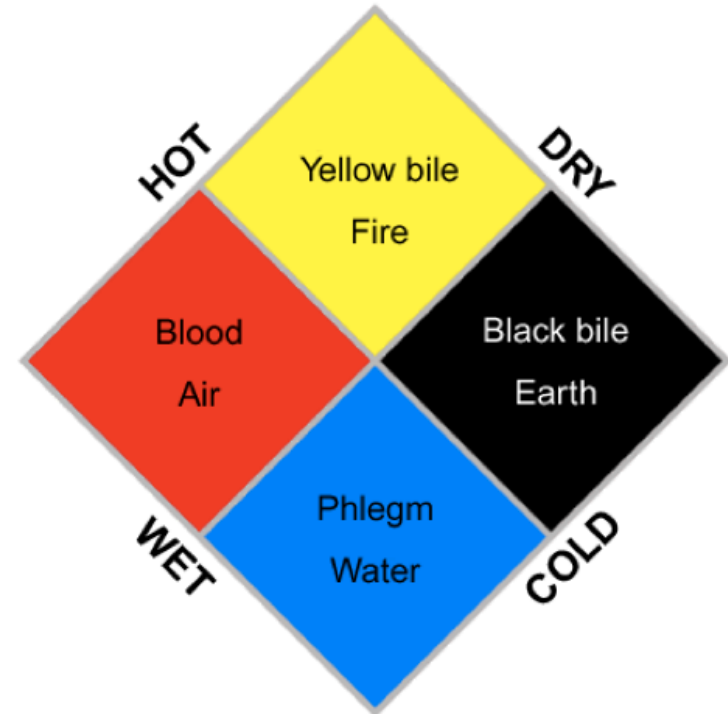
from Gk. *organon* "implement", lit. "that with which one works," from PIE...

We know a lot about
form...



The Anatomy Lesson of Dr. Nicolaes Tulp
Rembrandt 1632

...but
not enough about
function



medicine in the 1600s

Connecting form to function

- Definitions & measures of *function*
 1. **Offline** diagnostic: sensitivity matrix
 2. **Test-harness** performance: column with parameterized large-scale dynamics
 3. **Inline**: super-param (vs. under-resolved)

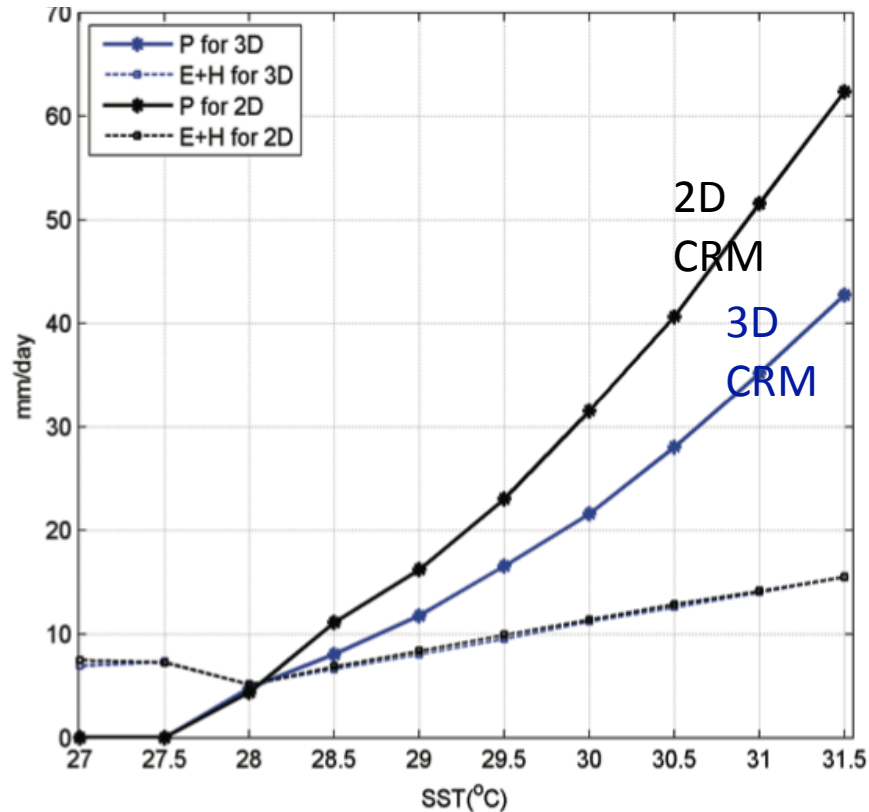


- Ways to control for *form*
 - **Domain size and shape**; vertical wind shear
 - Conditional sampling (a route for using obs?)

Hypothesis: more organized convection *couples more strongly to large scales* e.g. more-2D vs. isotropic 3D

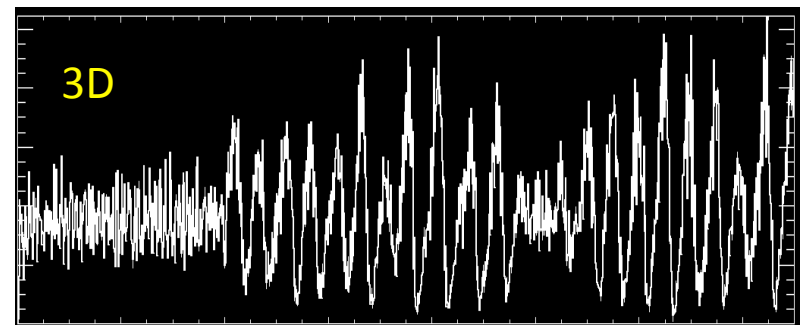
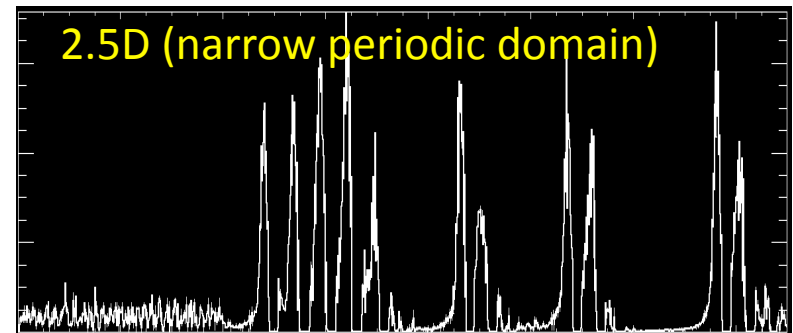
in 'parameterized LSD' test harnesses for periodic CRMs

WTG harness for CRM



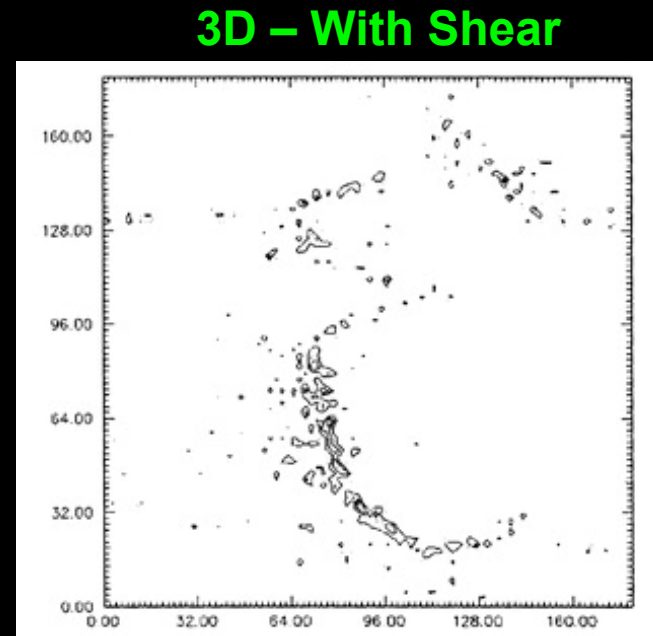
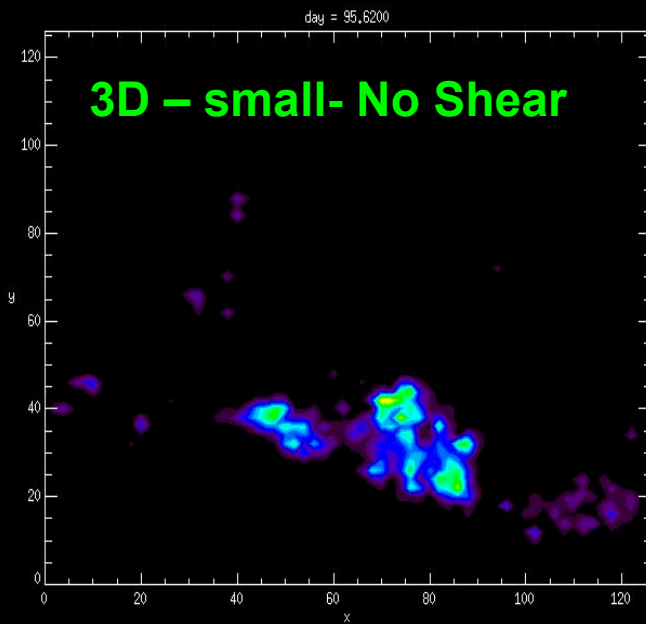
Wang and Sobel 2011

Linear gravity wave coupling (Kuang 2010)



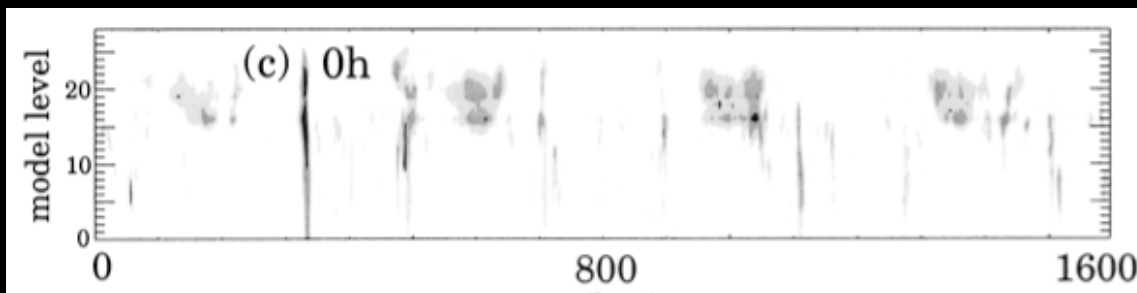
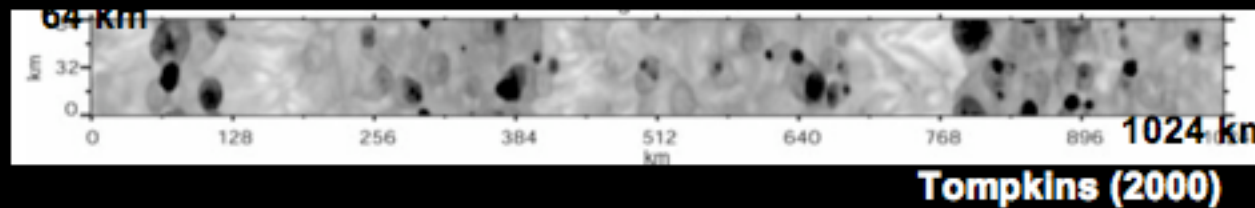
Riley, Mapes, Kuang – in prep.

Organization: A 2D-3D continuum?



Robe and Emanuel 2001

“2.5D” LONG 3D doubly periodic



Strict 2D
Mapes (2004)

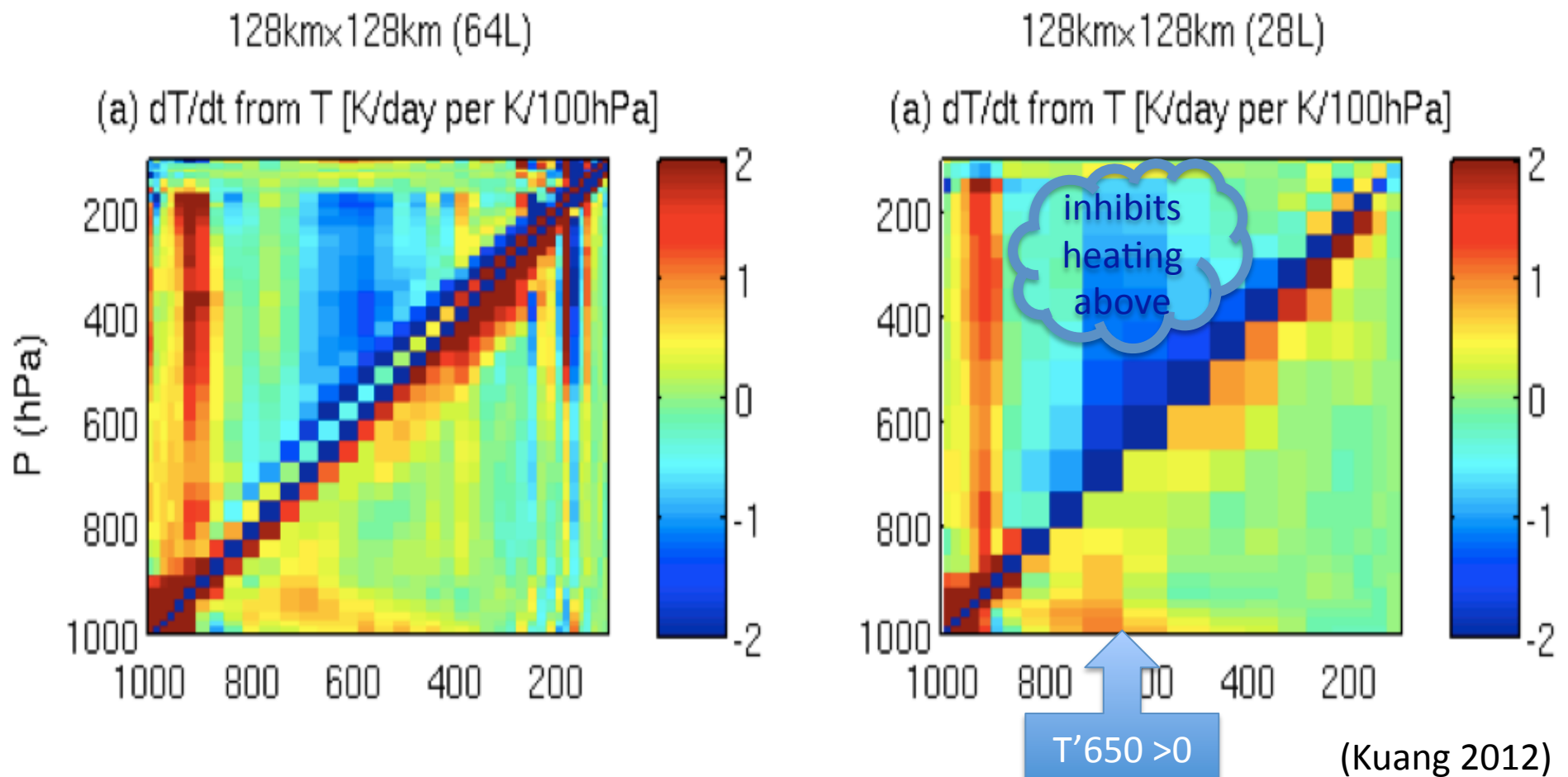
Linear response function (or sensitivity matrix) \mathbf{M}

$$\begin{bmatrix} \dot{T}_{CRM}(p) \\ \dot{q}_{CRM}(p) \end{bmatrix} = [\mathbf{M}] \begin{bmatrix} T'(p) \\ q'(p) \end{bmatrix}$$

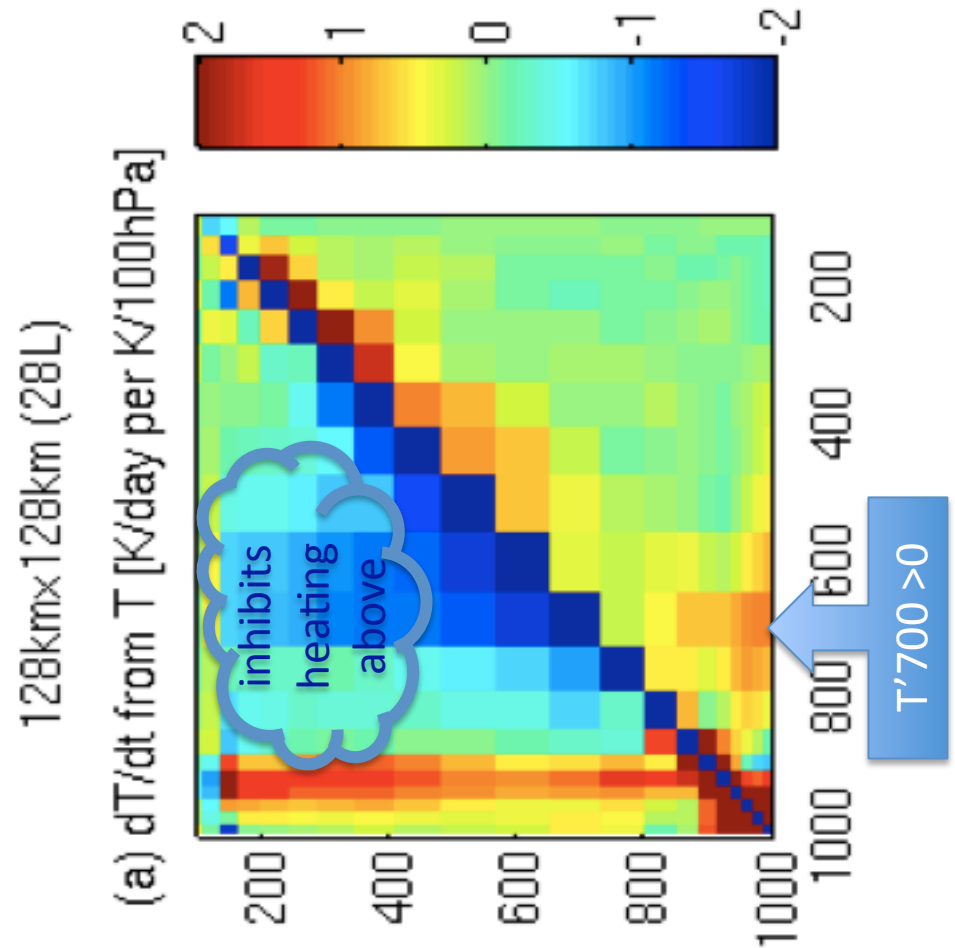
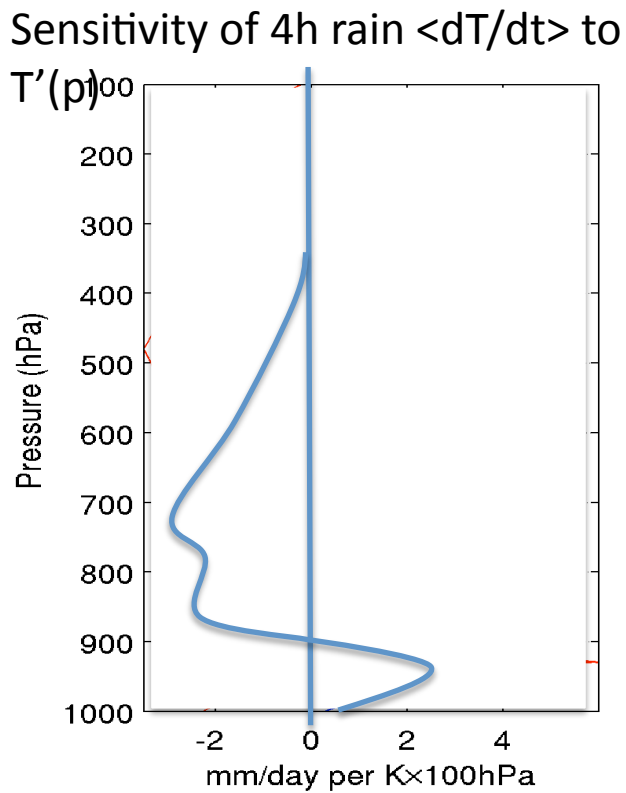
- Kuang (2010 JAS) devised one way to build it
 - using a set of long eq'm runs of a periodic CRM, with mild forcing perturbations that span the space (2NP runs)
 - build \mathbf{M} 's inverse this way, and do matrix inversion
 - edit small eigenvalues of \mathbf{M} (\rightarrow negative; it's a stable system)

Effect of T' on subsequent 4h heating p coordinates view

each built from >100,000 days of CRM time



Sensitivity of *column integrated* heating to T' at various pressure levels

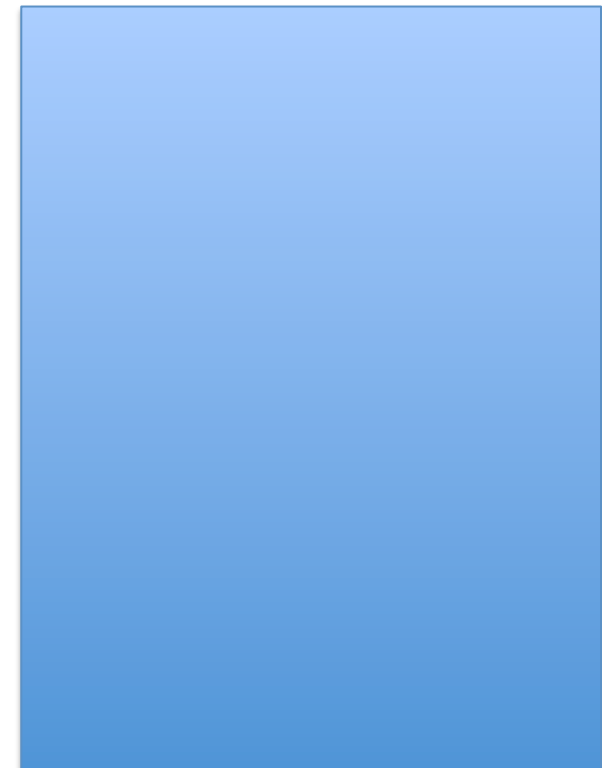
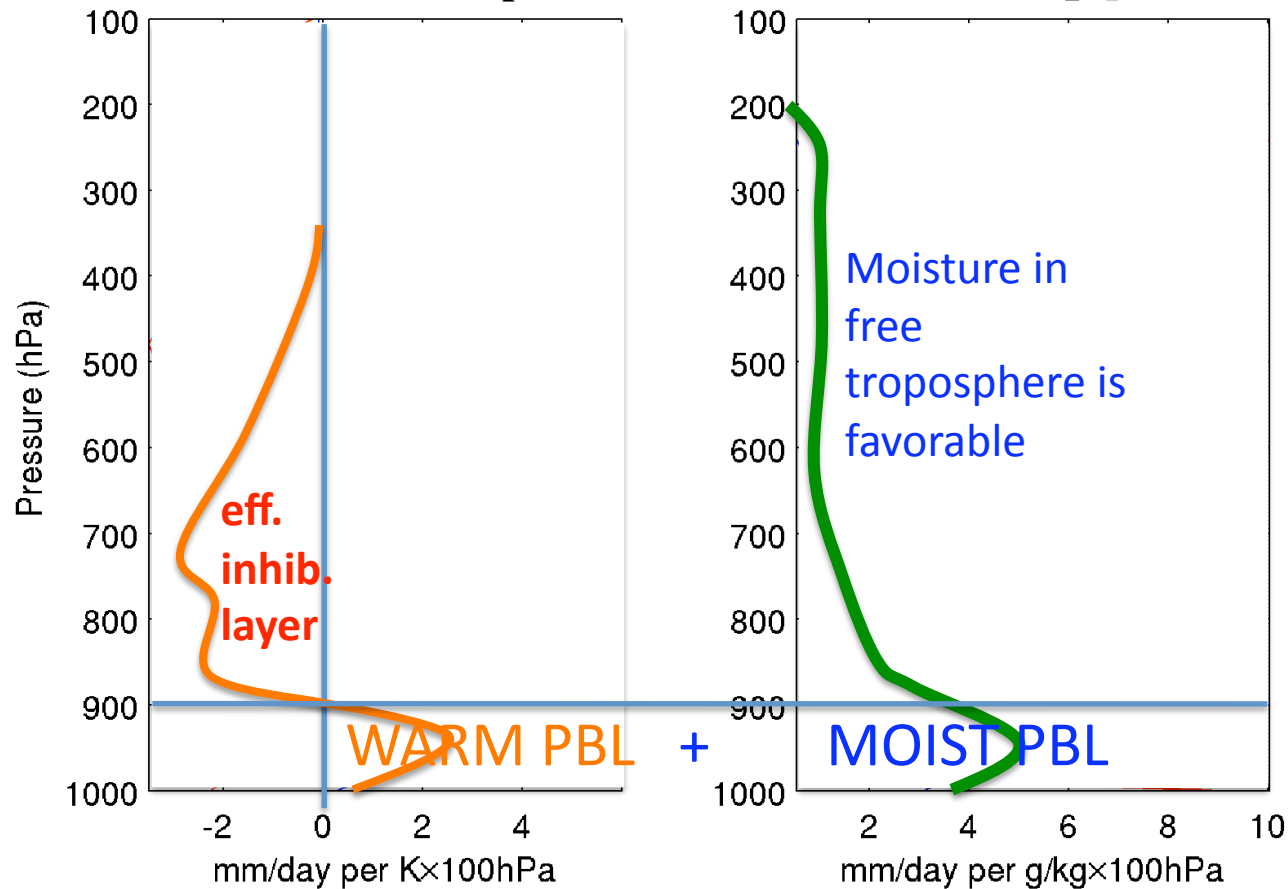


Sensitivity profiles: from 3D small CRM

$$S_T(p) = \frac{d\langle Q_1 \rangle_{next4h}}{dT(p)}$$

$$S_q(p) = \frac{d\langle Q_1 \rangle}{dq(p)}$$

$$S_{aer}(p) = \frac{d\langle Q_1 \rangle}{d[aerosol(p)]}$$

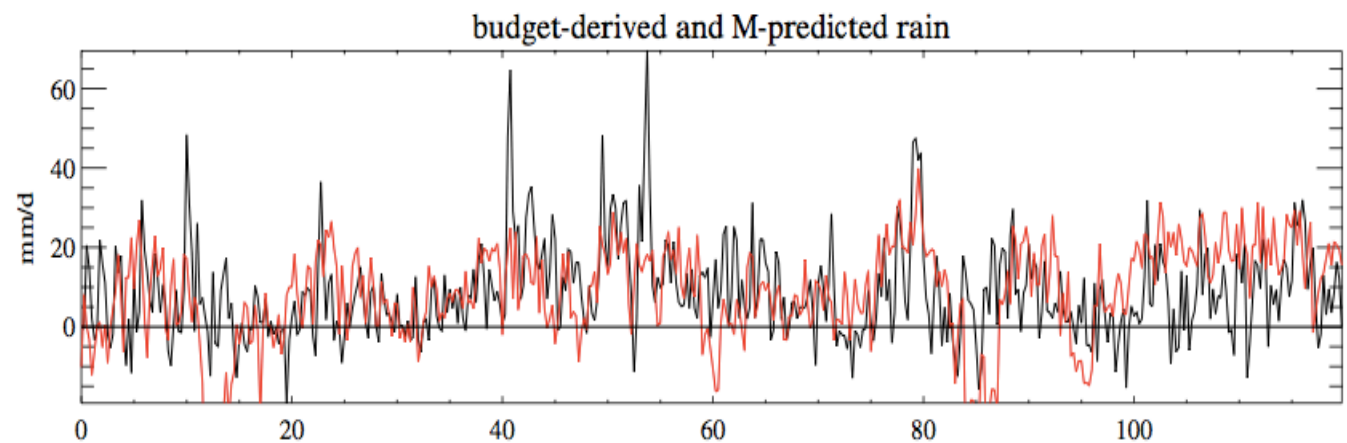
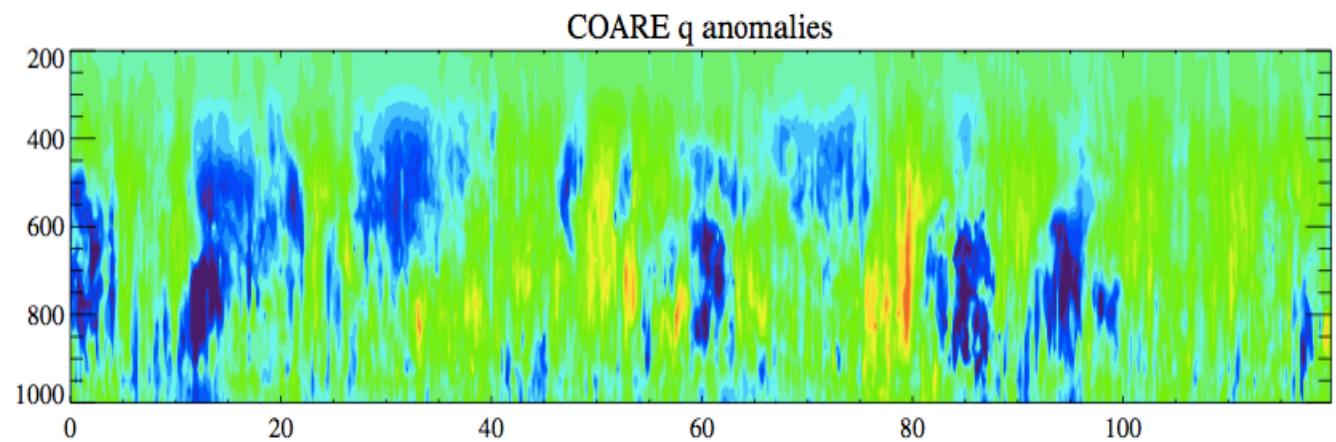
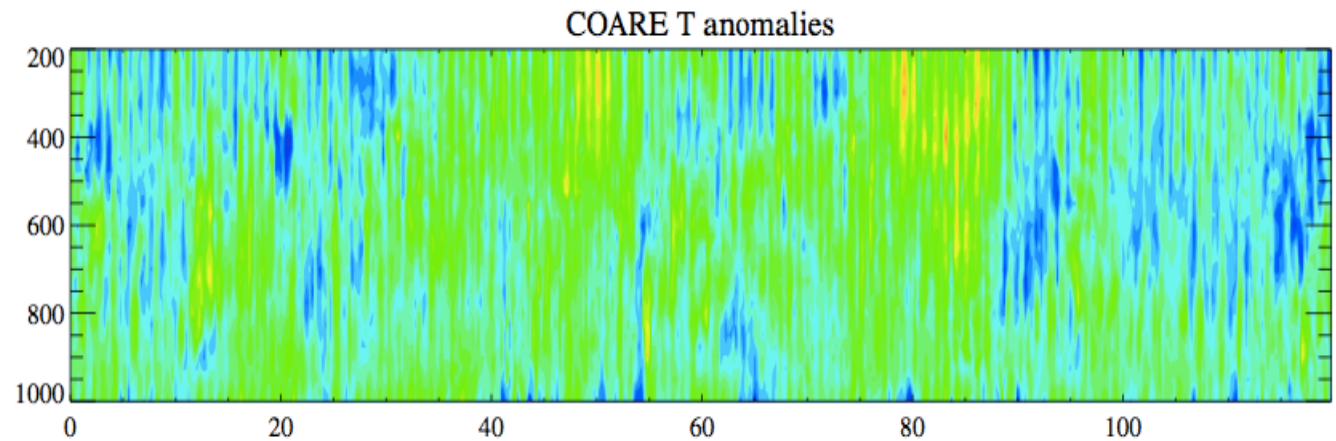


Computations: Kuang (2010) / Figs: Mapes and Kuang in prep.

Test of
 $\langle M \rangle$

COARE
sonde
array

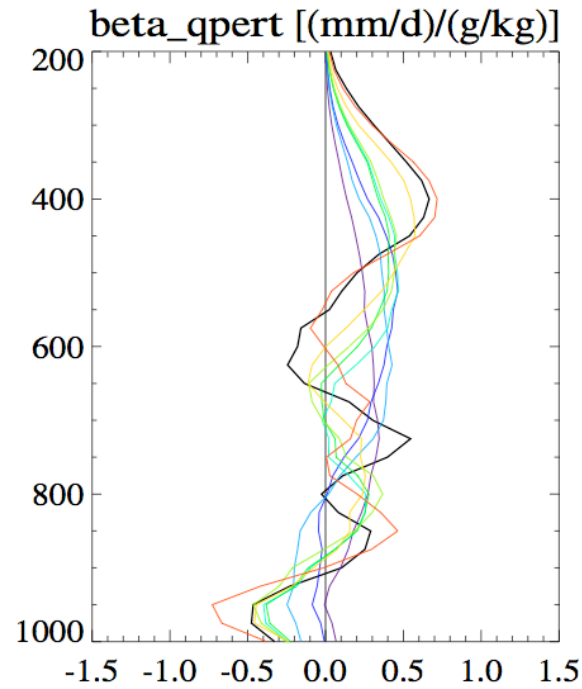
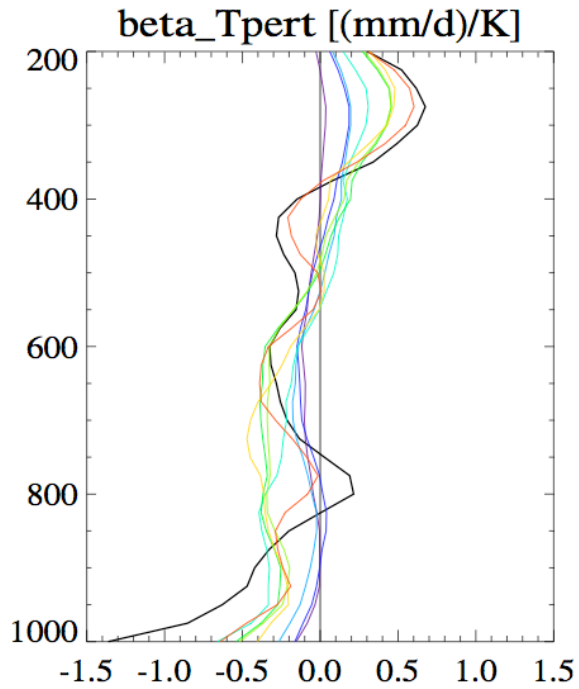
120d of
6h data



Or, try to estimate $\langle M \rangle$ by multiple linear regression

- Regress COARE budget-derived rainrate onto (first few EOFs of) $T'(p)$ and $q'(p)$ profiles

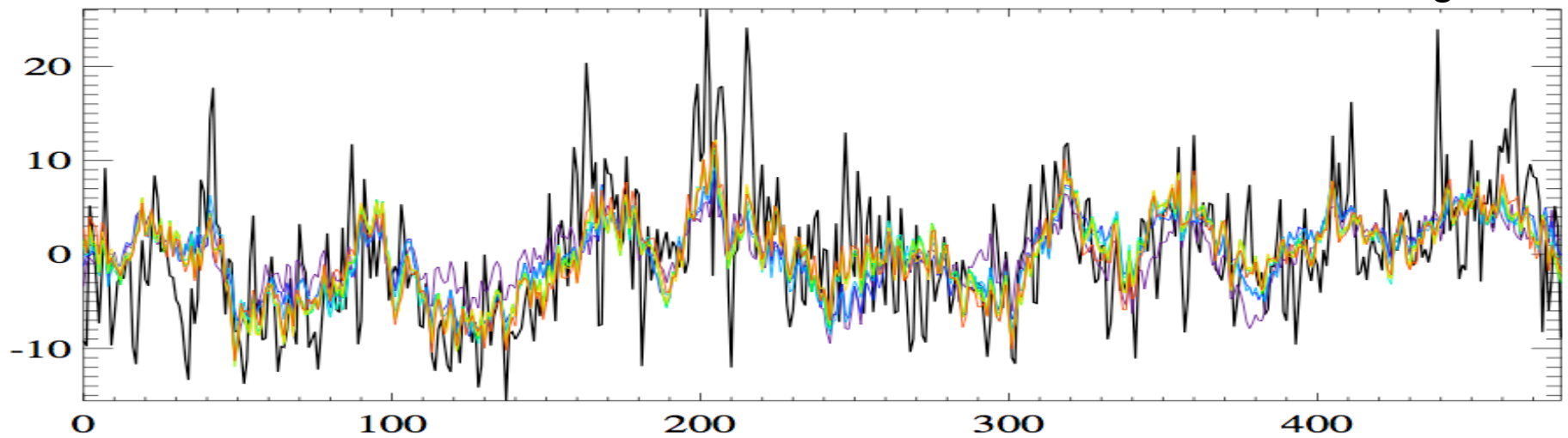
Regression sensitivity profiles from EOFs of T&q



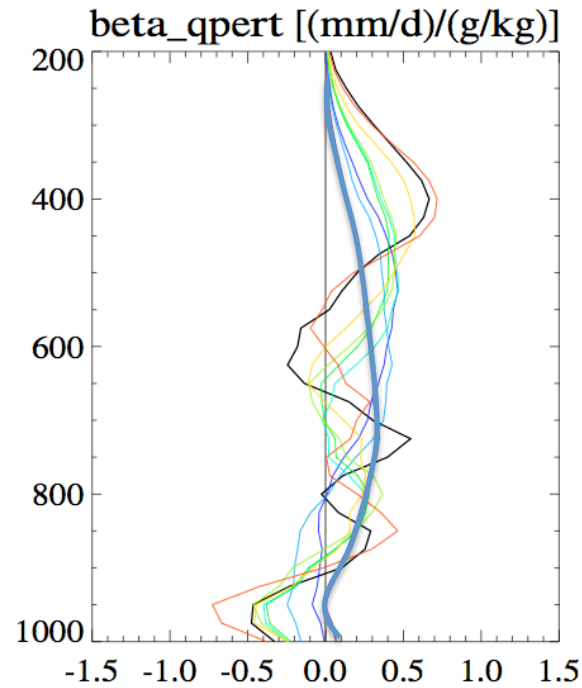
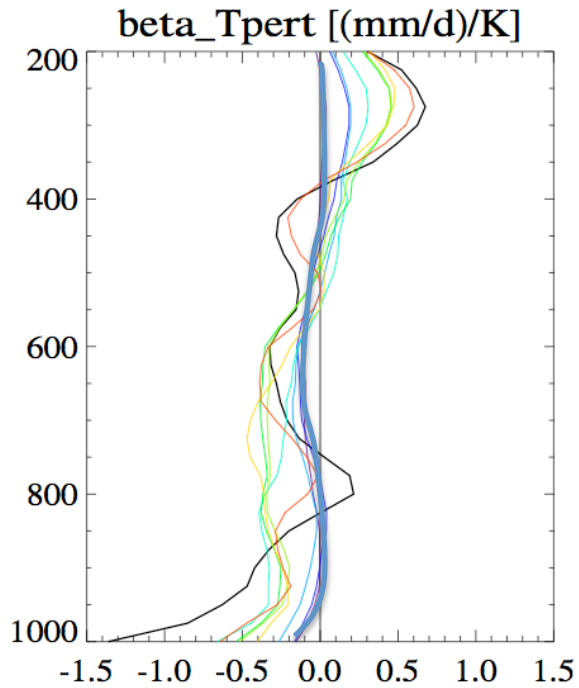
Black: 10 modes

2(purple) to 9(red) modes

from Siwon Song



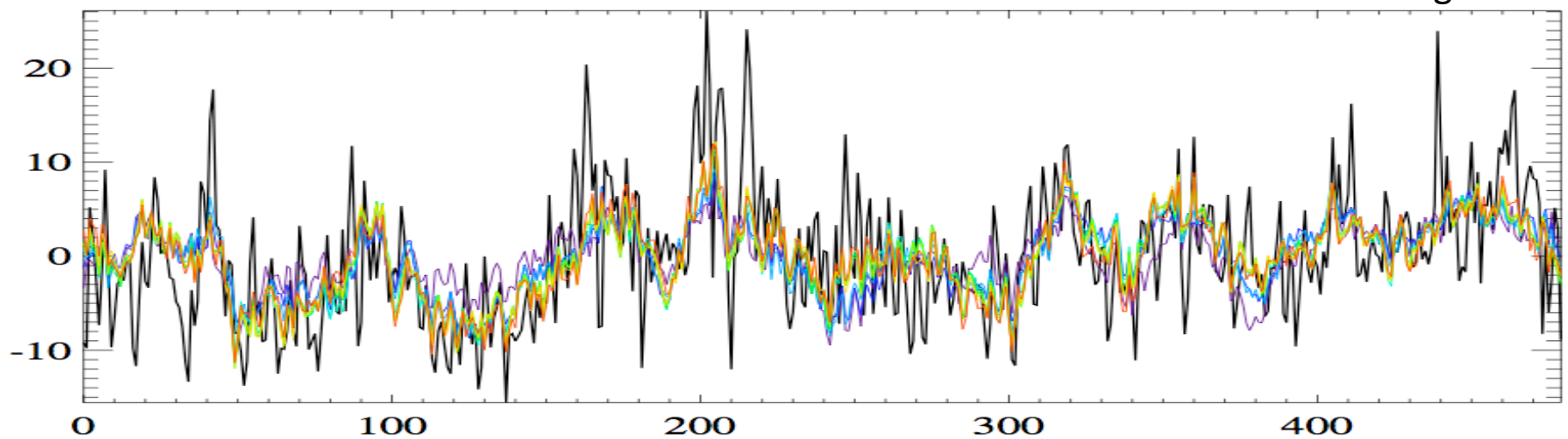
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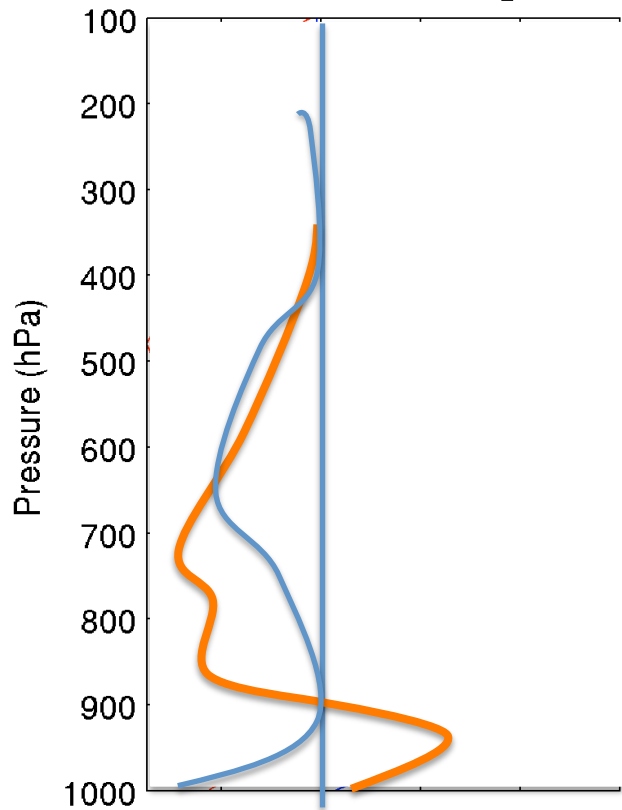
2(purple) to 9(red) modes

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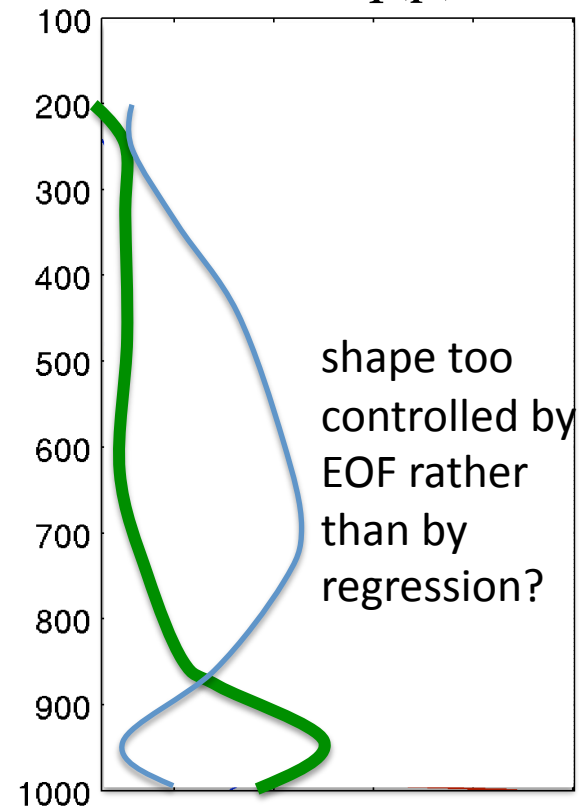


3D small domain CRM and 1-CEOF mode regression

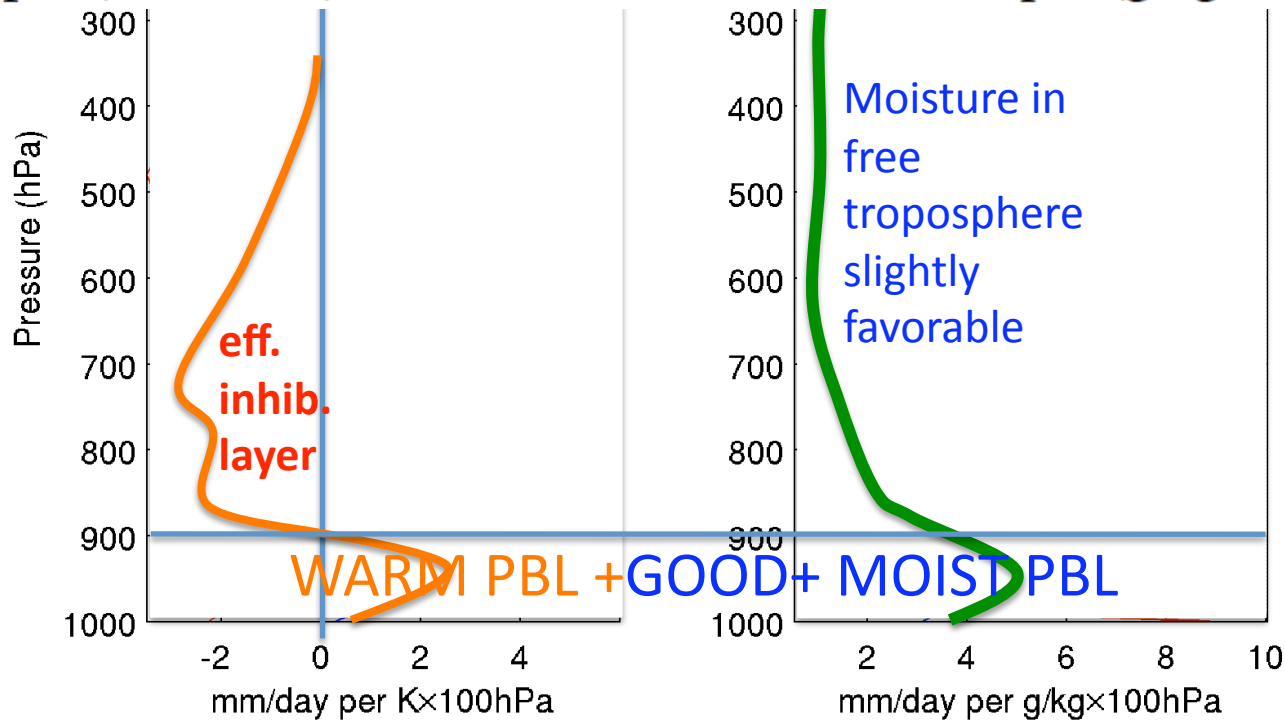
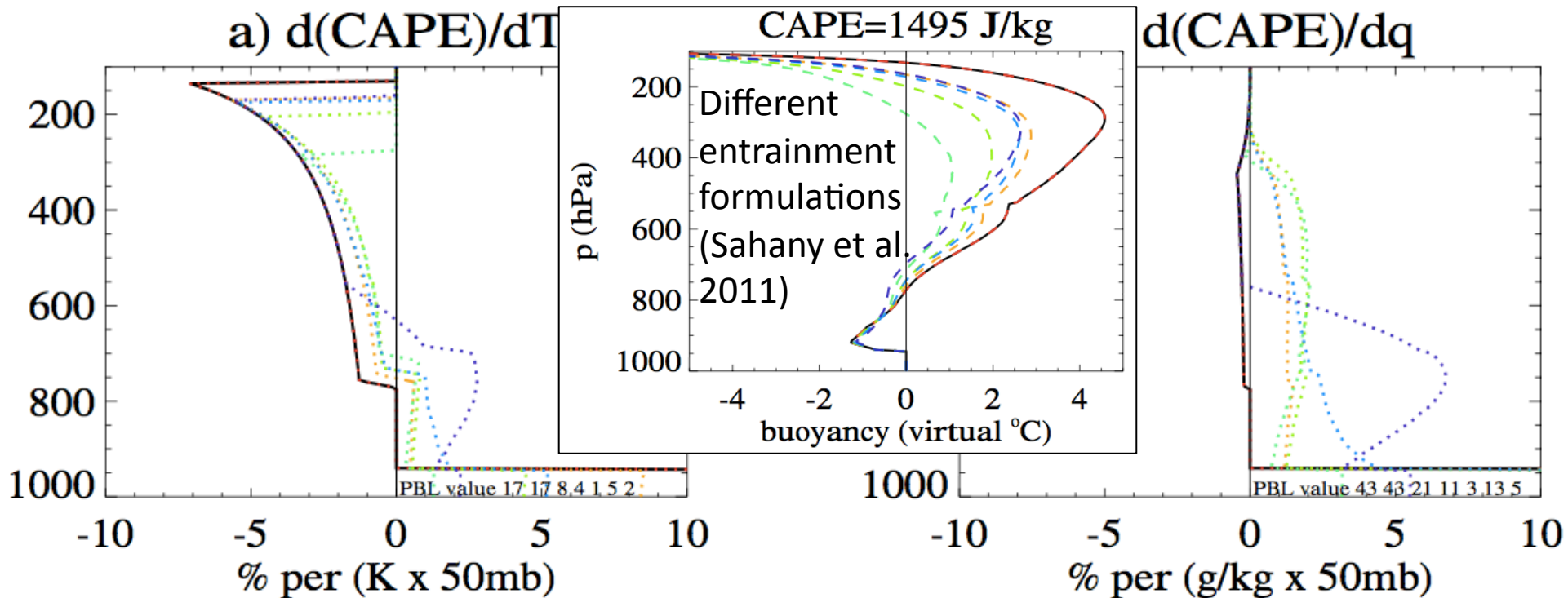
$$S_T(p) = \frac{d\langle Q_1 \rangle_{4h}}{dT(p)}$$



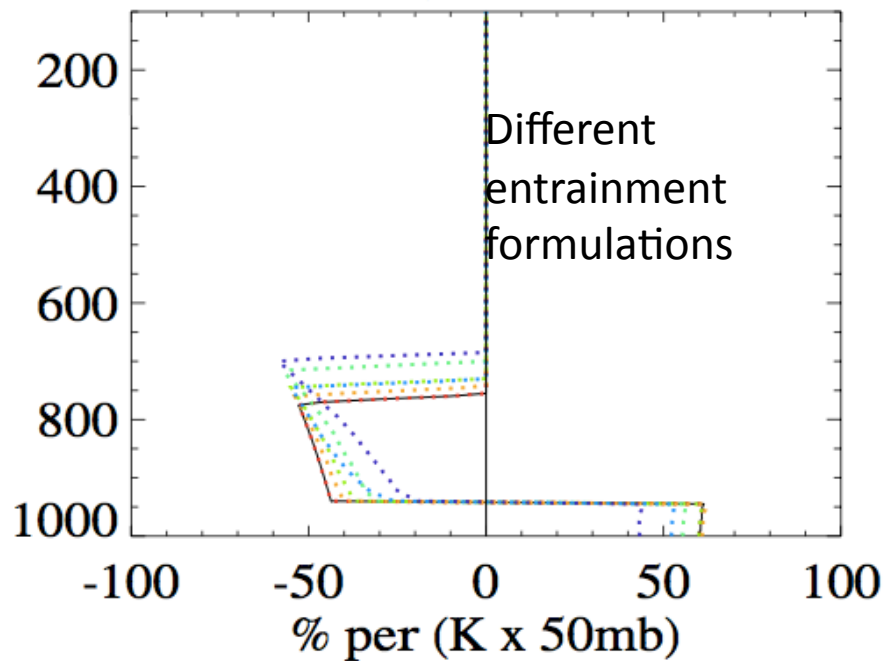
$$S_q(p) = \frac{d\langle Q_1 \rangle_{4h}}{dq(p)}$$



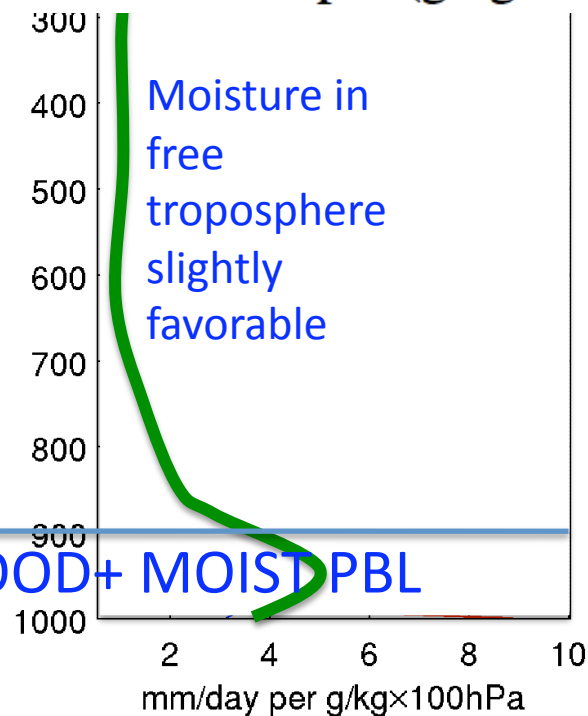
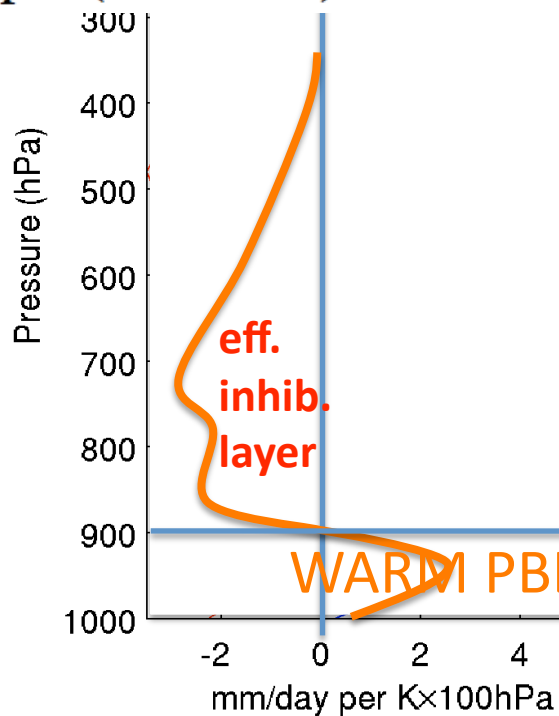
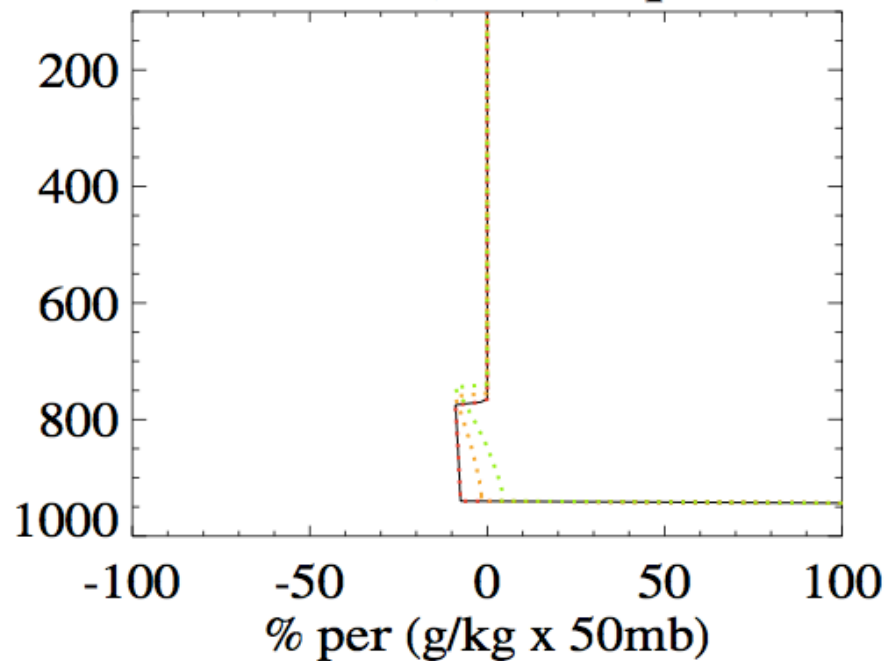
Siwon Song, work in progress



c) $d(\text{CIN})/dT$

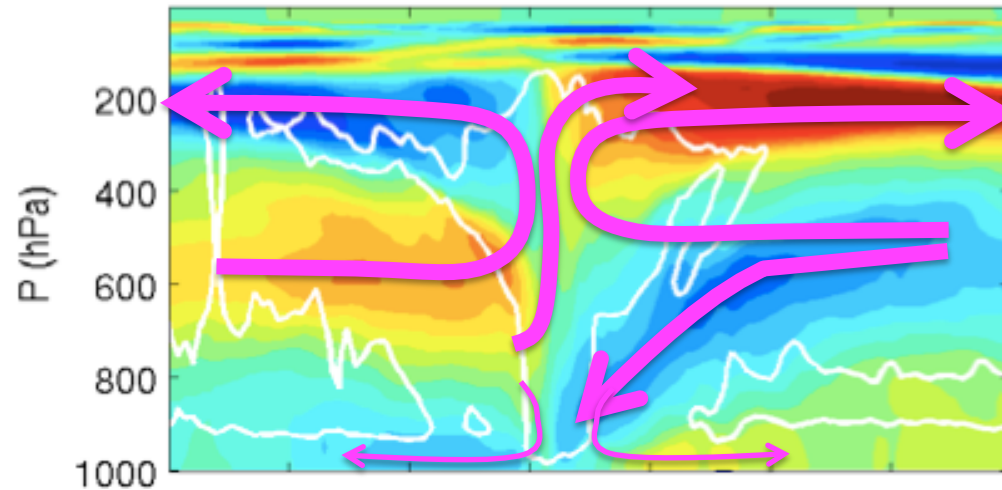


d) $d(\text{CIN})/dq$



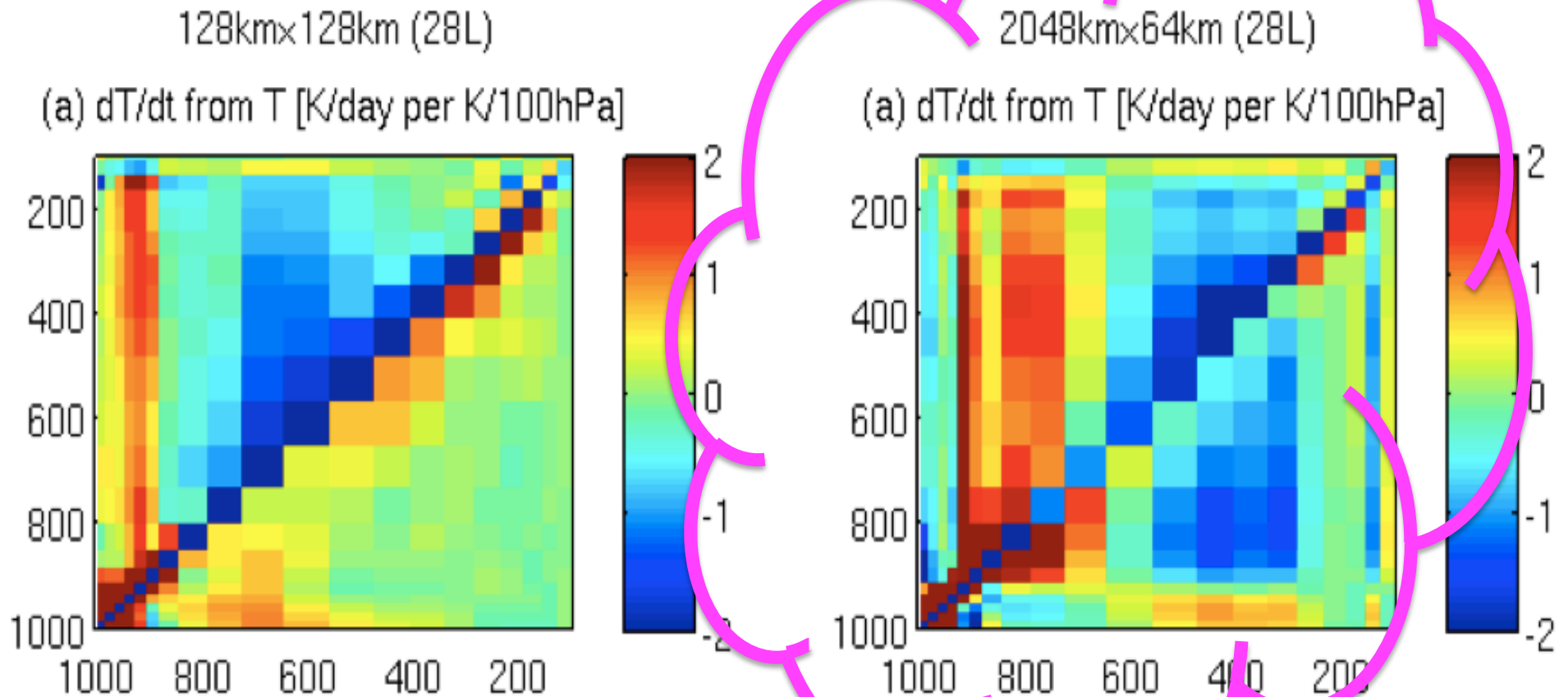
Organized convection: different sensitivity

Storms in 2048 x 64 km domain (unsheared RCE)



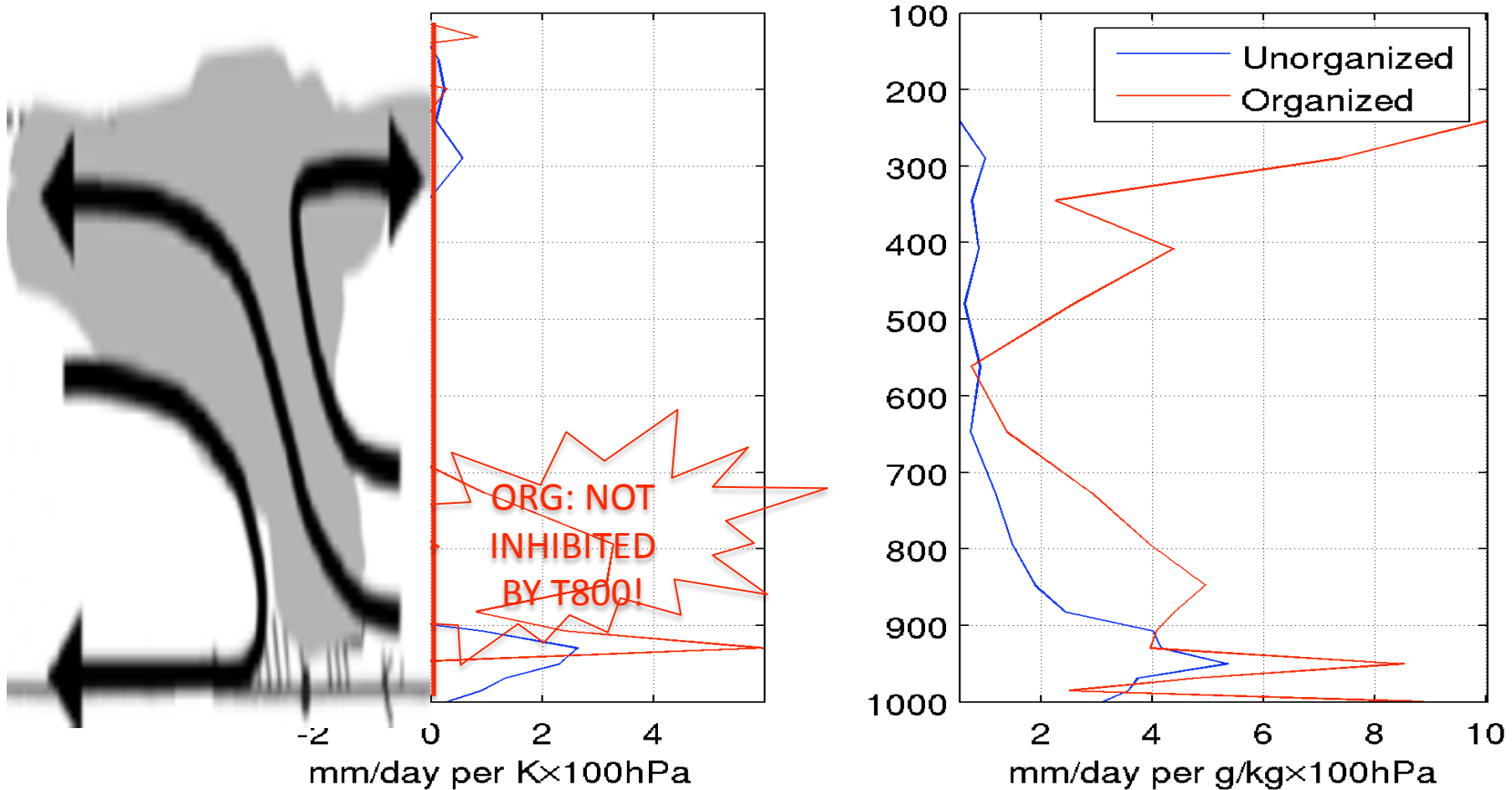
- Midlevel inflows, “layer overturning”
- Coherent structures \leftrightarrow fewer of them, so ZK had to use >200,000 days of CRM time for...

Organized convection sensitivities to large-scale (domain-mean) T anomalies:



Sensitivity of *big domain* rain to LS

T' and q'



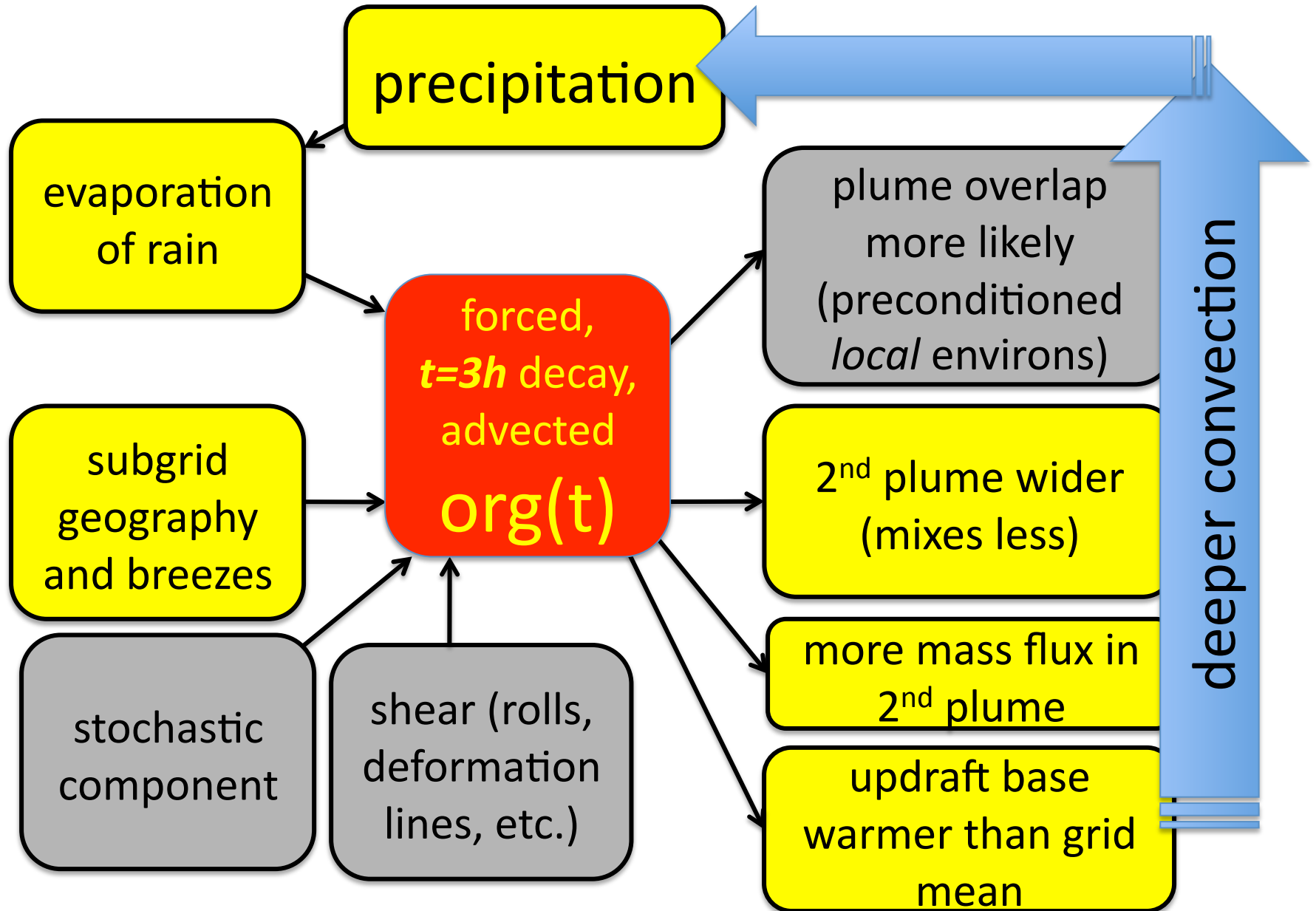
Jump to GCM experimentation...

org Ω \Leftrightarrow access to less-diluted plume

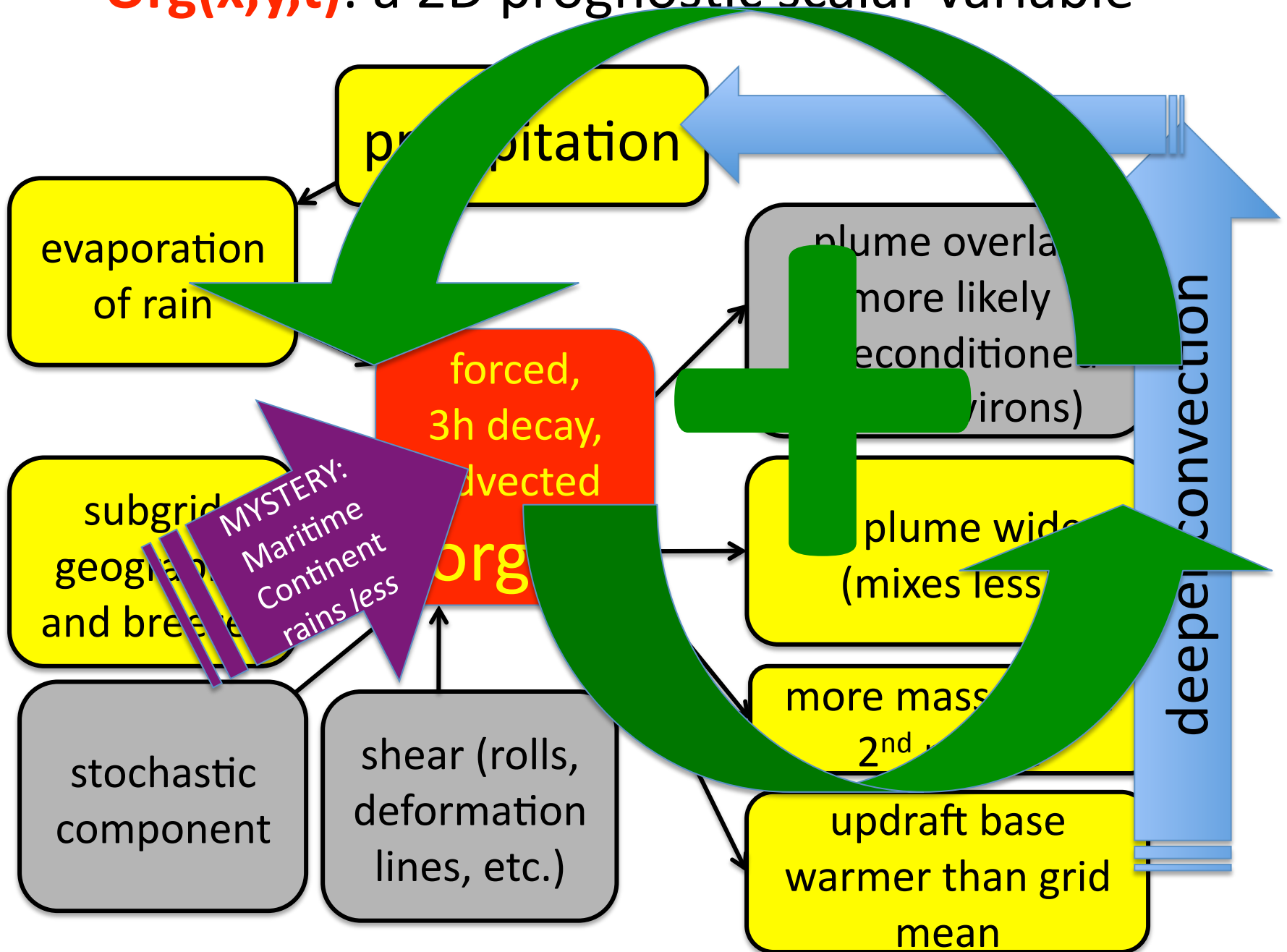
By this def., trad. GCMs have *ubiquitous org.*, not lack of it!



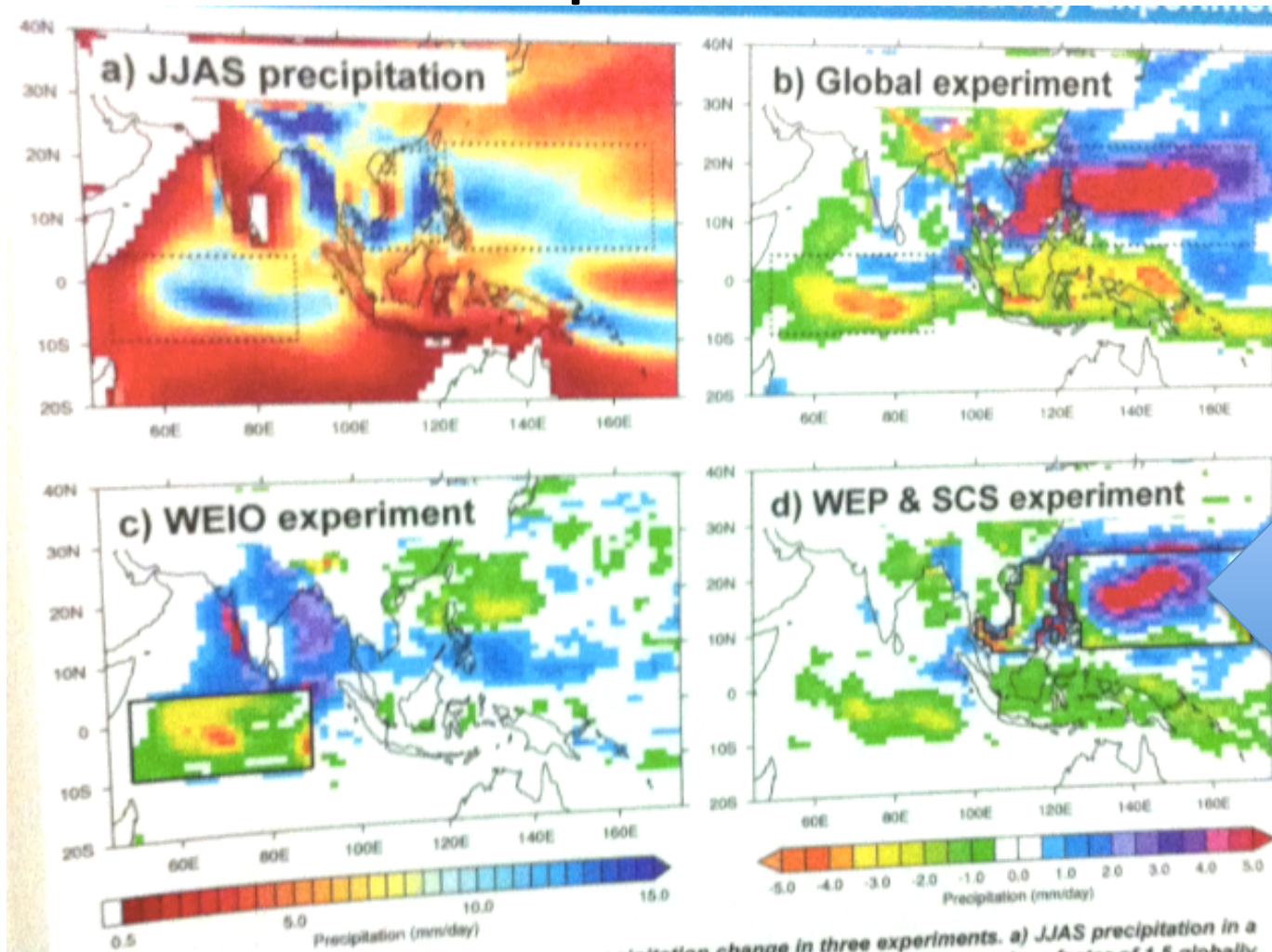
Org(x,y,t): a prognostic scalar in CAM5-UWens scheme with 2 plumes (more vs. less mixing)



Org(x,y,t): a 2D prognostic scalar variable



Similar mystery from S. Bush, A. Turner Met Office model clandestine pers. comm. 2012



...precipitation change in three experiments. a) JJAS precipitation in a... factor of 1.5 globally.

Key points/ conclusions

- Mesoscale/multiscale structure confounds obs-model connections
- Need an account of how form relates to function
- Defining “*function*” is half the battle
- Controlling form is the other half
- Is org. a continuum from isotropic 3D to 2D?

Results

- **Offline** diagnostic of function: matrix M
 - 4 hour $\langle Q1 \rangle$ sensitivity profile, from 128km 3D CRM:
 - +sensitivity to PBL (“parcel”), free trop q; inhibition to 600mb
 - Sensitivity of 2048 x 128 w/ mesoscale org **differs**:
 - More sensitive to q' , T' at 700mb a *positive* influence
 - ‘inhibition’ layer extends up to 400-300 mb
- **Param: org** \leftrightarrow **access to less dilute updrafts**
 - By this def, org *too ubiquitous* in trad. GCMs, not missing
 - Mystery: some places more org *reduces* rainfall
 - or more entrainment *increases* rainfall (Reading/UKMO)
- **Working/thinking how to bring in obs better**