Toward a moist dynamics that takes account of cloud systems

(mainly deep convection, although issues are broader)

Invited review article for JMSJ in preparation

Brian Mapes
University of Miami
WCRP Open Science Conference, Denver
October 2011
B6_Mapes.pptx Plaza C room

Motivation

- Disconnect between detailed observations and large-scale desires that justify them
  - Observations are 4+ dimensional with rich mesoscale texture (cloud systems)
  - This obstructs mapping to model space

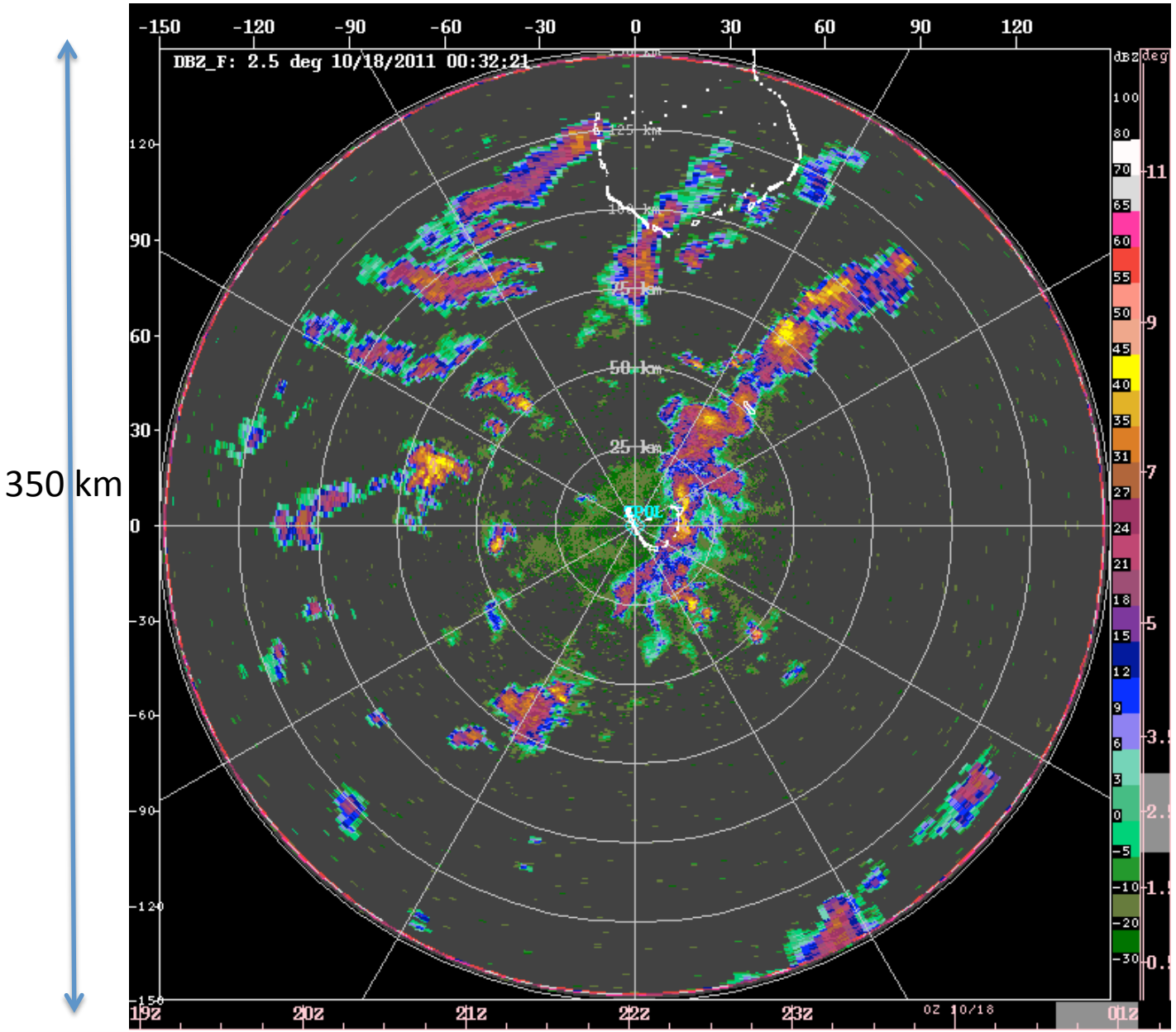
Example: mixing in convection

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 the entrainment rate coefficient



Last Weds (Oct 18-19), 30 hour loop

DYNAMO campaign, equatorial Indian Ocean (Maldives)

S-POL radar reflectivity

4+ dimensional mesoscale/multiscale

- t, z, x, y -- but time *scale* is another dimension

  – adds slippery layers to causality
    - proximate, contributing, ultimate, etc.
    - response-to-forcing, balance-maintenance, fulfilling-reason-for-existence, etc.

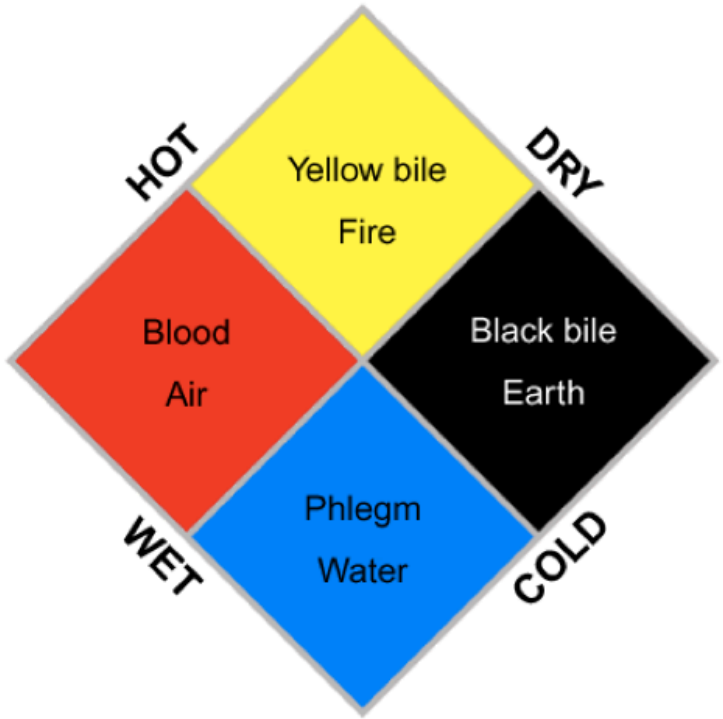
Stages of a science

1. Exploration (observant fun)
2. Explanation (heady fun)
3. Exploitation (hard work; may require unpleasant revisitations of 1,2)

- Need to keep 1 and 2 alive (e.g. for students) even as 3 justifies the enterprise

Our disconnect:

Form vs. Function



Humour	Season	Element	Organ	Qualities	Ancient name	Modern	MBTI	Ancient characteristics
Blood	spring	air	liver	warm & moist	sanguine	artisan	SP	courageous, hopeful, amorous
Yellow bile	summer	fire	gall bladder	warm & dry	choleric	idealist	NF	easily angered, bad tempered
Black bile	autumn	earth	spleen	cold & dry	melancholic	guardian	SJ	despondent, sleepless, irritable
Phlegm	winter	water	brain/lungs	cold & moist	phlegmatic	rational	NT	calm, unemotional

Form – function disconnect

- Without an account of the relationship, we don't know what to make of all that form (detail)

- Need:
  - 1. definitions & measures of *function*
  - 2. ways of sifting or manipulating *form*
    - e.g. surgery (in models)
      - mustn't be too invasive..

How might mesoscale/multiscale *form* matter, in a convection context?

- Determines local setting for true physics
  - mixing (turbulence and molecular flux)
  - microphysics & other chemistry
  - radiation
- Affects stochasticity/ predictability
  - fewer degrees of freedom per (km^2 hour)
- Affects mean via nonlinearities (rectification)
  - incl. exotic momentum flux effects
- Connects smaller to larger scales?

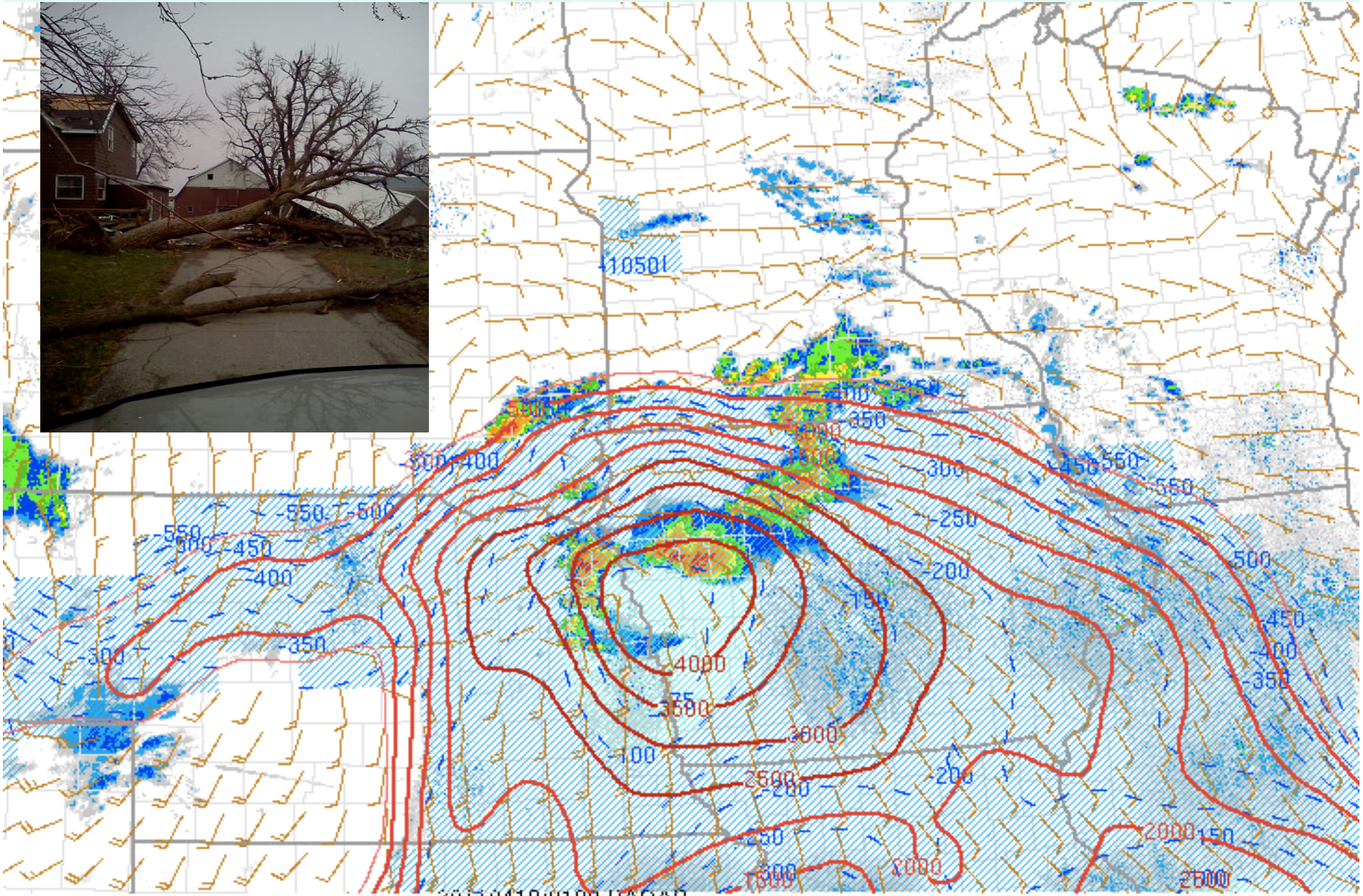
Two kinds of mesoscale in convection

1. Forced: spectrum tail of large-scale motions
   – via deformation

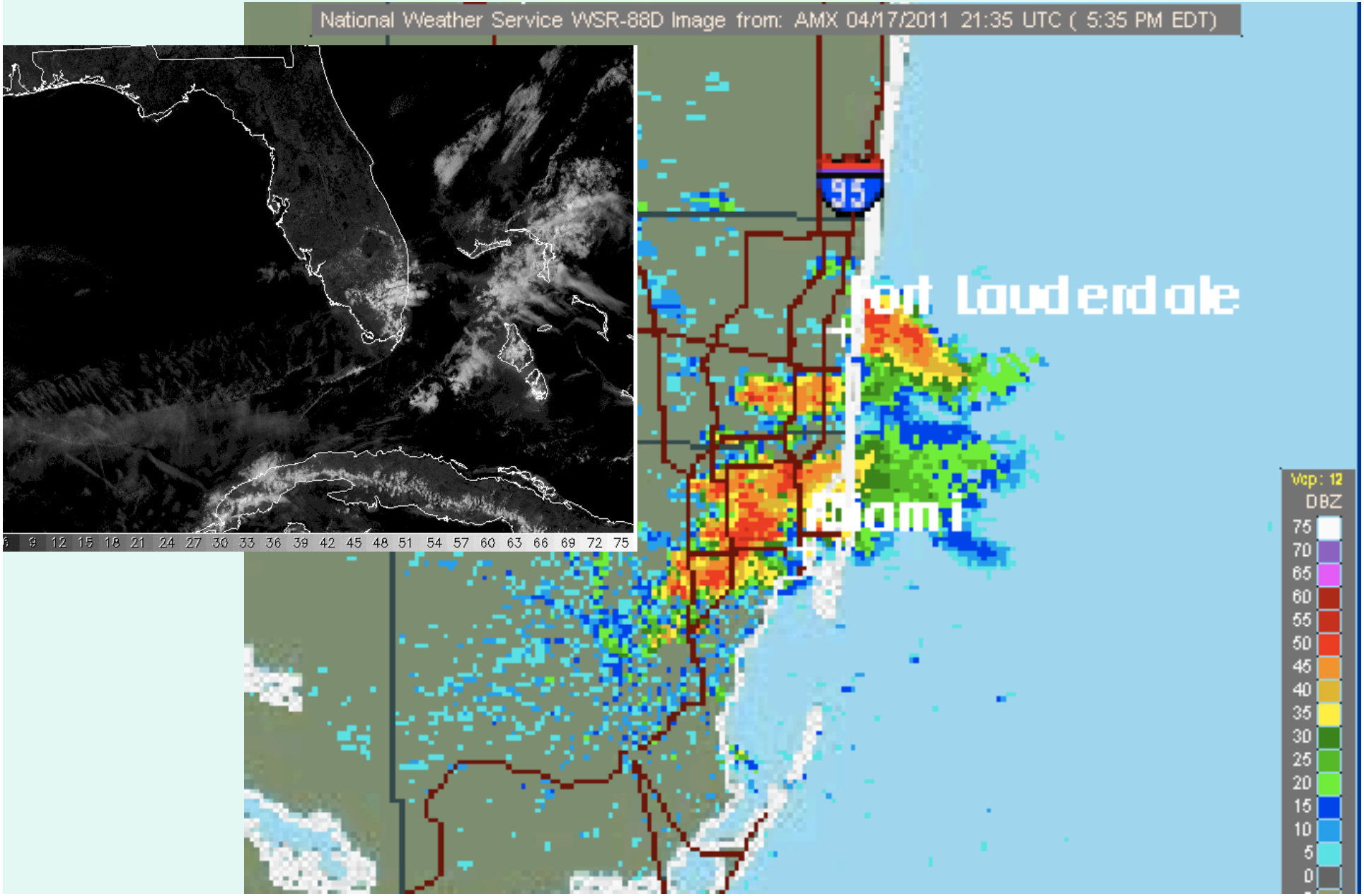
2. Spontaneous: develops from convective processes

What is their relative importance for large scales and climate?

Forced: destroyed my grandparents farm, good 24h forecast



Spontaneous: ruined my cieling, no warning



Connecting form to function

- Need:
  - 1. definitions & measures of *function*
  - 2. ways to manipulate (in models) or conditionally sample (in obs) *form*

Connecting form to function:

- Need definitions / measures of *function*
  1. Offline diagnostic: sensitivity matrix
  2. Test-harness performance: with parameterized large-scale dynamics
  3. Full 'inline' tests: global models with explicit convection

- Need ways to control *form*
  - Domain size and shape; vertical wind shear
    - Can't manipulate nature – only conditionally sample it

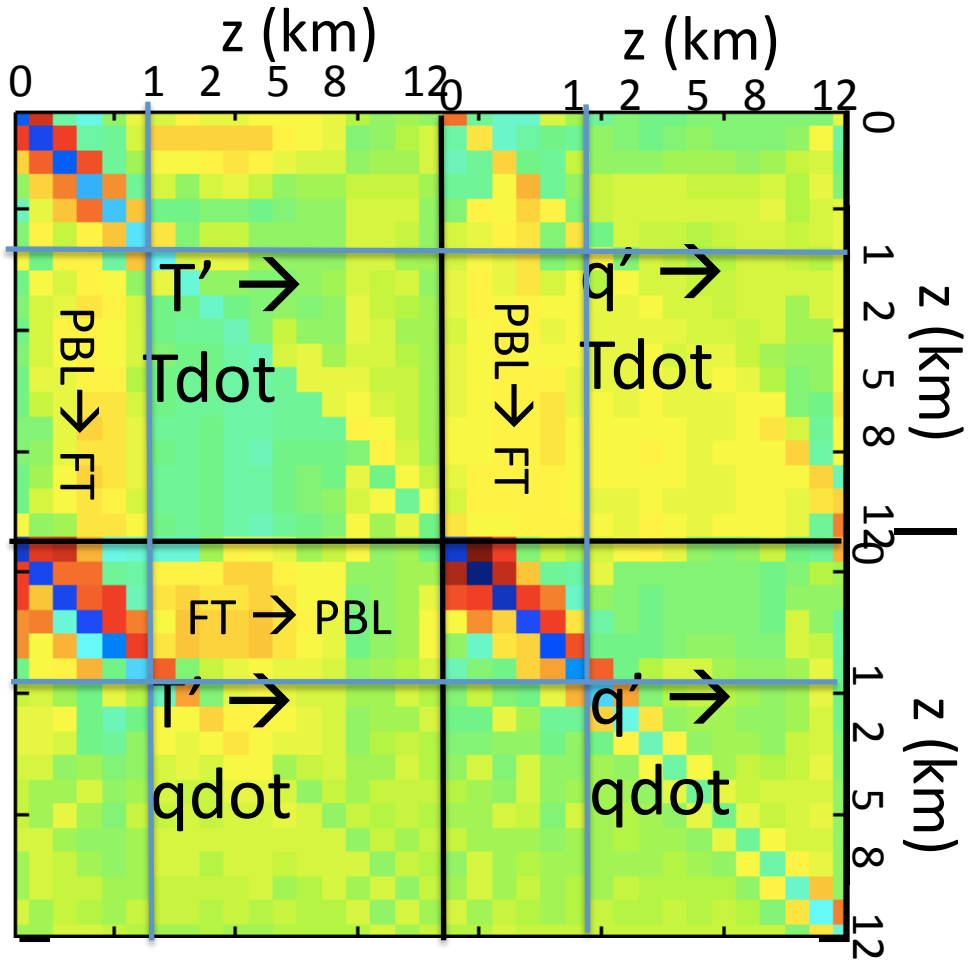
Connecting form to function:

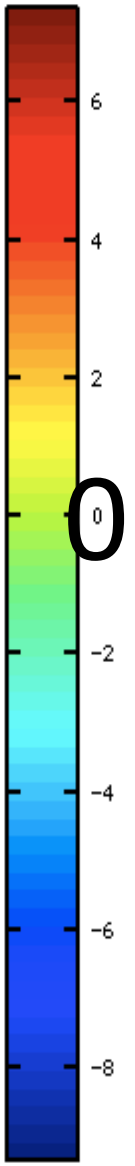
- Need definitions / measures of *function*
  1. Offline diagnostics: sensitivity matrix **M**
     - Kuang (2010 JAS) devised a way to build it
       - using a CRM in eqm, too cleverly to explain here
       - because convection is linear enough
         - » shown also in Tulich and Mapes 2010 JAS

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

Image of M

$$\begin{bmatrix} \dot{T}_c(z) \\ \hline \dot{q}_c(z) \end{bmatrix} = \begin{bmatrix} T \\ \hline q \end{bmatrix}$$

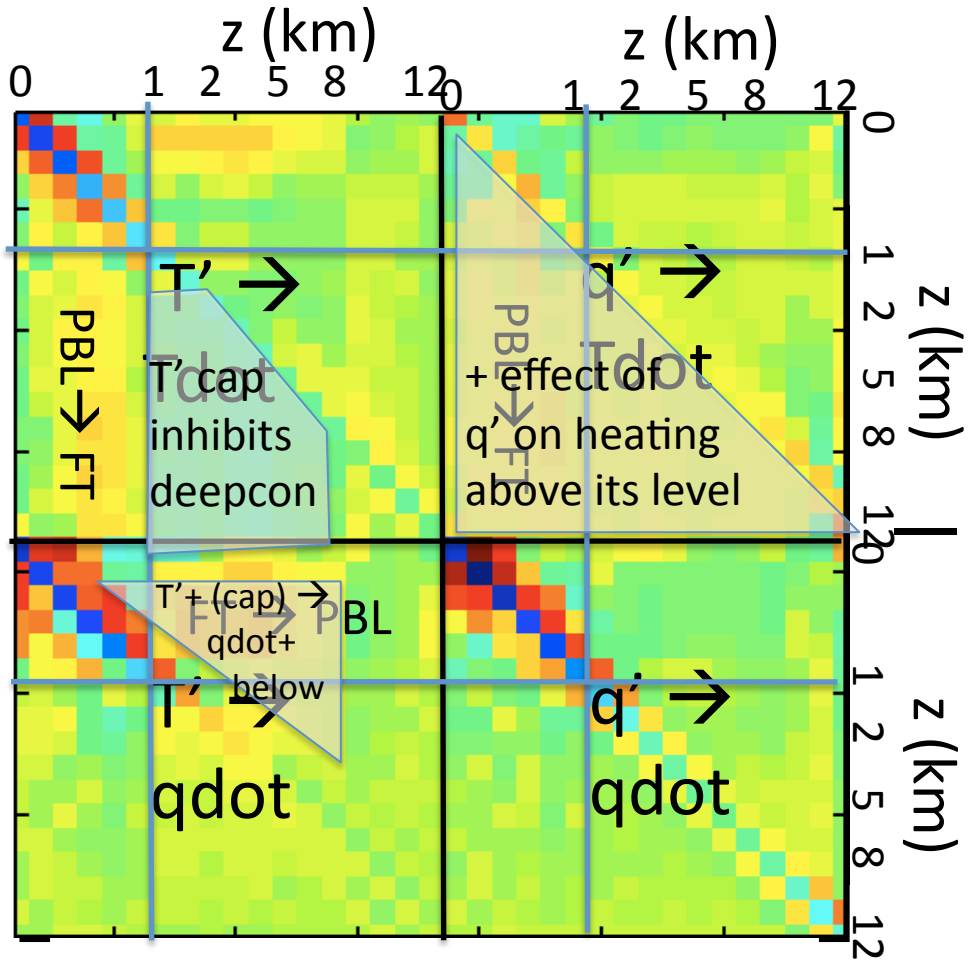


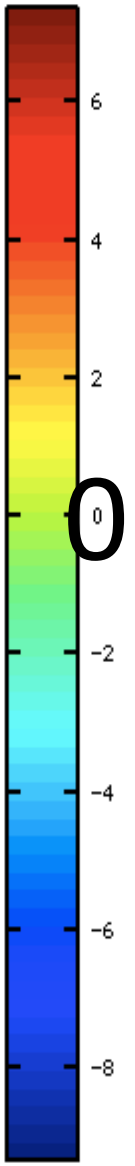


square root color scale

Image of M

$$\begin{bmatrix} \dot{T}_c(z) \\ \hline \dot{q}_c(z) \end{bmatrix} = \begin{bmatrix} T \\ \hline q \end{bmatrix}$$

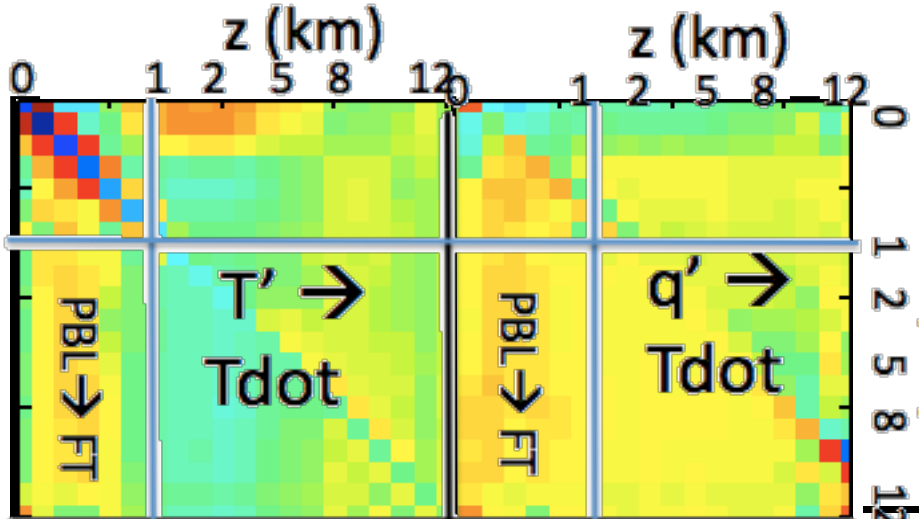


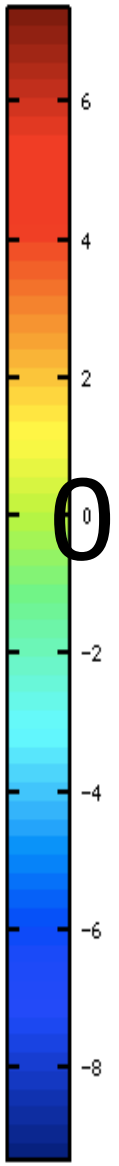


square root color scale

Integrate columns in top half x dp/g

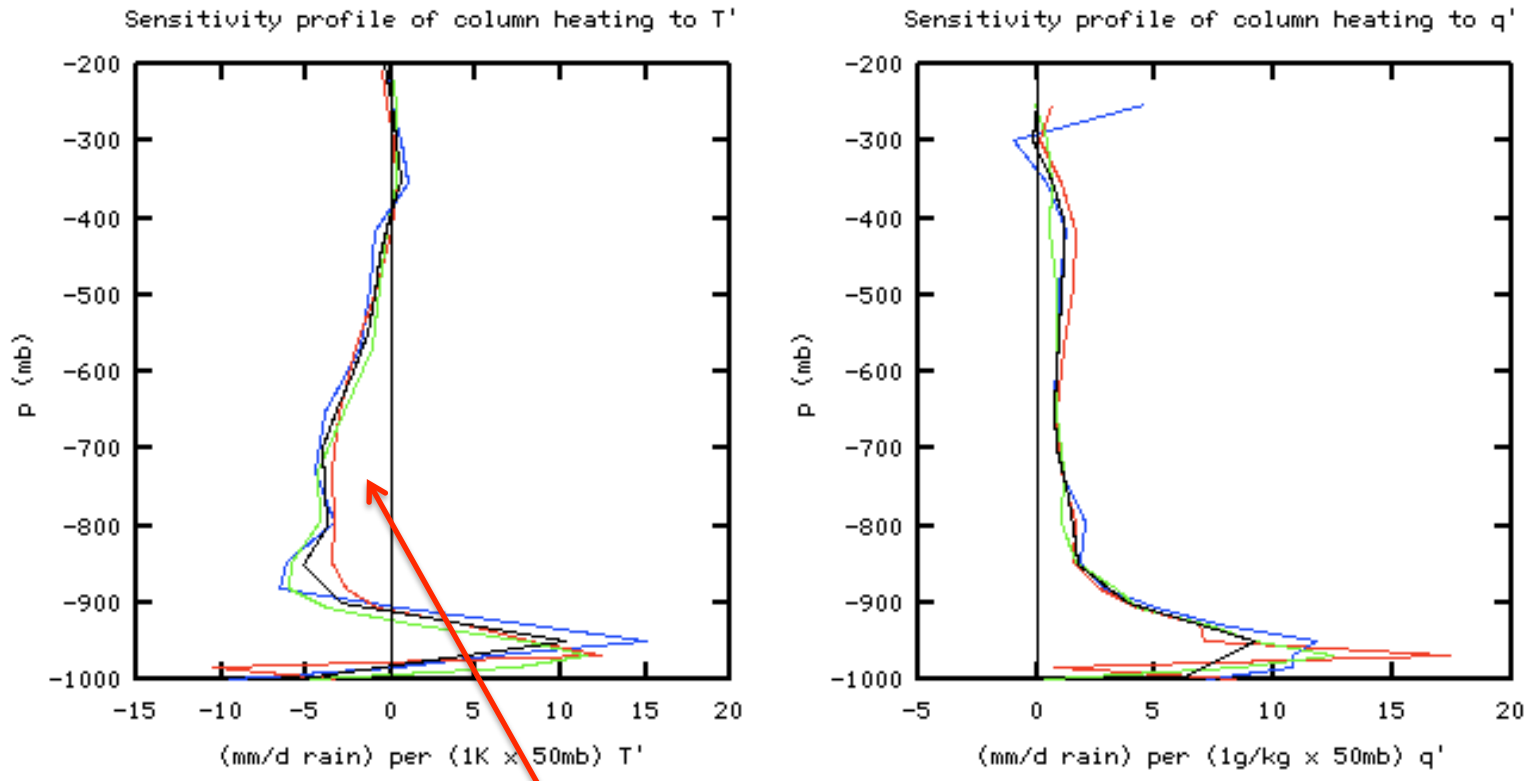
$$\left[\dot{T}_c(z)\right] = \left[\frac{T}{q}\right]$$





square root color scale

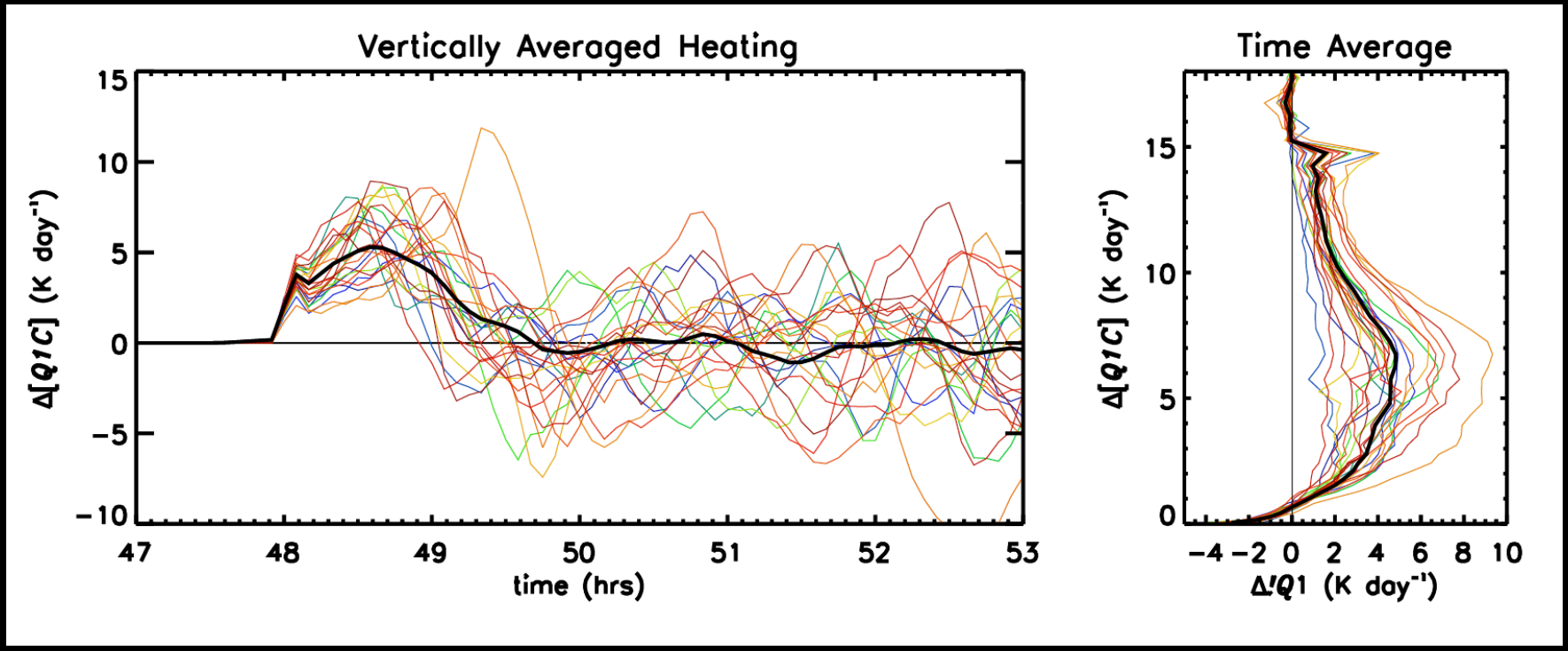
sensitivity profiles of column heating (rain) to T and q at various levels



Effective inhibition layer for deep convection is much deeper than official “CIN” (negative buoyancy of undilute parcel): it reaches up to ~500mb!

Very linear expectation value, even when not purely deterministic

Ensemble Spread



Courtesy Stefan Tulich (2006 AGU)

Connecting form to function:

- Need definitions / measures of *function*
  1. offline M
  2. Test-harness performance: with parameterized large-scale dynamics

- Much progress in treating large-scale dynamics as an interaction with convective heating (not a 'forcing'!)
  - Weak Temperature Gradient assumption
  - Linear wave dynamics treatment

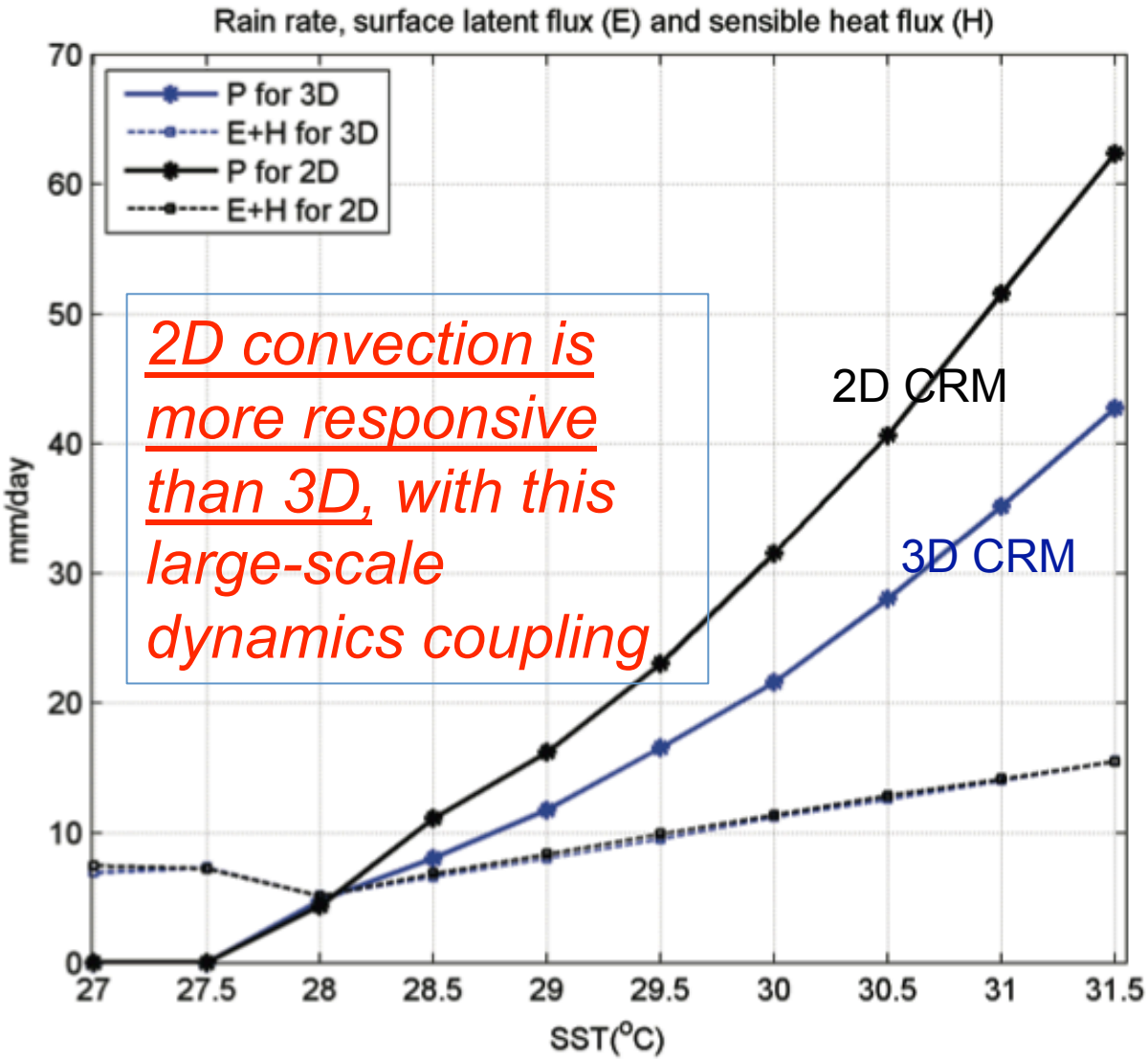
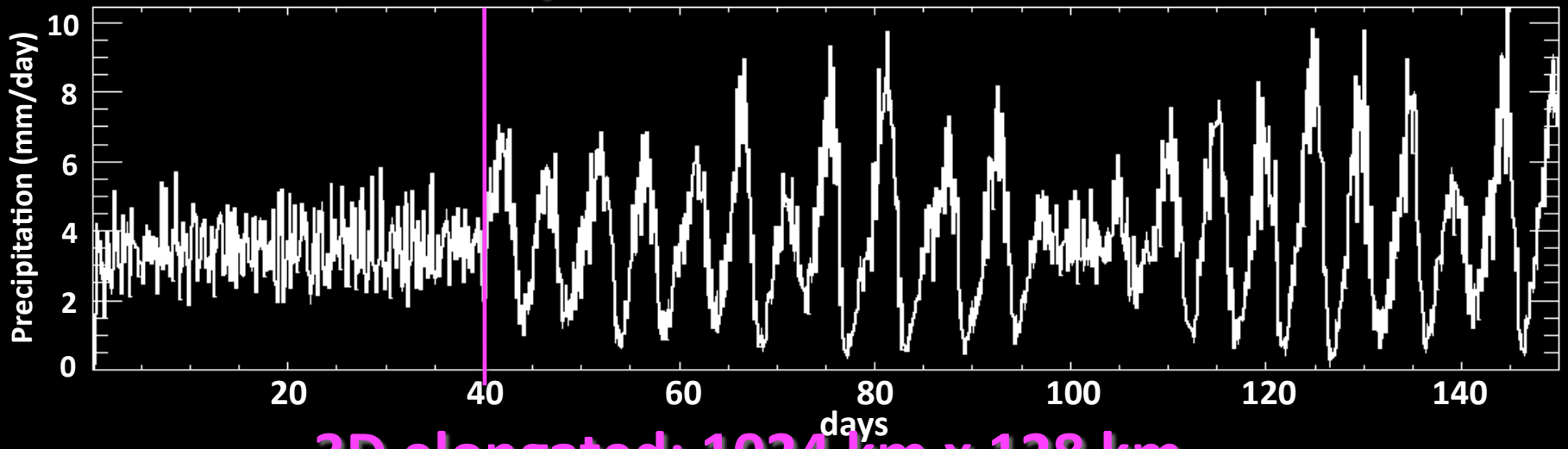


Figure 3. Daily rain rate *P* (mm/day, solid) and surface fluxes (latent and sensible heat flux, E+H, in the unit of mm/day, dashed) versus SST for 2D and 3D. Surface fluxes in 3D are almost the same as in 2D.

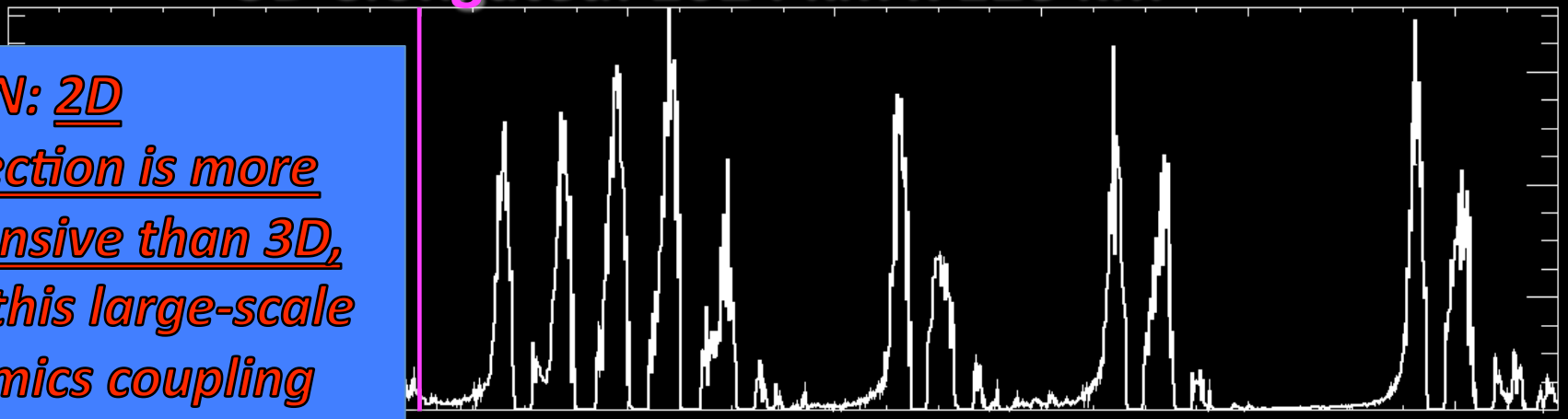
Wang and Sobel 2011

Instability of a periodic CRM coupled to a 5000km linear wave

3D isotropic: 128 km x 128 km



3D elongated: 1024 km x 128 km



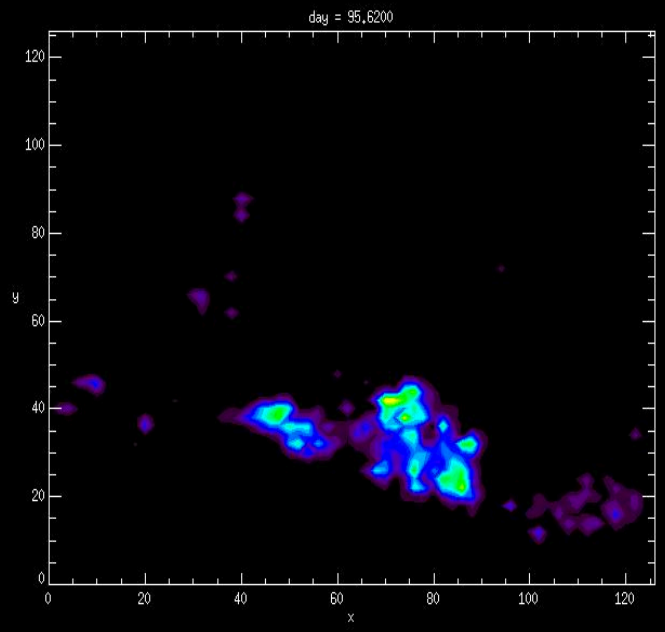
AGAIN: 2D convection is more responsive than 3D, with this large-scale dynamics coupling

2D CRM is even more unstable...

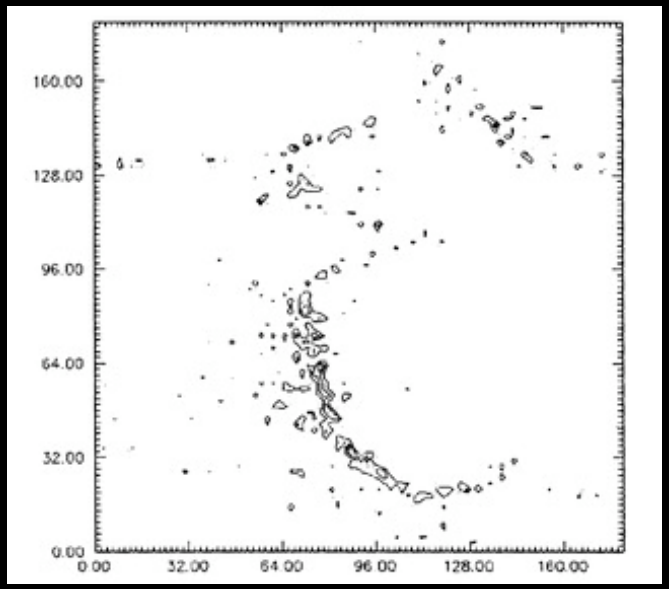
Riley, Mapes, Kuang, in preparation

A 2D-3D continuum?

3D - No Shear

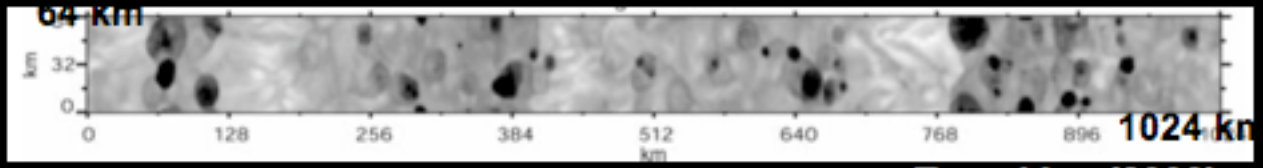


3D – With Shear

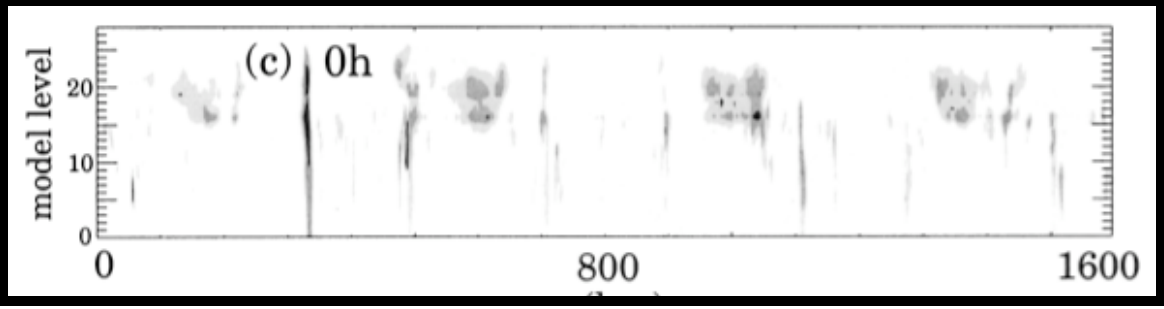


Robe & Emanuel (2001)

"2.5D" LONG 3D doubly periodic



Tompkins (2000)



Strict 2D

Mapes (2004)

Connecting form to function:

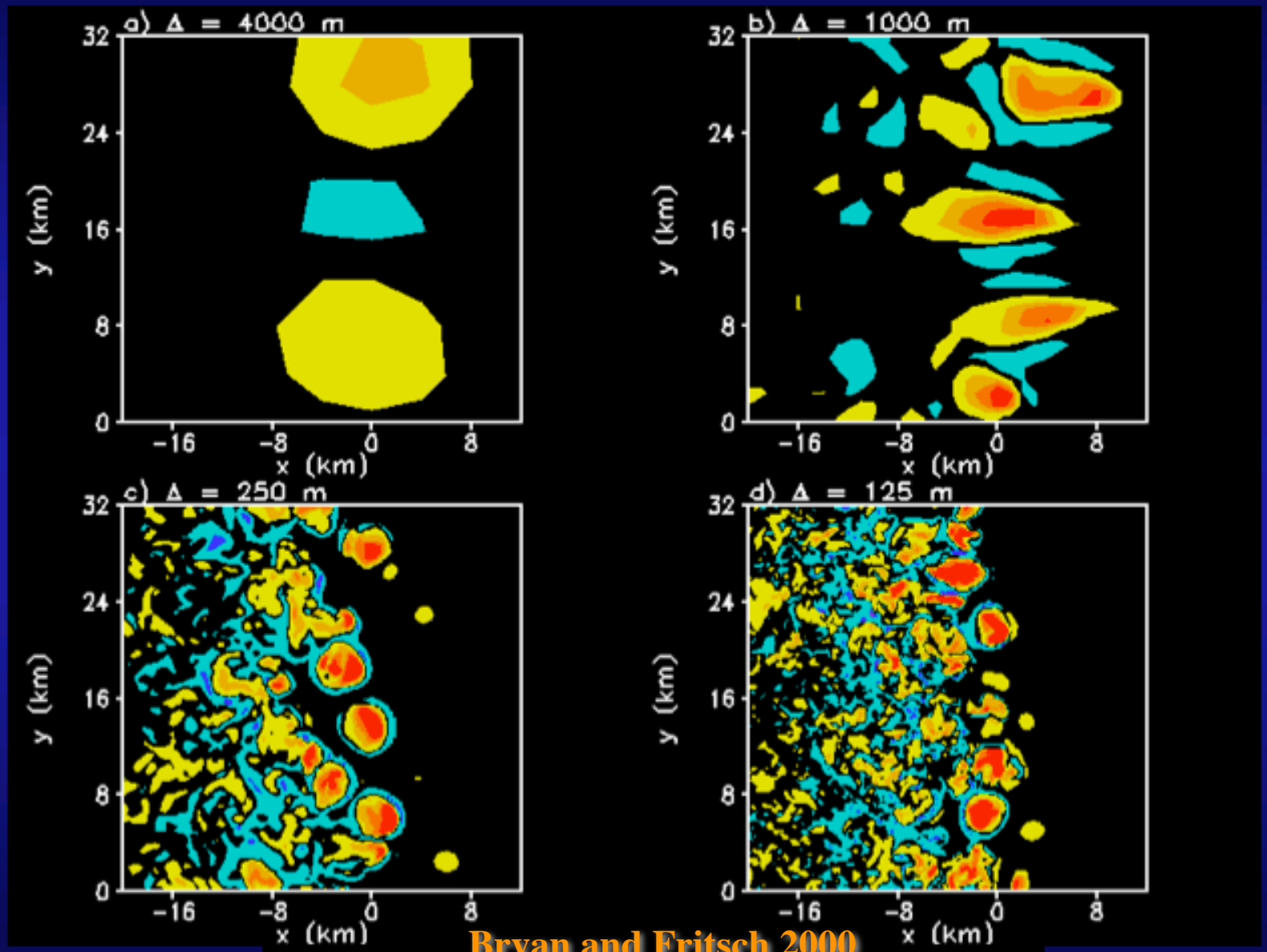
- Need definitions / measures of *function*

1.
2.
3. Full ‘inline’ tests: global models with explicit convection

Super-parameterization vs. Under-resolved convection


Super-parameterization: a small *sample* of convective scales, coupled to large scales across a formal scale separation
Under-resolved convection: a full global grid (seamless large → meso scales), but with 10s of km resolution
J. Uelsmann, Untitled (1983)

Vertical velocity (w) at z = 5 km, t = 5 h

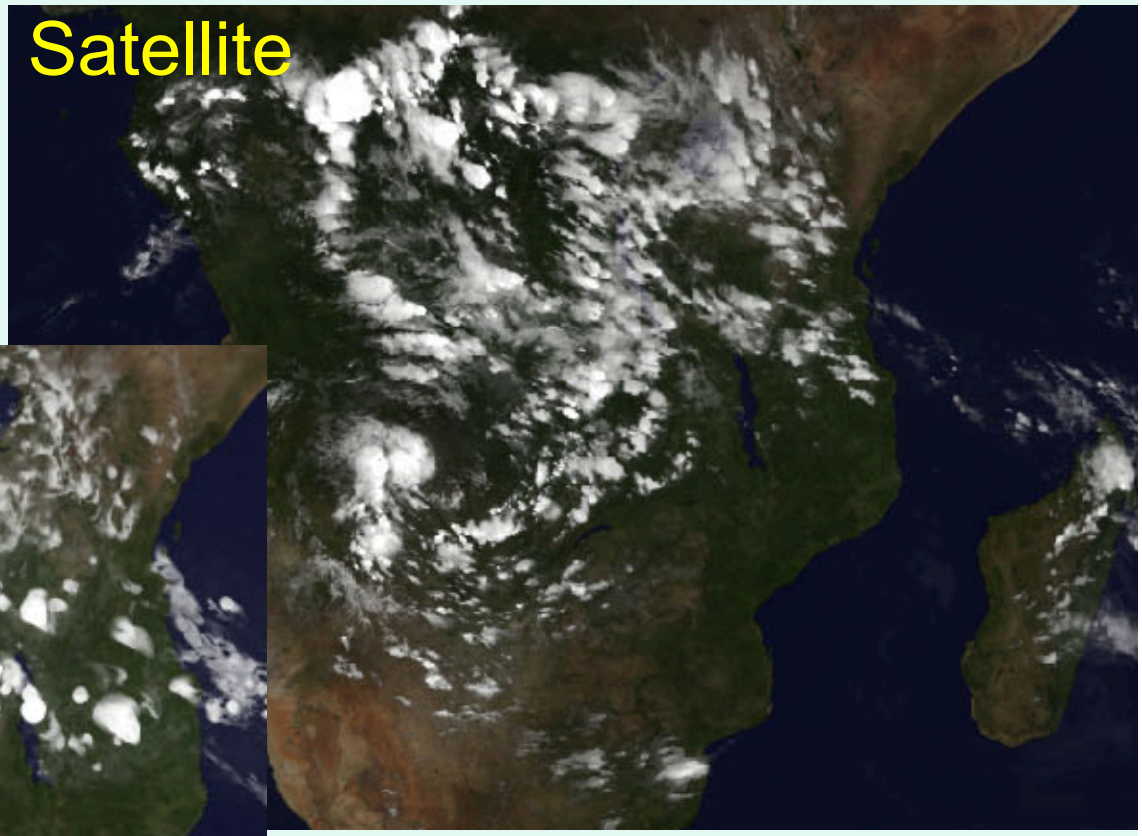


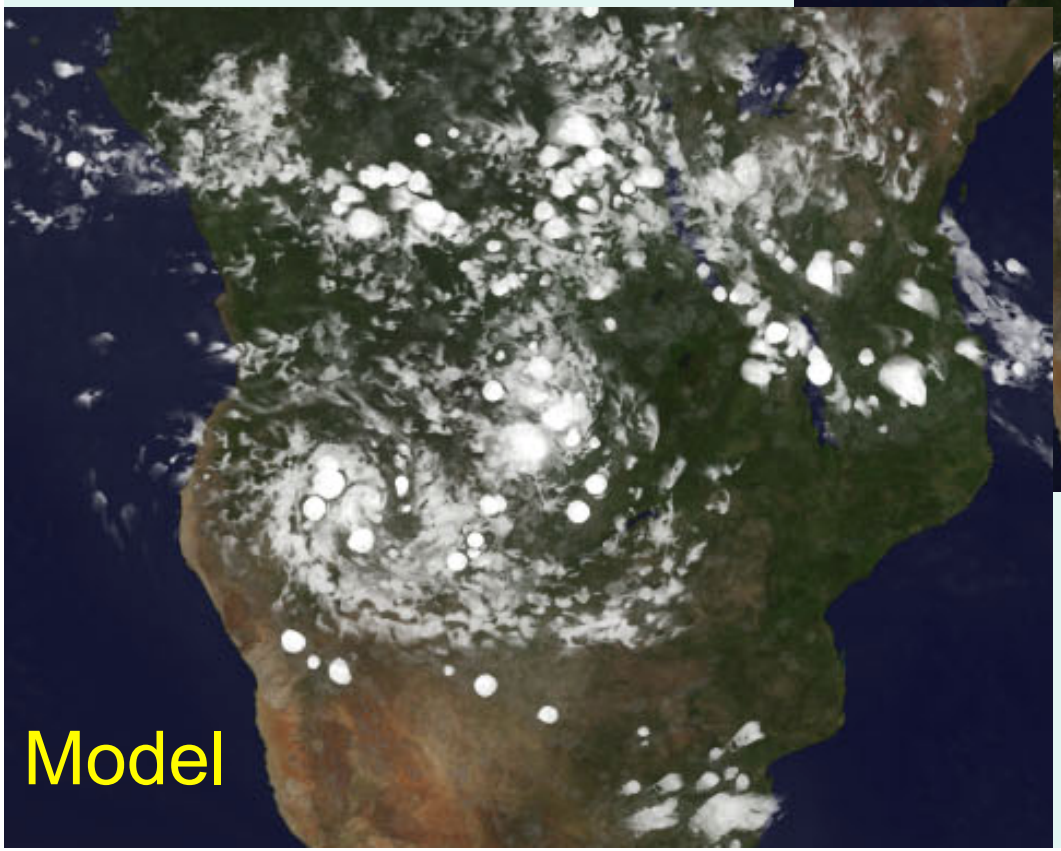
Bryan and Fritsch 2000

Under-resolved (5km mesh)

predicted cloud features for
February 6, 2010

2 weeks into simulation



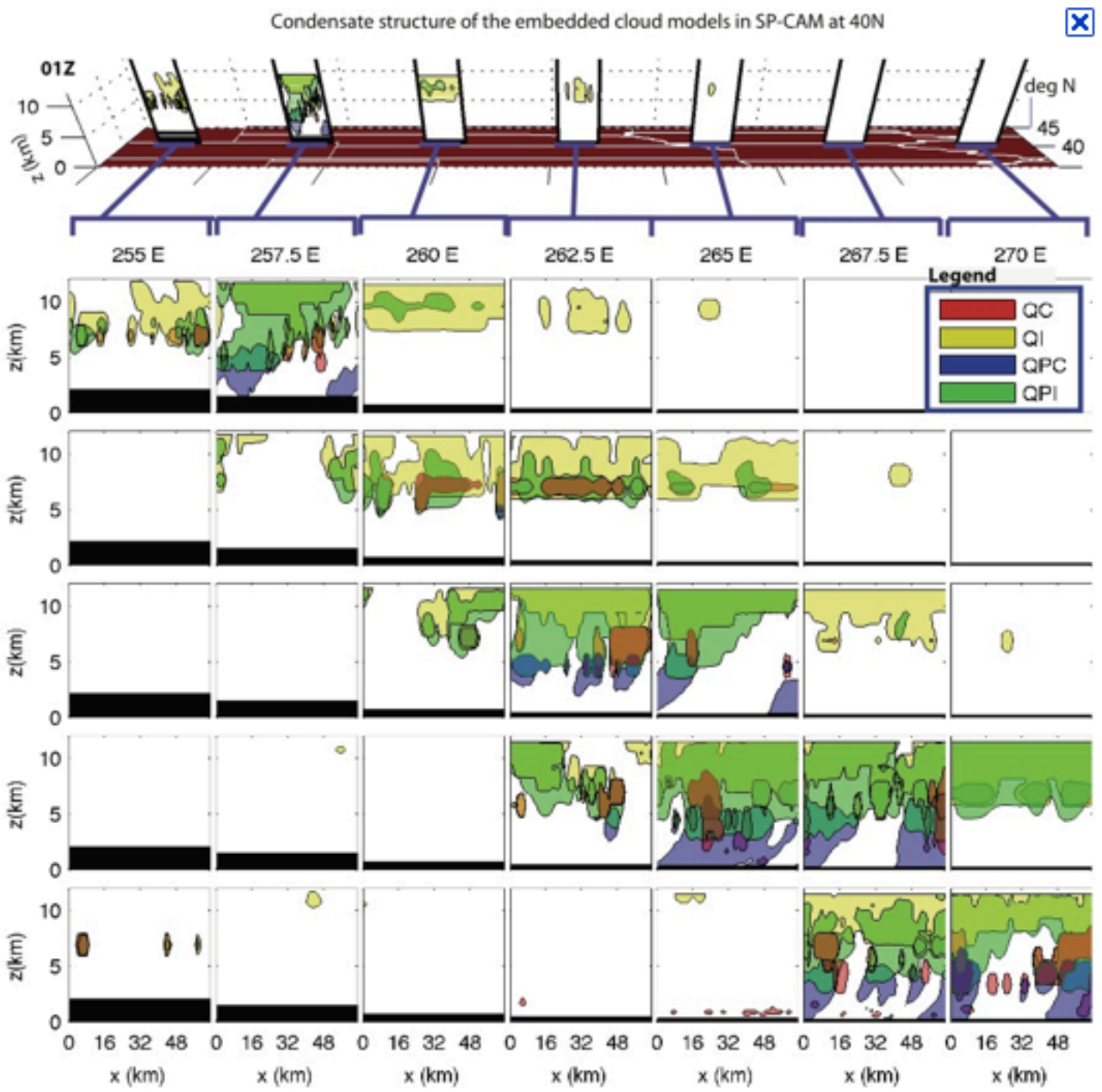


http://
earthobservatory.nasa.gov
/IOTD/view.php?
id=44246&src=eoa-iotd

Putman & Suarez (2011) simulations
Song, Mapes, Putman study in prep.

"Super-parameterized"

(embedded 2D CRMs within GCM)



Pritchard, Moncrieff, Somerville 2011 JAS

Super-CAM was tried with 2D vs. 3D CRMs

Khairoutdinov, Randall, DeMott 2005

Differences not super clear
(length of run, sampling, diagnosis detail)

but momentum flux in 3D “helped”
(and was not dared with 2D which distorts it)

Connecting form to function:

'Super' vs 'Under' global models

- *Teraflop for teraflop*, which one gives better performance? (by what metrics?)
- Answer relates to the 2 mesoscales:
  - 'Under' keeps the seamless (spectrum tail) mesoscale, but compromises on convection
  - 'Super' emphasizes convective scales and accepts a scale seam or gap

Key points/ conclusions

- Mesoscale/multiscale structure confounds obs-model connections
  - both the forced mesoscale (tail of LS motions)
  - and the spontaneous mesoscale (from convection)

- Need an account of how form relates to function
  - We have an *accounting system* (budgets, primes and bars), but an *account* is more than that

- Defining "*function*" is half the battle
- Manipulating/ categorizing form is the other half

Defining 'function' of cloud fields

- Offline diagnostics of function:
  - Linearization: tendencies = **M** [state vector]
  - Timeless object(s) **M** can be studied & compared
    - linearized about different weather 'regimes'
    - with/without mesoscales: sculpted by domain size/shape & shear
- Test harnesses for **M**s, CRMs, SCMs
  - interactive parameterizations of large-scale dynamics
    - 2D more strongly coupled than 3D convection?
    - A continuum from isotropic 3D to strict 2D?
- Inline approaches:
  - Super-parameterization vs. under-resolved convection
    - wishing for a lively, opinionated "bake-off," for same # flops