Organized Convection Parameterization for GCMs

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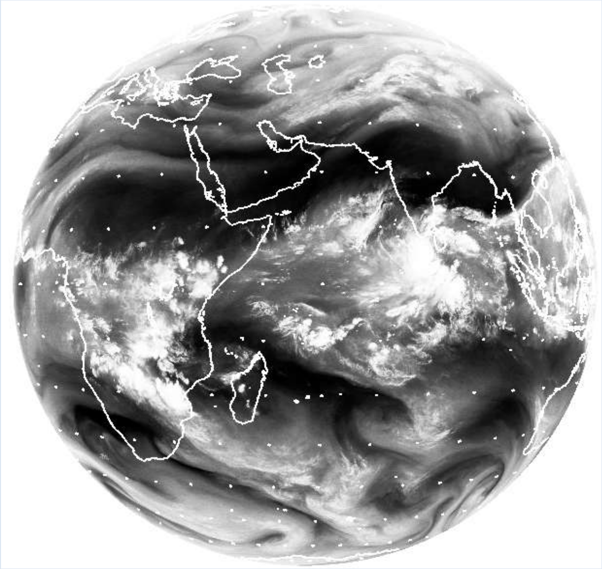
Organized Moist Convection:

Multiscale Coherent Dynamical Structures Embedded in a Turbulent Environment



Organized Moist Convection in GCM context

- **“Dreary state” of precipitation distribution, character, intensity in GCMs: Vexing long-standing deficiencies can arguably be alleviated by organized moist convection parameterization**

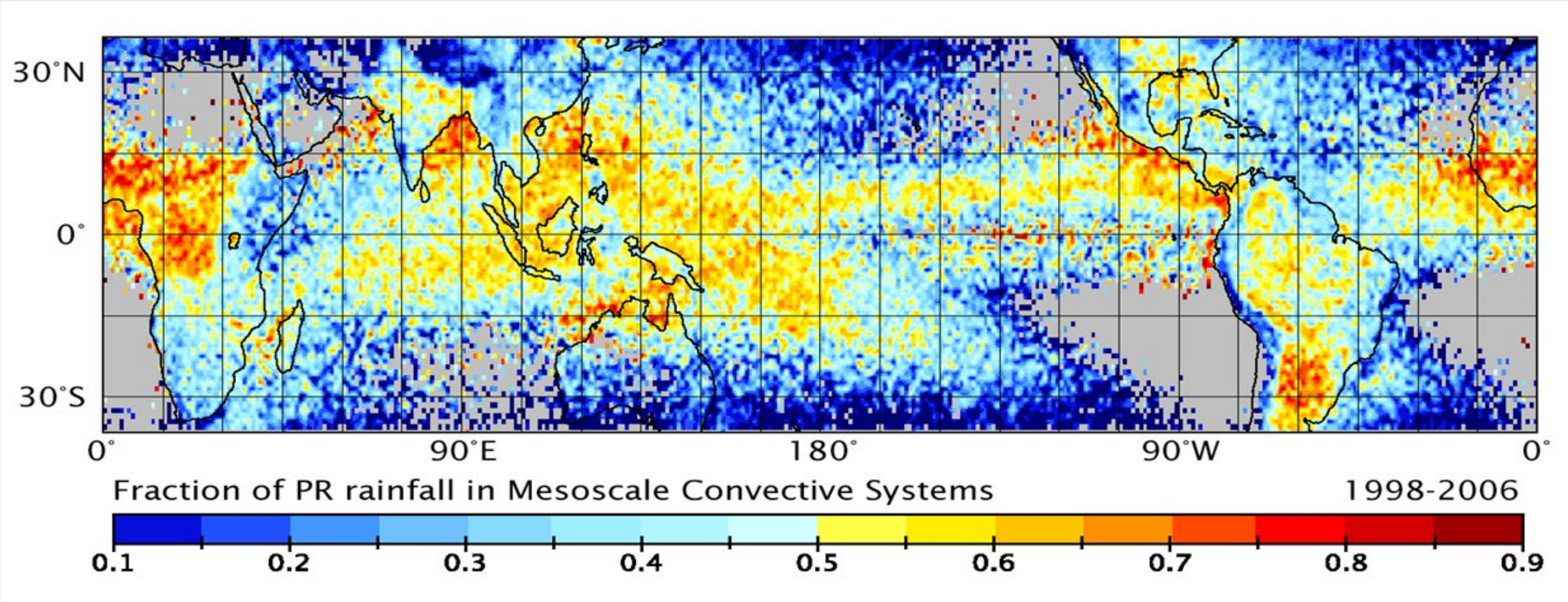
- **Non-dissipative character of organized scale-interaction: Upscale evolution, top-heavy convective heating, counter-gradient convective momentum transport; functional dependence on the regime of organization; relationship to convectively generated gravity waves**

- **Excellent sets of field-campaign & satellite data on scales ranging from mesoscale to global**

- **Global weather models with advanced data-assimilation systems provide “virtual global field experiments” (YOTC): Now sub-10km-scale**

- **Development Imperative for GCMs: Parameterization of mesoscale physical & dynamical processes aided by explicit simulations & obs**

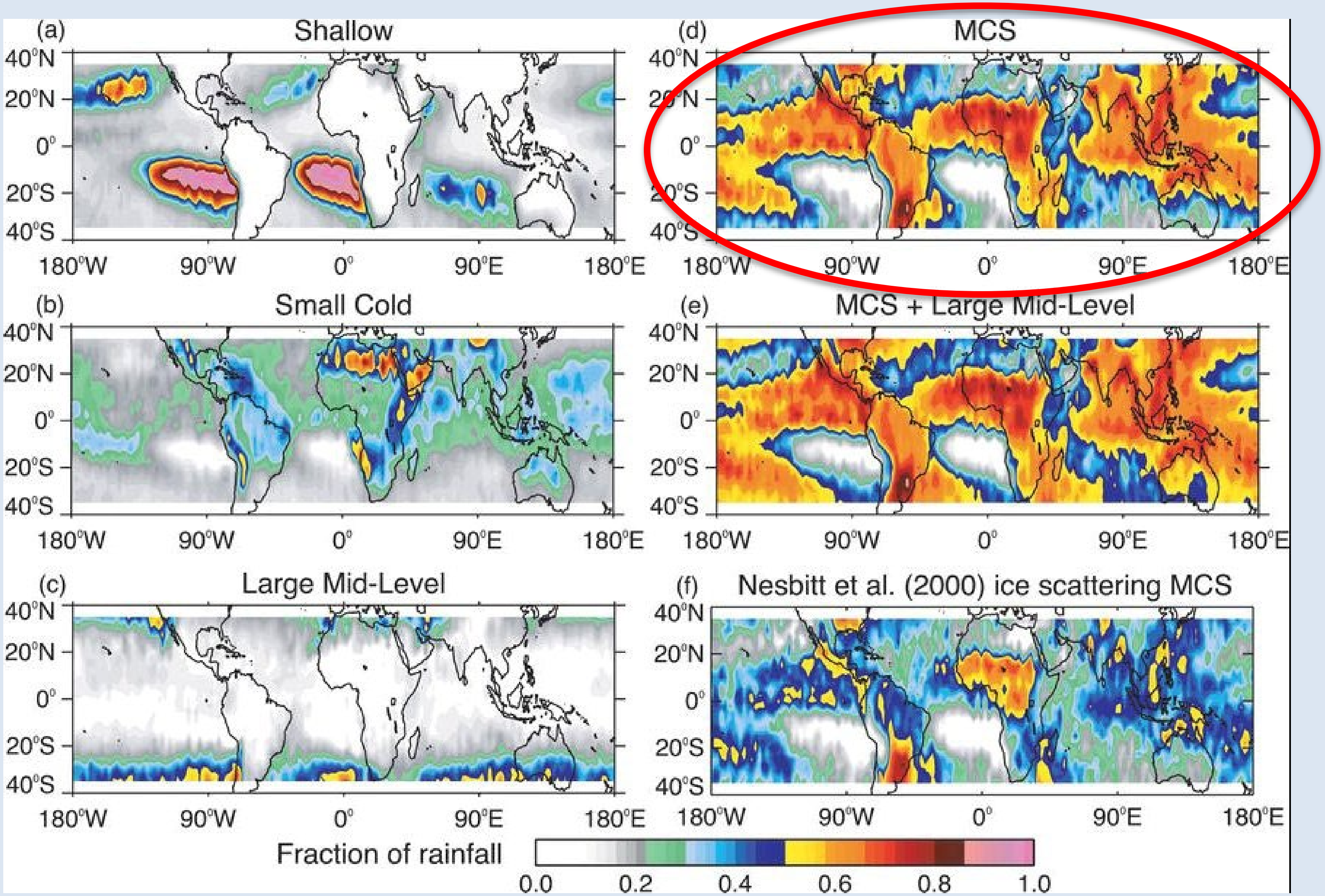
50-70% of Tropical Precipitation from MCSs



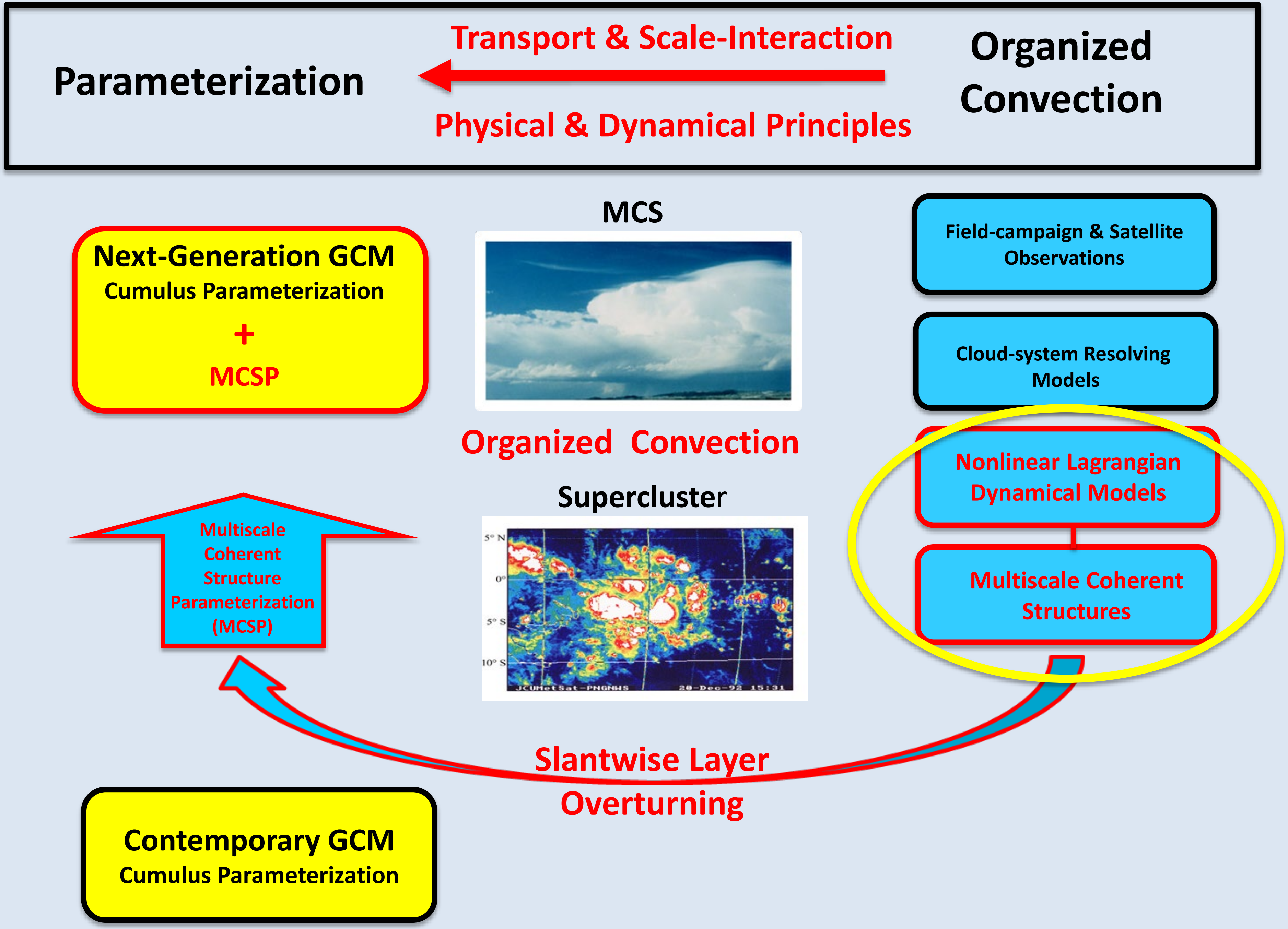
Tao & Moncrieff (2009)

- **TRMM Satellite Data: MCSs embedded in phenomena that challenge GCMs, e.g. MJO, CCEWs, ITCZ, monsoons**
- **Motivation for organized convection parameterization**

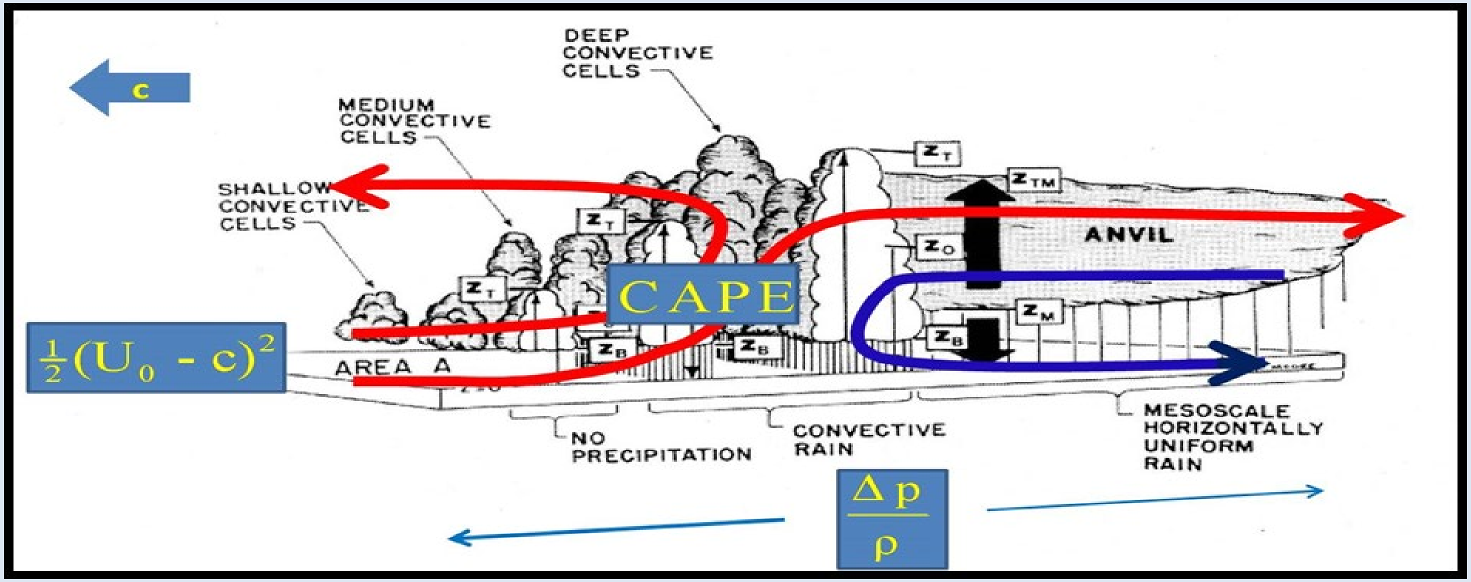
Storm Morphology & Rainfall Characteristics of TRMM Precipitation Features



Nesbitt et al. (2006)



Parameterization
Transport & Scale-Interaction
Physical & Dynamical Principles
Organized Convection
Next-Generation GCM
Cumulus Parameterization
+
MCSP
MCS
Organized Convection
Supercluster
5° N
0°
5° S
10° S
JCUMetSat-PNGNWS
20-Dec-92 15:31
Field-campaign & Satellite Observations
Cloud-system Resolving Models
Nonlinear Lagrangian Dynamical Models
Multiscale Coherent Structures
Multiscale Coherent Structure Parameterization (MCSP)
Slantwise Layer Overturning
Contemporary GCM
Cumulus Parameterization



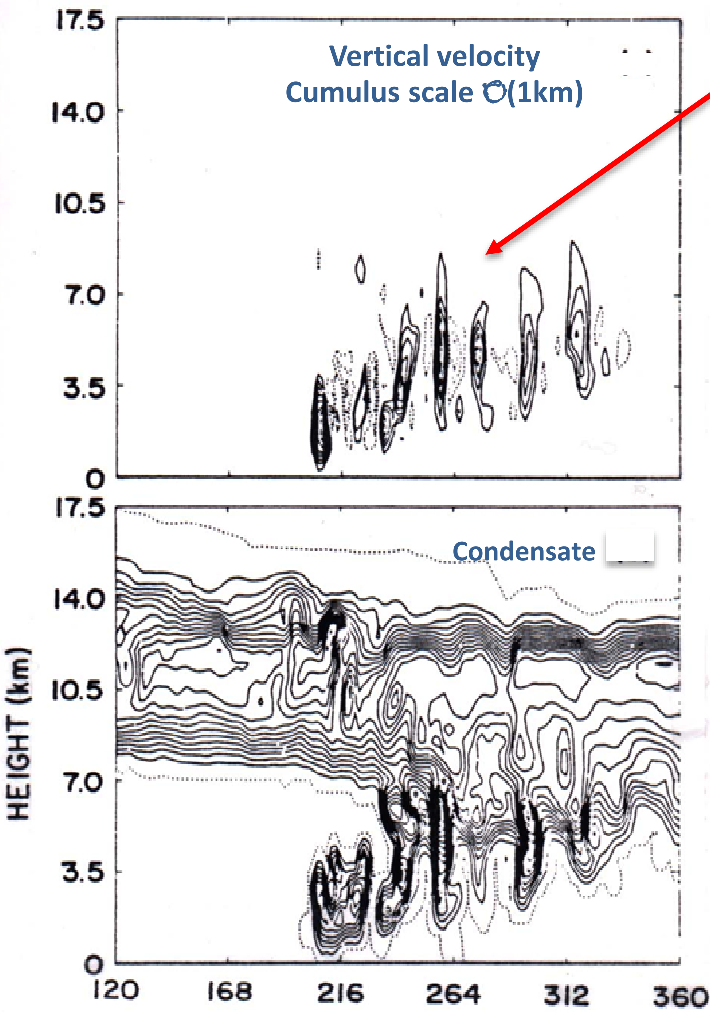
- **Slantwise layer overturning exchanges entire tropospheric layers, distinguishes organized transport from local cumulus mixing**

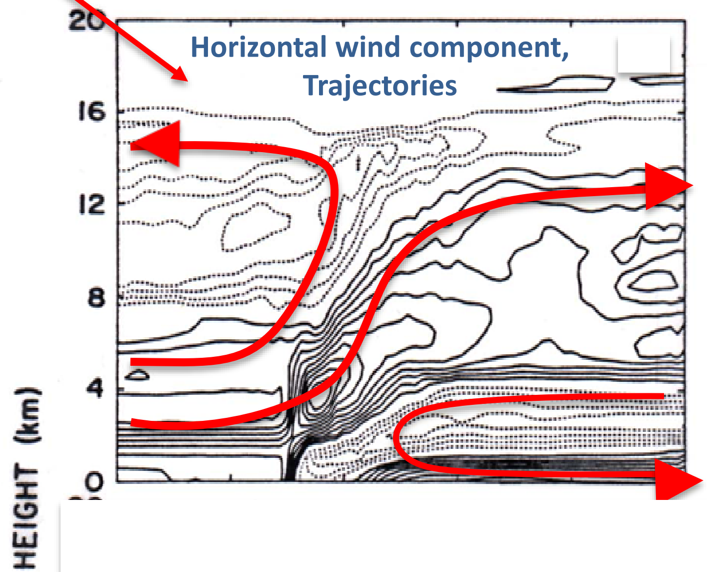
- **Vertical shear and mesoscale pressure gradient provide dynamical sources of energy in addition to thermodynamic convective available potential energy (CAPE):**

Available kinetic energy AKE = $\frac{1}{2}(U_0 - c)^2$

Pressure-gradient work PGW = $\Delta p/\rho$

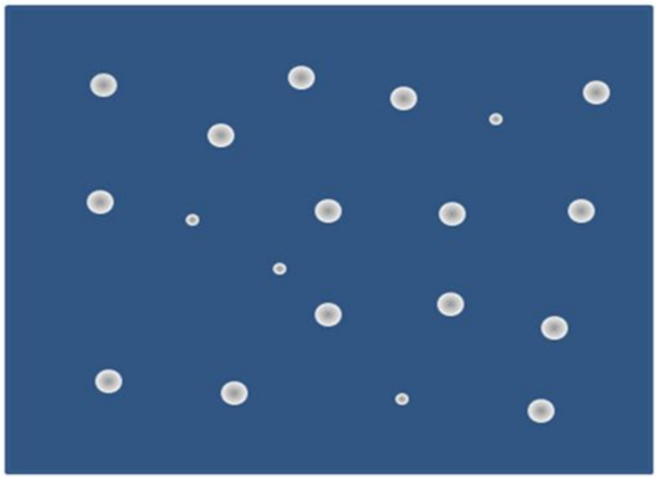
Mesoscale slantwise layer overturning: Driven by pressure gradients generated by cumulus ensembles in shear-flow



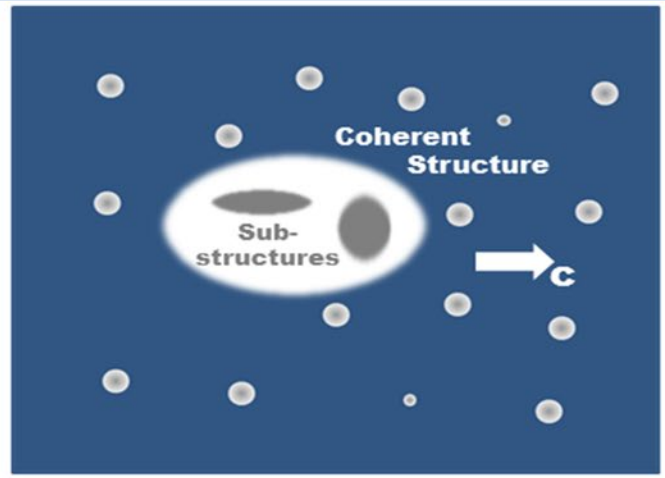


Multiscale Coherent Structure Parameterization (MCSP)

Cumulus Parameterization



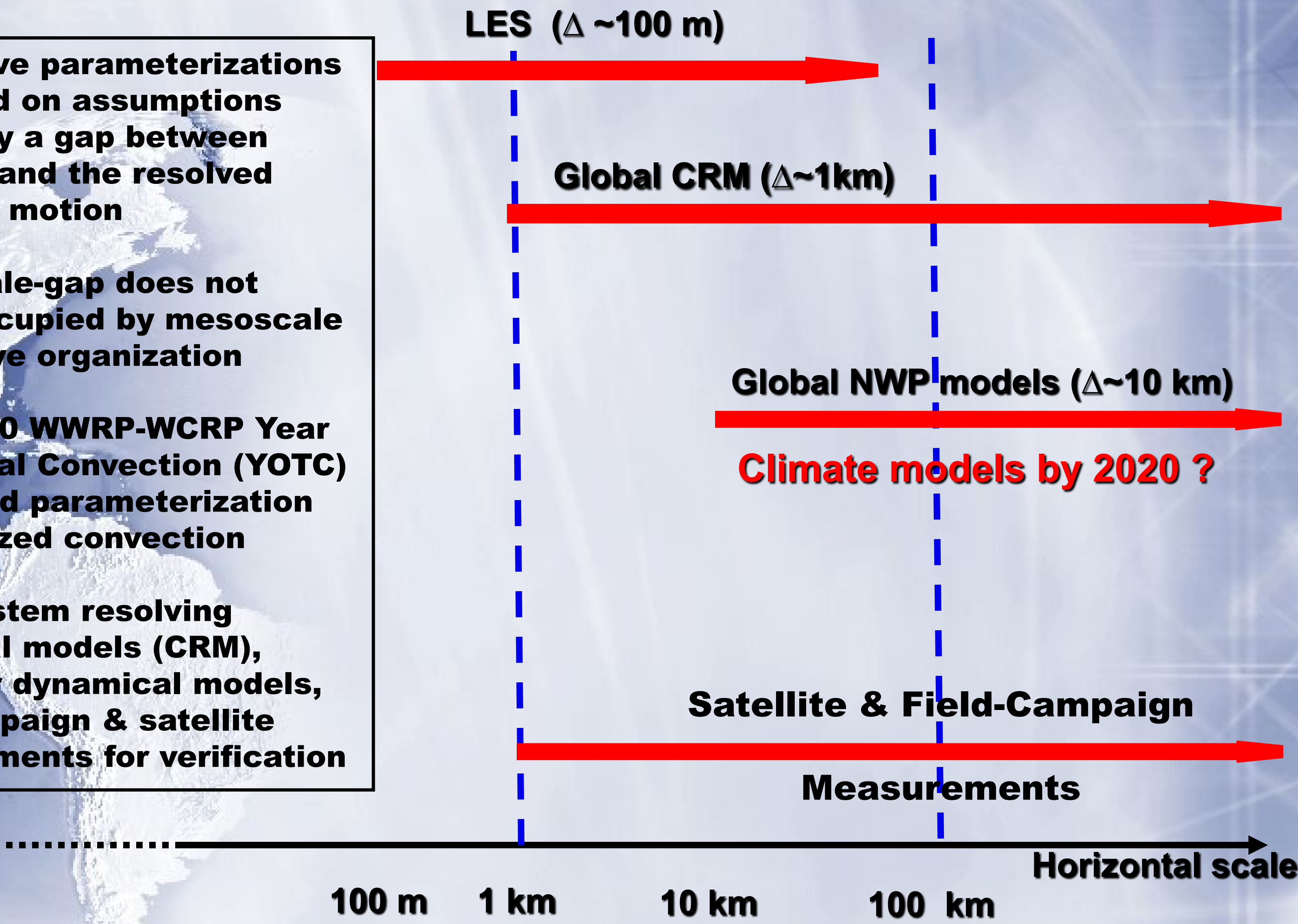
MCSP



Entraining Plume

Slantwise Layer Overturning

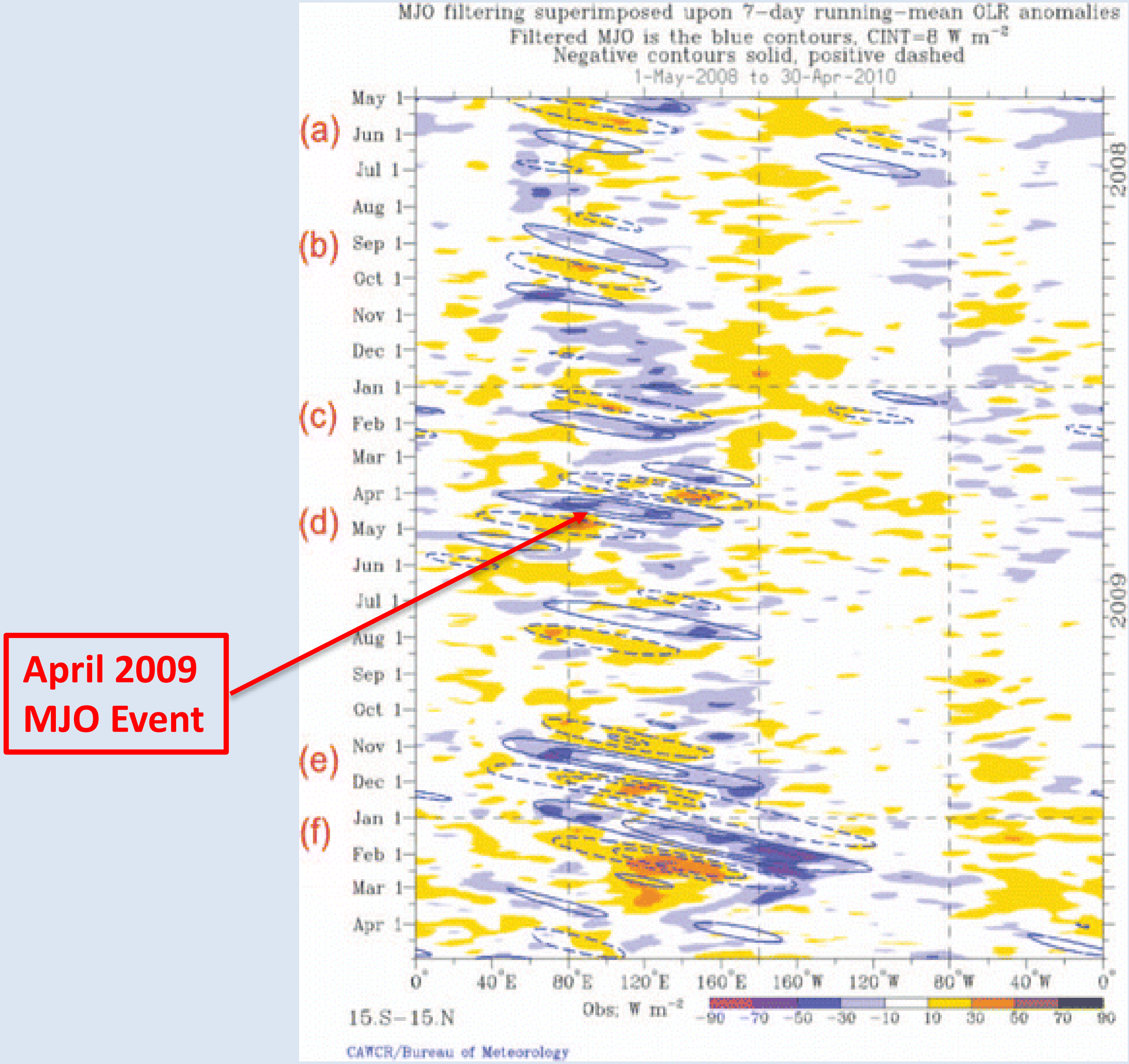
- Convective parameterizations are based on assumptions that imply a gap between cumulus and the resolved scales of motion
- But a scale-gap does not exist: Occupied by mesoscale convective organization
- 2008-2010 WWRP-WCRP Year of Tropical Convection (YOTC) addressed parameterization of organized convection
- Cloud-system resolving numerical models (CRM), nonlinear dynamical models, field-campaign & satellite measurements for verification



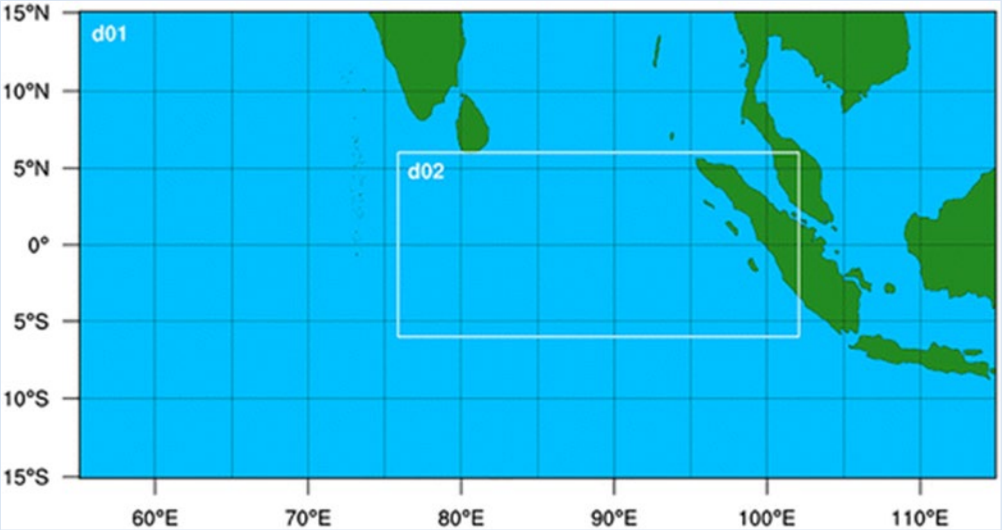
Bridging the Scale Gap

Courtesy: 2010 WCRP-WWRP Scientific, International & Interagency Meeting

MJOs during YOTC Virtual Global Field Campaign (5/1/2008 – 4/30/2010), averaged 10S-10N



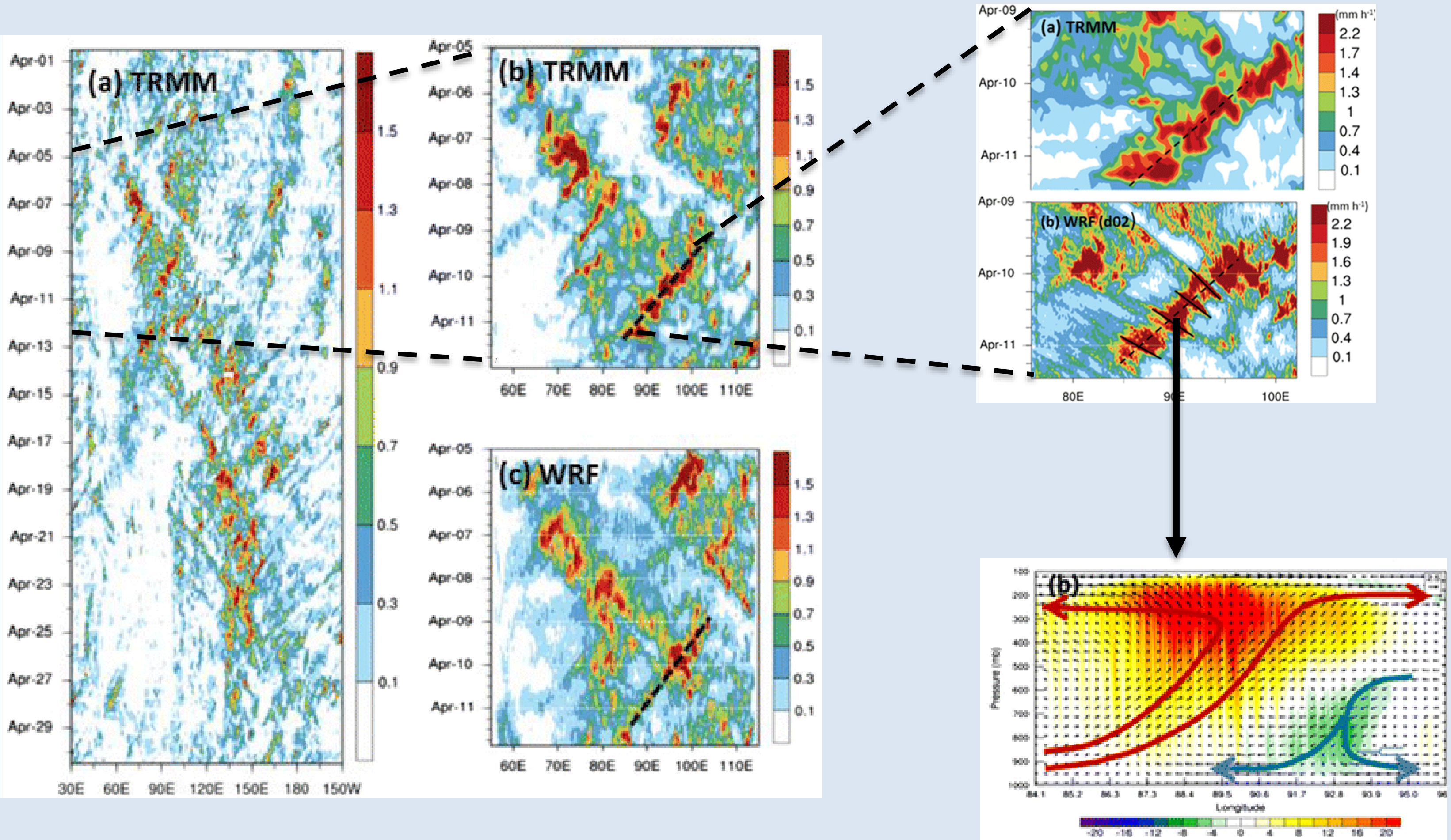
WRF Simulation of April 2009 YOTC MJO



- **65 levels**
- **4km grid (D1)**
- **1.3 km grid (D2)**
- **Thompson microphysics**
- **YSU planetary boundary layer**
- **RRTMG radiation s**
- **Noah-MP land surface**
- **ERAI initial & lateral boundary conditions**

Moncrieff, Liu and Bogenschutz (2017)

Slantwise Layer Overturning: Structure of organized moist convection in a westward-moving 2-day wave embedded in a Kelvin-wave and, in turn, the April 2009 MJO during YOTC



Moncrieff, Liu and Bogenschutz (2017)

MCSP: Add the Missing Mesoscale Tendencies

$$\left[\frac{\delta}{\delta t}\right]_{total} = \left[\frac{\delta}{\delta t}\right]_{cumulus} + \left[\frac{\delta}{\delta t}\right]_{mesoscale}$$

Total Grid-scale Tendency

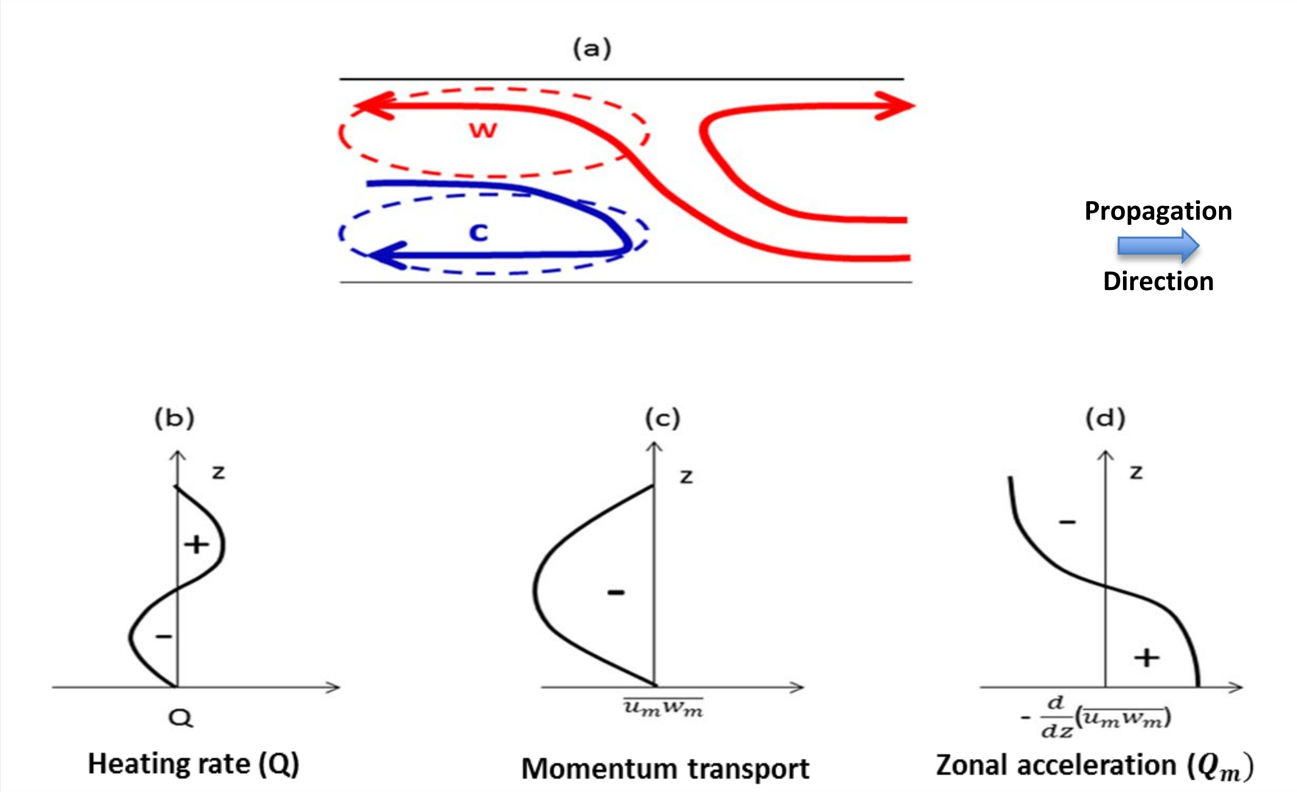
Sub-grid-scale Parameterization

Sur-grid-scale MCSP

- **Effects of organized convection unambiguously quantified as differences between GCM runs with & without MCSP**

- **Prototype MCSP implemented in CAM 5.5 with minimal computational overhead (Moncrieff, Liu & Bogenschutz 2017)**

Proof-of-Concept: Use Simplified Heat & Momentum Tendencies



$$Q(p,t) = -\alpha_1 Q_c(t)\,\sin 2\pi\left(\frac{p_s - p}{p_s - p_t}\right)$$

2nd baroclinic

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

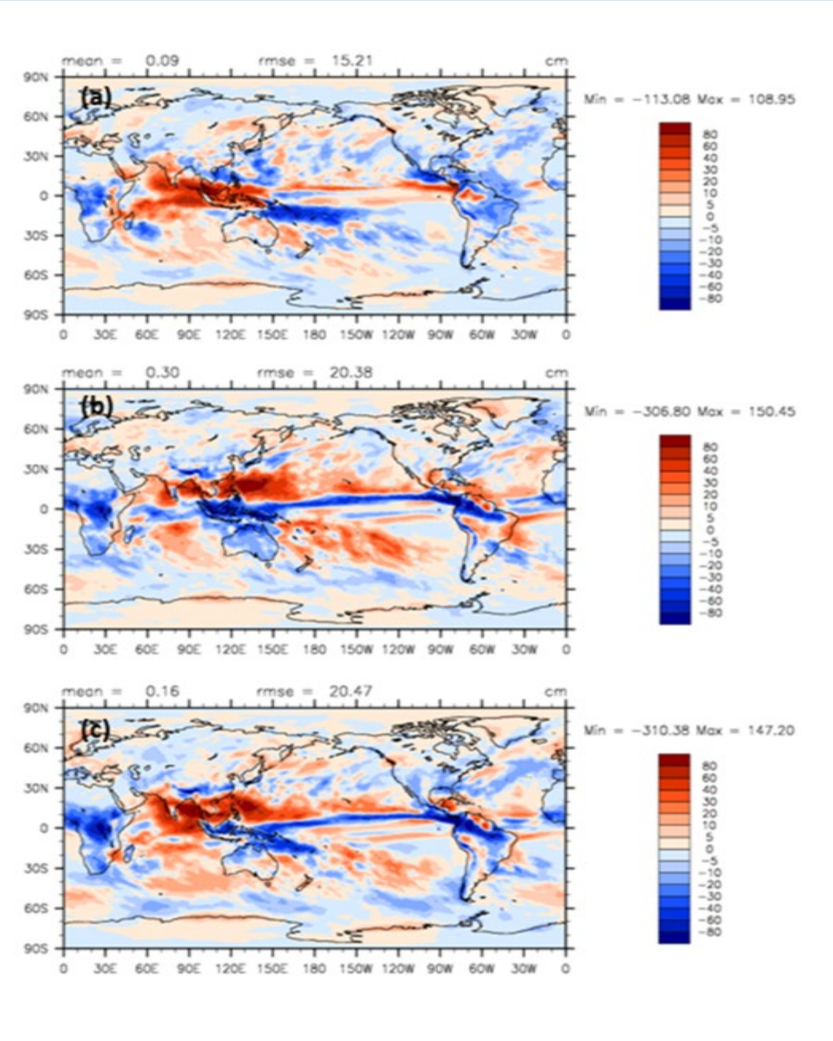
1st baroclinic

Effects of MCSP on annual precipitation (8 years)

1st Baroclinic momentum transport ($\alpha_3 = 1$)

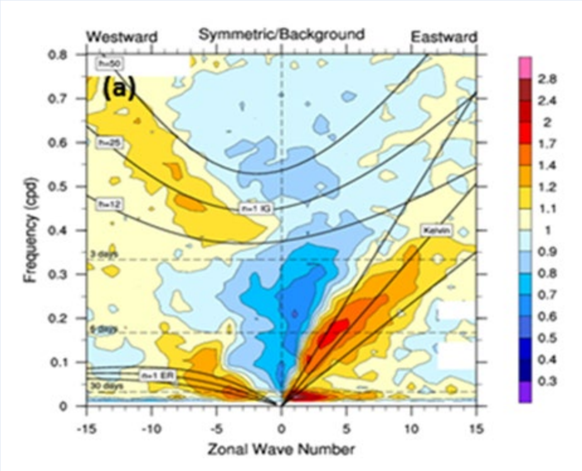
2nd Baroclinic heating (α_1 =1)

Momentum transport & heating

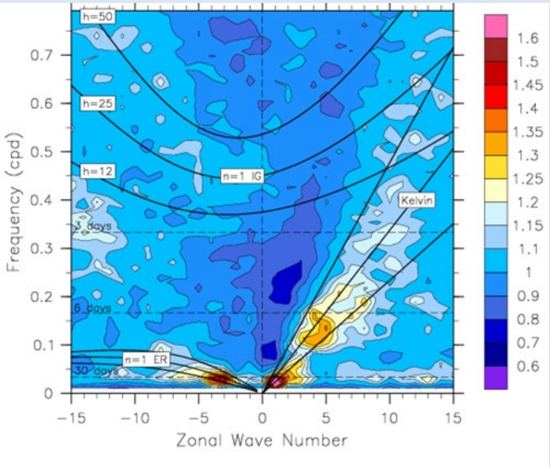


Moncrieff, Liu, and Bogenschutz (2017)

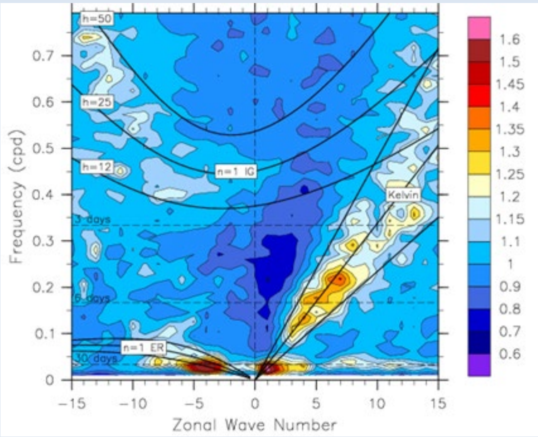
Effects of MCSP on MJO & CCEWs



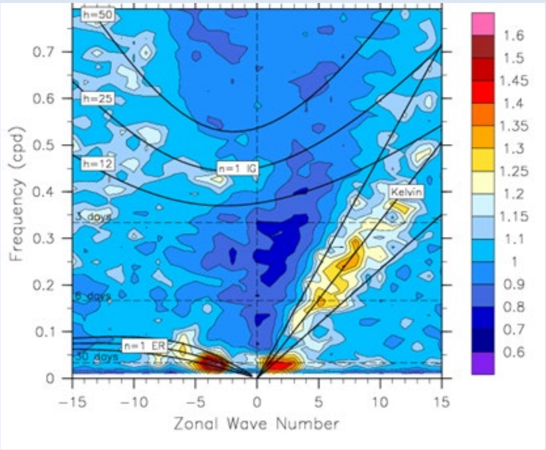
NCEP Reanalysis



CAM 5.5 Control



MCSP: 2nd Baroclinic Heating



MCSP: Momentum Transport.

Moncrieff, Liu, Bogenschutz (2017)

MCSP in Energy Exascale Earth System Model (E3SM, atmosphere-only)

J. Chen, C. Liu, Y. Richter, M. Moncrieff

- MCSP in E3SM: Similar to formulation in CAM 5.5 except amplitude parameter α_1 is cumulus-top dependent which increases spatial variability and convective intensity (especially over land):

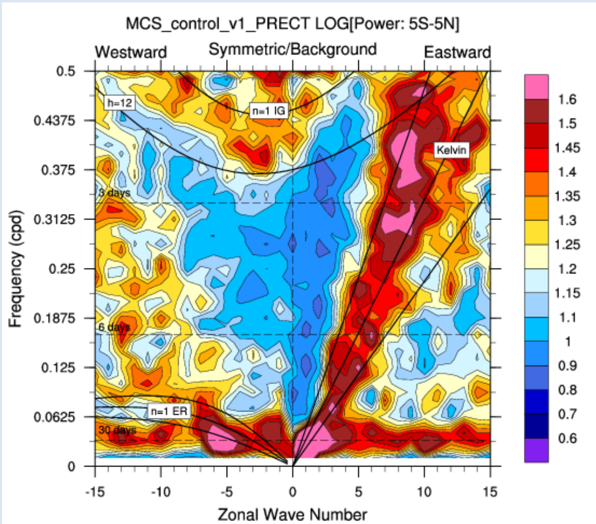
$$\alpha_1 = \text{Max}\left[\, 0, \frac{\pi}{2}\left(\frac{\text{Cumulus\_top} - 300}{400}\right)\right]$$

- Implement MCSP momentum transport via a shear-selection criterion

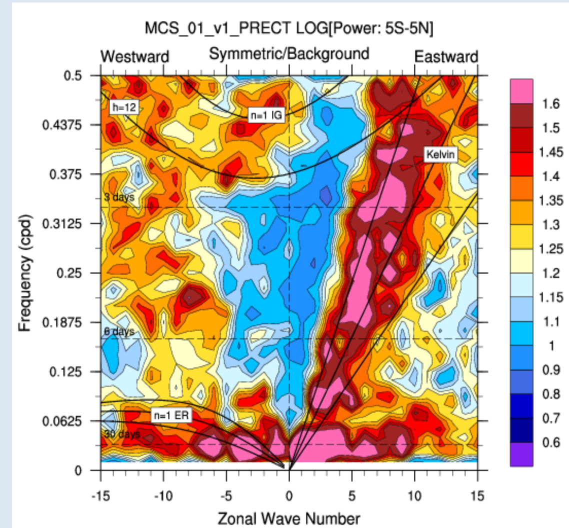
- E3SM has much stronger effects on all tropical wave categories

Convectively Coupled Equatorial Waves (CCEWs)

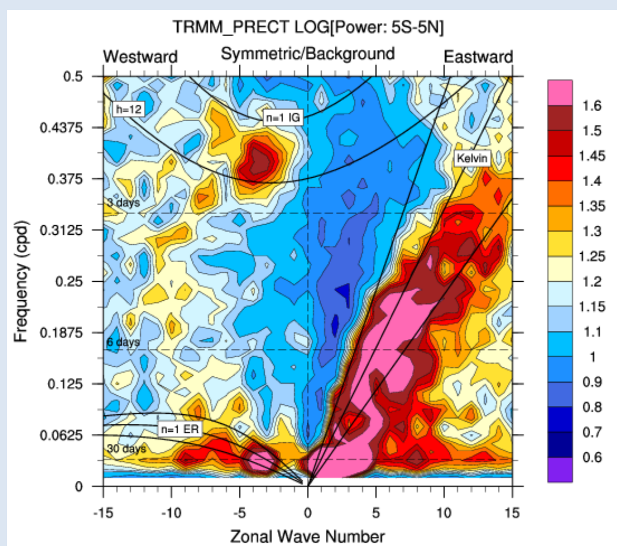
Standard E3SM



E3SM with MCSP

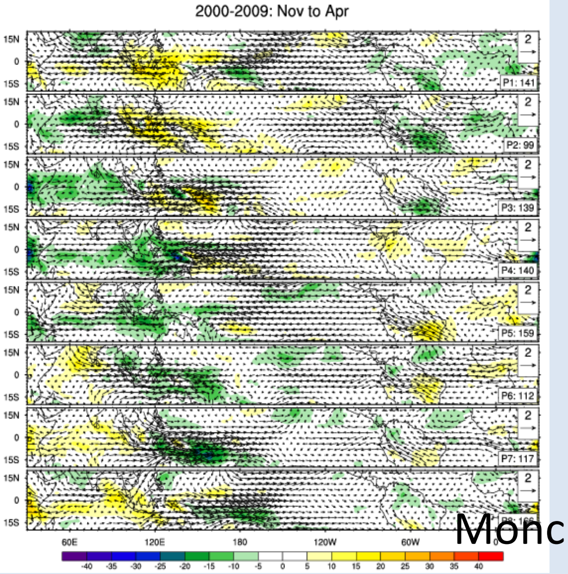


TRMM

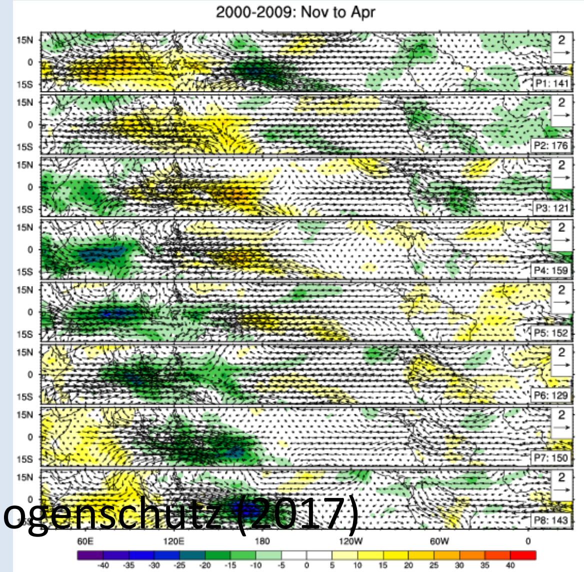


MJO

Standard E3SM

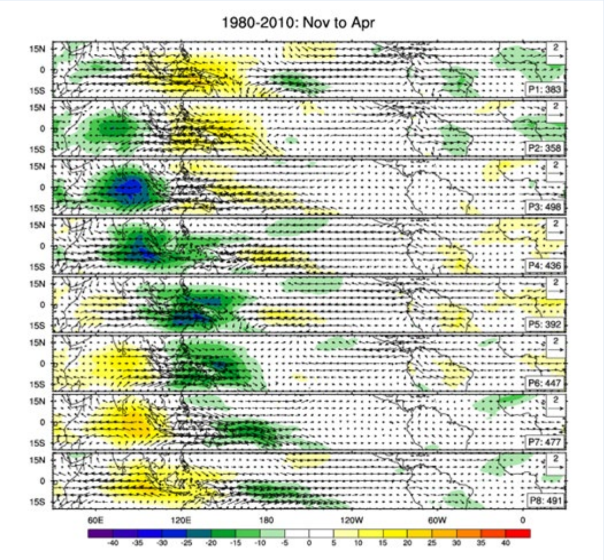


E3SM with MCSP



Moncrieff, Liu and Bogenschutz (2017)

ERA



Summary & Conclusion

- Observational Motivation for MCSP: 50-70% of rainfall from MCSs which are missing from contemporary GCMs
- MCSP treats classical convective organization, i.e., MCS and generalizes to Multiscale Coherent Structure Parameterization in the form of tropical convection – tropical wave interaction
- Proof of Concept: Prototype MCSP implemented in CAM 5.5
- MCSP affects all tropical wave modes, albeit too strongly in E3SM, ranging from large-scale low-frequency MJO to meso-synoptic westward propagating 2-day inertio-gravity waves (IGWs)
- Key properties of slantwise layer overturning: Ubiquitous, scale-invariant, upscale interaction, top-heavy heat transport, counter-gradient momentum transport ('negative viscosity')
- Next steps:
  - Add shear-selection criteria
  - Test MCSP in coupled versions of CESM and E3SM
  - Interaction between 2-day IGWs & Kelvin waves → QBO ?
  - Distinction between shear-parallel & shear-perpendicular MCS
- Collaborative activities
  - Interaction between MCS /orographic waves over US continents (NCAR Water System Program, R. Rasmussen)
  - Implement MCSP in UNICON (Sungsu Park & colleagues)
  - Affinity between MCSP & Multiscale Cloud Model Parameterization (A.Majda, B. Khouider & colleagues)

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