# Organized Convection, Weather-Climate Intersection, and the YOTC Project

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## OBJECTIVES

1) Bring mesoscale processes (weather) to climate models

2) Bring physical/dynamical concepts to convective parameterization

3) Demonstrate advantages of mesoscale resolution for GCMs

4) YOTC: Prototype "Virtual global field-campaign" framework for weather-climate intersection (weeks-months)

Clouds, Convection and Tropical Meteorology: Ramanujan Lectures of Andrew Majda" , IISc, Bangalore, 21-26 January,2103

# Introduction

- Atmospheric "mesoscale" consists of a range of scales ~(1km - 1000 km) with ~100 km particularly significant for organized convection

- Physical resolution ("resolved-scale") of a numerical model is about an order of magnitude coarser than the computational mesh

- Therefore:

  i) 1-km mesh *resolves* most of the mesoscale range

  ii) 10- km mesh *permits* key mesoscale circulations

- We are entering a new era: *mesoscale permitting global models* (weather & climate), needing new approaches to convective parameterization

# Organized cloud systems

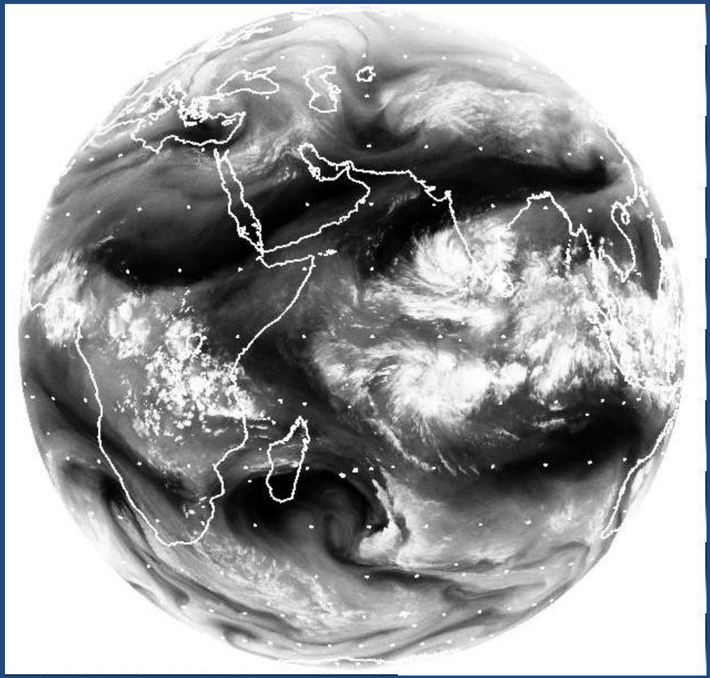
- Organized cloud systems have underlying chaotic order, and feature upscale and downscale effects ,poorly represented by parameterizations

Cumulonimbus

~ 1-10 km

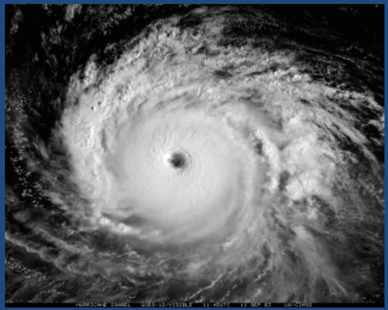
Supercell tornadic storm

~ 100 km



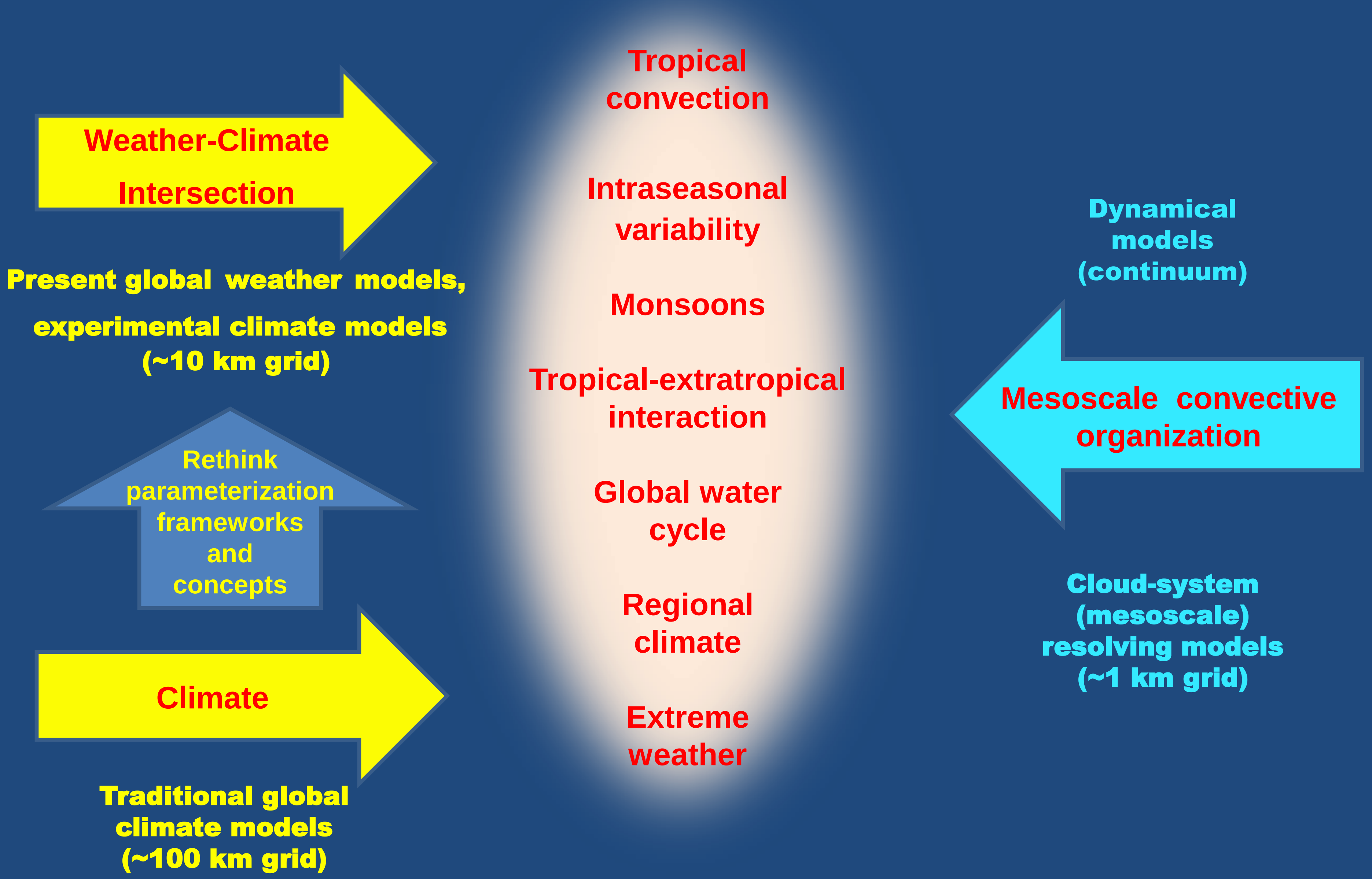
MJO / Intraseasonal variability ~10000 km

Mesoscale convective system (MCS) ~ 100s km



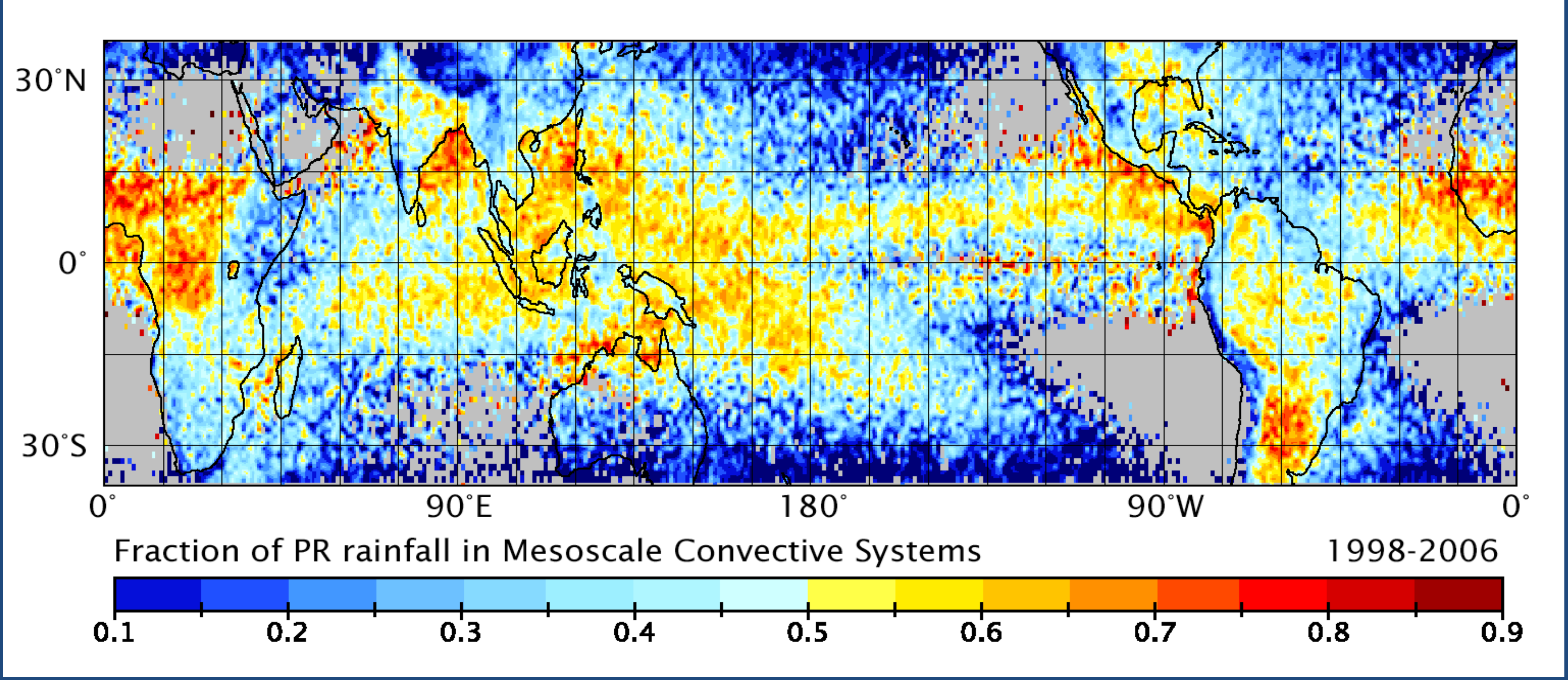
Tropical cyclone ~1000 km

# Convective organization in weather-climate context



# MCS: building block of larger-scale convective organization

# Fraction of tropical rainfall from MCS
## (TRMM satellite measurements)




Tao & Moncrieff (2009)

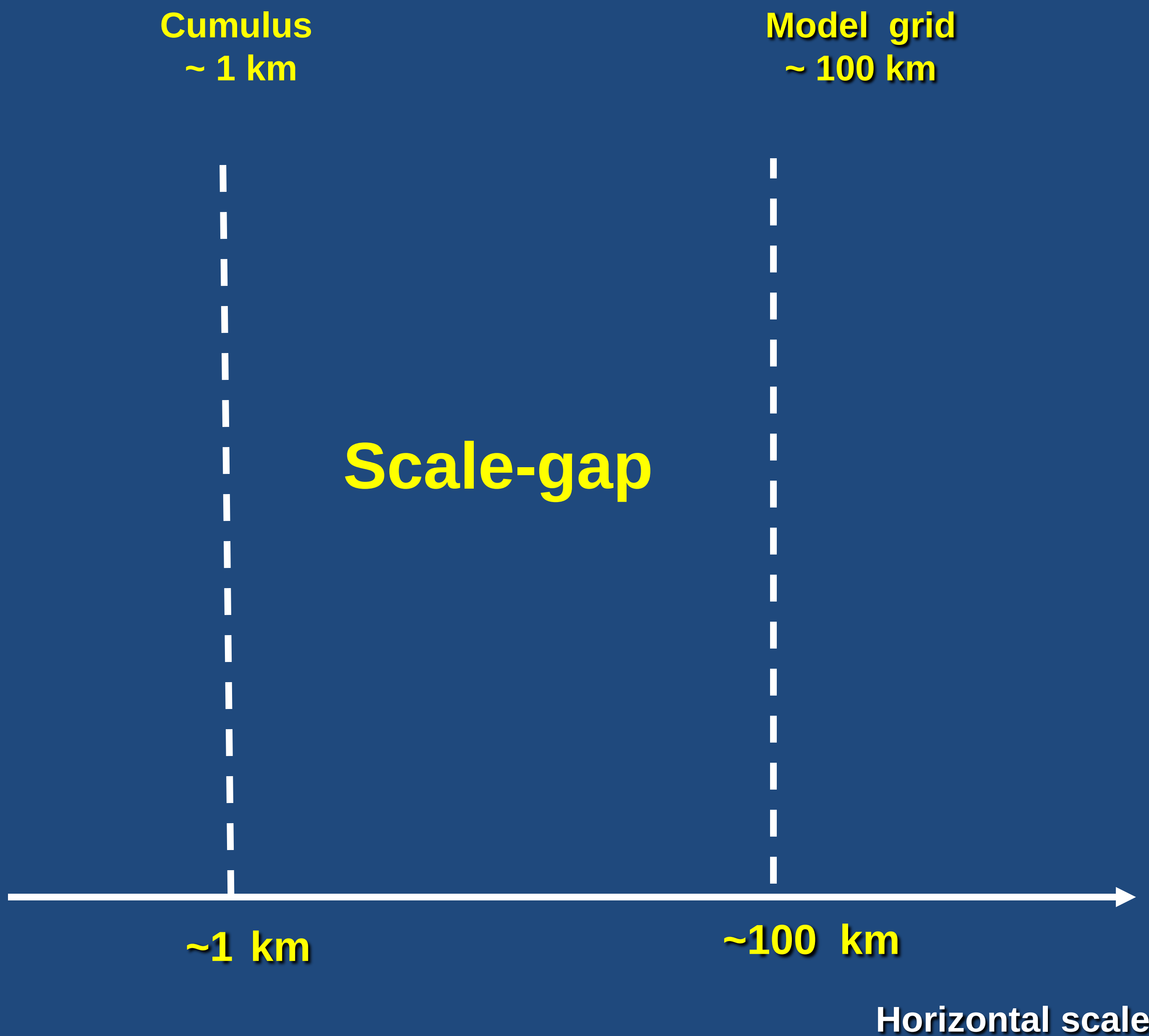
# Mesoscale convective systems (MCS)

- Provide about half the total tropical rainfall, important part of the tropical water cycle
- Upscale energy transport maintains circulation against dissipation
- Elevates convective heating maximum; enlarges its horizontal extent; counter-gradient momentum transport, etc
- We have excellent knowledge of MCS from observations, simulation and theory

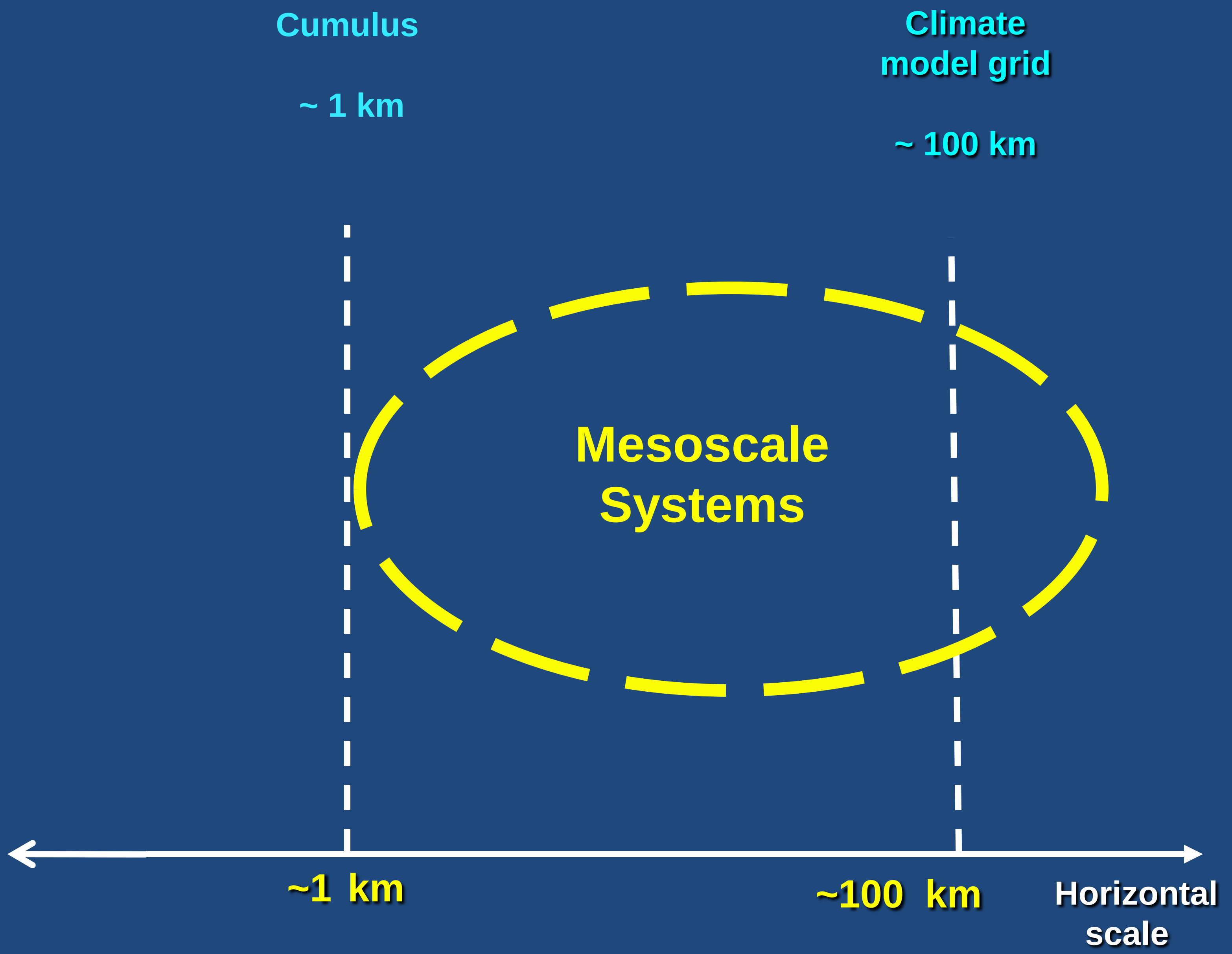
**But MCS are missing from climate models**

- Parameterizations do not represent organized structures
- Resolution too coarse to simulate them

# Scale gap and
# convective parameterization



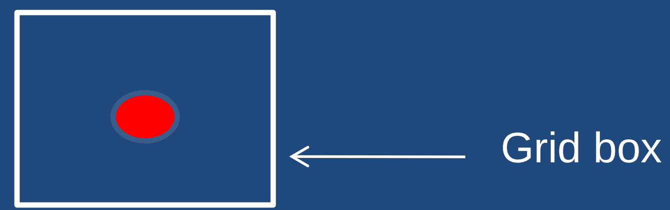

**Traditional parameterization assumes a ‘scale-gap’**




**But … no scale gap in the real world!**

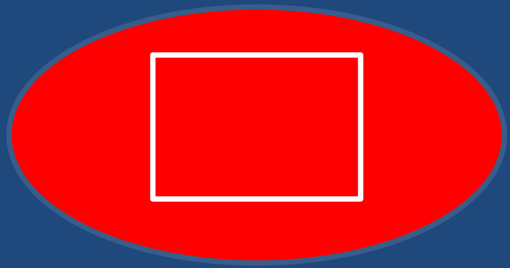
# Representing convective cloud systems scale L in models with grid-length Δ

**a) Traditional parameterization**




$\Delta$□ L

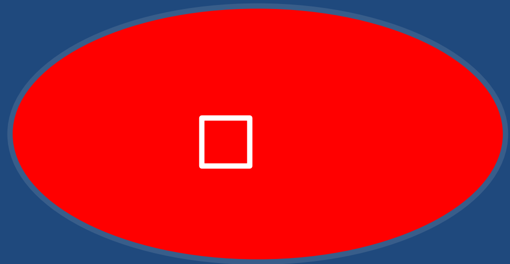
**b) Hybrid parameterization**



$\Delta \sim L$

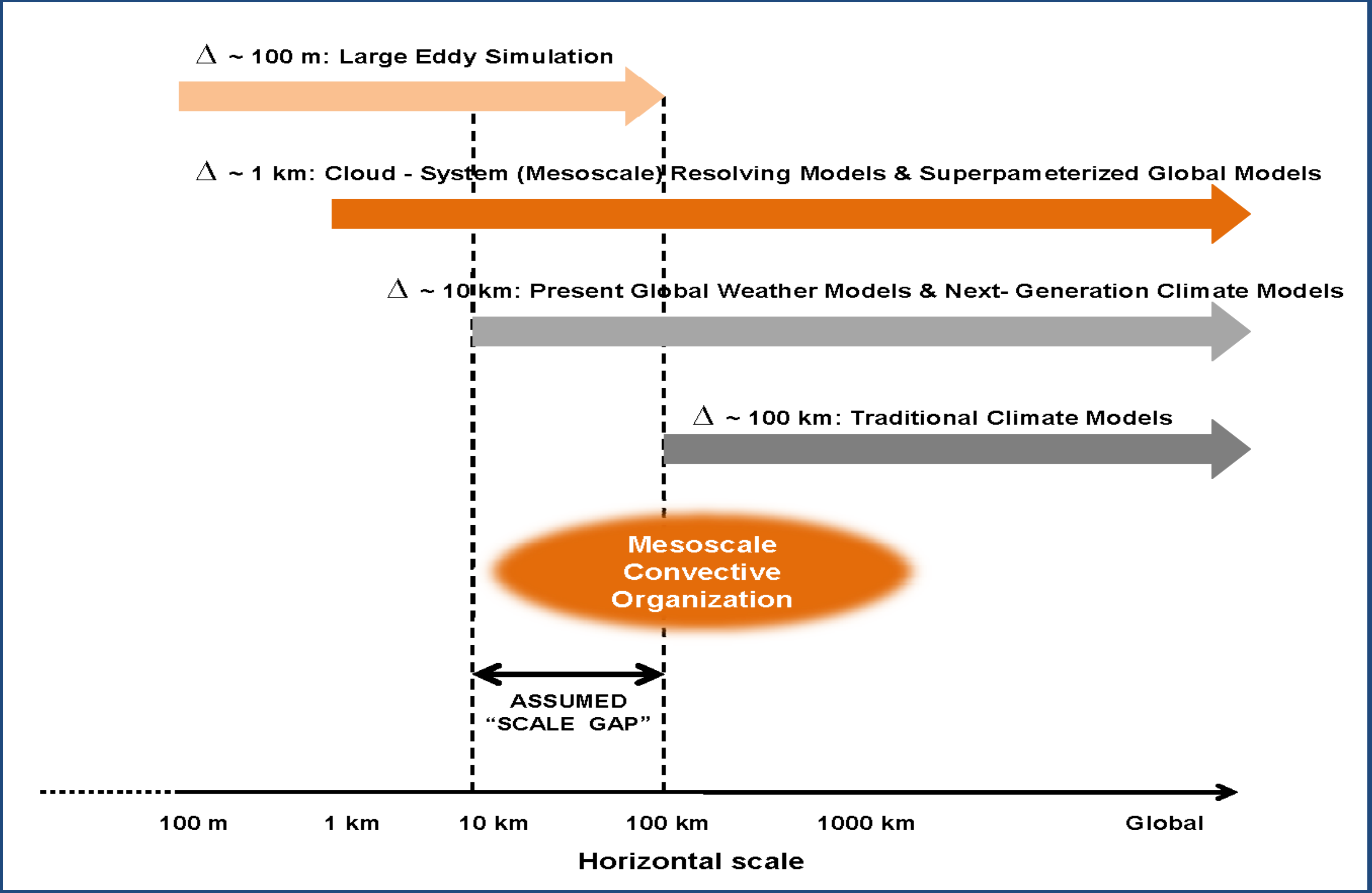
**c) Explicit**

**(CRM & LES)**



$\Delta$□ L

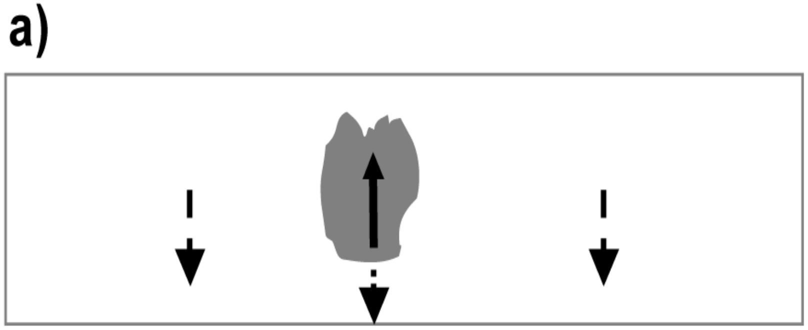
# A hierarchy of models span "the gap"



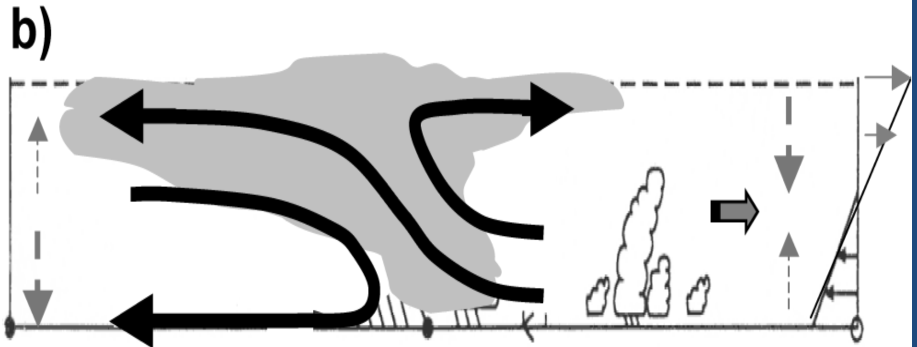

Moncrieff et al. (2012)

## Cumulus parameterization

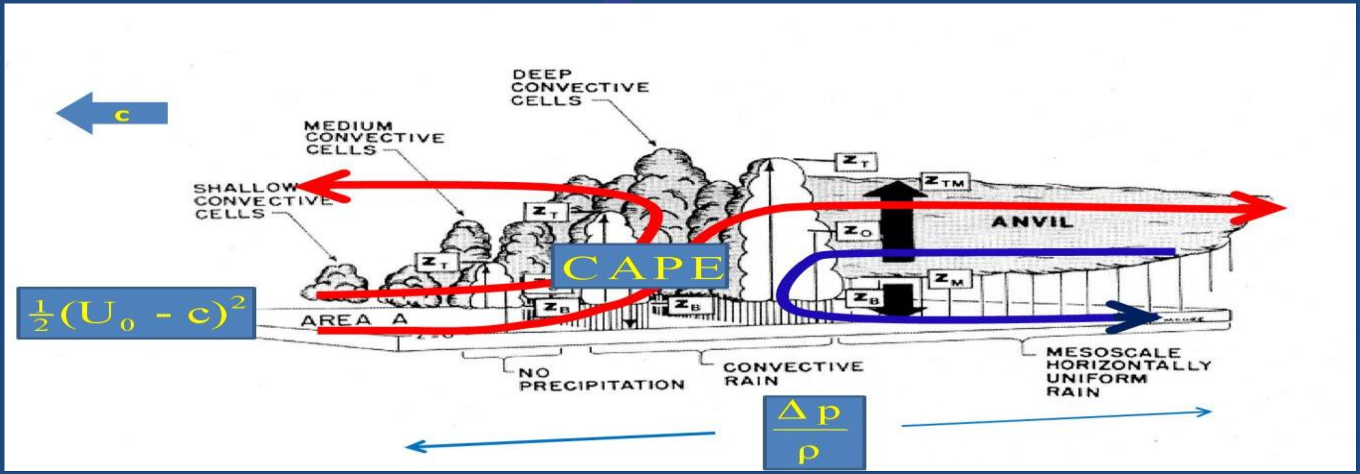
## MCS




Isolated convection, single grid volume



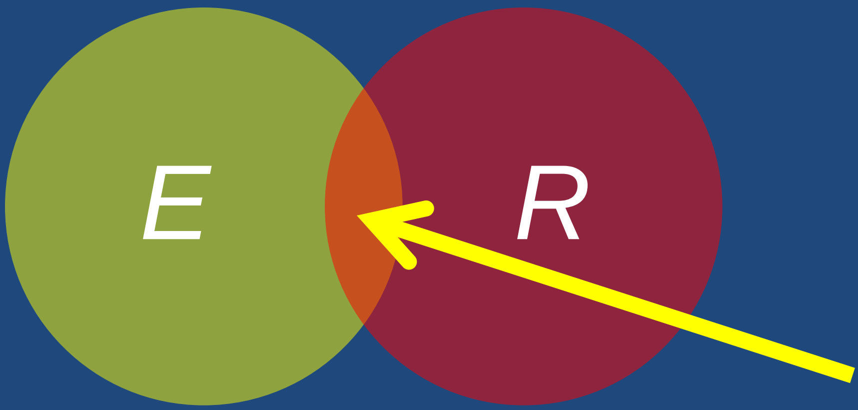

Organized convective system, many grid volumes



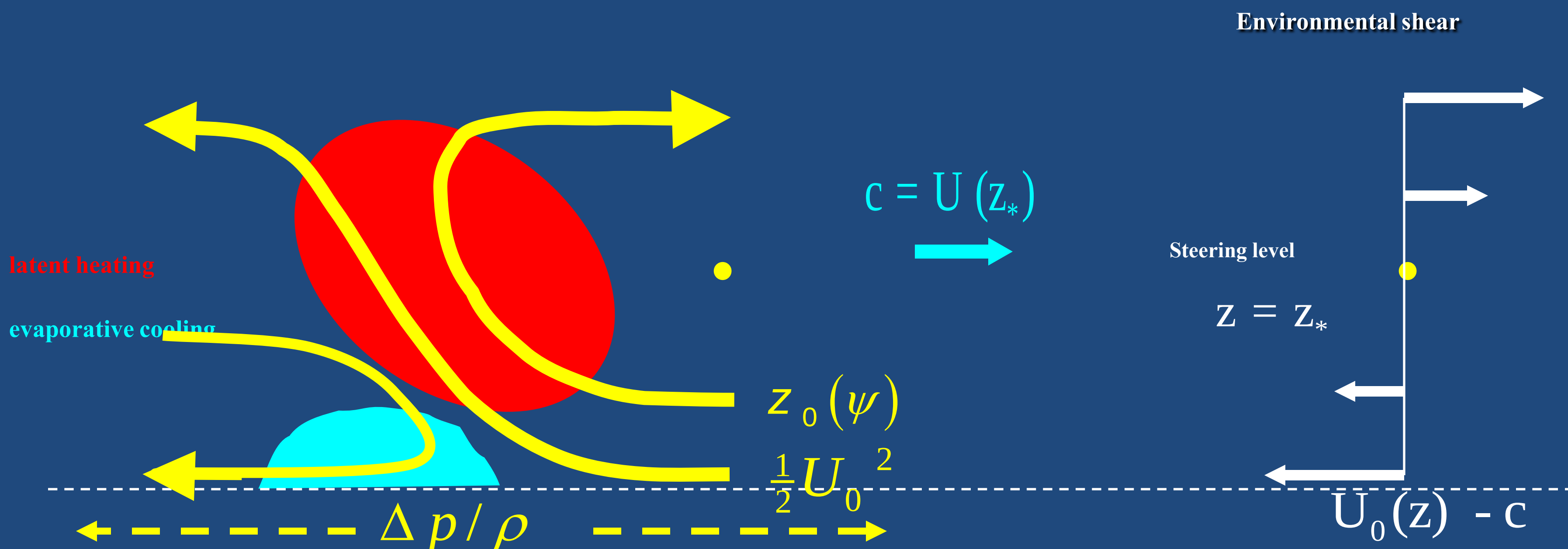
## MCS as slantwise layer overturning: 3 kinds of energy - potential; kinetic; work done by pressure gradient and 2 dimensionless quantities

$$E = \frac{\Delta p}{\rho \frac{1}{2}(U_0 - c)^2}$$

$$R = \frac{CAPE}{\frac{1}{2}(U_0 - c)^2}$$




MCS- type convective organization




**Convective Froude number:** $F_c = \sqrt{U_0^2/\text{CAPE}}$

**Bernoulli Number:** $E = \Delta p / \frac{1}{2}\rho U_0^2$

$$\nabla^2\psi = G(\psi) + \int_{z_0}^{z}\left(\frac{\partial F}{\partial \psi}\right)dz$$

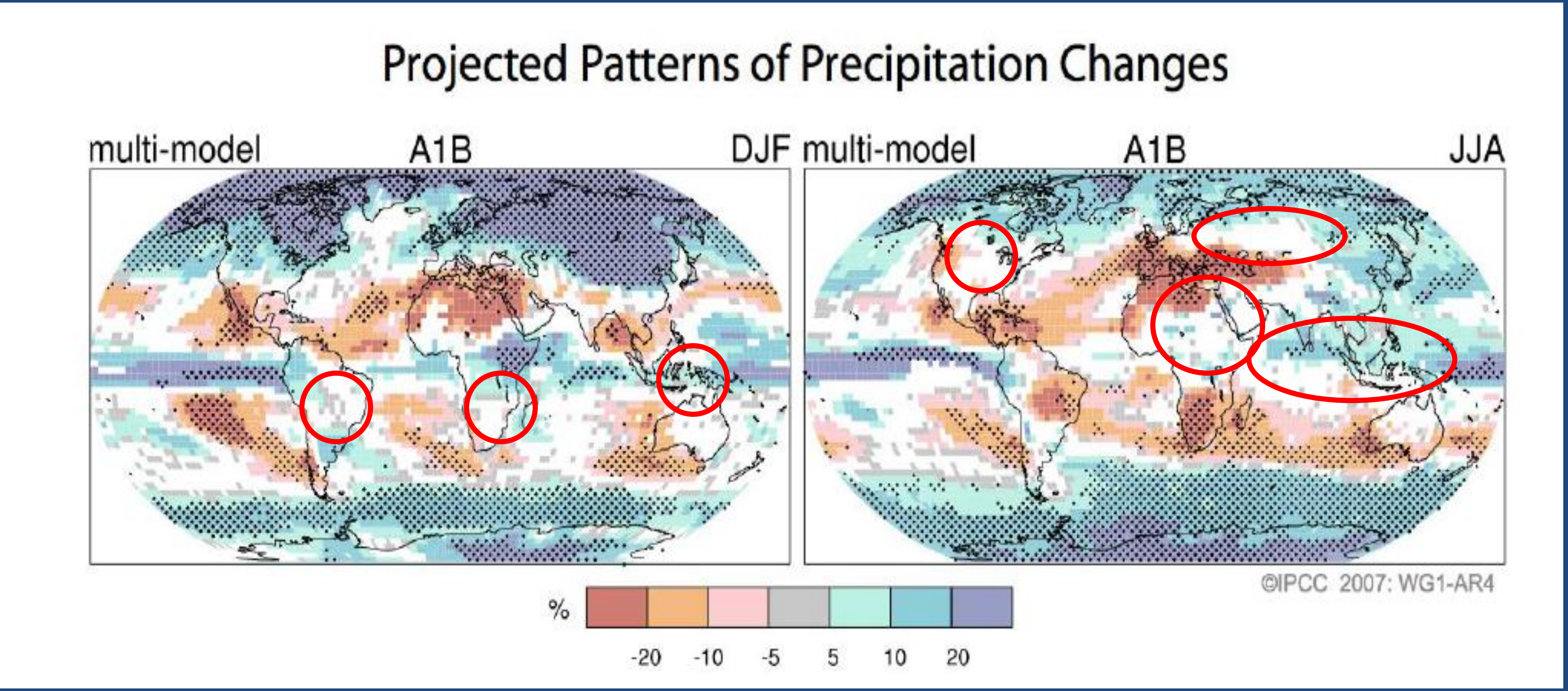
**Vorticity** **Shear** **Baroclinic generation of vorticity**

$F(\psi, z, c)$ **buoyancy**

**Moncrieff (2010)**

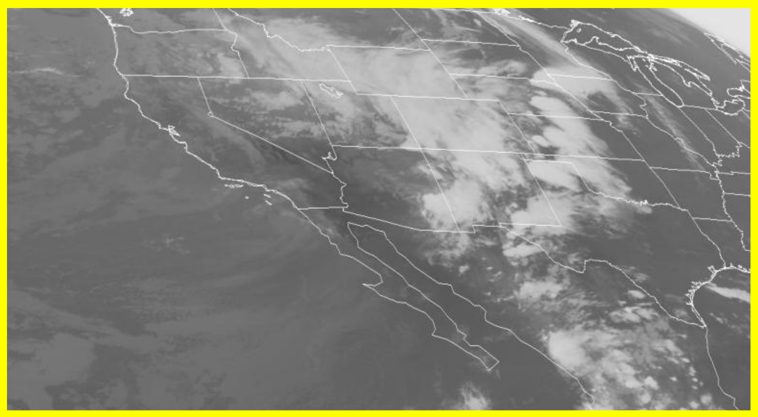
# Example 1
# Orogenic MCS over continents

# Projected precipitation changes (2090-2099 *c.f.* 1990-1999): No confidence over continents in summer hemispheres, even in the sign of changes

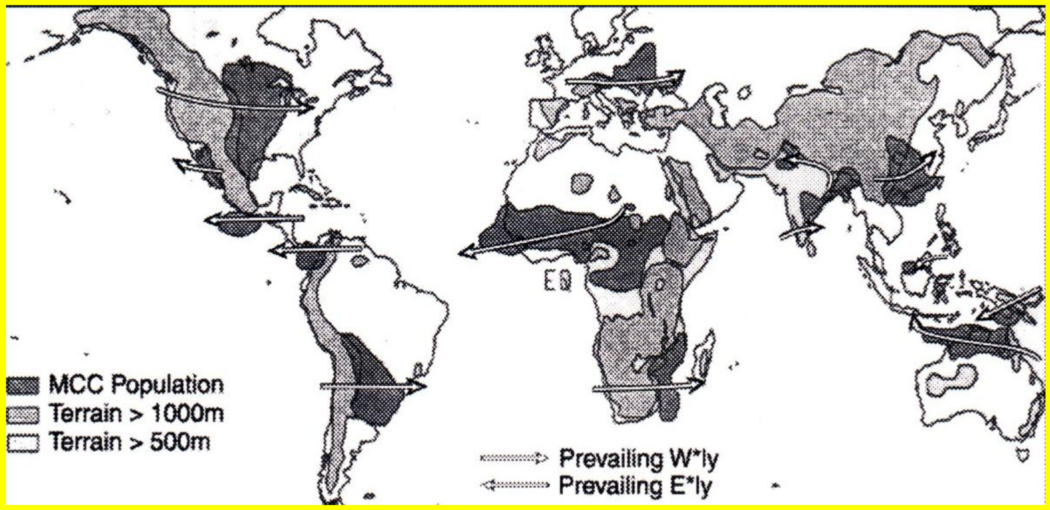



From IPCC AR4 Report

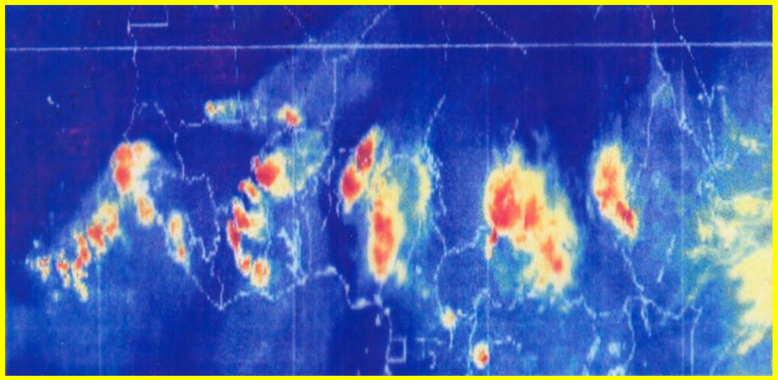
# Areas of low confidence are downstream of mountains –where propagating MCS occur



Continental US




Laing and Fritsch (1997)

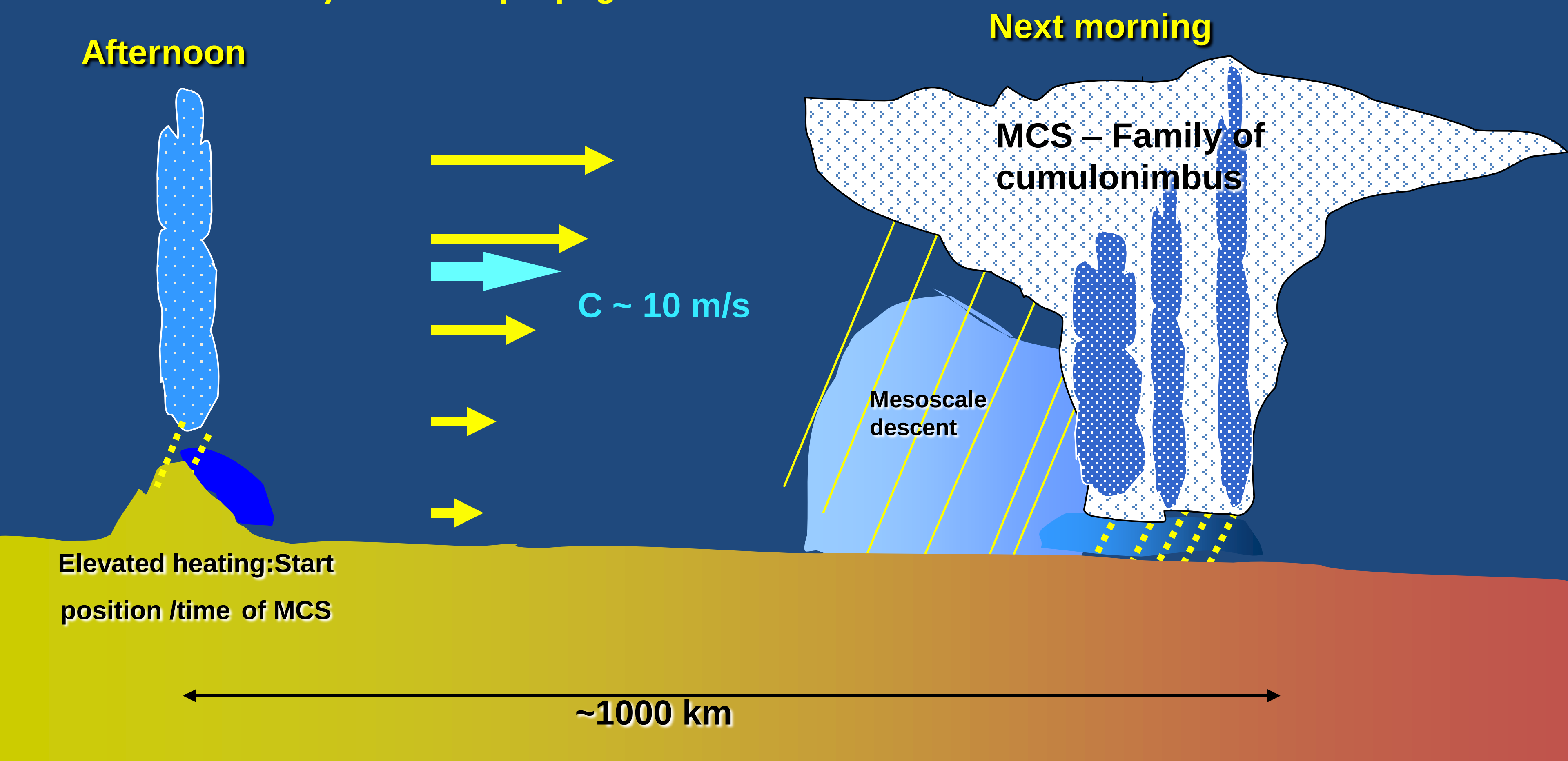


W. Africa

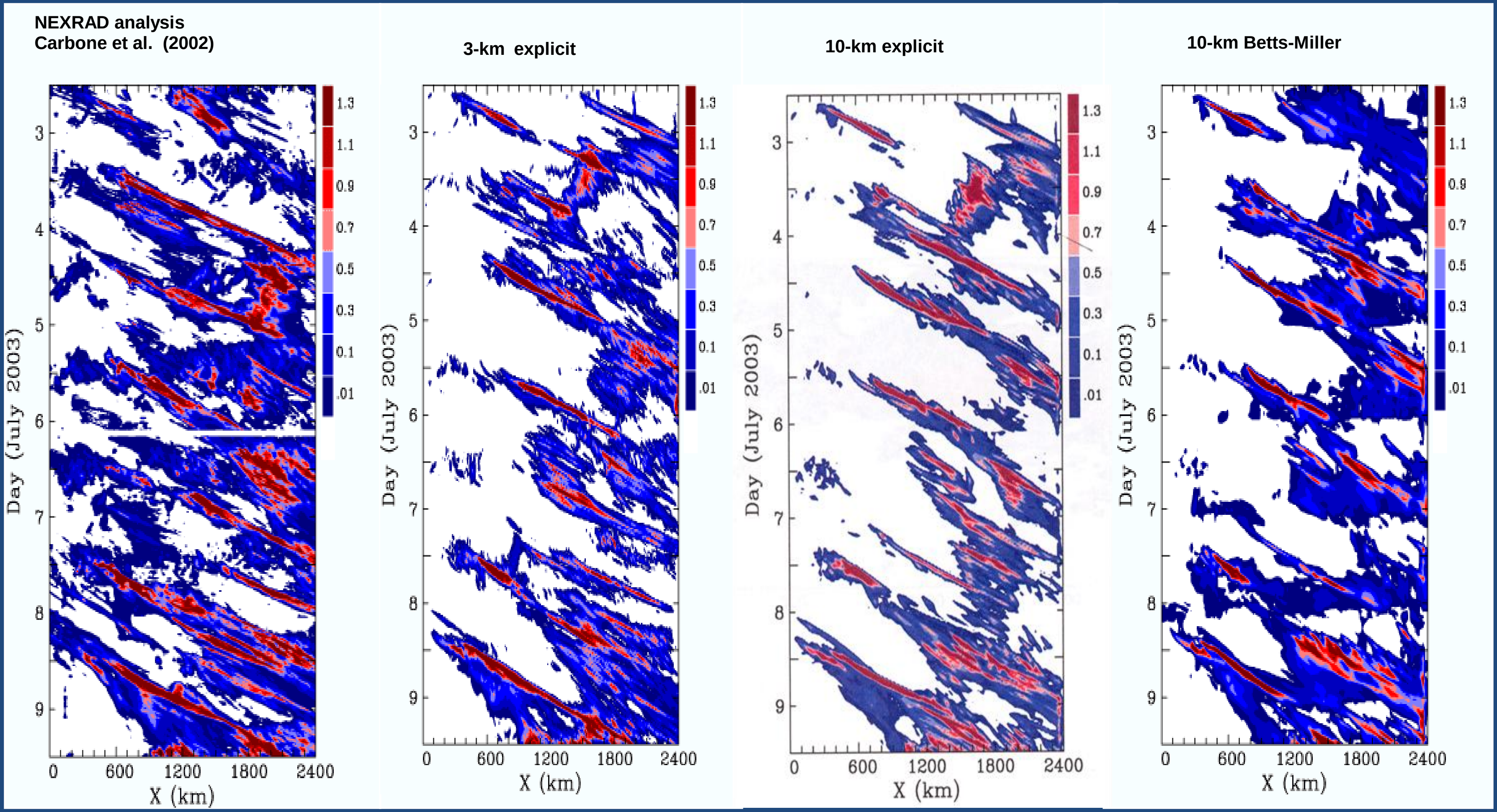
# MCS propagation and the diurnal cycle

## Vertical shear

a) Organizes mesoscale dynamics
b) Controls propagation

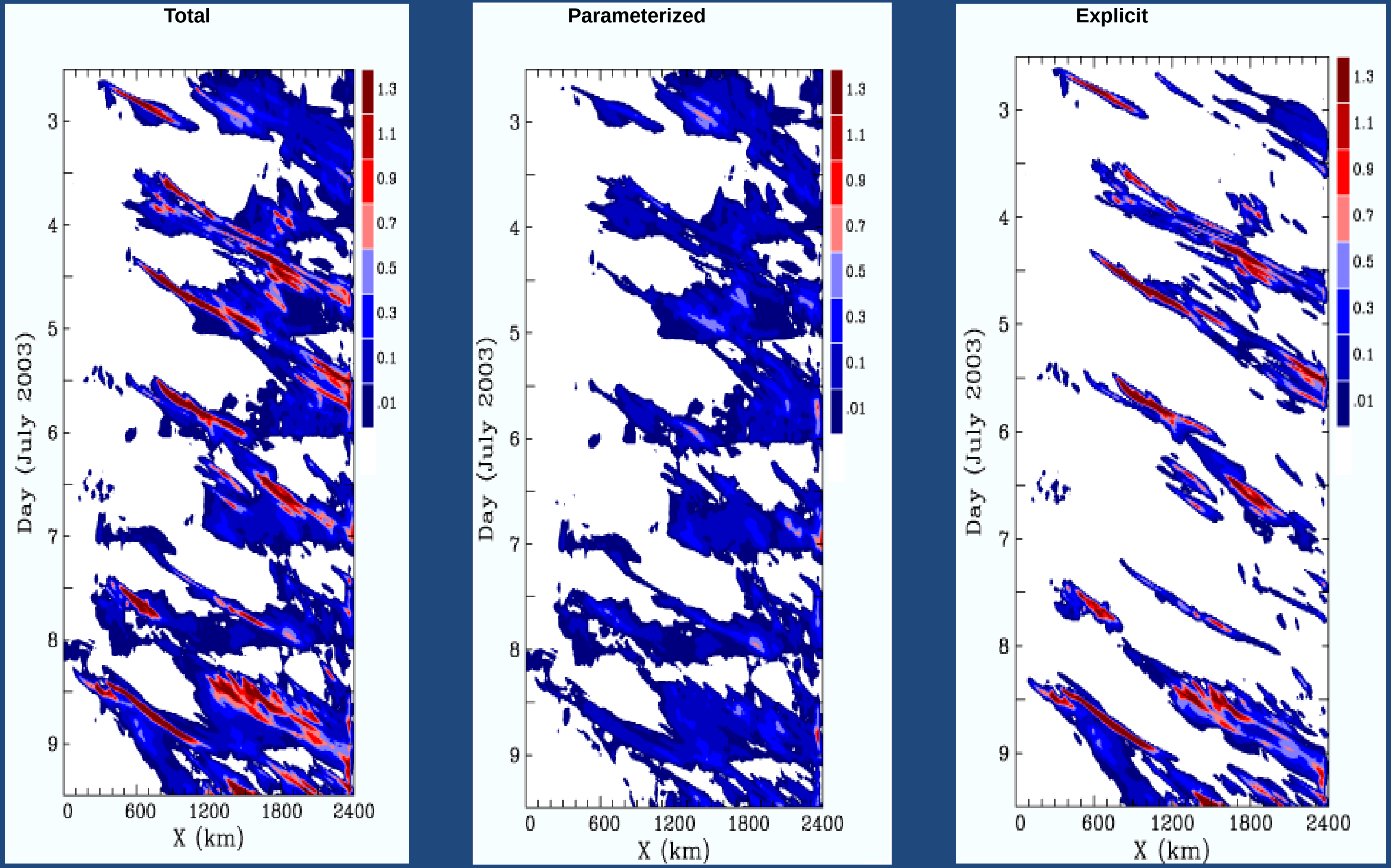


# Meridionally averaged rain-rate: Propagating systems

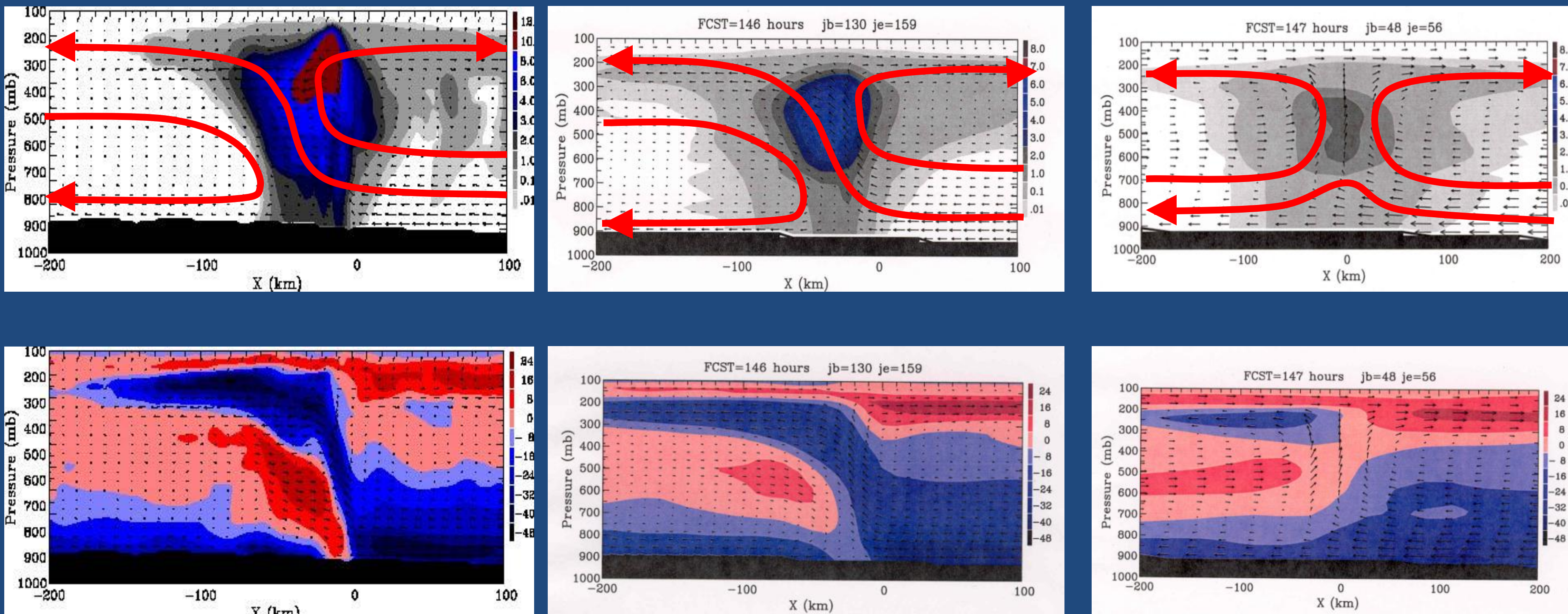



Moncrieff and Liu (2006)

# Propagating 'grid-scale' circulations, stationary parameterized cumulus



# Resolution dependence




Δ =3 km Δ =10 km Δ =30 km

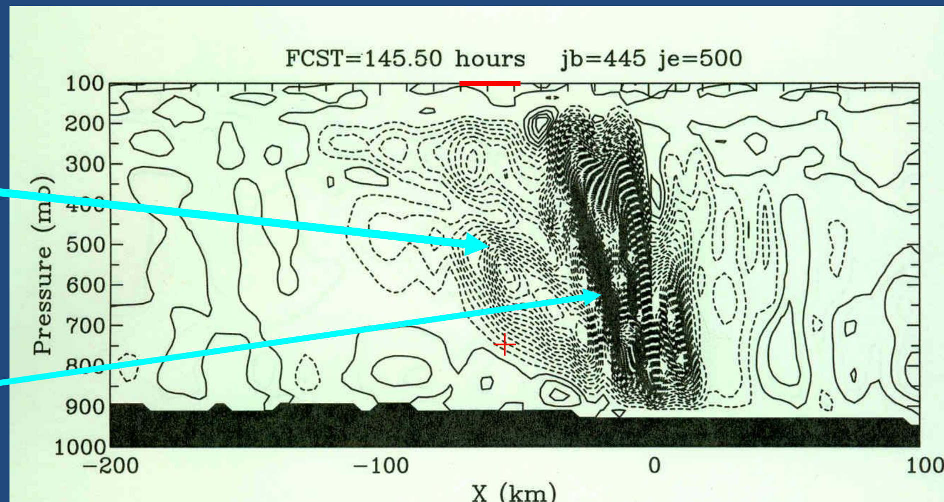
**3-km & 10-km grids – similar morphology**
**30-km grid – unrealistic morphology**

# Effect of resolution on CMT:

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

Mesoscale circulation

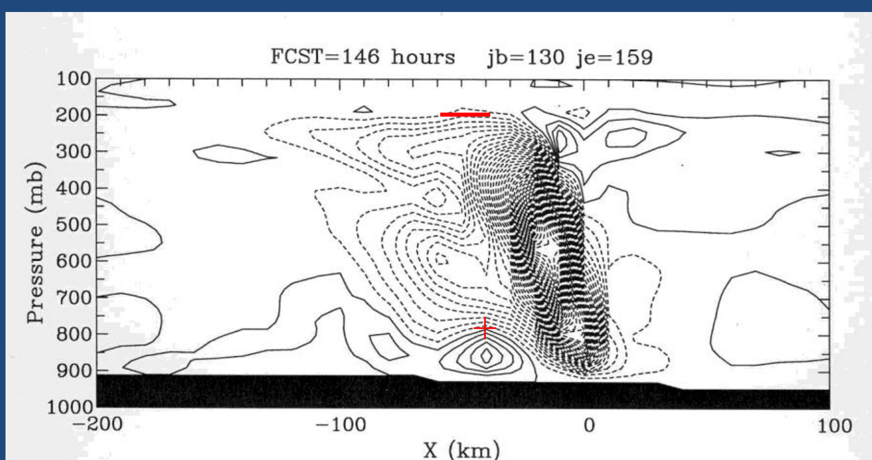
Cumulonimbus family



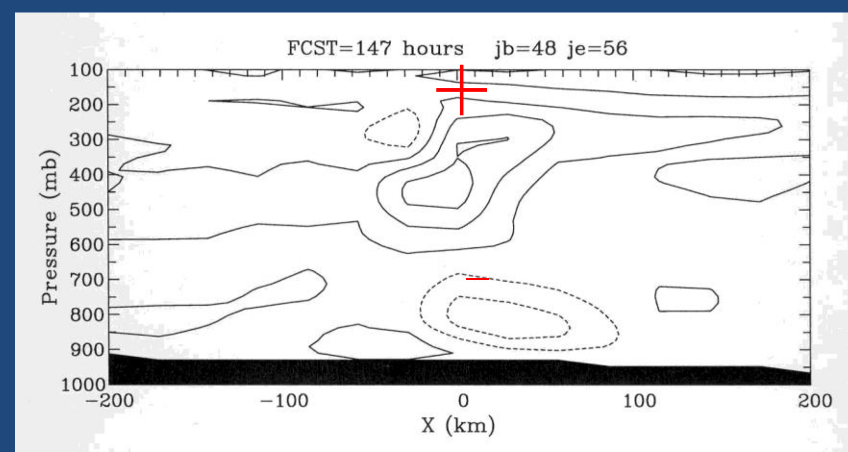

$\Delta = 3\text{km}$

c

**Sign of CMT : Opposite to propagation vector due to rearward-tilted flow**



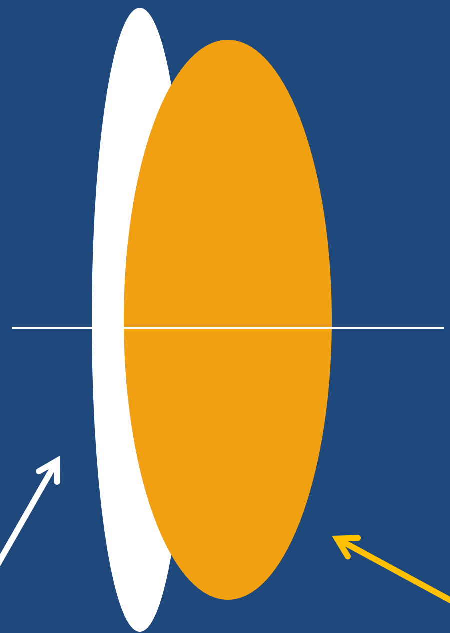

$\Delta = 10\text{km}$

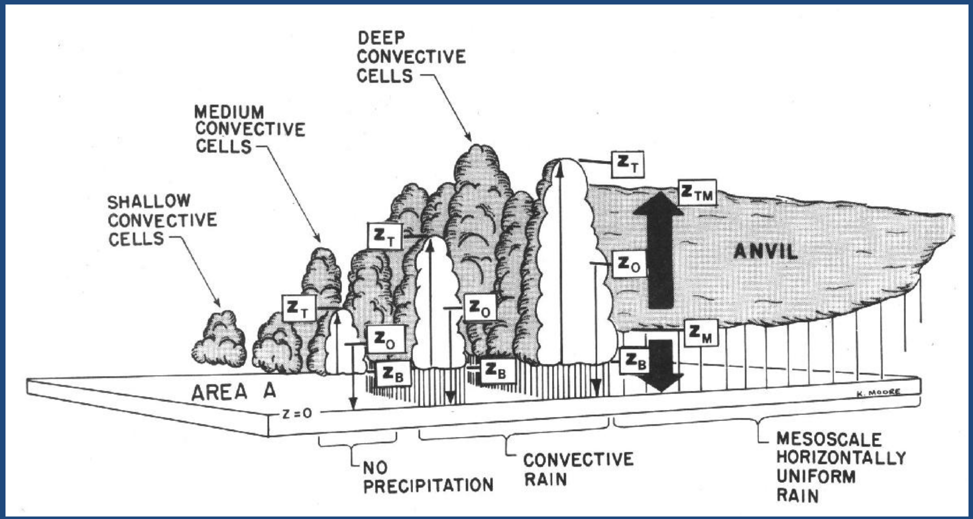



$\Delta = 30\ \text{km}$

# Two-scale convective parameterization

C = propagation






100s km

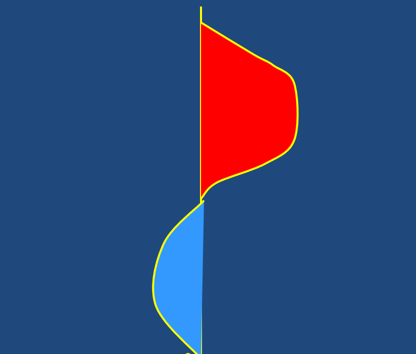
Deep convection: ~ 10 km

Mesoscale organization ~ 100 km

# Parameterization of mesoscale heating

*Stratiform ascent /mesoscale downdrafts*

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




$$Q = Q_c + Q_m$$

**$Q_m$ = Heating by mesoscale overturning**

**$Q_c$ = Heating by deep cumulus**

**$\propto_1$ = Ratio of mesoscale and cumulus heating**

**$\propto_2$ = Ratio of 1st baroclinic and 2nd baroclinic mesoscale heating, i.e., 'top-heaviness'**

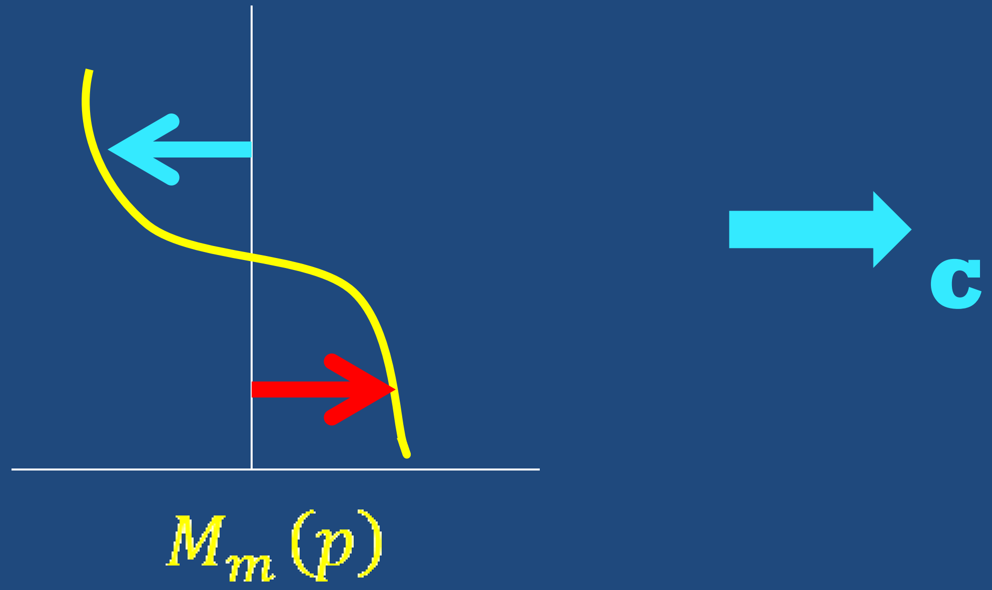
**$p_t$ = Cloud-top pressure**

**$p_s$ = Surface pressure**

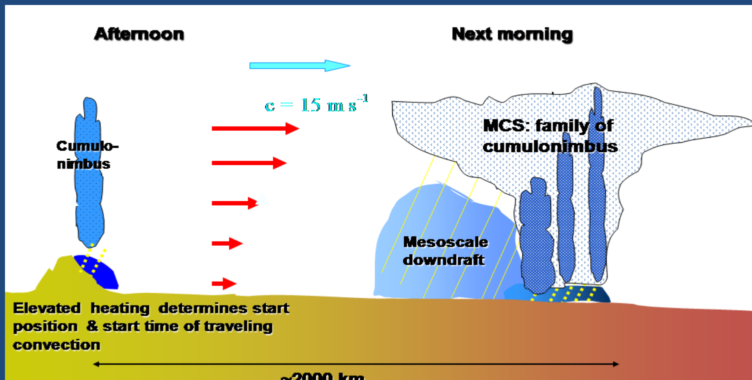
# Parameterization of  mesoscale momentum transport

$$M_m(p) = \propto_3 \left[\cos 2\pi \left(\frac{p_s - p}{p_s - p_t}\right)\right], \qquad p_* \le p \le p_s$$

$$M_m(p) = -\propto_4 \left[\cos 2\pi \left(\frac{p_s - p}{p_s - p_t}\right)\right], \qquad p_t \le p \le p_*$$



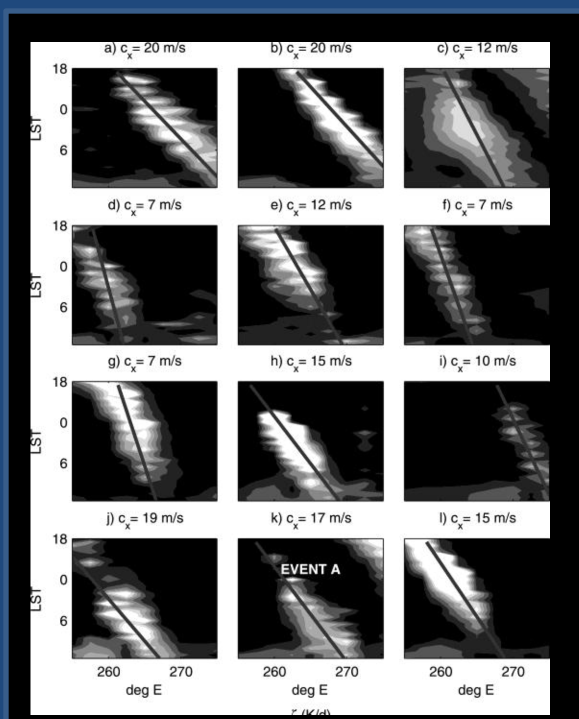
# Superparameterized Community Atmospheric Model (SP-CAM)

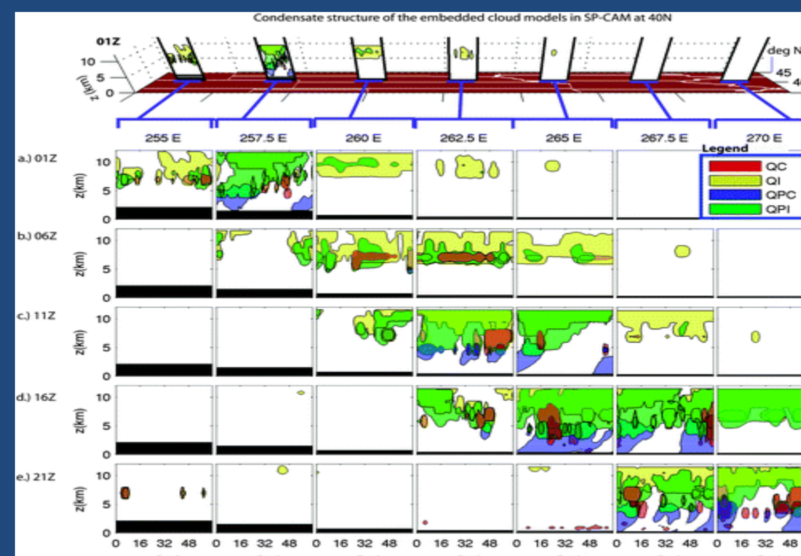



**Standard CAM - no MCS**

**SP- CAM - Propagating MCS**

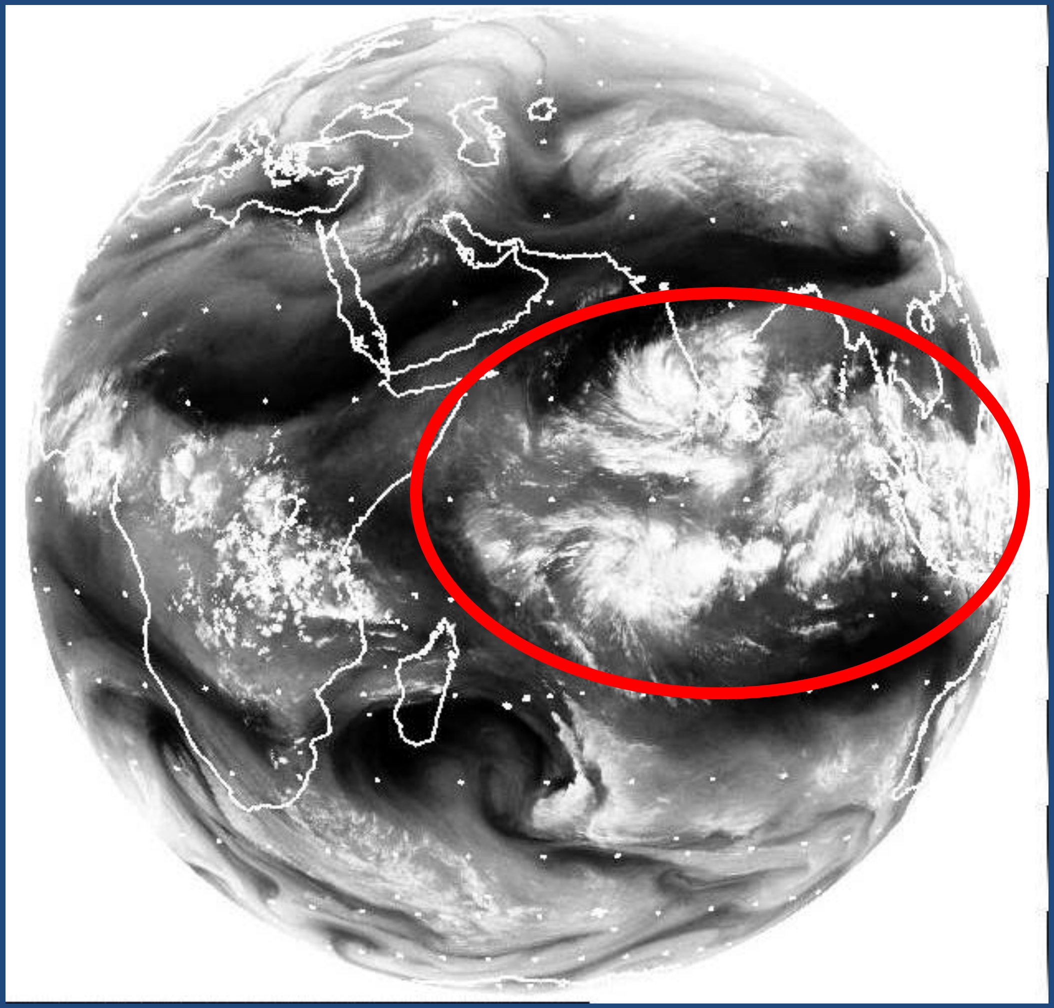
**Second-baroclinic heating/cooling communicated from CRM grid to climate grid organized by vertical shear**



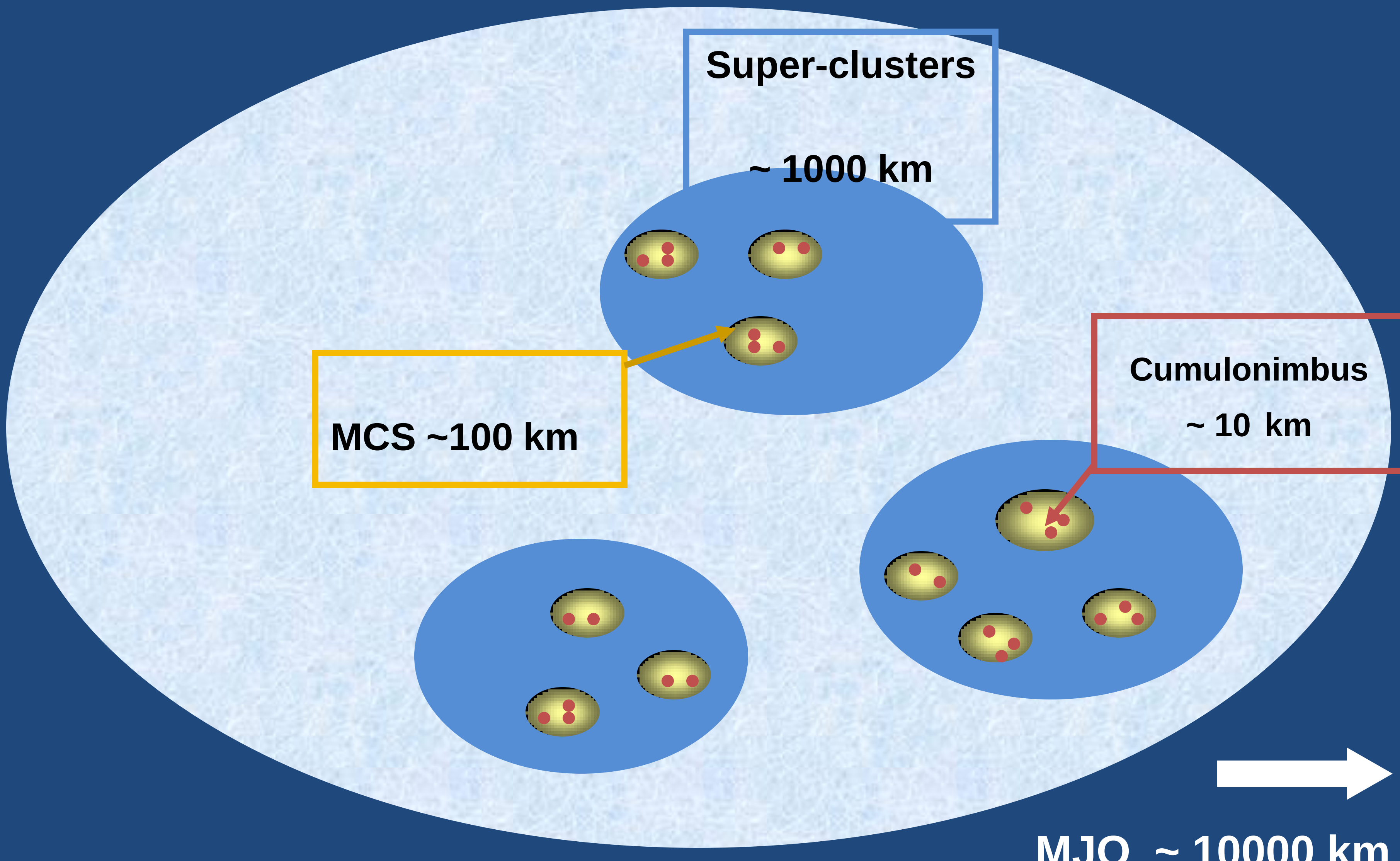




Pritchard, Moncrieff and Somerville (2011)

# Example 2
# Madden-Julian Oscillation (MJO)



# MJO: Multiscale convective organization



# Multiscale organization in modeling frameworks

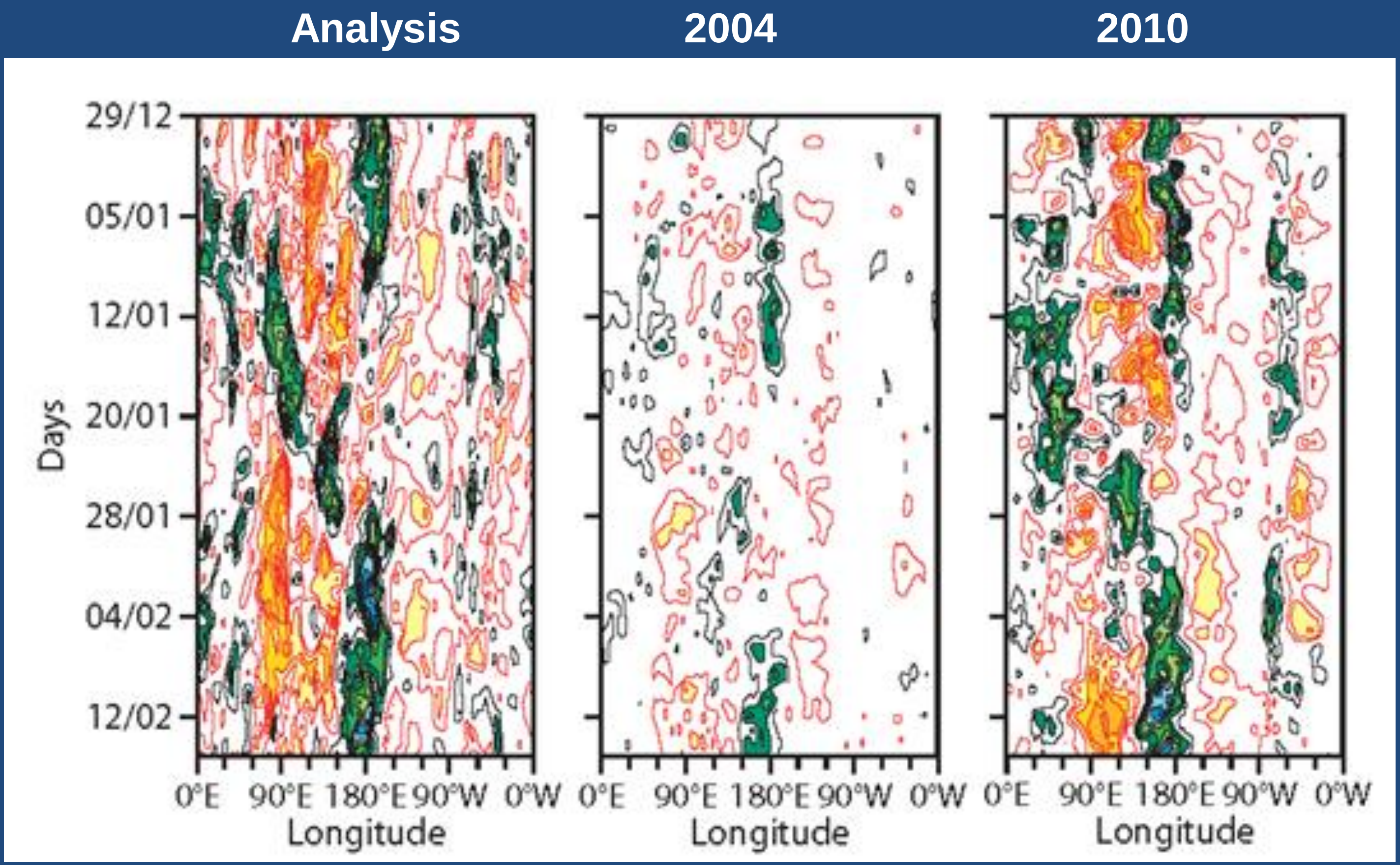
A) High-resolution global NWP

B) Traditional climate models

C) Global cloud-system resolving models

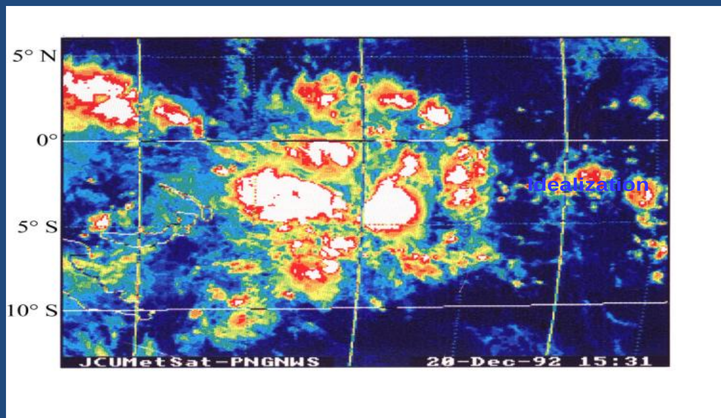
D) Superparameterized global models

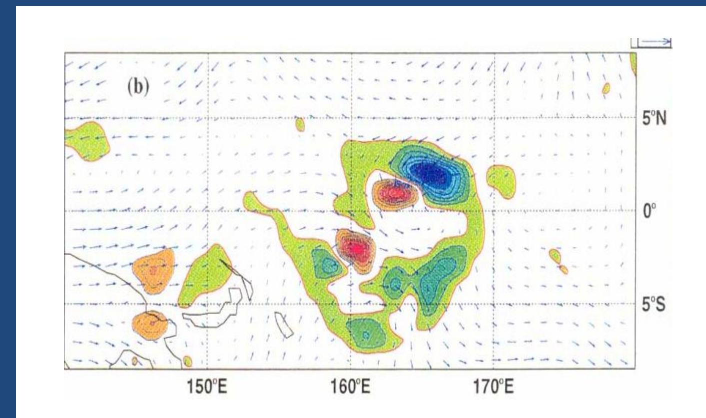
# A) Progressive Improvement of MJO in ECMWF IFS

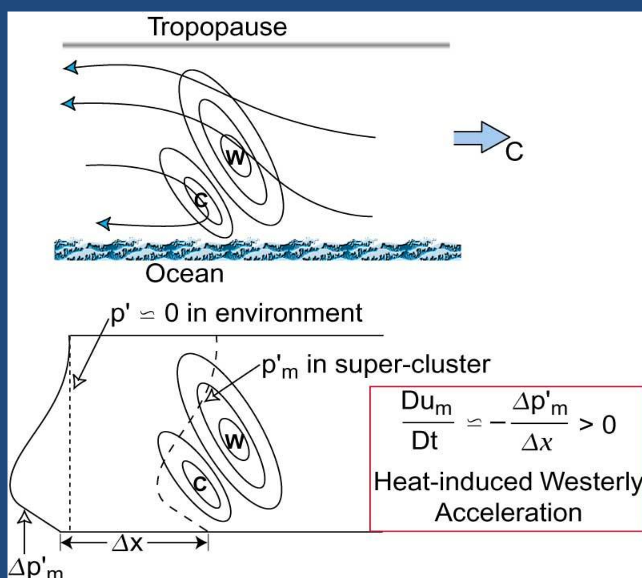



Vitard et al (2011)

# Superclusters in ECMWF T213 (80 km) IFS

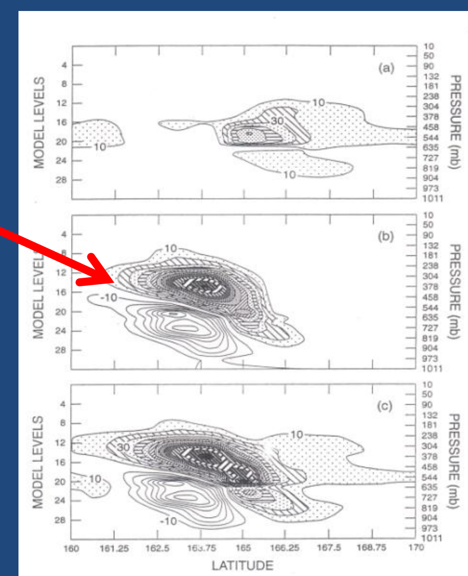



**Organized**

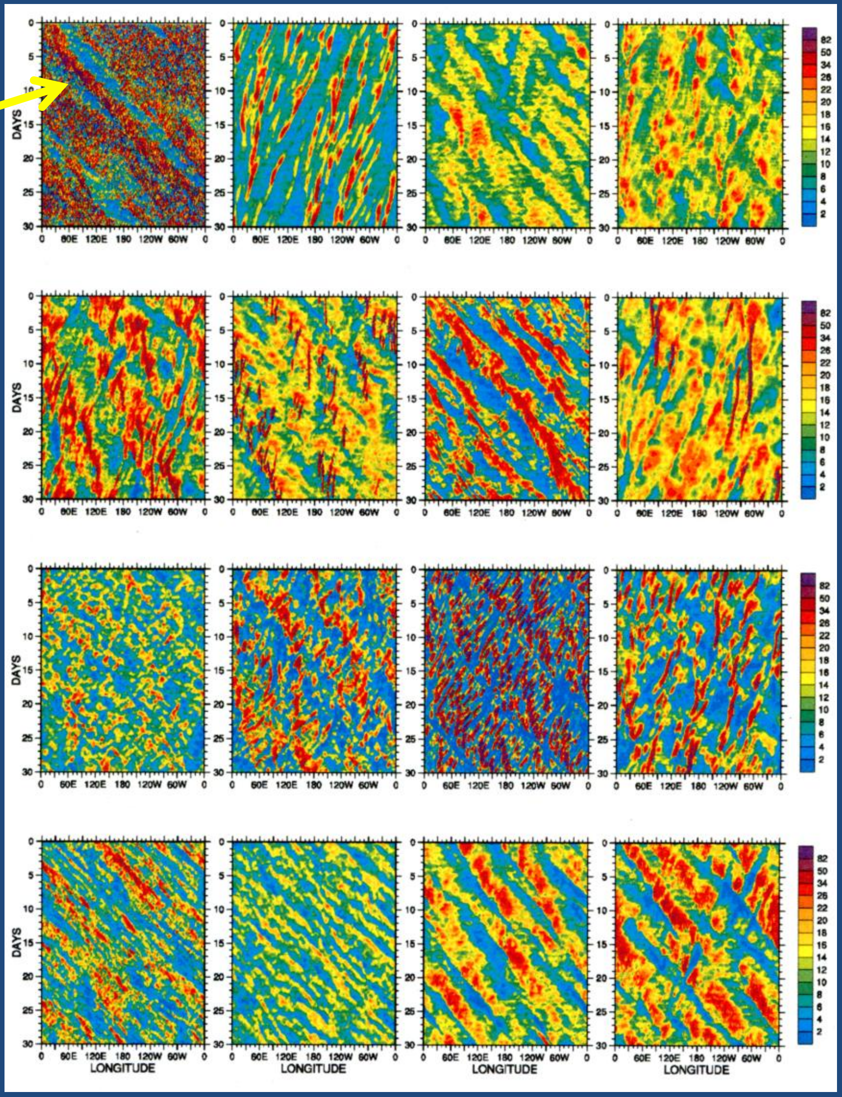
**Heating**




**Moncrieff & Klinker (1997)**

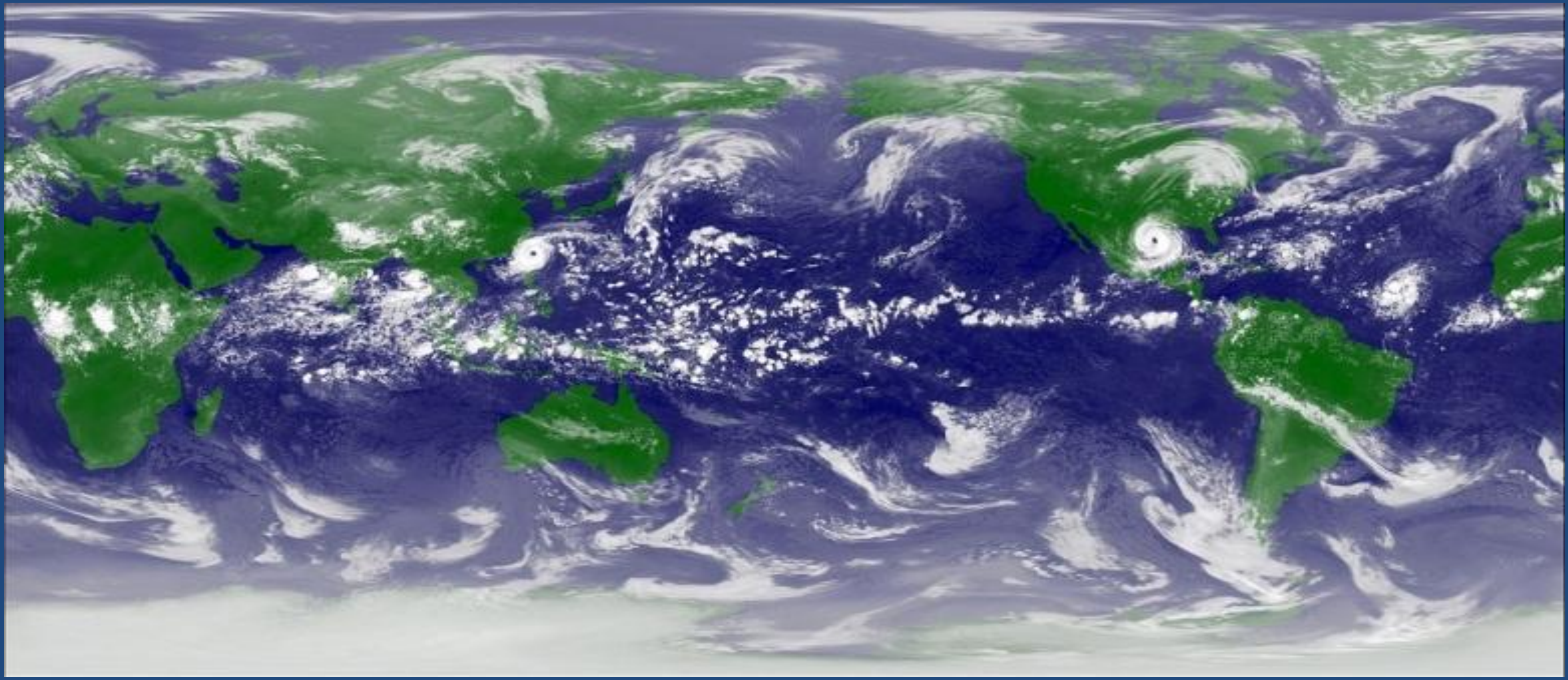
# B) Tropical precipitation in aquaplanet climate models

"Truth"
Global Cloud-System
Resolving Model
(NICAM)



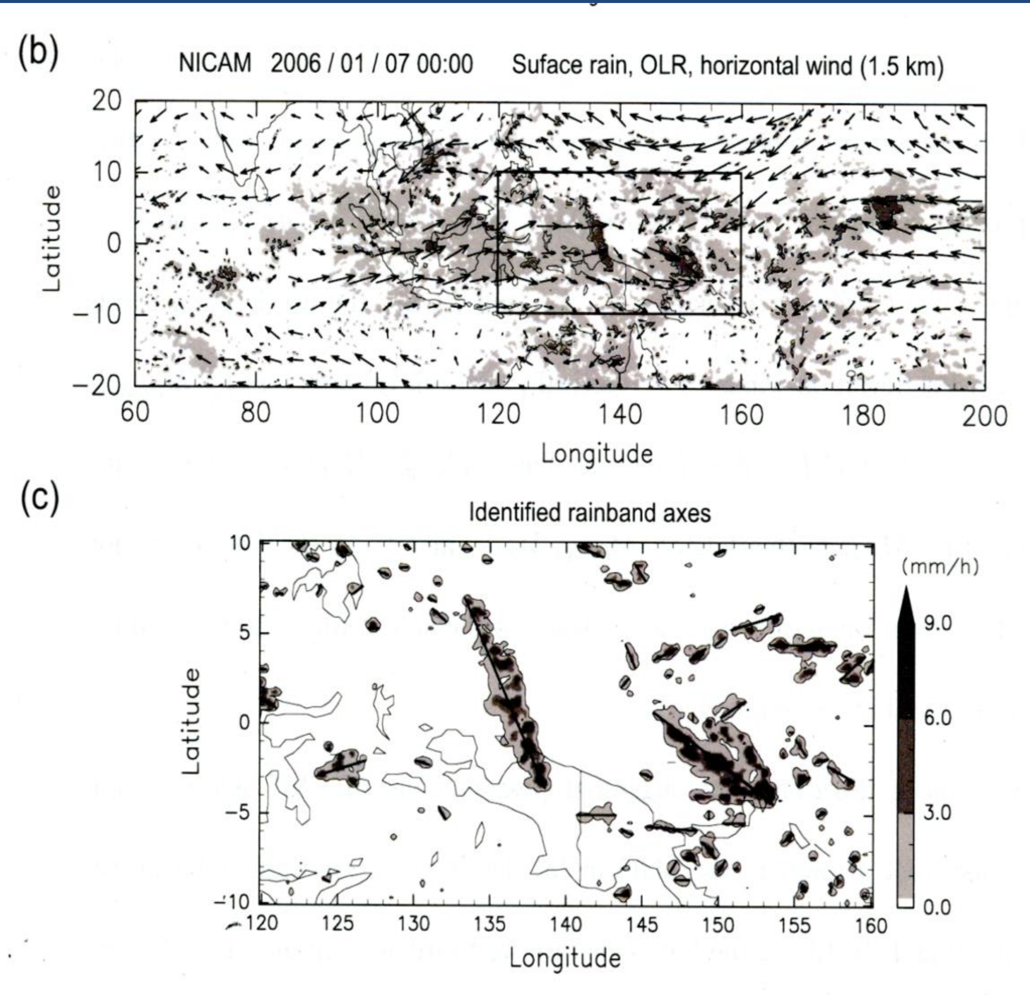

D. Williamson (NCAR), M. Blackburn (U. Reading)

# C) Global cloud-system resolving models



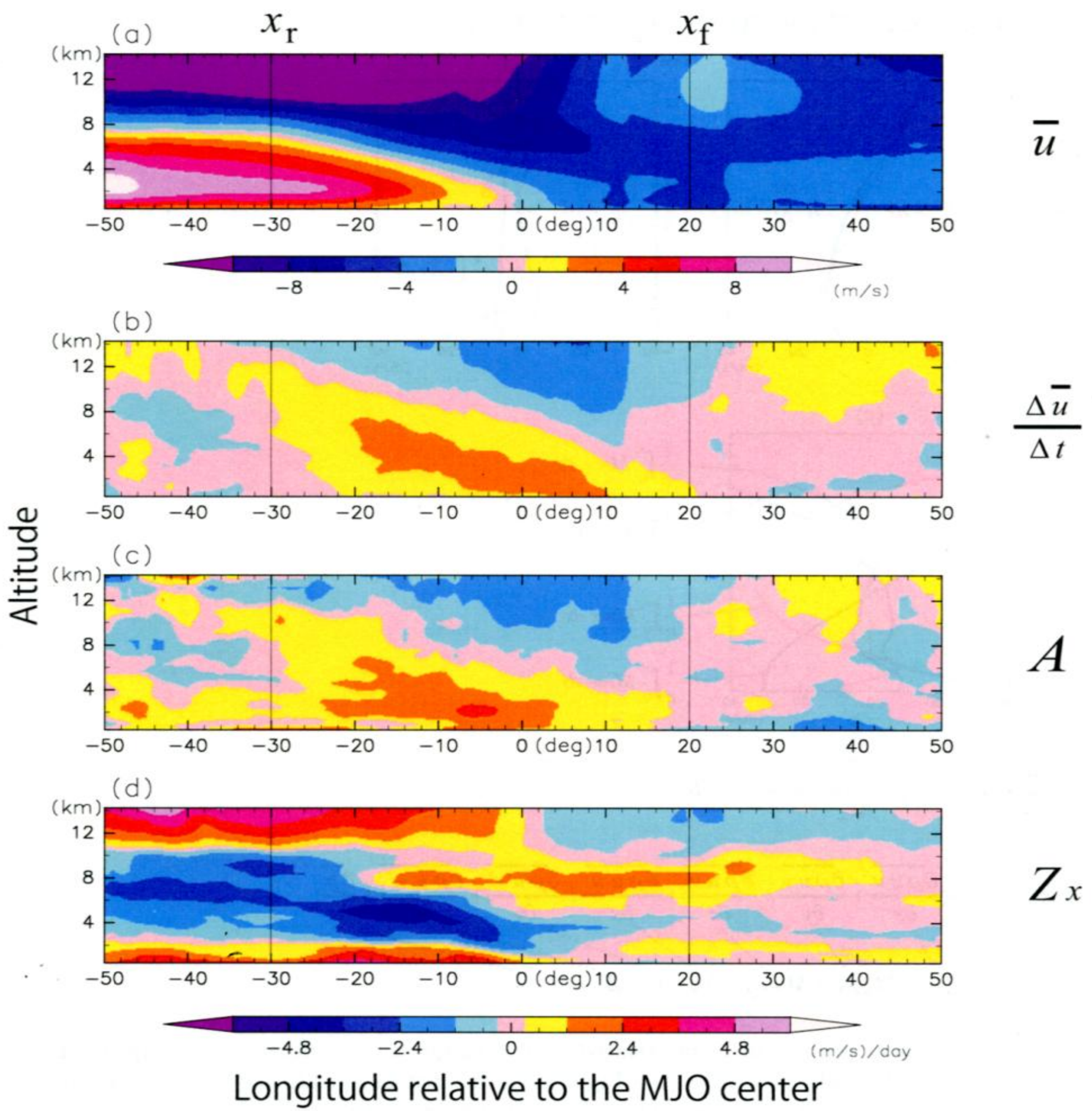
The NICAM Team

# MJO-like systems in NICAM: Organized Convective Momentum Transport




**[13,000 realizations ]**

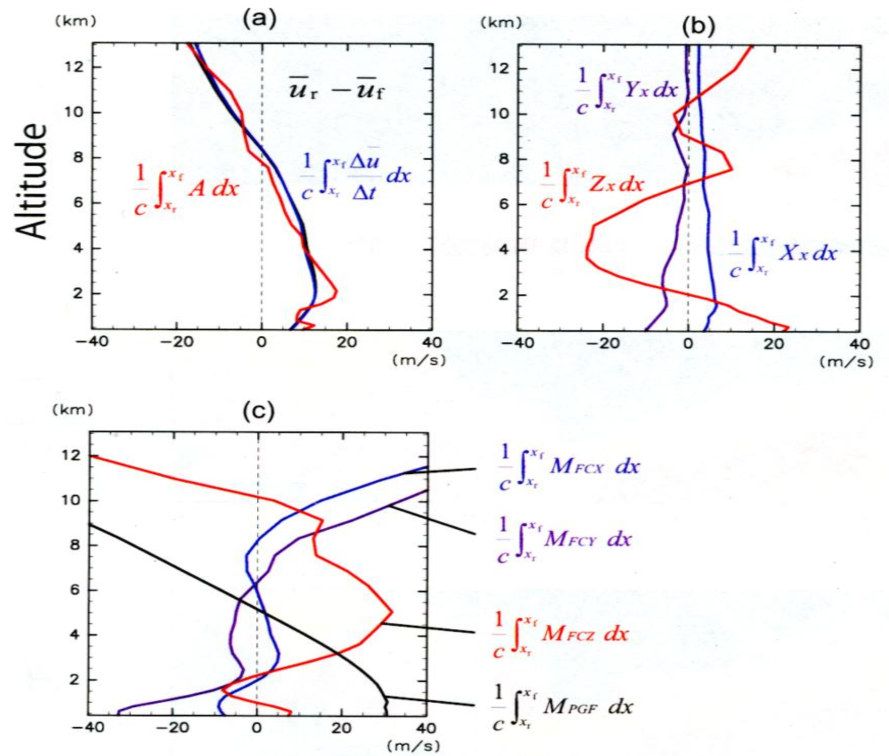
**Miyakawa et al. (2012)**



(a)
$x_r$
$x_f$
(km)
12
8
4
−50 −40 −30 −20 −10 0 (deg) 10 20 30 40 50
−8 −4 0 4 8
(m/s)
$\bar{u}$
(b)
$\frac{\Delta \bar{u}}{\Delta t}$
(c)
$A$
(d)
$Z_x$
Altitude
−4.8 −2.4 0 2.4 4.8
(m/s)/day
Longitude relative to the MJO center

# Zonal momentum budget

Diagnosis of the zonal momentum budget

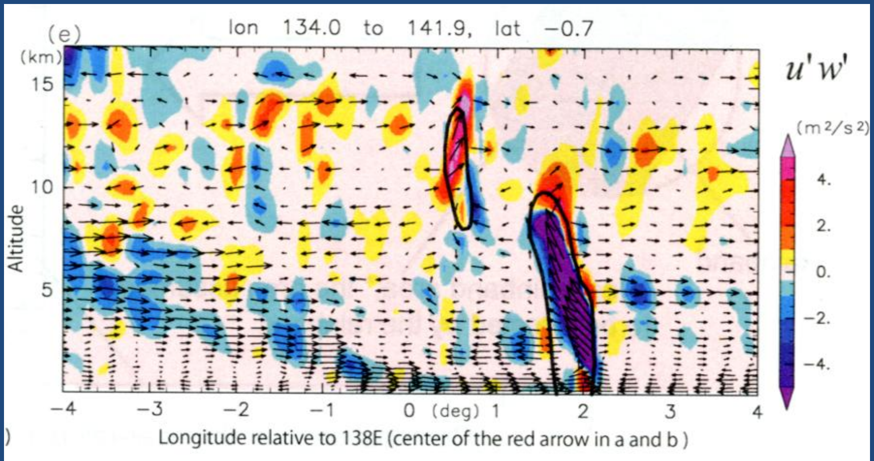


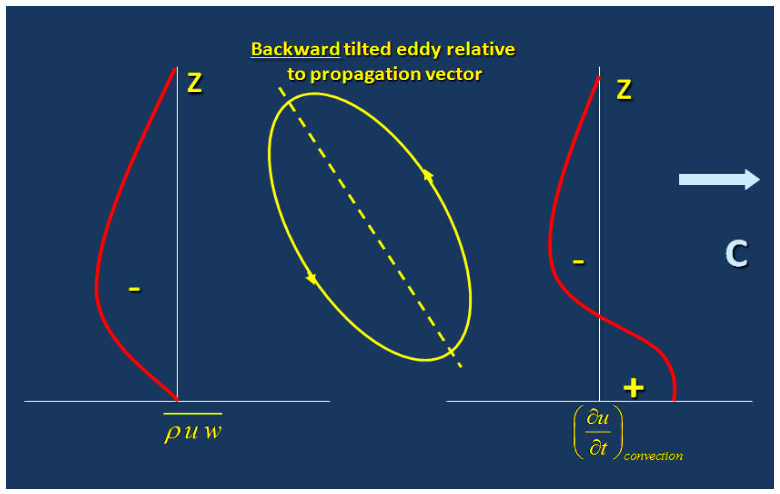

$$\bar{u}_r - \bar{u}_f \approx \frac{1}{c}\int_{x_r}^{x_f} \frac{\Delta \bar{u}}{\Delta t}\,dx \approx \frac{1}{c}\int_{x_r}^{x_f} A\,dx$$

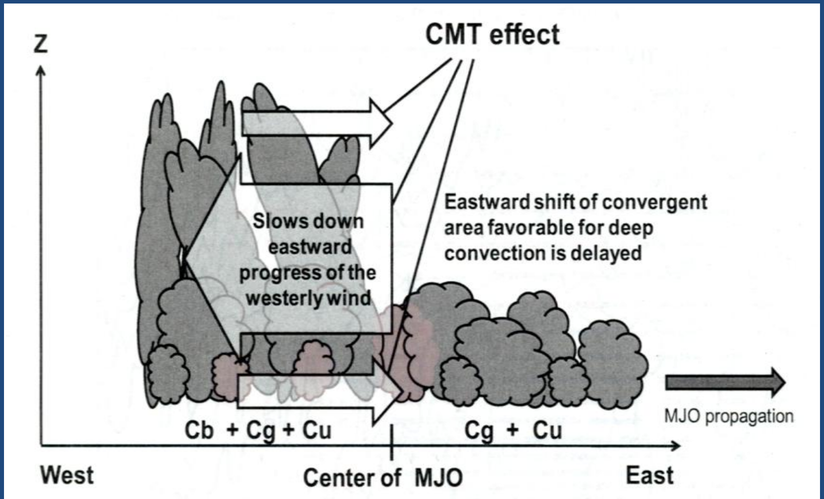
$$A = -\frac{1}{\bar{\rho}}\left(\frac{\partial \bar{\rho}\bar{u}\bar{u}}{\partial x} + \frac{\partial \bar{\rho}\bar{u}\bar{v}}{\partial y} + \frac{\partial \bar{\rho}\bar{u}\bar{w}}{\partial z} + \frac{\partial \bar{\rho}\overline{u'u'}}{\partial x} + \frac{\partial \bar{\rho}\overline{u'v'}}{\partial y} + \frac{\partial \bar{\rho}\overline{u'w'}}{\partial z} + \frac{\partial \bar{p}}{\partial x}\right)$$

$$= M_{FCX} + M_{FCY} + M_{FCZ} + X_x + Y_x + Z_x + M_{PGF}$$

# Mesoscale momentum transport

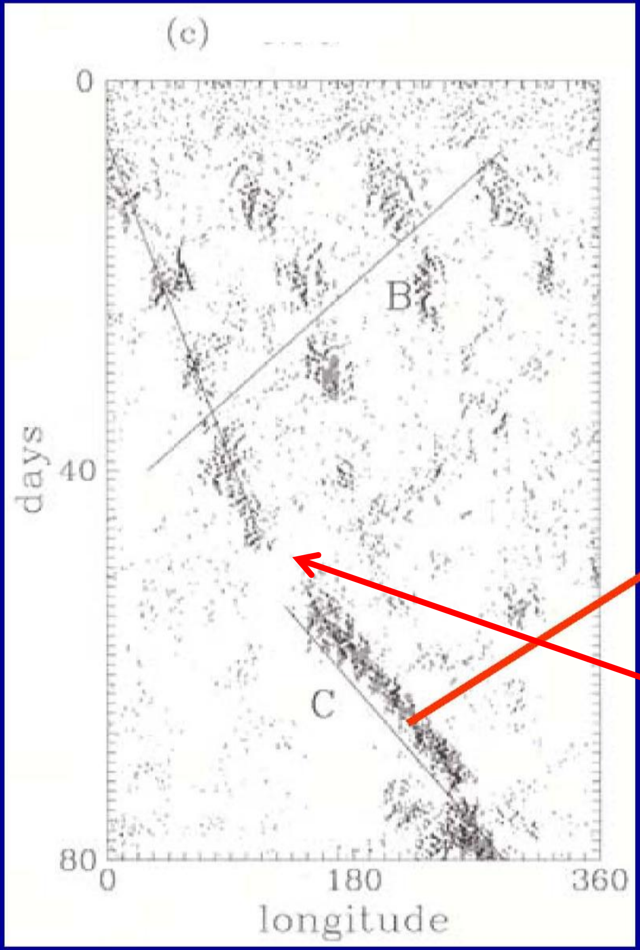


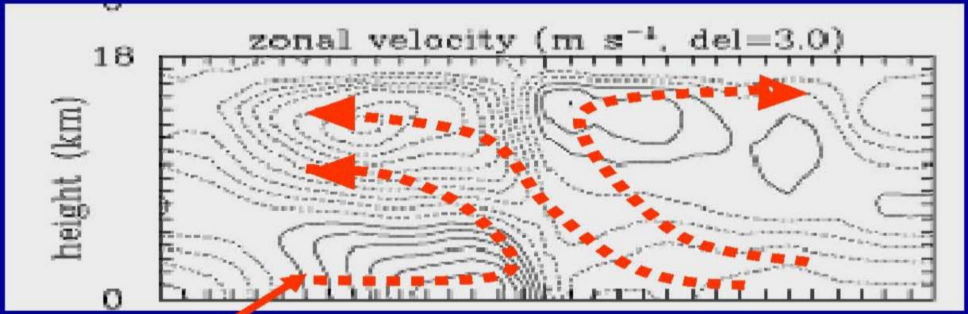




$$\frac{\partial \bar{u}}{\partial t} + \ldots\ldots\ldots\ldots = - \frac{\partial}{\partial z}\left(\overline{u_m w_m}\right) = \left(\frac{\delta u}{\delta t}\right)_{convection}$$

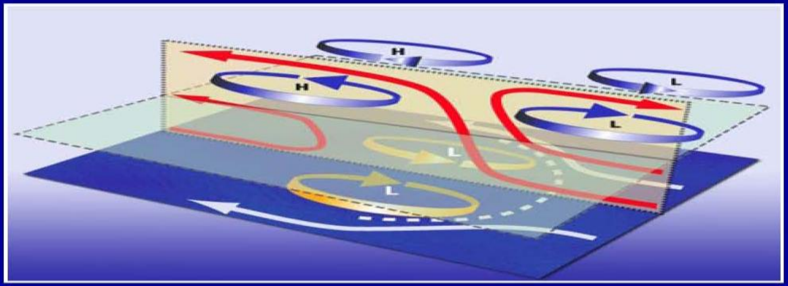
# D) Superparameterization and dynamical interpretation




Vertical structure of the eastward propagating supercluster-like system

Formation of Rossby gyres

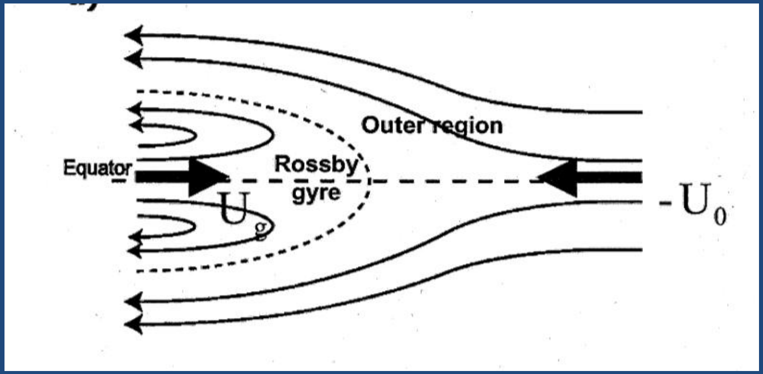


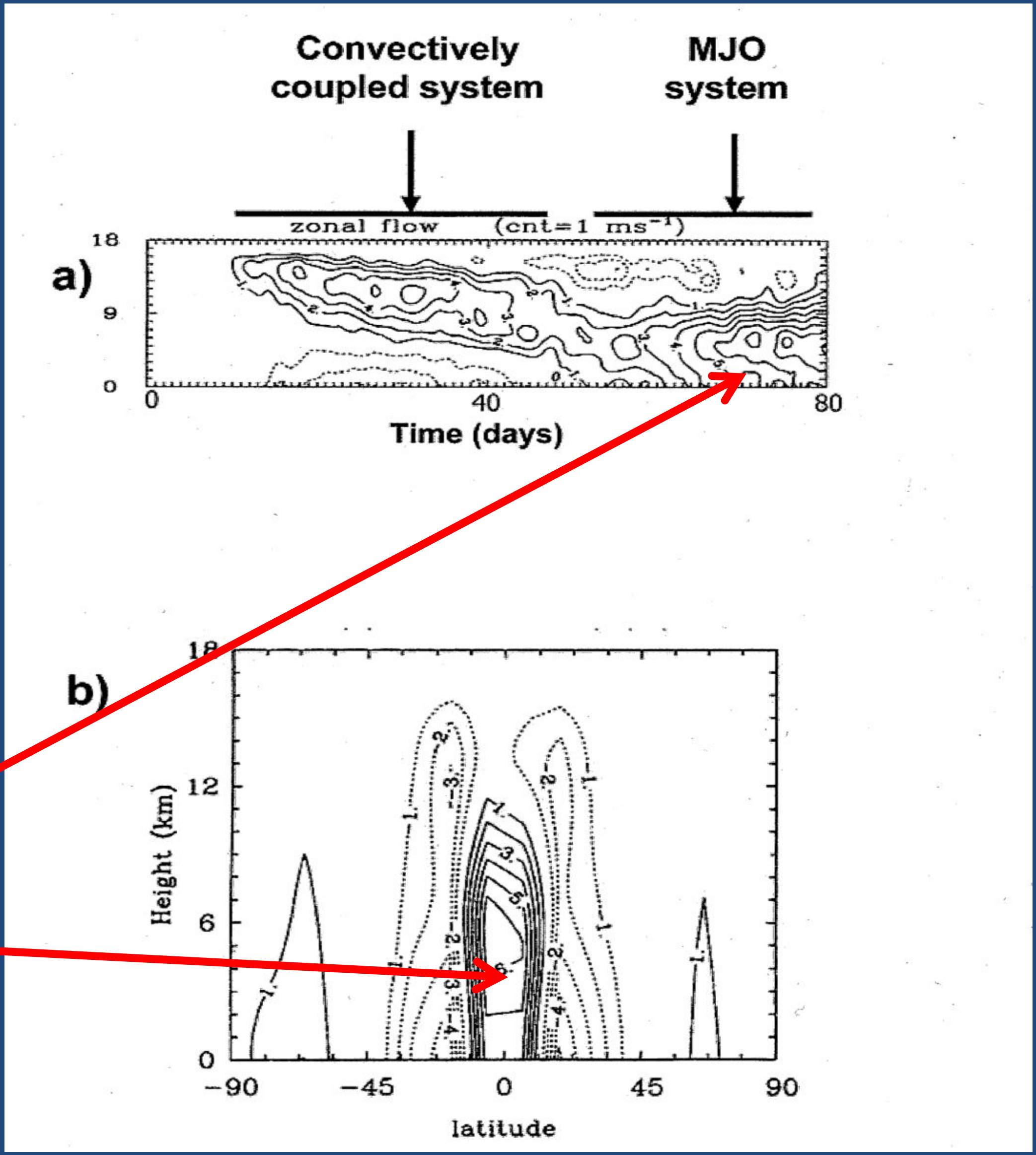

Dynamical model of organized convection interlocked with a Rossby-gyre circulation

Grabowski (2001)
Moncrieff (2004)

# Super-rotation and the MJO

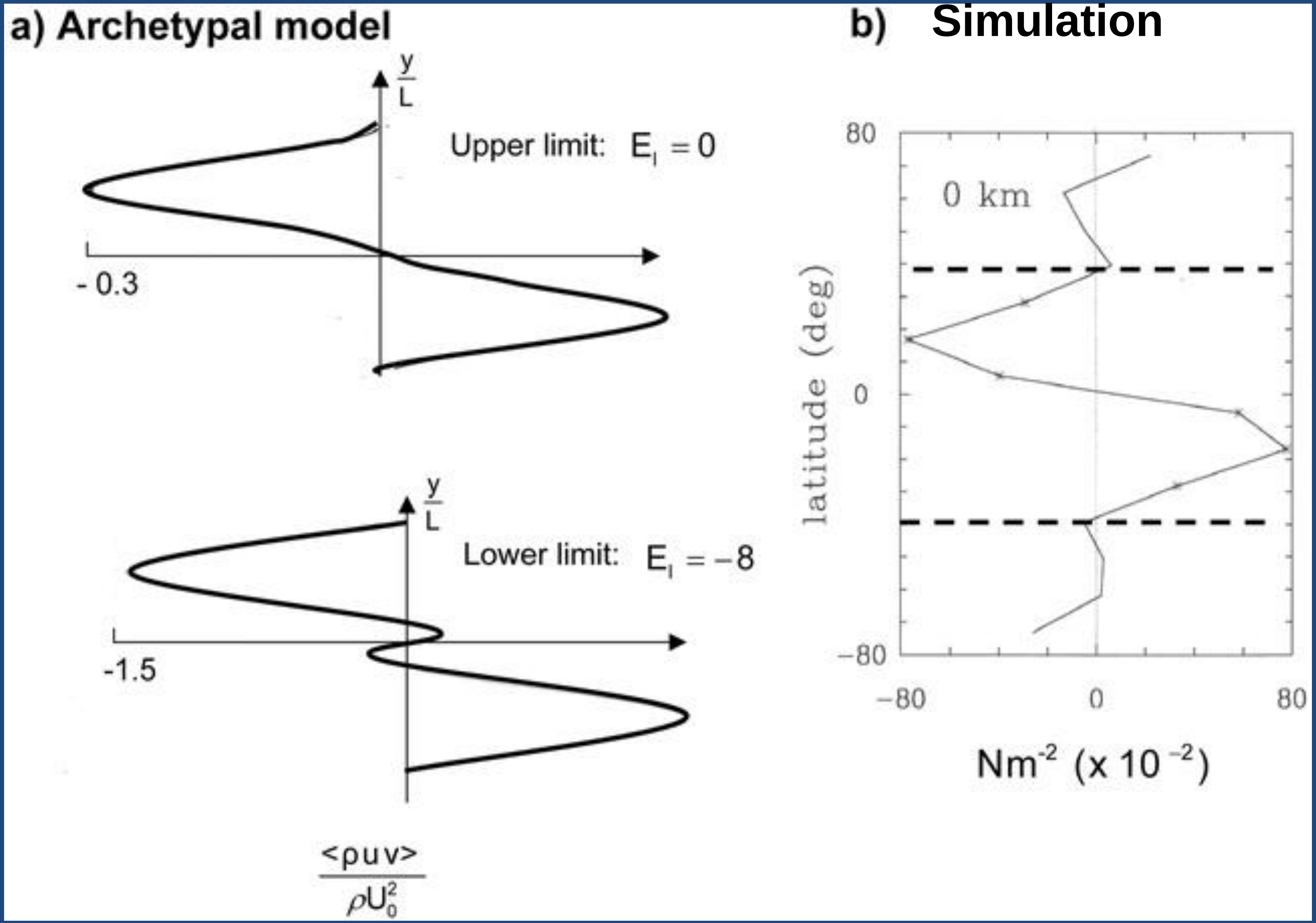
**Mechanism: Slantwise meridional overturning**



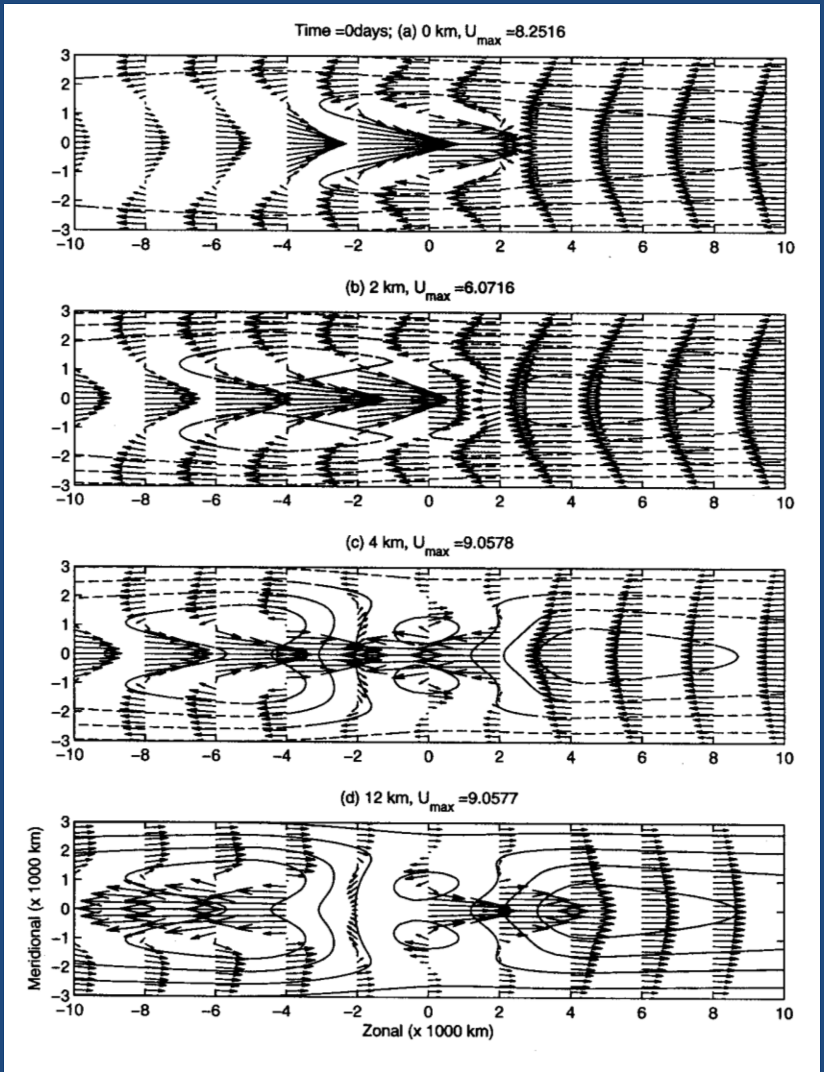

**Super-rotation induced by the simulated MJO system**

# Evaluation of analytic model of meridional momentum flux using Grabowski (2001) simulation




Moncrieff (2004)

# Upscale effects of superclusters on MJO




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

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

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

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

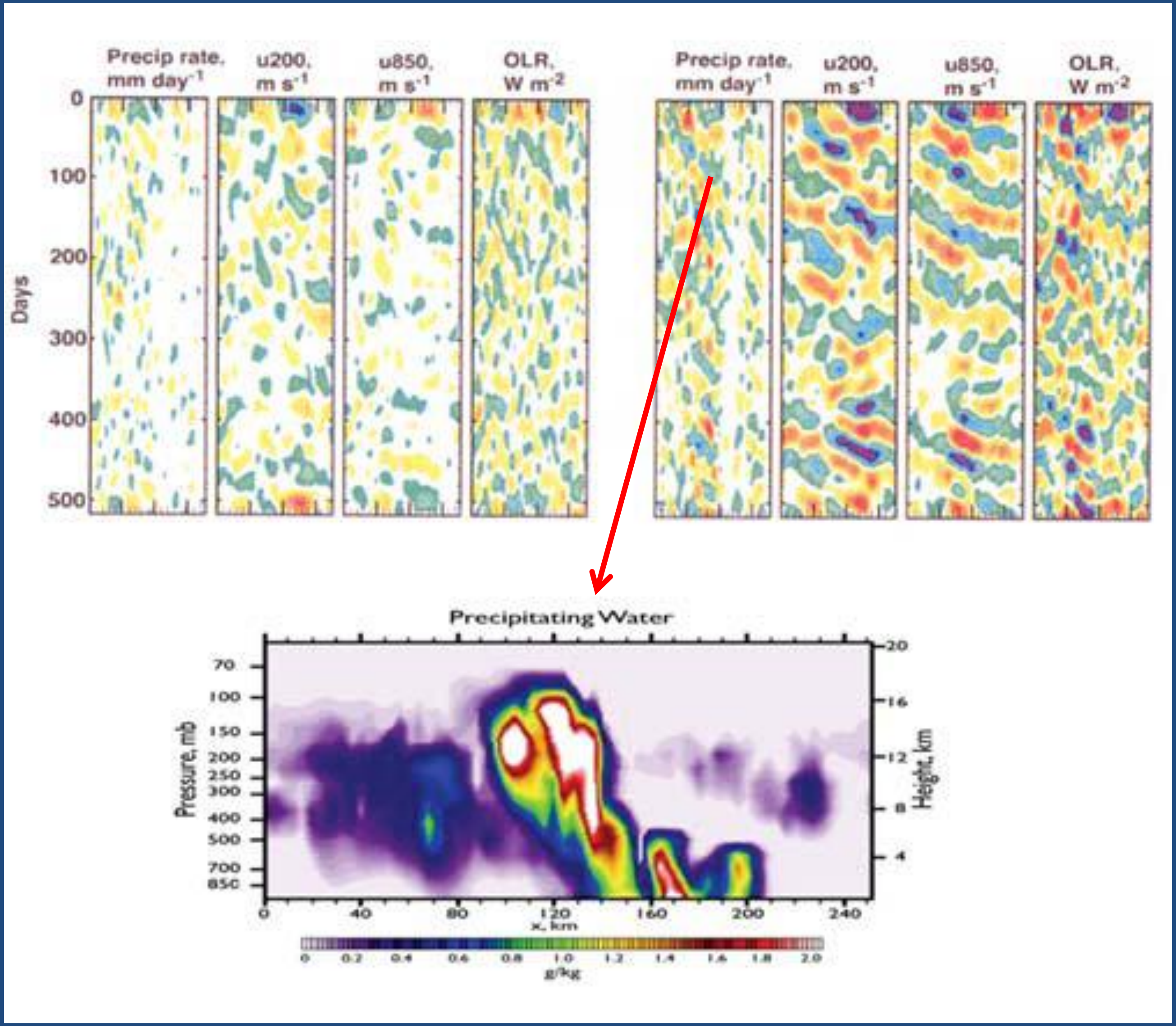
$$\bar{U}_X + \bar{V}_y + \bar{W}_z = 0$$

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

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

**Biello, Majda, Moncrieff (2007)**

# D) Superparameterized MCS-like systems and MJO-like organization



# WCRP/WWRP
# Year of Tropical Convection (YOTC)

Mitch Moncrieff (NCAR) & Duane Waliser (JPL)

Co-Chairs, YOTC Science Planning Group

ECMWF T799 (25 km/16km) Integrated Forecast System (IFS)
global analysis and subgrid tendencies

www.ucar.edu/yotc

# Collaborative research at the intersection of weather and climate

by Mitchell W. Moncrieff, Melvyn A. Shapiro, Julia M. Slingo and Franco Molteni

***WMO Bulletin*, 56, 204-211**

# Virtual Global Field Campaigns

A surrogate for actual global field campaigns which are logistically & financially impossible; extends scope of actual field experiments, e.g., DYNAMO

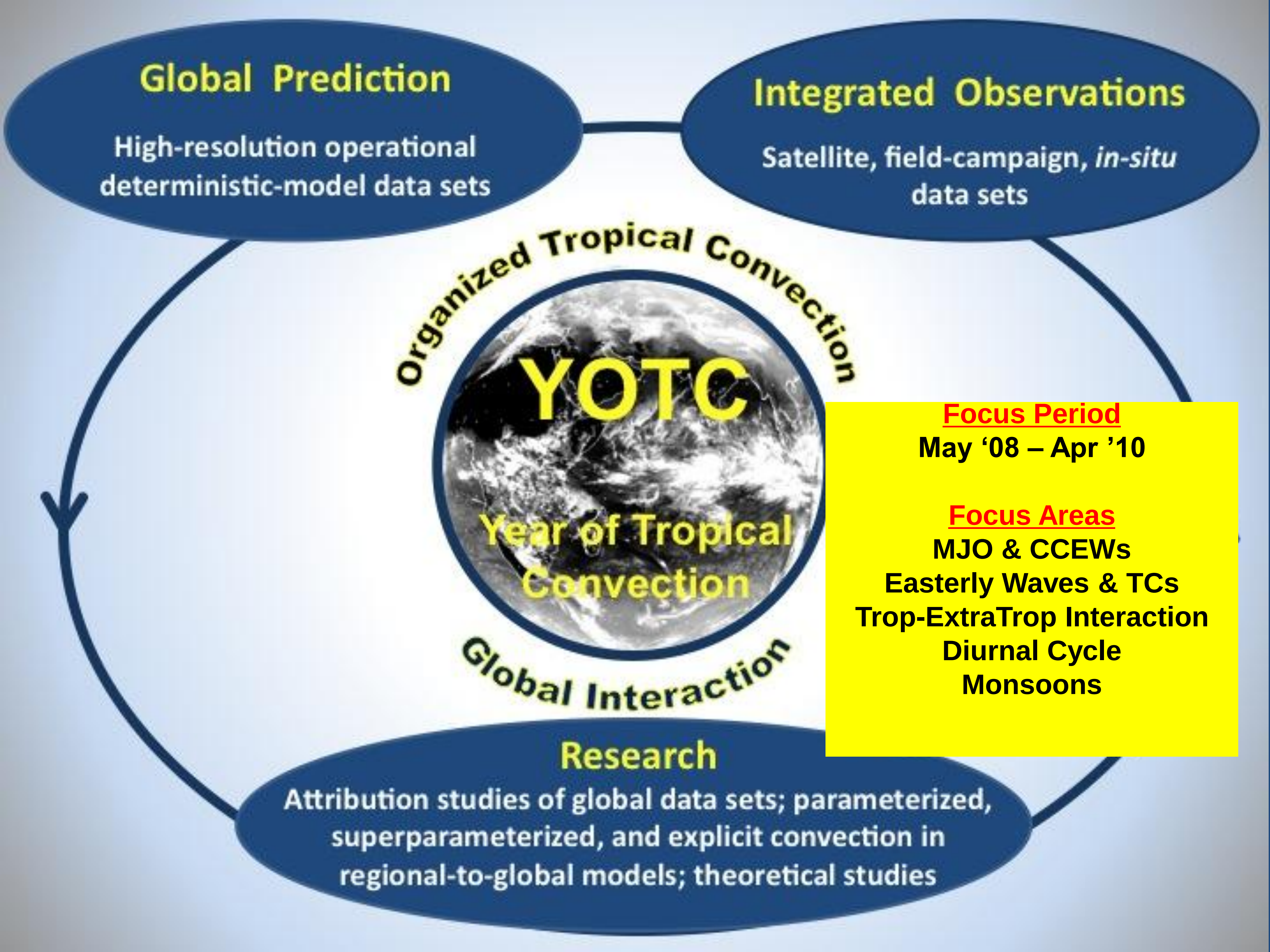
Prototype:

ECMWF-YOTC (May 2008-April 2010; 26 km mesh)

1) Full global analysis

2) 10-day global forecasts

3) Over 30 sub-grid tendencies


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”

**Utilizes 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**

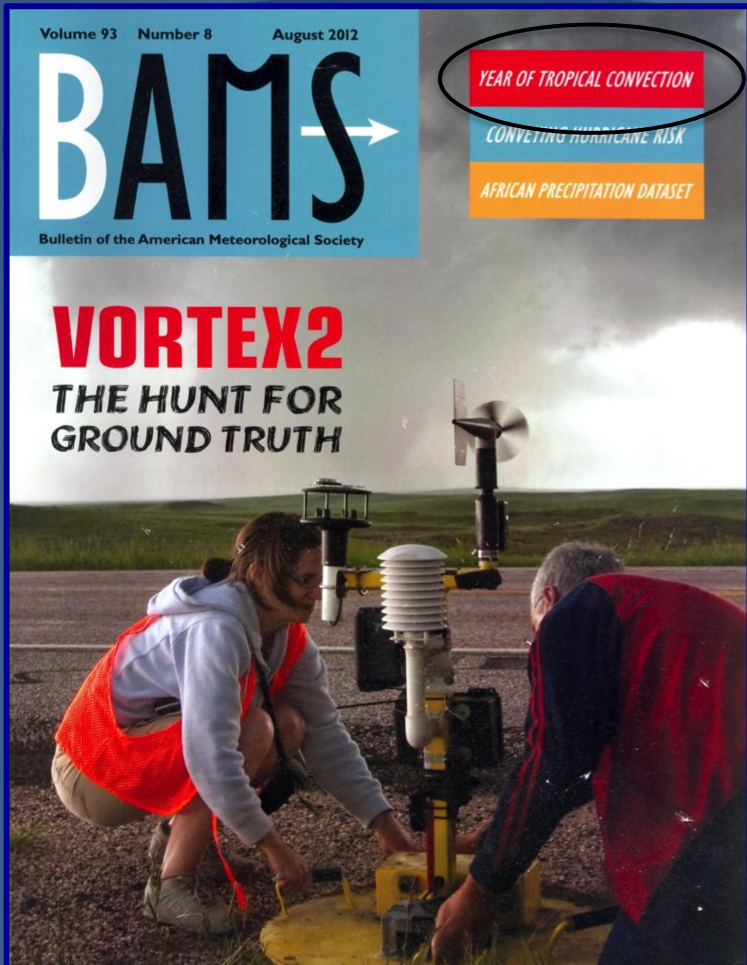
=

**YOTC**

**Virtual Global Field Campaign:**

**ECMWF IFS May 2008-April 2010**

Moncrieff et al (2012), Waliser et al (2012)




# PROGRESS AND DIRECTION IN TROPICAL CONVECTION RESEARCH

## YOTC International Science Symposium

BY MITCHELL W. MONCRIEFF, DUANE E. WALISER, AND JAMES CAUGHEY

# MULTISCALE CONVECTIVE ORGANIZATION AND THE YOTC VIRTUAL GLOBAL FIELD CAMPAIGN

BY MITCHELL W. MONCRIEFF, DUANE E. WALISER, MARTIN J. MILLER, MELVYN A. SHAPIRO, GHASSEM R. ASRAR, AND JAMES CAUGHEY

Vastly improved satellite and in situ measurements, data assimilation, and modeling make possible a virtual field study of multiscale Earth system problems, such as convective organization and its interaction with larger-scale circulation.

# THE "YEAR" OF TROPICAL CONVECTION (MAY 2008–APRIL 2010)

## Climate Variability and Weather Highlights

BY DUANE E. WALISER, MITCHELL W. MONCRIEFF, DAVID BURRIDGE, ANDREAS H. FINK, DAVE GOCHIS, B. N. GOSWAMI, BIN GUAN, PATRICK HARR, JULIAN HEMING, HUANG-HSUING HSU, CHRISTIAN JAKOB, MATT JANIGA, RICHARD JOHNSON, SARAH JONES, PETER KNIPPERTZ, JOSE MARENGO, HANH NGUYEN, MICK POPE, YOLANDE SERRA, CHRIS THORNCROFT, MATTHEW WHEELER, ROBERT WOOD, AND SANDRA YUTER

May 2008–April 2010 provided a diverse array of scientifically interesting and socially important weather and climate events that emphasizes the impact and reach of tropical convection over the globe.

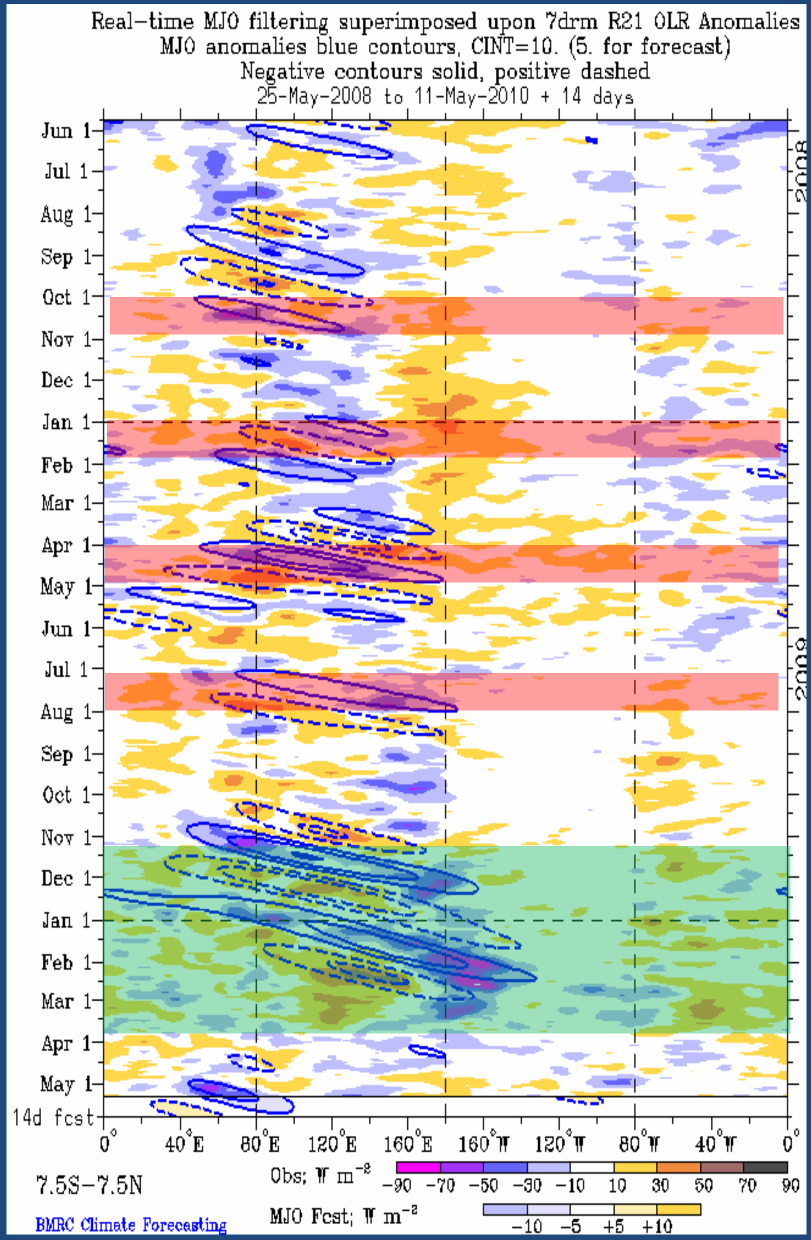
# MJOs during YOTC

## (May '08 – Apr '10)

2
0
0
8

2
0
0
9

2
0
1
0



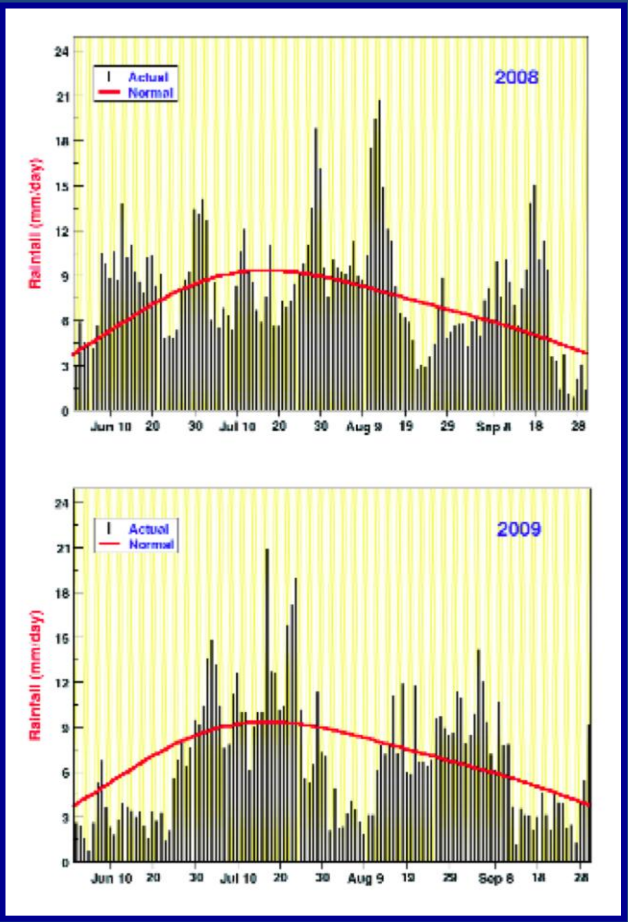

*La Nina* conditions

*El Nino* conditions

# Summer Monsoons during YOTC

India
BN Goswami

S. America
Jose Marengo




2008

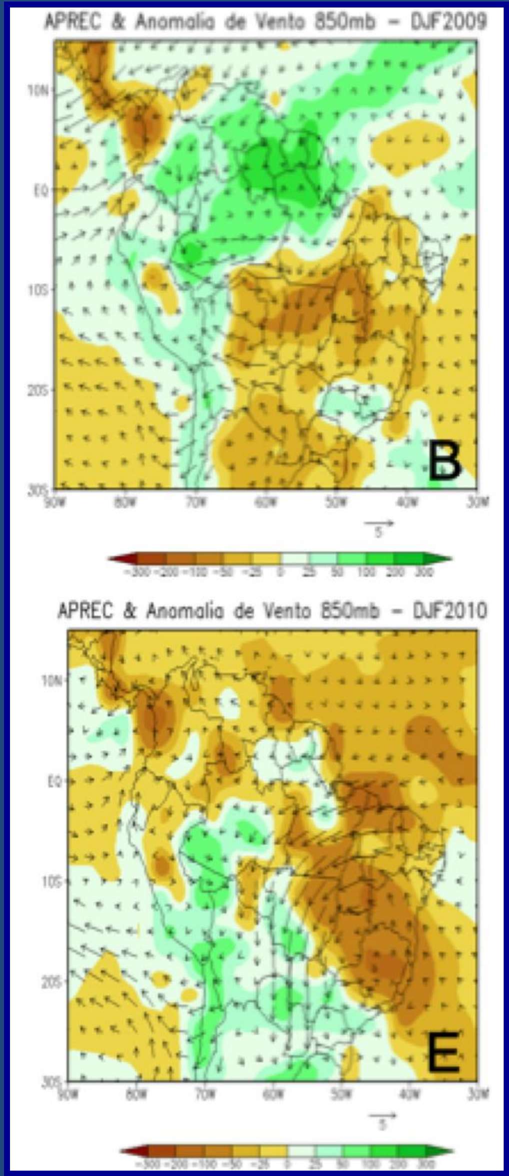
“Normal
98% rain

Wet-north
Dry-south

2009

Drought
78% rain

Dry-northeast
Wet-south

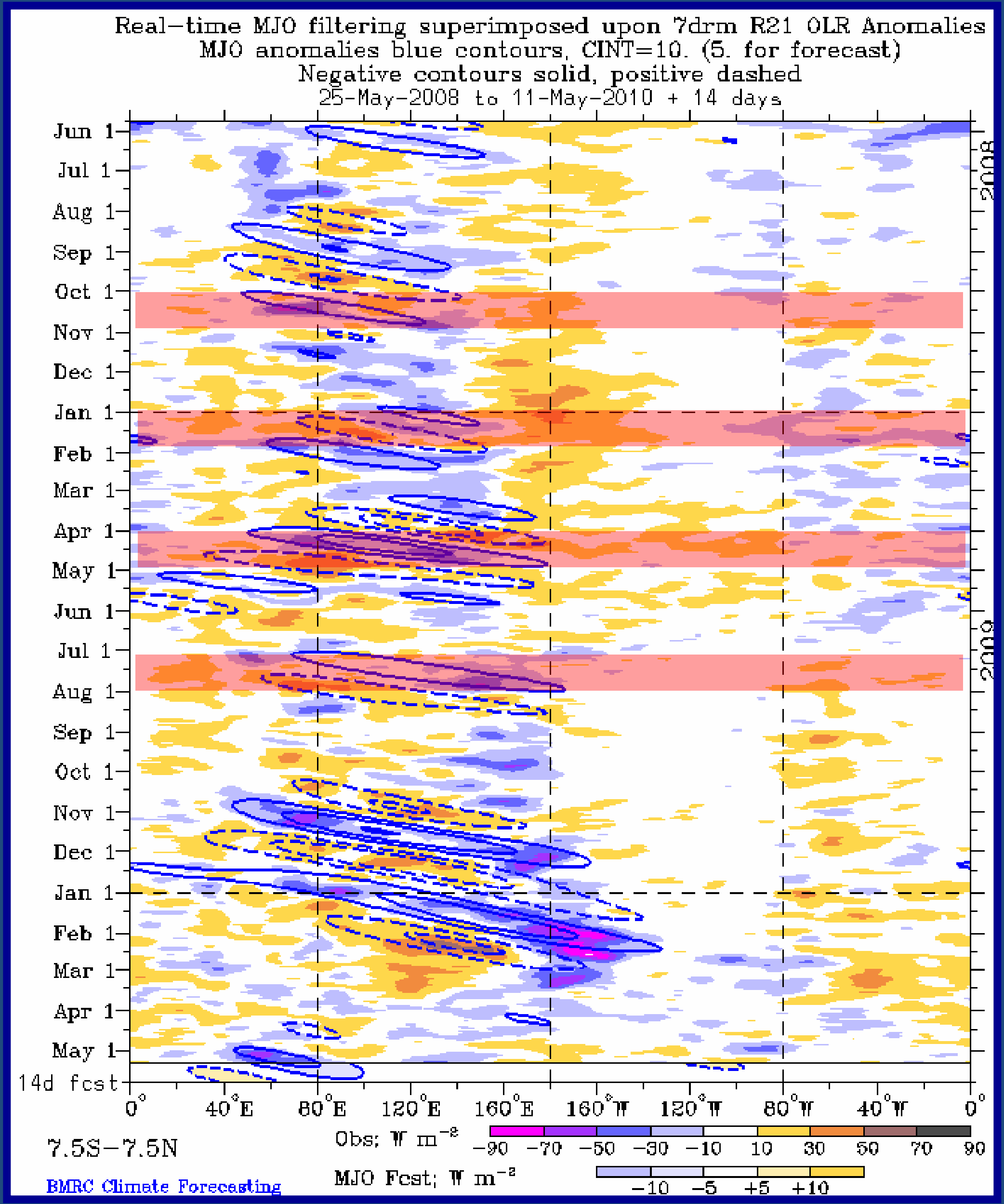



*Breaks influenced by ISV*

# YOTC

## Working Group on Numerical Experimentation (WGNE): Transpose AMIP Hindcasts

- 4 periods: each has 16 5-day hindcasts of MJOs for La Nina conditions of YOTC
- 9 Subprojects
- 8 Modeling Groups




See hadobs.metoffice.com/tamip

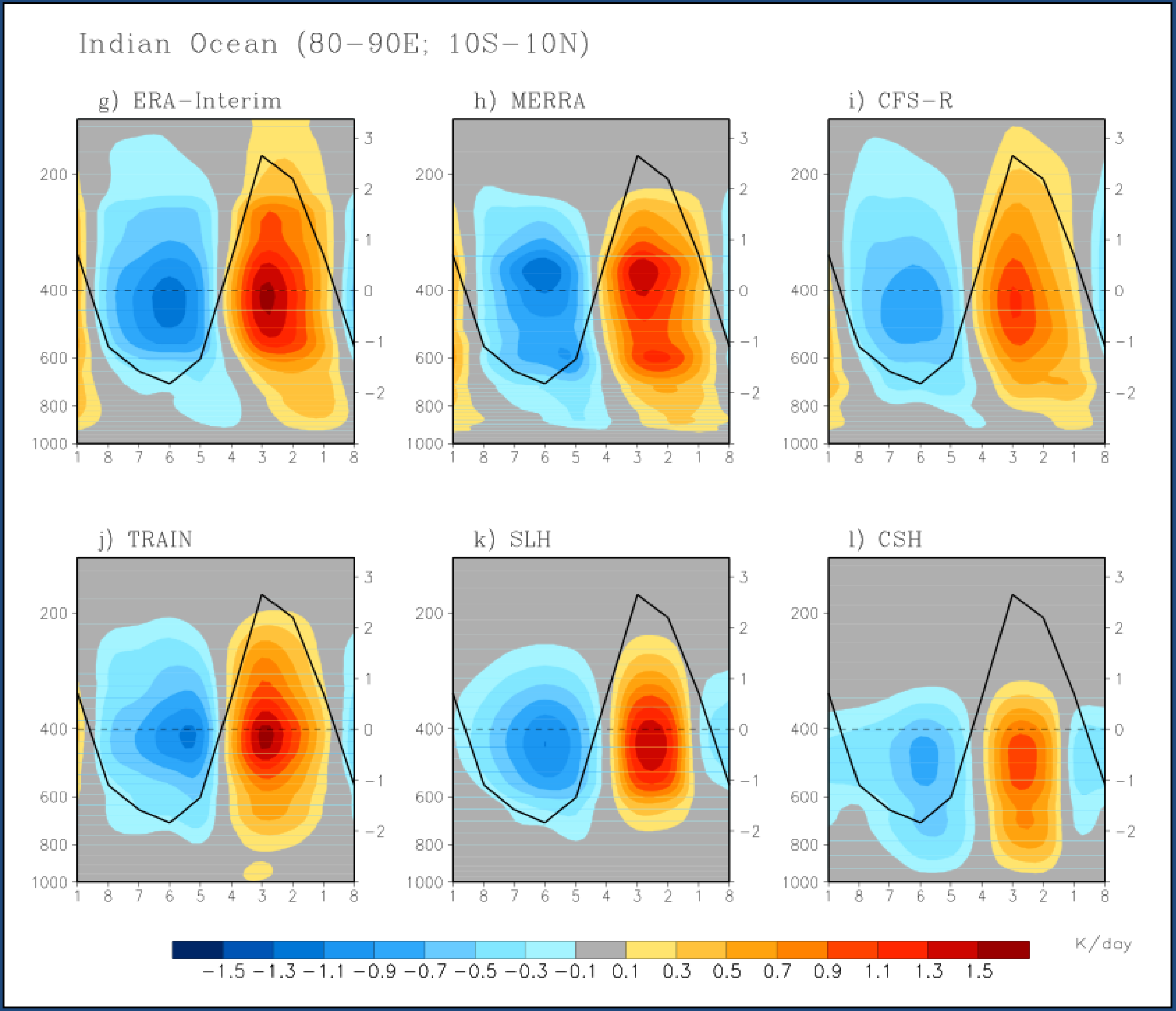
# Vertical Structure and Diabatic Processes of the MJO: *Global Model Evaluation Project*

MJO Task Force/YOTC , GASS

*Jon Petch (Met Office), Duane Waliser (JPL)*
*Xianan Jiang (JPL/Caltech), Prince Xavier (Met Office)*
*Nick Klingaman & Steve Woolnough (NCAS - Climate)*

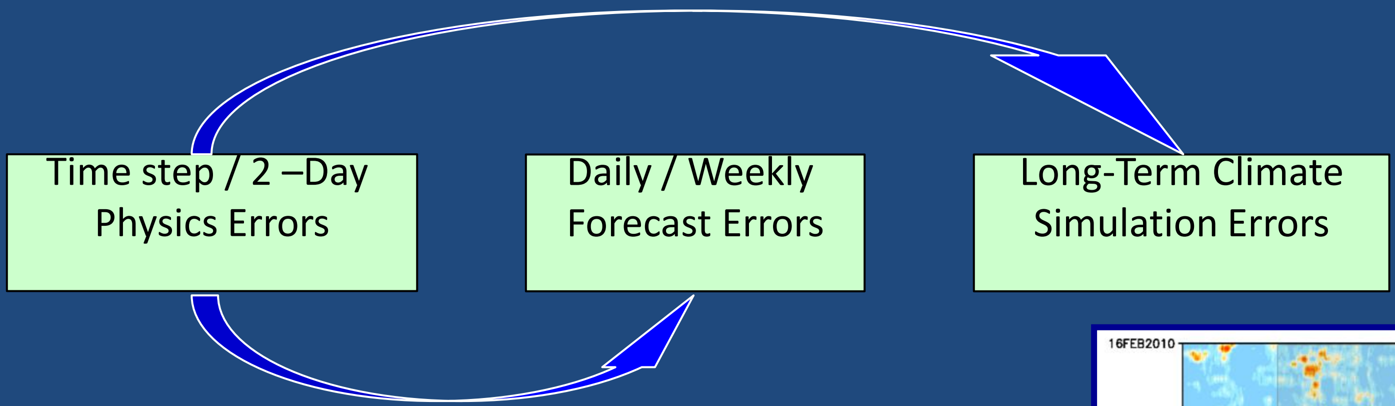
WCRP World Climate Research Programme MJO TF THORPEX A World Weather Research Programme
WWRP GASS GEWEX Atmospheric System Studies YOTC

# MJO Diabatic Heating in Recent Reanalysis and TRMM



# Vertical Structure and Diabatic Processes of the MJO: Global Model Evaluation Project

MJO Task Force/YOTC and GASS

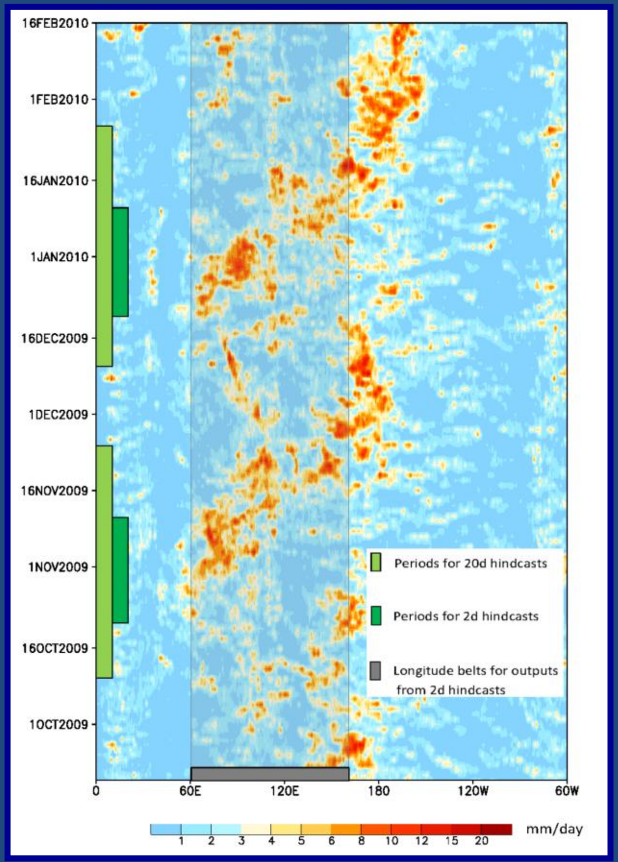



1. **Climatological** – multi-year simulations coupled or atmosphere only

2. **Short-range hindcasts** – daily 48hr lead during ~20 days of the MJO

3. **Medium-range hindcasts** – daily 20-day lead time

www.ucar.edu/yotc/mjodiab.html



# Vertical Structure and Diabatic Processes of the MJO: *Global Model Evaluation Project*

(MJO Task Force/YOTC and GASS)

WCRP MJO TF THORPEX WWRP GASS YOTC

www.ucar.edu/yotc/mjodiab.html

| Model Experiment | Science Focus | Exp. POC |
|---|---|---|
| I. **20 Yr Climatological Simulations**<br>(1991-2010 if AGCM)<br>6-hr, Global Output<br>Vertical Structure, Physical Tendencies | Model MJO Fidelity<br>Vertical structure<br>Multi-scale Interactions:<br>(e.g., TCs, Monsoon, ENSO) | **UCLA/JPL**<br>X. Jiang<br>D. Waliser |
| II. **2-Day MJO Hindcasts**<br>YOTC MJO Cases E & F (winter 2009)*<br>Time Step, Indo-Pacific Domain Output<br>Very Detailed Physical/Model Processes | Heat and moisture budgets<br>Model Physics Evaluation<br>(e.g. Convection/Cloud/BL)<br>*Short range Degradation* | **Met Office**<br>P. Xavier<br>J. Petch |
| III. **20-Day MJO Hindcasts**<br>YOTC MJO Cases E & F (winter 2009)*<br>3-hr, Global Output<br>Elements of I & II | MJO Forecast Skill<br>State Evolution/Degradation<br>Elements of I & II | **NCAS/Walker in.**<br>N. Klingaman<br>S. Woolnough |

*DYNAMO Case TBD

Commitments: Over 40 Modeling Groups with AGCM and/or CGCM

# Conclusions

- New challenges, e.g.,

  - Bringing mesoscale processes (weather) to climate models is necessary if we are ever to understand severe weather events and their variability in a warming world

  - Bringing dynamical concepts to convective parameterization is necessary especially as global models achieve ever higher resolution, but not yet cloud-resolving resolution

- We are making substantial progress via

  - Higher resolution models

  - Dynamical theory and idealized simulations, e.g., CMT

  - Virtual global field-campaigns which extend actual field campaigns -- individual investigations and major international collaborative projects

# References


- **Moncrieff, M.W., M. Shapiro, J. Slingo, and F. Molteni, 2007: Collaborative research at the intersection of weather and climate. *WMO Bulletin*, 56, 204-211.**

- **Moncrieff, M.W., 2010: The multiscale organization of moist convection and the intersection of weather and climate. Why does Climate Vary? Ed. D. Sun and F. Bryan, *AGU Geophys. Monog,* 189, 3-26, doi: 10.1029/2008GM000838.**

- **Moncrieff, M.W., D.E. Waliser, M. J. Miller, M.A. Shapiro, G.R. Asrar, and J. Caughey, 2012: Multiscale convective organization and the YOTC virtual global field campaign. *Bull. Amer. Meteorol. Soc.,* August Edition.**

- **Moncrieff, M.W, D.E. Waliser, and J. Caughey, 2012: Progress and direction in tropical convection research. *Bull. Amer. Meteorol. Soc.,* August Edition.**

- **Waliser, D.E., M.W. Moncrieff, 2008: Year of Tropical Convection (YOTC) Science Plan,WMO/TD-No. 1452, WCRP -130, WWRP/THORPEX- No 9, 26 pp.**

- **Waliser, D. E., M. Moncrieff, and Co-authors, 2012: The "Year" of Tropical Convection (May 2008 to April 2010): Climate variability and weather highlights. *Bull. Amer. Meteorol.* Soc., August Edition**