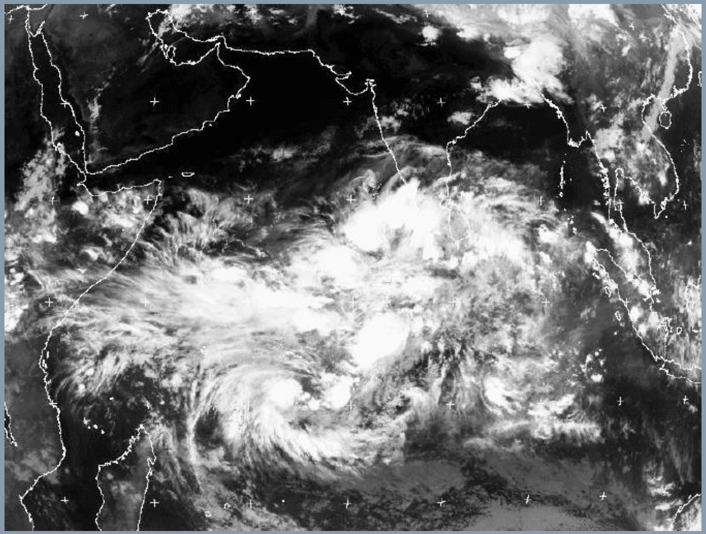
Organized Tropical Convection and the Weather-Climate Intersection

Mitchell W. Moncrieff
Climate & Global Dynamics Division
NCAR Earth System Laboratory



YOTC International Science Symposium
Session 1: Generic Elements of YOTC
CMA , Beijing, China
16-18 May, 2011

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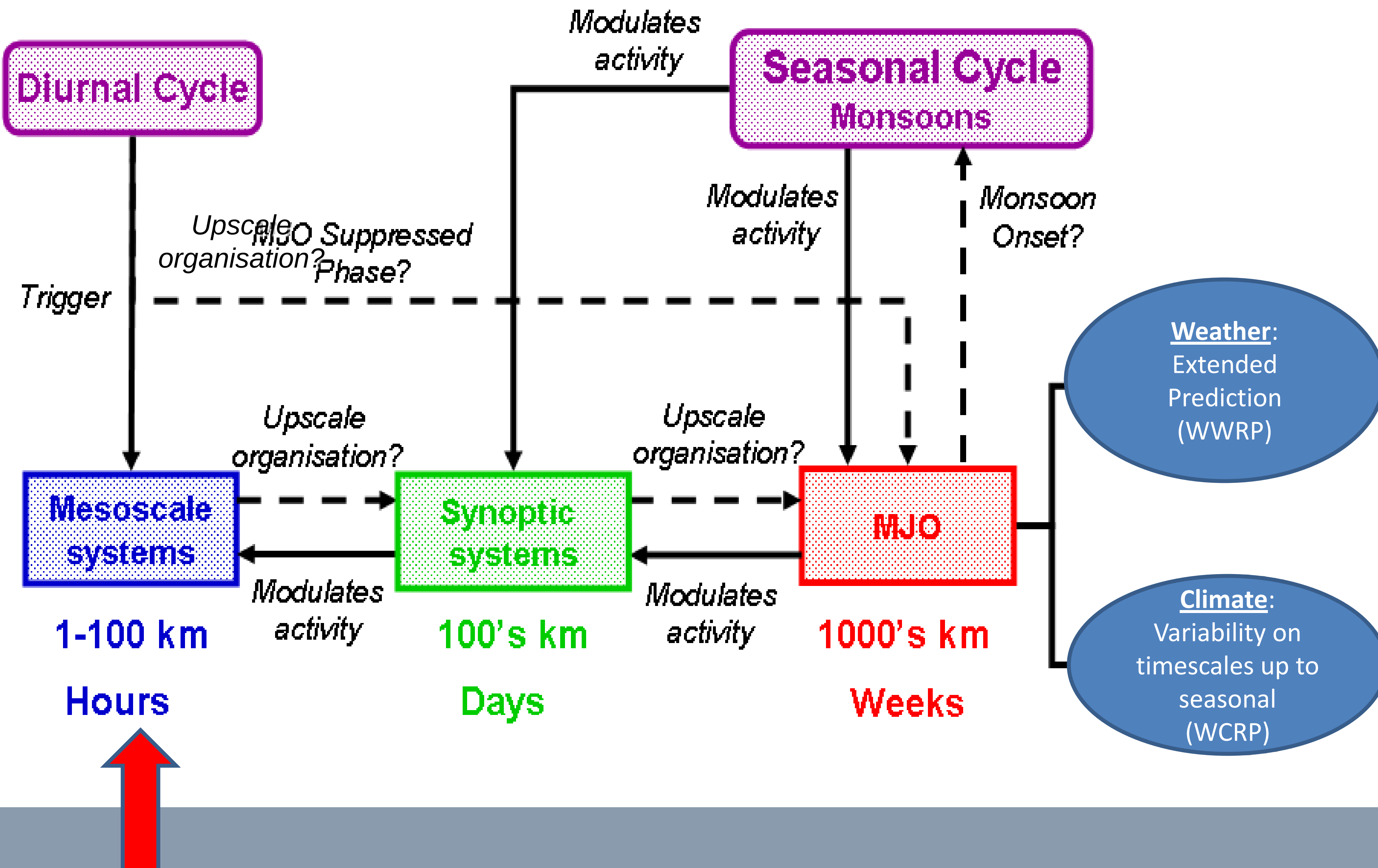
Discrete spectrum of organized tropical convection



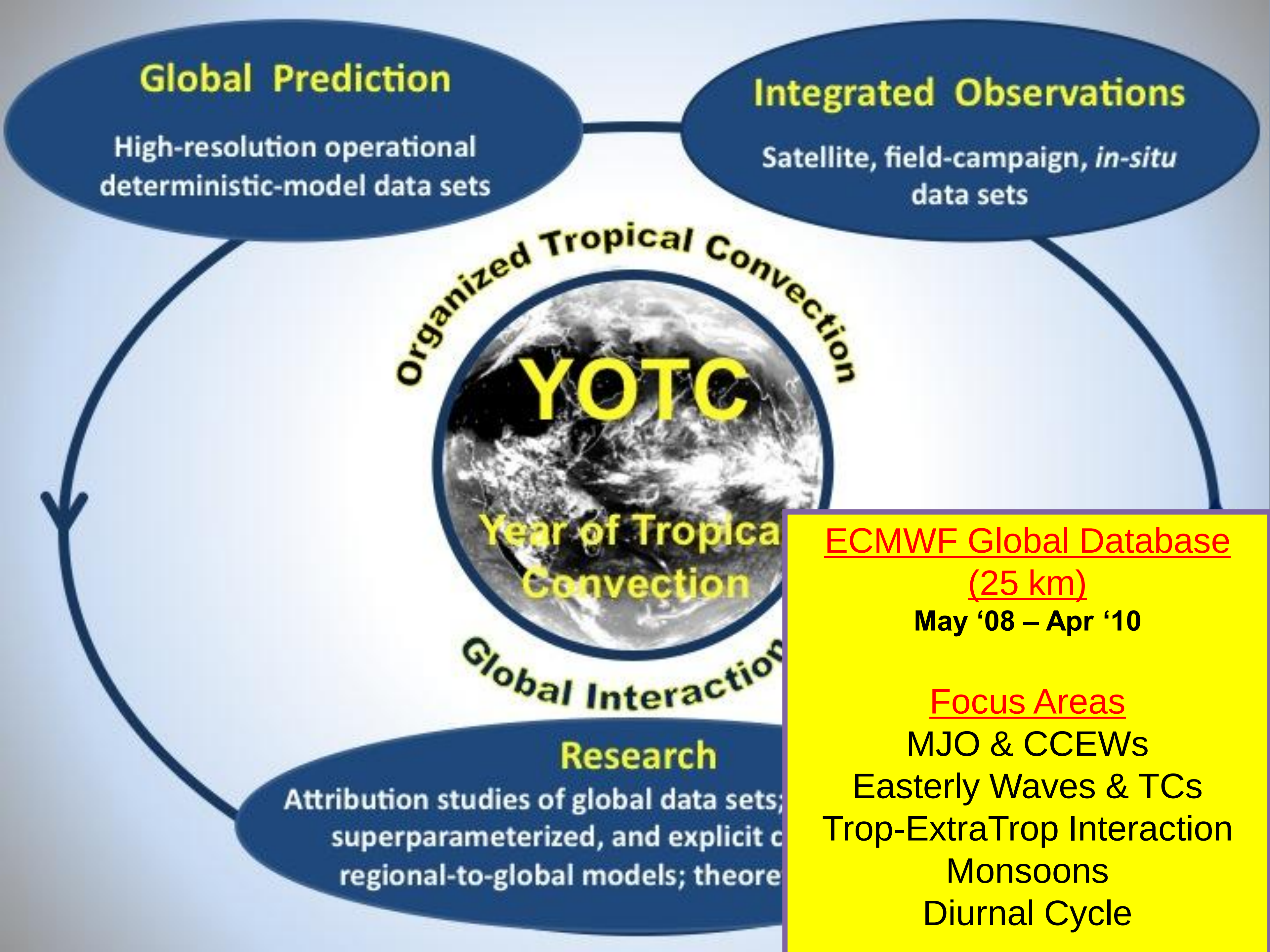
Building Block ?

Adapted from Moncrieff et al. (2007)

Year of Tropical Convection (YOTC)

Collaborative research at the intersection of weather and climate (timescales up to seasonal) with emphasis on multi-scale convective organization and its interaction with the large-scale circulation

A focused contribution to Seamless Prediction



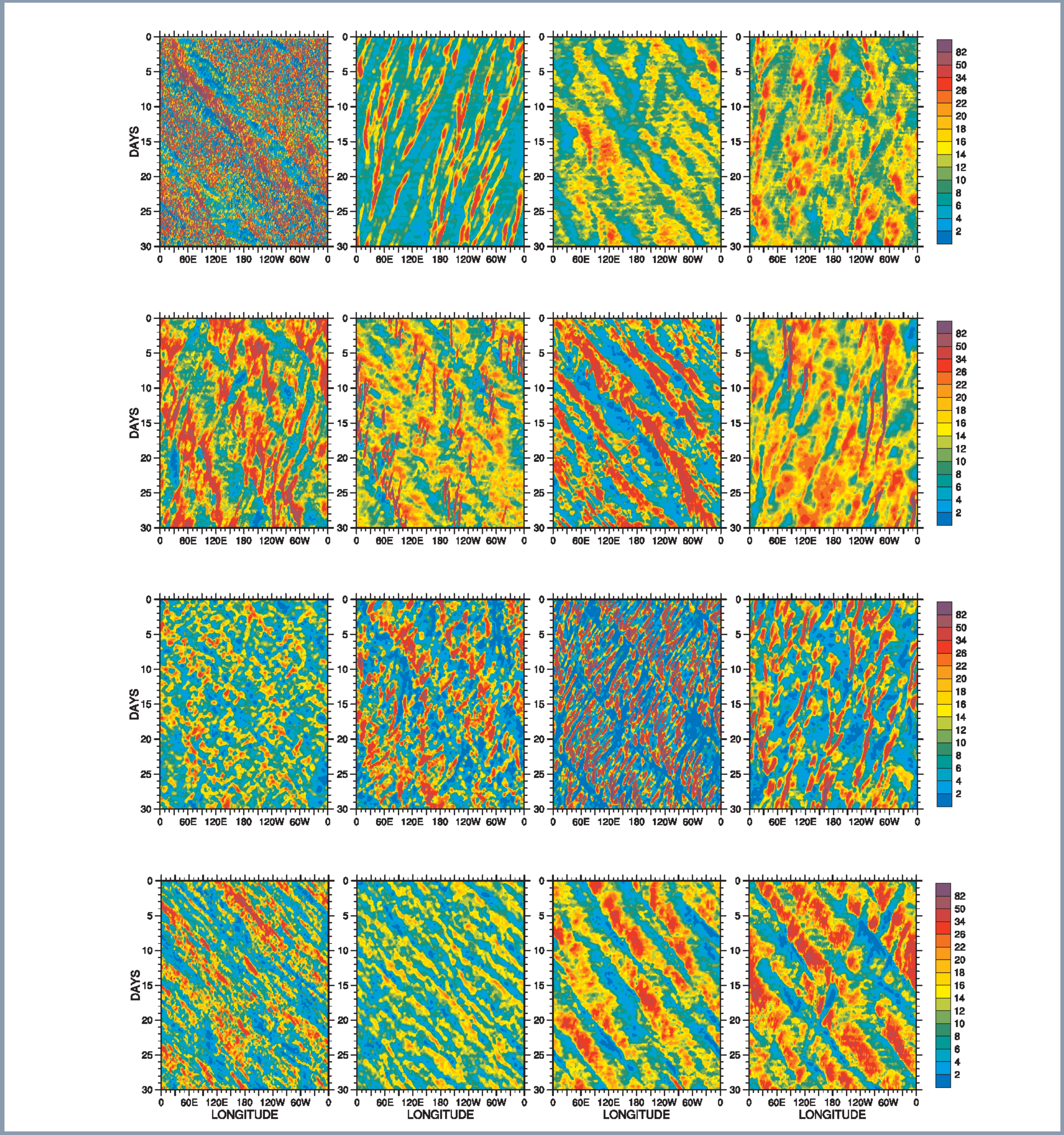
<u>ECMWF Global Database (25 km)</u>

May '08 – Apr '10

<u>Focus Areas</u>

MJO & CCEWs
Easterly Waves & TCs
Trop-ExtraTrop Interaction
Monsoons
Diurnal Cycle

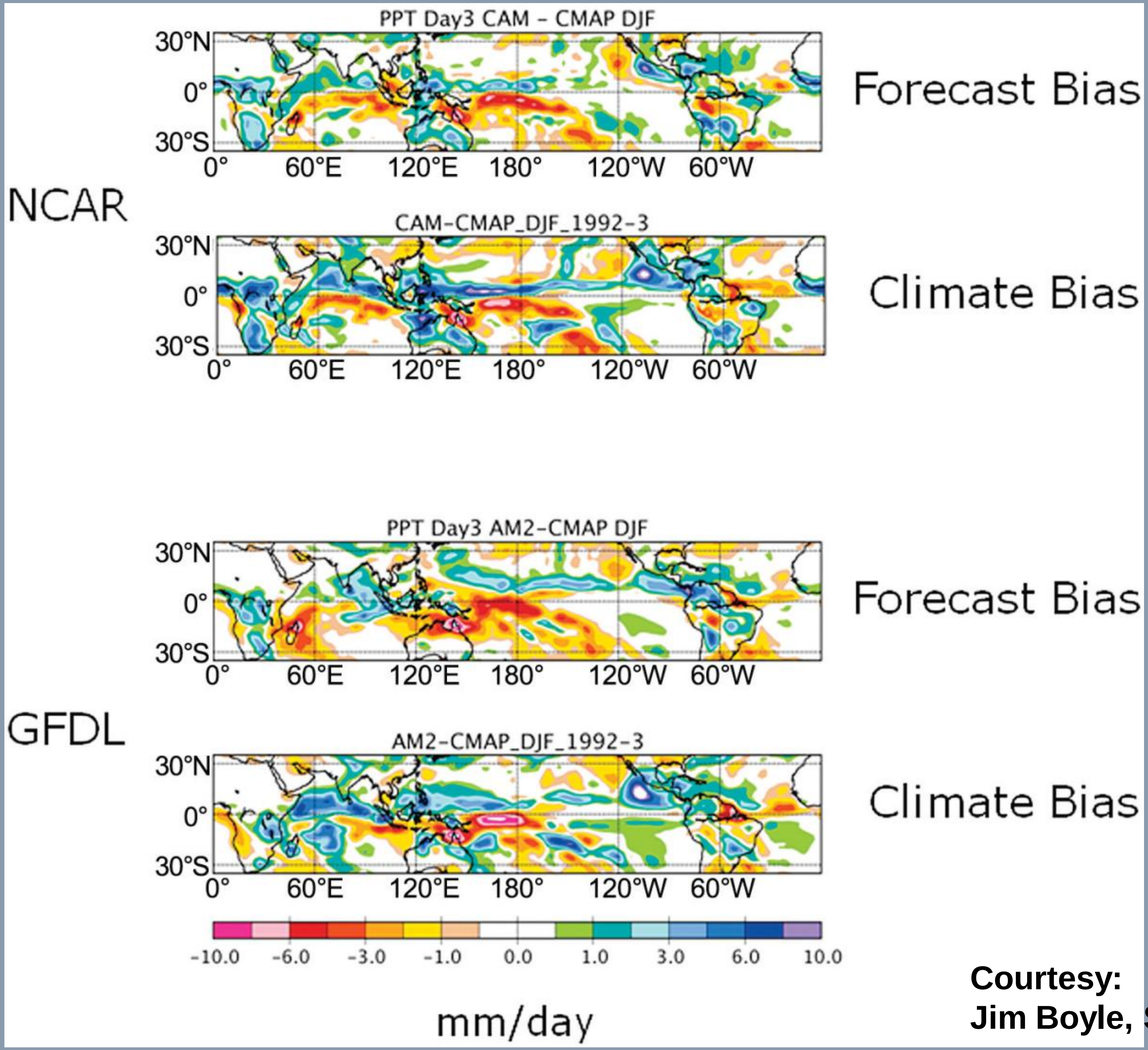
WCRP Aqua-planet model intercomparison project



Courtesy: Dave Williamson and Mike Blackburn

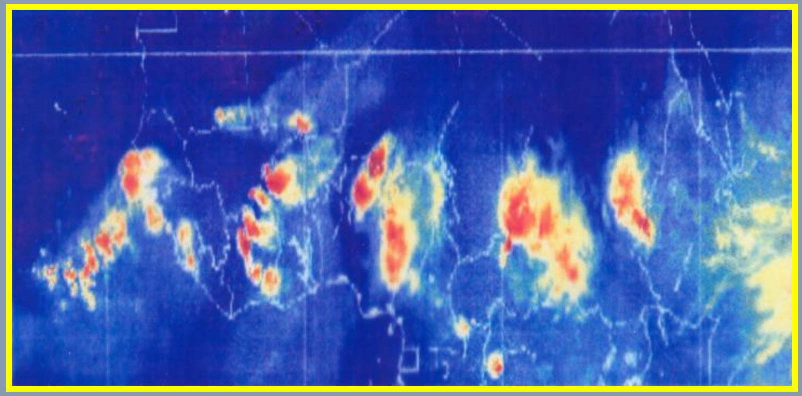
Large-scale precipitation bias

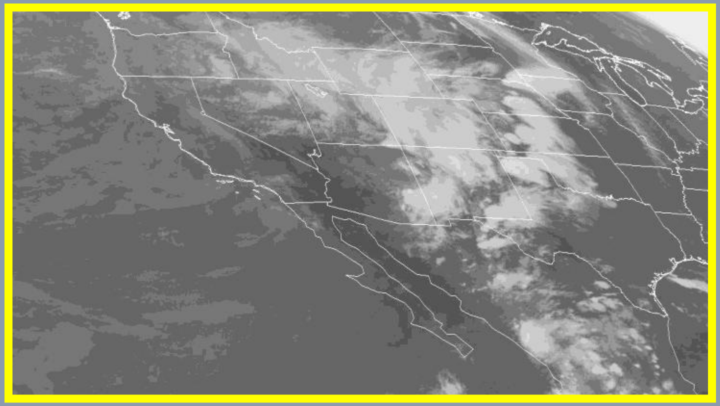
Similar at weather and climate timescales; linked to global circulation features

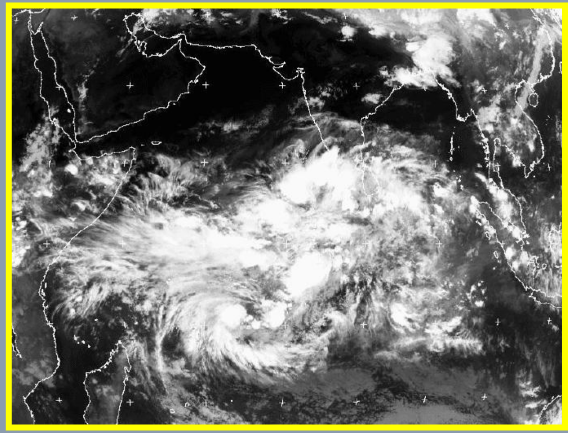


Courtesy:
Jim Boyle, Steve Klein

Role of organized moist convection







Multiscale convective organization O(1 – 1000 km)

- **Moist convection organizes into mesoscale convective systems (MCS), superclusters, and other phenomena; interacts with atmospheric waves, notably in the Tropics**

- **Mesoscale convective organization:**

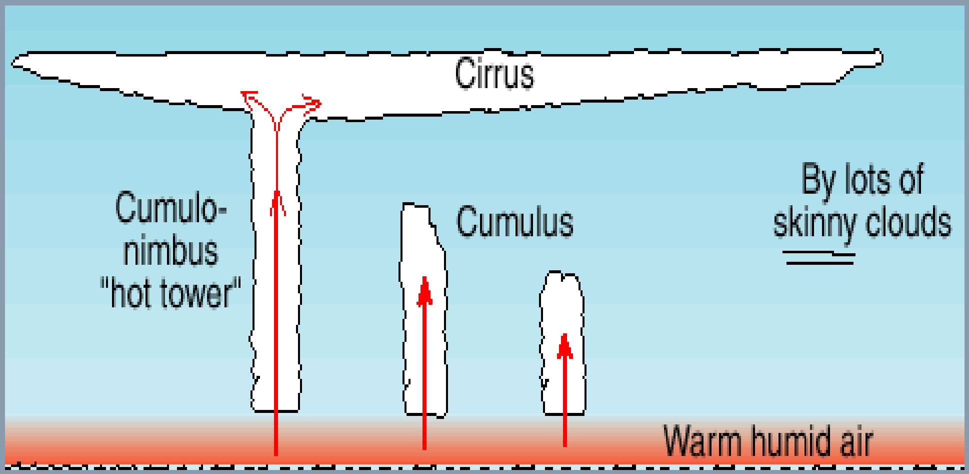
  - Is <u>missing from climate models</u> – insufficient resolution, organized dynamics not represented in parameterizations

  - Is <u>explicit</u> in <u>cloud-system resolving models (CRM</u>s), and as 2D CRMs in superparamerized global models

  - Is <u>explicit but under-resolved</u> in high-resolution <u>global NWP models</u>

  - Its properties are quantified by <u>theoretical-dynamical models</u>

- **<u>Vertical shear</u> has a fundamental effect on convective organization, but shear is not taken into account in convective parameterizations**



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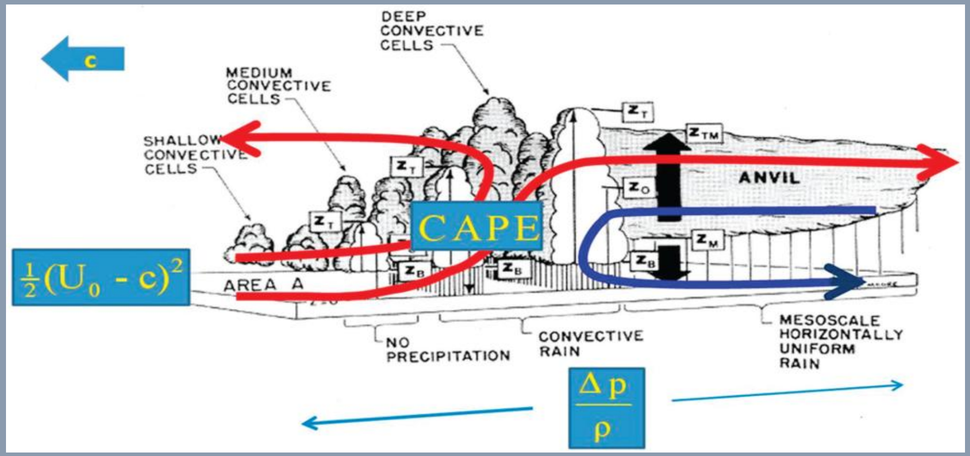
< 10 km

Weakly interacting cumulus

Cumulus convection
Riehl & Malkus (1958)

Parameterization:
Arakawa & Schubert (1974)



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> 100 km

Strongly interactive dynamical system

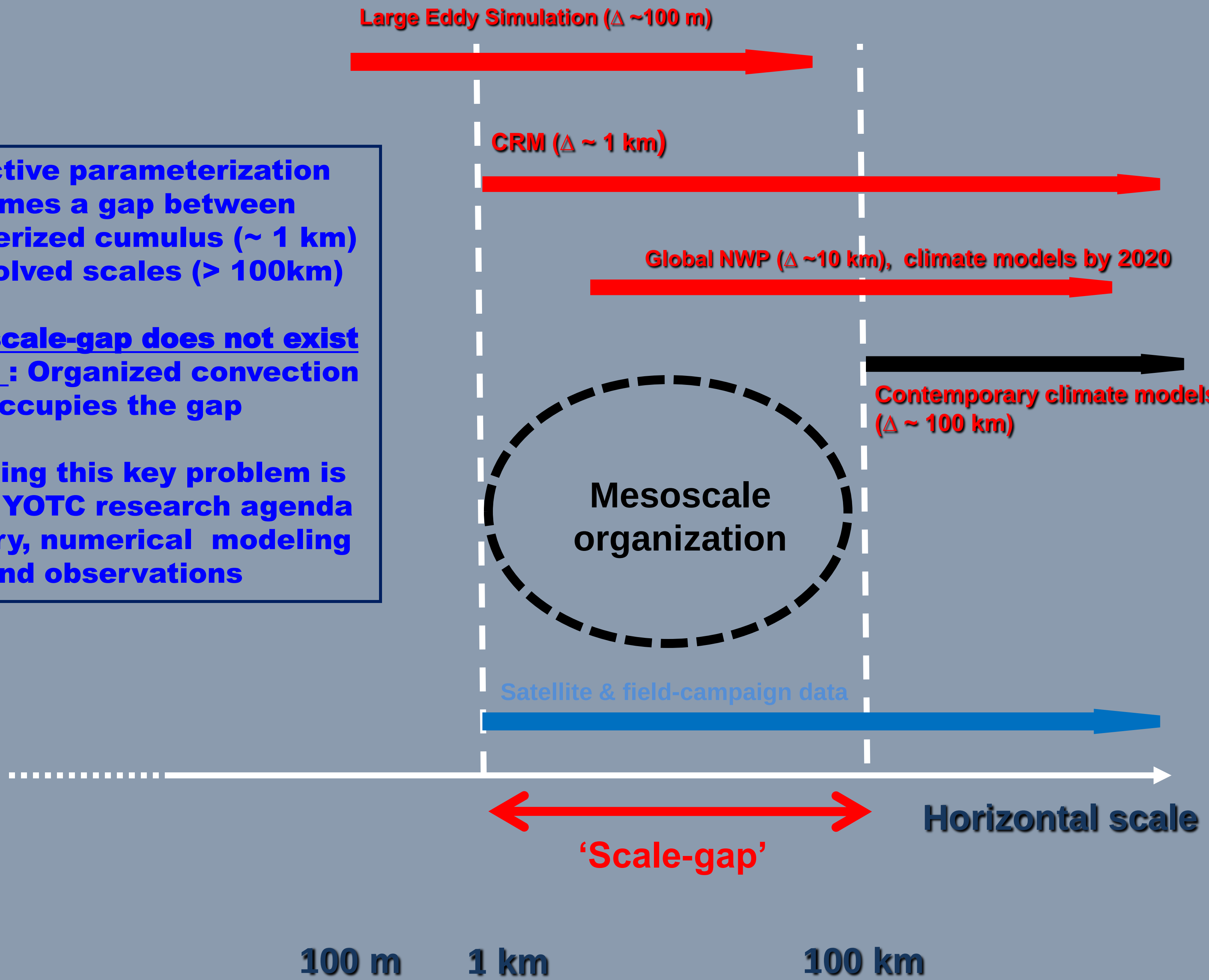
Organized convection
(e.g., MCS; Houze(2004)

Key dynamical properties not represented by parameterization

Convective parameterization assumes a gap between parameterized cumulus (~ 1 km) and resolved scales (> 100km)

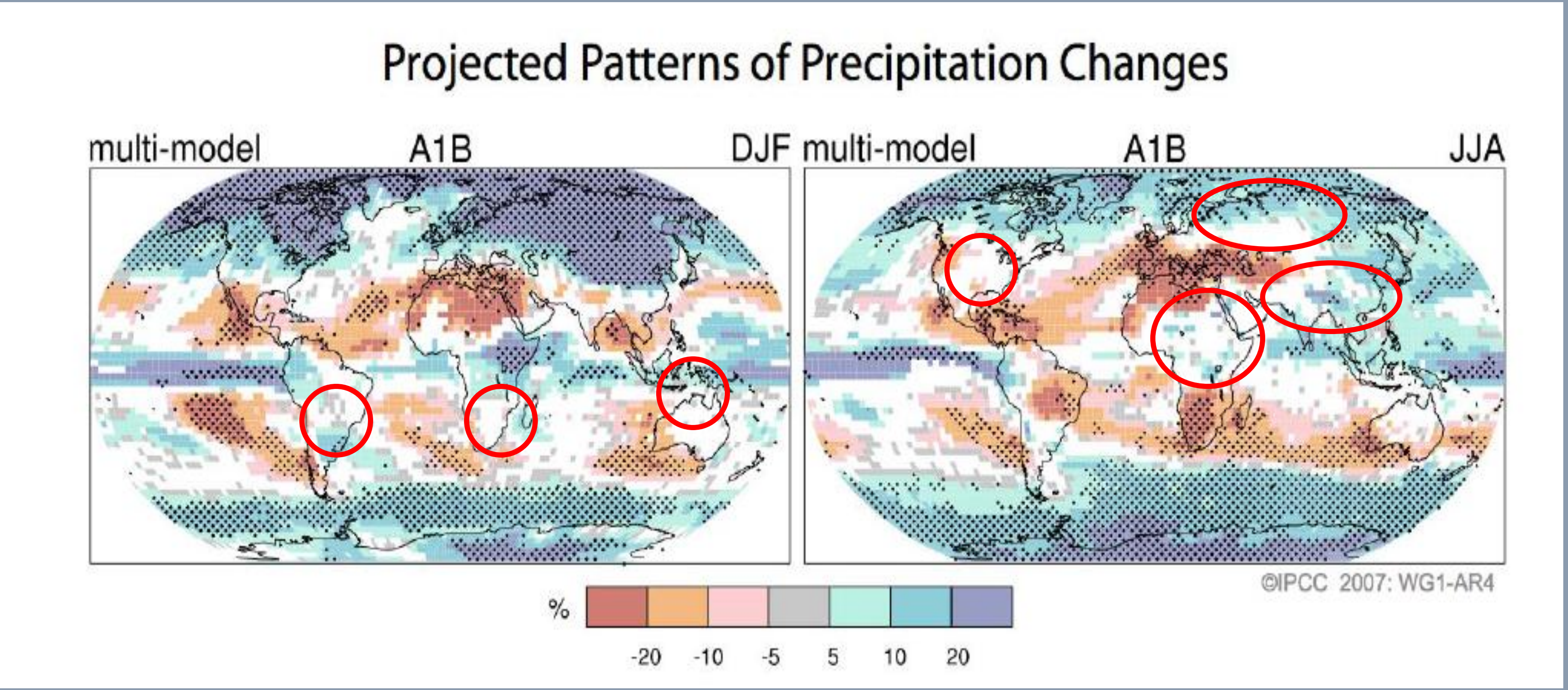
But the scale-gap does not exist in nature : Organized convection occupies the gap

Addressing this key problem is high the YOTC research agenda *via* theory, numerical modeling and observations

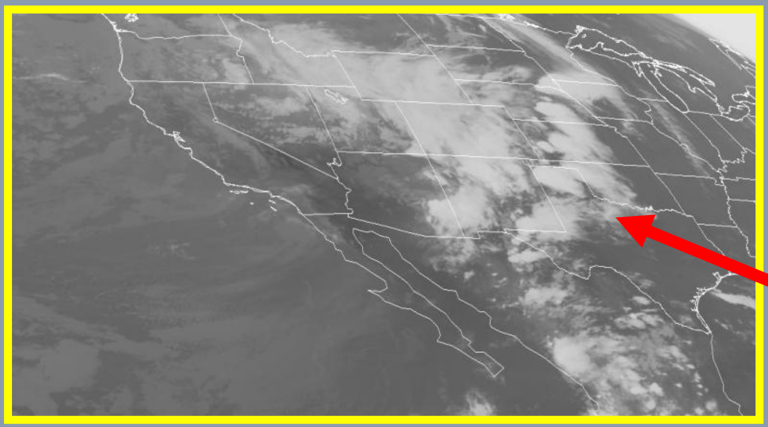


Projected changes in precipitation (2090-2099 compared to 1980-1999) **from IPCC AR4** climate models for most populated regions: **low confidence especially in the summer hemisphere**

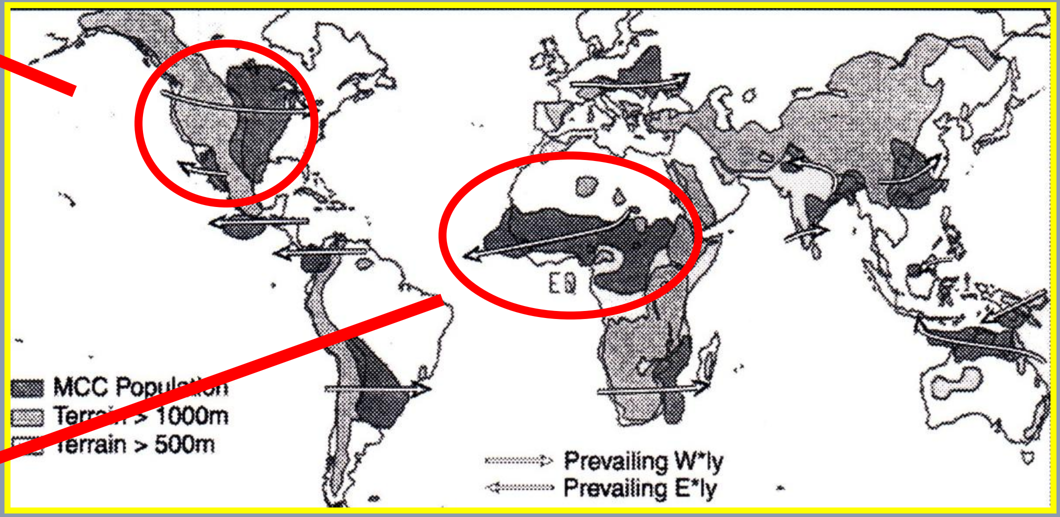
Due to the absence of organized convection in climate models ?

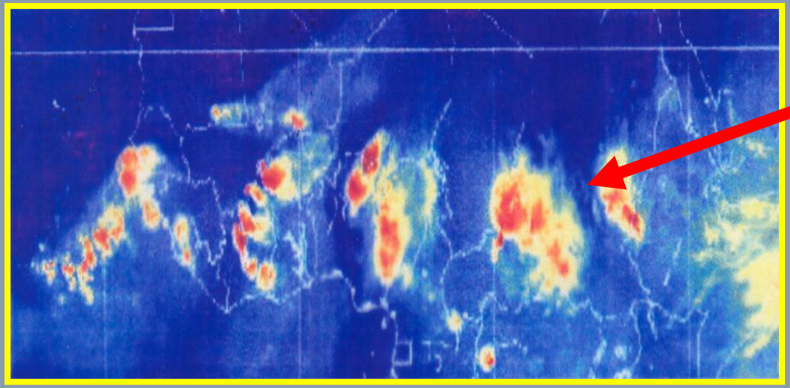


MCS: A world-wide phenomenon



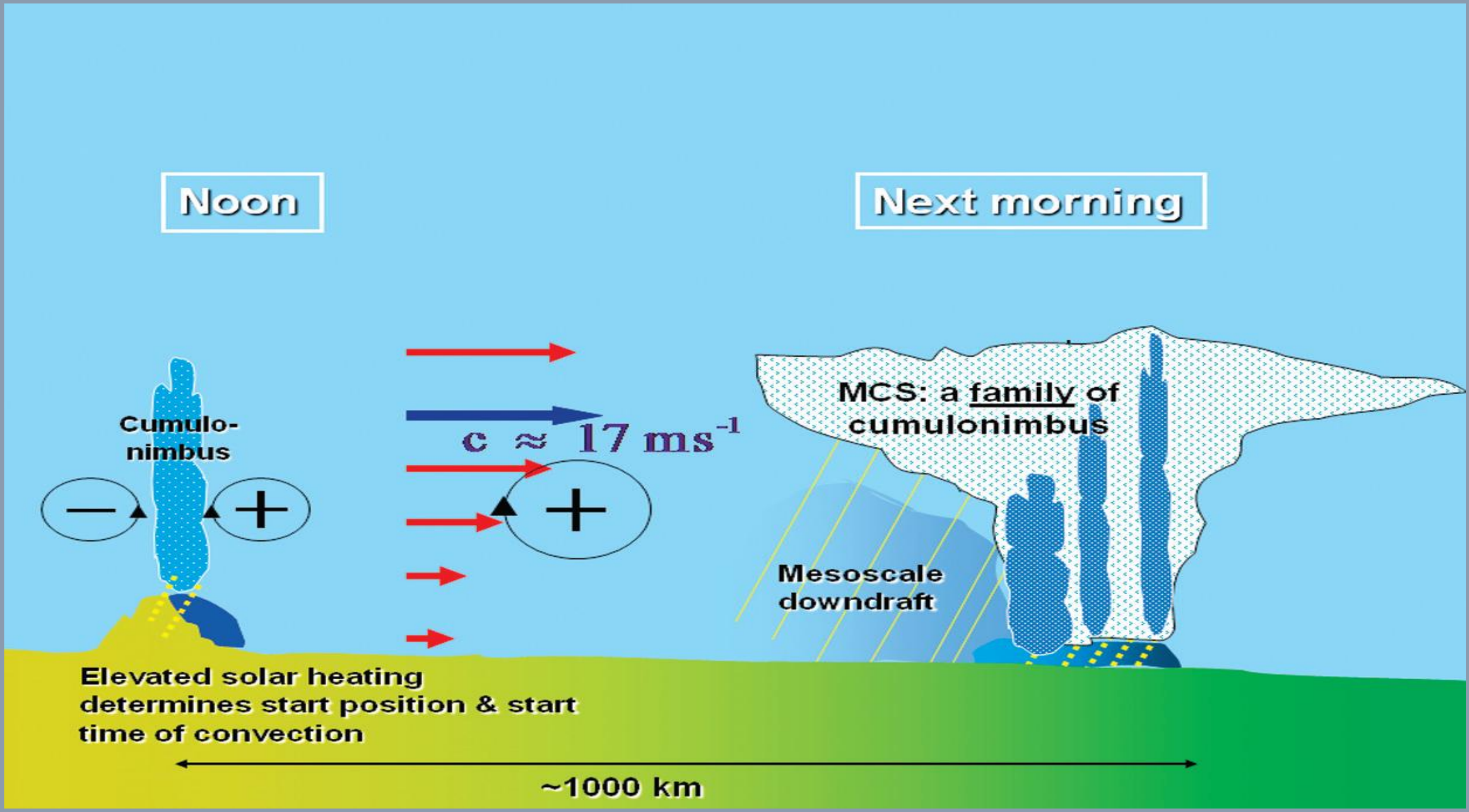
Continental US





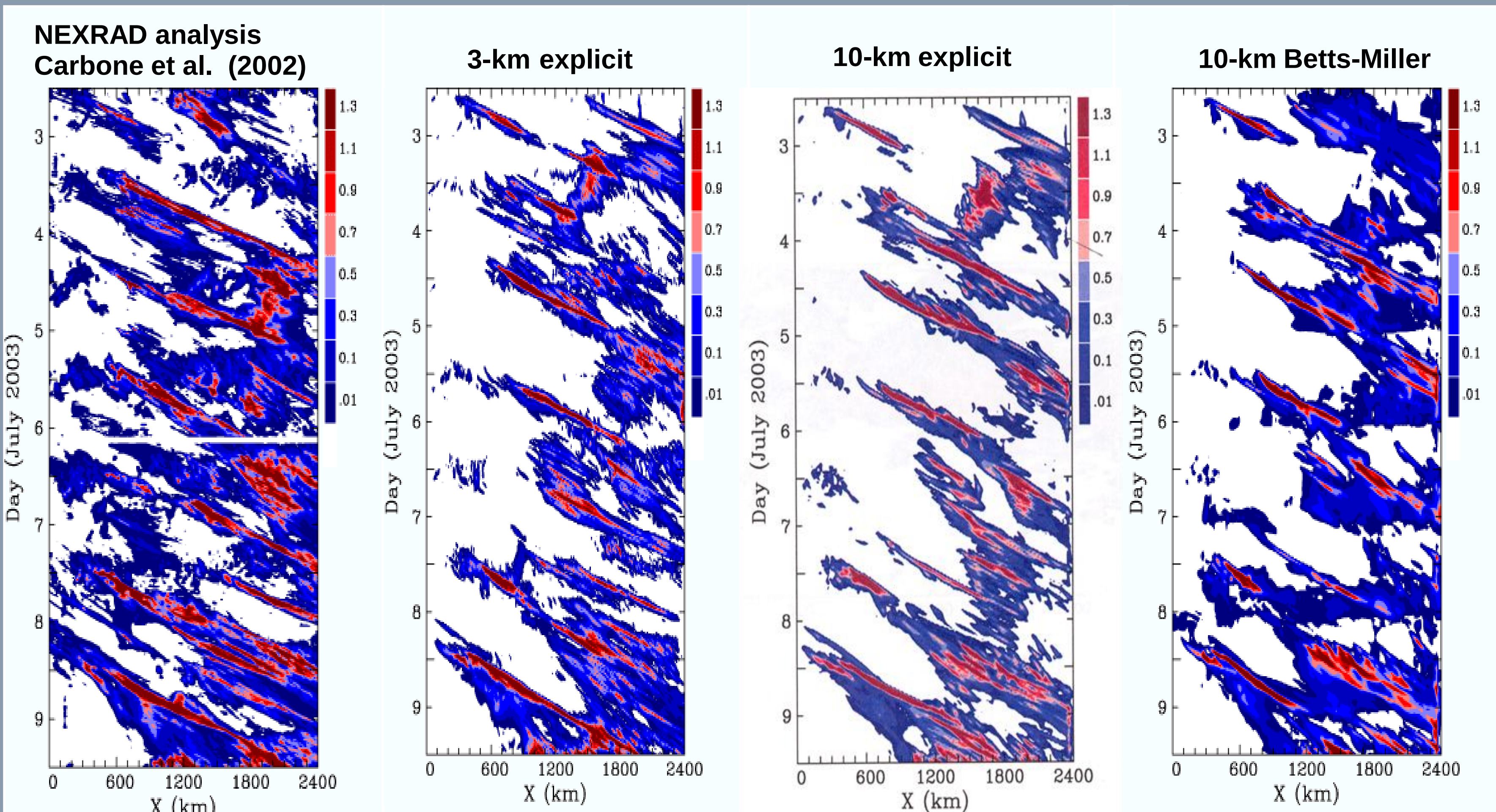
W. Africa

Satellite analysis: Laing and Fritsch (1997)



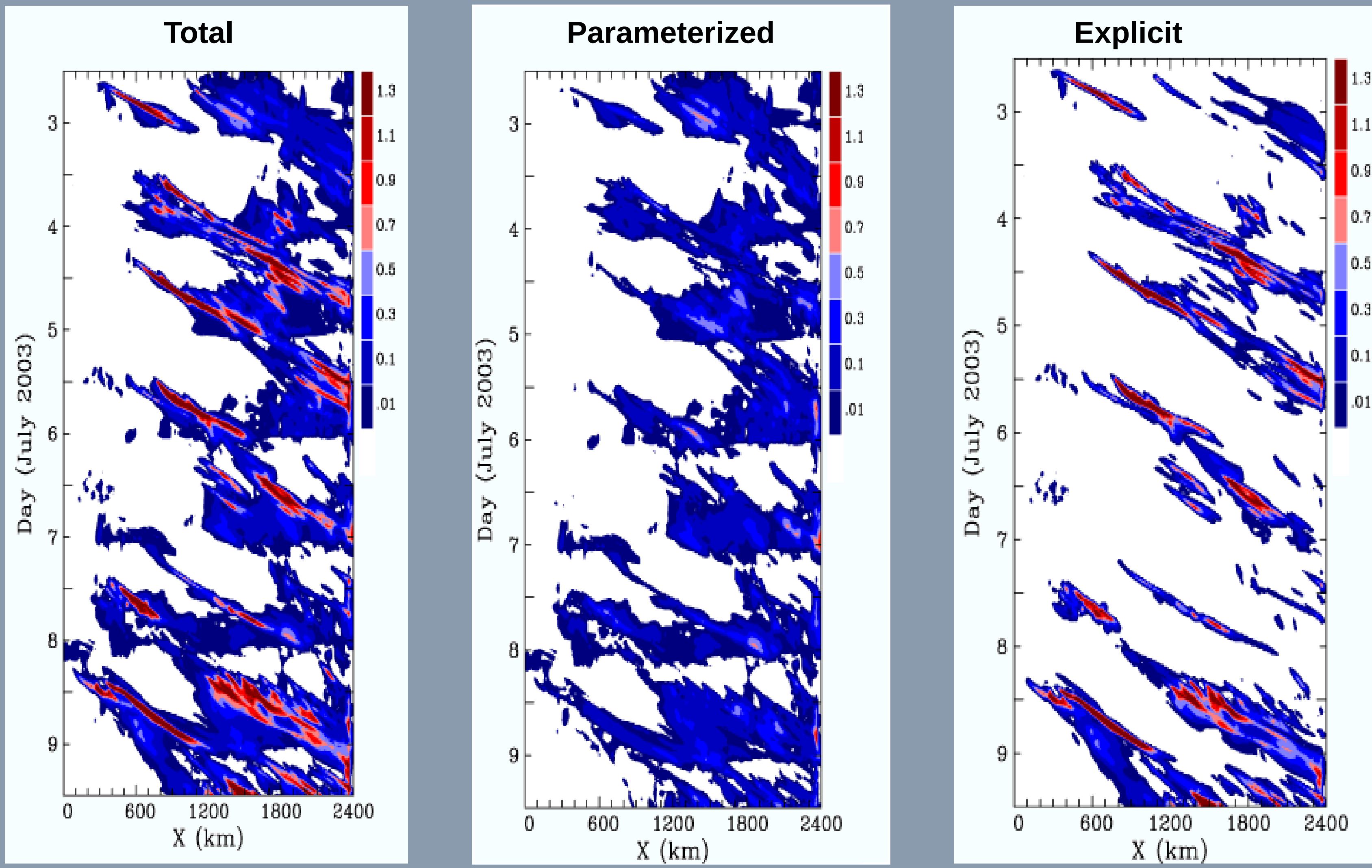
Noon
Next morning
Cumulo-
nimbus
c ≈ 17 ms-1
MCS: a family of
cumulonimbus
Mesoscale
downdraft
Elevated solar heating
determines start position & start
time of convection
~1000 km

Meridionally averaged rain-rate

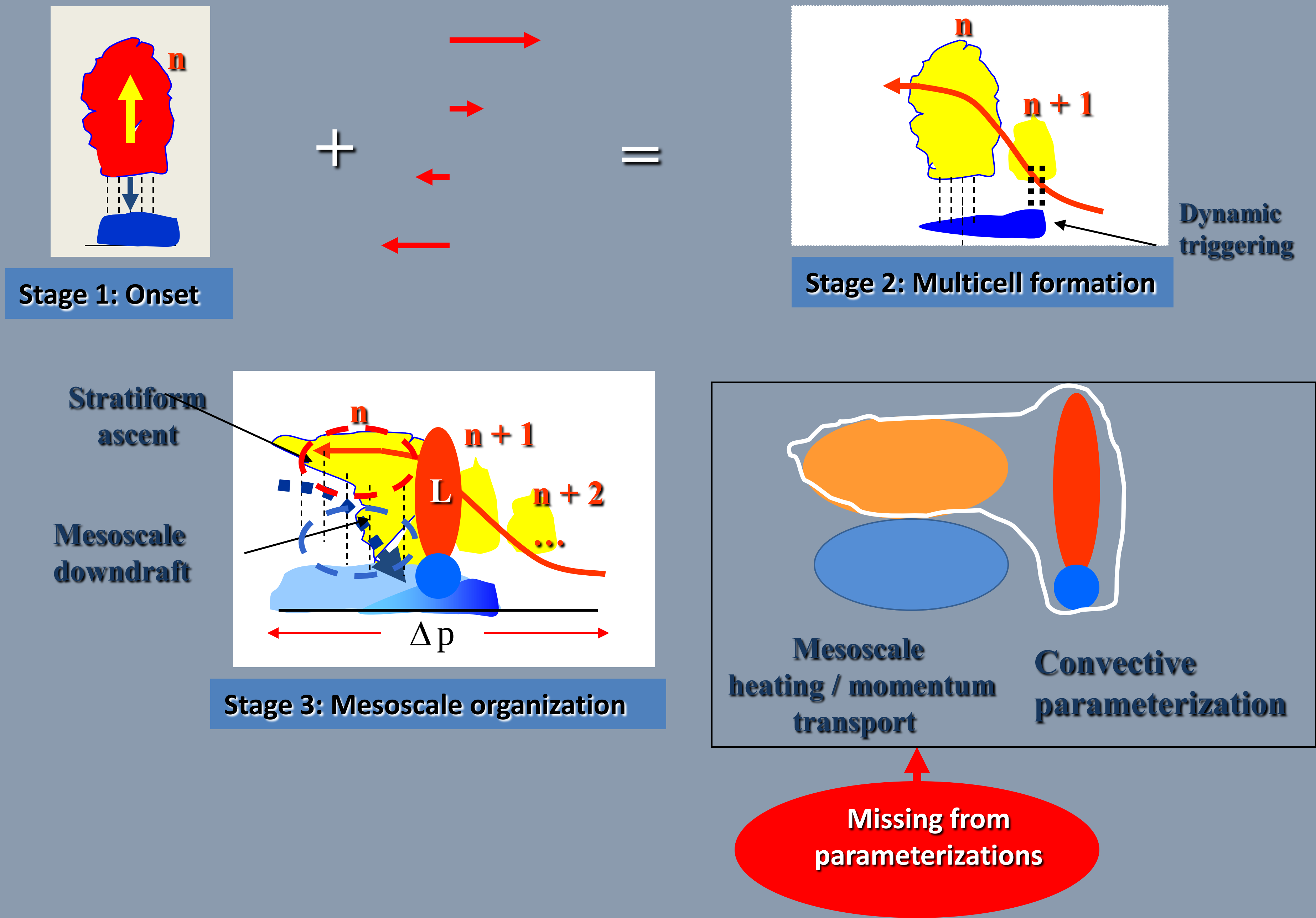


Moncrieff and Liu (2006)

Grid-scale circulations represent propagating systems



Upscale evolution of MCS

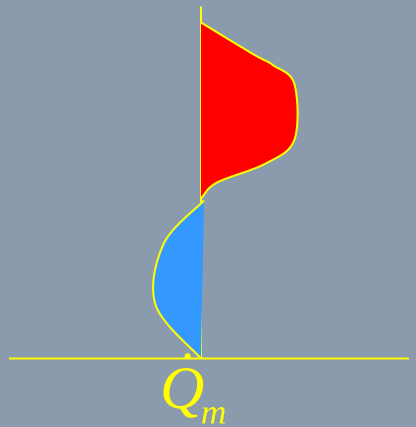


Parameterizing mesoscale overturning

Stratiform heating and mesoscale downdraft cooling

$$Q_m(p,t) = \propto_1 Q_c \;(p,t)\left[\sin\pi\left(\frac{p_s - p}{p_s - p_t}\right) - \propto_2 \sin 2\pi\left(\frac{p_s - p}{p_s - p_t}\right)\right]$$

$$\boldsymbol{Q = Q_c + Q_m}$$



Q_m = Heating by slantwise mesoscale overturning

Q_c = Cumulus heating

$\propto_1$ = Heating by slantwise mesoscale overturning/cumulus heating

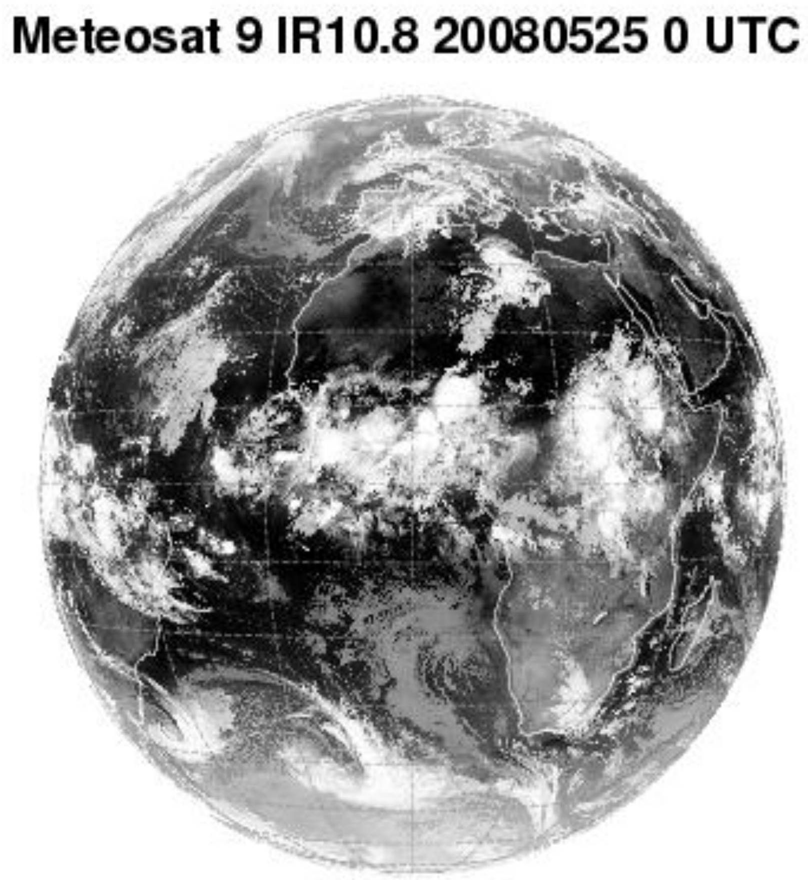
$\propto_2$ = First-baroclinic heating/second-baroclinic heating

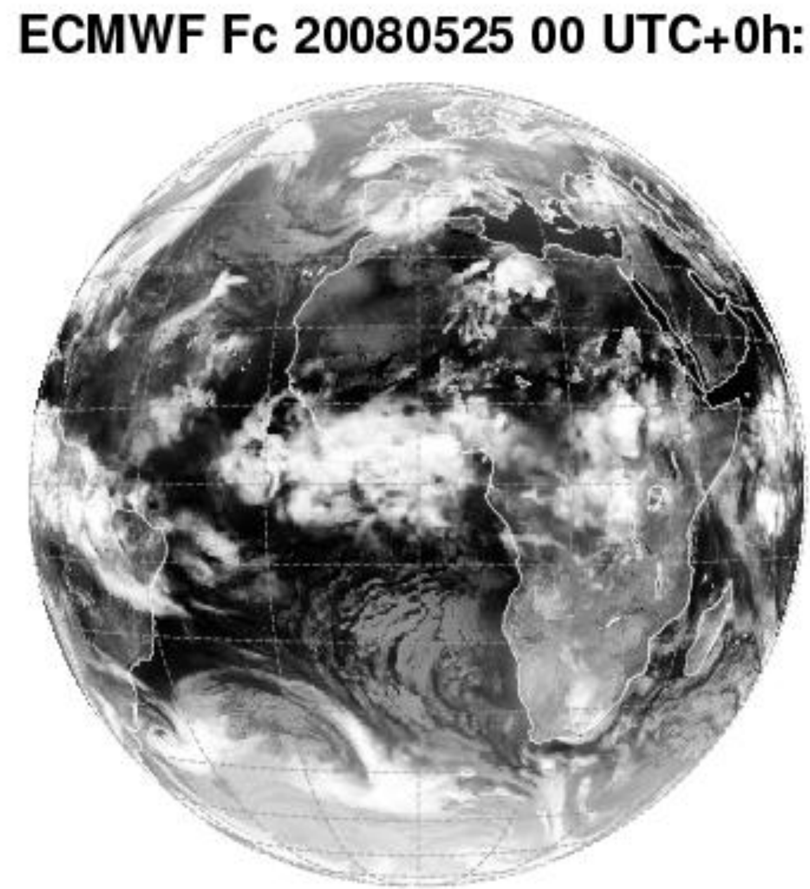
p_t = Cloud-top pressure

p_s = Surface pressure

Weather Prediction (T1279, ~15 km) compared with Satellite Observations

ECMWF predictions and Meteosat observations



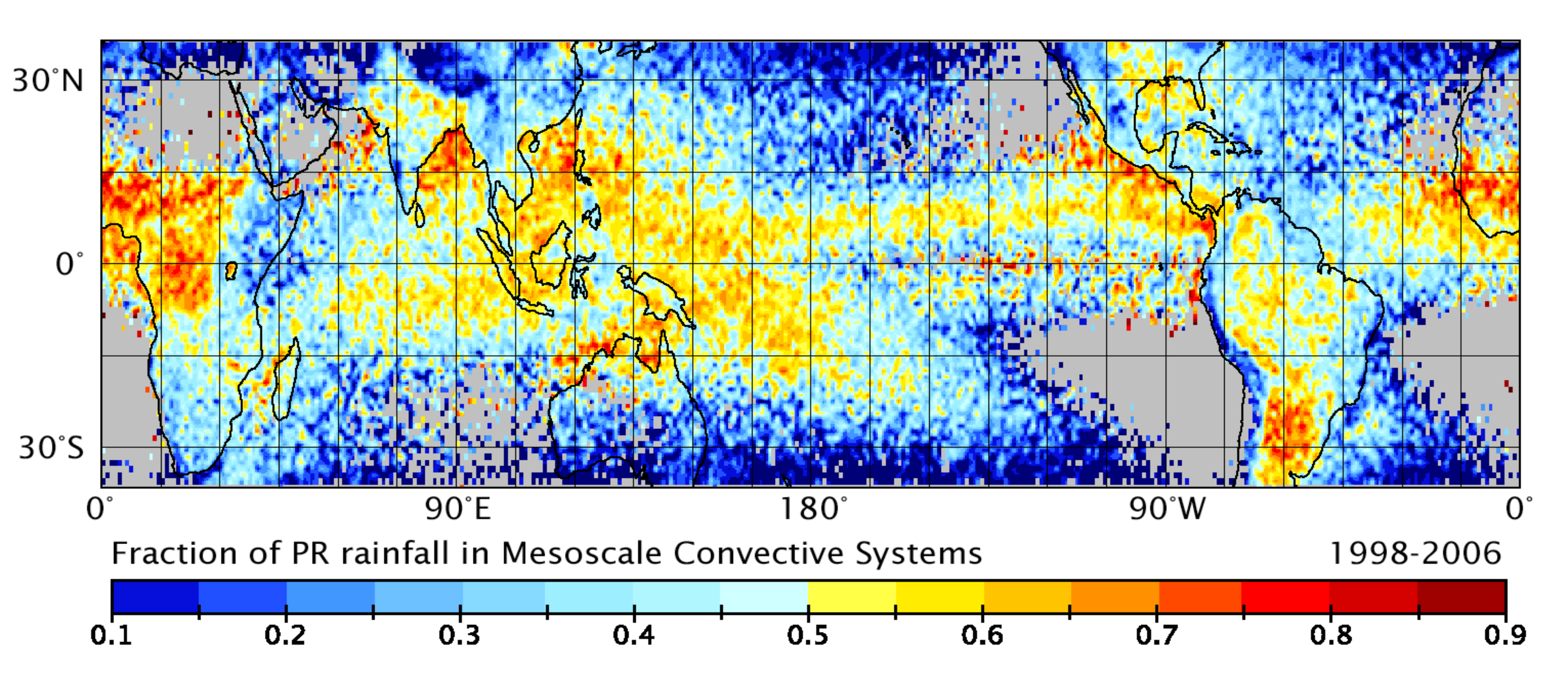


Courtesy: Martin Miller

Multiscale Tropical Convective Organization:

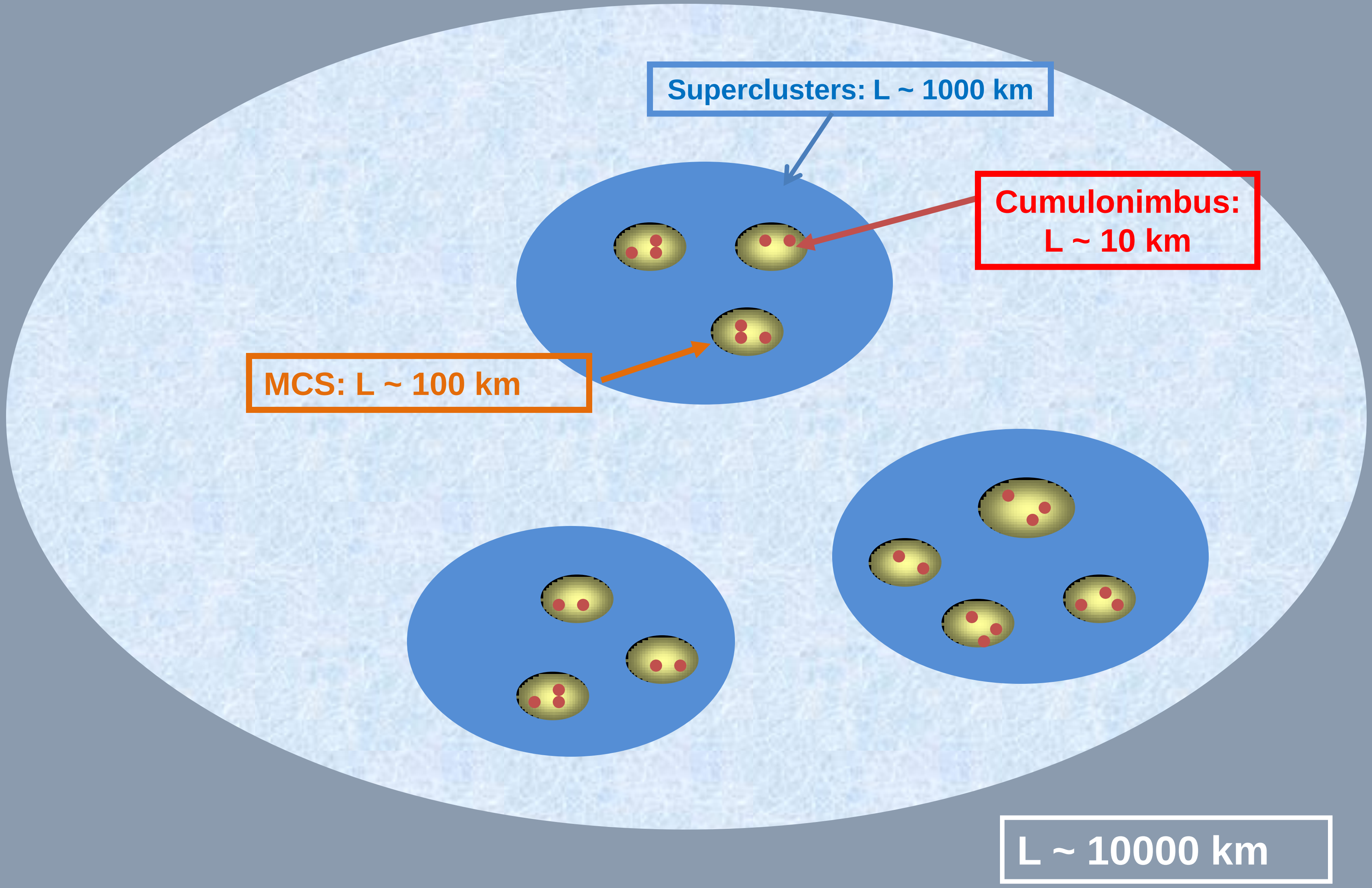
Progress with the MJO, from coupled climate models to dynamical theory

Tropical MCS observed by TRMM

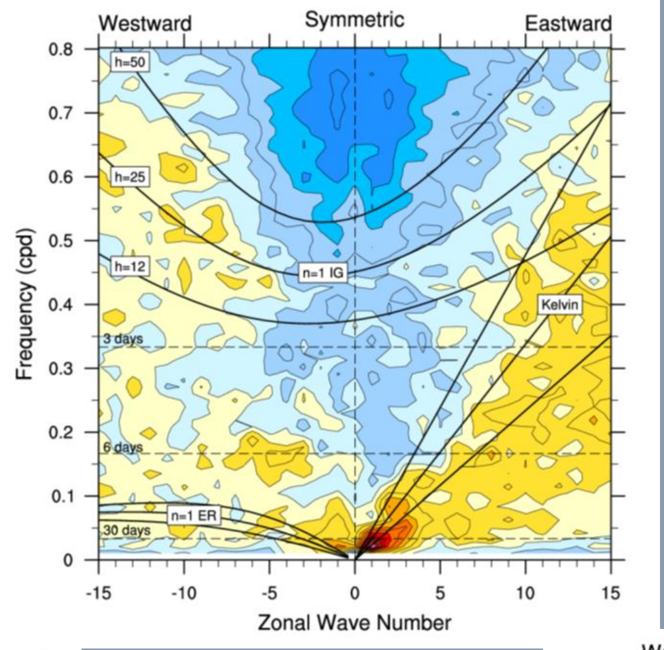


Tao and Moncrieff (2009)

Upscale cascade of energy: organized tropical convection
Downscale control: waves and shear



Improved Intraseasonal Variance Community Atmospheric Model (CAM4)

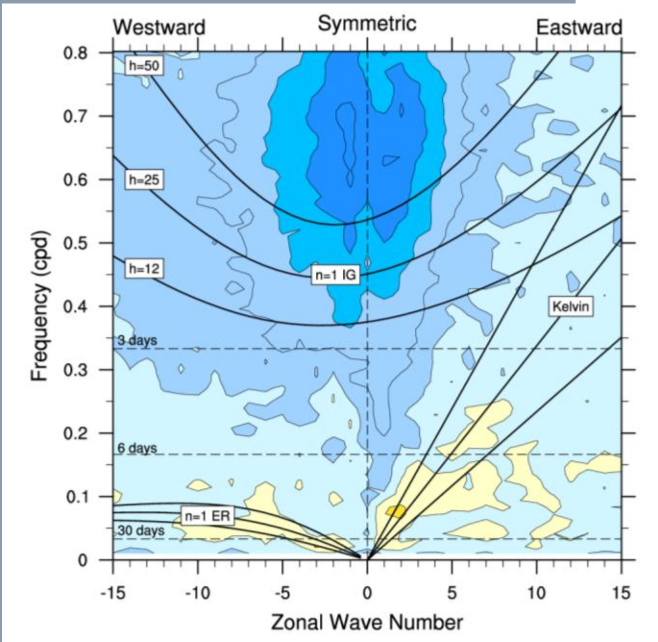


CAM3+ (CMT+DIL)

CAM3

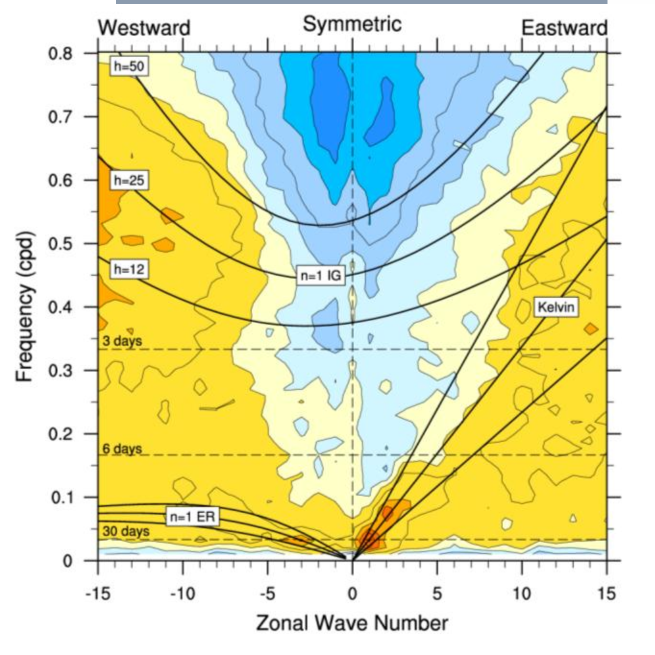
CAM3+CMT

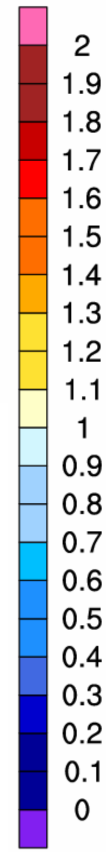
CAM3



CAM3+DIL

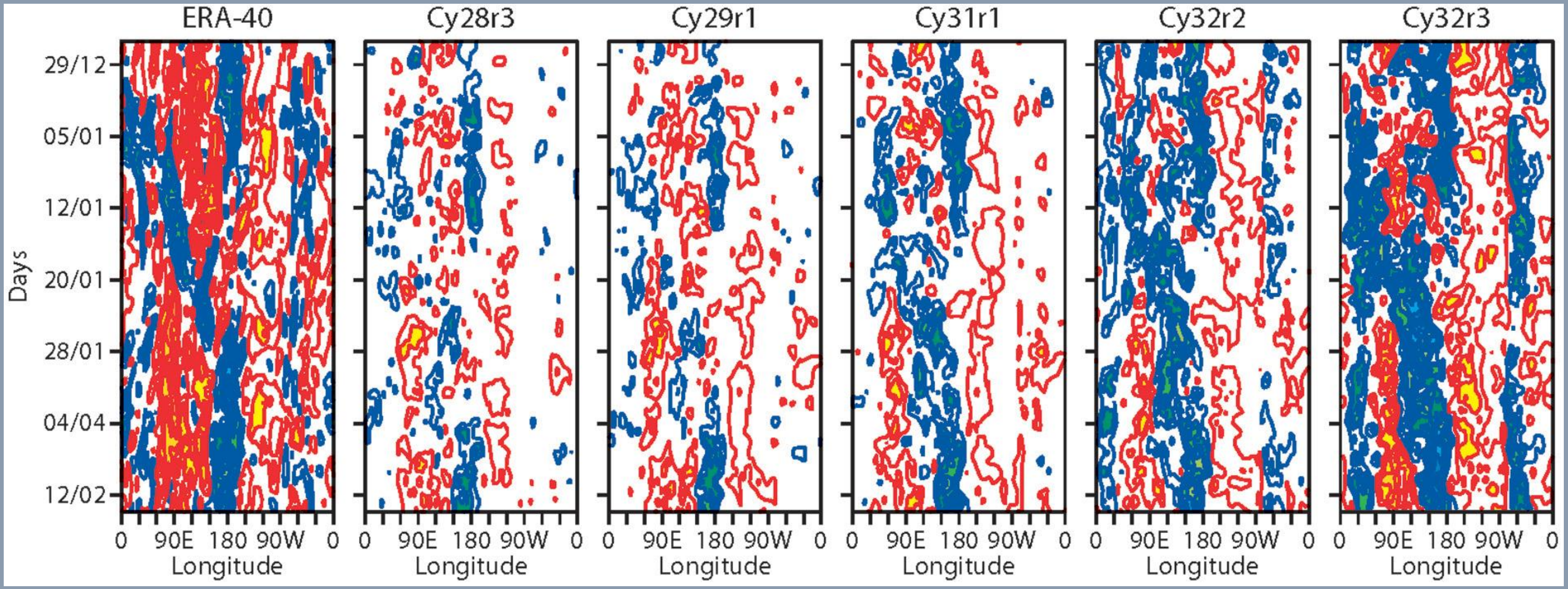
CAM3



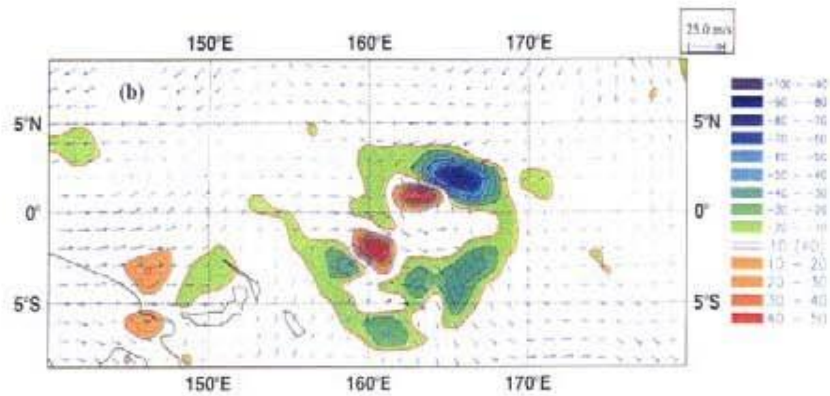


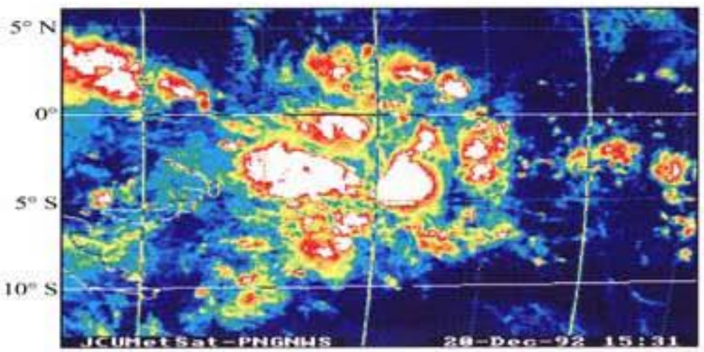
Courtesy: Rich Neale

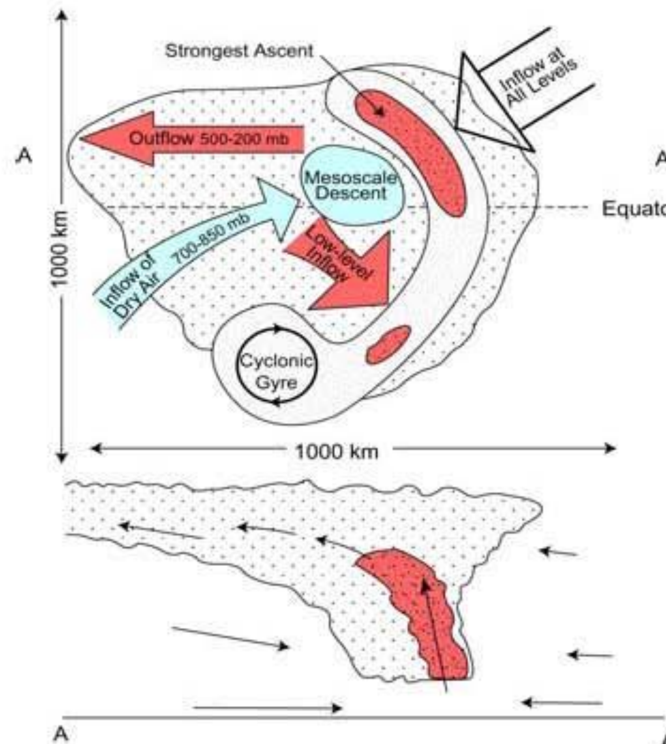
Improved MJO in ECMWF model



Scale-invariant structure of superclusters (~1000 km) and MCS (~100 km)

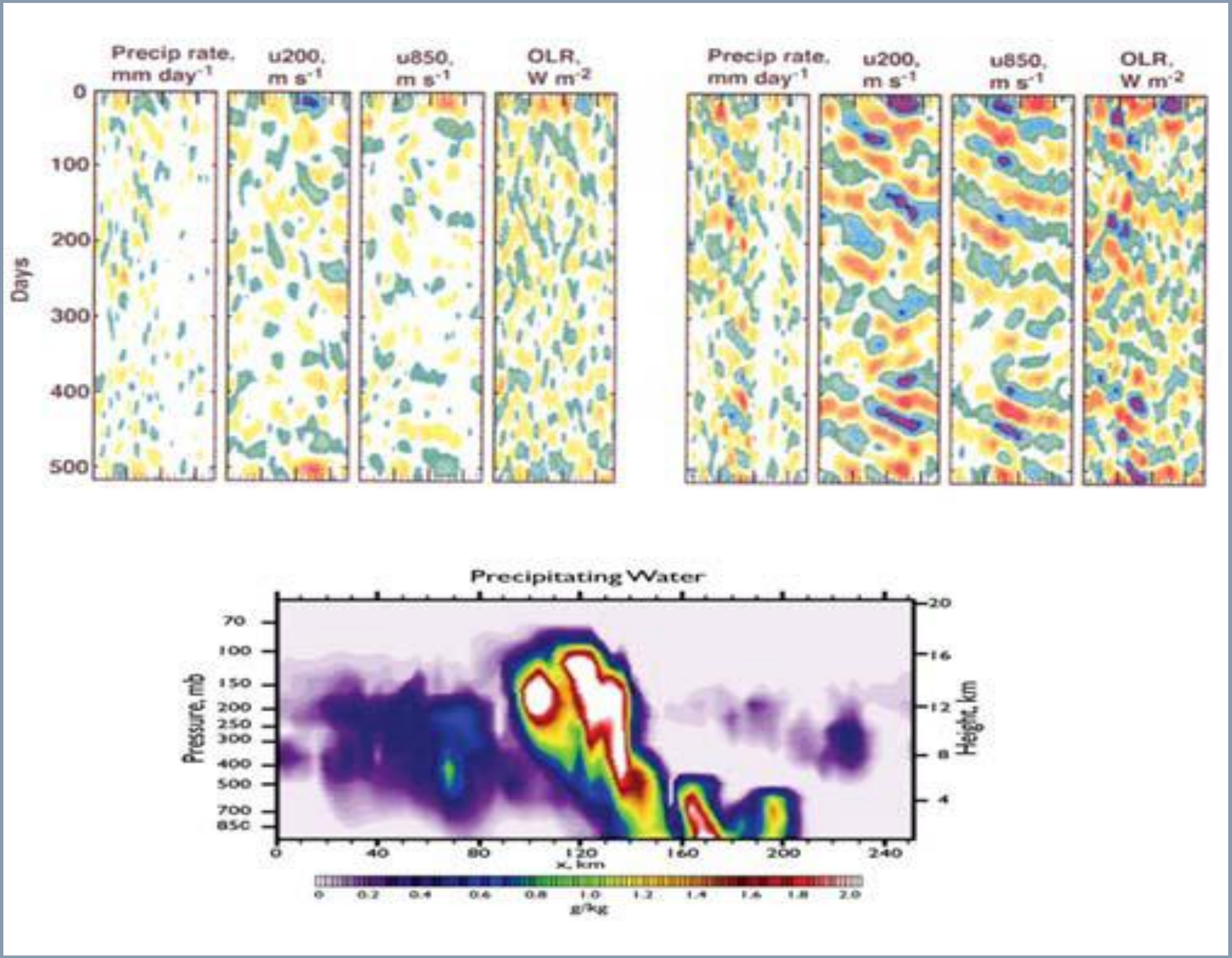






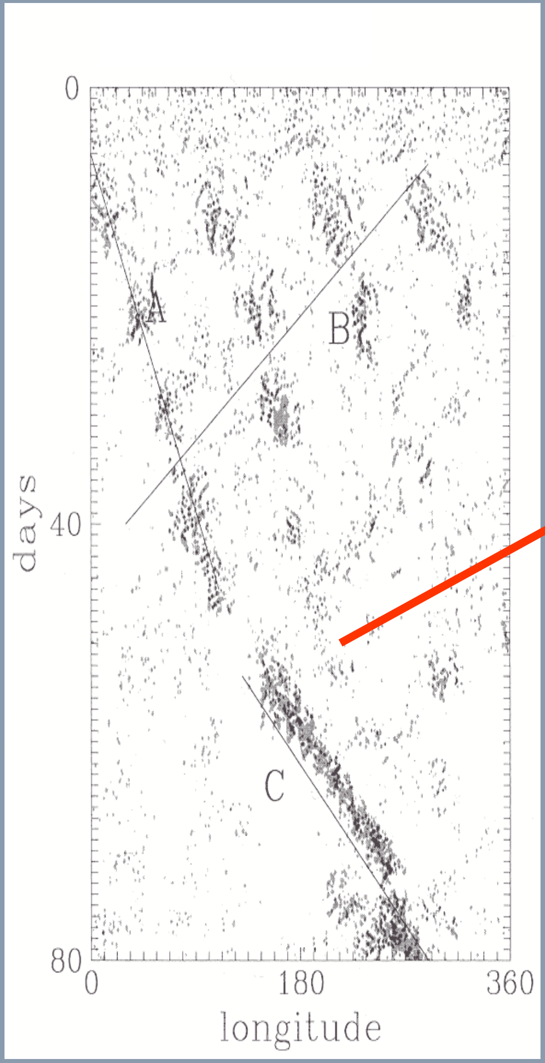
Moncrieff and Klinker (1997)

MJO in a superparameterized global model

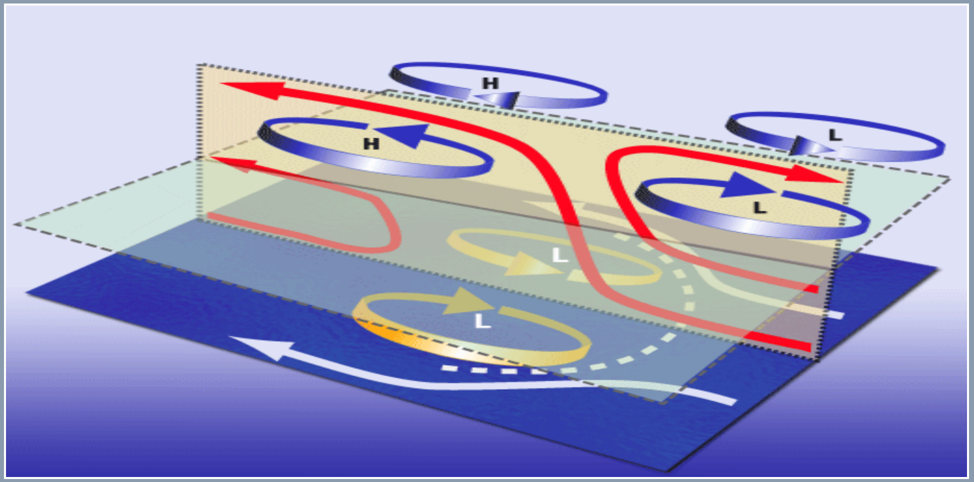


Courtesy: Marat Khairoutdinov

MJO-like systems & propagating organized convection in idealized superparameterized global model

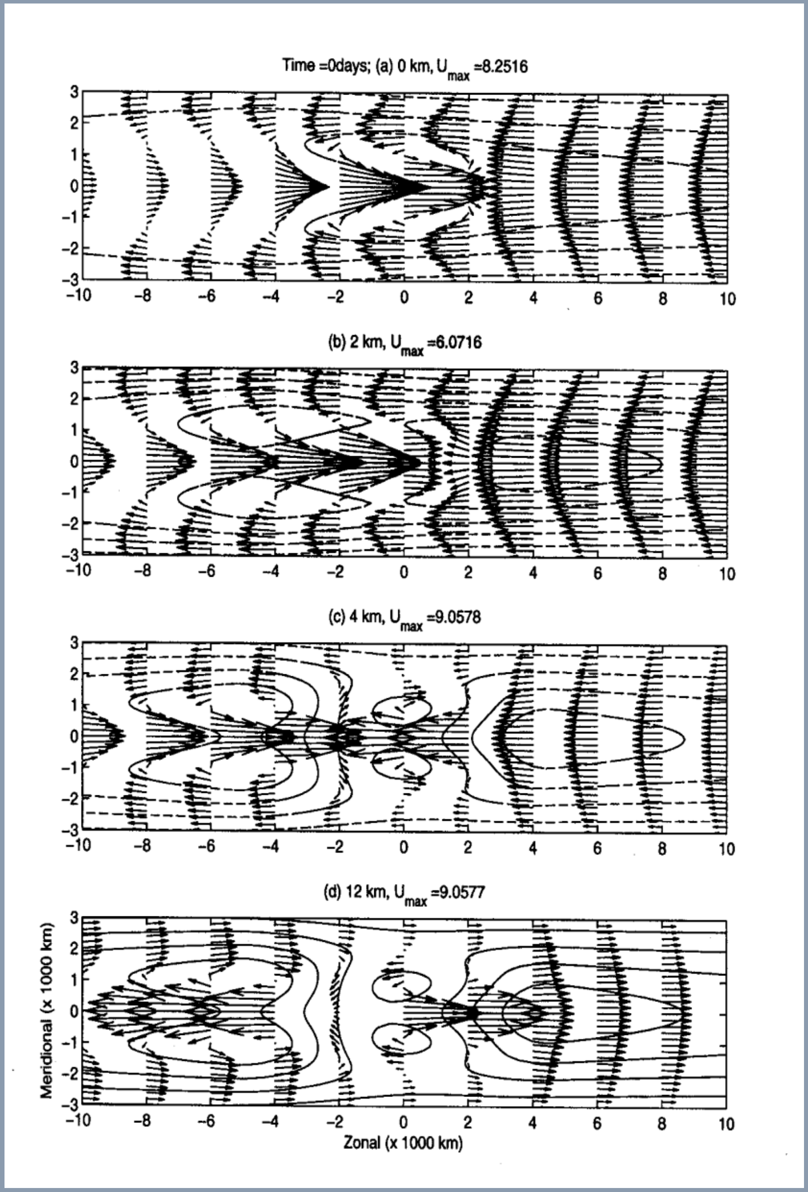


Superparameterized convention in a global model (Grabowski 2001)



Organized convective overturning interlocked with MJO (Moncrieff 2004)

Upscale effects of organized convective momentum transport



Planetary-scale equations

$$\bar{U}_t - y\bar{V} + \bar{P}_X = F^U - d_m \bar{U}$$

$$y\bar{U} + \bar{P}_y = 0$$

$$\bar{\theta}_t + \bar{W} = F^\theta - d_\theta + \bar{S}_\theta$$

$$\bar{P}_z = \bar{\theta}$$

$$\bar{U}_X + \bar{V}_y + \bar{W}_z = 0$$

Synoptic-scale momentum convergence

$$F^U = -\overline{(v'u')}_y - \overline{(w'u')}_z$$

$$F^\theta = -\overline{(v'\theta')}_y - \overline{(w'\theta')}_z$$

Biello, Majda & Moncrieff (2006)

Multiscale theory of the MJO

a) MJO "skeleton" – global-scale cloud envelope

- Majda & Stechmann (2010)

Neutrally stable interaction between:

i) Planetary-scale lower-tropospheric moisture and

ii) Planetary-scale envelope of synoptic-scale convective activity

explains slow eastward phase speed; dispersion relationship dώ/dk ~ 0;
horizontal quadrupole vortex

b) MJO "muscle" - convection

- Majda & Stechmann (2011)

Consistent with:

i) Positive effect of lower-tropospheric humidity in global models

ii) **MJO satellite observations,**

Iii) Dynamics of coupling between organized convection/ and large-circulation

Summary

- We are at an interesting juncture:

  - Progress being made with theory, modeling and observations of organized moist convection,

    e.g., orogenic convection over continents and MJO

  - Applying this knowledge to advance prediction and understand predictability

WCRP/WWRP-THORPEX YOTC Project : Global effects of organized tropical convection on time scales up to seasonal (intersection of weather and climate)

www.ucar.edu/yotc

Thanks for your attention