Organized Convection Parameterization for GCMs

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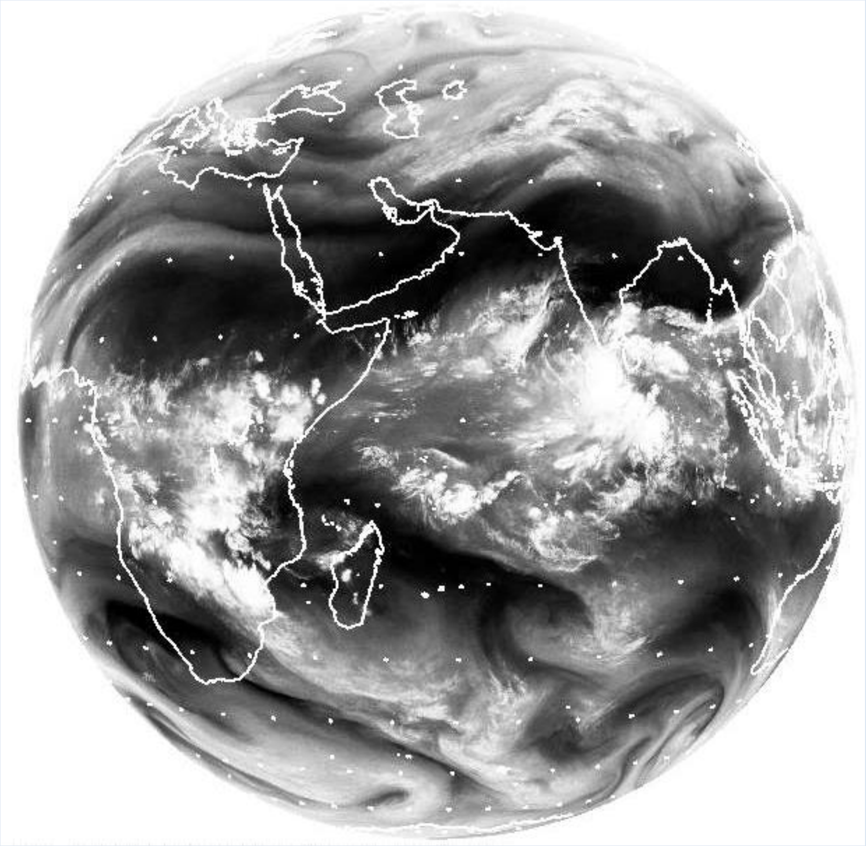
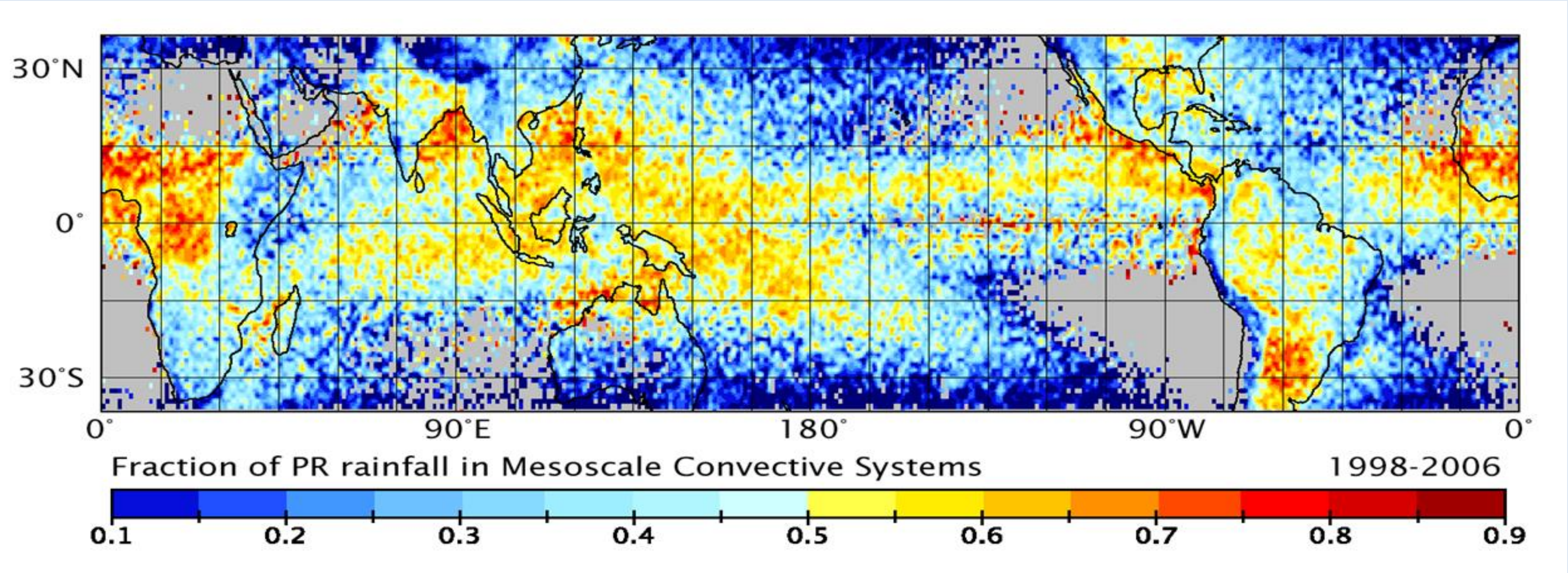
Dynamical-system Paradigm for Organized Convection Parameterization



CESM Variability & Change Working Group Winter Meeting, 2/27/19

MCSs in Large-scale Context



Tao & Moncrieff (2009)

TRMM data indicate that MCSs are:

- **Building blocks of the tropical water cycle, multiscale convective variability, etc.**
- **Embedded in meteorological phenomena that confound GCMs**
- **Provide >50% of tropical precipitation, >70% in certain regions**

Methodology

- Impressive progress made over half-a-century in our knowledge of **organized convection processes** (notably MCSs) *via* field & satellite observations, cloud-system simulations, and dynamical models.

- **Organized convection is missing from GCMs,** being neither resolved nor parameterized despite a key process in weather and climate.

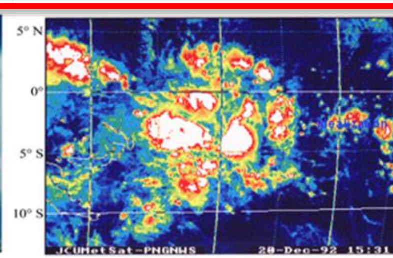
- **Mesoscale convective system parameterization** *a.k.a.* **multiscale coherent structure parameterization (MCSP)** incorporate physical & dynamical properties of moist convective organization.

- Effects of a **prototype MCSP** on precipitation distribution, convection-wave interaction, and the MJO **in CAM 5.5** provides proof-of-concept.

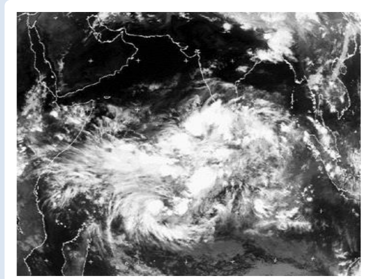
Self-similar organized moist convection features important upscale effects (Moncrieff 2004)

𝒪 (10 km, hours)
Cumulonimbus

𝒪 (100 km, day)
MCS



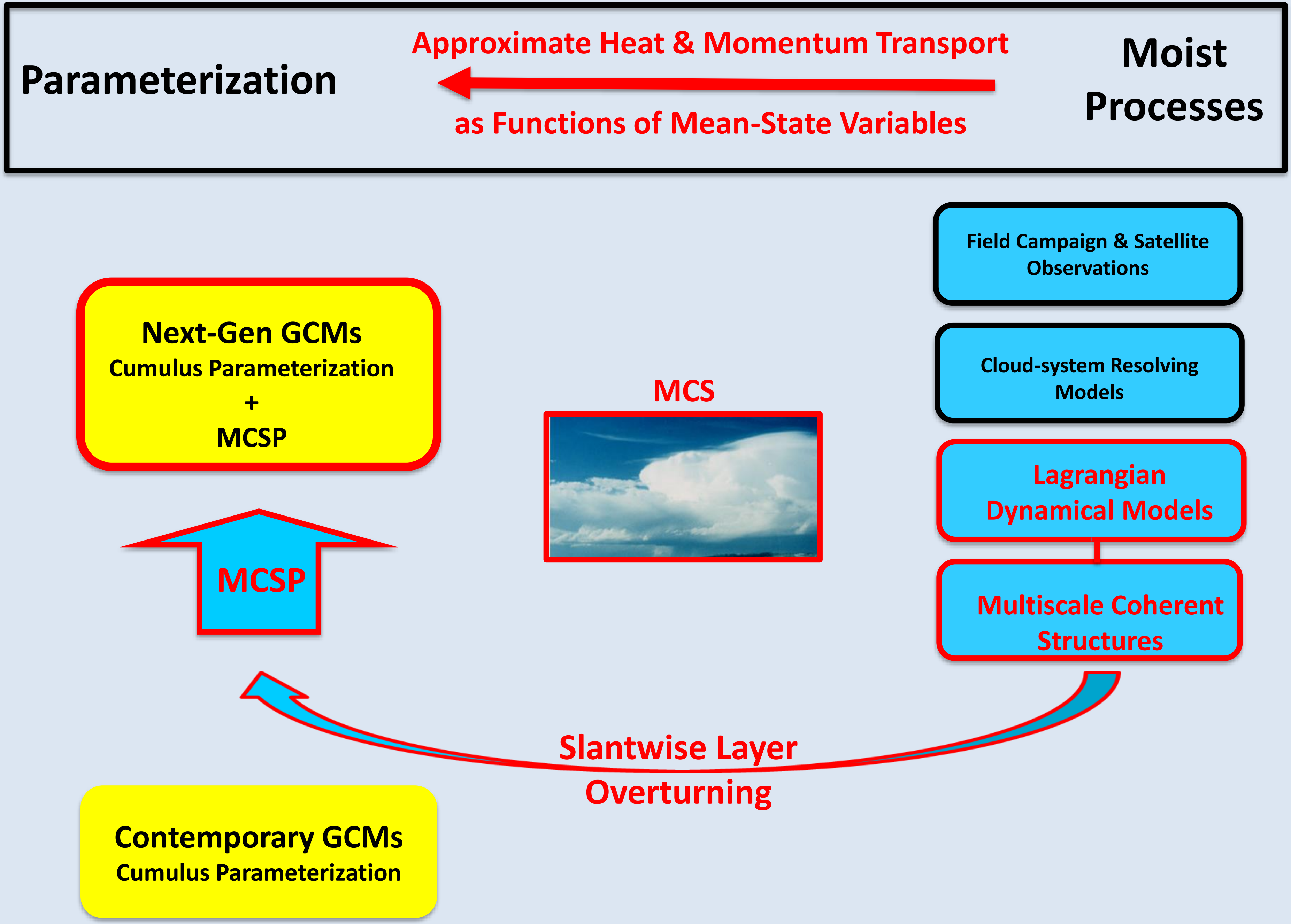
𝒪 (1,000 km, week)
Tropical Supercluster



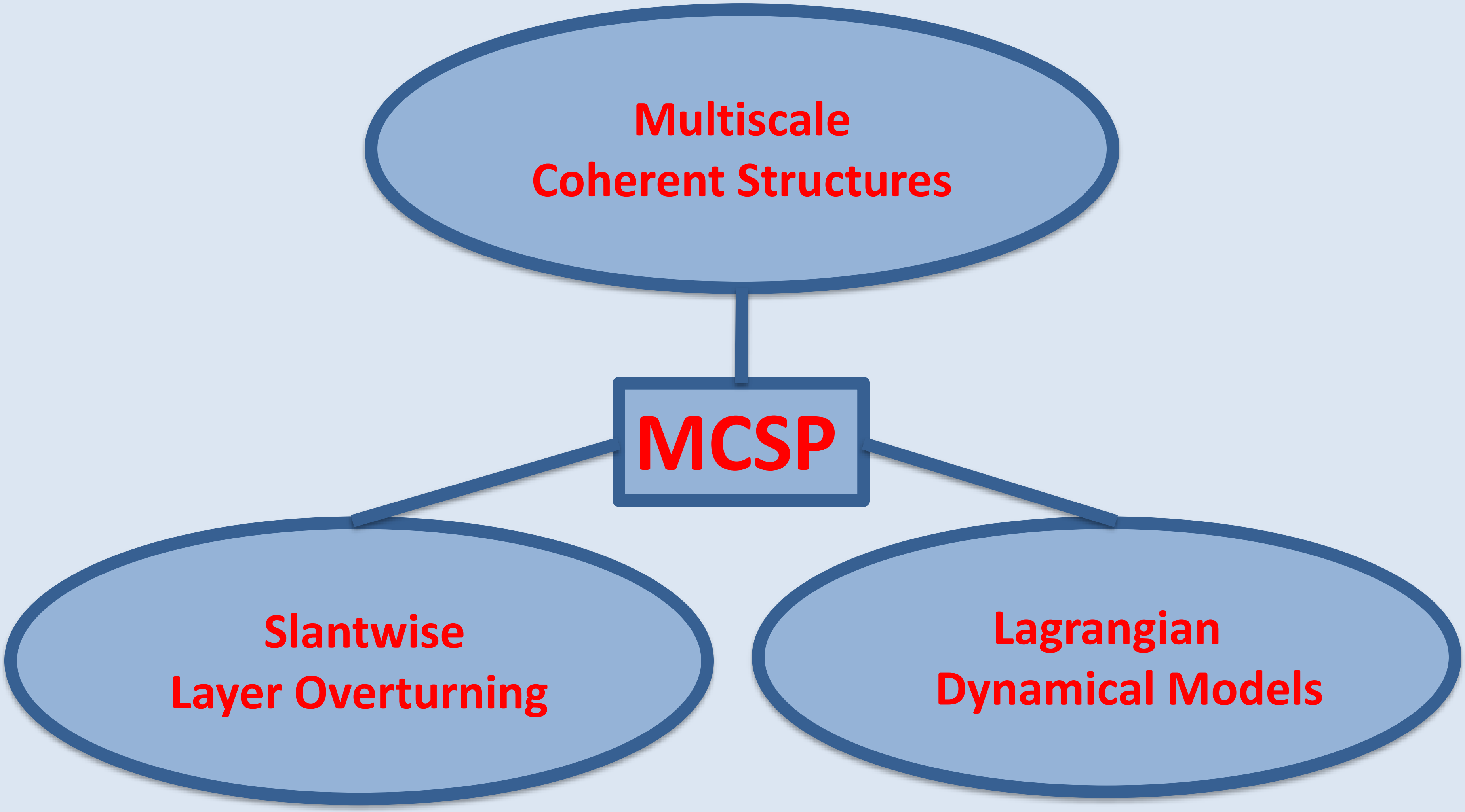
𝒪 (10,000 km, months)
MJO

Basic Questions

- **Is organized convection parameterizable?**
- **What are the key physical & dynamical principles?**
- **What's the minimalist prototype parameterization?**
- **How does prototype parameterization affect GCMs?**


Parameterization
Approximate Heat & Momentum Transport
as Functions of Mean-State Variables
Moist Processes
Field Campaign & Satellite Observations
Cloud-system Resolving Models
Lagrangian Dynamical Models
Multiscale Coherent Structures
Next-Gen GCMs
Cumulus Parameterization
+
MCSP
MCS
MCSP
Slantwise Layer Overturning
Contemporary GCMs
Cumulus Parameterization

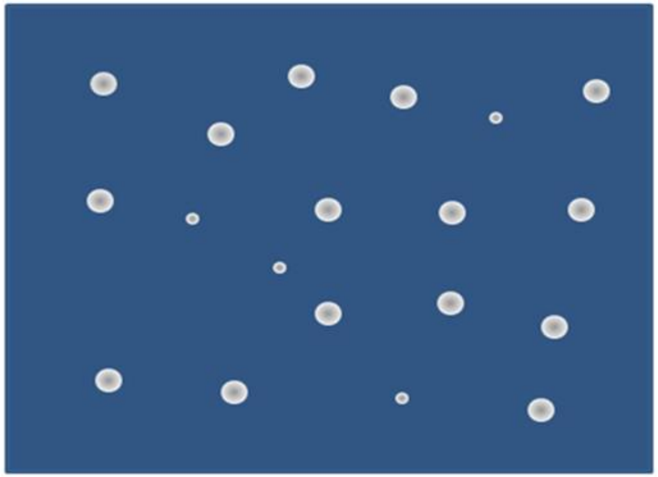
Three Basic Principles



Multiscale Coherent Structures

Classical Paradigm

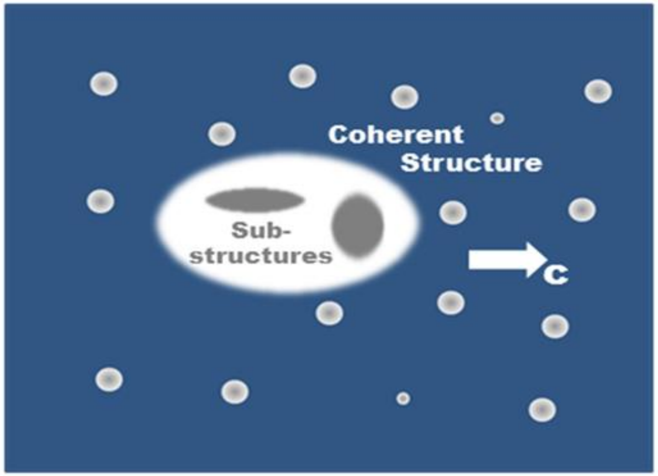
Field of transient cumulus



Turbulent Plume

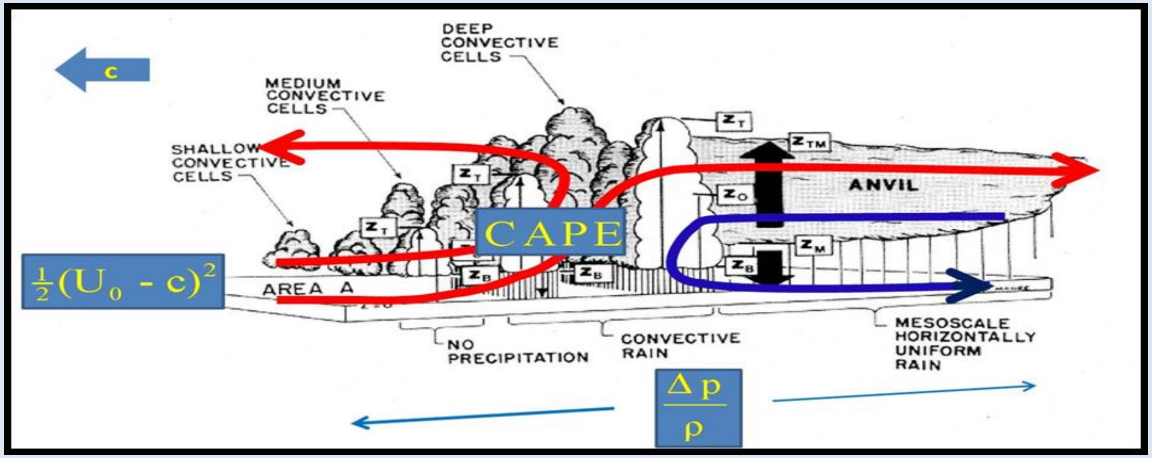
New Paradigm

Multiscale Coherent Structures Embedded in a Field of Transient Cumulus



Slantwise Layer Overturning

Slantwise Layer Overturning



- Tropospheric layers exchanged, distinct from local turbulent mixing
- Mesoscale pressure gradient (Δp) & vertical shear are forms of energy additional to CAPE:

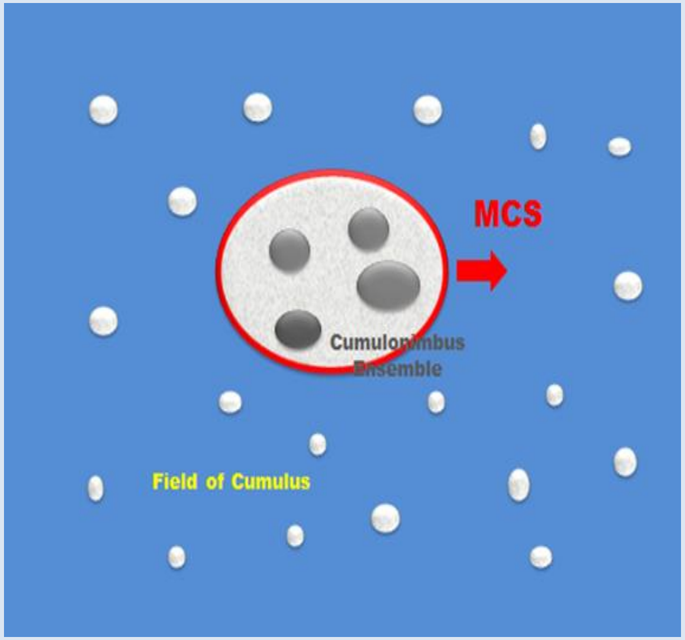
  - Available kinetic energy AKE = $\frac{1}{2}(U_0 - c)^2$
  - Pressure-gradient work APG = $\Delta p/\rho$

- Key mean-state parameters, R = CAPE/AKE & E = APG/AKE
- Distinctive non-diffusive heat & momentum transport

Lagrangian Dynamical Models

Lagrangian slantwise layer overturning models approximate coherent structures that propagate steadily in system-relative coordinates and also incorporate bothersome partial derivatives:

$$\frac{\mathrm{D}}{\mathrm{Dt}} = \frac{\partial}{\partial x} + \frac{\partial}{\partial y} + \frac{\partial}{\partial z}$$



- **Transform the nonlinear equations into exactly integrable form,** $DF_i/Dt = 0$
- **Integration along trajectories (**ψ**) provides a set of conserved quantities,** $F_i = C_i(\psi)$
- **Lagrangian models provide transports of mass, energy, momentum, vorticity, etc.**
- **Cloud-system resolving model & field-campaign analyses provide verification**

Prototype MCSP

- **Canonical formulation**

  - **1^{st} and/or 2^{nd} baroclinic (top-heavy) mesoscale heating**
  - **1^{st} baroclinic acceleration by momentum transport**

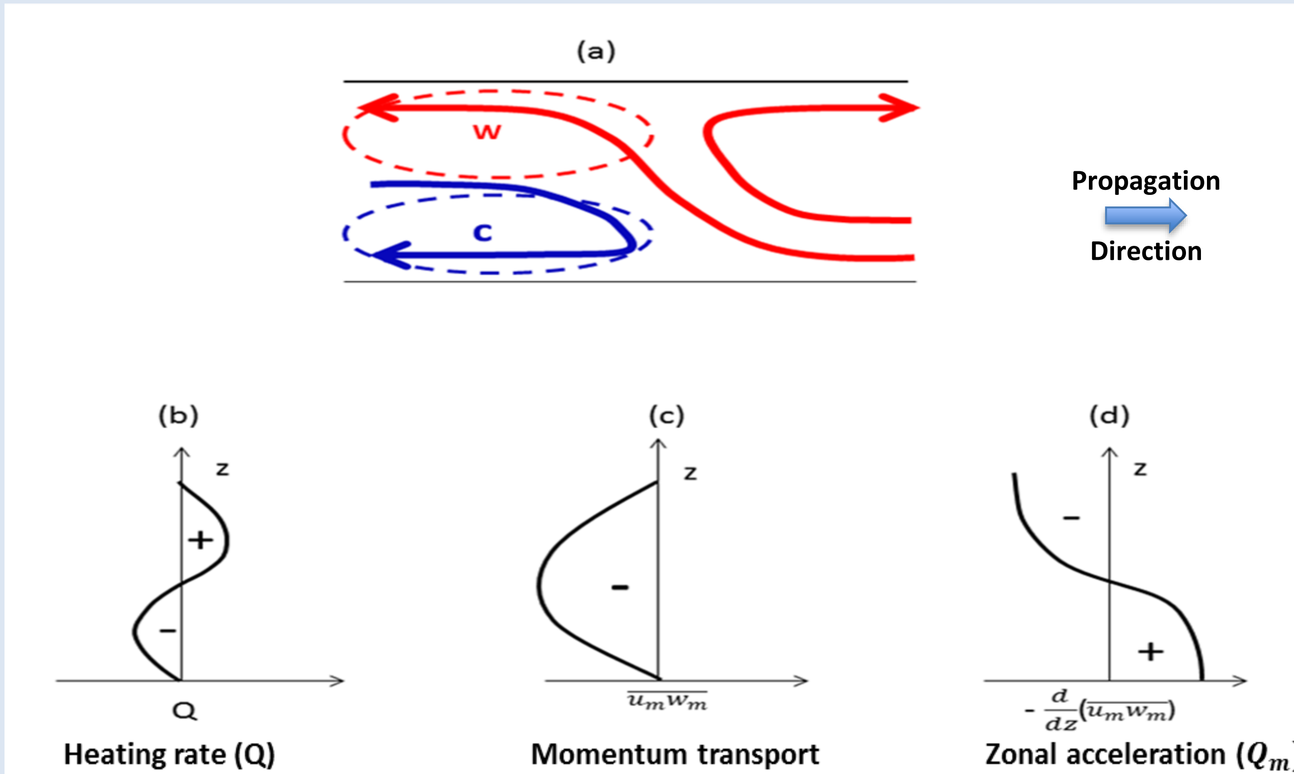
- **Add the “missing process” of mesoscale slantwise layer overturning to the existing cumulus parameterization, i.e.,**

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

- **Large-scale effects of organized convection unambiguously measured as differences between GCM runs with & without MCSP**

- **Minimal computational overhead**

Prototype Heat & Momentum Transport



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

1st baroclinic   2nd baroclinic

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

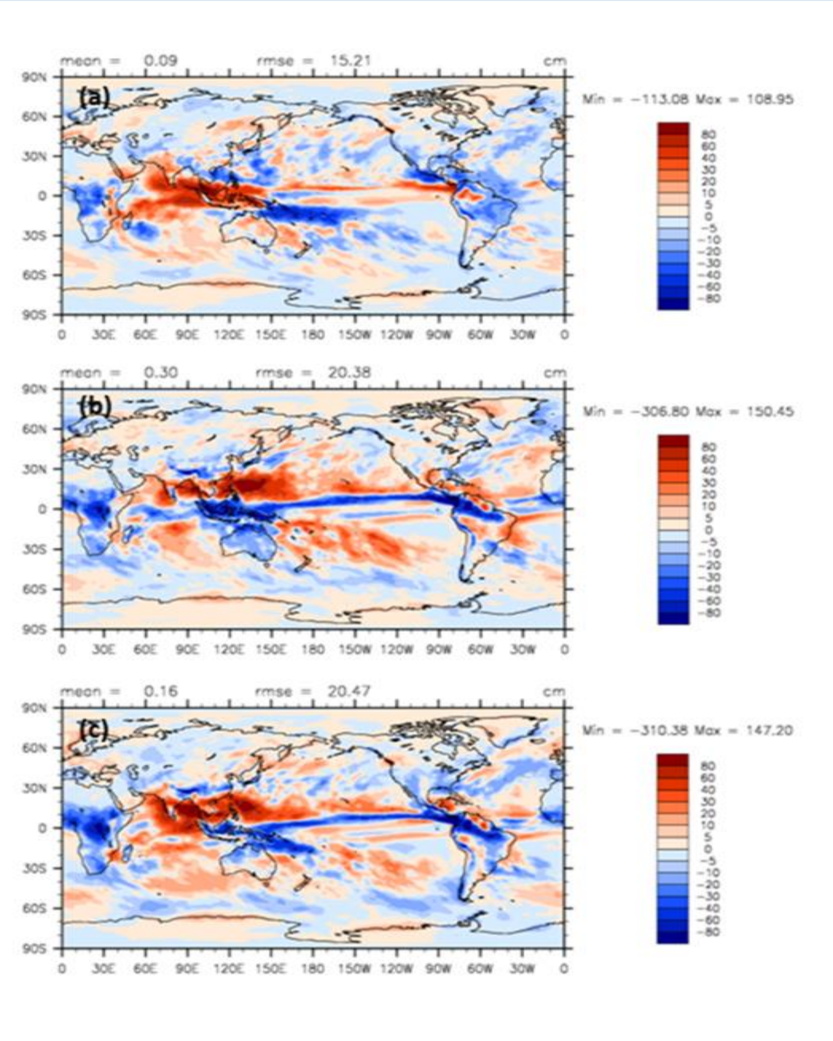
1st baroclinic

Effects of MCSP on Annual Precipitation (8-years)

1st Baroclinic momentum transport

2nd Baroclinic heating

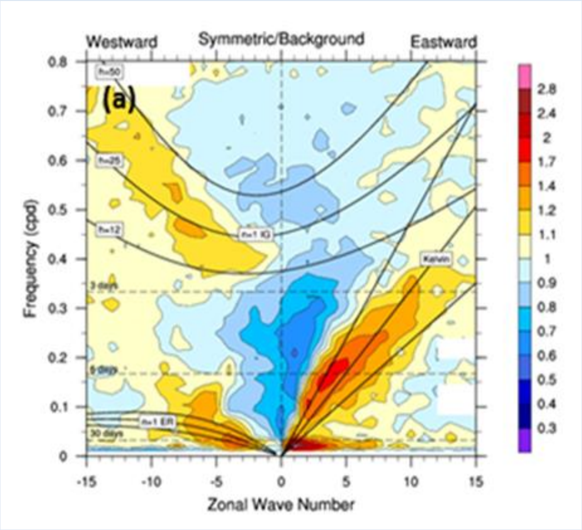
Momentum transport & heating



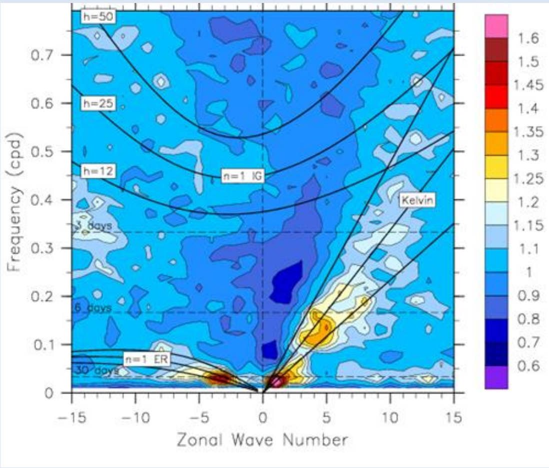
<u>**EFFECTS OF MCSP:**</u> **DIFFERENCE BETWEEN CAM RUNS WITH & WITHOUT MCSP**

Moncrieff, Liu, and Bogenschutz (2017)

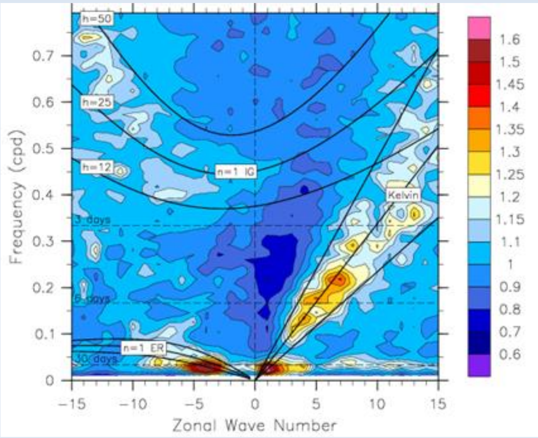
Effects of MCSP on Tropical Waves (8 years)



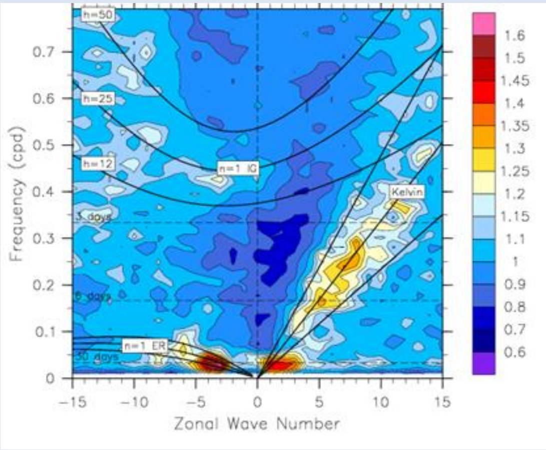
NCEP Reanalysis



CAM 5.5 Control



MCSP: 2nd Baroclinic Heating
($\alpha_1 = 0, \alpha_2 = 1$)



MCSP: 2nd Baroclinic Heating & Momentum Transport (α_3 = 1)

Moncrieff, Liu, and Bogenschutz (2017)

Conclusions

- **Prototype MCSP:**
  - **Organized convection indeed a ‘parameterizable’ process**
  - **Precipitation, convection-wave interaction, MJO consistent with TRMM**
  - **Organized heat & momentum transport effects are distinct**
  - **Unified cumulus & organized convection parameterization**
  - **Computationally efficient, useable in long-run GCMs**
  - **Implement in E3SM, focus on momentum transport**

- **Next-gen MCSP :**
  - **Incorporate shear selection criteria**
  - **Investigate impact on coupled GCMs**
  - **Cumulonimbus -> MCS -> Supercluster invariance**
  - **Scale-selection mechanisms for upscale evolution**
  - **Implications for convective parameterization ‘gray zone’**
  - **Organized convection in subseasonal-to-seasonal context**
  - **Gravity-wave generation by propagating convective systems**

References

Lafore, J-P. and Moncrieff, M.W, 1989: A numerical investigation of the organization and interaction of the convective and stratiform regions of lropical squall lines. *J. Atmos. Sci.,* 46, 521-544.

Moncrieff, M.W., 1992: Organized convective systems: Archetypal models, mass and momentum flux theory, and parameterization. *Quart. J. Roy. Meteorol. Soc.,* 118, 819-850.

Moncrieff, M.W., 2004: Analytic representation of the large-scale organization of tropical convection. J. Atmos. Sci., 61,1521-1538.

Moncrieff, M. W., 2010: The multiscale organization of moist convection and the intersection of weather and climate. In Climate Dynamics: Why Does Climate Vary? *Geophys. Monogr. Ser.,* 189, Eds. D-Z. Sun and F. Bryan, pp. 3–26, doi:10.1029/2008GM000838.

Moncrieff, M.W., D. E. Waliser, M.J. Miller, M.E. Shapiro, G. Asrar, and J. Caughey, 2012: Multiscale convective organization and the YOTC Virtual Global Field Campaign. *Bull. Amer. Meteorol. Soc.,* 93, 1171-1187, doi:10.1175/BAMS-D-11-00233.1.

Moncrieff, M.W., C. Liu and P. Bogenschutz, 2017: Simulation, modeling and dynamically based parameterization of organized tropical convection for global climate models. *J. Atmos. Sci*., 74, 1363-1380, doi:10.1175/JAS-D-16-0166.1.

Tao, W-K., and M. W. Moncrieff, 2009: Multiscale cloud system modeling, *Rev. Geophys.,* 47, RG4002, doi:10.1029/2008RG000276.

Yang, Q., A.J. Majda, and M.W. Moncrieff, 2019: Upscale impact of mesoscale convective systems and its parameterization in an idealized GCM for a MJO analog above the equator*. J. Atmos. Sci*., 76, in press.