Dynamical System Approach to Organized Convection Parameterization for GCMs

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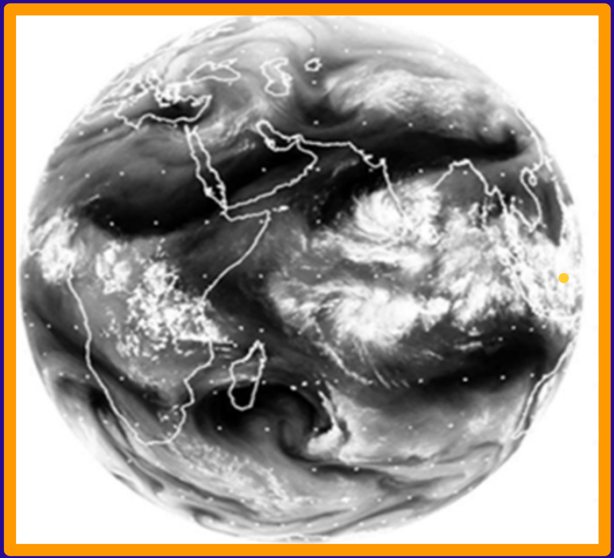
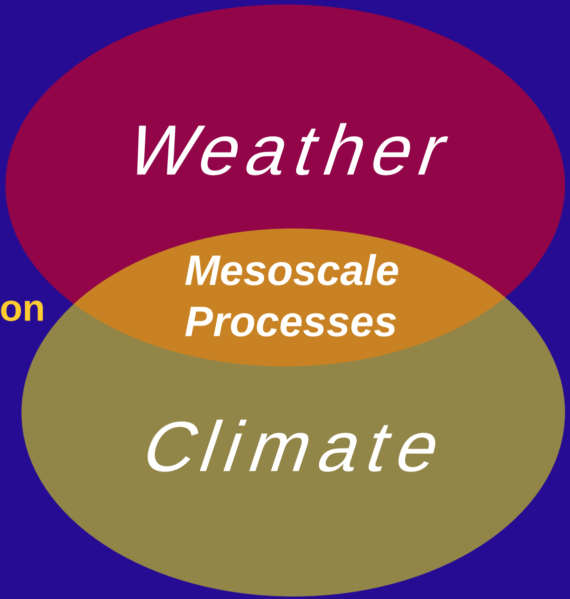


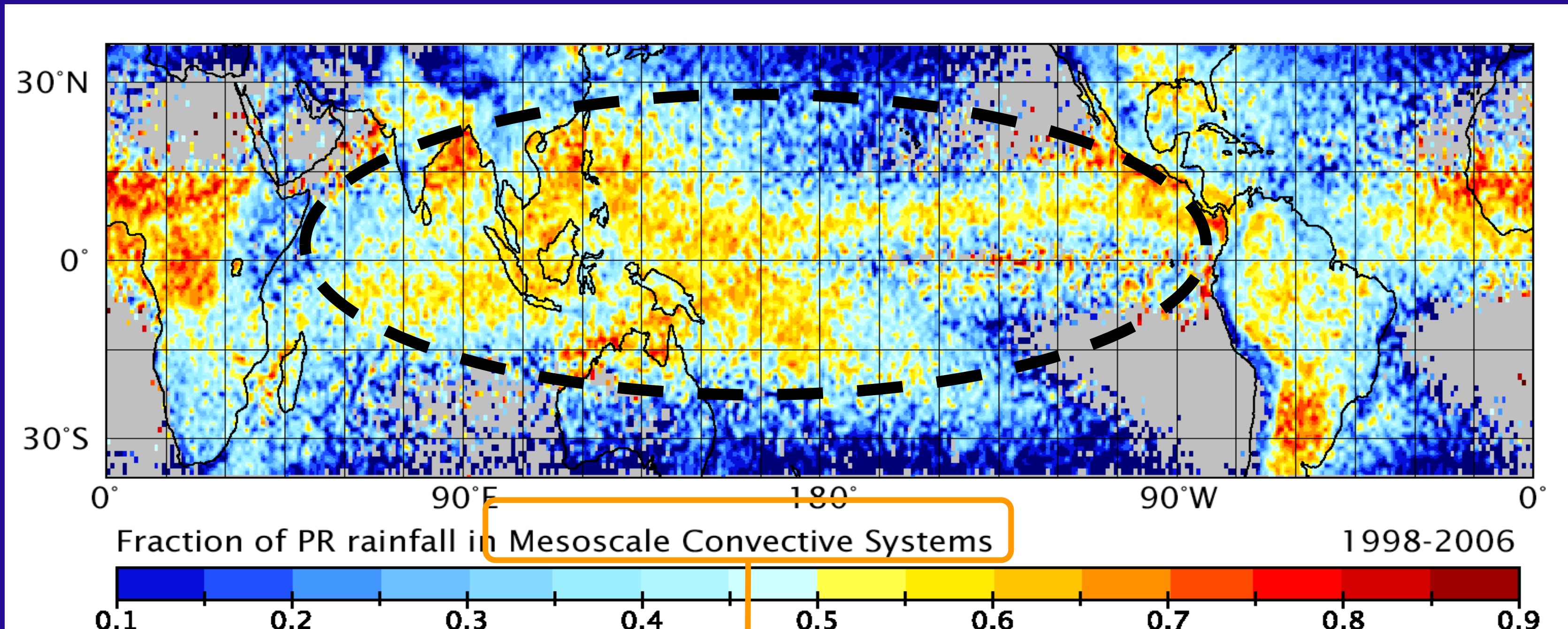
Year of Tropical Convection (YOTC)

Organized Convection & Parameterization



CESM AMWG Meeting, NCAR, 27 February – 1 March, 2017

Fraction of Tropical Rainfall from MCSs
(TRMM Precipitation Radar, PR)



Tao & Moncrieff (2009)

MCSs are missing from GCMs: Neither resolved nor parameterized

Properties of Organized Moist Convection

- Propagating systems affect the type, intensity, and distribution of precipitation; therefore land-ocean-atmosphere interaction; distinctive diabatic heating & momentum transport properties

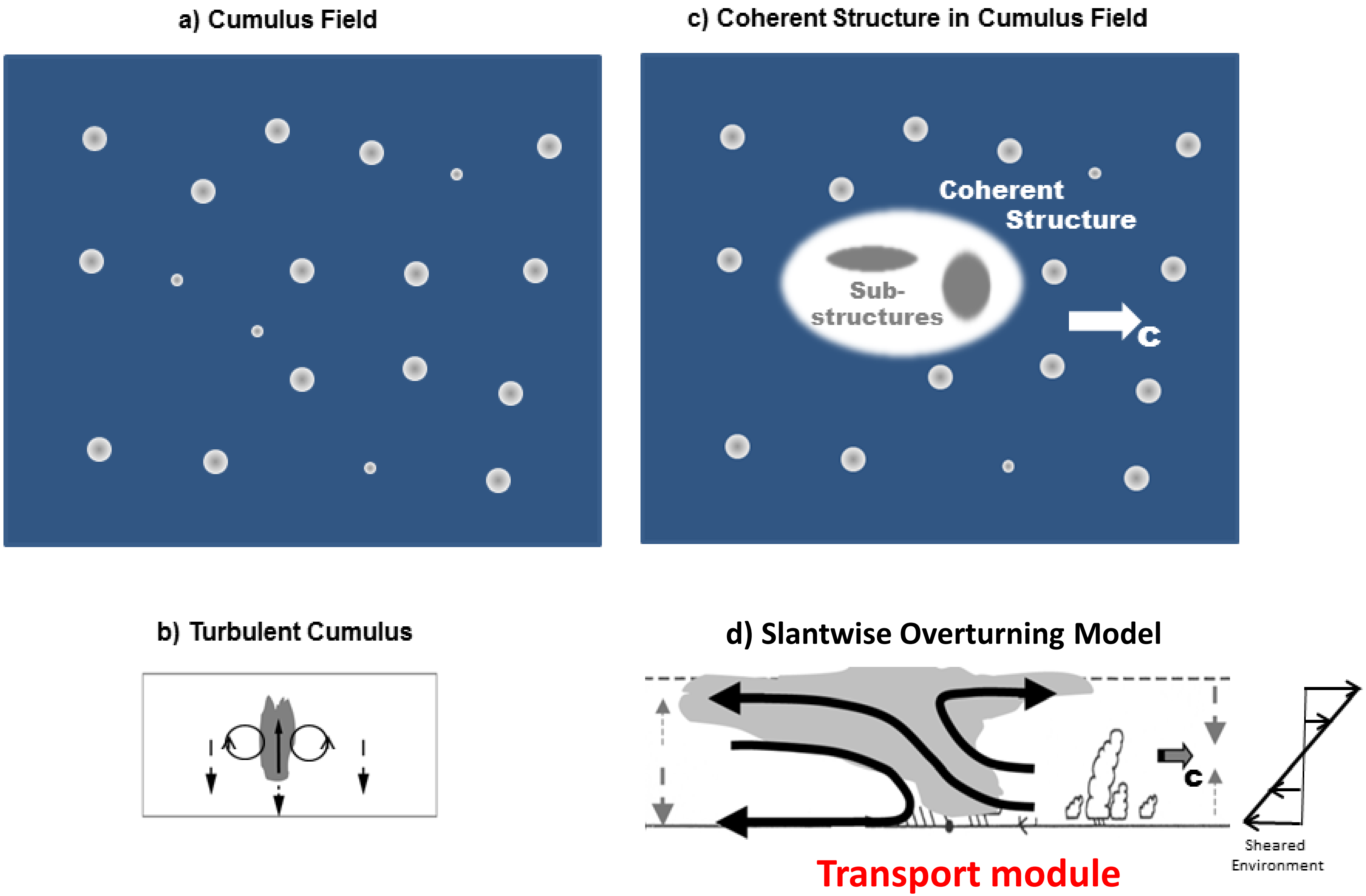
- Organized convection controlled by vertical shear; momentum transport has novel scale-interaction properties

- Advanced understanding of the observational, numerical, and theoretical aspects of organized convection processes but their parameterization has languished

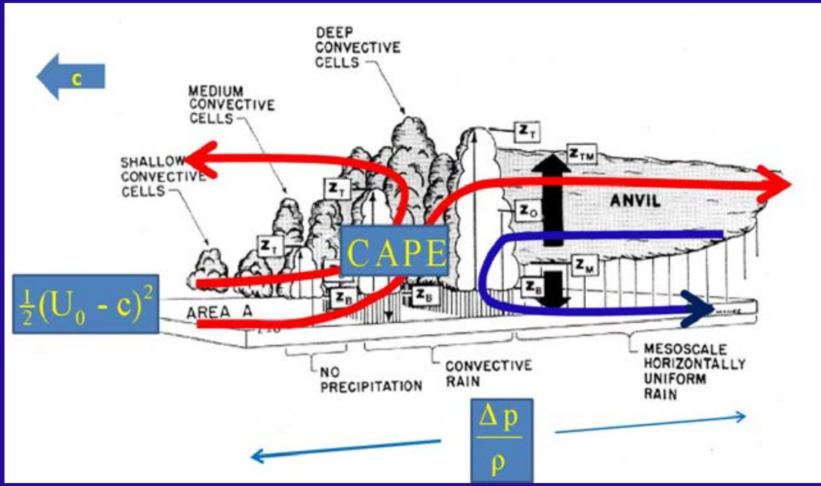
- New paradigm: Dynamical systems approach treating organized convection as coherent structures in a turbulent environment

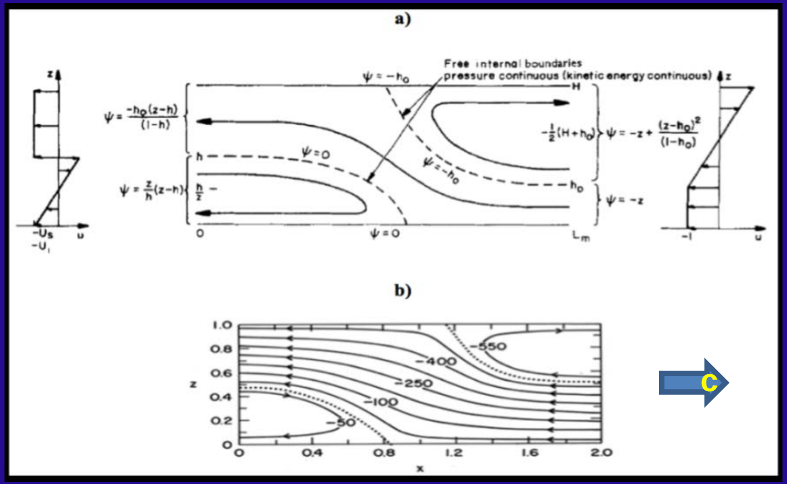
- Minimalist form described here, basically a proof-of-concept

Multiscale Coherent Structure Parameterization (MCSP)



Nonlinear Dynamical Models of Slantwise Overturning in Shear





- Slantwise overturning is a collective effect of cumulonimbus ensembles in shear flow

- <u>Lagrangian Slantwise Overturning Models</u> are steady solutions of the full nonlinear 2D vorticity equation. The sole assumption -- latent heating a separable function of vertical velocity -- holds for squall lines, MCS, superclusters, and convectively coupled waves. This demonstrates key scale-invariant properties

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

F : Buoyancy along trajectories
G: Environmental shear

- Models verified by field-campaign & CRM data

- 3D models are based on other Lagrangian conservation properties

Context

- **MCSP adds missing convective organization to cumulus parameterization**
- **Focus on tropical phenomena and regions (e.g., MJO, ITCZ, SPCZ, Warm-Pool, Maritime Continent) that particularly challenge GCMs**
- **Specifically, summarize parameterization aspects of:**

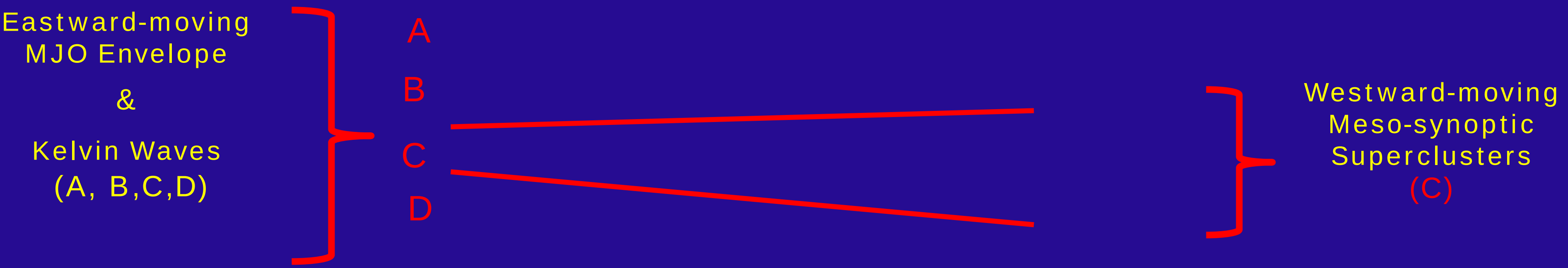
Moncrieff, M.W., C. Liu, and P. Bogenschutz, 2017: Simulation, modeling and dynamically based parameterization of organized tropical convection for GCMs. *J. Atmos. Sci.,* **74***,* in press.

More context:

Moncrieff, M.W., and Coauthors, 2012: Multiscalle convective organization and the YOTC Virtual Global Field Campaign. *Bull. Amer. Meteorol. Soc*., **93**, 1171-1187, doi:10.1175/BAMS-D-11-00233.

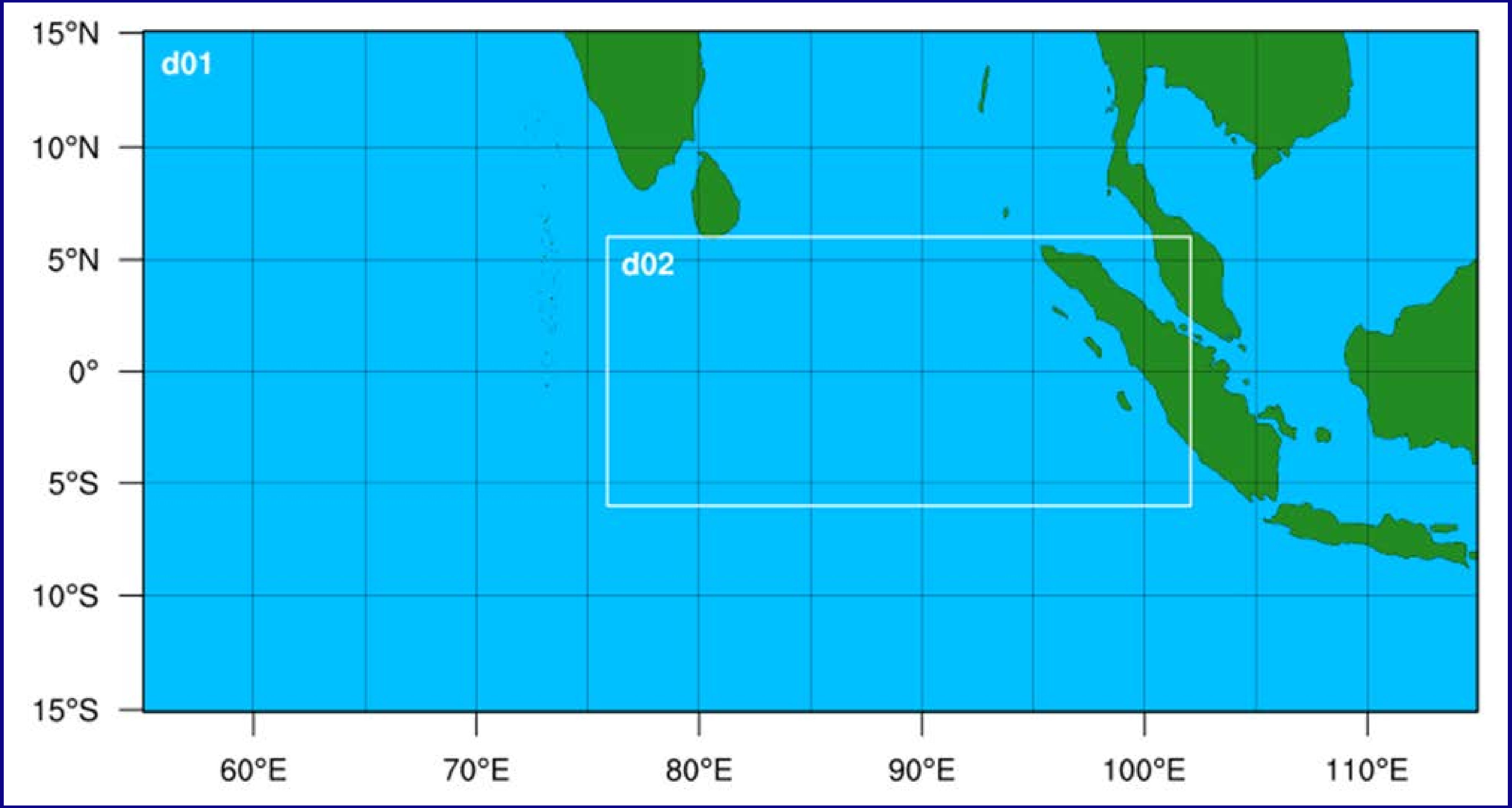
Moncrieff, M.W., and D.E. Waliser, 2015: Organized convection and the YOTC project. *Seamless Prediction of the Earth-System: From Minutes to Months*, (G. Brunet, S. Jones, P.M. Ruti, Eds.), WMO-No. 1156, ISBN 978-92-63-11156-2, Geneva.

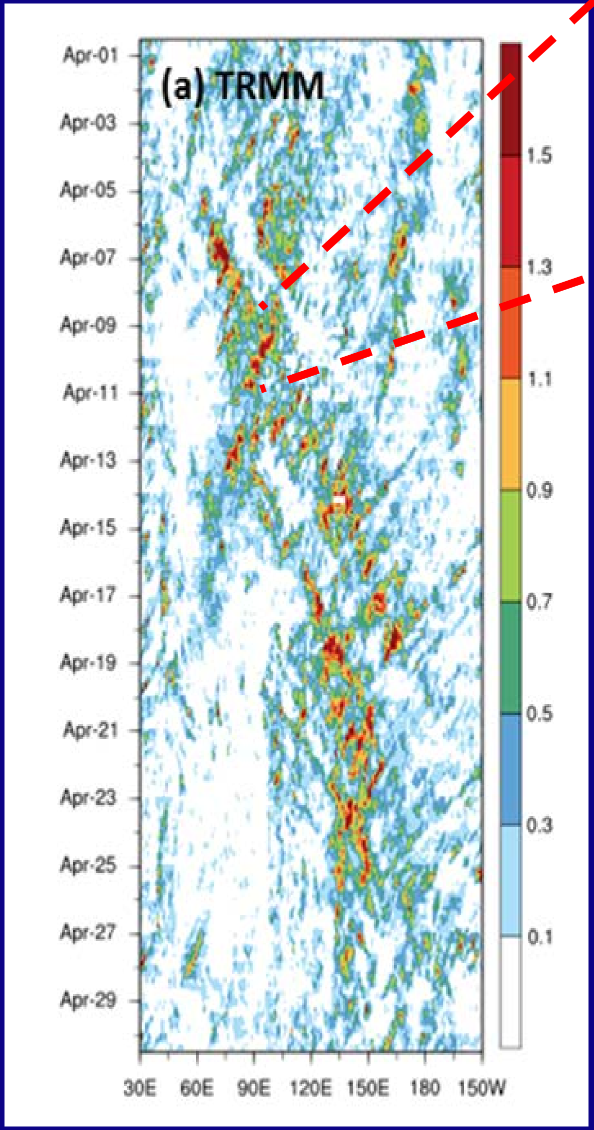
Westward-moving Meso-synoptic Superclusters are embedded in Eastward-moving MJO & Kelvin waves



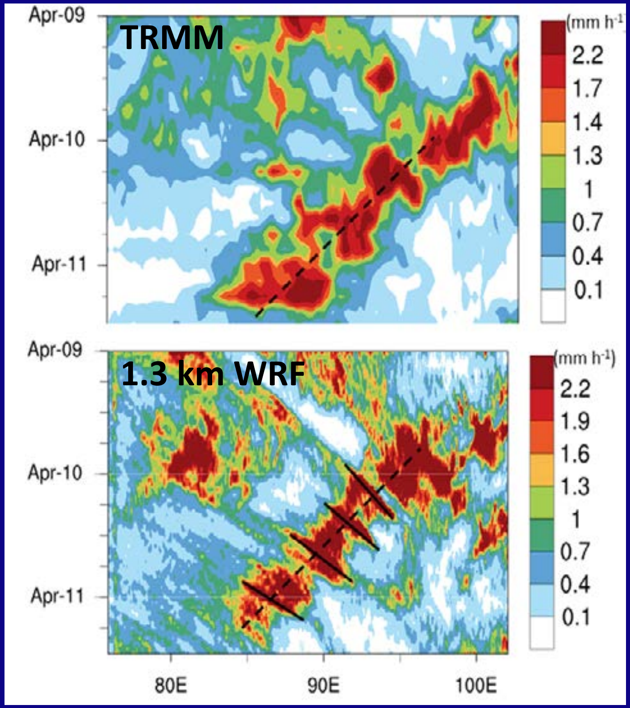
Nakazawa (1988)

WRF Nested Computational Domains
(d01 - 4 km grid; d02 - 1.3 km grid)
YOTC global analysis for lateral boundary conditions



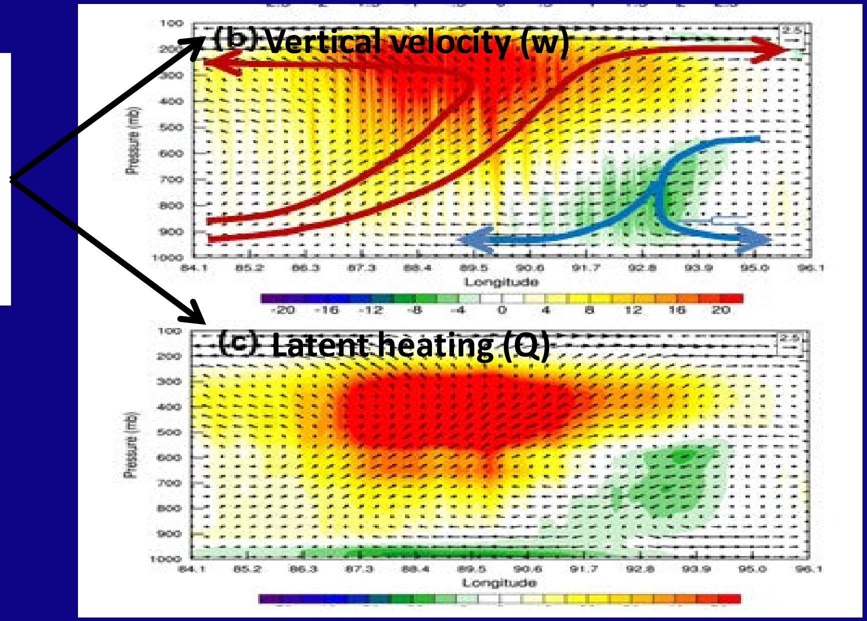


April 2010 MJO

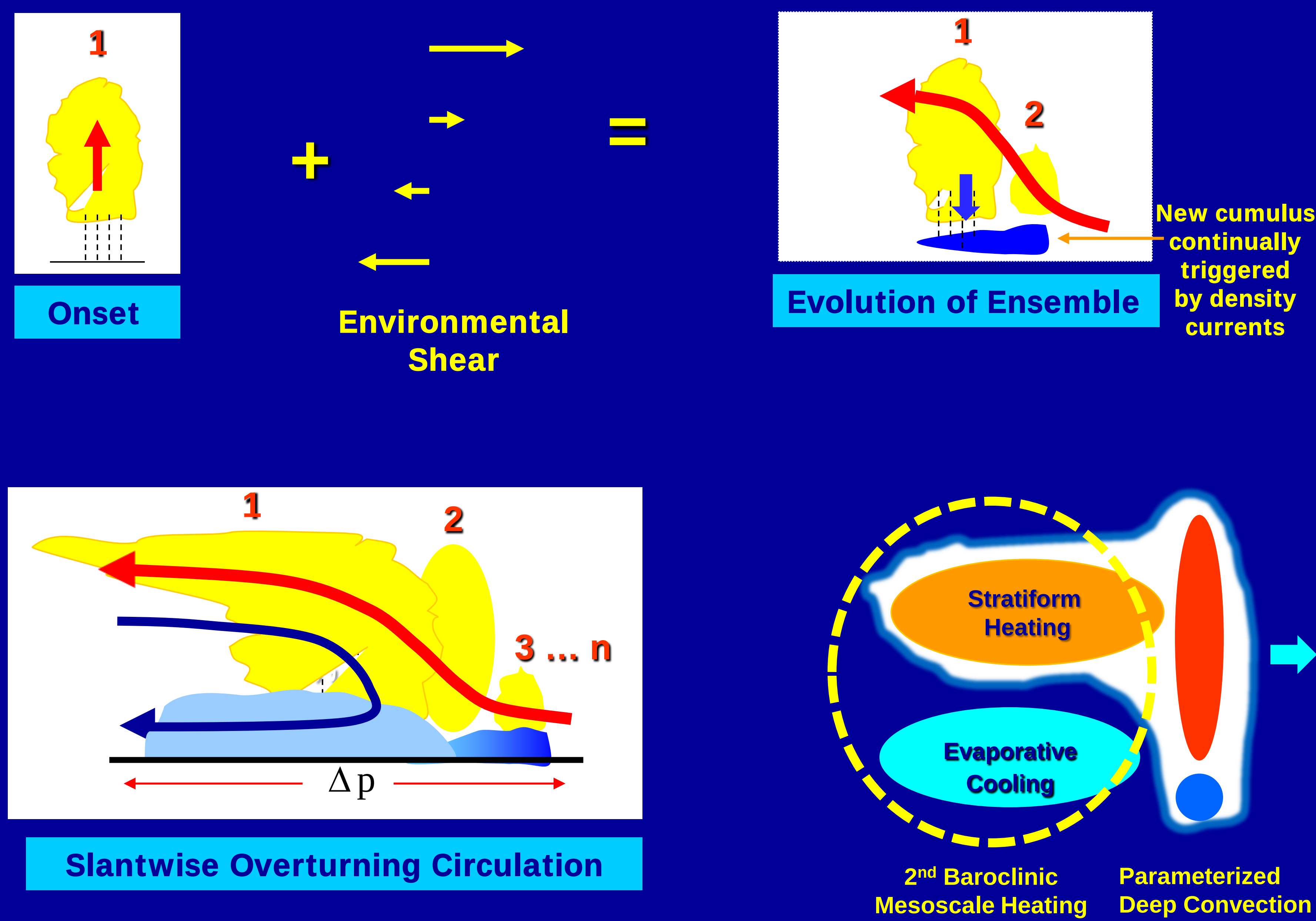


Note: Separable relationship

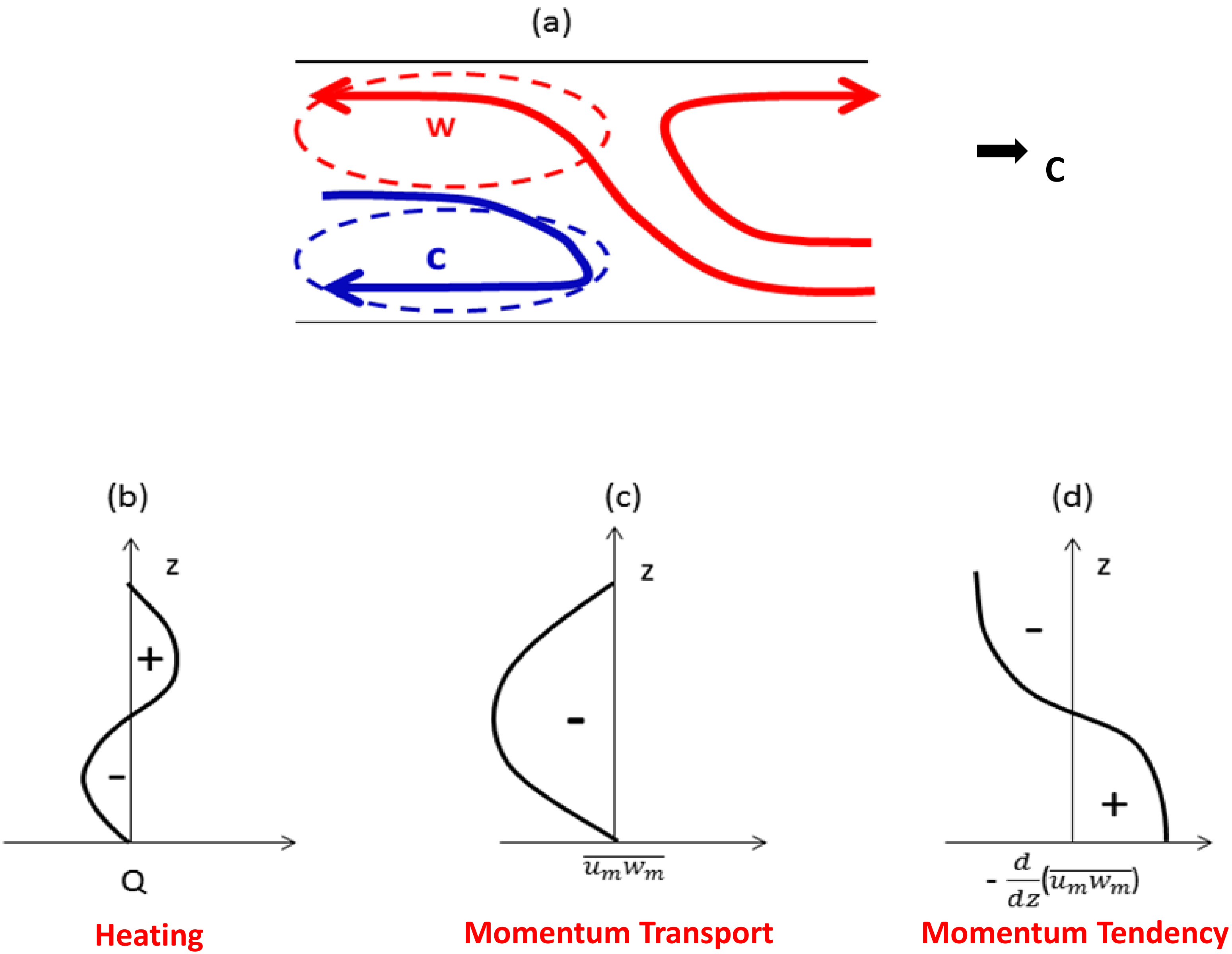
$$Q \propto w$$



Upscale Evolution of Cumulus Ensemble to MCS



2^{nd} Baroclinic Heat & Momentum Tendencies



CAM 5.5 MCSP Experiments

- Seek simplest possible (minimalist) formulation/explanation
- Does heat and momentum transport by slantwise overturning generate large-scale precipitation patterns seen in TRMM?
- 2nd baroclinic tendencies:
  - i) Top-heavy convective heating
  - ii) Counter-gradient momentum transport
- Analyze years 2-8 of 10-year CAM 5.5 simulations

Convective Heating Formulation

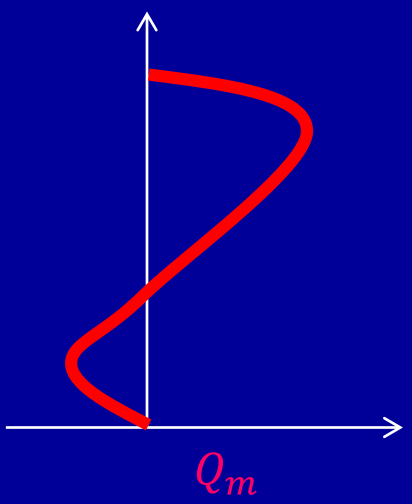
Vertical average of deep convection heating rate

$$Q_m\,(p,t) = \alpha_0 Q_c\,(t)\left[\alpha_1 \sin \pi\, \alpha \left(\frac{p_s - p}{p_s - p_t}\right) - \alpha_2 \sin 2\pi \left(\frac{p_s - p}{p_s - p_t}\right)\right]$$

Deep Heating (1st Baroclinic)

'Top heavy' Heating (2nd Baroclinic)

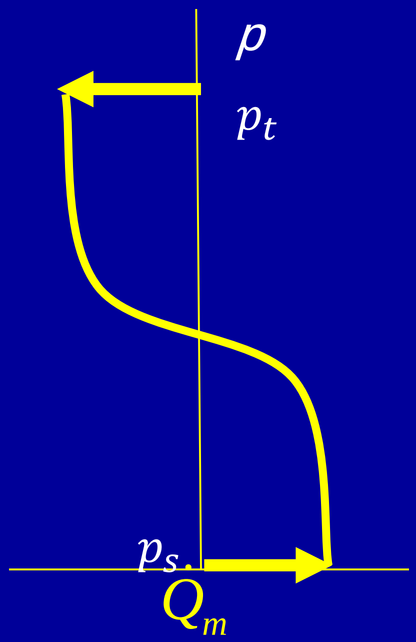
Minimalist formulation: 2nd Baroclinic Tendency ($\alpha_0 = 1$; $\alpha_1 = 0$)



$$\dot{Q}_{total} = \dot{Q}_c + \dot{Q}_m$$

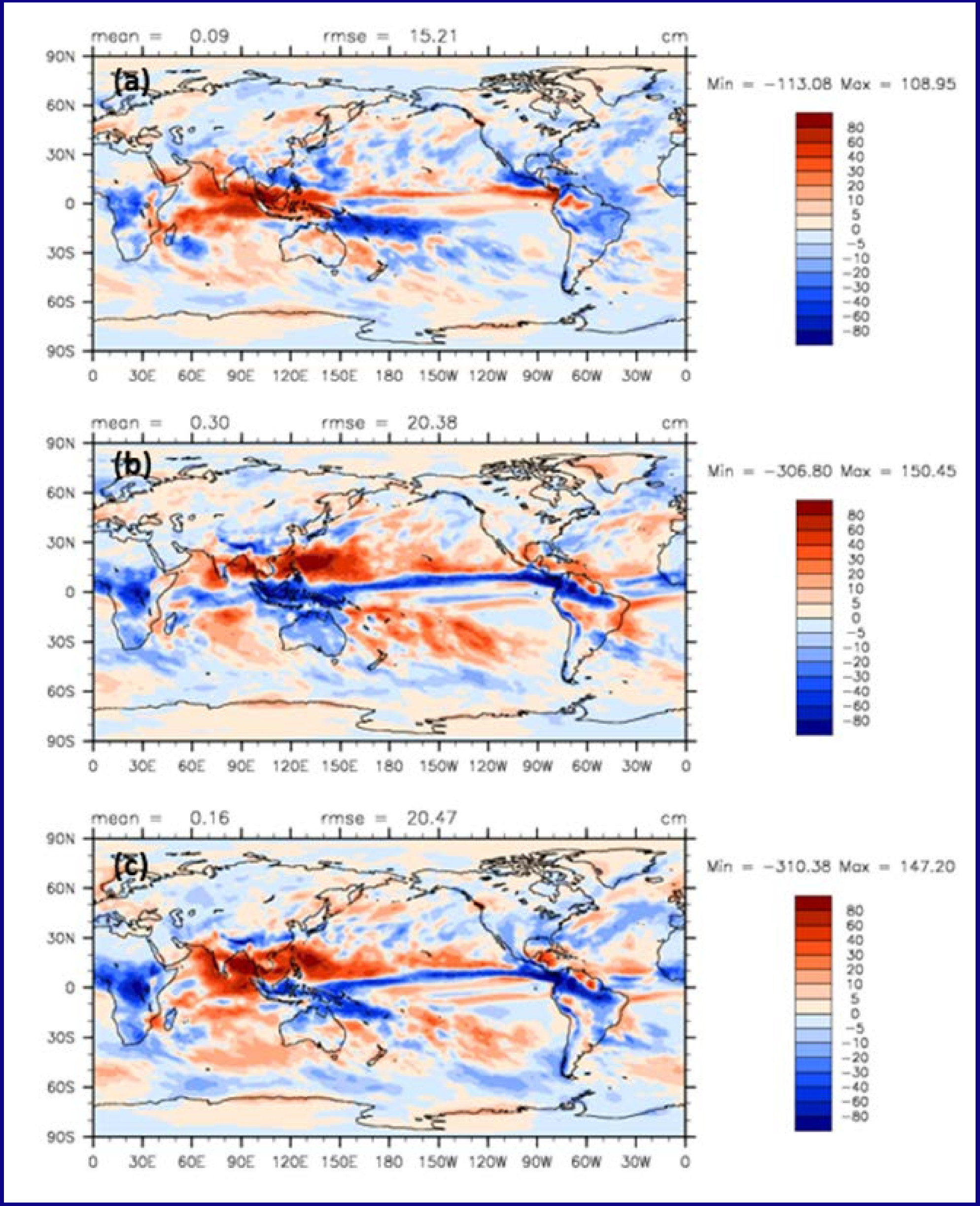
Momentum Transport Formulation

$$Q_m(\mathrm{p,t}) = \alpha_3 \cos \pi\left(\frac{p_s - p}{p_s - p_t}\right)$$



Propagation

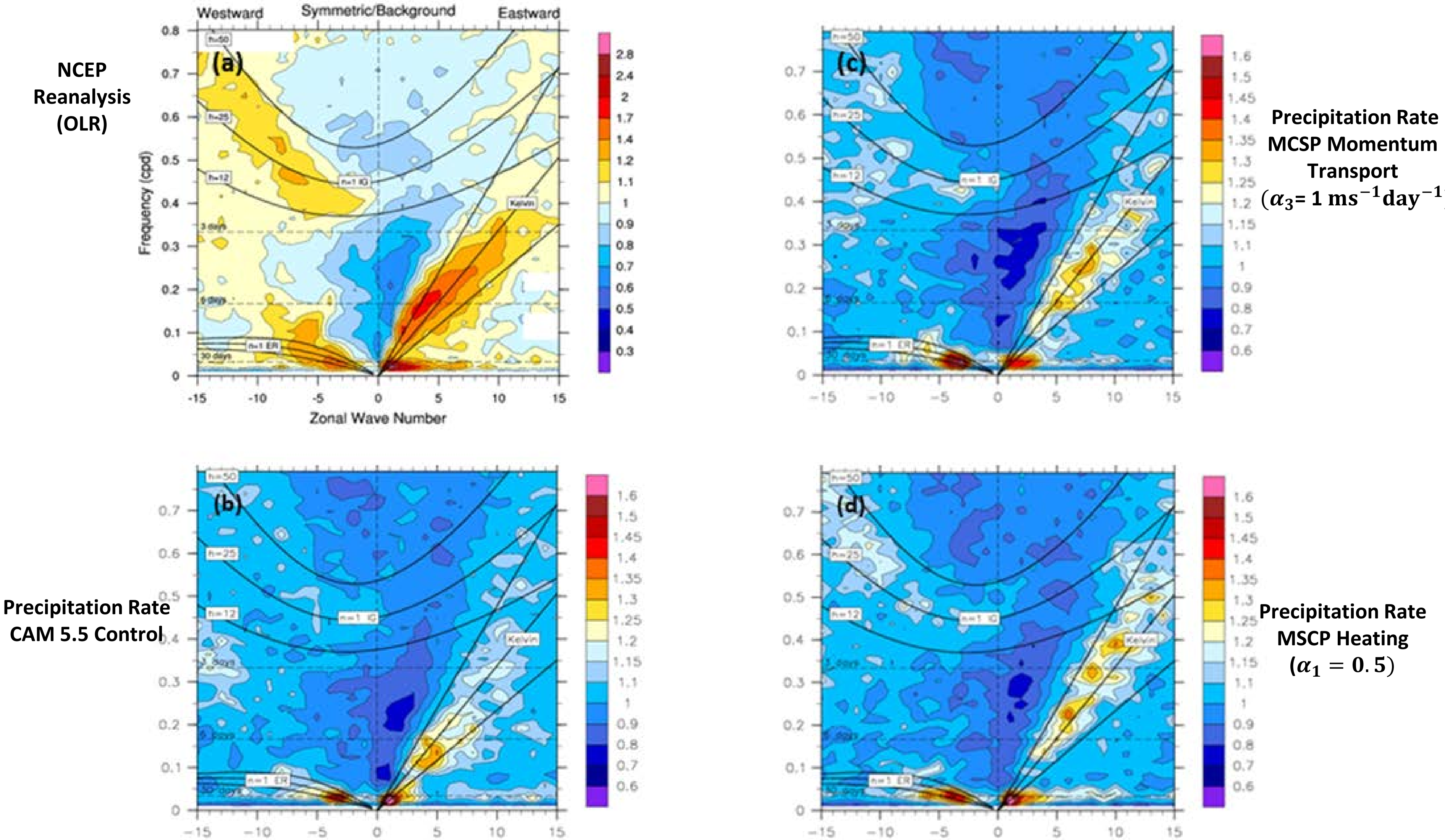
CAM 5.5 Global Precipitation



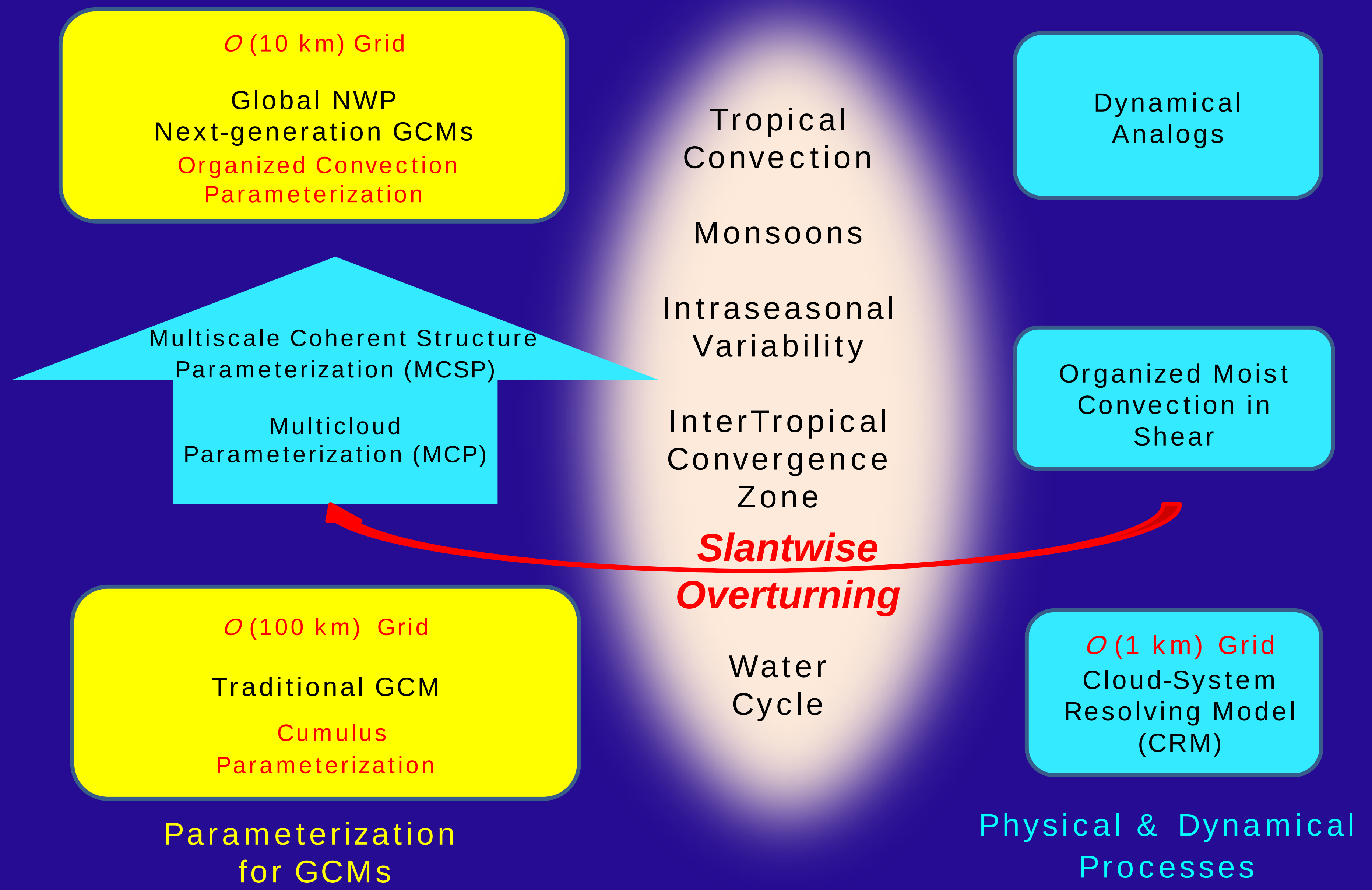
MCSP – CAM 5.5 Control
Momentum (α_3 = 1 $\mathrm{ms^{-1}day^{-1}}$)

MCSP – CAM 5.5 Control
Heating (α_2 = 0.5)

MCSP – CAM 5.5 Control
Heating & Momentum
(α_2= 0.5; α_3= 1 $\mathrm{ms^{-1}day^{-1}}$)


NCEP Reanalysis (OLR)
Westward
Symmetric/Background
Eastward
(a)
Frequency (cpd)
Zonal Wave Number
Kelvin
n=1 IG
n=1 ER
h=50
h=25
h=12
3 days
6 days
30 days
(c)
Precipitation Rate MCSP Momentum Transport
(α_3= 1 $\mathrm{ms^{-1}day^{-1}}$)
(b)
Precipitation Rate CAM 5.5 Control
(d)
Precipitation Rate MSCP Heating
($\alpha_1 = 0.5$)

Dynamical-System Approaches: MCSP & MCP



Conclusions

- MCSP (in minimalist form)
  - Upscale effects on ITCZ, SPCZ, warm-pool, equatorial Africa, Maritime Continent qualitatively agree with TRMM measurements
  - Quantifies large-scale effects of convective organization
  - Distinguishes between heating and momentum transport effects
  - Salient to role of moist mesoscale processes in regard to, for example: i) Next -generation GCMs; ii) Subseasonal-to-Seasonal prediction (S2S); iii) Year of the Maritime Continent (YMC)

- Examples of next steps in MCSP development
  - Observation-based α-parameters
  - Add shear-selection mechanisms
  - Add propagation direction to momentum parameterization
  - Apply in aquaplanet simulations
  - Compare with Khouider & Majda MCP that <u>replaces</u> cumulus parameterization
  - Compare with superparameterization

- Small computational overhead makes MCSP feasible for long integrations

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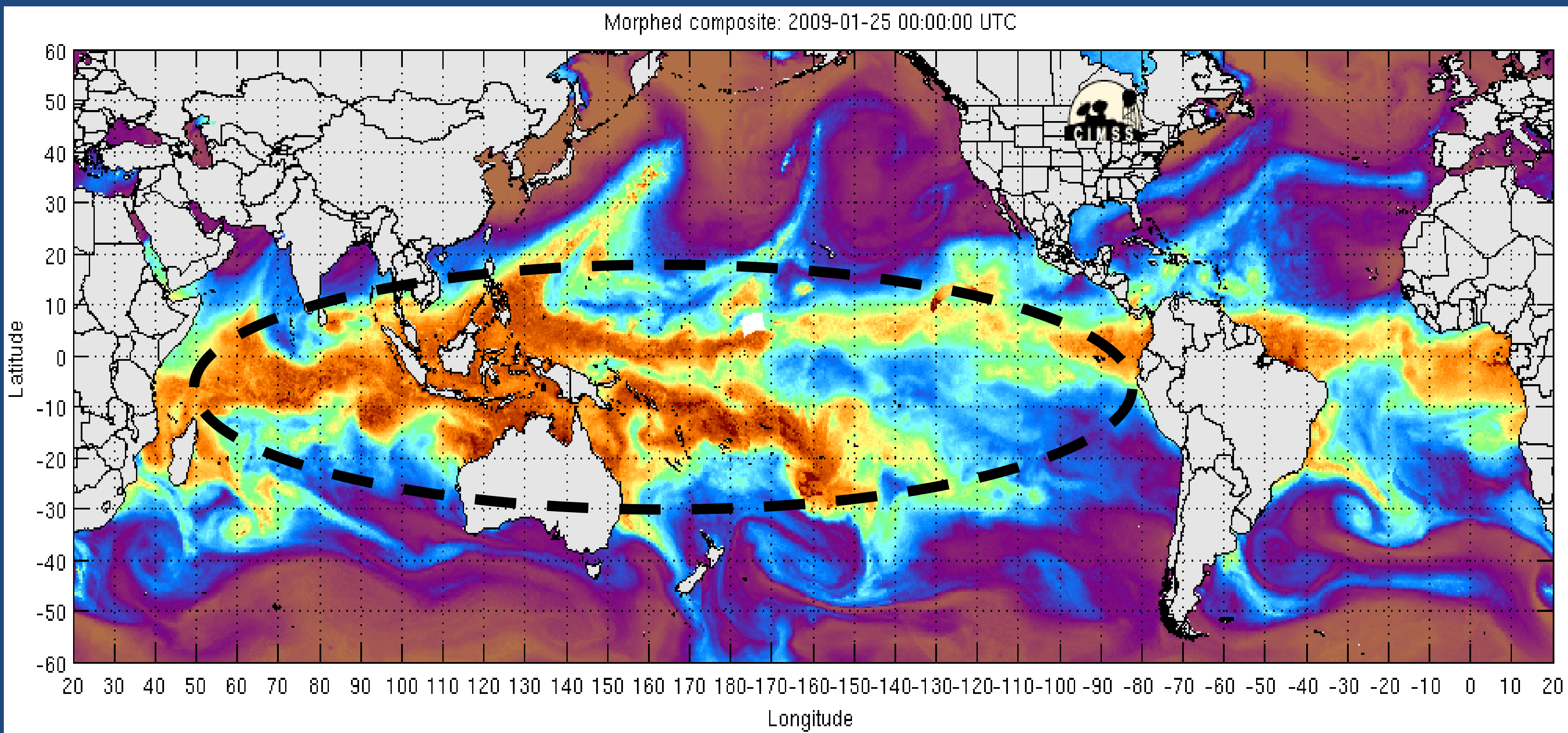
Total Water: SSMI & AMSRE



Courtesy: Tony Wimmer & Chris Velden, CIMSS,
University of Wisconsin at Madison

Complex Convection-Wave Interaction for the April 2010 MJO during YOTC