Convective Organization: The View from the Grid

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DOE Fall Meeting

Rockville, MD, 29 October-2 November 2012

Observational View (Leary and Houze, 1980)

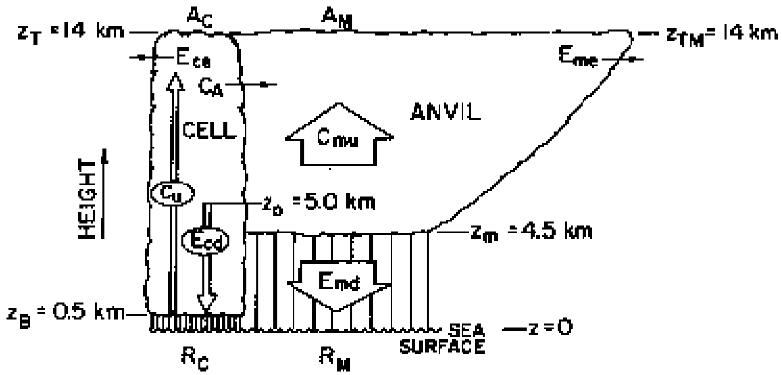
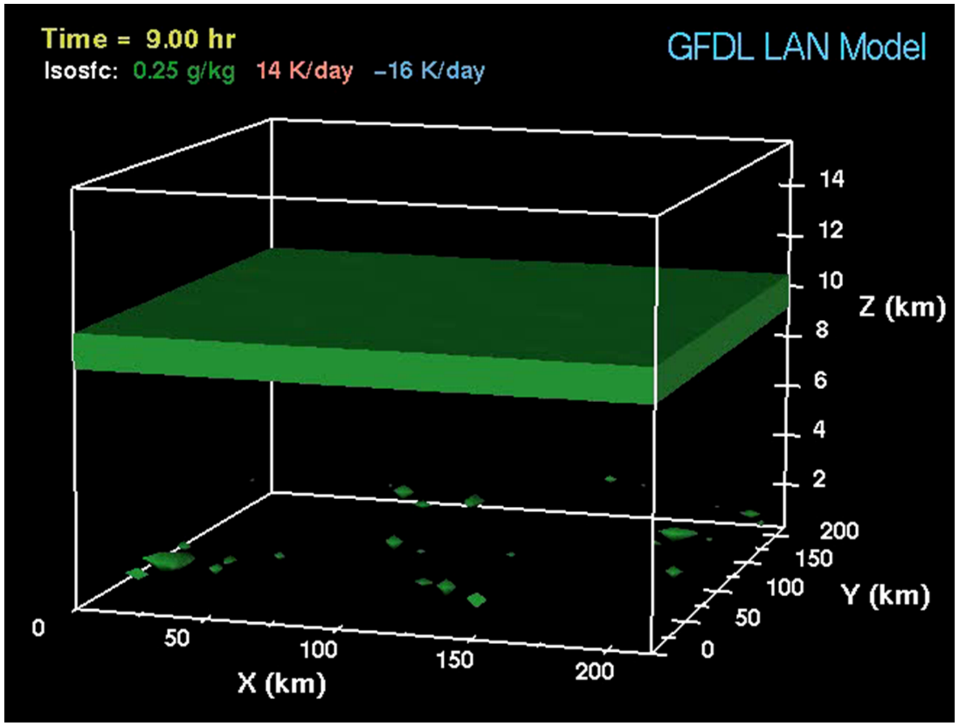


Fig. 2. Schematic vertical cross section of the idealized mesoscale system showing sources and sinks of condensed water. Symbols are defined in Section 2 of the text.

How much convective organization is sub-grid in a climate model?
Can we capture it by parameterization?
Can some types of convective organization only be simulated explicitly in models of sufficiently high resolution?



Donner *et al.* (1999, *J. Atmos. Sci.*)

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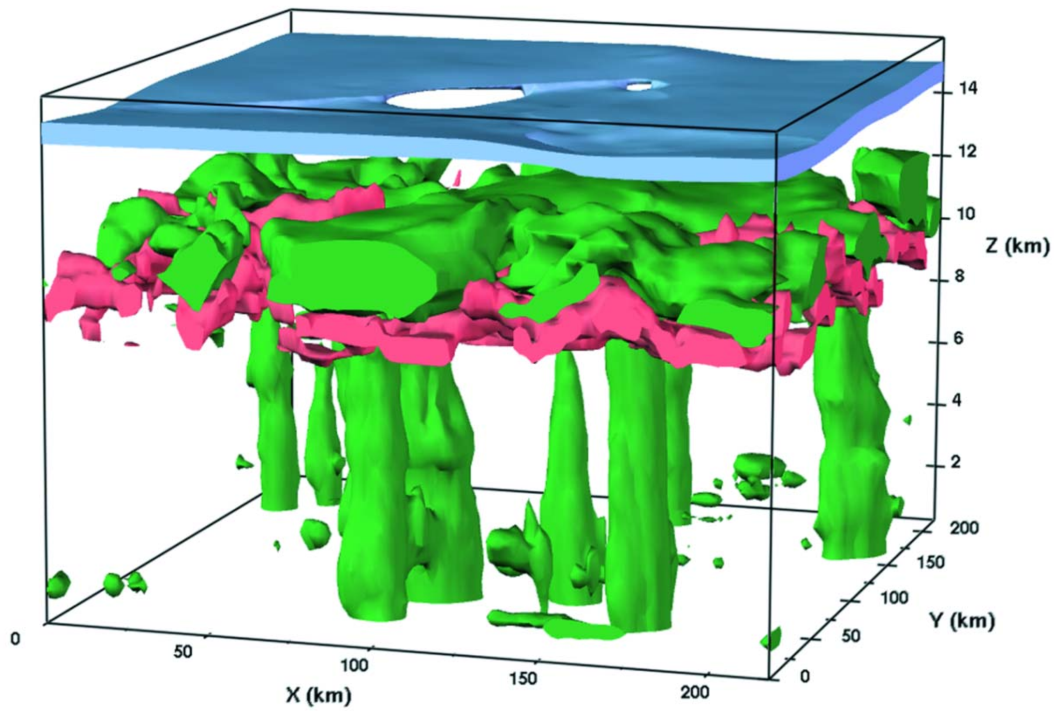
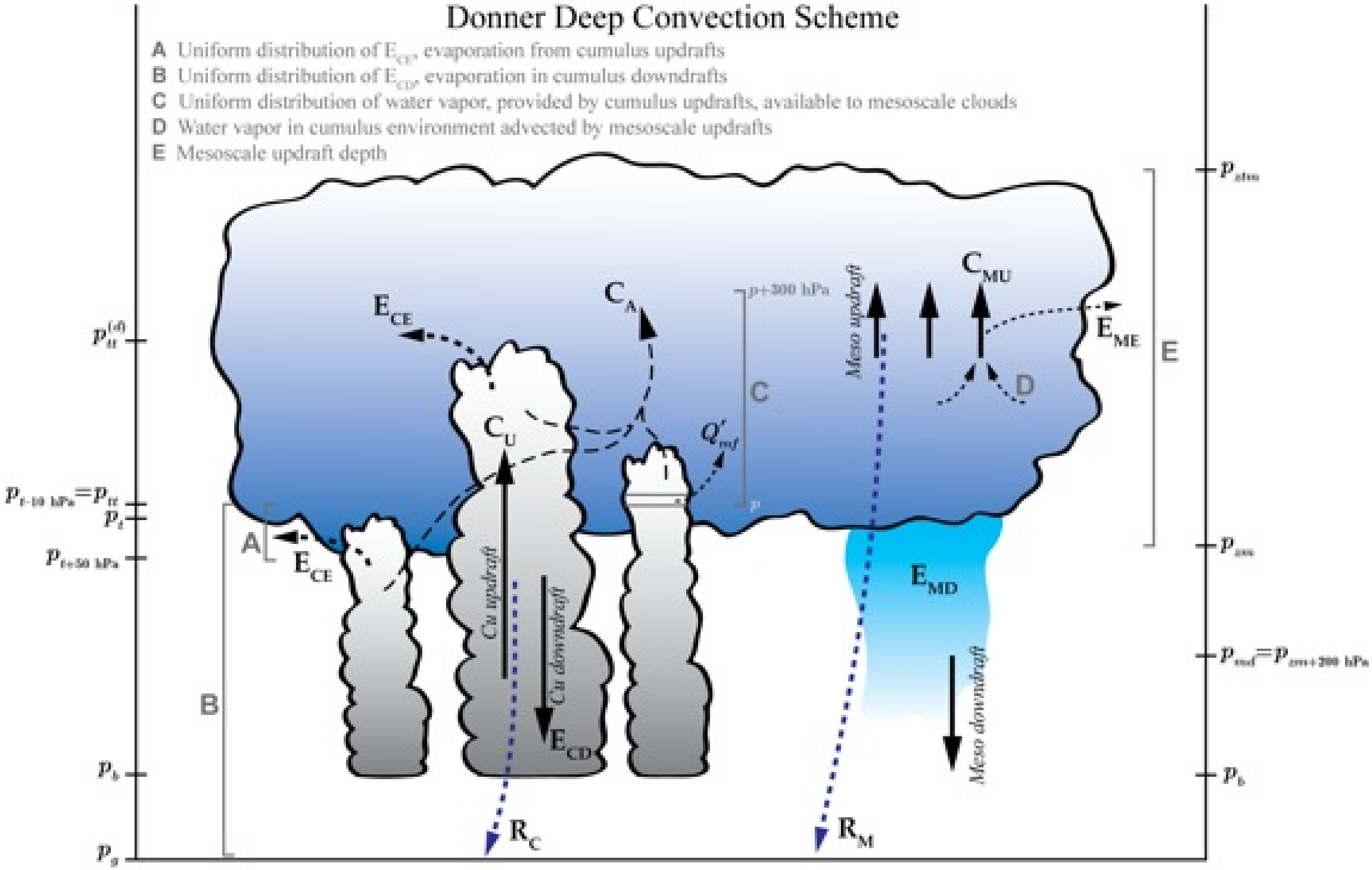


From Donner *et al.* (1999, *J. Atmos. Sci.*)

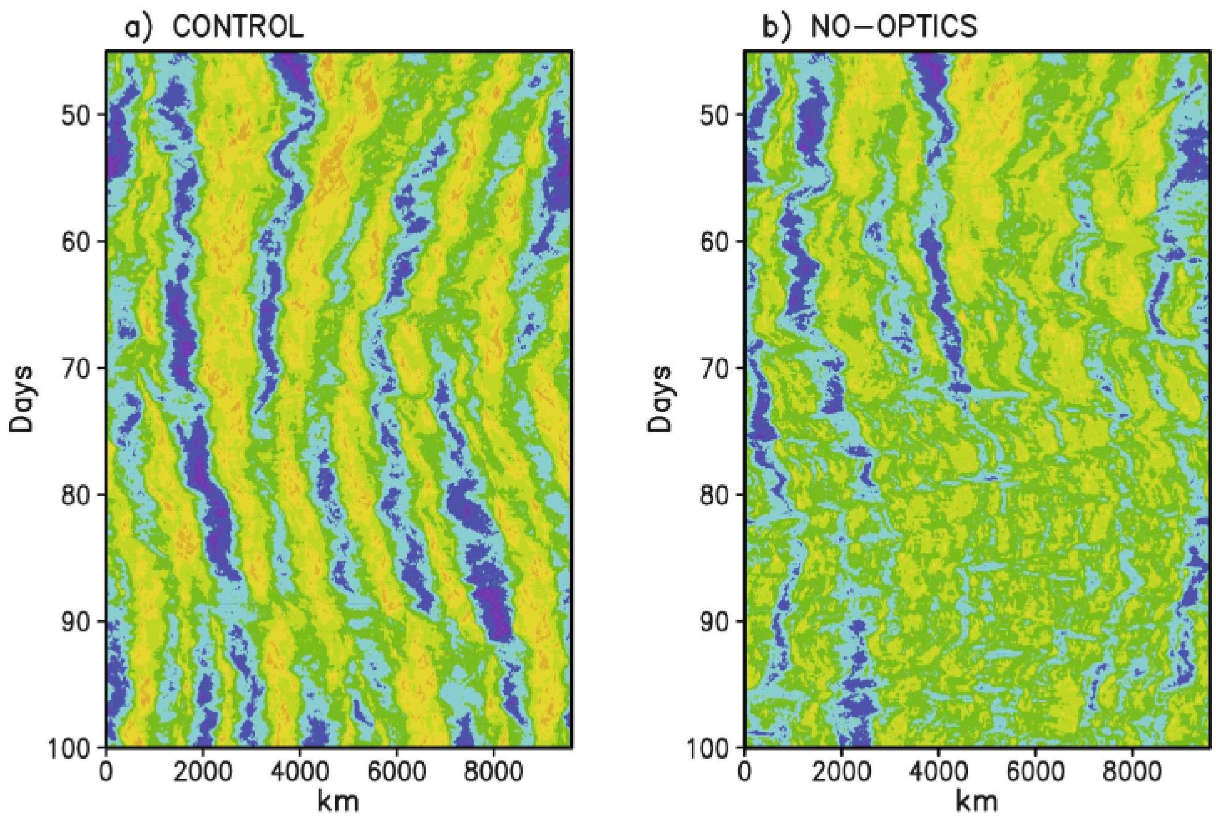
condensate > .25 g/kg; rad heating > 14 K/d; rad cooling < -16 /d

Convective Organization and Cumulus Parameterizations on Single Grid Columns



from Benedict *et al.* (2012, *J. Climate,* in press)

Radiative Influences

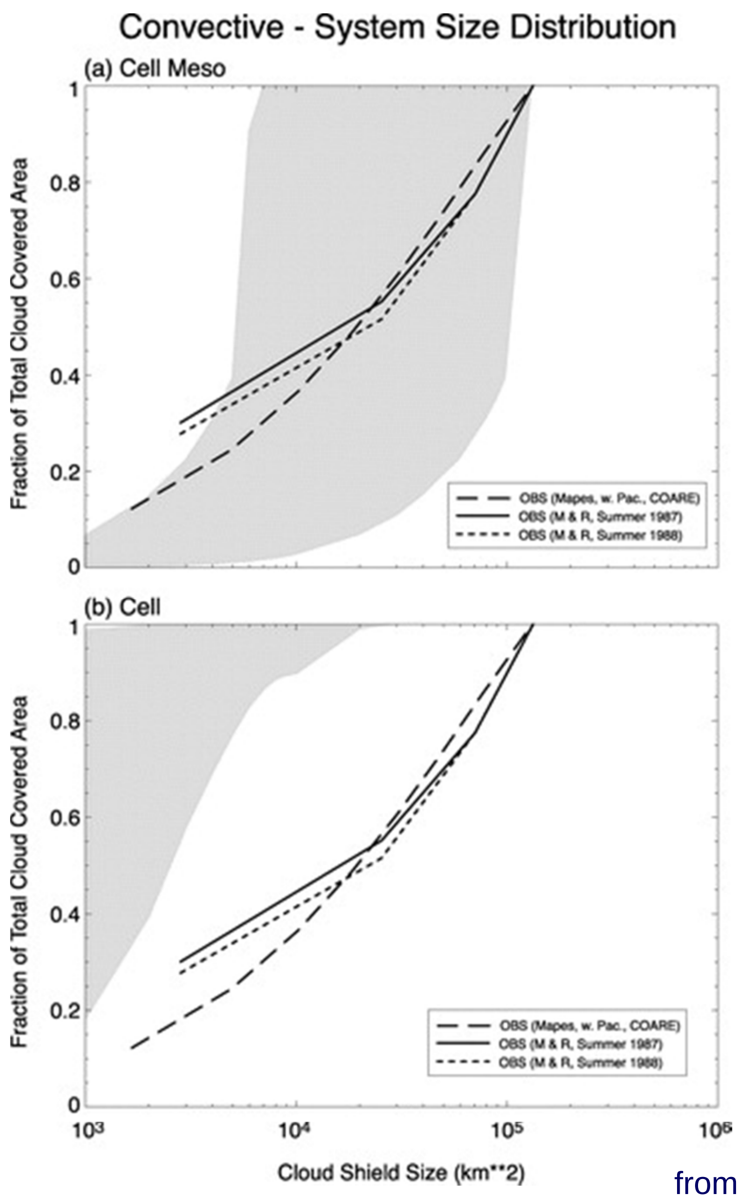


Time series of precipitable water (mm) for fully interactive radiation scheme (left) and interactive radiation without contributions by clouds and precipitation (after Stephens, van den Heever and Pakula, 2008)

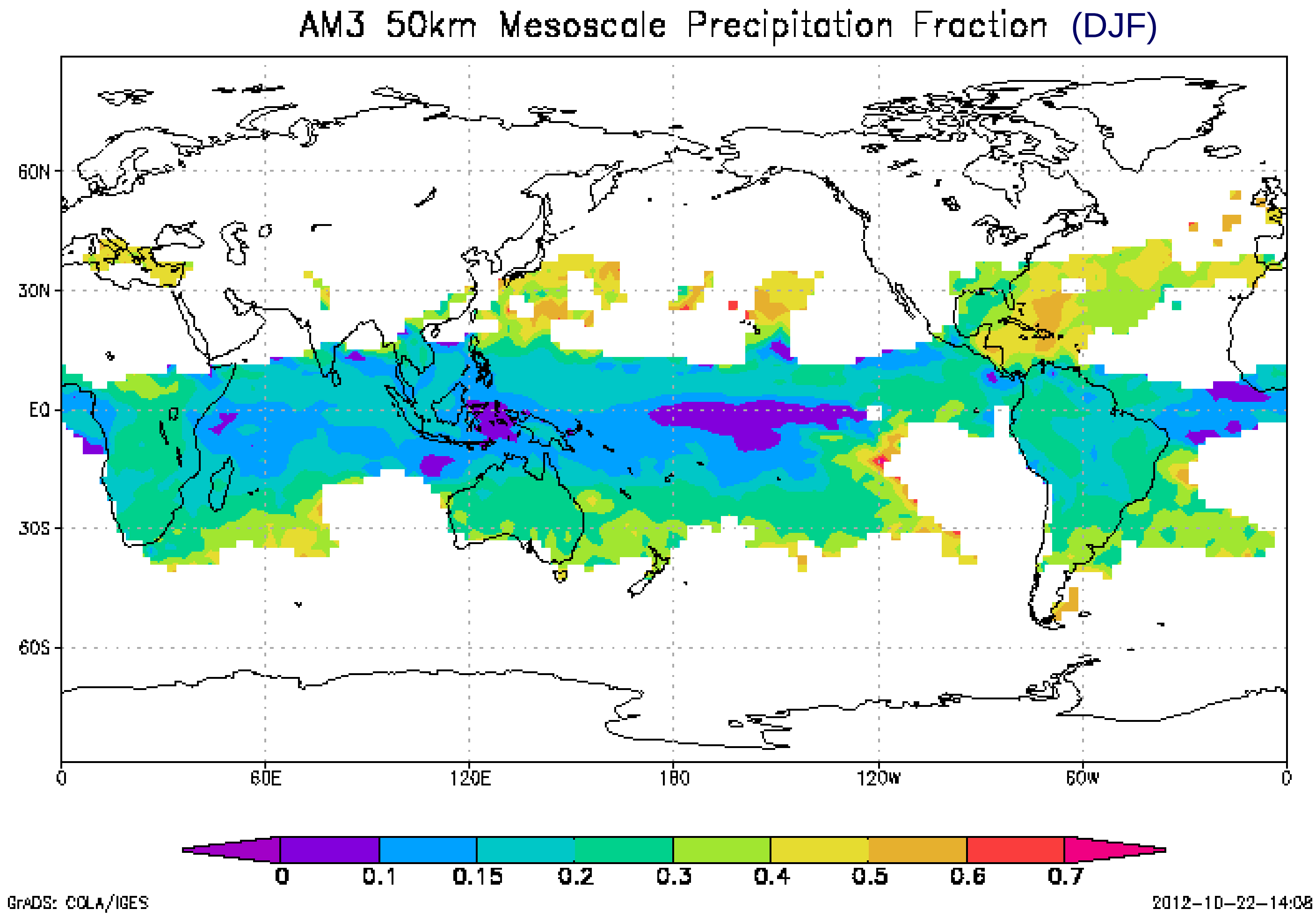
- Breakdown of banded organization
- Effects of clouds on radiative heating and feedbacks to convective organization important

from Sue Van Den Heever, CSU

Sizes of Convective Systems in GFDL AGCM



from Donner *et al.* (2001, *J. Climate*)


AM3 50km Mesoscale Precipitation Fraction (DJF)
60N
30N
EQ
30S
60S
0
60E
120E
180
120W
60W
0
0
0.1
0.15
0.2
0.3
0.4
0.5
0.6
0.7
GrADS: COLA/IGES
2012-10-22-14:08

Until recently, cumulus closures have mostly been based on a grid-mean view of interactions between cumulus plumes and their environment, *e.g.*, quasi-equilibrium.

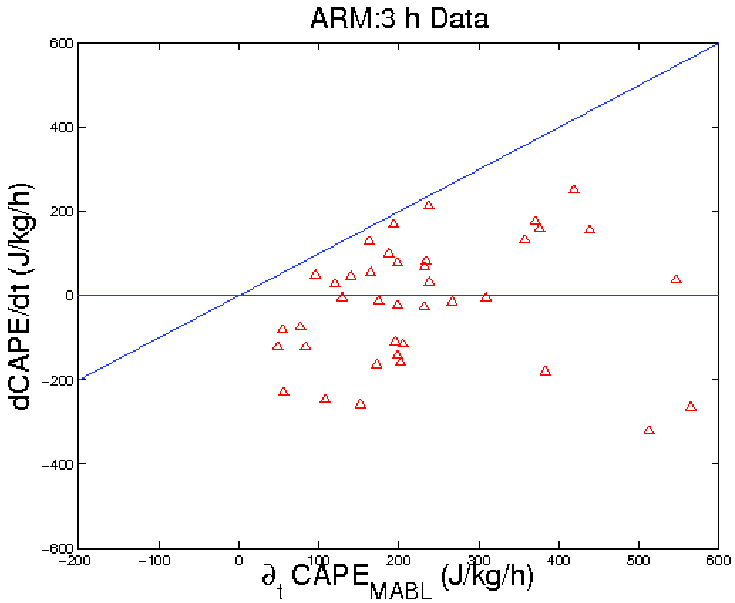
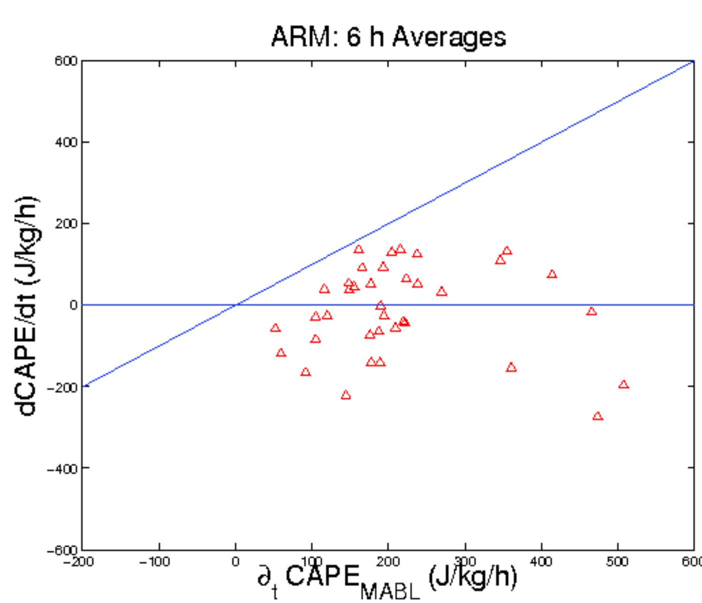


Fig. 4b



from Donner and Phillips (2003, *J. Geophys. Res.*)

Fig. 4c

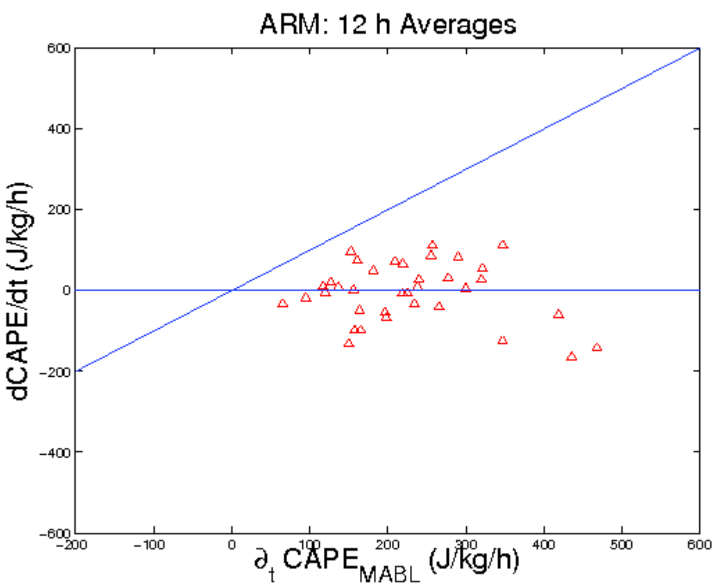
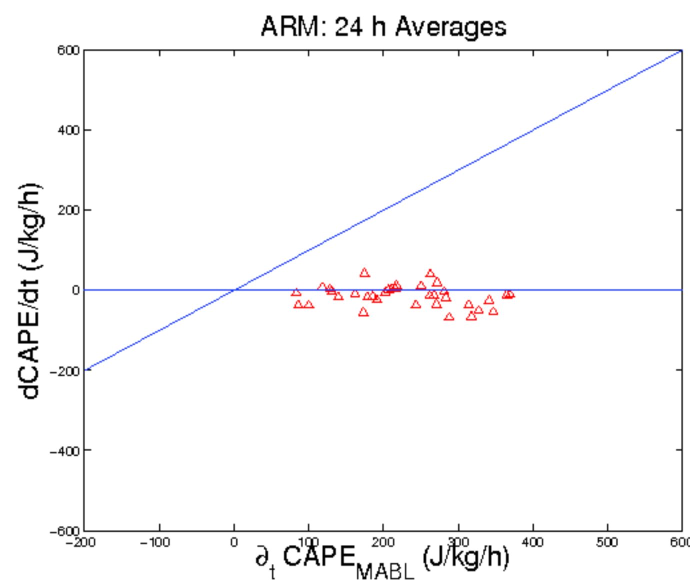
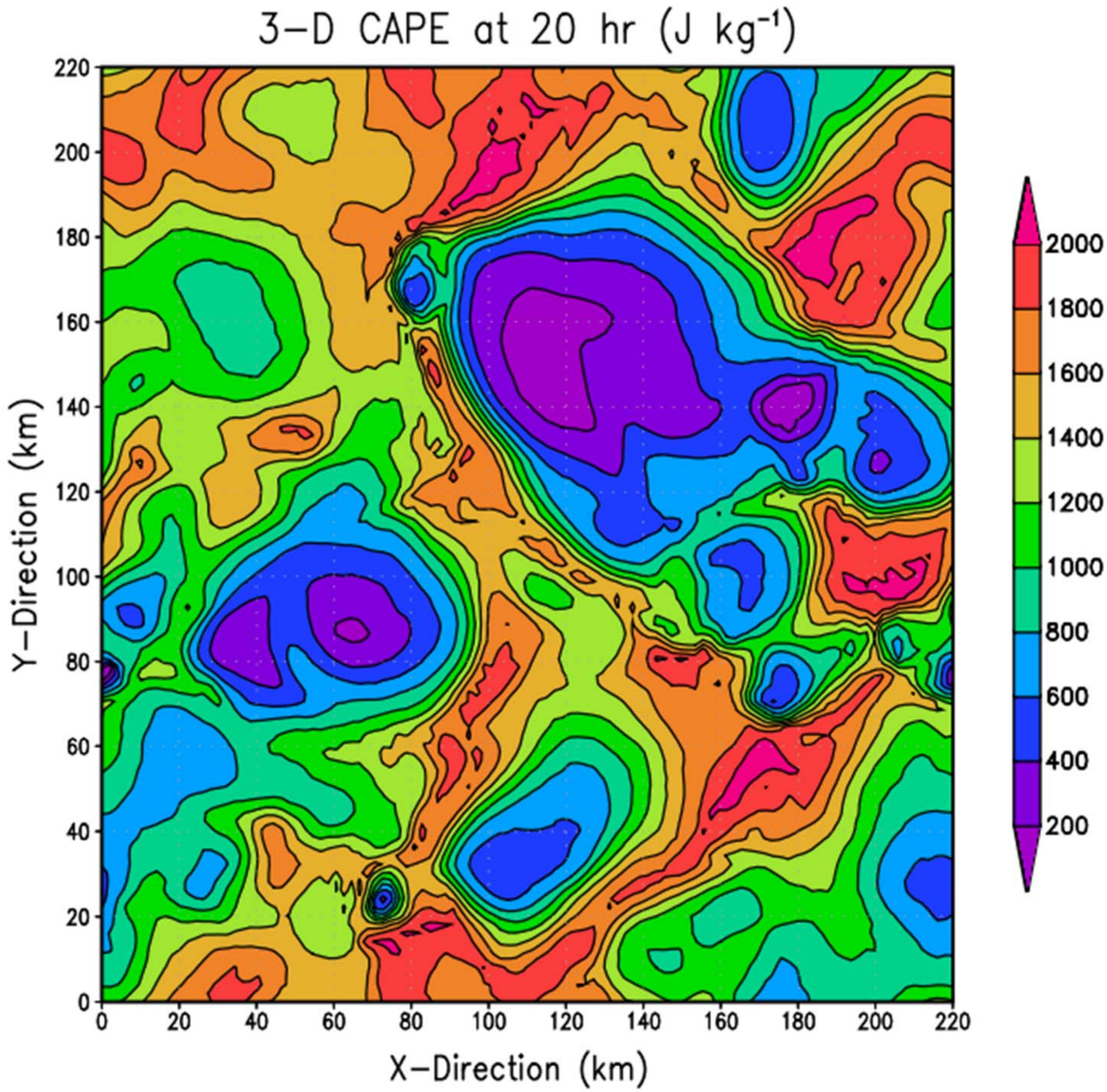


Fig. 4d



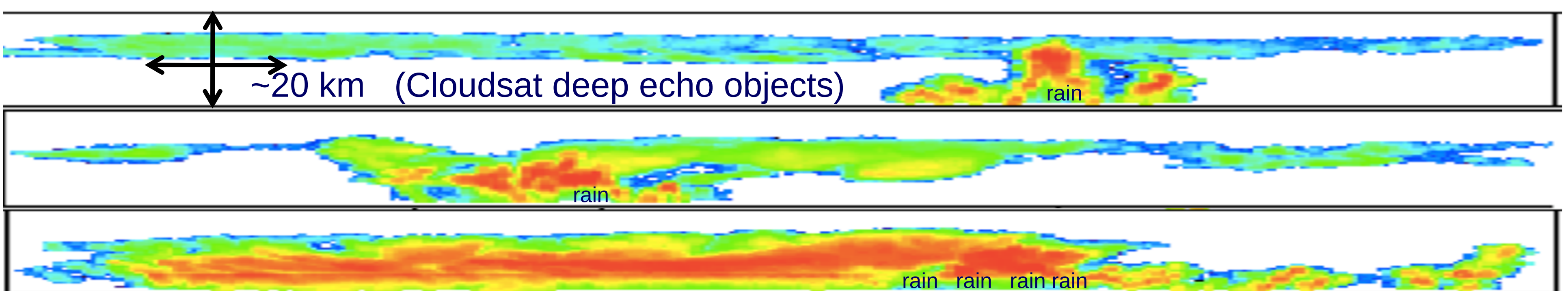
Cloud-resolving models suggest few cumulus plumes “see” grid mean properties. Sub-grid variability in cloud environments is more relevant.



from Donner *et al.* (2001, *J. Atmos. Sci.*)

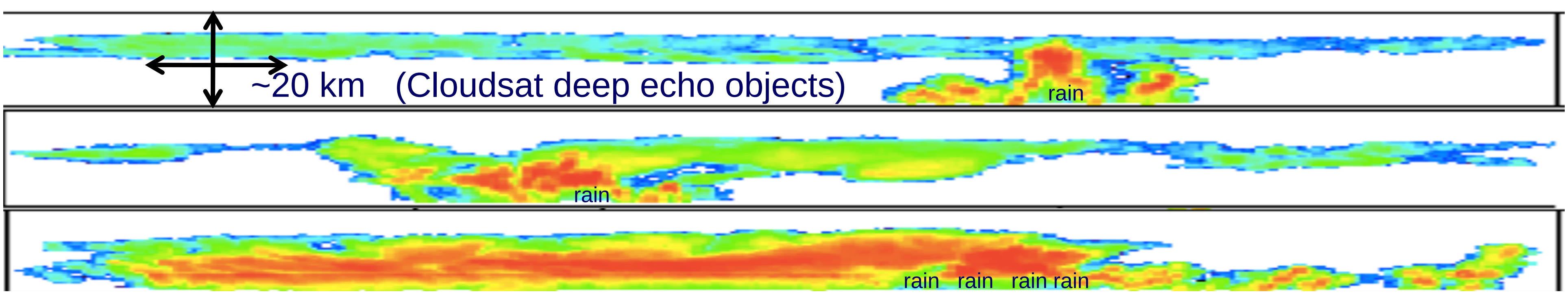
Organized Convection: Conceptual (from Brian Mapes)

- *local* conditions differ from large-scale mean
- preferentially *favorable* -- by natural selection
    - » unfavorable flucts & corrs just lead to non convection
- organization thus a *positive* effect on convection
    - » like boosted parcels, w/less dilution (in plume scheme terms)
- organization a positive *feedback*, but takes time
    - » new development updrafts struggle initially for lack of it
- tuned GCMs assume *ubiquitous org.*, not lack of it
    - » new convection encounters *mean* convection's advantages



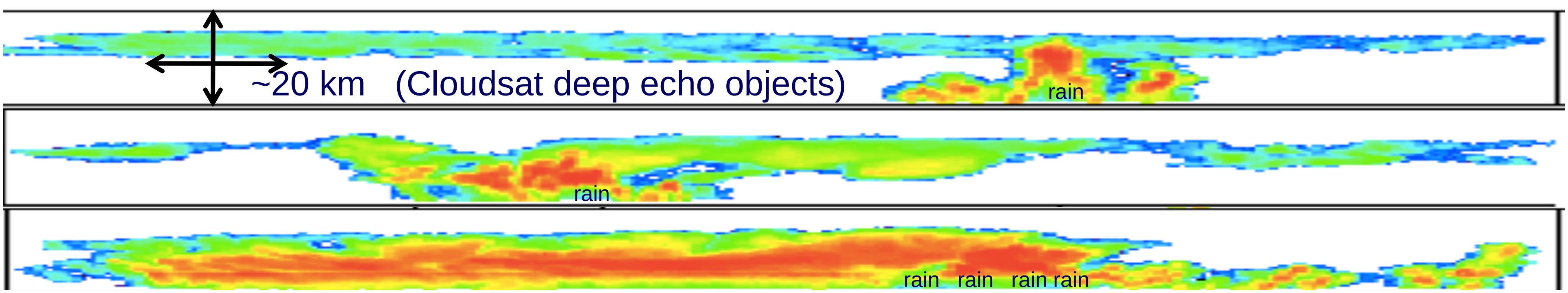
Organized Convection: Treatments (from Brian Mapes)

- There are many observed aspects to organization
  - preferential nonwake updraft source, outflow boundary triggering, moist patches aloft, CIN reduction by gravity wave T', correlations of all these, etc.
  - *natural selection exploits all* (although not with perfect efficiency)
- The concept thus has a footprint in many schemes
  - wake schemes, plume ensembles, "CKE/MKE", parcel boosts, entrained air preconditioning, tails & correlations in PDF scheme(s), nonlinear skews to stochastic CIN/CAPE, etc.
- None is wrong; all are incomplete; any could be tuned to give enough net *climatological boost & positive feedback*



Organized Convection: Other Effects (from Brian Mapes)

1. Anvil clouds abut convection in mesoscale storms
   - they have significant cross-isentrope flows, hinging on cloud & precipitation processes
     – treatments:
       » append to cumulus scheme (GFDL, Donner)
       » anvil category of LS cloudiness (GEOS-5, Bacmeister &al., Donner anvil also feeds LS cloudiness)
2. Exotic momentum flux effects (like 2D vs. 3D)
   - depends on details of geometry, not just clumping
     – hence on shear over various layers
     – uncertain to parameterize; cumulative impacts above noise (?)

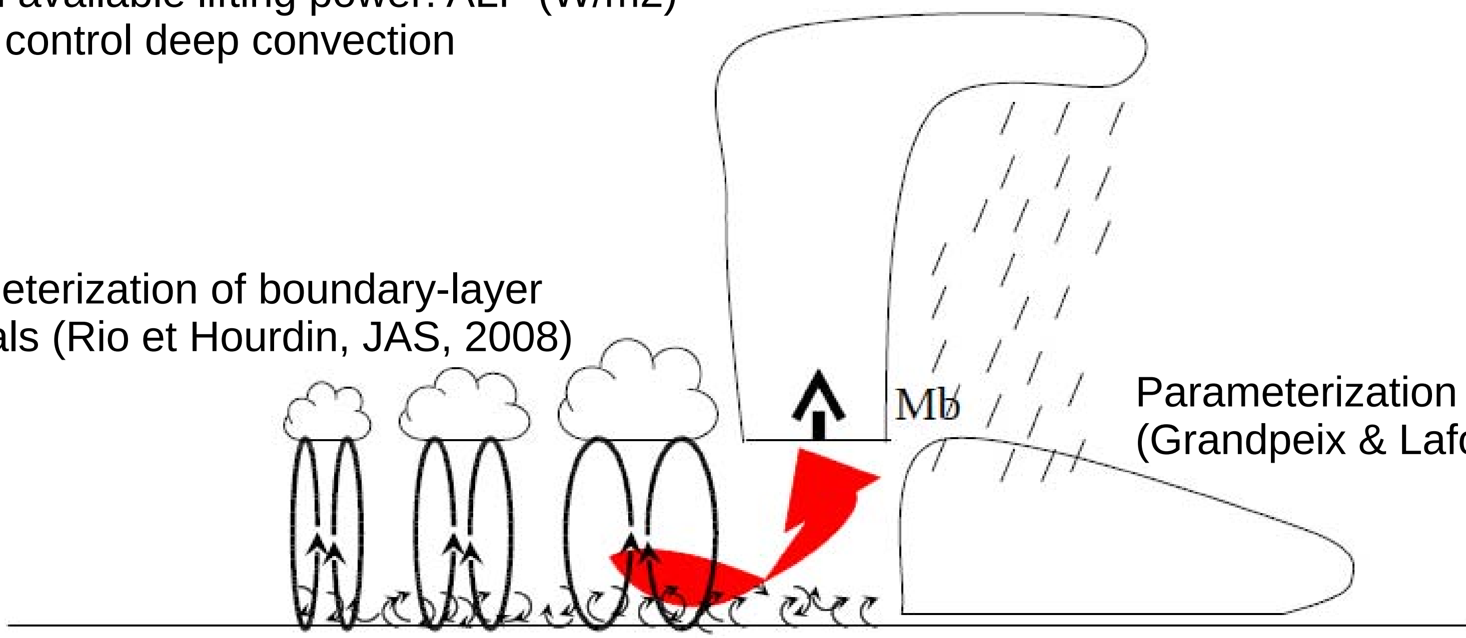


Control of deep convection by sub-cloud lifting processes: The ALP closure in the LMDZ5B general circulation model

Rio et al., *Clim. Dyn., 2012*

Sub-cloud lifting processes, boundary-layer thermals (th) and cold pools (wk), provide:
> an available lifting energy: ALE (J/kg) and
> an available lifting power: ALP (W/m2)
that control deep convection

Parameterization of boundary-layer thermals (Rio et Hourdin, JAS, 2008)



Parameterization of cold pools (Grandpeix & Lafore, JAS, 2011)

Triggering:

MAX(ALEth, ALEwk) > |CIN|

Closure:

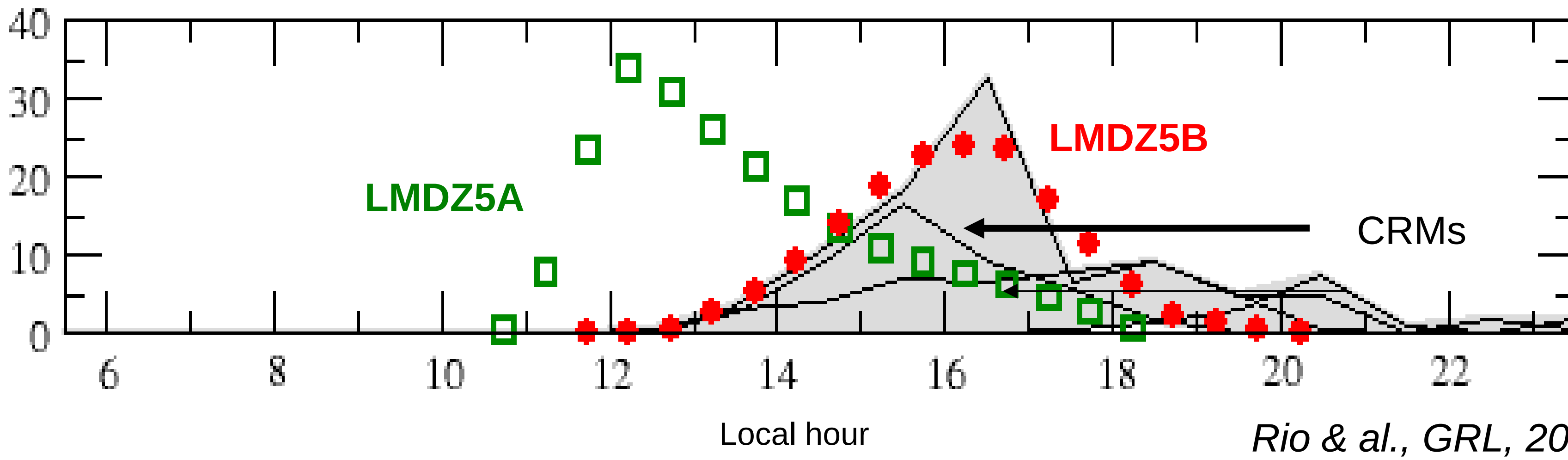
$$M_b = \frac{ALP}{[|CIN| + 2{w_b}^2]}$$

ALP = ALPth+ALPwk ~ w'3

wb=f(PLFC)

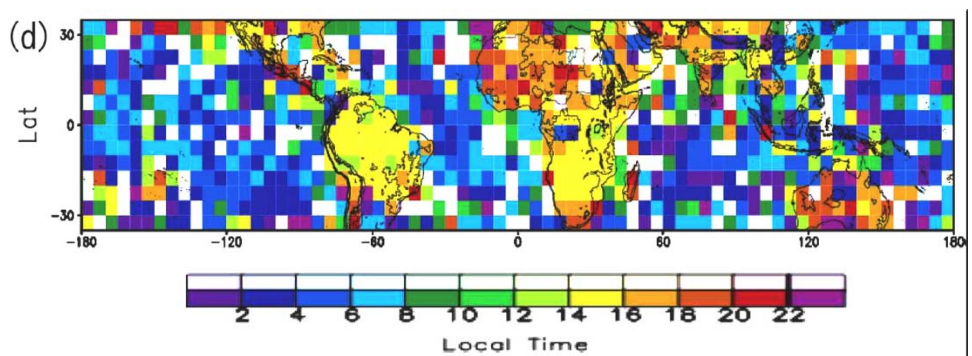
Diurnal cycle of convection over land: From 1D to global simulations

Diurnal cycle of precipitation (mm/day) the 27 of June 1997 in Oklahoma (EUROCS case)

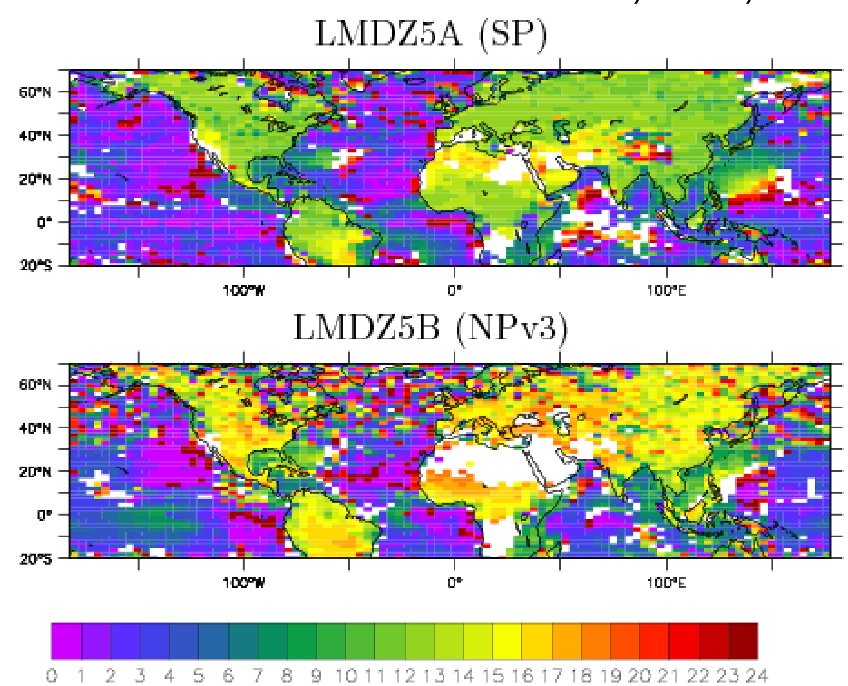


Rio & al., GRL, 2009

Shift of the local hour of maximum rainfall in 1D and 3D simulations



Observations (TRMM, from Hirose et al., 2008)



LMDZ5A: CAPE Closure LMDZ5B: ALP Closure

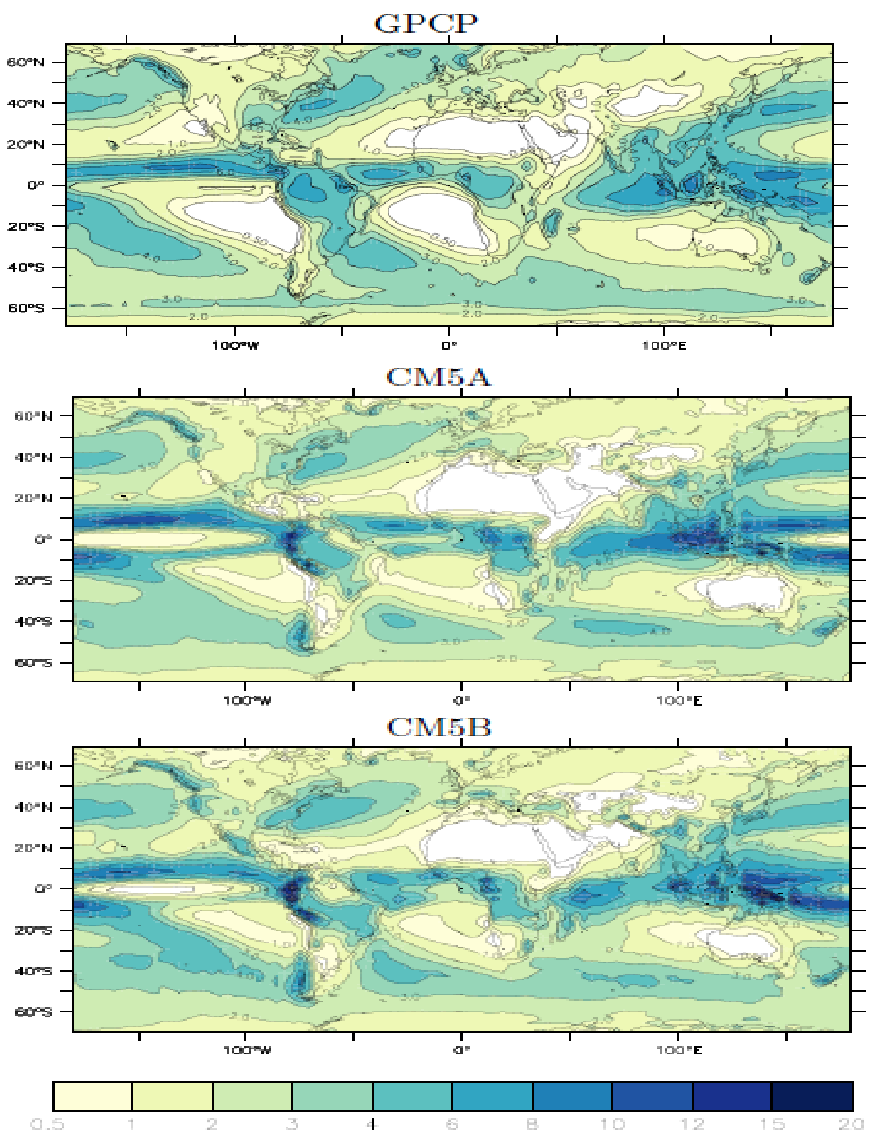
Rio & al., 2012

Impact on precipitation mean and variability

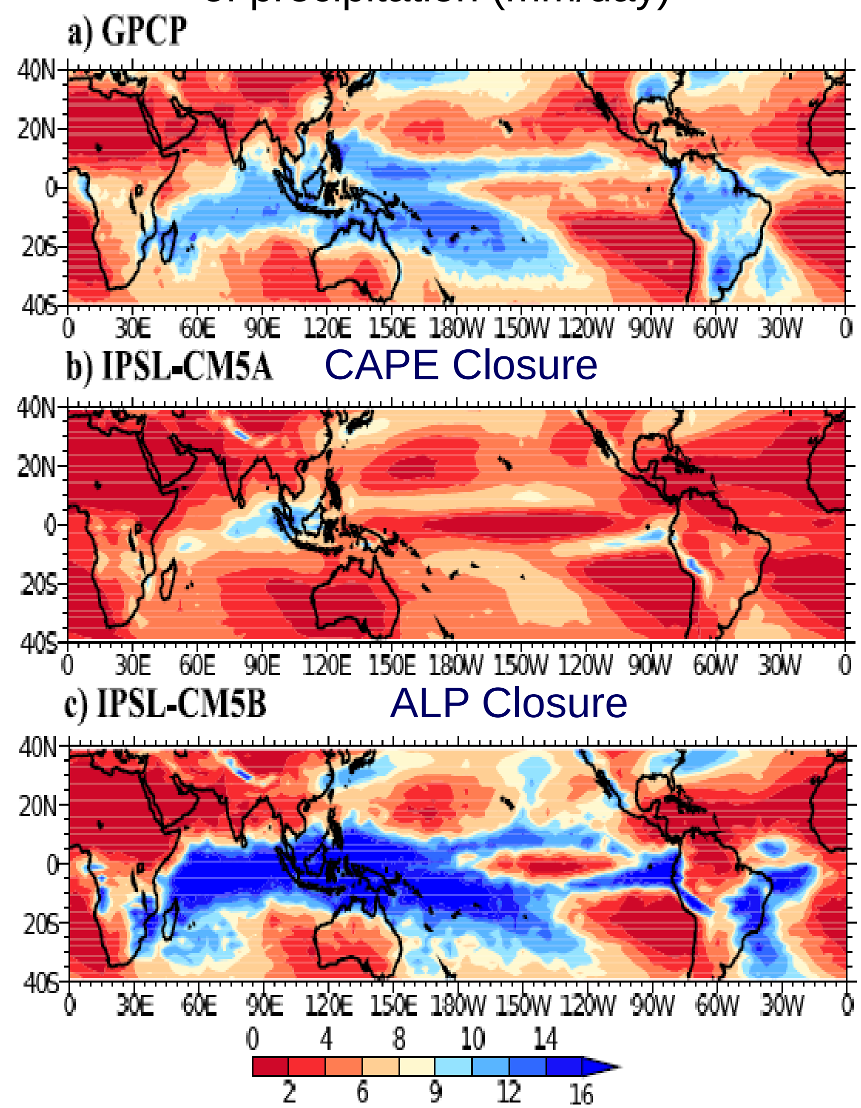
Hourdin et al., Clim. Dyn. 2012

IPSL-CM5A/CM5B: 10 years of coupled pre-industrial simulations

Mean precipitation (mm/day)



Intra-seasonal variability of precipitation (mm/day)



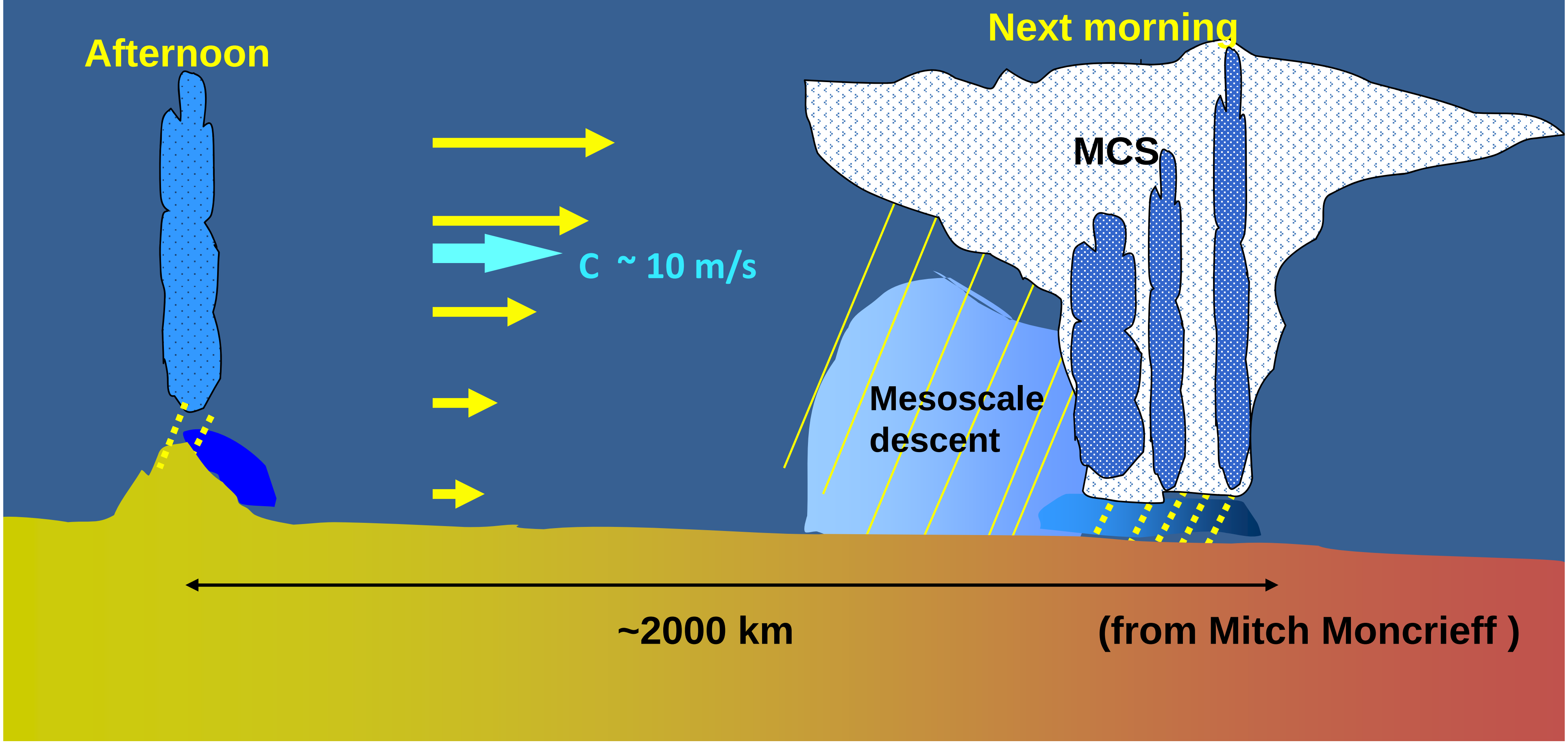
Some impact on precipitation annual mean

Strong impact on intra-seasonal variability

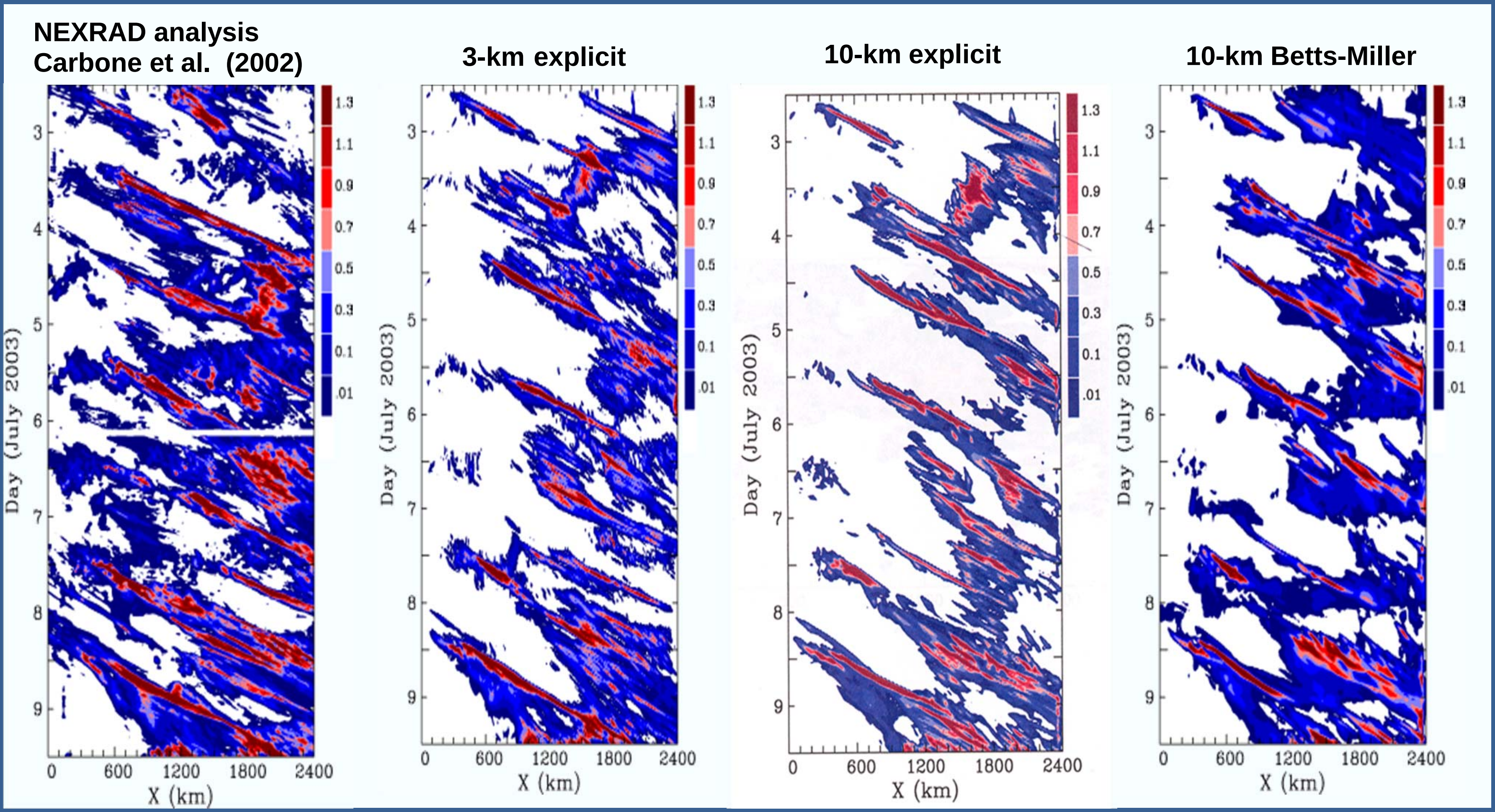
Some types of organized convection have such large space and time scales that they are most easily modeled explicitly in high-resolution models.

Orogenic MCS and the diurnal cycle of precipitation

Vertical shear organizes sequences of cumulonimbus into long-lasting mesoscale convective systems (MCS), which propagate across continents, efficiently transporting heat, moisture and momentum



Propagating MCS over U.S. continent



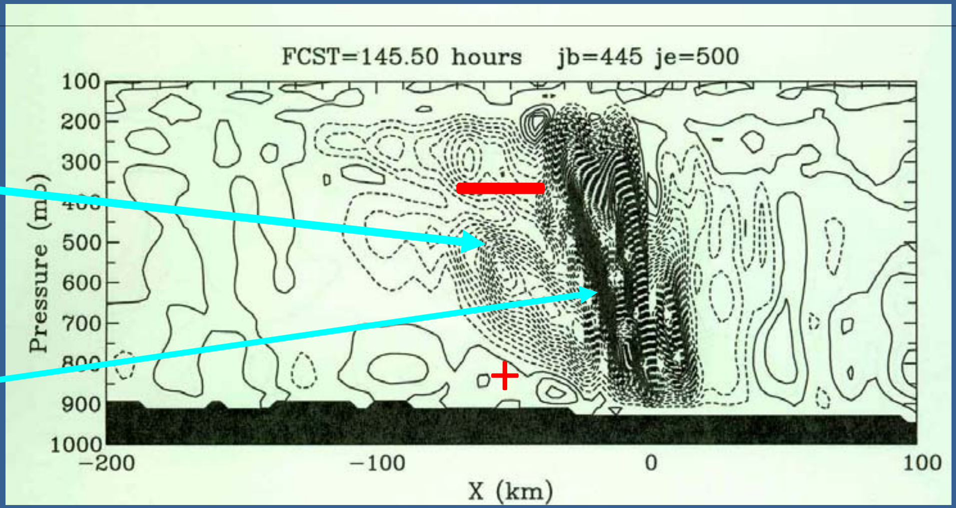
Moncrieff & Liu (2006)

Effect of resolution on CMT:

Negative for 3 km & 10 km grids, positive (incorrect) for 30 km grid

Mesoscale circulation

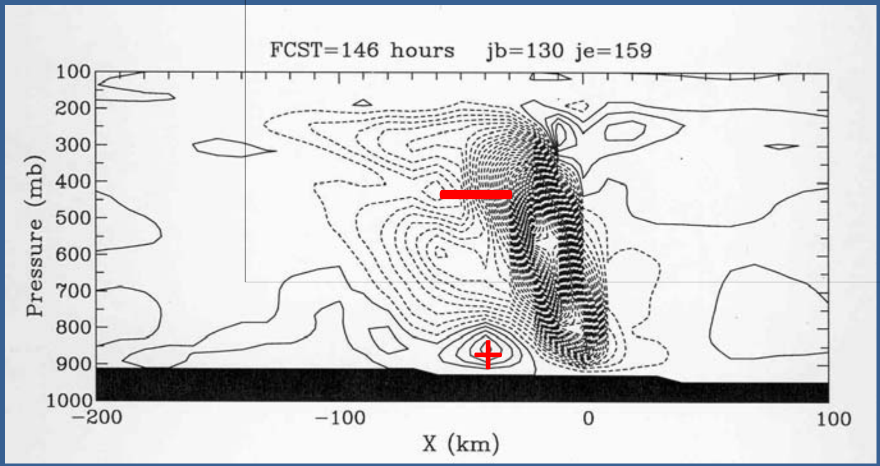
Cumulonimbus family



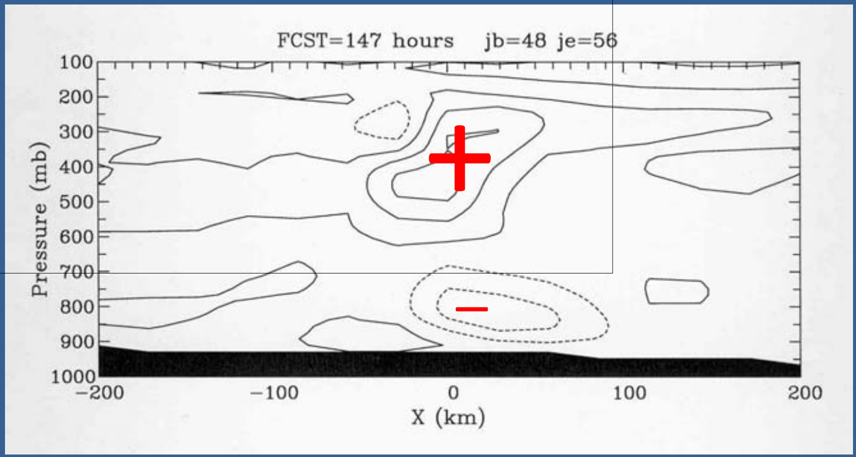
$\Delta = 3\,km$

C

Sign of CMT is <u>negative</u> -- opposite to propagation vector (C) -- due to rearward-tilted airflow



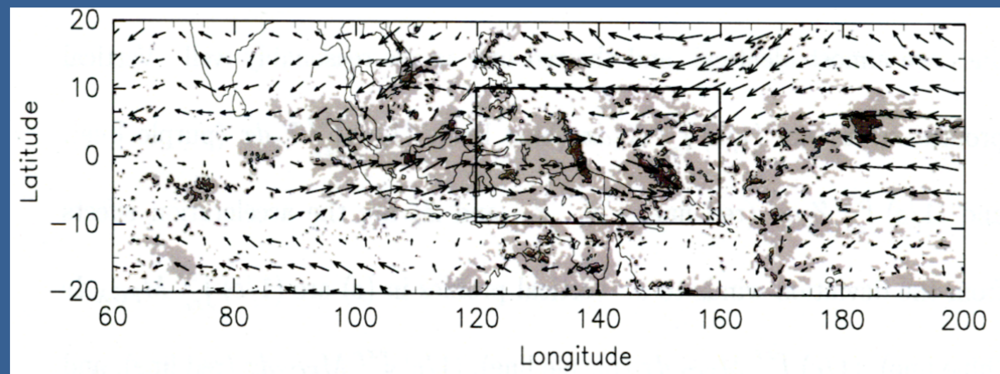
$\Delta = 10\,km$

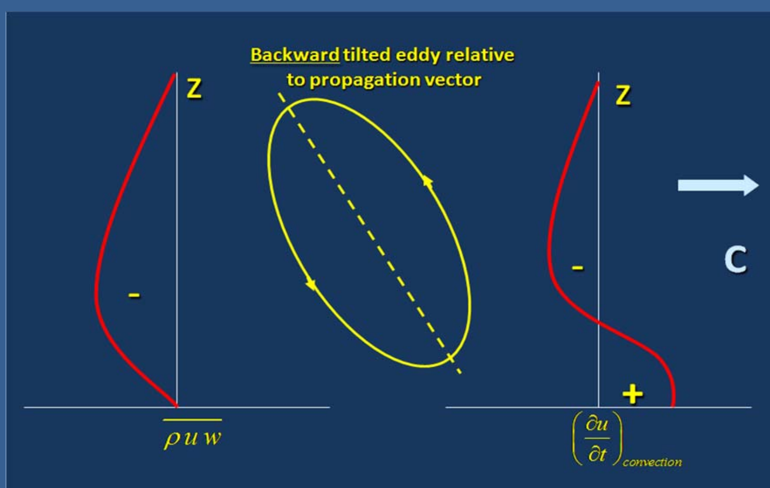


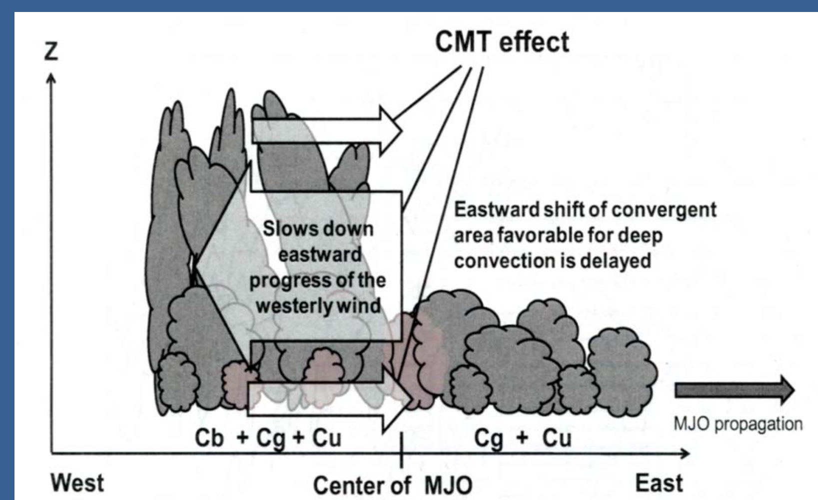
$\Delta = 30\ km$

from Mitch Moncrieff

Convective momentum transport by MCS in MJOs simulated by a global cloud-system resolving model (NICAM)







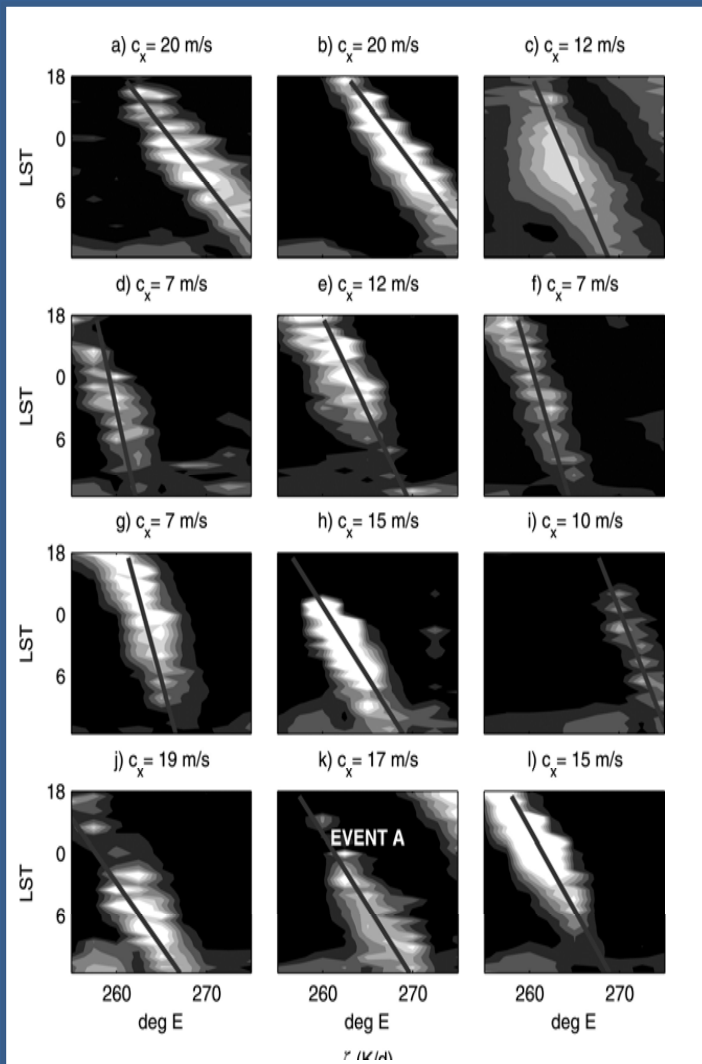
$$\frac{\partial \bar{u}}{\partial t} + \dots\dots\dots\dots = -\frac{\partial}{\partial z}\left(\overline{u_m w_m}\right) = \left(\frac{\delta u}{\delta t}\right)_{convection}$$

Miyakawa et al. (2011)

Even convective organization with large space and time scales can be simulated to some extent using appropriately cumulus parameterizations.

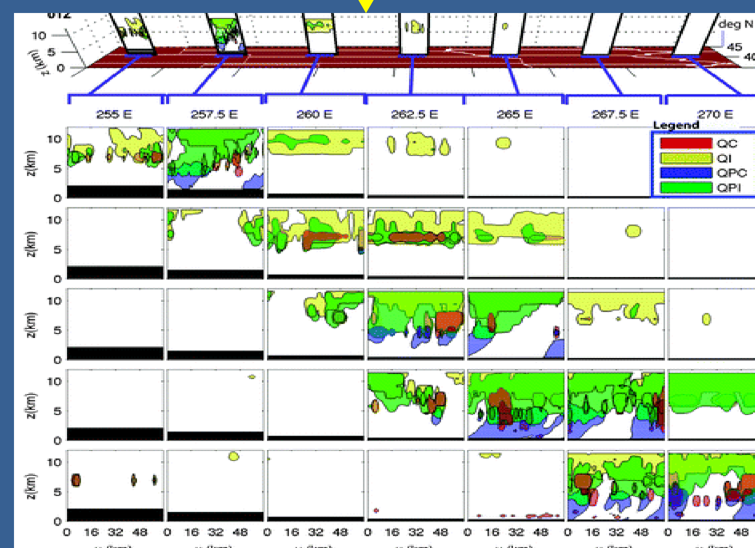
Orogenic MCS over U.S. continent

Superparameterized Community Atmospheric Model (SPCAM)

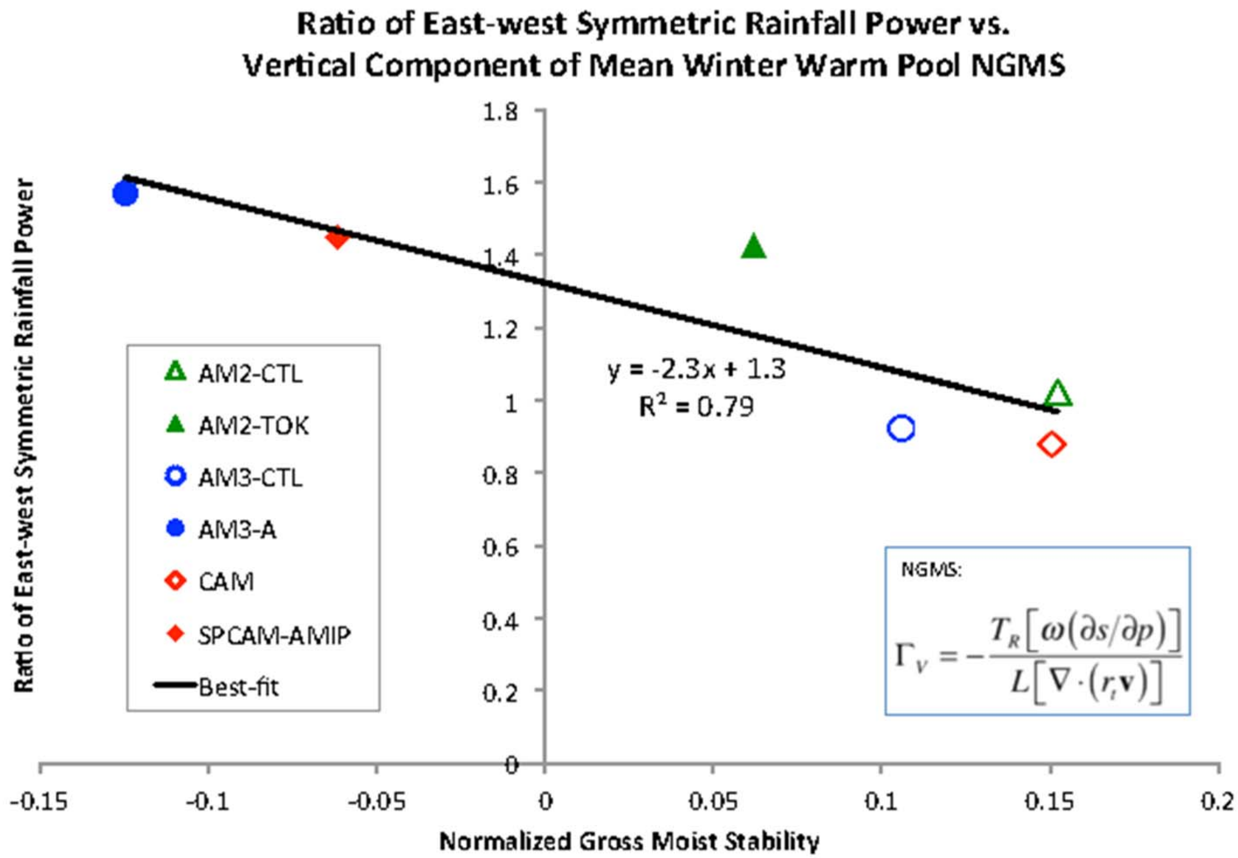


CAM: standard convection parameterization – No MCS

SPCAM: convective heating generated on 2-D CRM grid is organized by large-scale shear into propagating MCS on the climate model grid



Pritchard, Moncrieff & Somerville (2011)



AM3-CTL and AM3-A differ in their deep convective closures and triggers.

from Jim Benedict

Summary

- Convective organization occurs in both cloud morphology and cloud environments in observations and cloud-system-resolving models.
- GCMs are beginning to incorporate stratiform portions of convective systems and replace grid-mean closures and triggers with approaches that incorporate sub-grid organization in cloud environments and boundary layers.
- Some aspects of convective organization span space and time scales that are so large that they are best modeled explicitly by high-resolution models. Even these aspects can be at least partly captured by designing traditional cumulus parameterizations appropriately.