Organized Convection and the Weather-Climate Intersection

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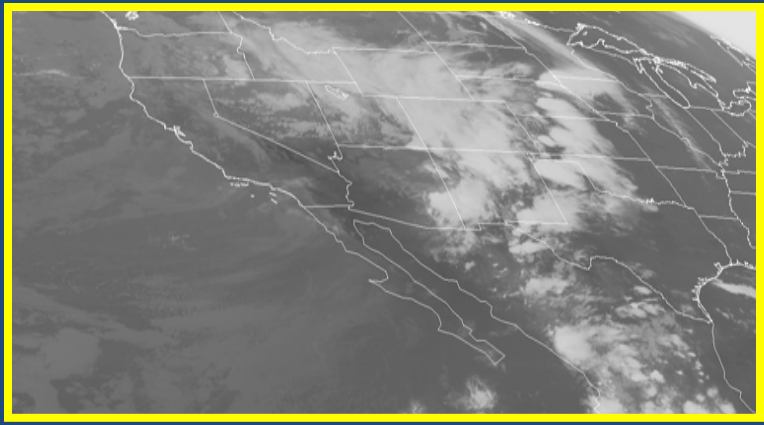
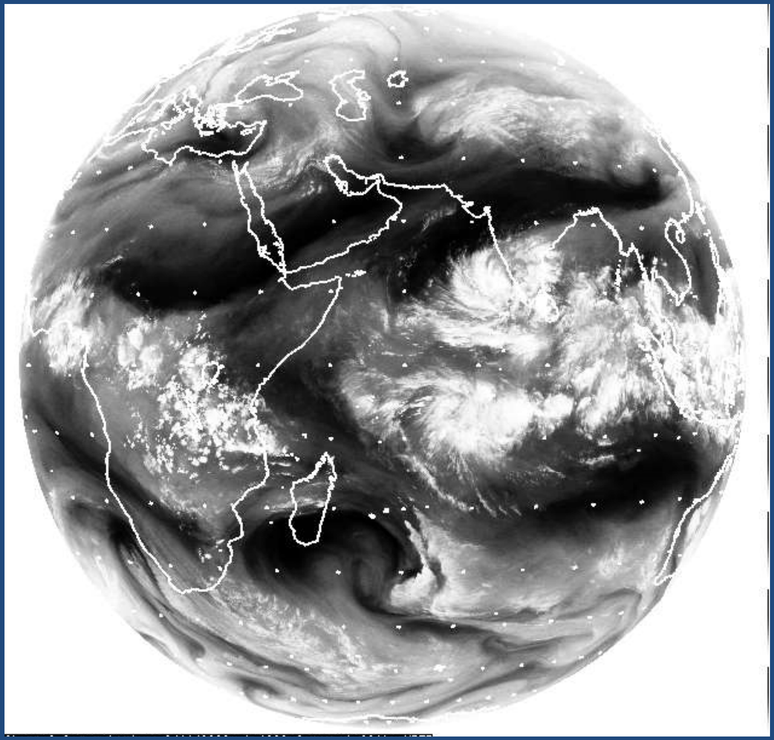




JPL, Dec 1, 2011

Synopsis of talk

1) Motivation

2) Regional-scale example: Orogenic convective systems over the US (prototype for other continents)

3) Global-scale example: Madden-Julian Oscillation (MJO)

4) Summarize the WWRP-THORPEX/WCRP Year of Tropical Convection (YOTC) -- a "Virtual Global Field Campaign"
(Co-chairs: Moncrieff & Waliser)

1) Motivation

Representing the effects of organized moist convection in global climate models, long-recognized to be an important issue and presently missing from these models, is becoming tractable due to advances in physical understanding, computation and observation

The Weather-Climate Intersection (time-scales up to seasonal) is where timely progress can be made in this respect

Major Weather-Climate Intersection Challenges

Extended Prediction

Global Weather Models
(~10 km grid)

Climate Variability and Predictability

Global Climate Models
(~100 km grid)

Atmospheric Water Cycle

Tropical Convection

Intraseasonal Variability

Tropical-extratropical Interaction

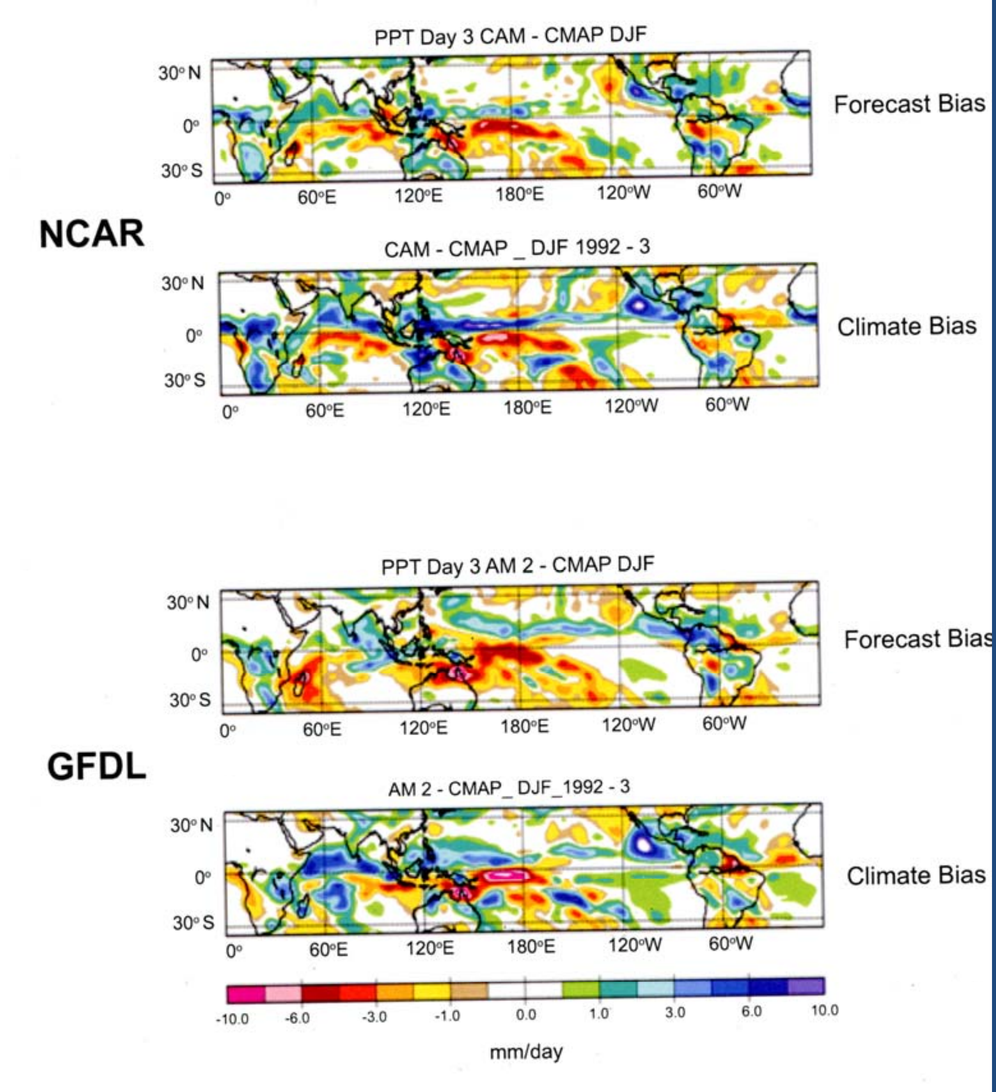
Convective Organization in Global Models

Dynamical Models

Effects of mesoscale processes

Cloud-system Resolving Models
(~1 km grid)

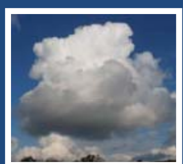
Errors in the global distribution of precipitation in weather & climate models have distinct and similar spatial distributions, suggesting basic interactions with the global circulation



Courtesy: J. Boyle (LLNL)

Convective Organization

- **Moist convection has a complex underlying order – ‘chaotic’ not ‘random’**
- **Convective organization – Chaotic dynamical coherence on meso- to-global scales ~ (10 km – 10000 km): Unexplored in climate, partly explored in weather**
- **In convective organization, upscale effects and downscale control work together: Vertical shear & convection-wave interaction are key elements**



cumulus/thunderstorm
~ 1-10 km

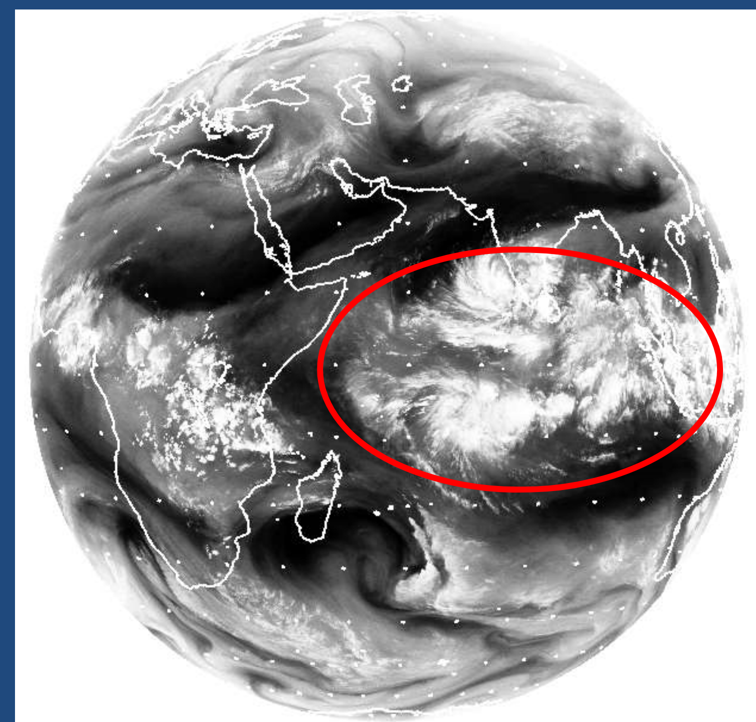
mesoscale convective system

~100 km

supercell thunderstorm
~ 100km

hurricane / tropical

cyclone ~ 1000km



Madden-Julian Oscillation: ~ 10000 km

Organized convection is missing from climate models because …

- Cumulus parameterizations fail to represent chaotic organized structures
- Model resolution too coarse to simulate these structures

Organized convection is important because it…

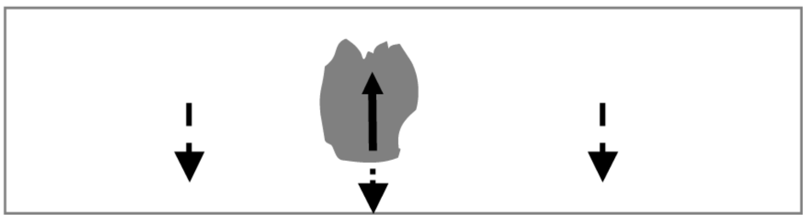
- Provides at least 40% of rainfall in the tropics, e.g., Mesoscale Convecive Systems (MCS)
- Has novel effects, e.g., upscale evolution, counter-gradient momentum transport ('negative viscosity'), maintains the atmospheric circulation against dissipation, equatorial super-rotation, elevates the height of maximum diabatic heating, changes the cloud-radiative heating profile

Timely now because we have …

- Improved physical understanding
- Necessary computational tools
- Necessary observations

Cumulus parameterization

a)

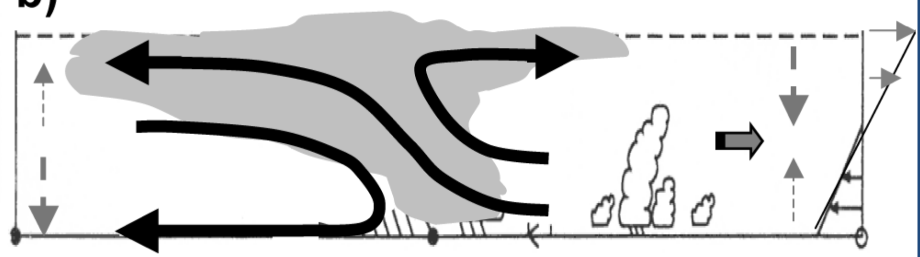


Isolated convection, single grid volume

- Entraining plume (turbulent mixing)
- No environmental shear
- Local response
- Closed system
- Weak scale-interaction
- No gravity waves

Missing convective organization, e.g., MCS

b)

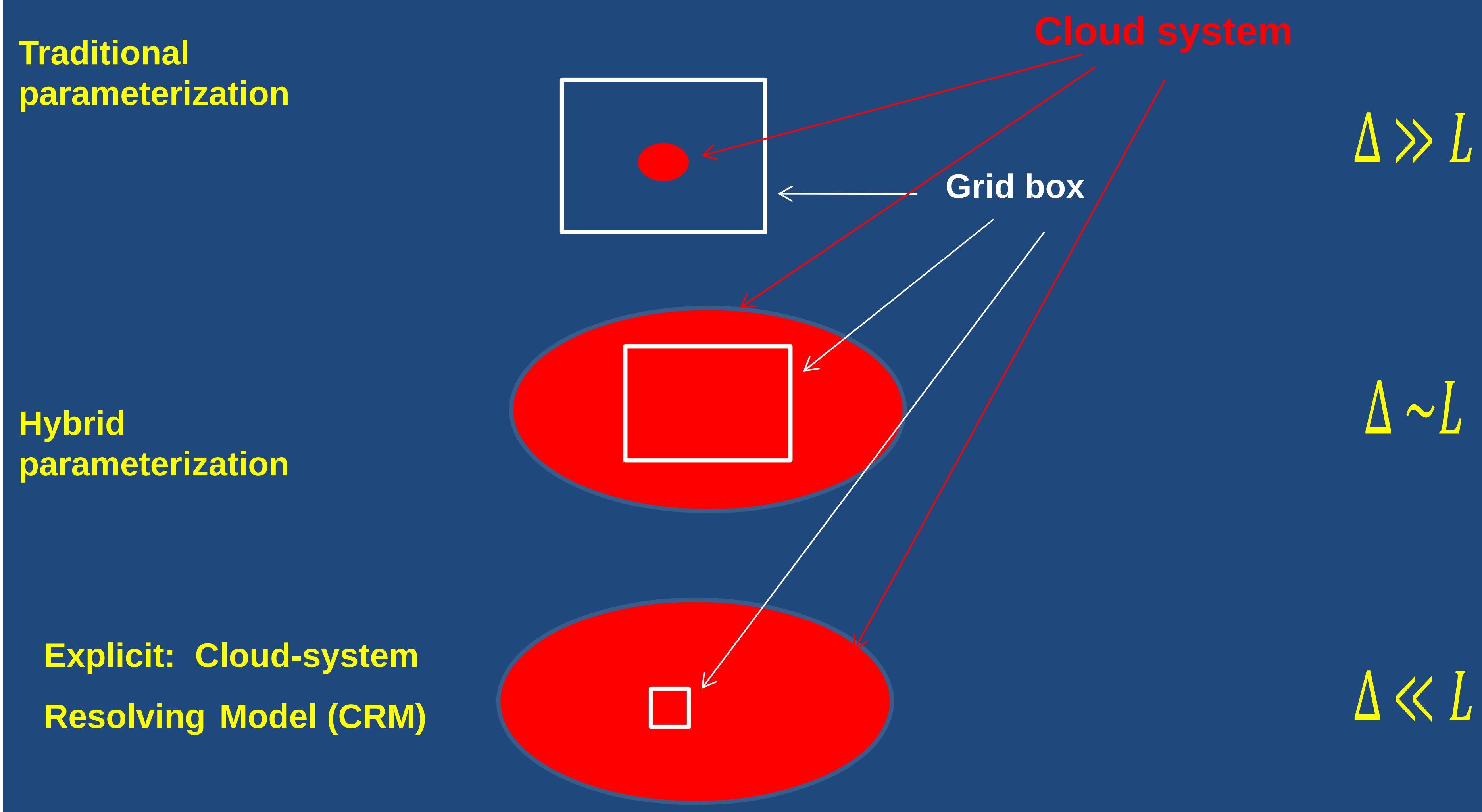


Organized convective system, many grid volumes

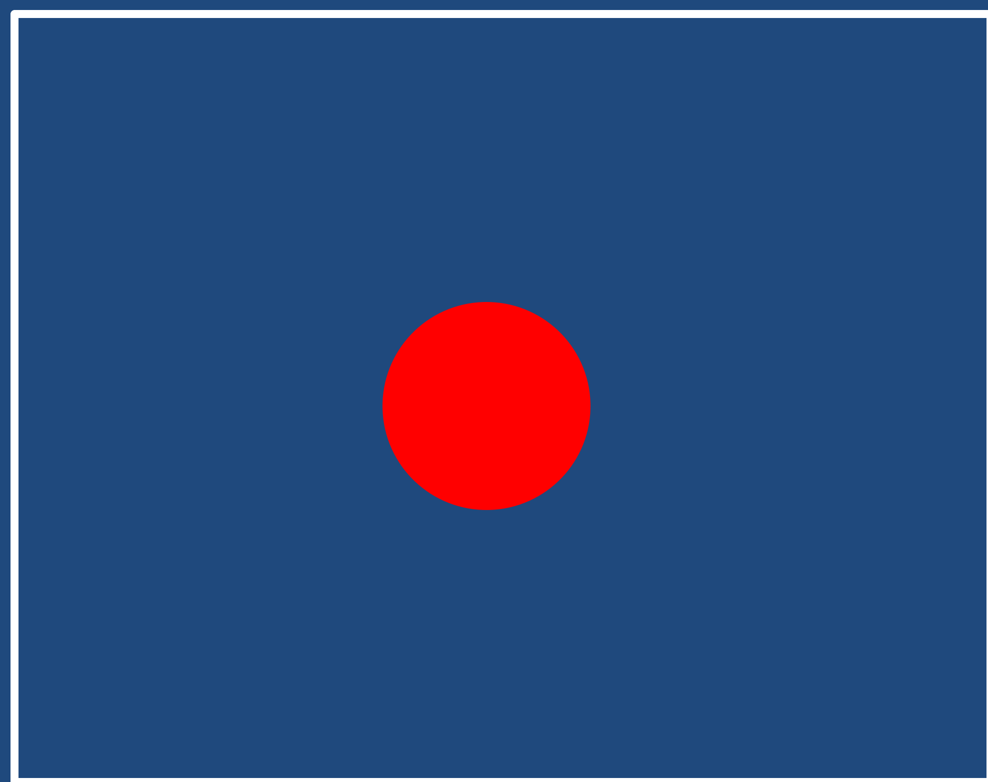
- Organized flow (mesoscale dynamics)
- Environmental shear
- Local and remote response
- Open system
- Strong scale-interaction
- Convectively-generated gravity waves

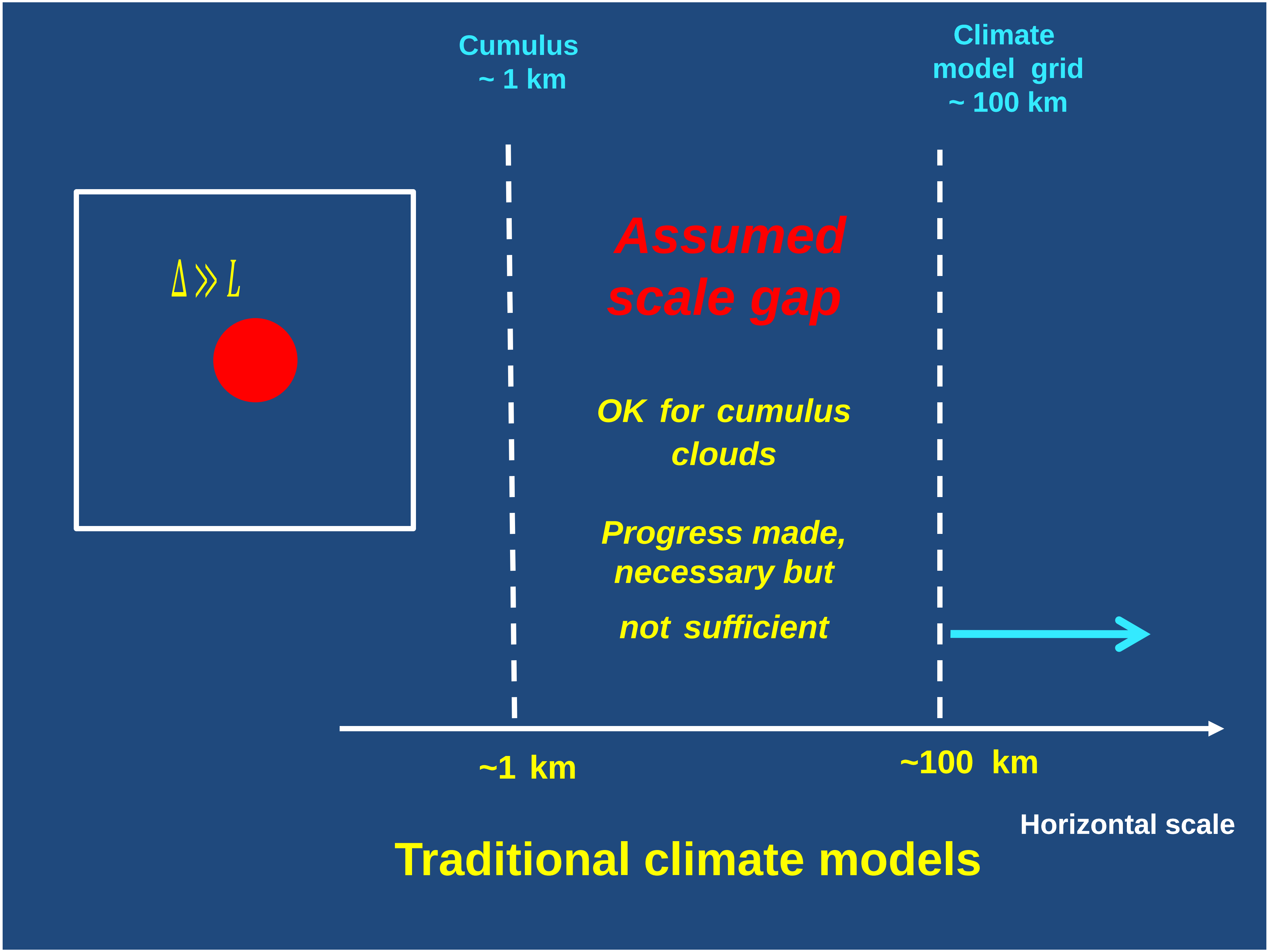
… next-generation NWP models (~ 10 km grid) must take such distinction into account

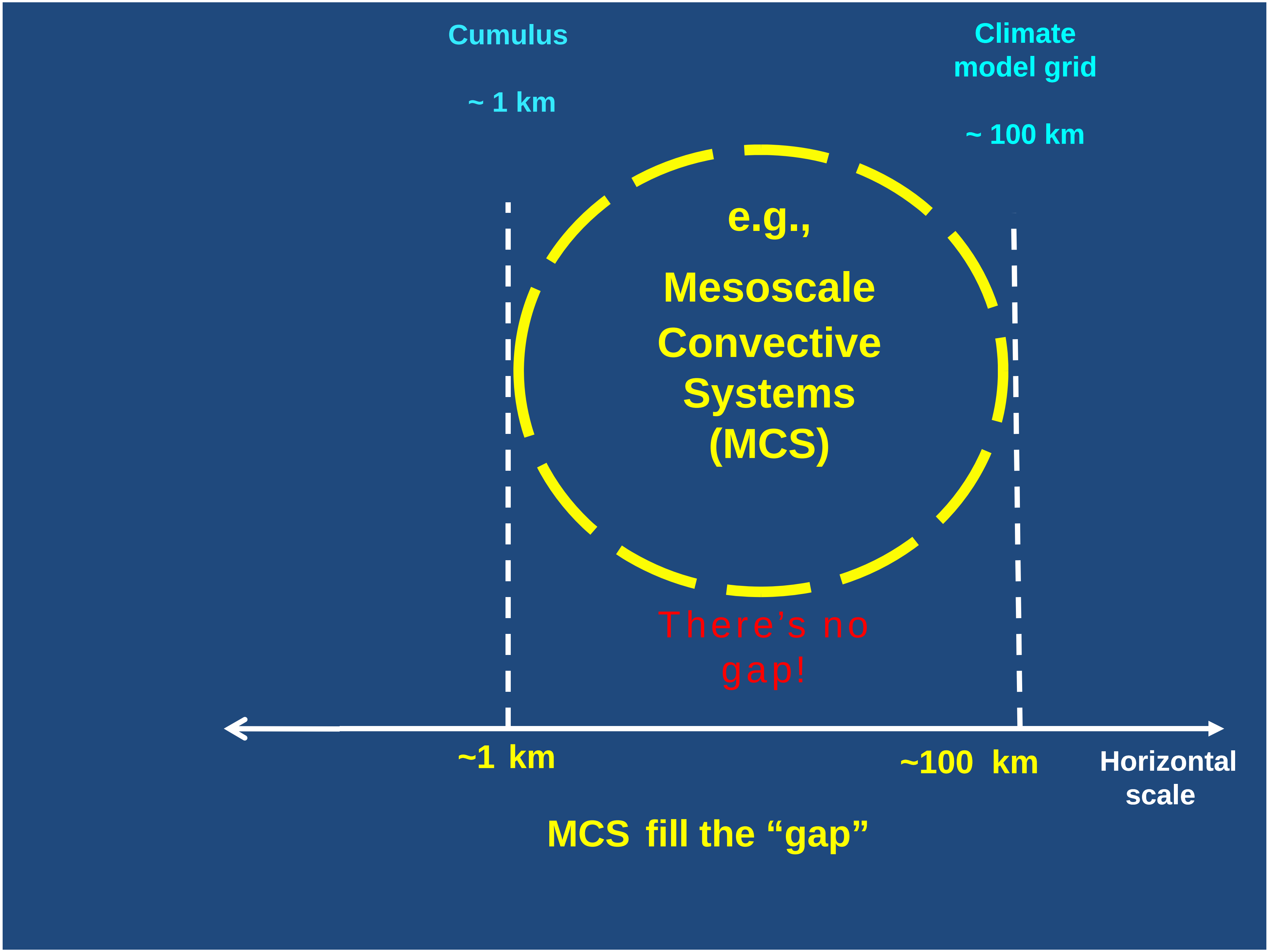
Representing cloud systems of scale L in a numerical model of grid-length Δ



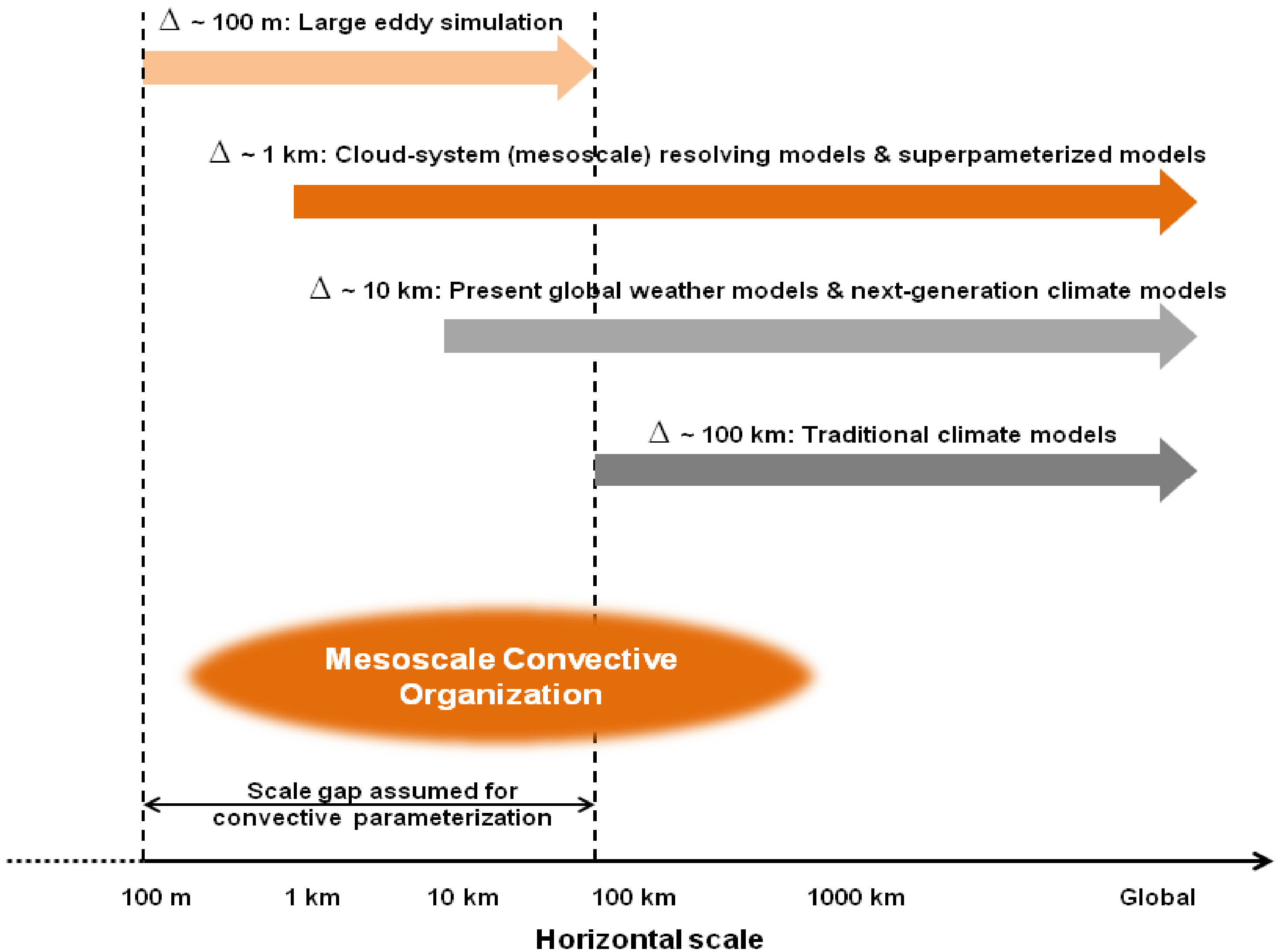
The ‘scale gap’ assumption of convective parameterization



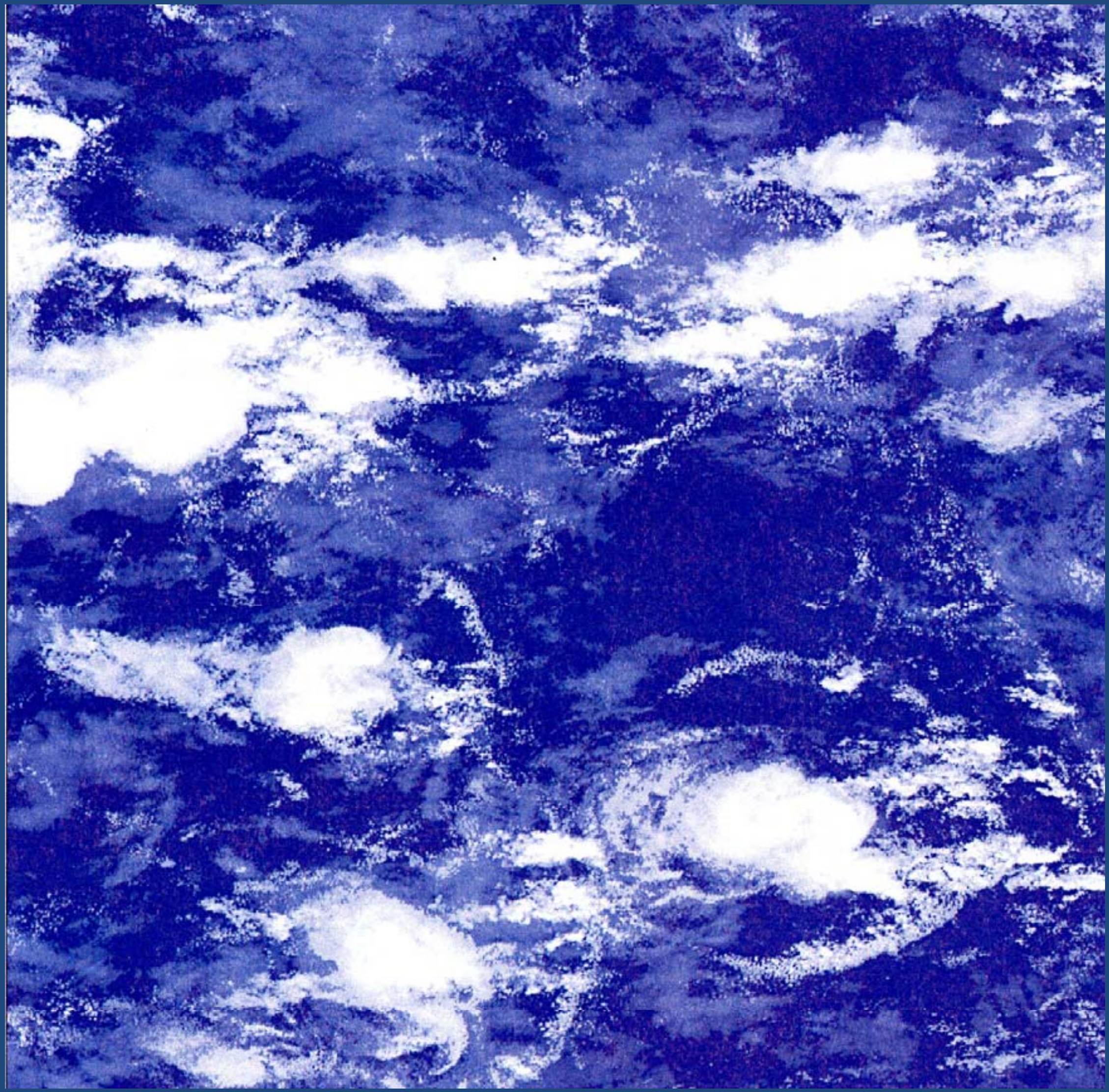

Cumulus
~ 1 km
Climate
model grid
~ 100 km
Δ » L
Assumed
scale gap
OK for cumulus
clouds
Progress made,
necessary but
not sufficient
~1 km
~100 km
Horizontal scale
Traditional climate models


Cumulus
~ 1 km
Climate
model grid
~ 100 km
e.g.,
Mesoscale
Convective
Systems
(MCS)
There's no
gap!
~1 km
~100 km
Horizontal
scale
MCS fill the "gap"

A hierarchy of models span the "gap"

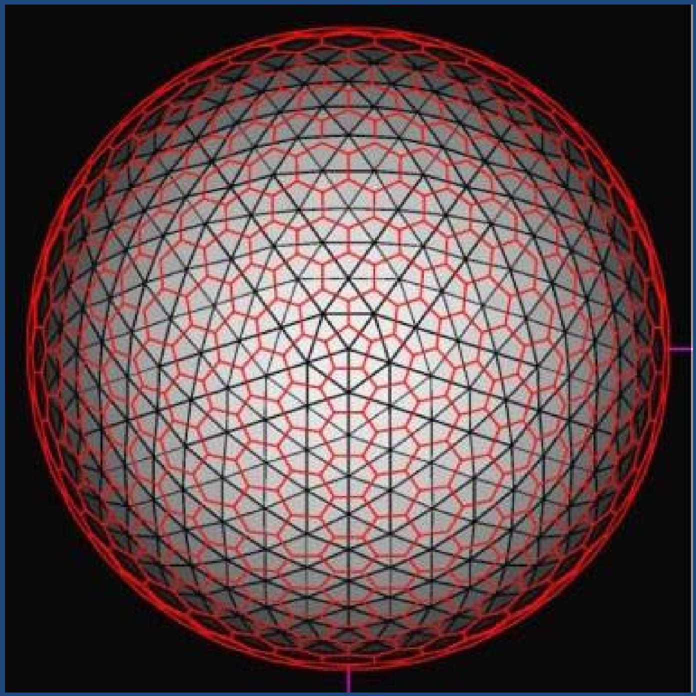


Tropical convection simulated by 100m mesh CRM (200 km x 200 km) horizontal domain, 1-day simulation

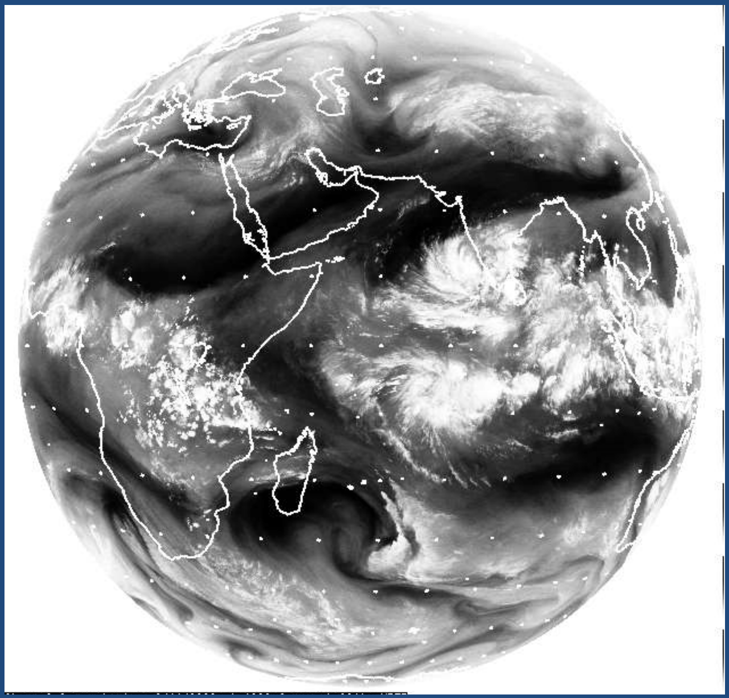


Courtesy: Marat Khairoutdinov, SUNY/Stony Brook

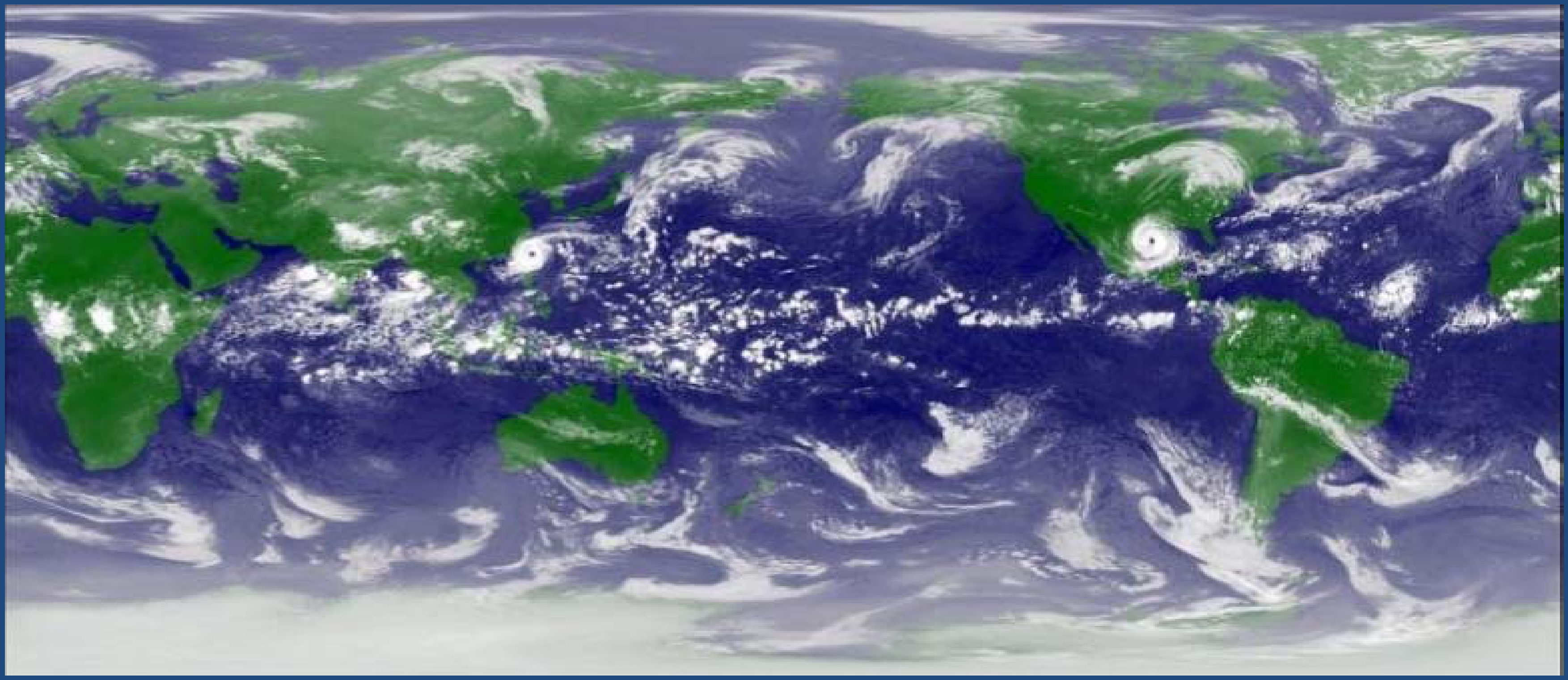
Resolved convective cloud systems



Japan's global cloud-system resolving Nonhydrostatic Icosahedral Atmospheric Model (NICAM)



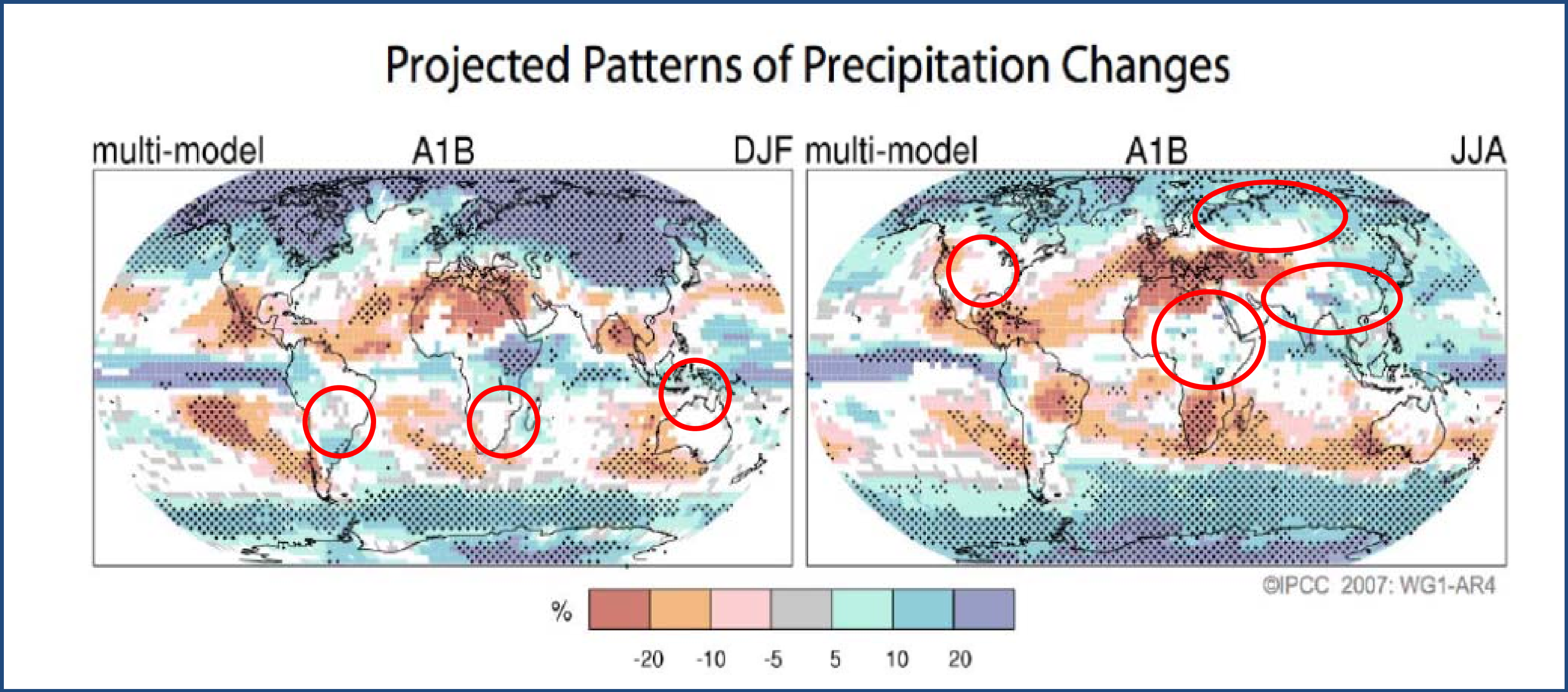
Global cloud-system resolving model: 3.5 km NICAM



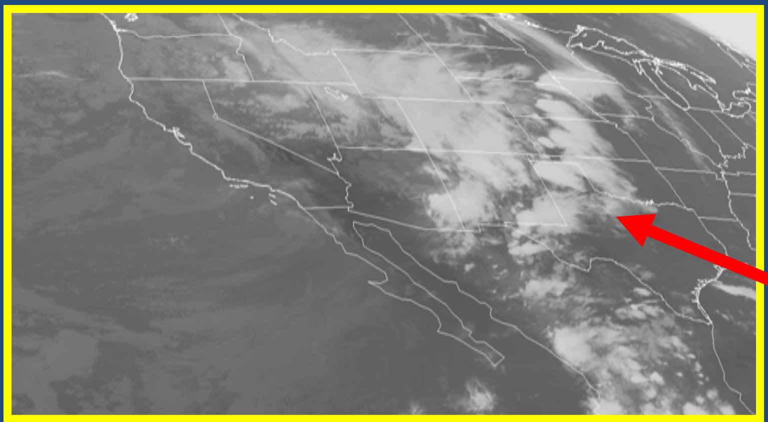
Courtesy: The NICAM Team

Projected changes in precipitation (2090-2099 compared to 1980-1999) from IPCC AR4 climate models: low confidence

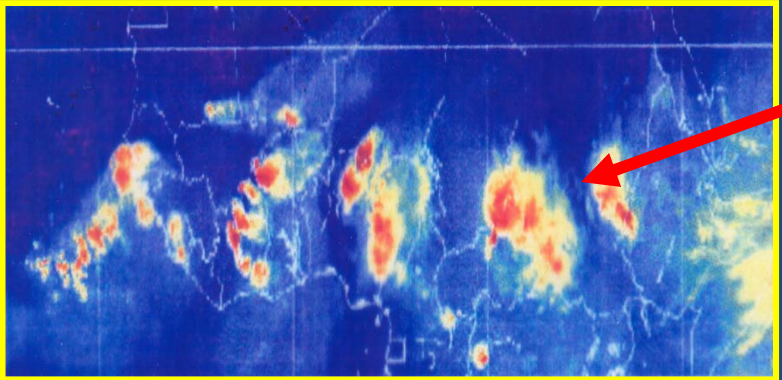
Due to absence of organized convection ?



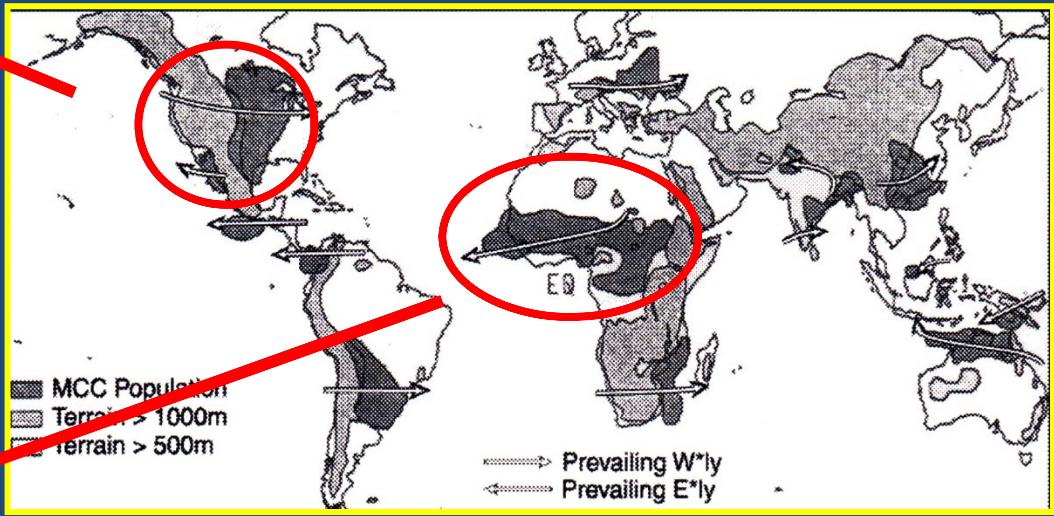
MCS occur downstream of mountains worldwide …



Continental US

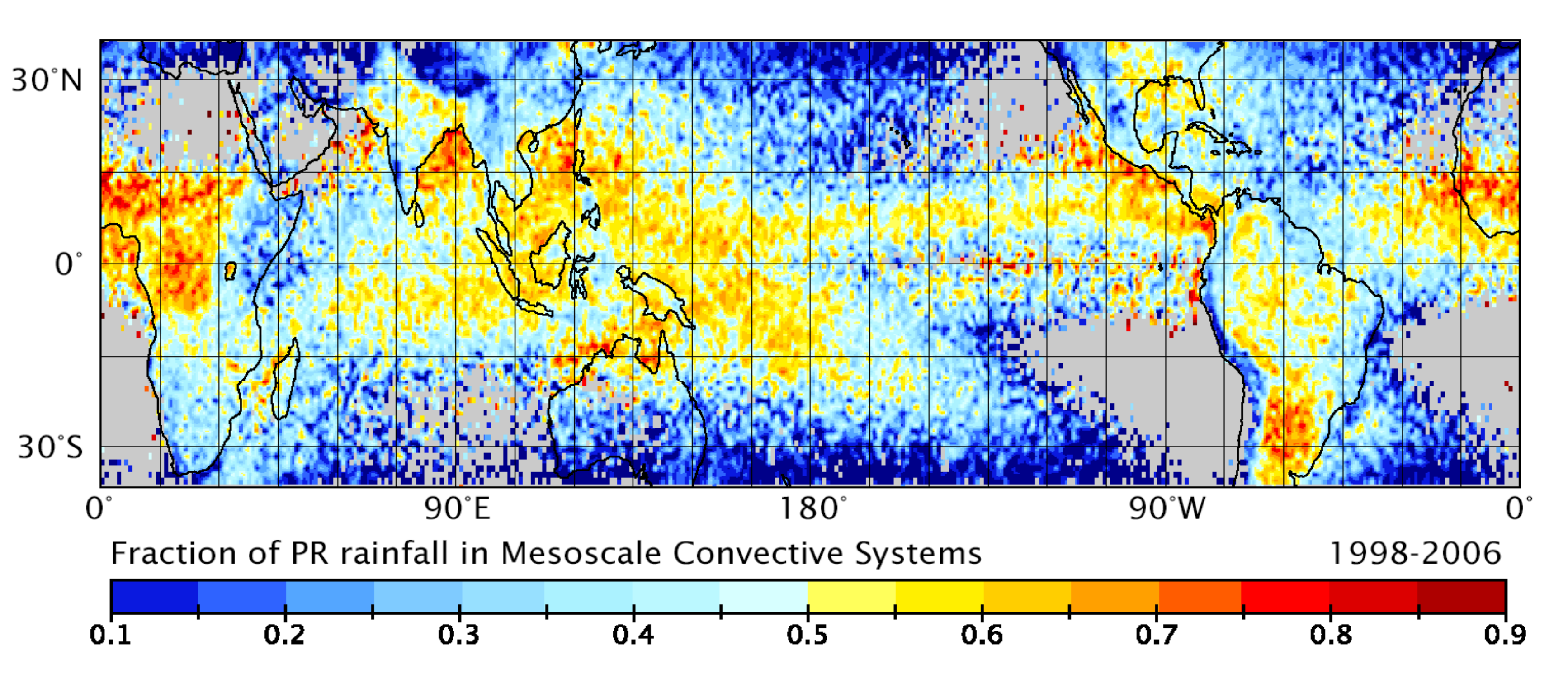


W. Africa



Laing and Fritsch (1997)

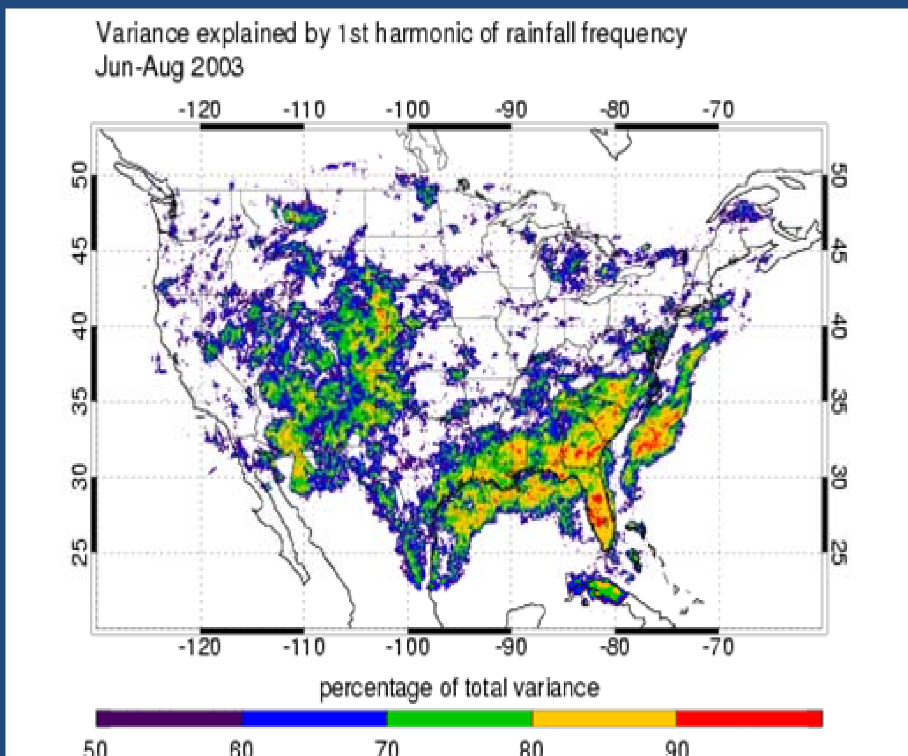
Tropical rainfall from MCS (TRMM measurements)

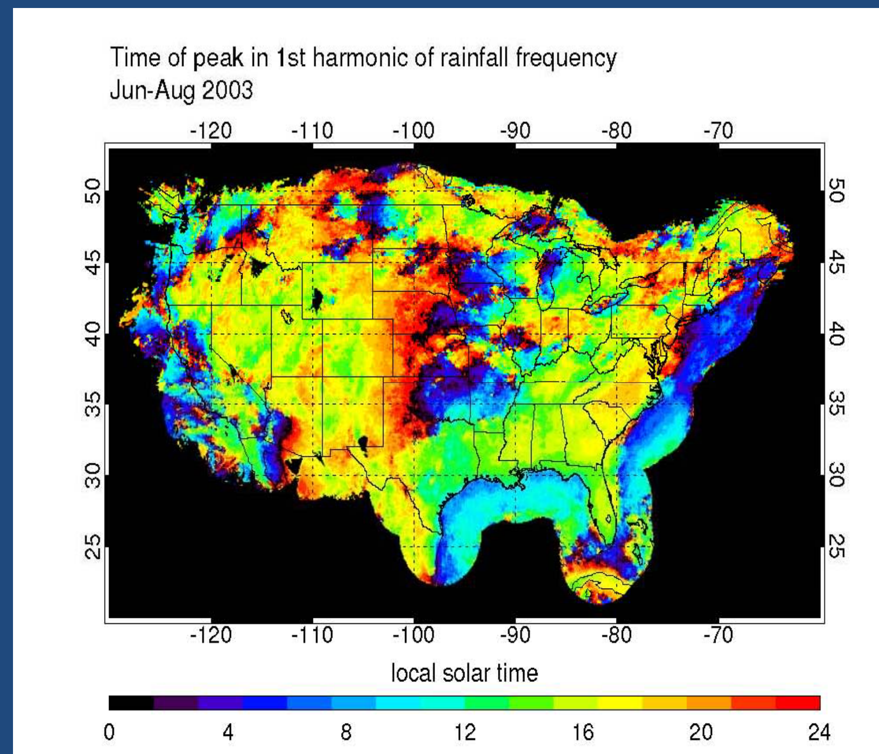


Tao & Moncrieff (2009)

2) Orogenic mesoscale convective systems over the US

Diurnal variability of summer precipitation

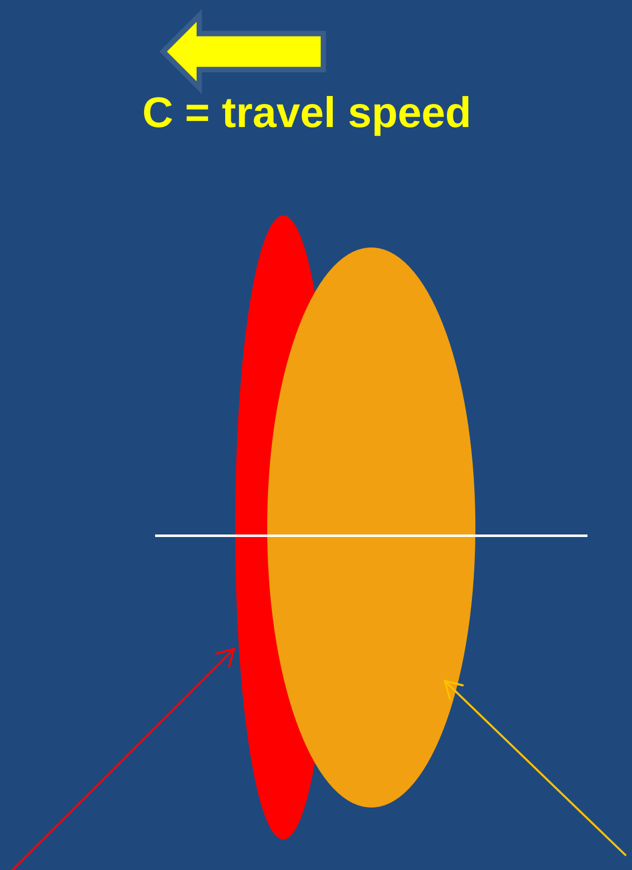


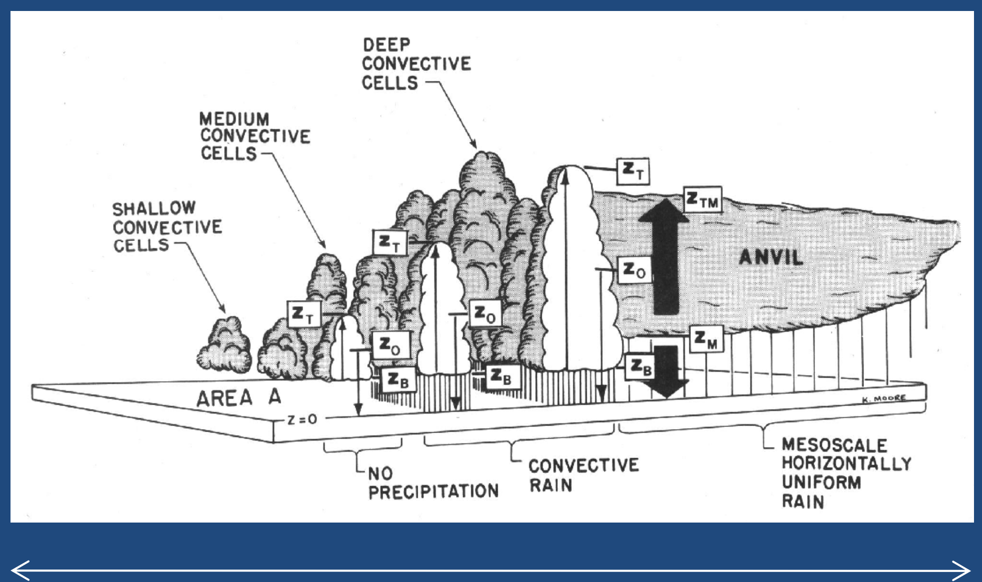


Knievel et al. (2004)

Mesoscale convective systems: A building block for large-scale convective organization ?

Two primary scales of MCS

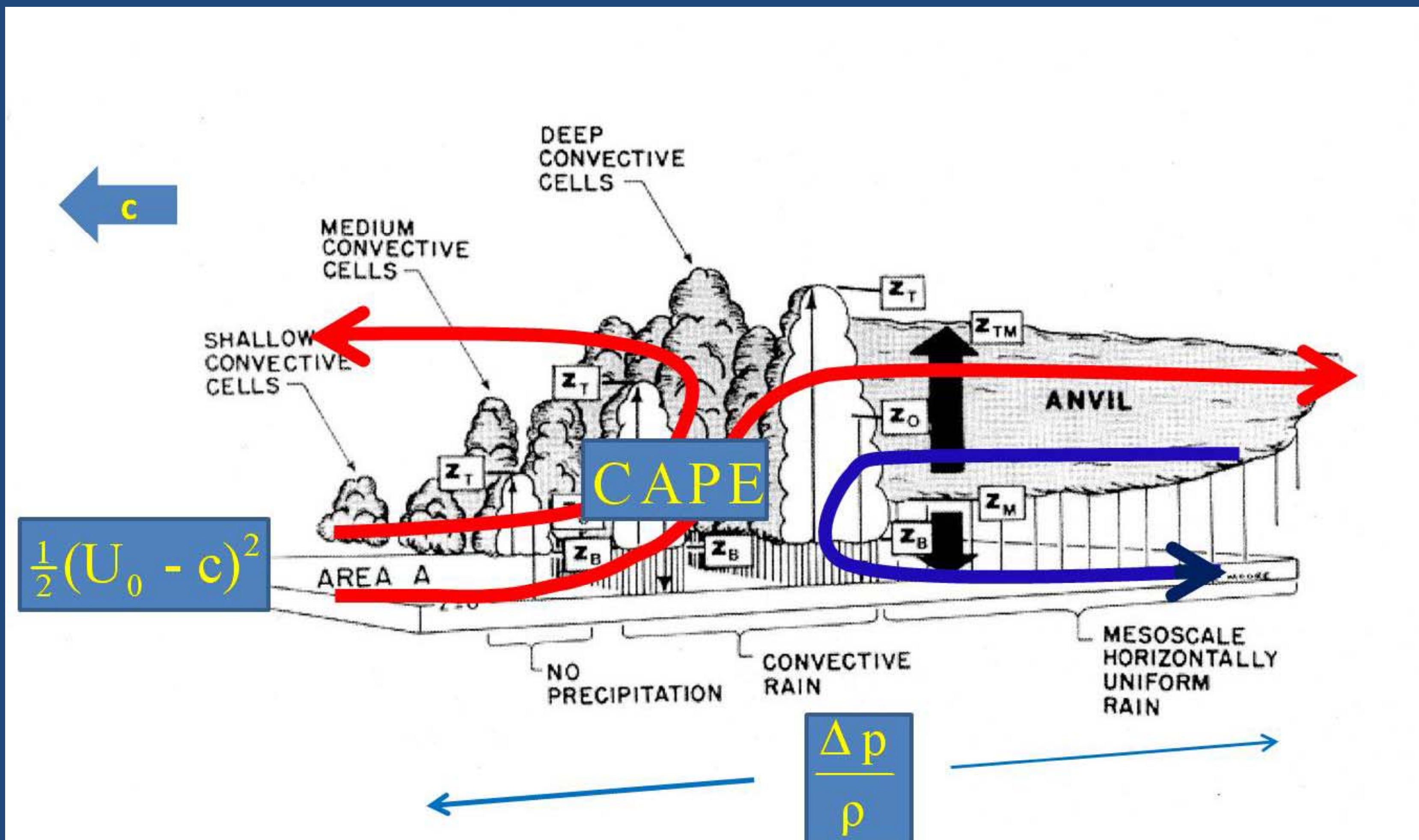




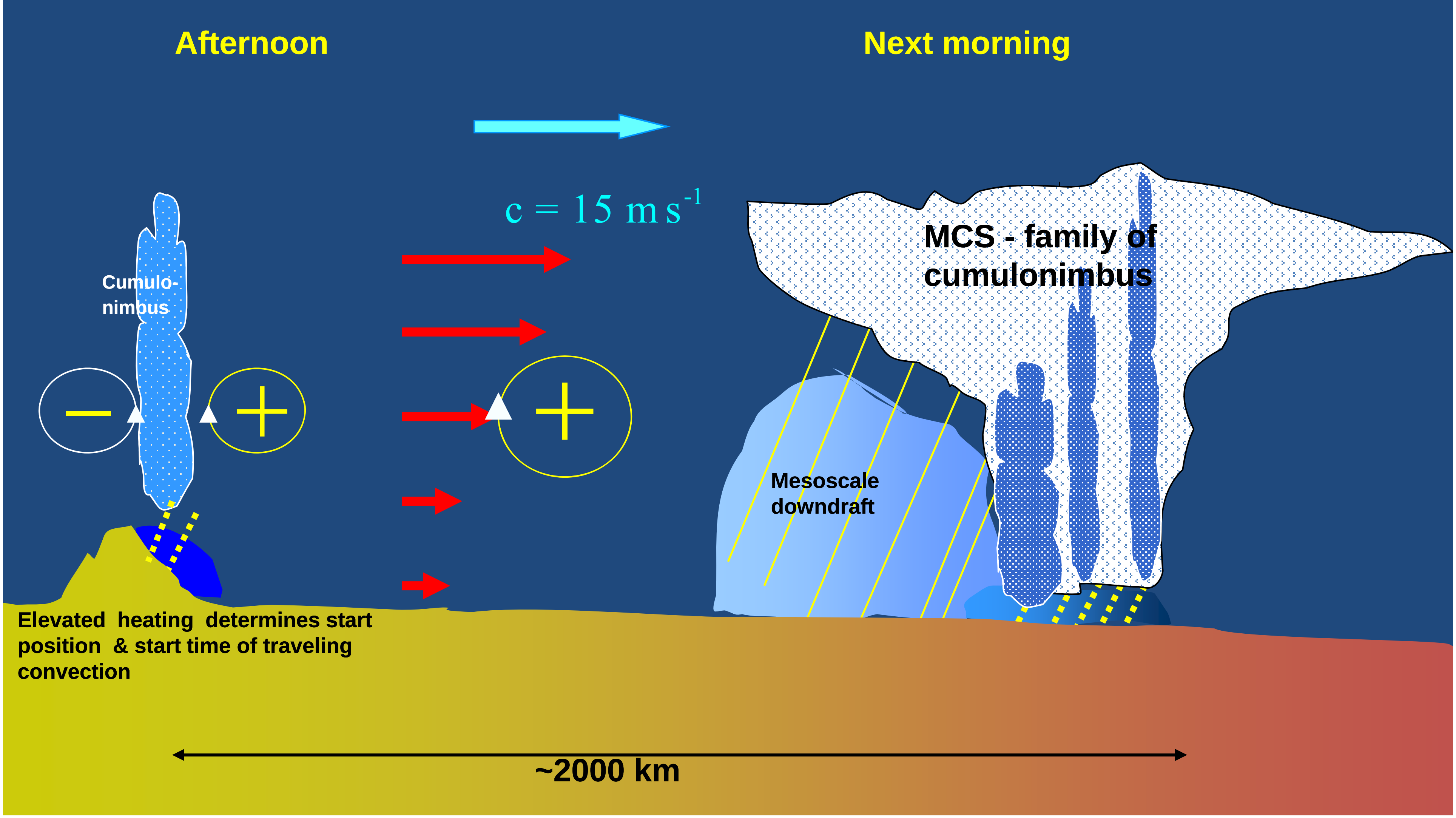
Deep convection
~ 10 km

Stratiform region
~ 100 km

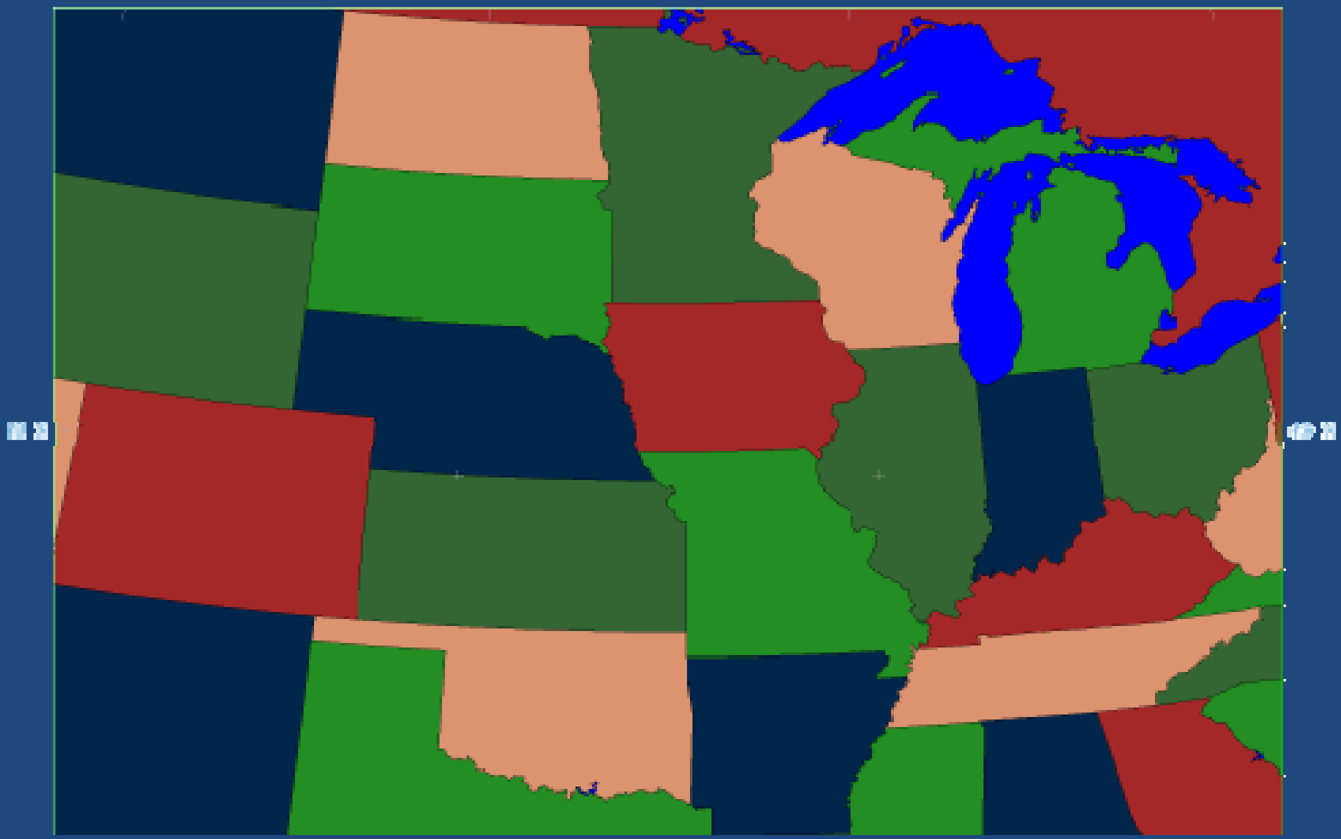
Slantwise layer overturning dynamics



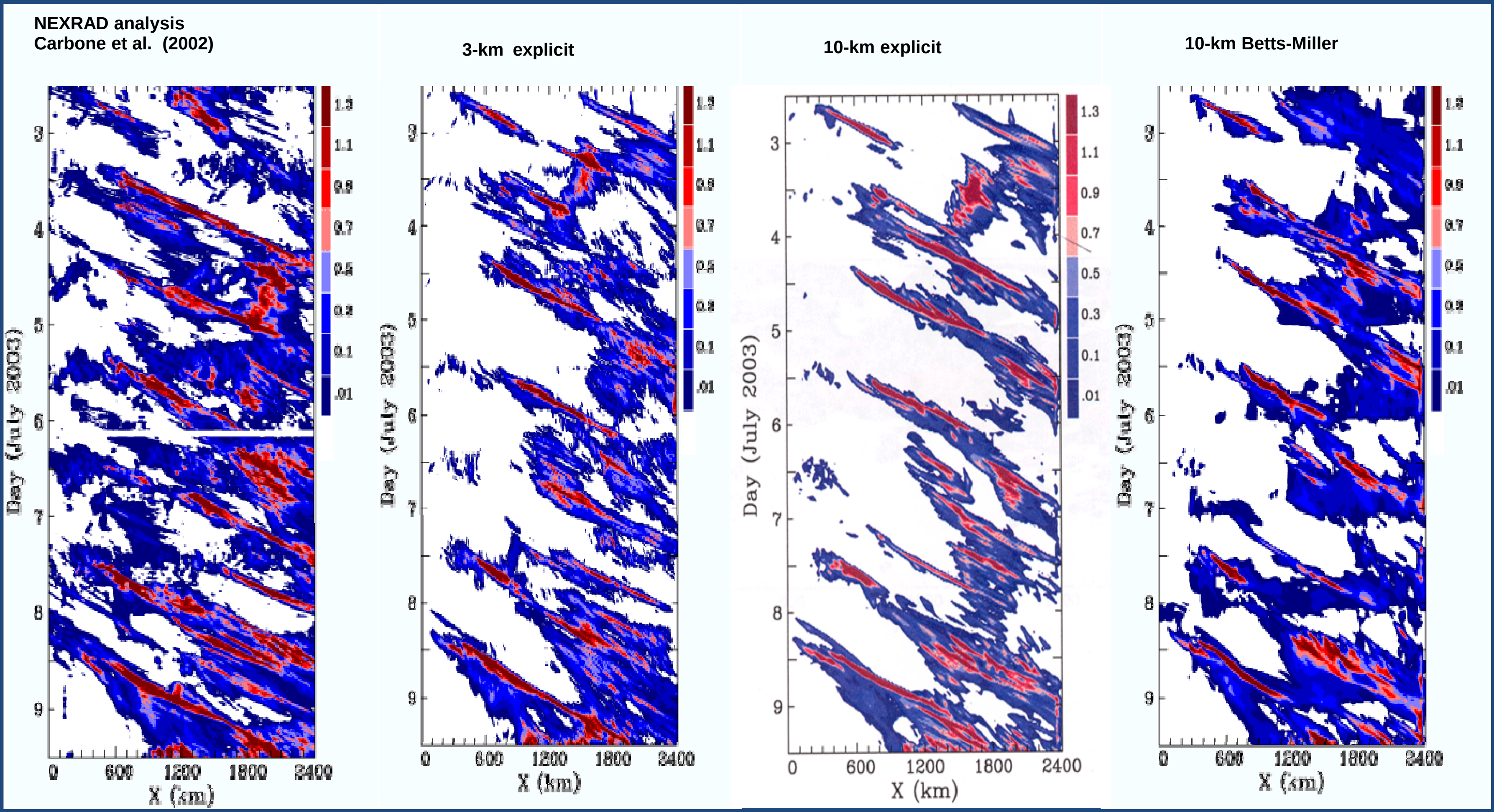
MCS over the U.S.



Cloud-resolving numerical simulation

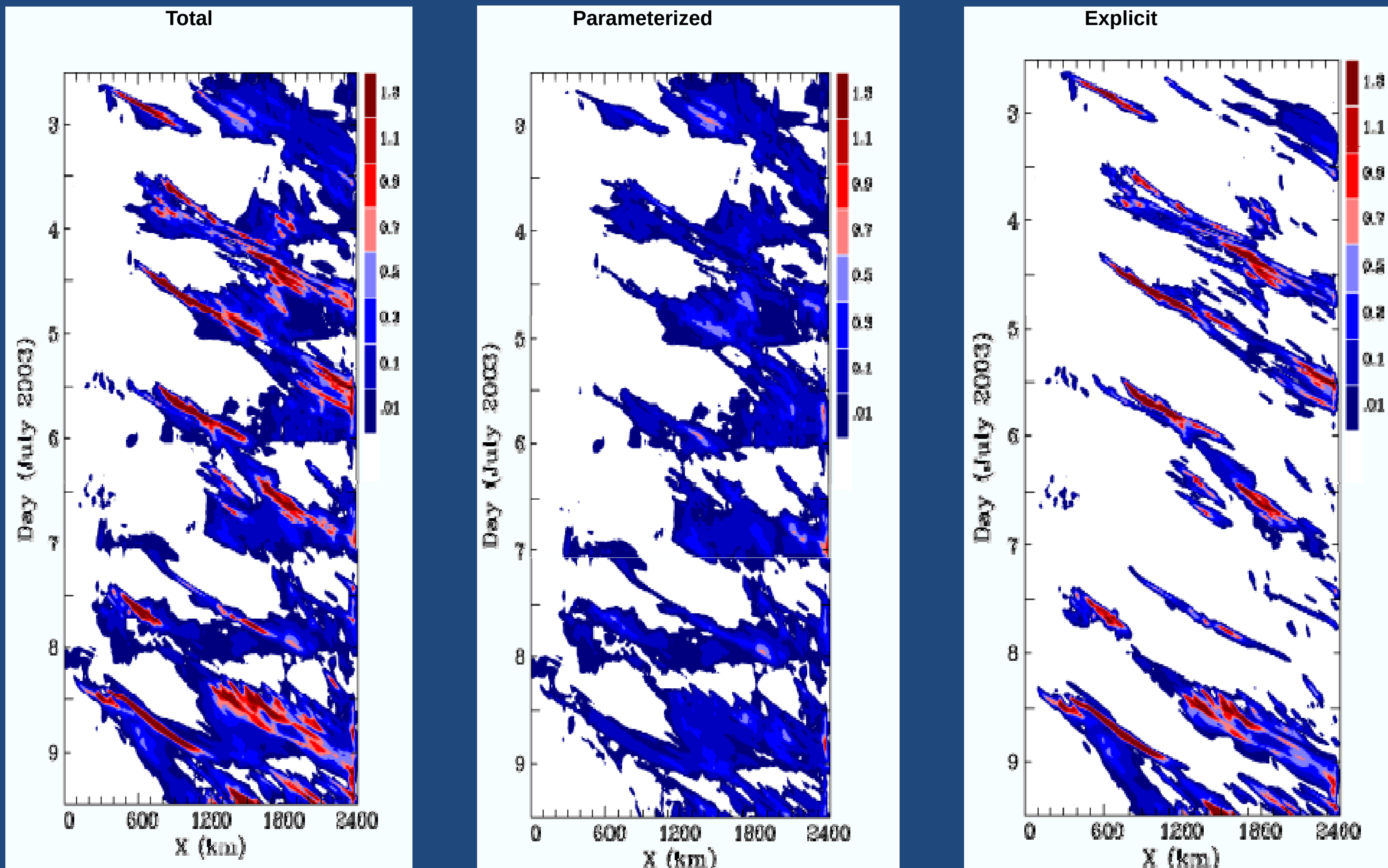


Meridionally averaged rain-rate

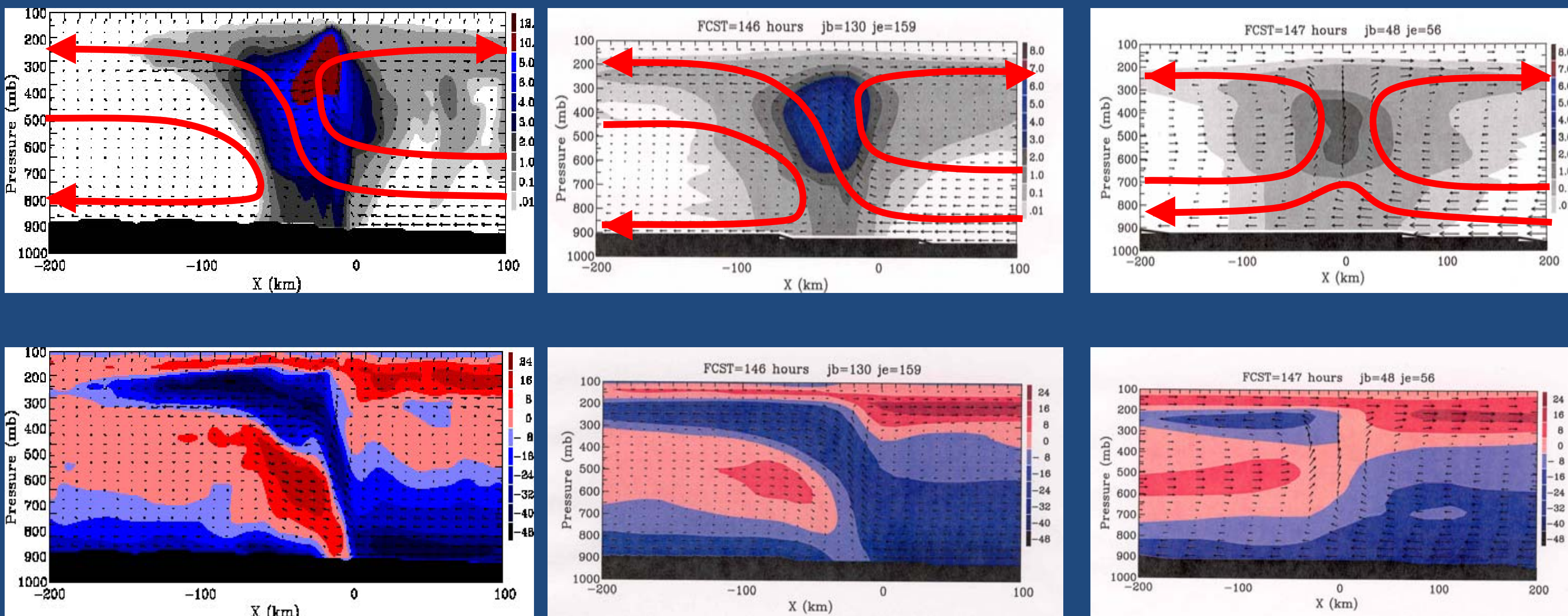


Moncrieff and Liu (2006)

‘Grid-scale’ circulations represent propagating MCS



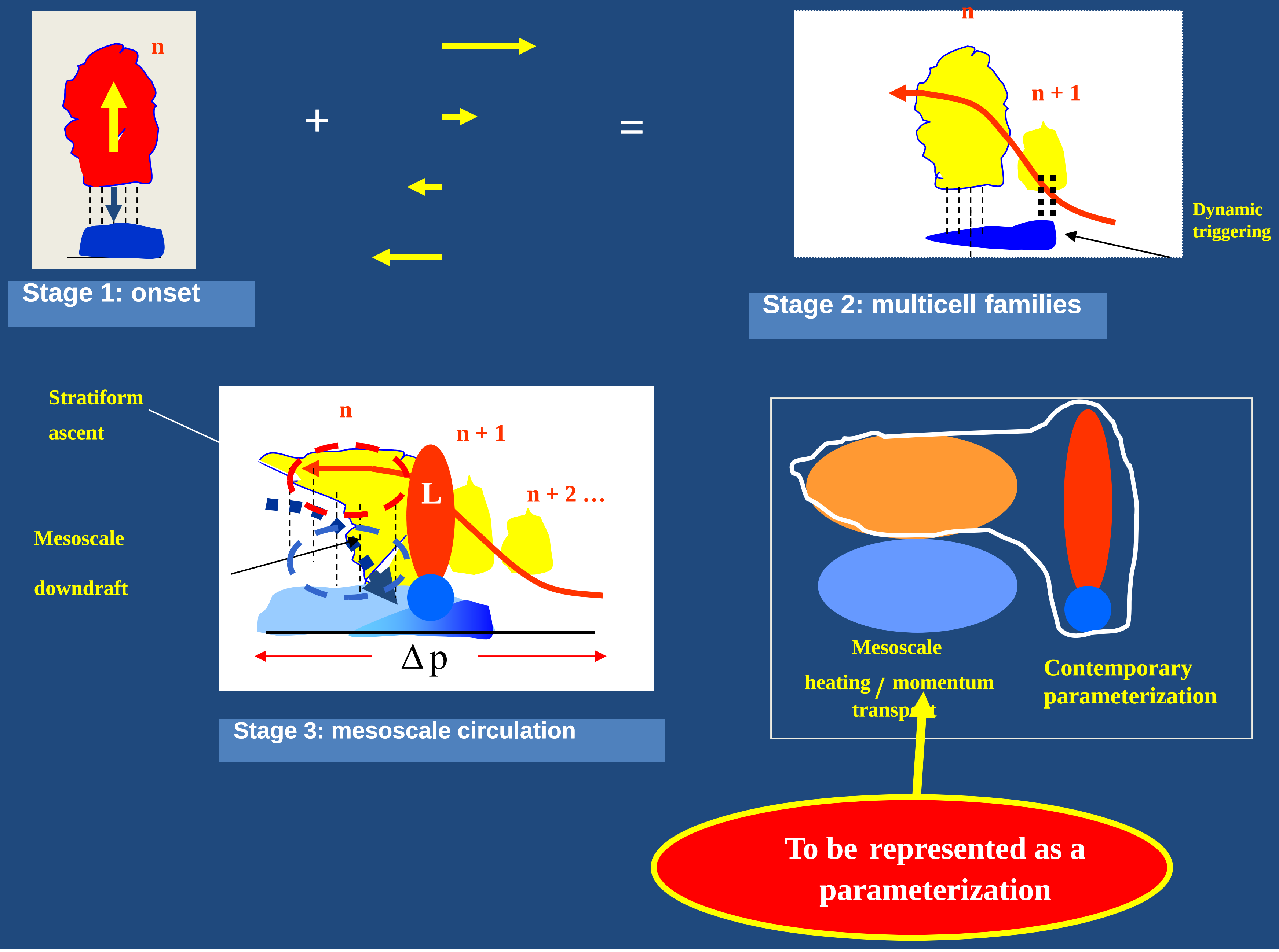
Resolution dependence



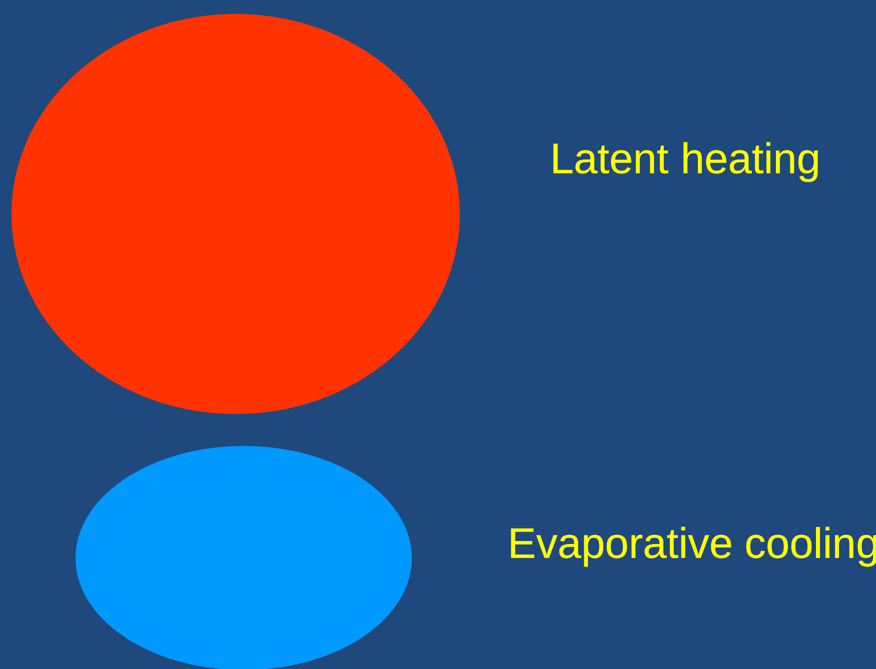
$\Delta = 3$ km $\qquad \Delta = 10$ km $\qquad \Delta = 30$ km

3-km & 10-km grids – similar
30-km grid – unrealistic

Upscale evolution of cumulus into MCS



Slantwise layer overturning generates ‘top-heavy’ heating

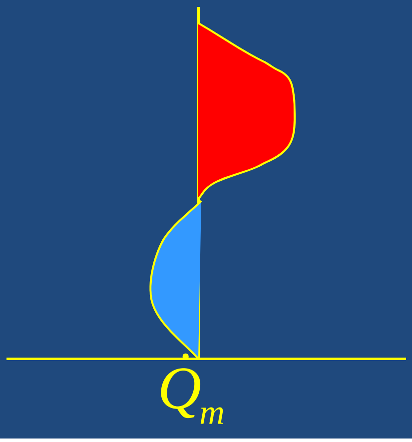


Parameterizing slantwise mesoscale overturning

Stratiform heating + mesoscale evaporative descent

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

$$Q = Q_c + Q_m$$



Q_m = Heating by slantwise mesoscale overturning

Q_c = Cumulus heating

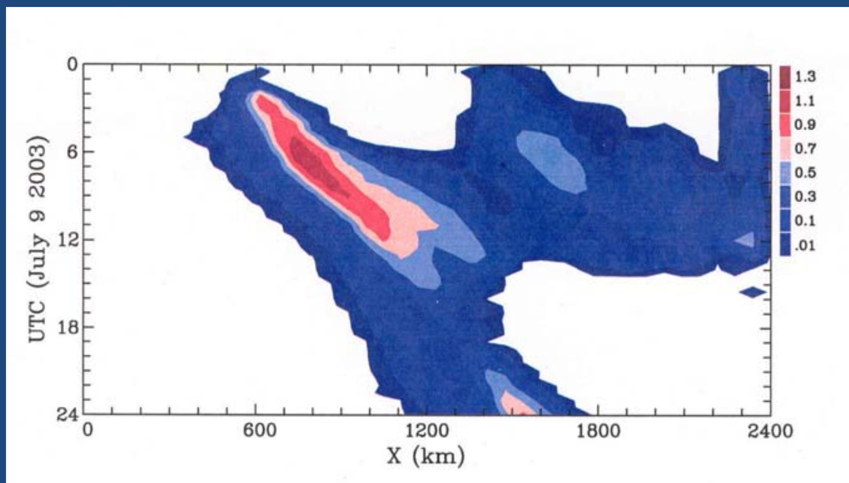
$\propto_1$ = Quotient of heating by slantwise mesoscale overturning and cumulus heating

$\propto_2$ = Quotientof first-baroclinic heating and second-baroclinic heating

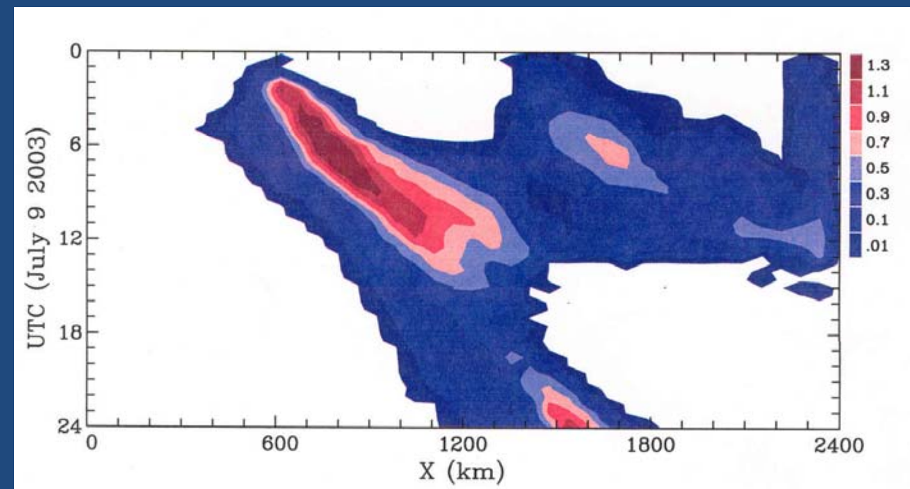
p_s = Cloud-top pressure

p_s = Surface pressure

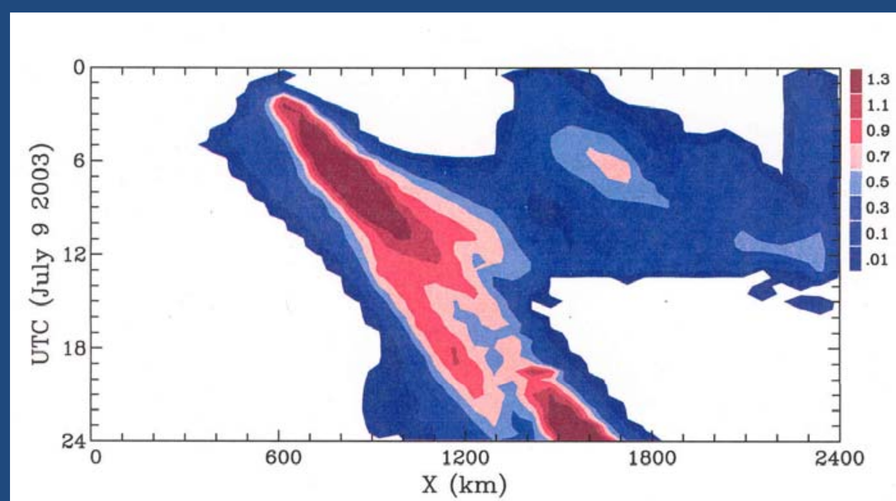
Δ = 60 km



Cumulus parameterization

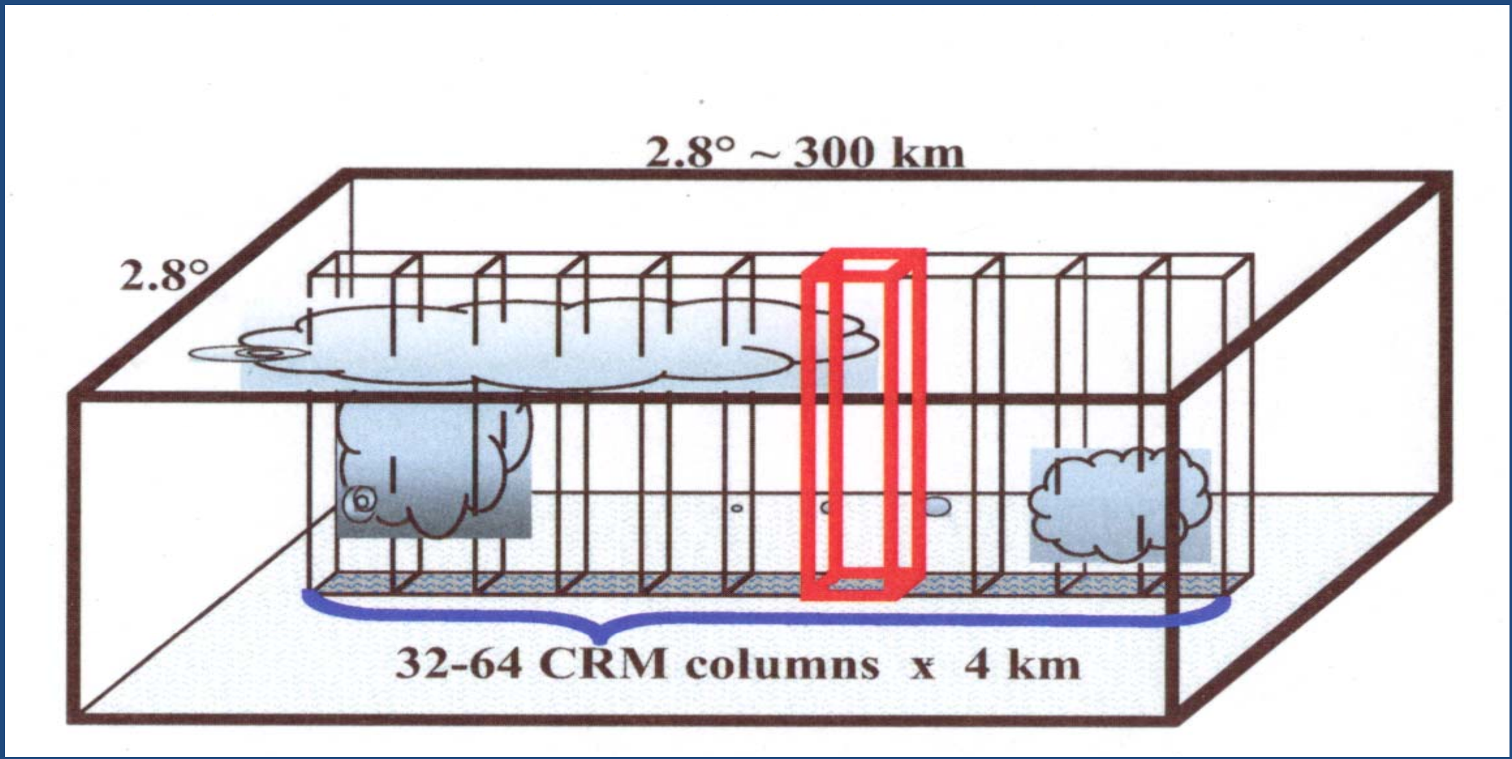


Cumulus param + mesoscale param

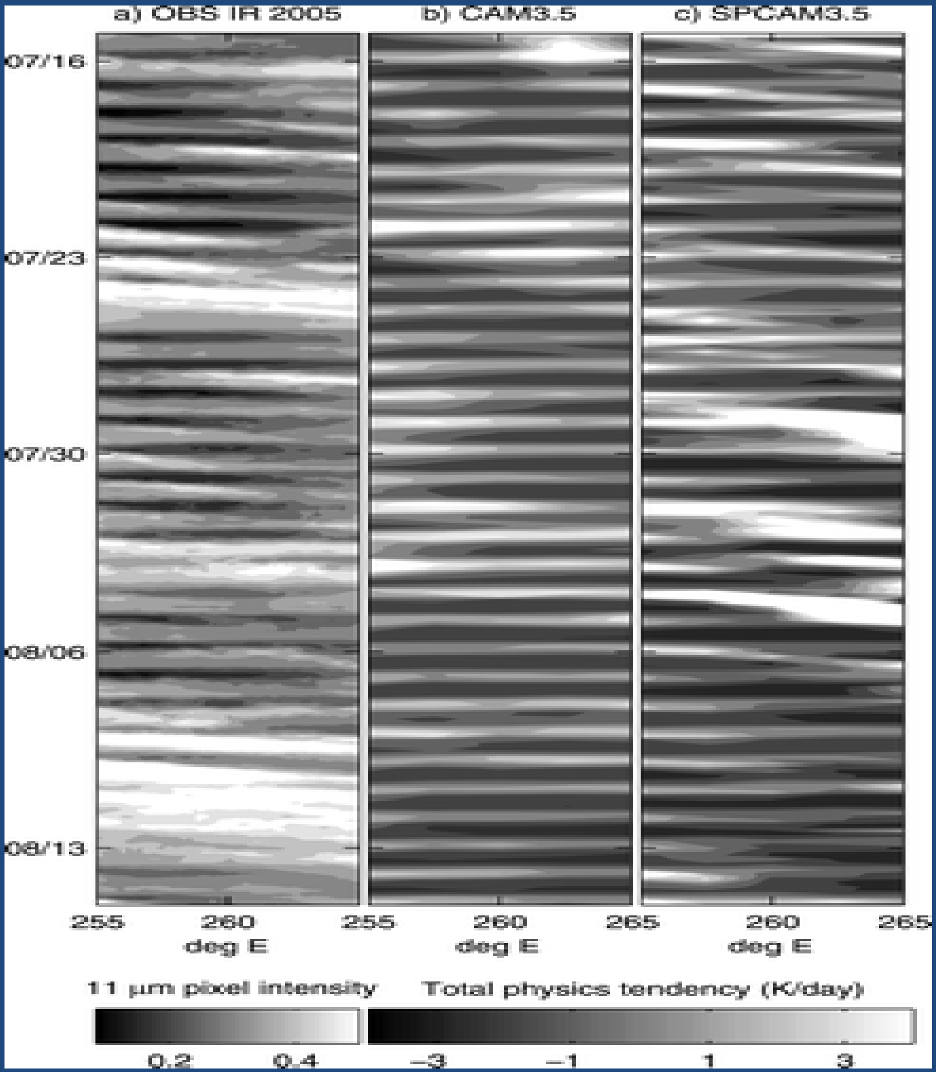


Cumulus param + mesoscale param + grid-scale circulation

Superparameterization

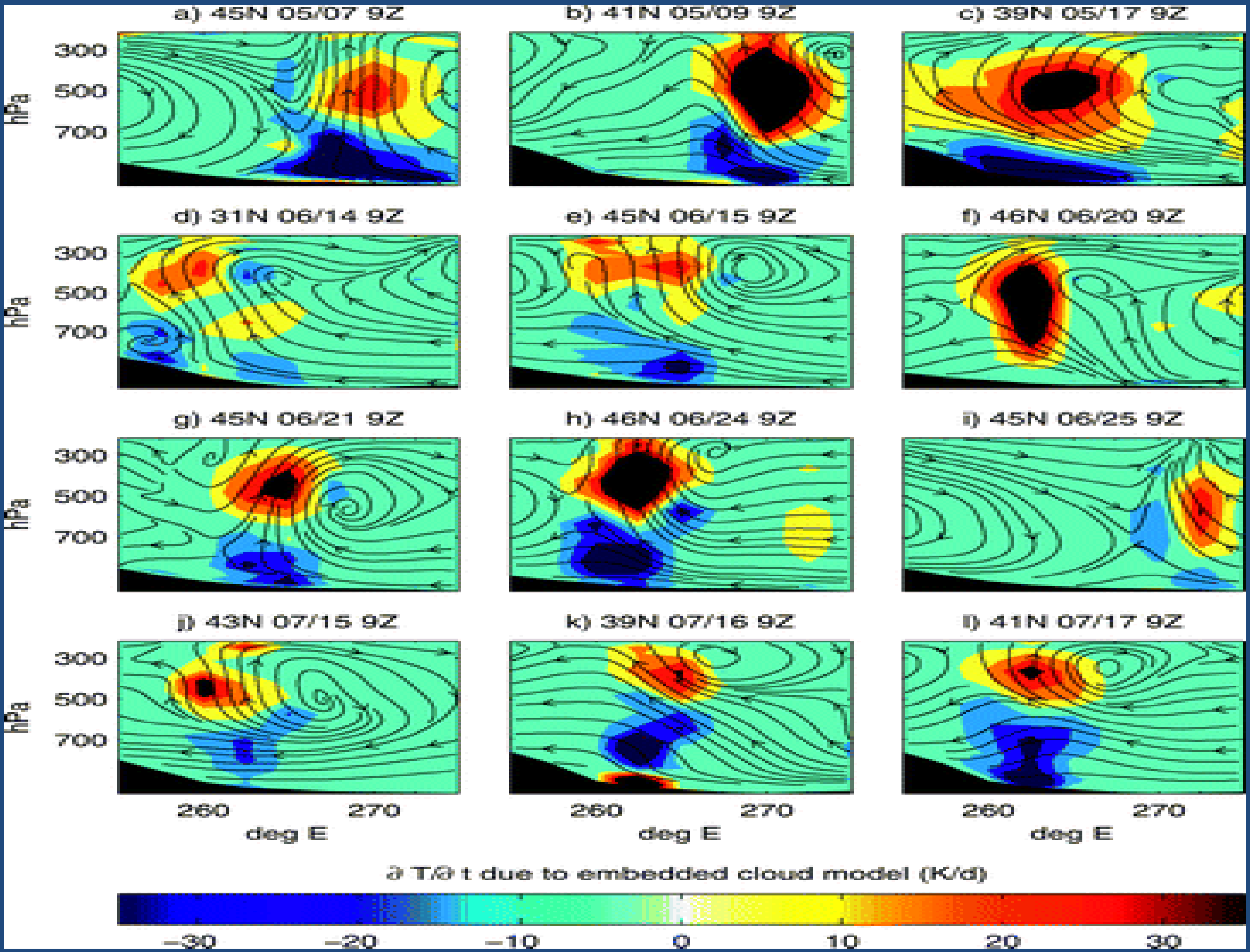


Superparameterization in NCAR Community Atmosphere Model (CAM 3.5)

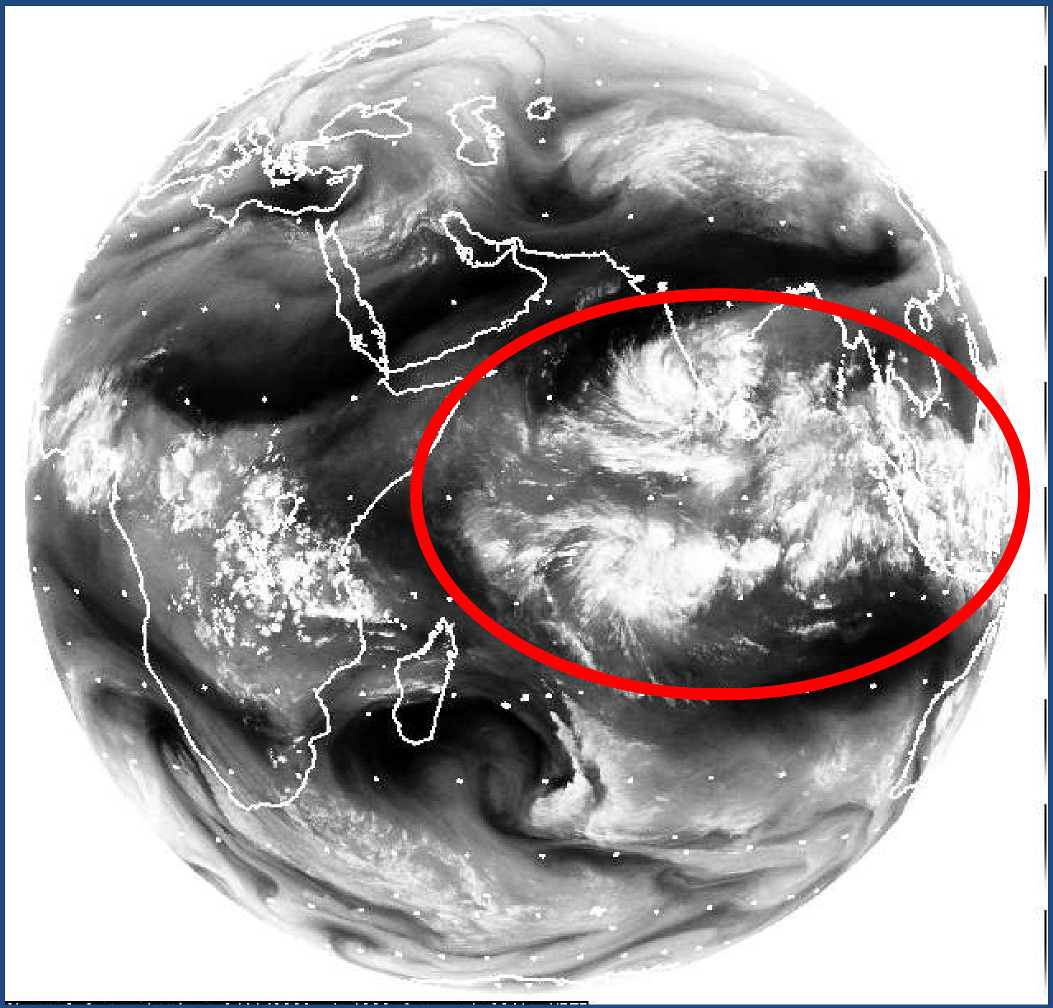


Pritchard Moncrieff, Somerville (2010)

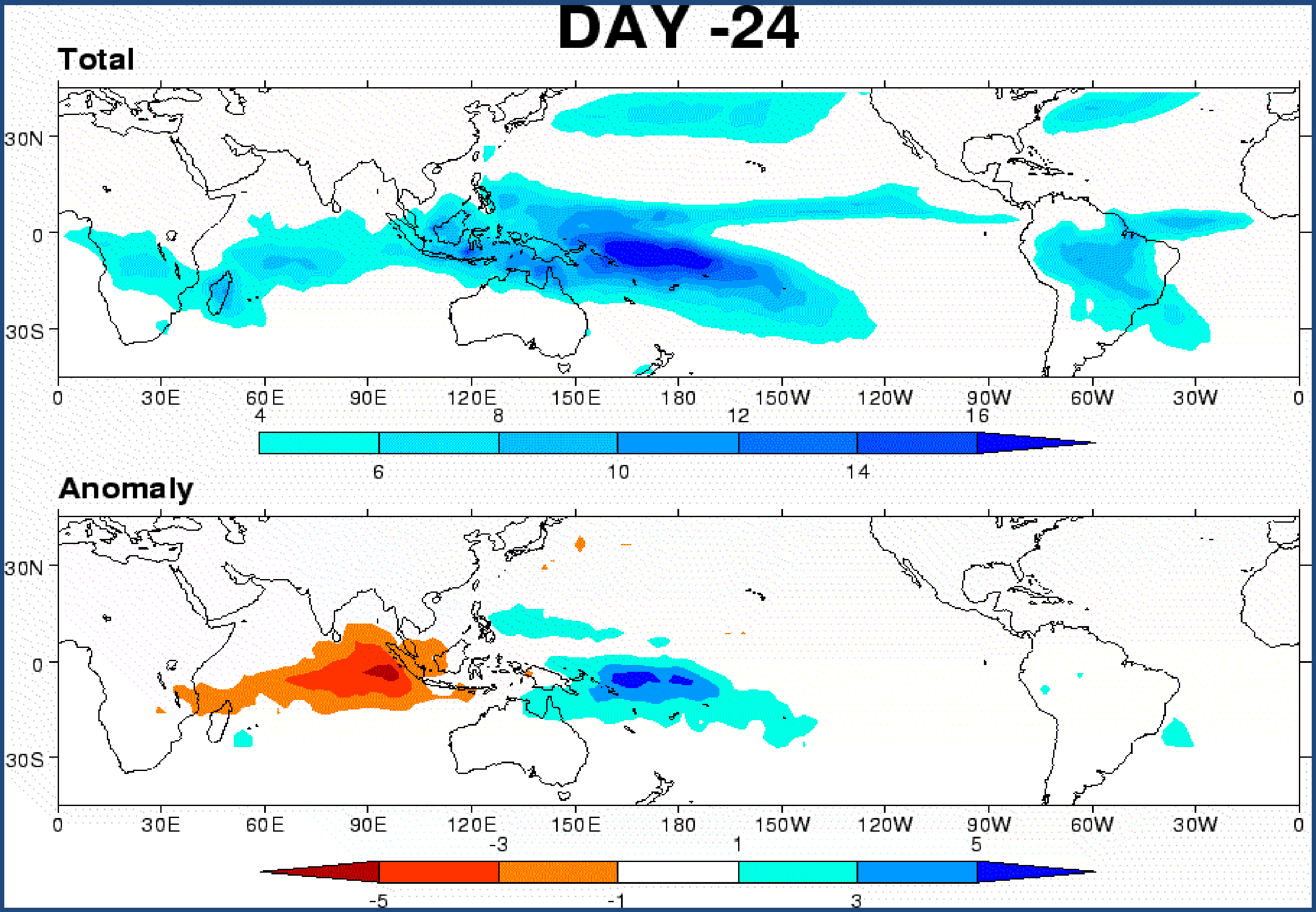
Vertical structure



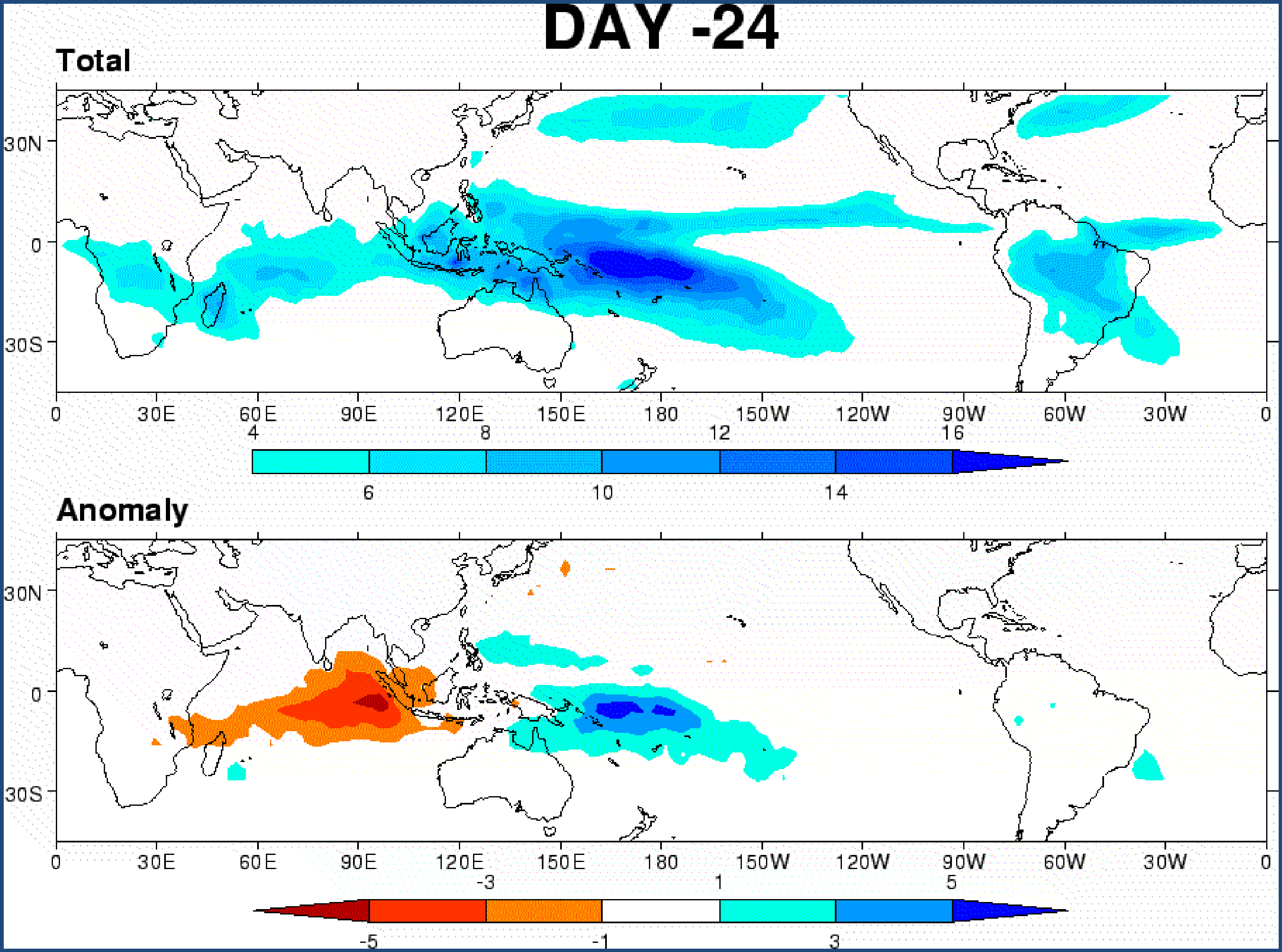
3) Madden-Julian Oscillation (MJO)



Outgoing Longwave Radiation (OLR)

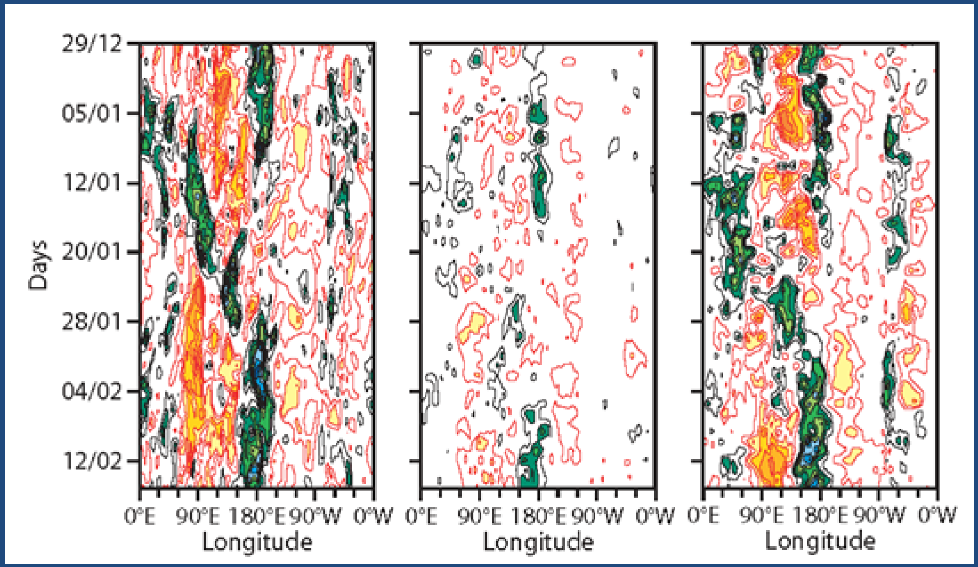


Courtesy: Adrian Matthews, U.E. Anglia, UK



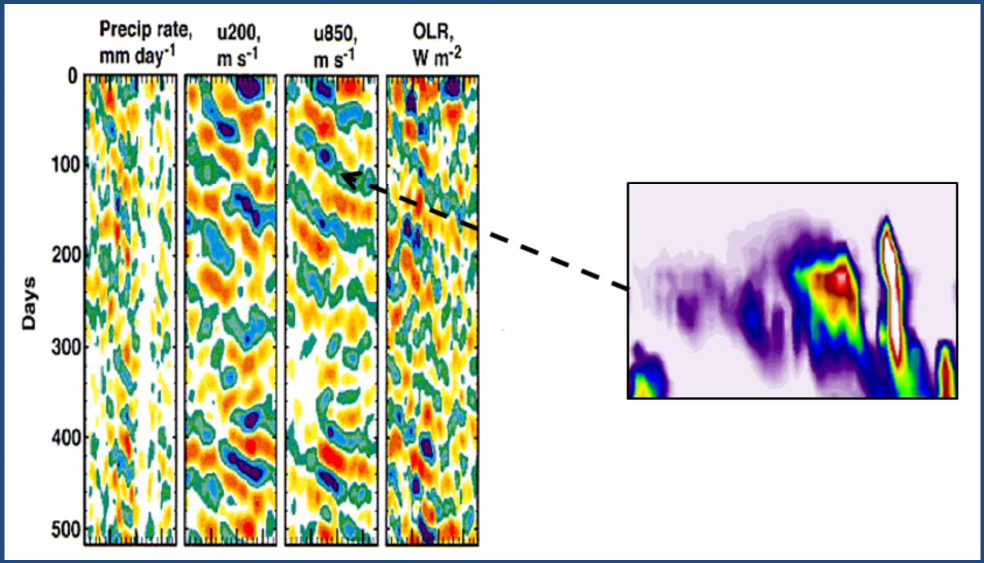
Courtesy: Adrian Matthews, U.E. Anglia, UK

ECMWF Integrated Forecast System (IFS) – Vitard et al (2011)

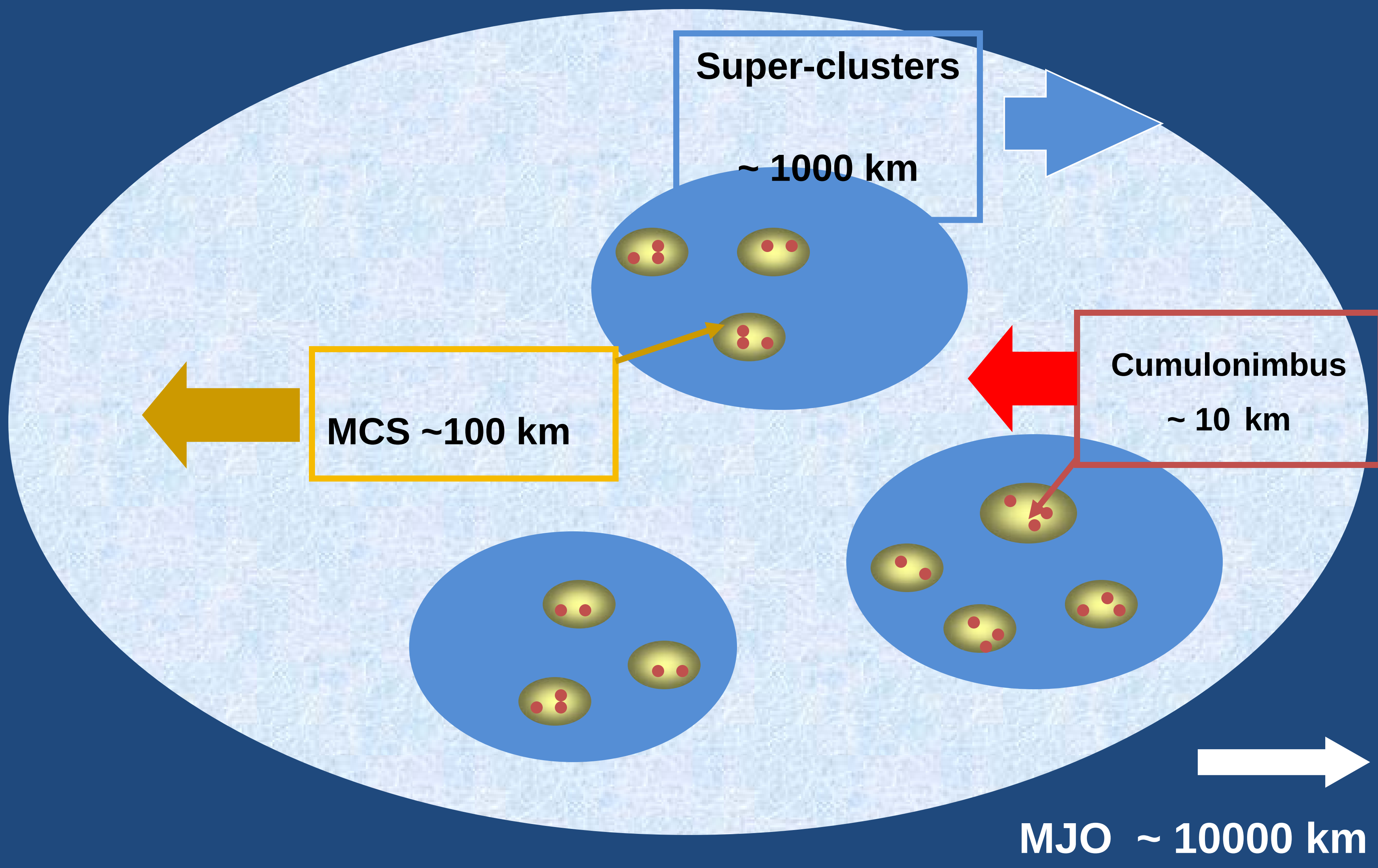


Superparameterization – Khairdoutdinov et al (2003)

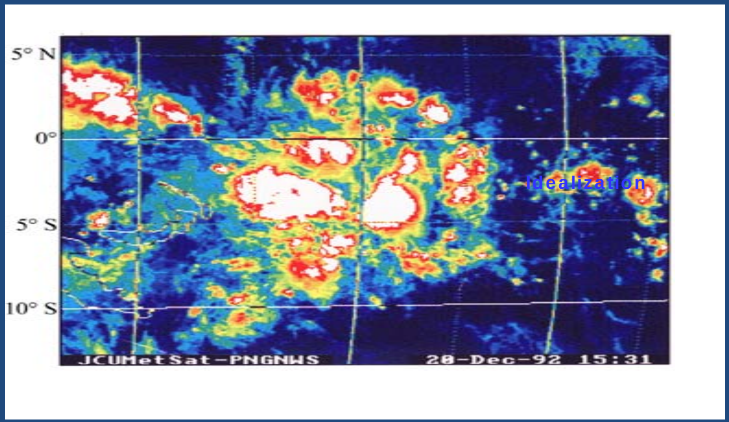
Progress with the MJO

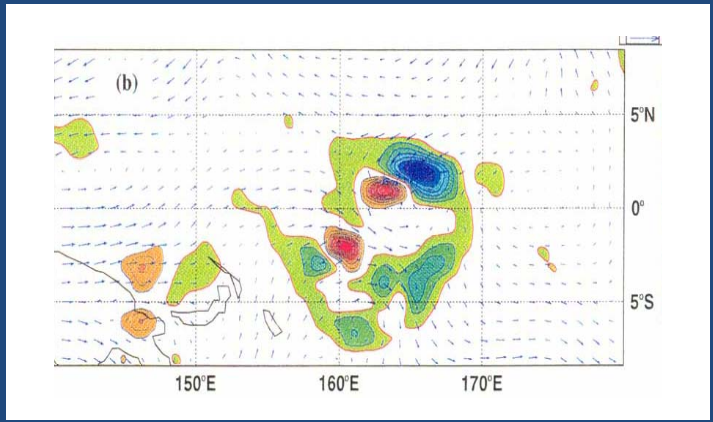


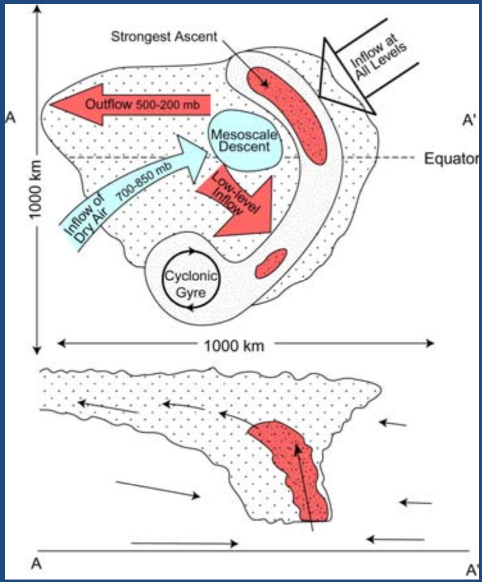
Role of Hierarchical Organization ?

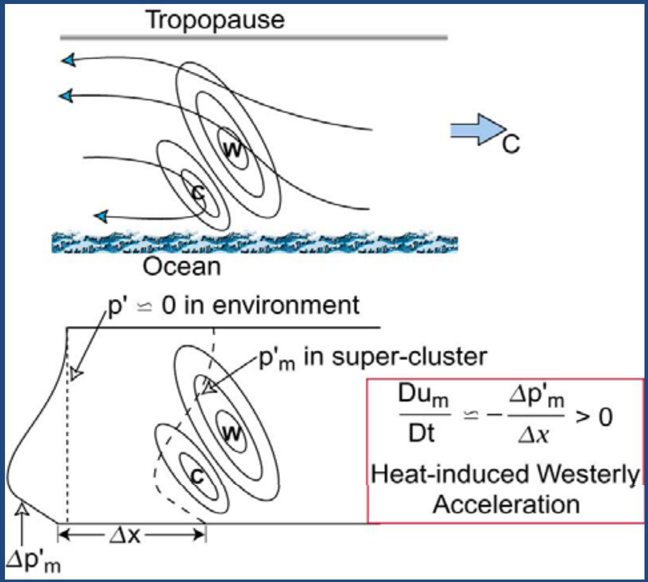


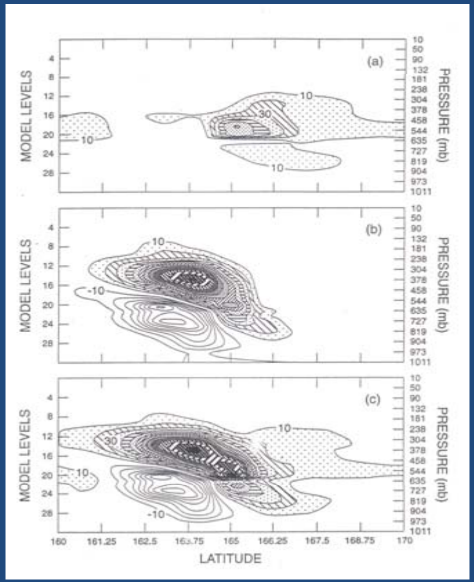
“Superclusters” in ECMWF T213 (80 km) model





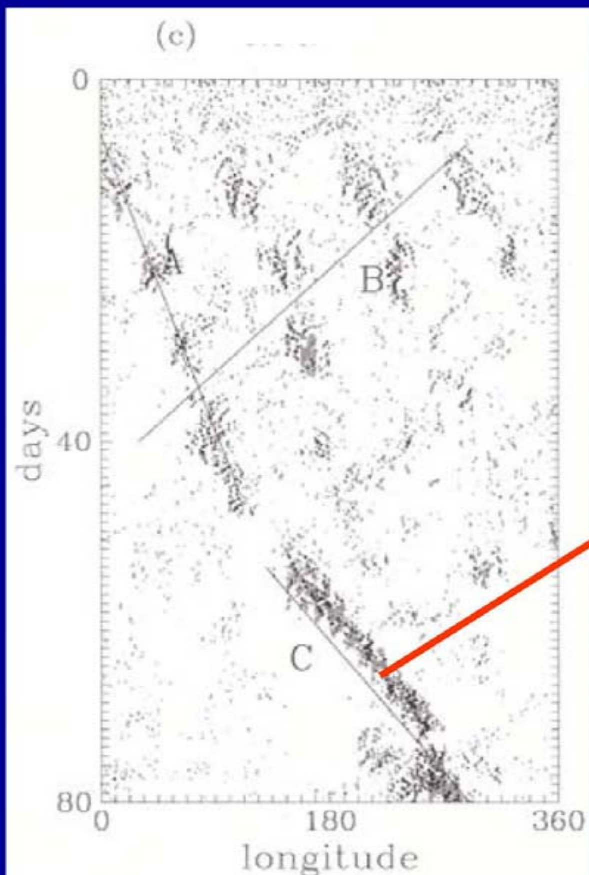


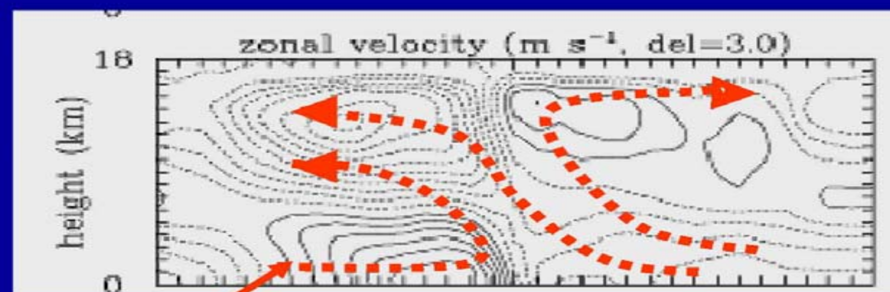




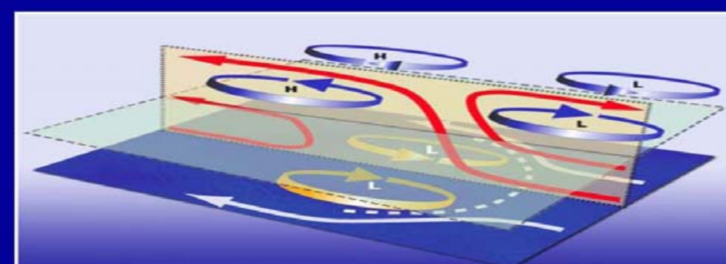
Moncrieff & Klinker (1997)

MJO-like & supercluster-like organization in a superparameterized global model





Vertical structure of the eastward propagating supercluster-like system

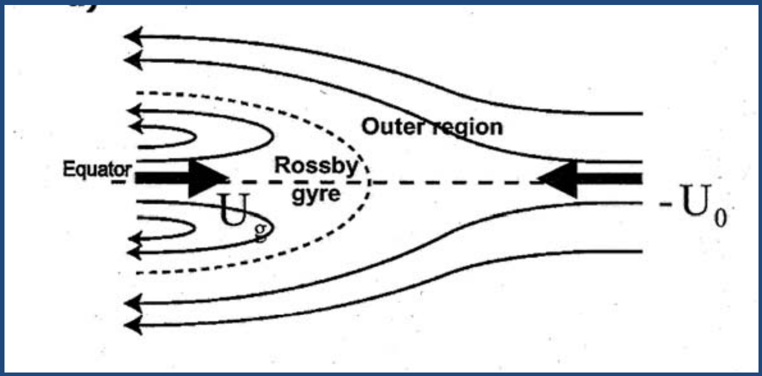


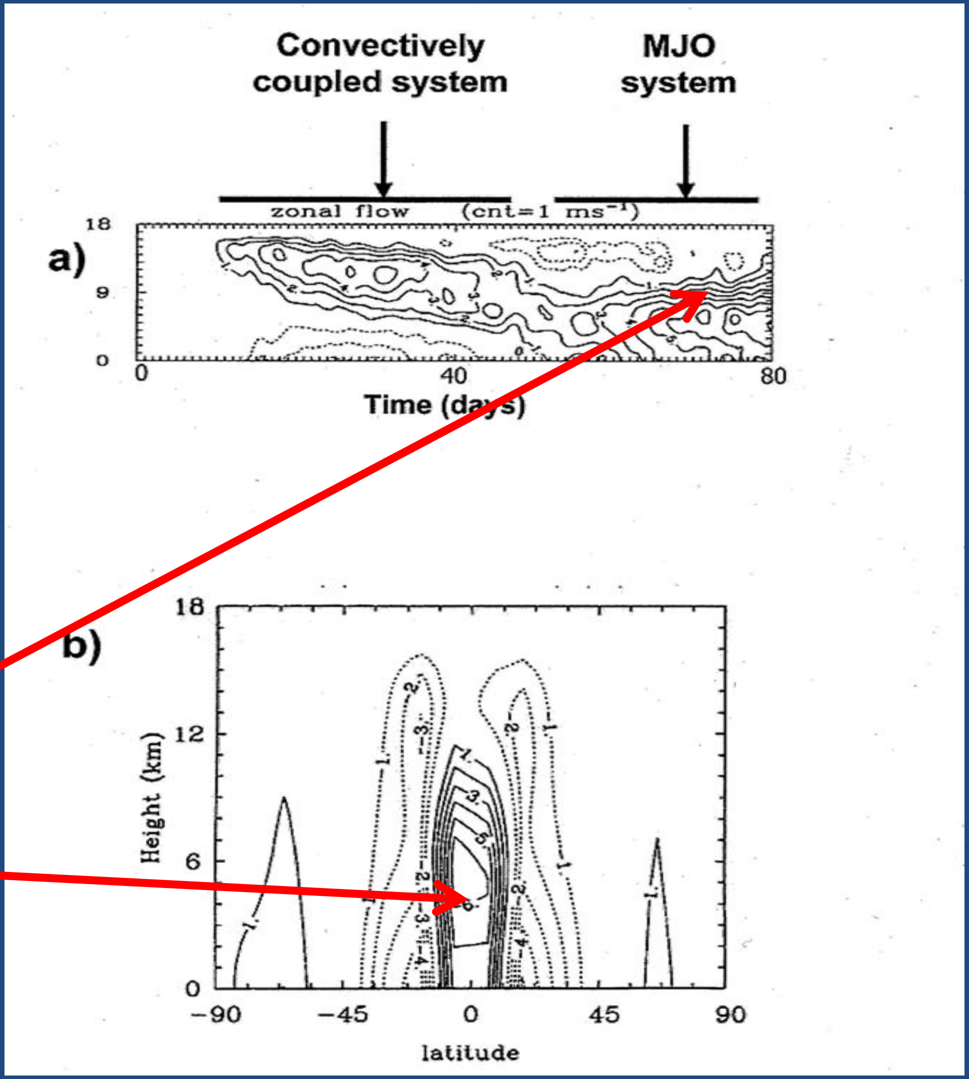
Dynamical model of organized convection interlocked with a Rossby-gyre circulation

Moncrieff (2004)

Super-rotation & westerly bursts

Mechanism: Slantwise meridional layer overturning

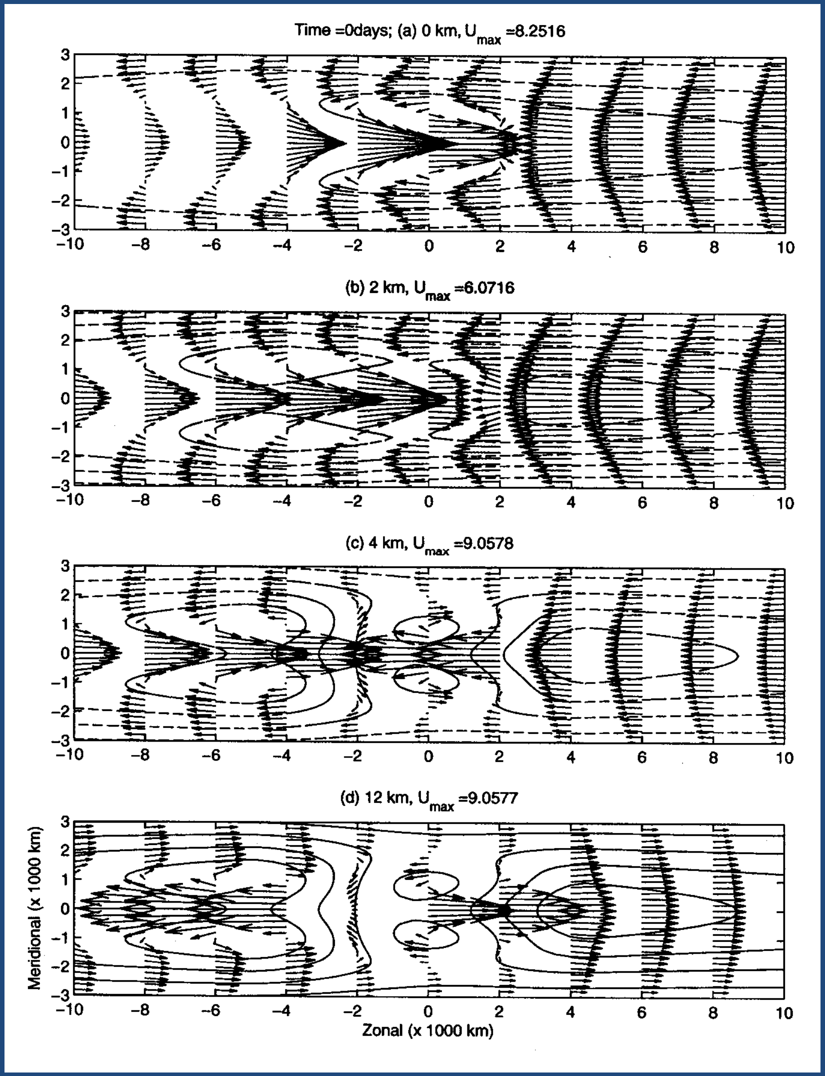




Super-rotation induced by the simulated MJO system will

affect atmospheric-ocean interaction…. important in nature?

Upscale effects of MCS/superclusters on MJO



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

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

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

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

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

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

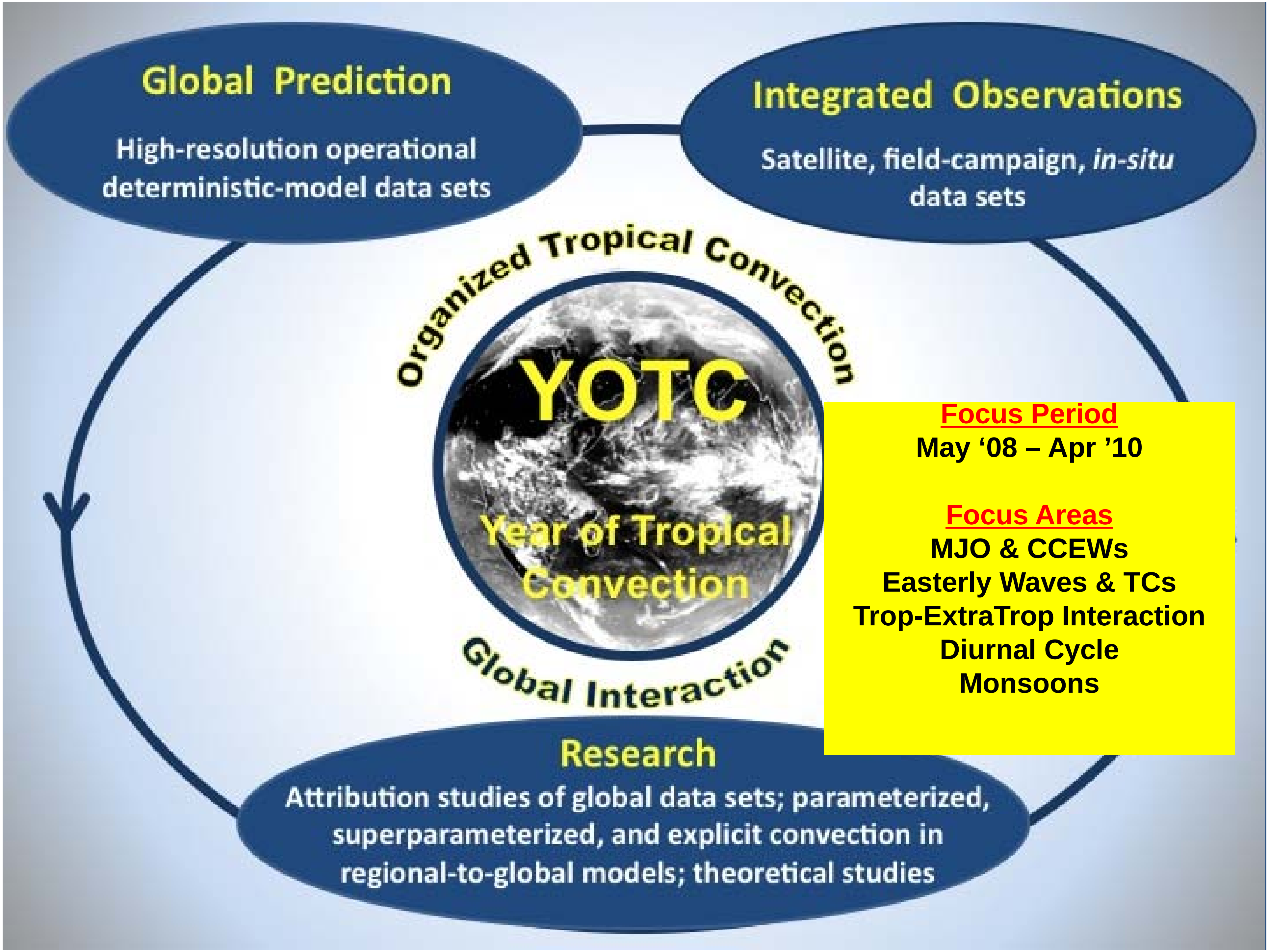
$$F^\theta = -\overline{(v'\theta')}_y - \overline{(w'\theta')}_z$$

Biello, Majda and Moncrieff (2007)

4) Year of Tropical Convection (YOTC)

Organized Tropical Convection and its Global Interaction

“ Virtual Global Field Campaign”
for the Weather-Climate Intersection


Global Prediction
High-resolution operational deterministic-model data sets
Integrated Observations
Satellite, field-campaign, *in-situ* data sets
Organized Tropical Convection
YOTC
Year of Tropical Convection
Global Interaction
Research
Attribution studies of global data sets; parameterized, superparameterized, and explicit convection in regional-to-global models; theoretical studies
Focus Period
May ‘08 – Apr ’10
Focus Areas
MJO & CCEWs
Easterly Waves & TCs
Trop-ExtraTrop Interaction
Diurnal Cycle
Monsoons

"Virtual Global Field Campaign" utilizing existing resources with model, parameterization & forecast improvement as the chief objective

New/Improved Resources

Conceptual Framework

- **Satellite Observations**
- **In-Situ measurements**
- **Global Ocean Observing System**
- **Global NWP Analyses**
- **Regional-global Cloud-Resolving models**

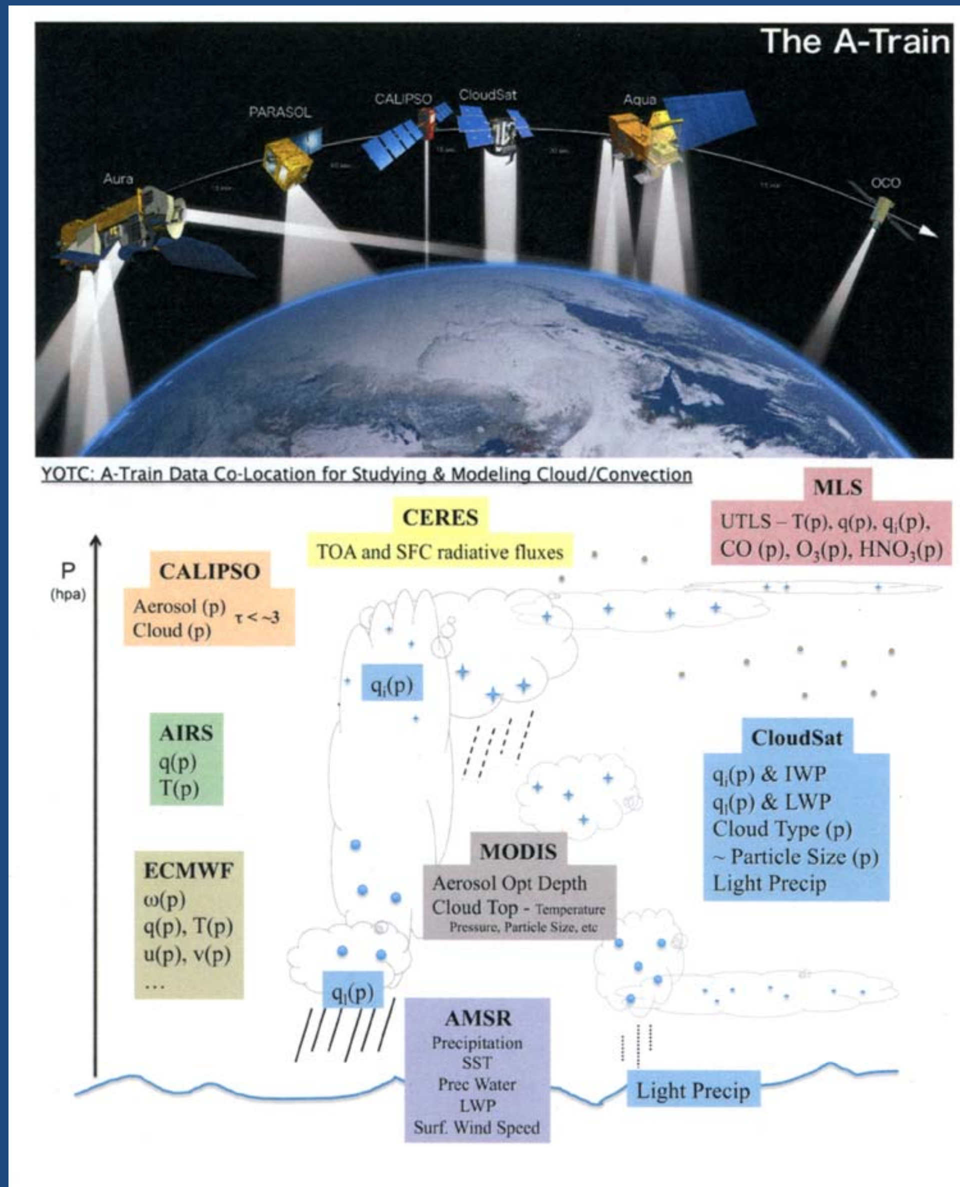
+

Traditional field experiments

=

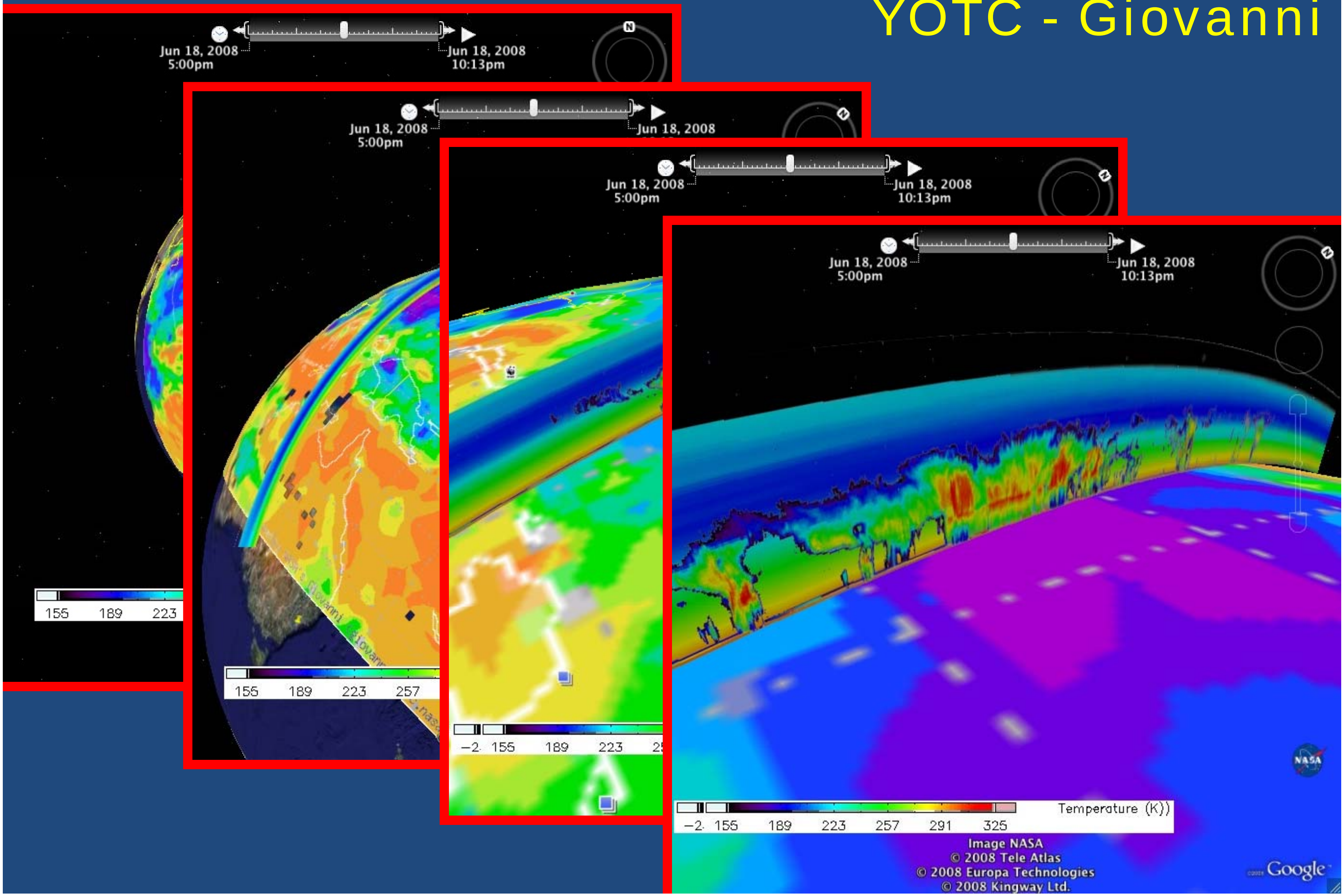
YOTC

"Virtual Field Campaign"

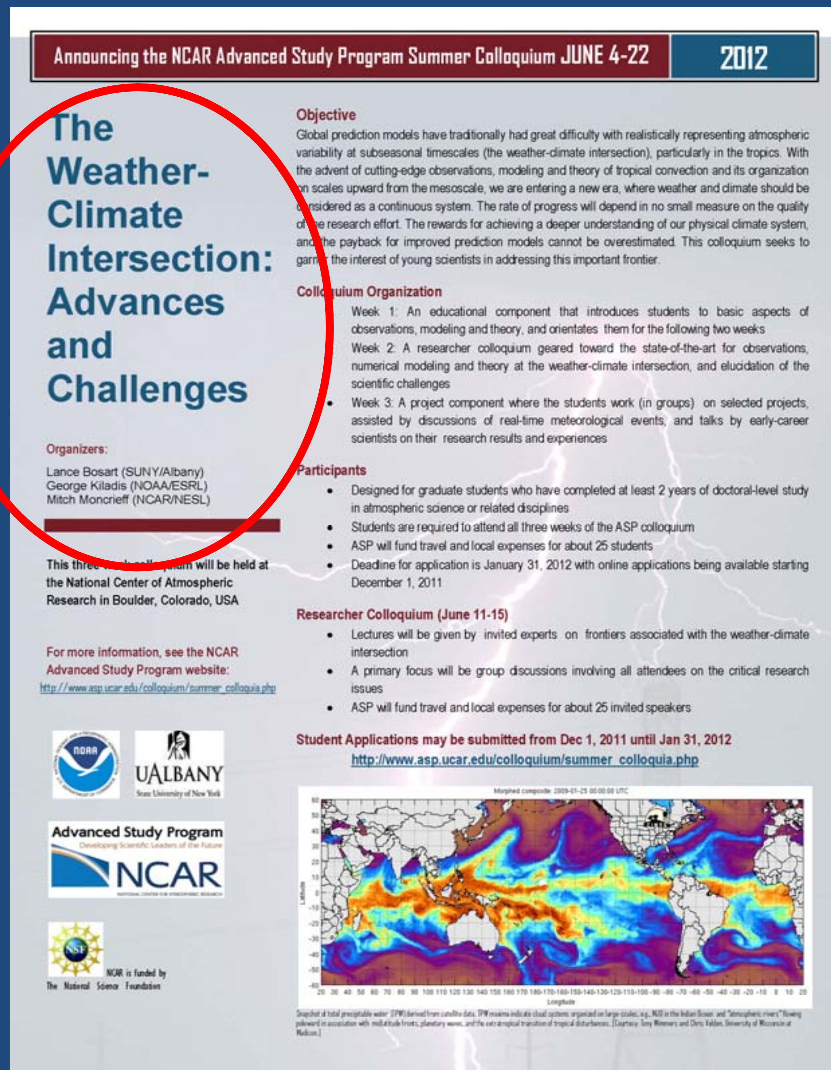


The A-Train
Aura
PARASOL
CALIPSO
CloudSat
Aqua
OCO
YOTC: A-Train Data Co-Location for Studying & Modeling Cloud/Convection
P
(hpa)
CERES
TOA and SFC radiative fluxes
MLS
UTLS – T(p), q(p), q_i(p),
CO (p), O_3(p), HNO_3(p)
CALIPSO
Aerosol (p)
Cloud (p)
τ < ~3
q_i(p)
AIRS
q(p)
T(p)
CloudSat
q_i(p) & IWP
q_l(p) & LWP
Cloud Type (p)
~ Particle Size (p)
Light Precip
ECMWF
ω(p)
q(p), T(p)
u(p), v(p)
…
MODIS
Aerosol Opt Depth
Cloud Top - Temperature
Pressure, Particle Size, etc
q_l(p)
AMSR
Precipitation
SST
Prec Water
LWP
Surf. Wind Speed
Light Precip

Satellite Data Analysis & Dissemination: YOTC - Giovanni



2012 NCAR Advanced Study Program (ASP) Summer Colloquium



Announcing the NCAR Advanced Study Program Summer Colloquium JUNE 4-22 2012

The Weather-Climate Intersection: Advances and Challenges

Organizers:

Lance Bosart (SUNY/Albany)
George Kiladis (NOAA/ESRL)
Mitch Moncrieff (NCAR/NESL)

This three-week colloquium will be held at the National Center of Atmospheric Research in Boulder, Colorado, USA

For more information, see the NCAR Advanced Study Program website:
http://www.asp.ucar.edu/colloquium/summer_colloquia.php

NCAR is funded by The National Science Foundation

Objective

Global prediction models have traditionally had great difficulty with realistically representing atmospheric variability at subseasonal timescales (the weather-climate intersection), particularly in the tropics. With the advent of cutting-edge observations, modeling and theory of tropical convection and its organization on scales upward from the mesoscale, we are entering a new era, where weather and climate should be considered as a continuous system. The rate of progress will depend in no small measure on the quality of the research effort. The rewards for achieving a deeper understanding of our physical climate system, and the payback for improved prediction models cannot be overestimated. This colloquium seeks to garner the interest of young scientists in addressing this important frontier.

Colloquium Organization

- Week 1: An educational component that introduces students to basic aspects of observations, modeling and theory, and orientates them for the following two weeks
- Week 2: A researcher colloquium geared toward the state-of-the-art for observations, numerical modeling and theory at the weather-climate intersection, and elucidation of the scientific challenges
- Week 3: A project component where the students work (in groups) on selected projects, assisted by discussions of real-time meteorological events, and talks by early-career scientists on their research results and experiences

Participants

- Designed for graduate students who have completed at least 2 years of doctoral-level study in atmospheric science or related disciplines
- Students are required to attend all three weeks of the ASP colloquium
- ASP will fund travel and local expenses for about 25 students
- Deadline for application is January 31, 2012 with online applications being available starting December 1, 2011

Researcher Colloquium (June 11-15)

- Lectures will be given by invited experts on frontiers associated with the weather-climate intersection
- A primary focus will be group discussions involving all attendees on the critical research issues
- ASP will fund travel and local expenses for about 25 invited speakers

Student Applications may be submitted from Dec 1, 2011 until Jan 31, 2012
http://www.asp.ucar.edu/colloquium/summer_colloquia.php

Conclusions

- We are entering a new era of integrated global weather & climate modeling -- many formidable and fundamental challenges but good prospect for timely progress at “the weather-climate intersection”
- Climate models are now required to provide information down to regional scales and addressing ‘high-impact’ weather -- that’s linked to convective organization and other mesoscale processes, not least the precipitation distribution and type
- This is motivating high-resolution global climate models with computational grids similar to global weather models (~10 km)
- Representing how mesoscale processes interact with the large scales is a key problem
- Progress will depend in no small measure on the integration of theory, computation, and observational approaches – for the first time, we have both the tools and the motivation to address this important task