Multiscale Coherent Structure Parameterization for Organized Tropical Convection for GCMs

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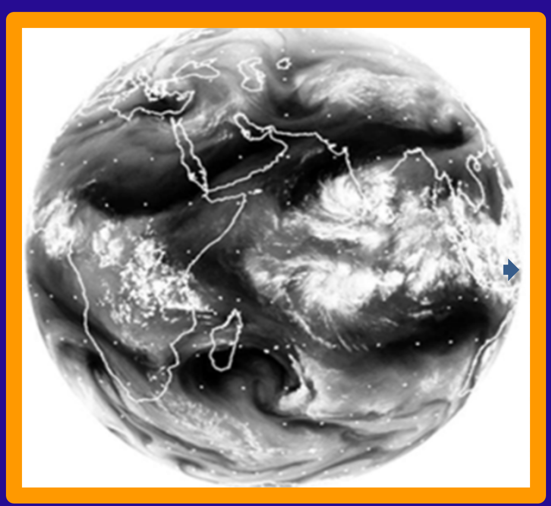
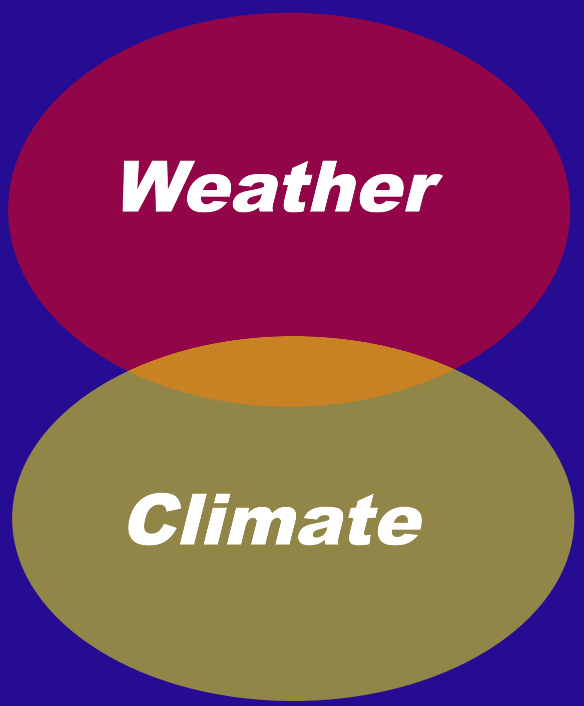


Mesoscale

Processes



Rossow Symposium: Clouds, their Properties & Climate Feedbacks, Columbia University, 6/8/2017

Summarize parameterization aspects of the recent publication:

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.

supported by a NASA ROSES grant between NCAR, CCNY and GISS: *Diagnostic Analysis and Cloud-System Modeling of Organized Tropical Convection in the YOTC - ECMWF Global Database to Develop Climate Model Parameterizations*

Preamble

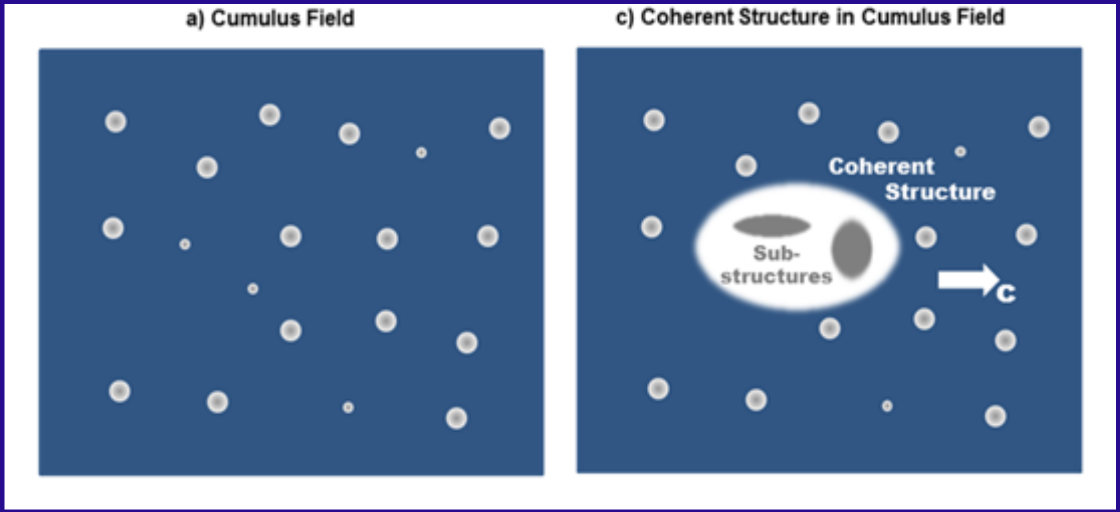
Atmospheric convection observed to organize into "coherent structures", a dynamical property linked to mean-state conditions notably vertical shear.

But this feature is not treated by traditional convective parameterizations.

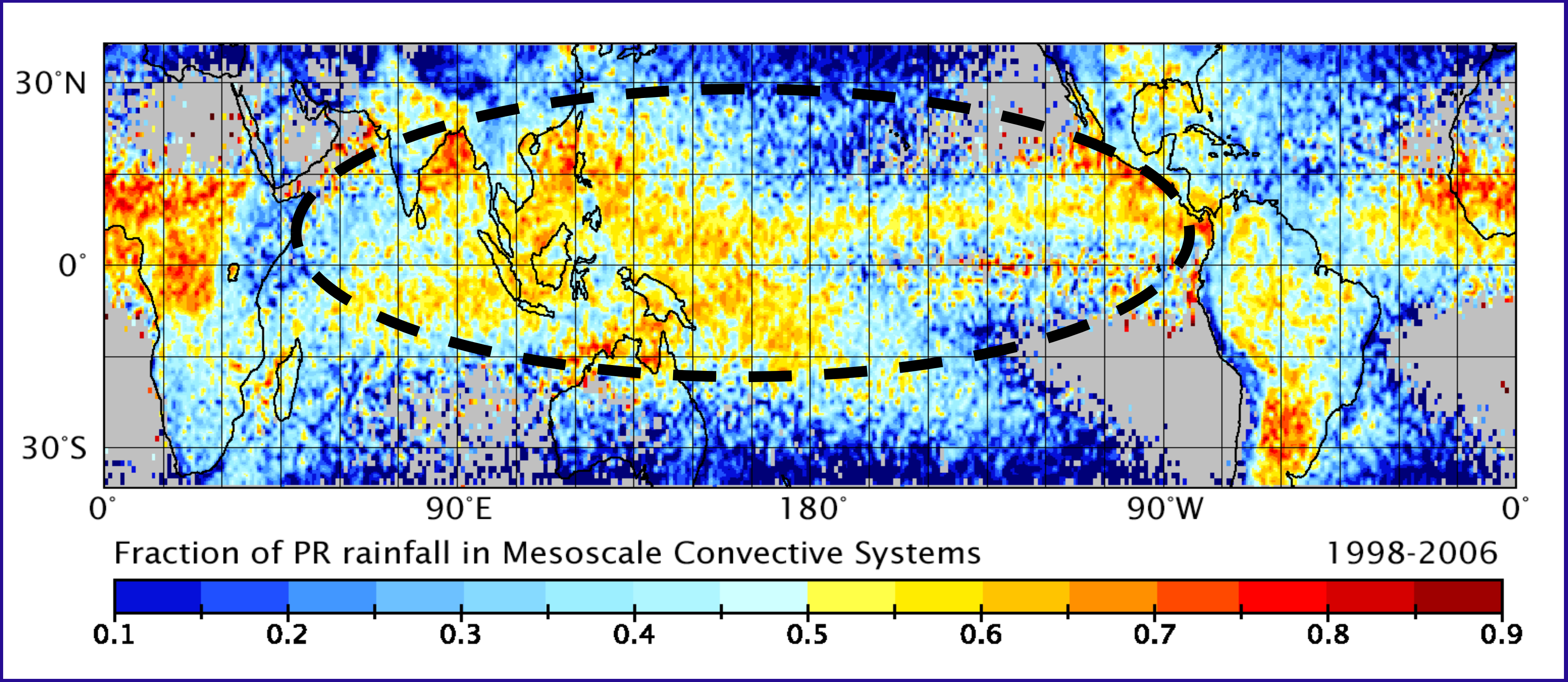
Coherent structures are fundamental to fluids & plasmas.

Seek the simplest possible (minimalist) parameterization for organized convection represented by coherent structures based on observationally verified nonlinear dynamical models

Focus on eastward- propagating tropical systems

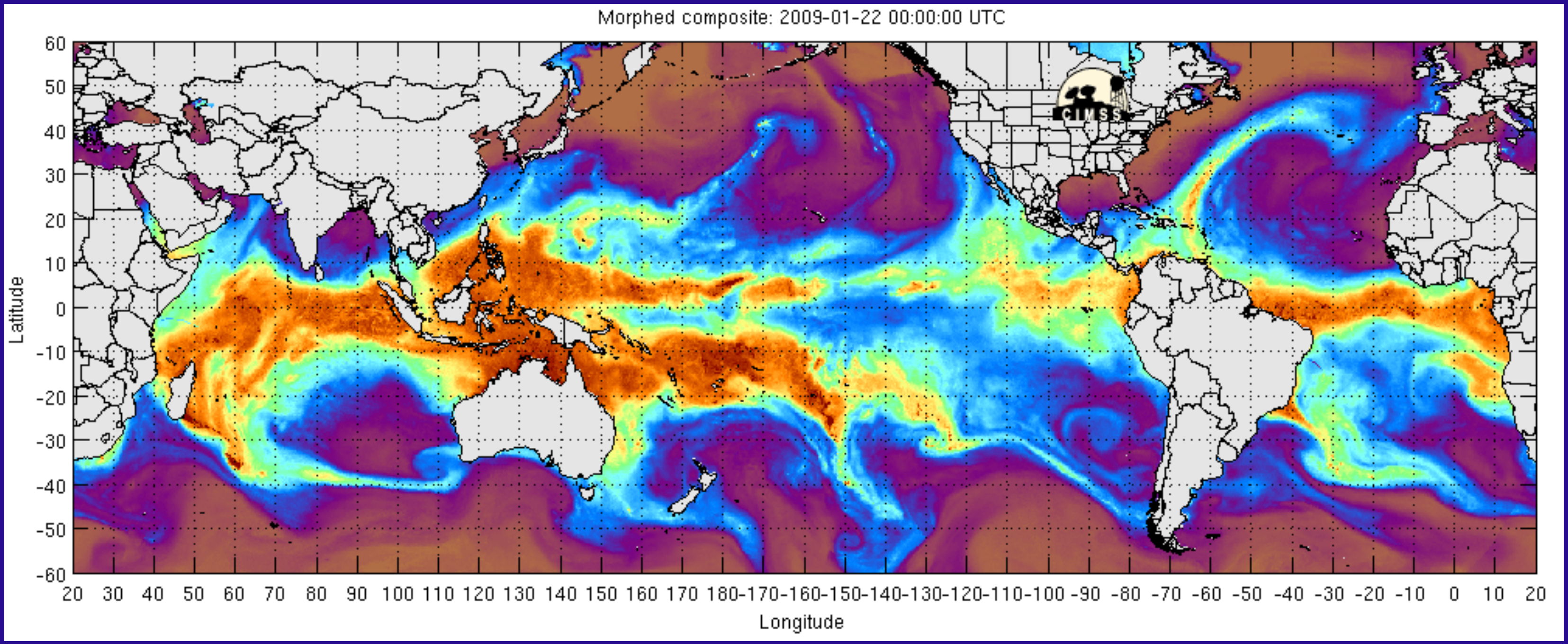


Fraction of Rainfall in MCS (TRMM)



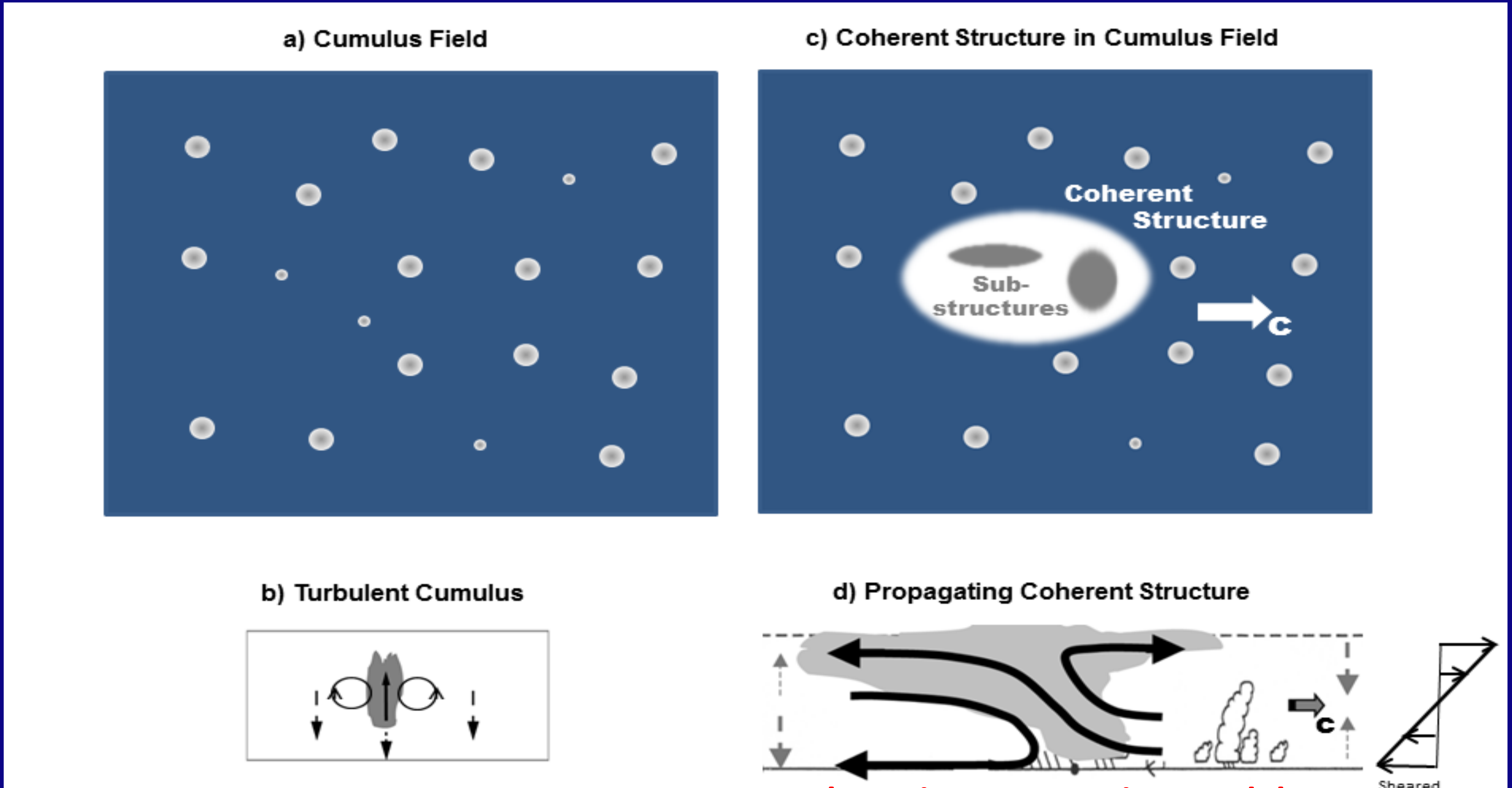
Tao & Moncrieff (2009)

Precipitable Water from TRMM data for YOTC (La Nina Conditions)



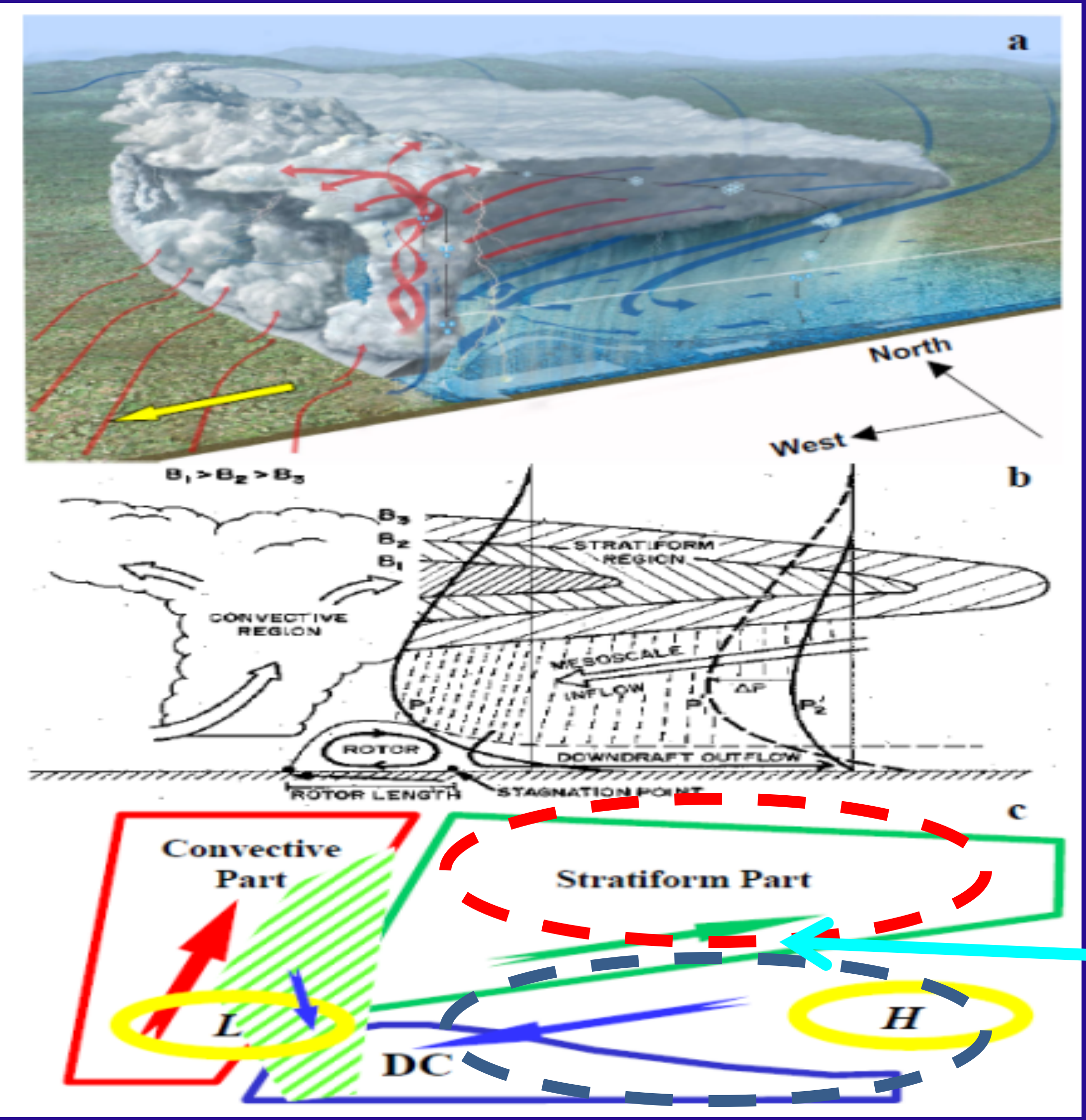
Tony Wimmers & Chris Velden (CIMSS, U. Wisconsin at Madison)

Multiscale Coherent Structure Parameterization (MCSP)



Slantwise Overturning Model

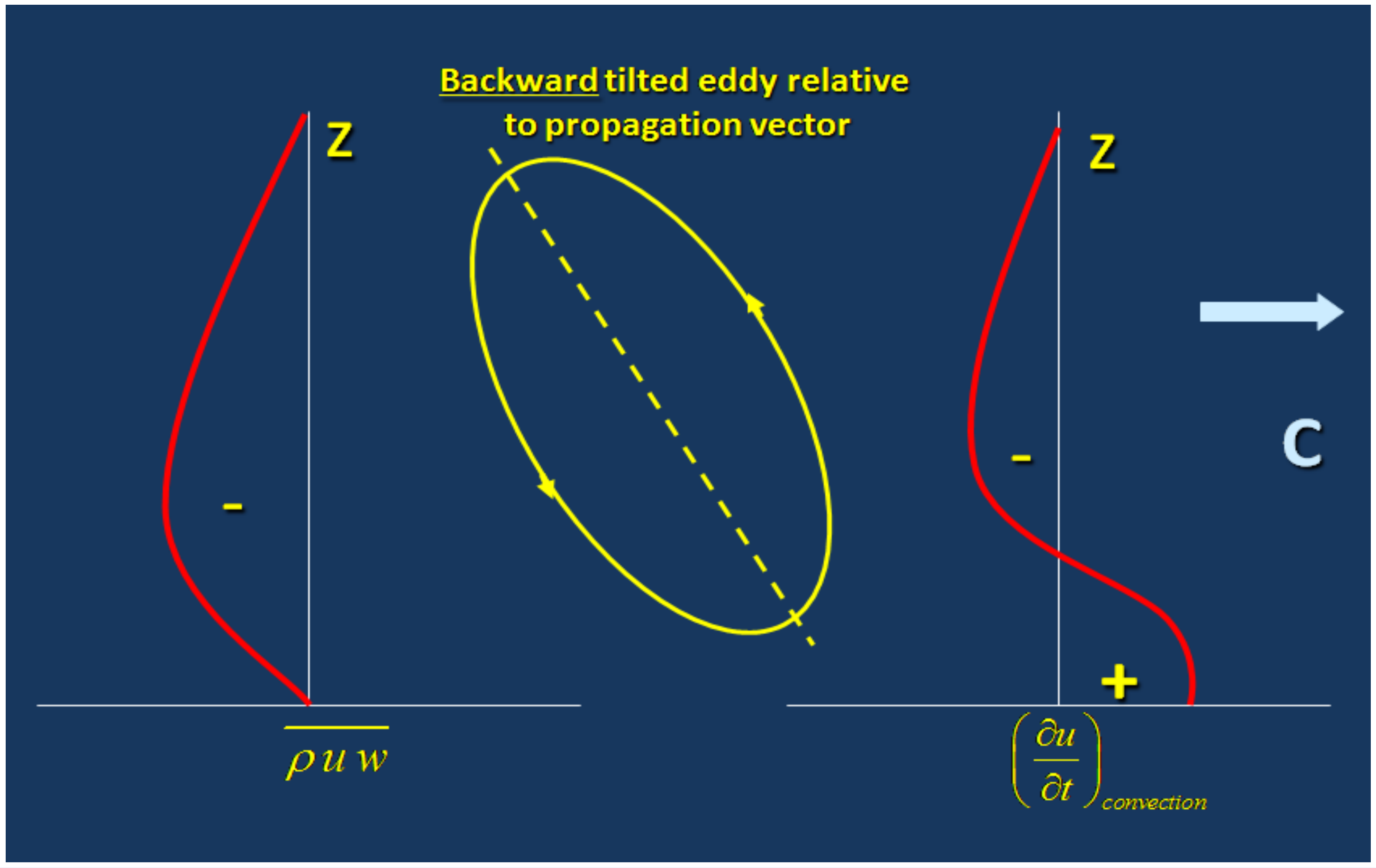
Convective-Mesoscale Anatomy of MCS



2nd Baroclinic vertical structure for mesoscale heating & acceleration

Lafore & Moncrieff (1987); Lafore et al. (2017)

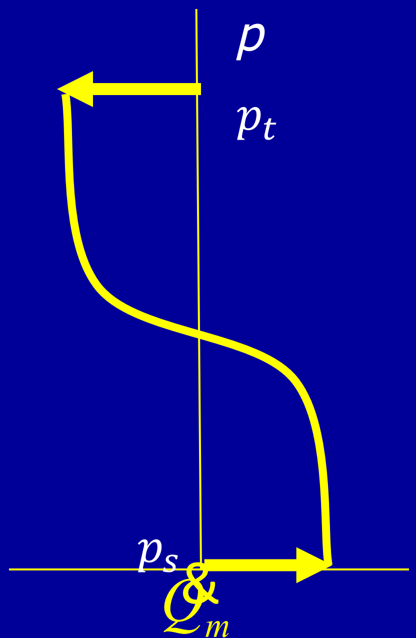
2nd Baroclinic Organized Momentum Transport



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

Momentum Transport Parameterization

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



Propagation Direction

1st & 2nd Baroclinic Modes of Convective Heating

Cumulus heating ↓

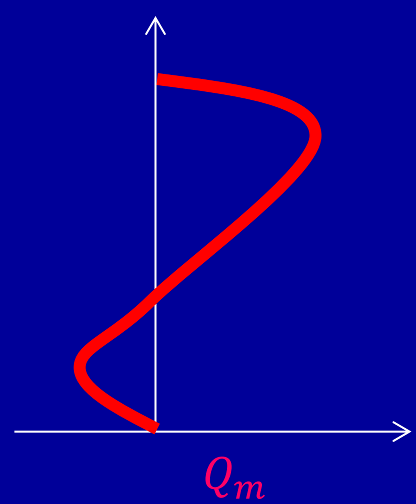
1st baroclinic mode

2nd baroclinc mode

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

↑ Deep Heating: 1st baroclinic Convective Mode

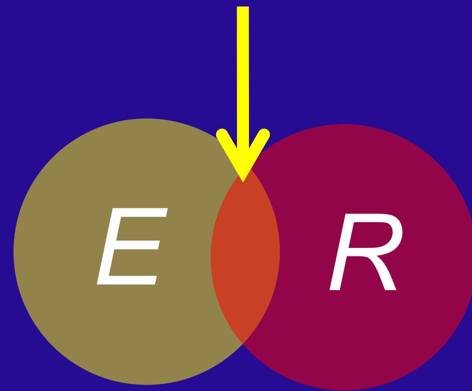
↑ Top-heavy Heating: 2nd baroclinic Mesoscale Mode



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

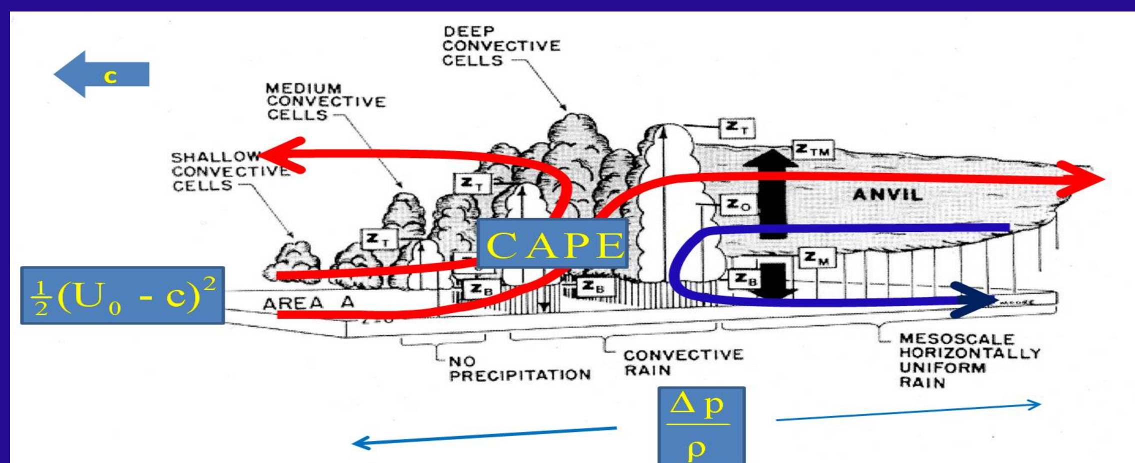
Lagrangian Slant-wise Overturning Model

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



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

Three Energy Sources: Potential, Kinetic, Work done by Pressure Gradient



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

F: Along–trajectory buoyancy
G: Environmental shear

Multiscale self-similarity assumption: Convective heating proportional to vertical velocity

Experiments with CAM 5.5 GCM

- Organized convection represented by slantwise overturning affects the large-scale distribution of precipitation and tropical-waves, with particular attention to regions identified by the TRMM (e.g., ITCZ, SPCZ, Maritime Continent, warm-pool) concerning MCS activity

- Address issues in the minimalist way focused on 2nd baroclinic tendencies:

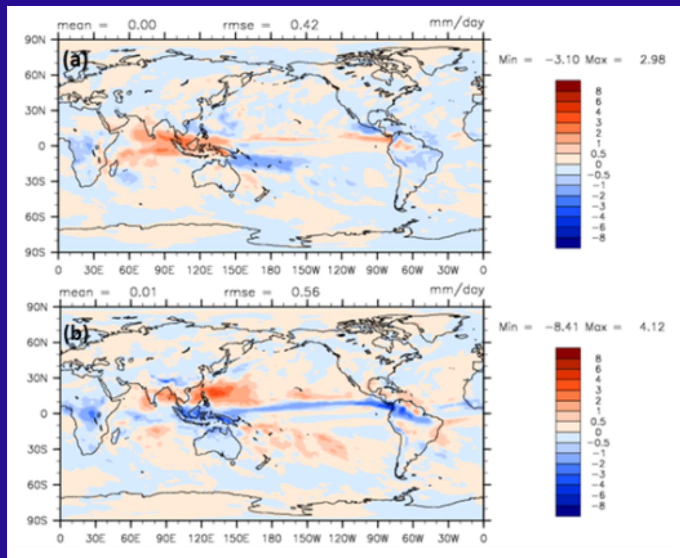
  i) 'Top-heavy' convective heating

  ii) Organized momentum transport

- Analyze years 2-8 of 10-year CAM 5.5 simulations

MCSP Effects on Precipitation

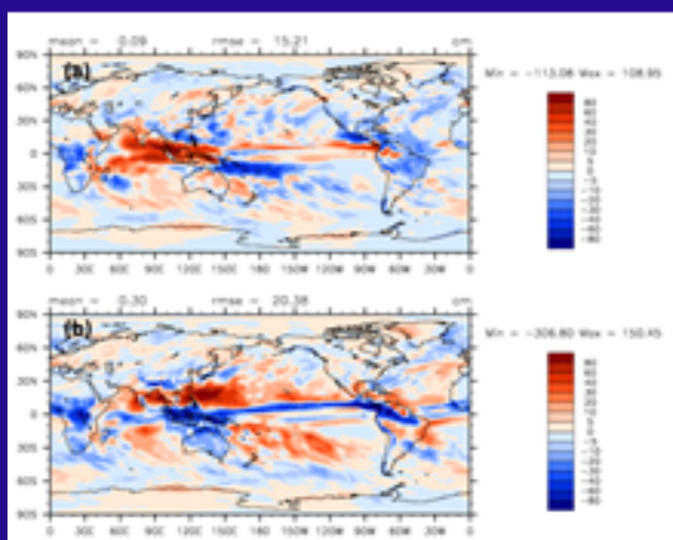
Precipitation rate
(8-year average)



Momentum Transport

Top-heavy Heating

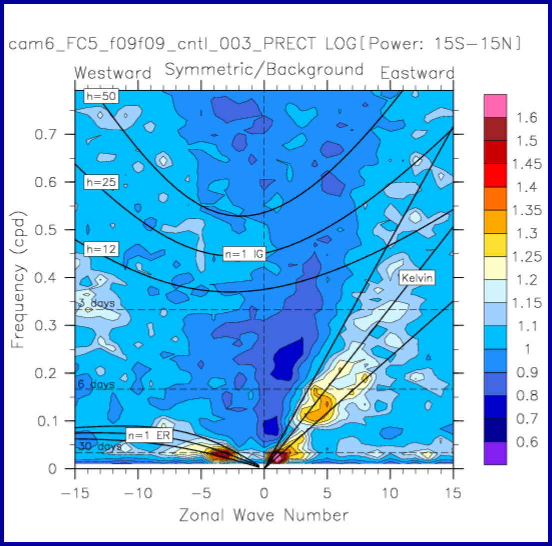
Annual precipitation
(8-year average)



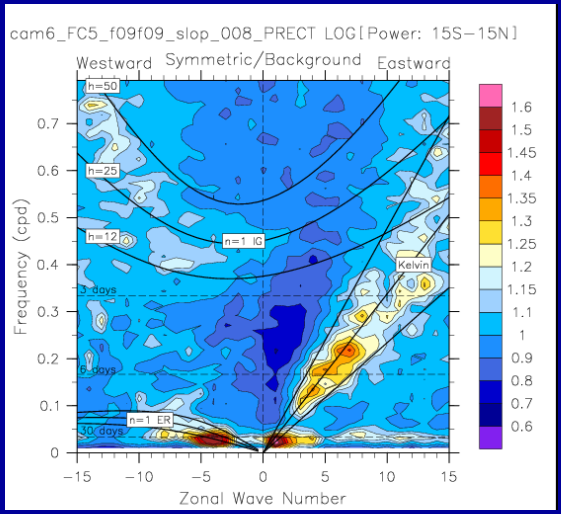
Momentum Transport

Top-heavy Heating

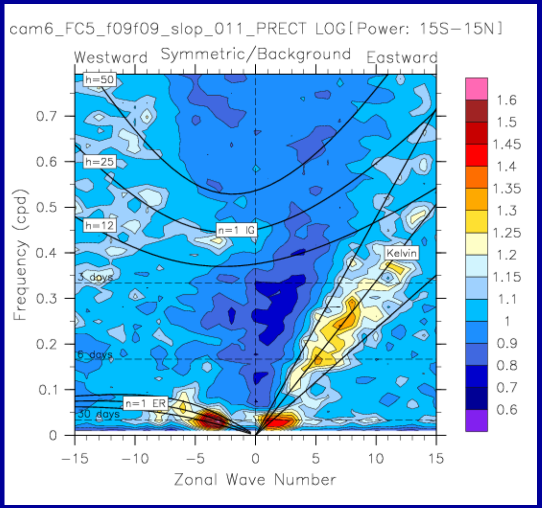
Precipitation Rate (15S -15N)



CAM 5.5 Control

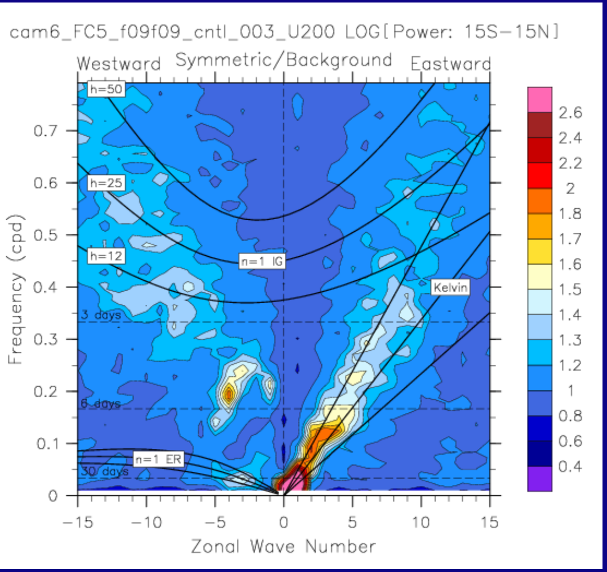


MCSP: 2nd Baroclinic Heating

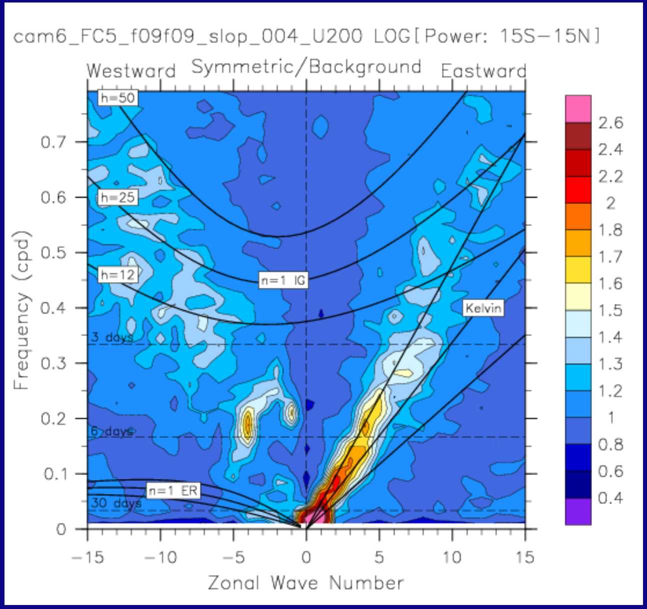


MCSP: Momentum Transport

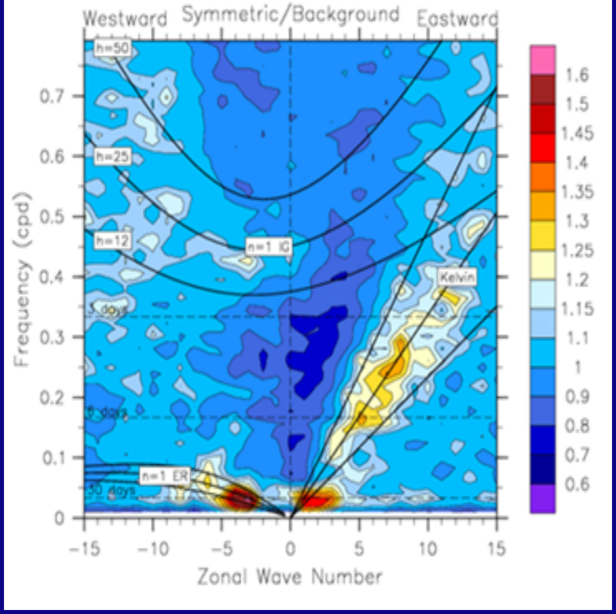
Zonal Wind at 200 hPa (15S – 15N)



CAM 5.5 Control



MCSP: 2nd Baroclinic Momentum Transport ($\alpha_3 = 1ms^{-1}\ day^{-1}$)



MCSP: 2nd Baroclinic Heating (α_1 = 1)

Conclusions

- **Multiscale Coherent Structure Parameterization (MCSP) with slantwise overturning as the transport module adds mesoscale organization to traditional convective parameterization.**

- **Multiscale self-similarity of squall lines, MCSs, supercluster etc. stems from proportionality between convective heating and cnvective vertical velocity**

- **MCSP demonstrates the global role of organized convection**

- **Consisting of a few lines of code, MCSP is useable for long climate simulations**

- **Coherent response to 2nd baroclinic heating & momentum transport in Indian Ocean, Maritime Continent and Tropical Western Pacific, ITCZ -- broadly consistent with TRMM**

- **Coherent structure paradigm implies new scale-selection mechanisms for organized convection at meso-to-synoptic scales**

- **Much more remains to be done, e.g.,**
  - Relationship to Khouider-Majda multicloud parameterization (MCP)
  - Analysis of 9 km ECMWF IFS *Virtual Global Field Campaign database* for PPP & YMC in the July 2017-July 2019 period.
  - Effects outside the Warm Pool

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