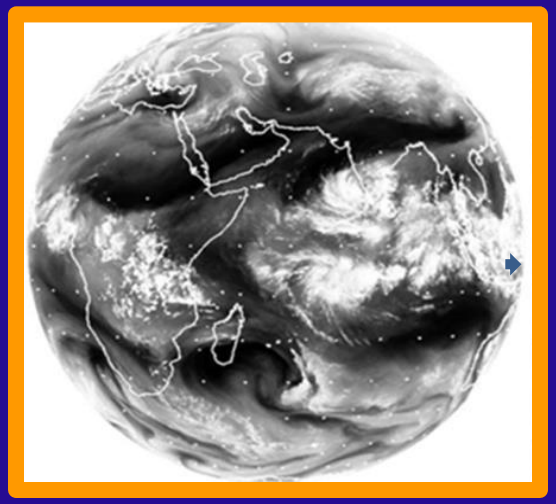
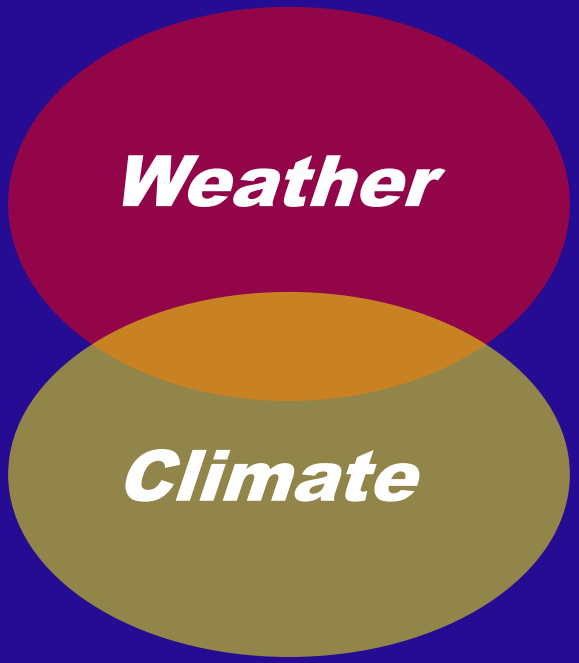
Parameterization of Organized Tropical Convection

Mitch Moncrieff
Climate & Global Dynamics Laboratory
NCAR



Mesoscale

Processes



GEWEX Convection- Permitting Climate Modeling Workshop
NCAR, September 6-8 2016

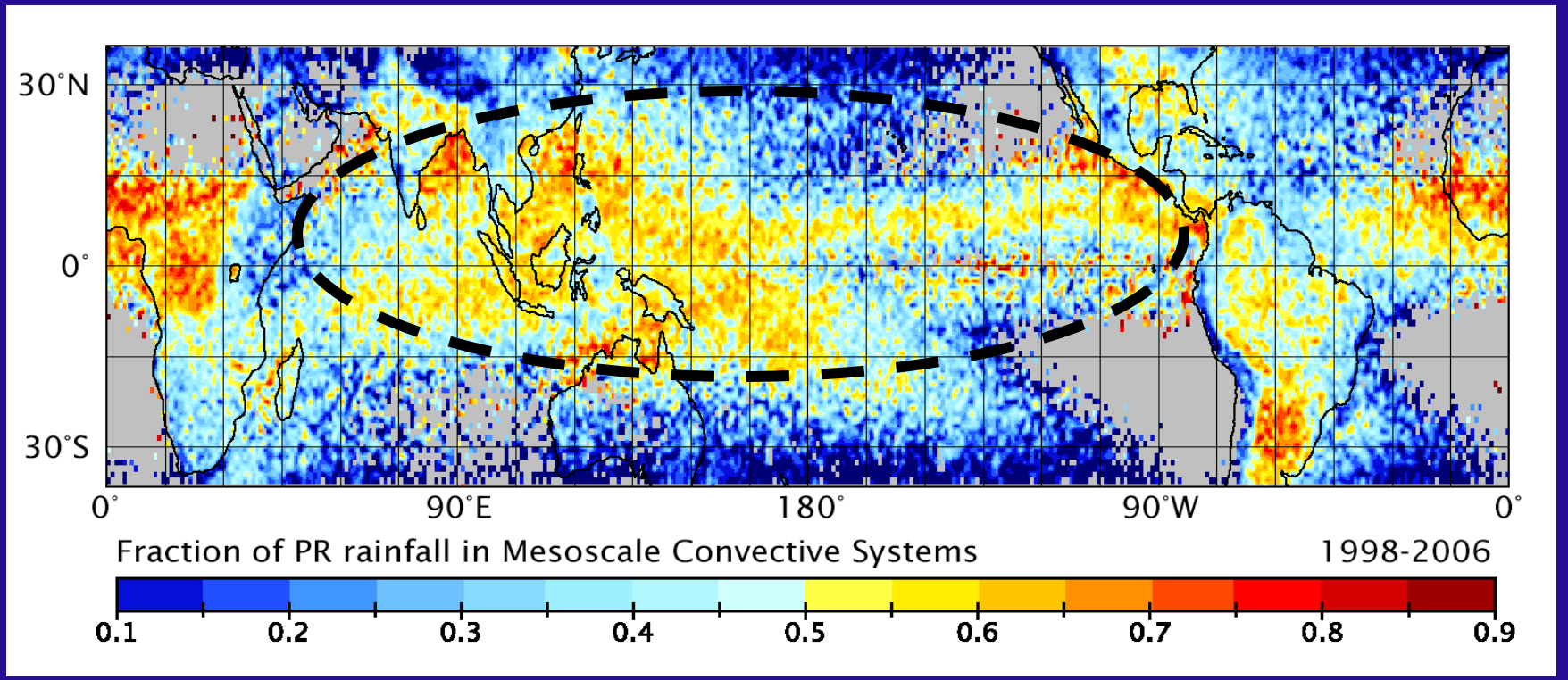
Hypothesis

- **Organized tropical convection has coherent effects at large-to-global scales**
- **Minimalist fundamental explanations sought**

Complete description …

Moncrieff, M.W. , C. Liu, and P. Bogenschutz, 2016: Simulation, analytic models, and dynamical-based parameterization of organized moist convection coupled to tropical waves. *J. Atmos. Sci.,* conditionally accepted

Fraction of Tropical-Subtopical Rainfall from MCS from TRMM Database



Tao & Moncrieff (2009)

Organized Convection Parameterization

1) EXPLICIT APPROACH:

- **Global Cloud-system Resolving Models with computational grid 1-10 km, e.g., MPAS, NICAM (e.g., Miyakawa et al. 2012)**

- **Superparameterization: Analysis of large-scale convective organization in Grabowski (2001) aquaplanet simulation identified key role of MCS-like dynamics represented by nonlinear analytic slantwise overturning models (Moncrieff 2004), encouraged investigation in a full GCM (CAM)**

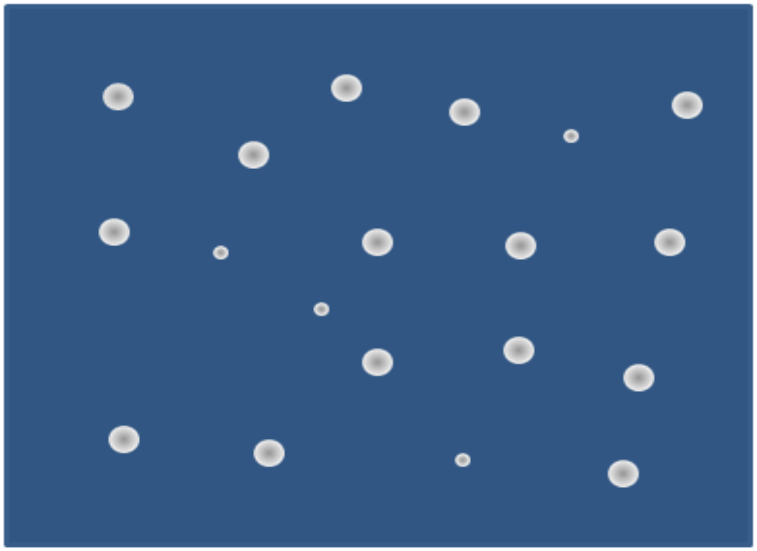
2) DYNAMICAL - BASED APPROACH:

- **Multicloud Model Parametrization (Khouider & Majda 2006, 2007): Replaces traditional convectiveparameterization, excellent success with MJO (NYU Courant Institute; NYU Abu Dhabi Institute)**

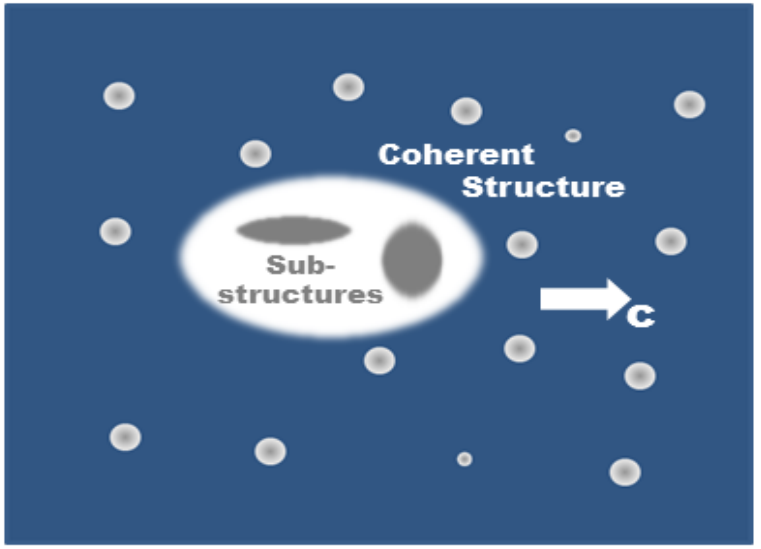
- **Multiscale Coherent Structure Parameterization (MCSP): Nonlinear slantwise overturning model (Moncrleff 2004; 2010) adds "missing organized convection" to traditional parameterization**

Multiscale Coherent Structure Parameterization (MCSP)

a) Cumulus Field



c) Coherent Structure in Cumulus Field

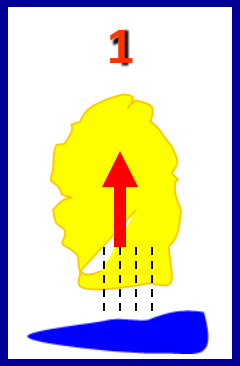


b) Turbulent Cumulus

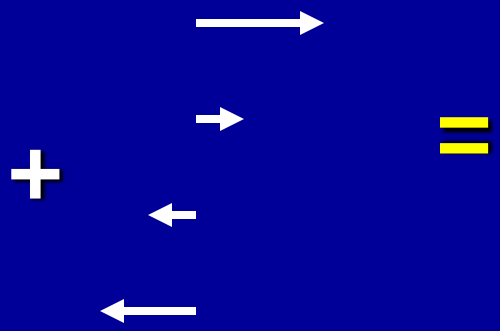
d) Propagating Coherent Structure

Slantwise Overturning Model

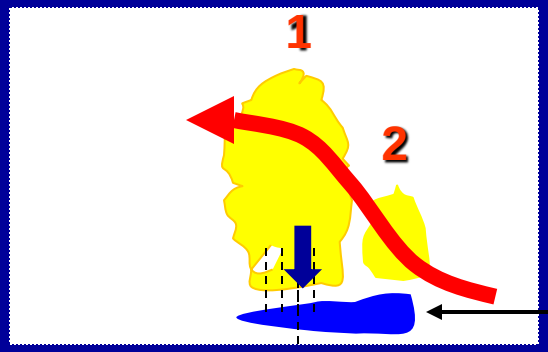
Upscale Evolution: Cumulonimbus to Mesoscale Circulation



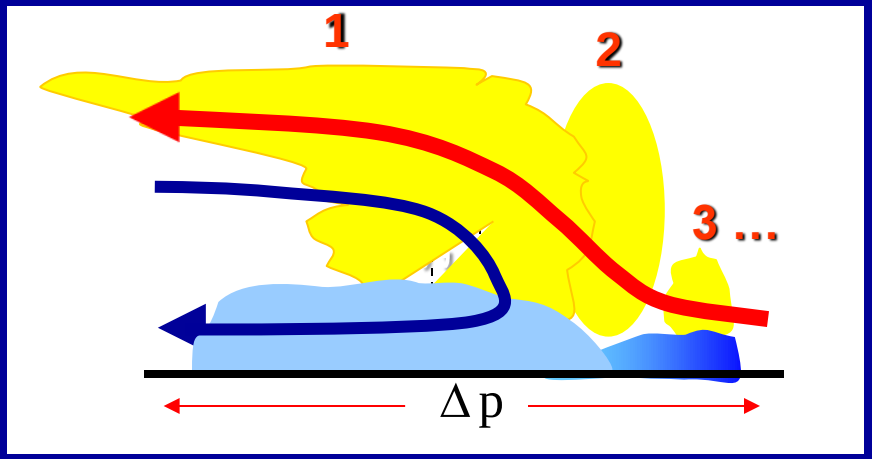
Onset



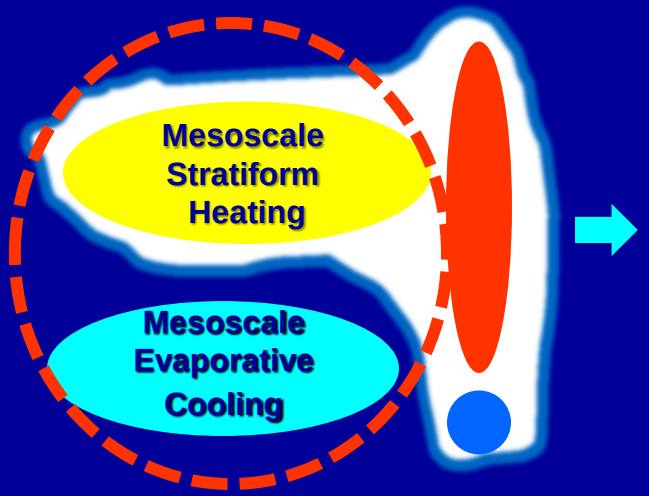
Vertical Shear



Evolution of Cumulonimbus Ensemble



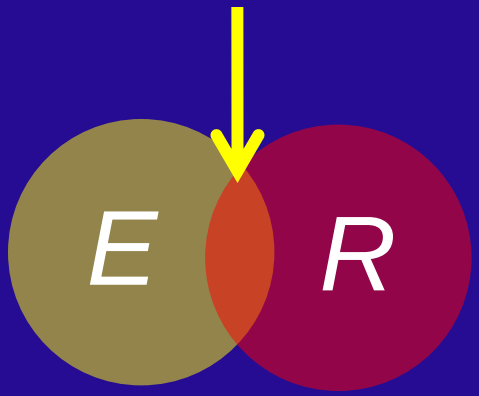
Slantwise Overturning



2nd Baroclinic 'top-heavy' heating, missing from GCMs

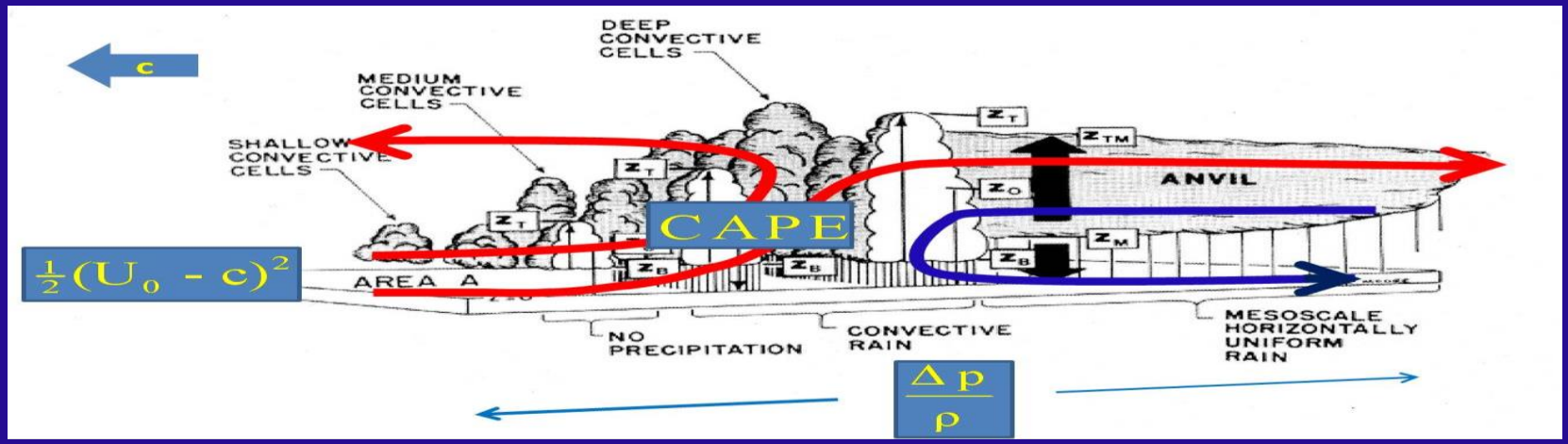
Lagrangian-based Steady Slantwise Overturning Model

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



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

3 Sources of Energy: Potential, Kinetic, Work done by Pressure Gradient

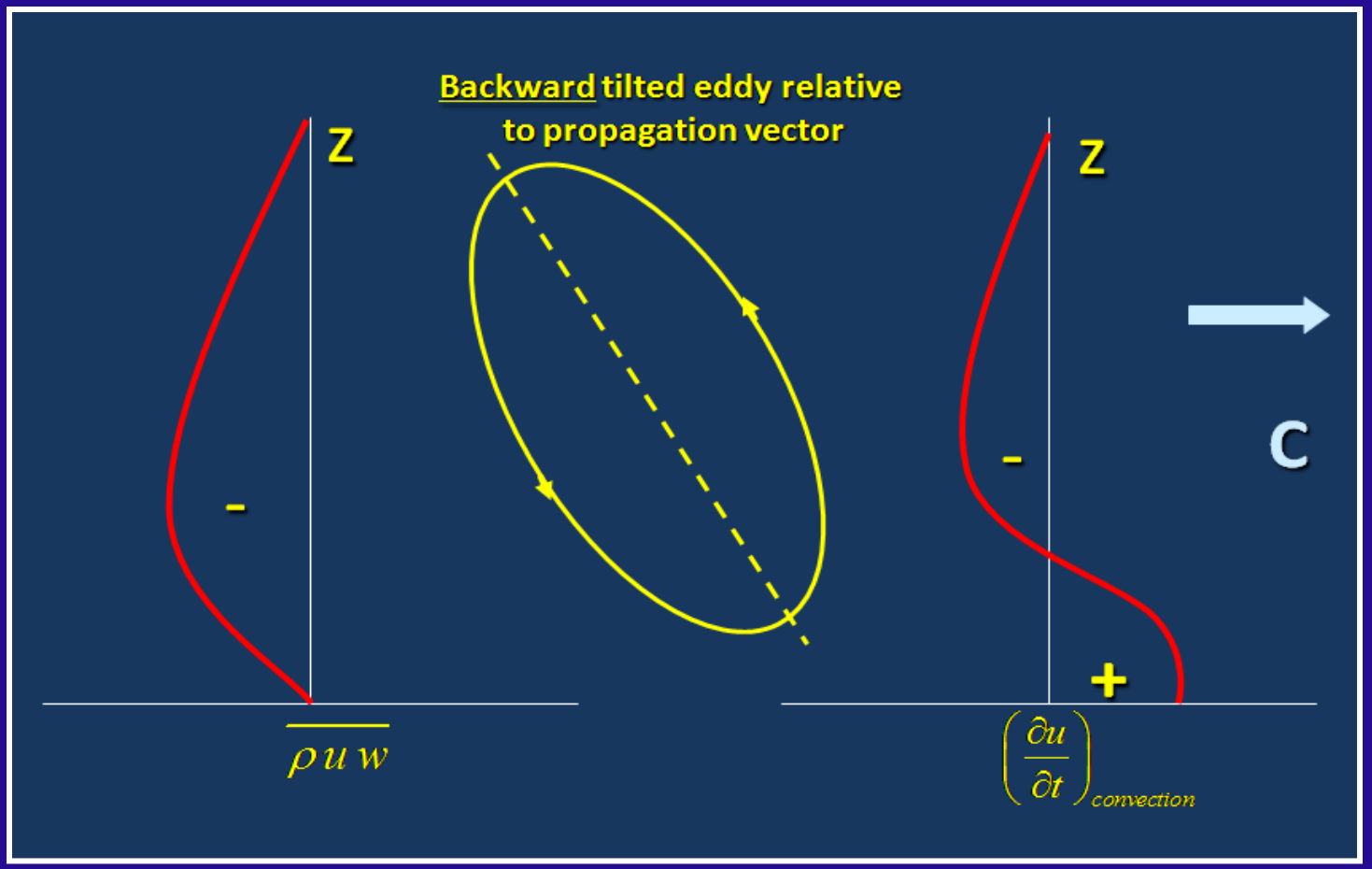


$$\nabla^2 \psi = G(\psi) + \int_{z_0}^{z} \left(\frac{\partial F}{\partial \psi} \right) dz$$

F: Buoyancy measured along trajectories
G: Environmental shear

Key approximation valid across scales (i.e., self-similarity):
Convective heating is proportional to vertical Velocity

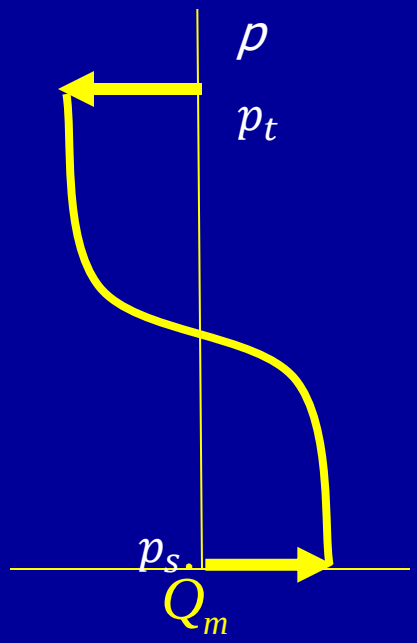
2nd Baroclinic Organized Momentum Transport



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

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

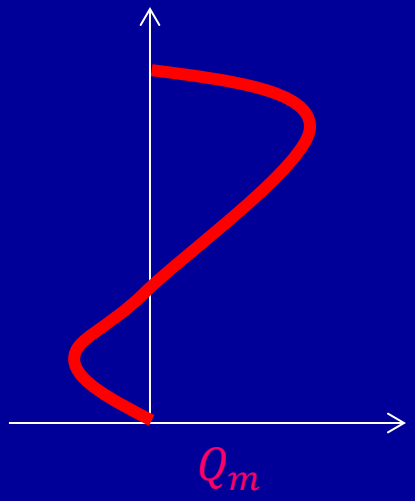
1st baroclinic mode

2nd baroclinc mode

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

Deep Heating (1st Baroclinic)

'Top heaviness' (2nd Baroclinic)

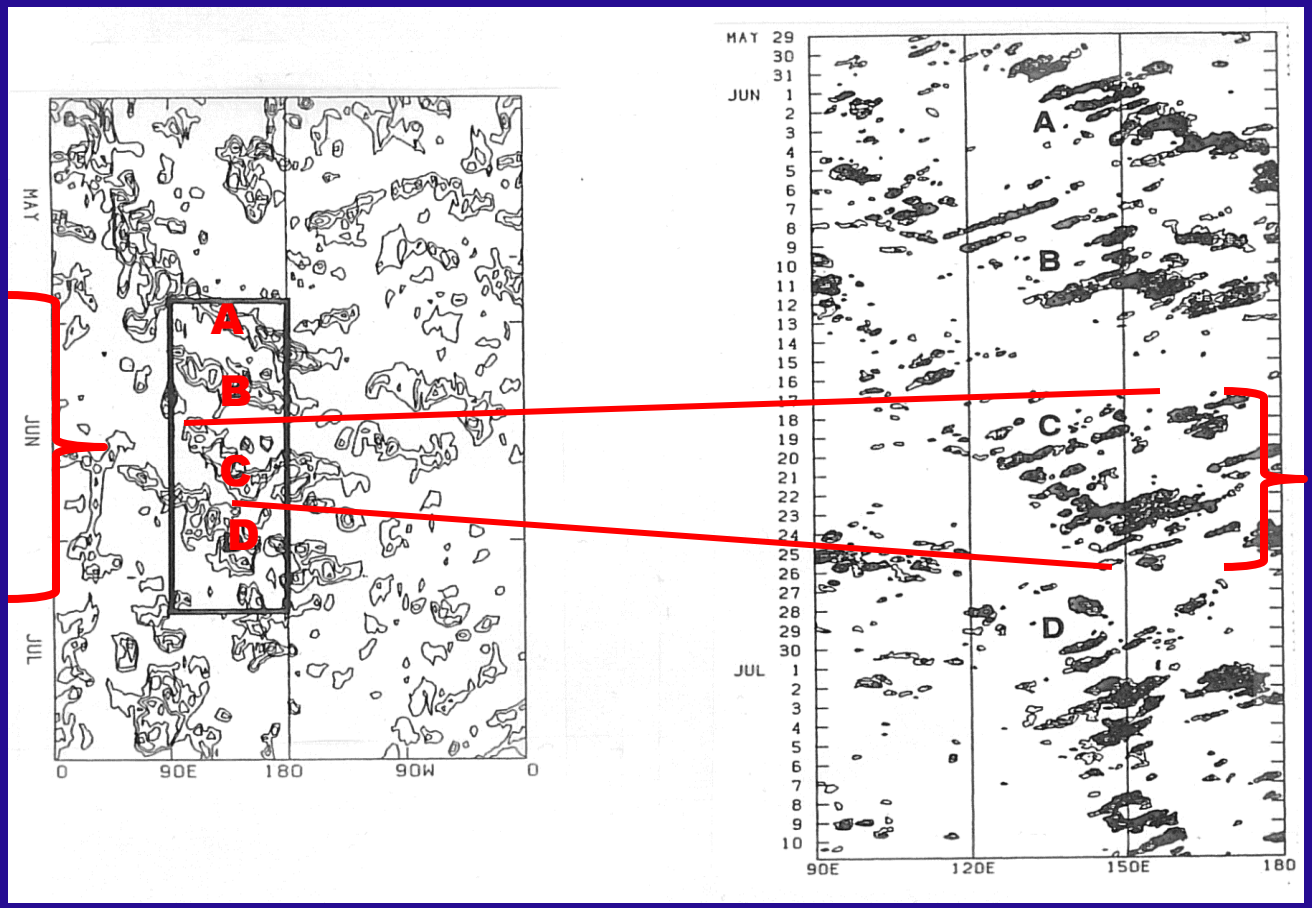


$$\dot{Q}_{total} = \dot{Q}_c + \dot{Q}_m$$

Eastward Propagating MJO & Embedded Westward Propagating Meso-Synoptic Systems

Eastward Propagating Cloud Envelopes

MJOs (A, B,C,D)



Westward Propagating Meso-synoptic Features (C)

Nakazawa (1988)

CAM6 Sensitivity Experiments

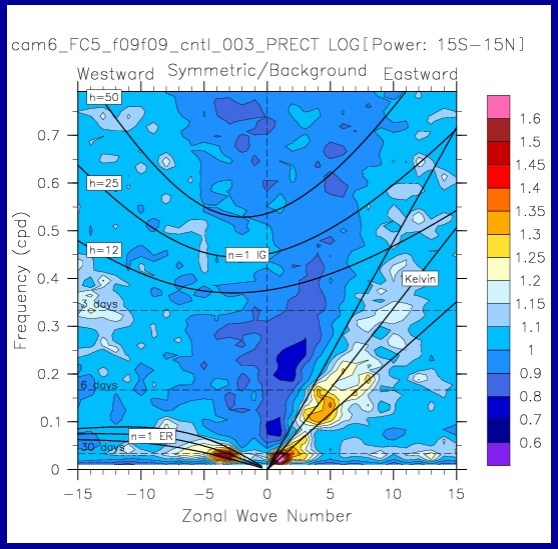
Objective: Investigate the large-scale effects of two key elements of MCS-type convective organization

i) 2nd baroclinic 'top-heavy' convective heating

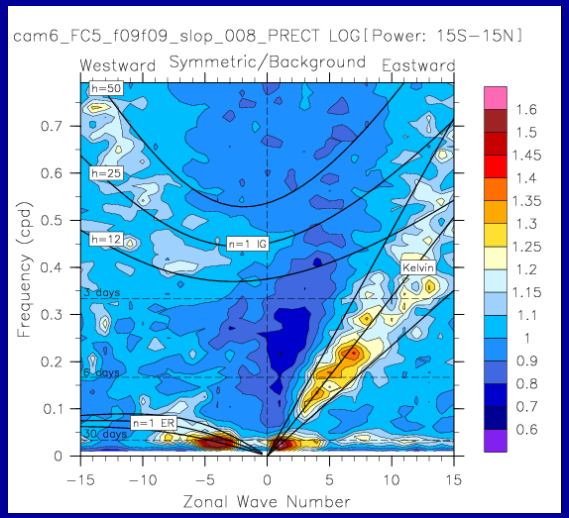
ii) 2nd baroclinic convective momentum transport

- **10-year CAM6 integrations, years 2-10 analyzed**

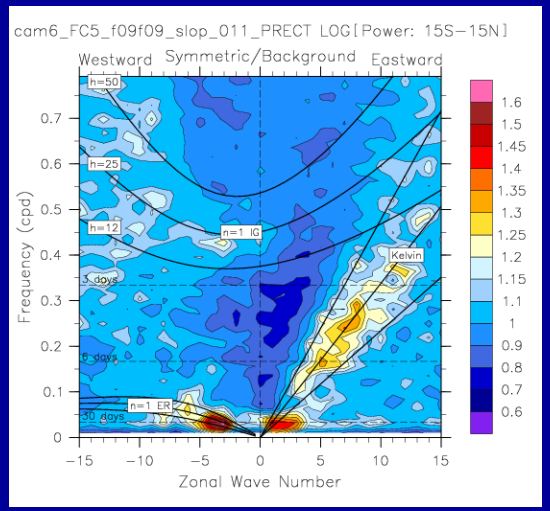
Precipitation Rate (15S -15N)



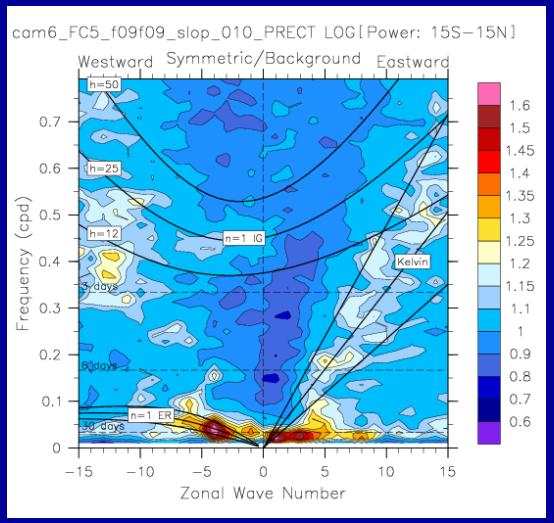
CAM6 Control



MCSP: 2nd Baroclinic Heating

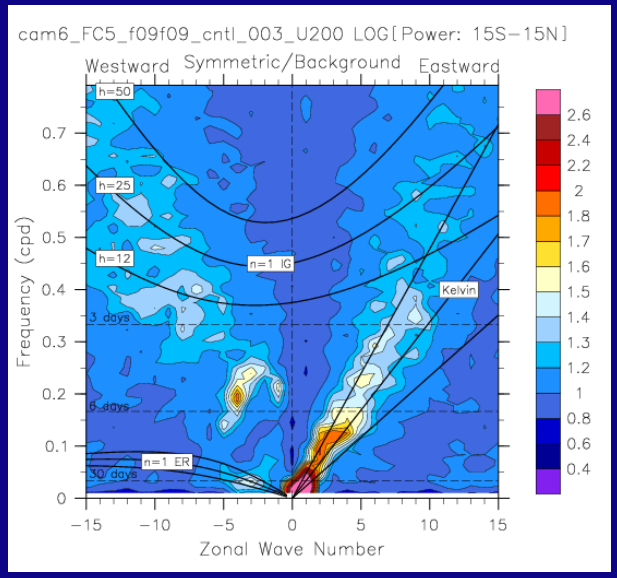


MCSP: 2nd Baroclinic Heating & Momentum Transport (α_3 = 1)

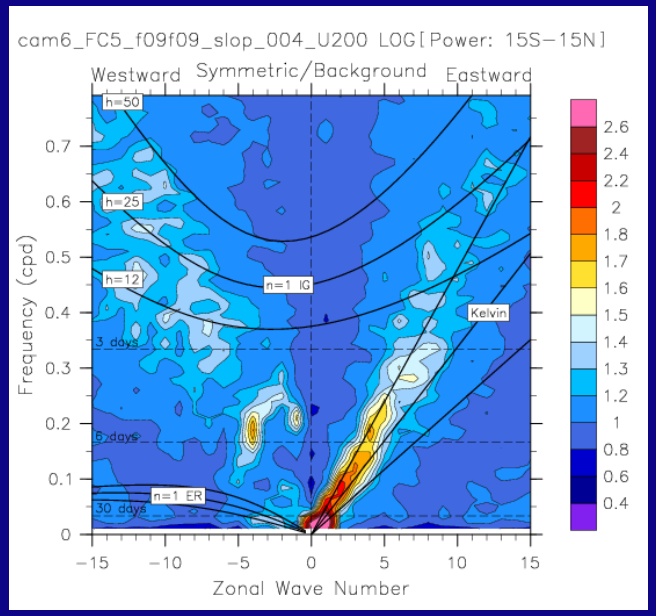


MCSP: 2nd Baroclinic Heating & Momentum Transport (α_3 = 5)

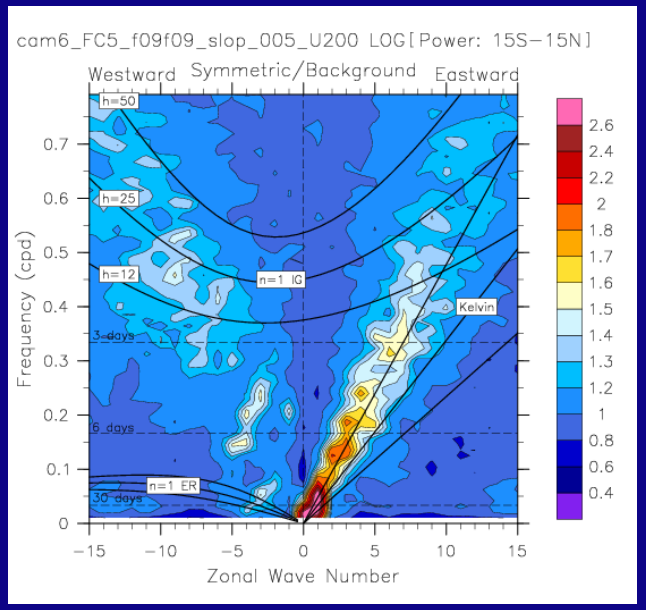
Zonal Wind at 200 hPa (15S – 15N)



CAM6 Control

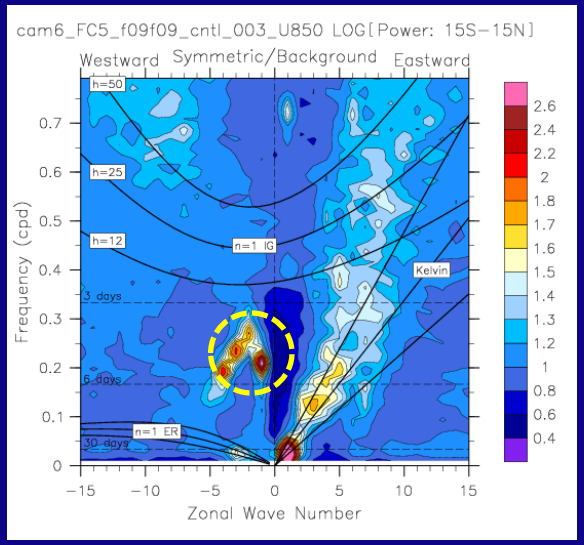


MCSP: 2nd Baroclinic Momentum Transport (α_3 = 1)

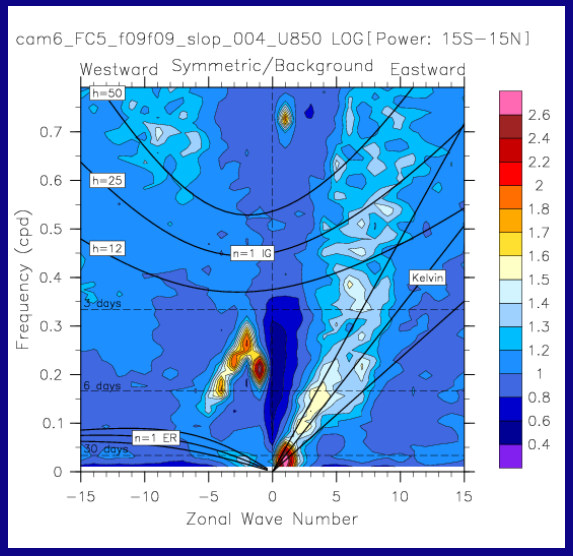


MCSP: 2nd Baroclinic Momentum Transport (α_3 = 5)

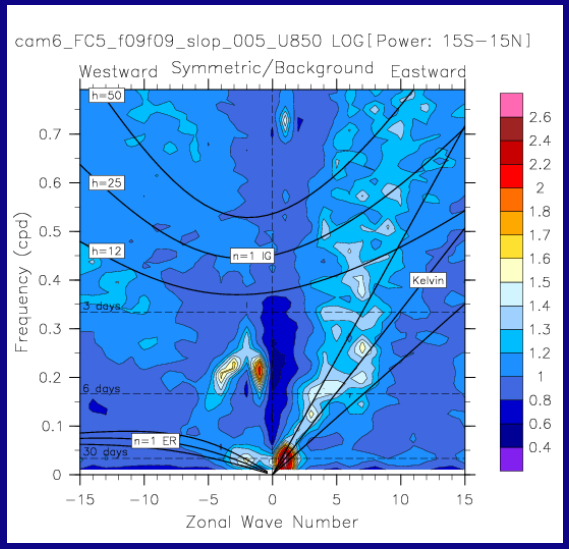
Zonal Wind at 850hPa: Rossby-Haurwitz Waves (15S-15N)



CAM6 Control

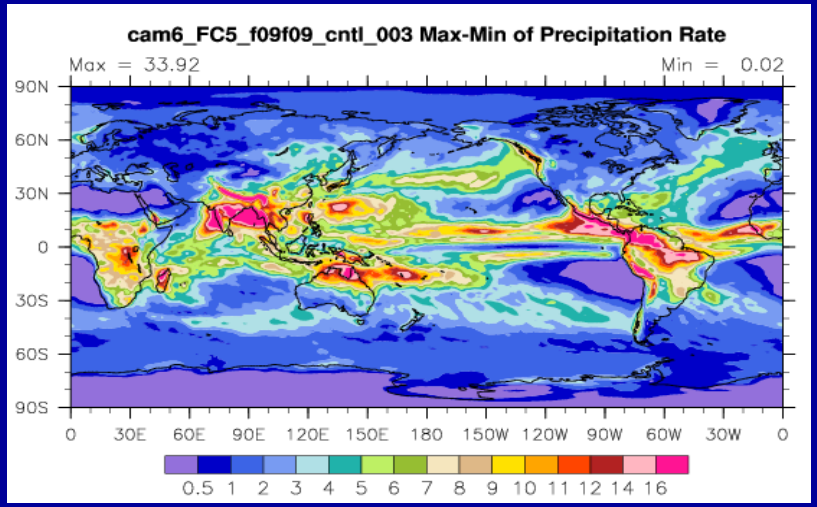


MCSP: 2nd Baroclinic Momentum Transport (α_3 = 1)

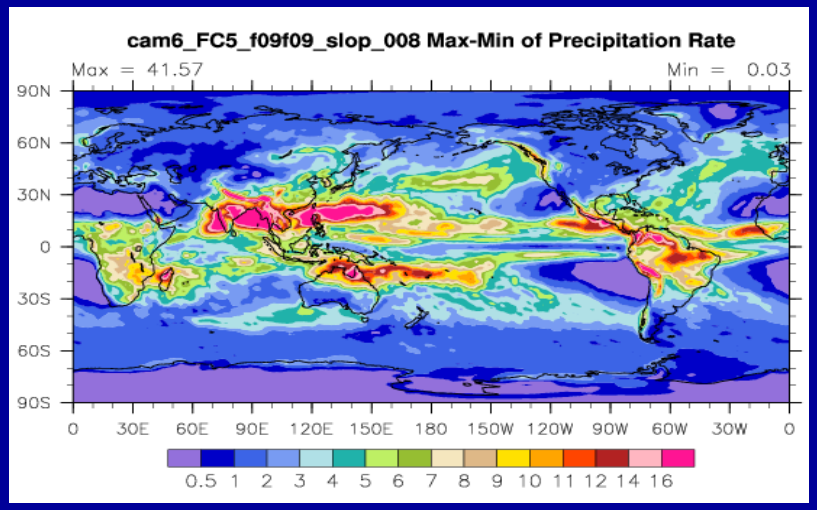


MCSP: 2nd Baroclinic Momentum Transport (α_3 = 5)

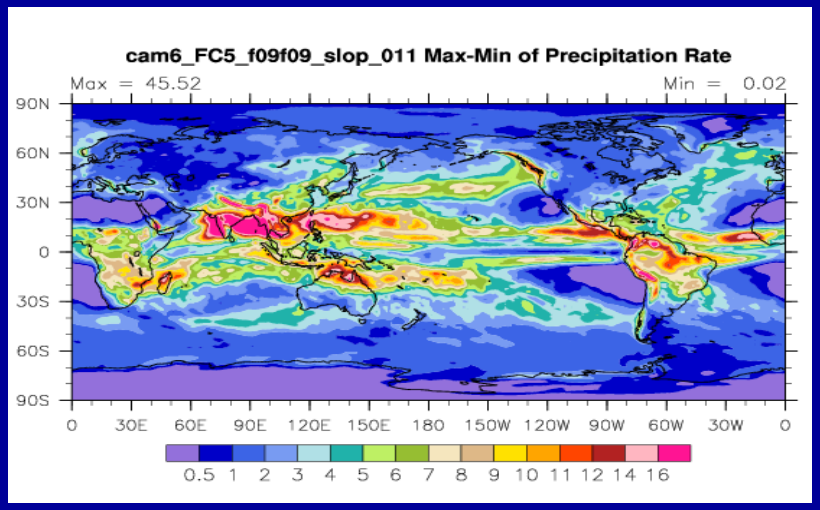
Precipitation ‘Amplitude’



CAM6 Control

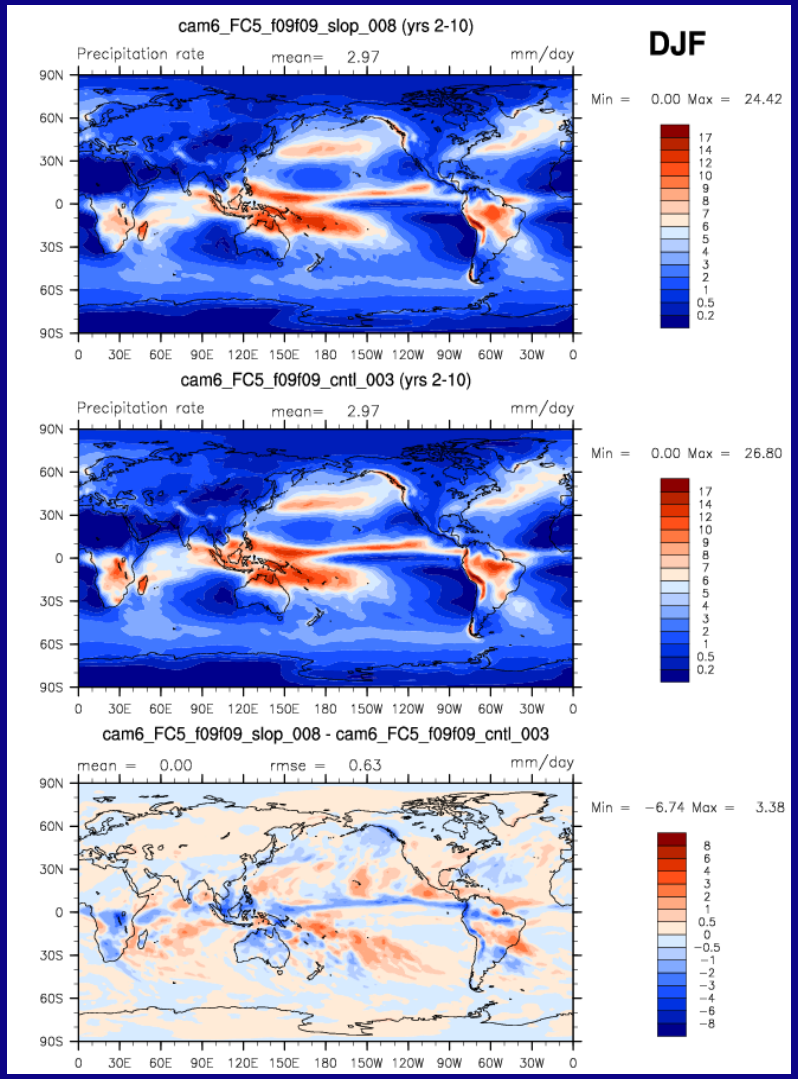


MCSP: 2nd Baroclinic Heating



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

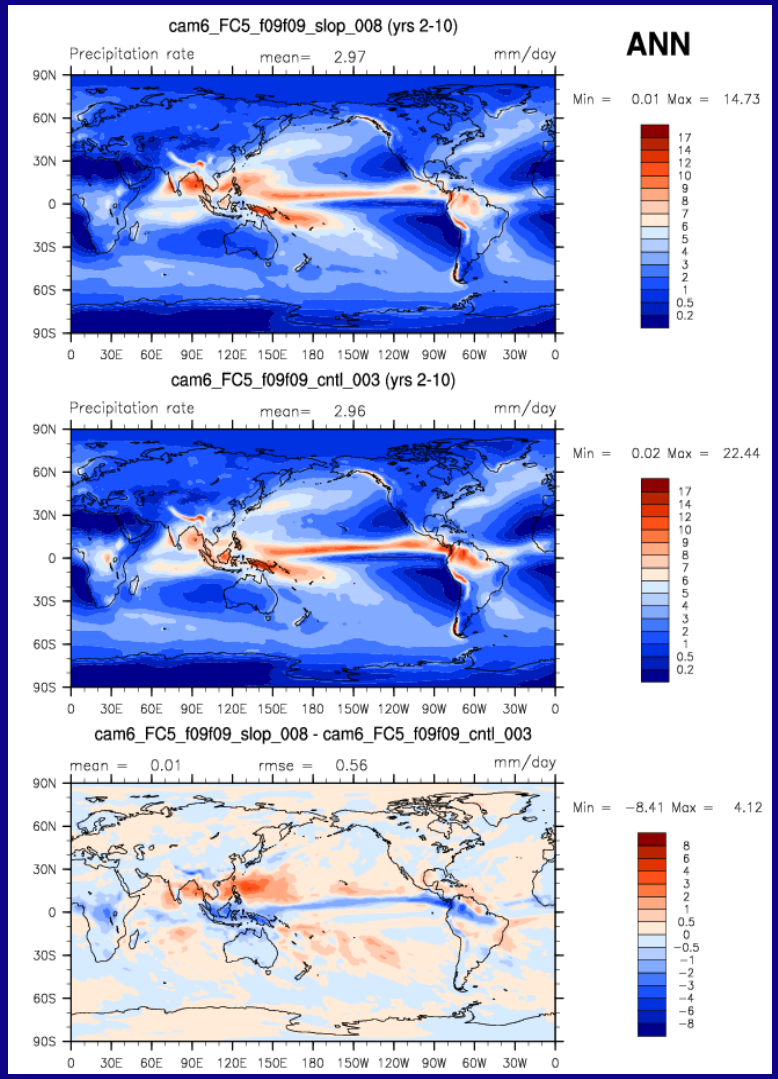
Global Precipitation Rate



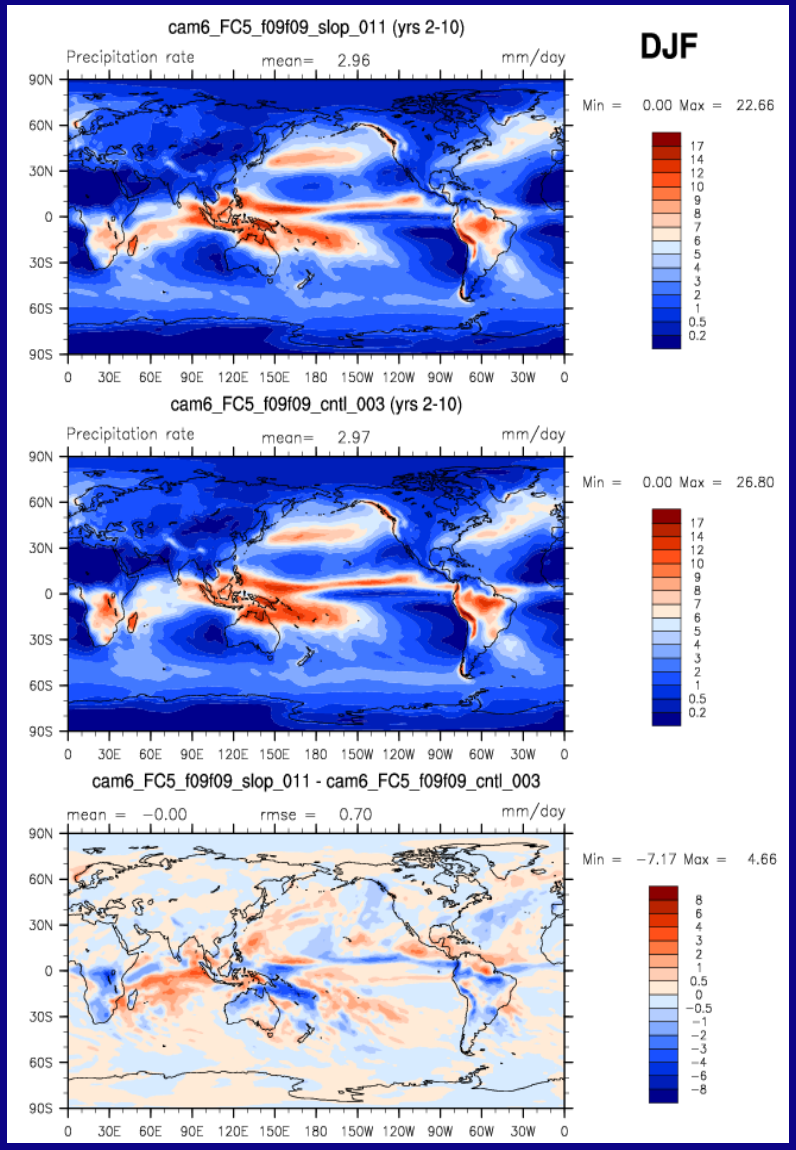
MCSP: 2nd Baroclinic Heating

CAM6 Control

MCSP – CAM6



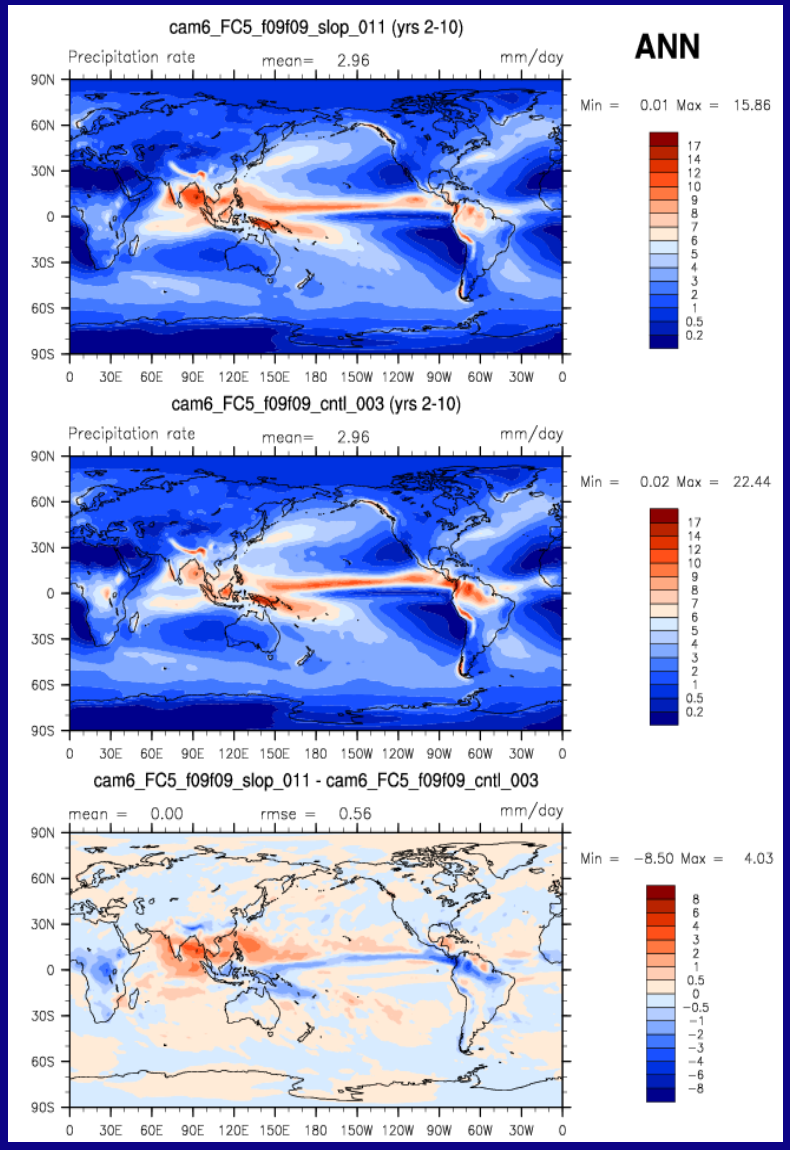
Global Precipitation Rate



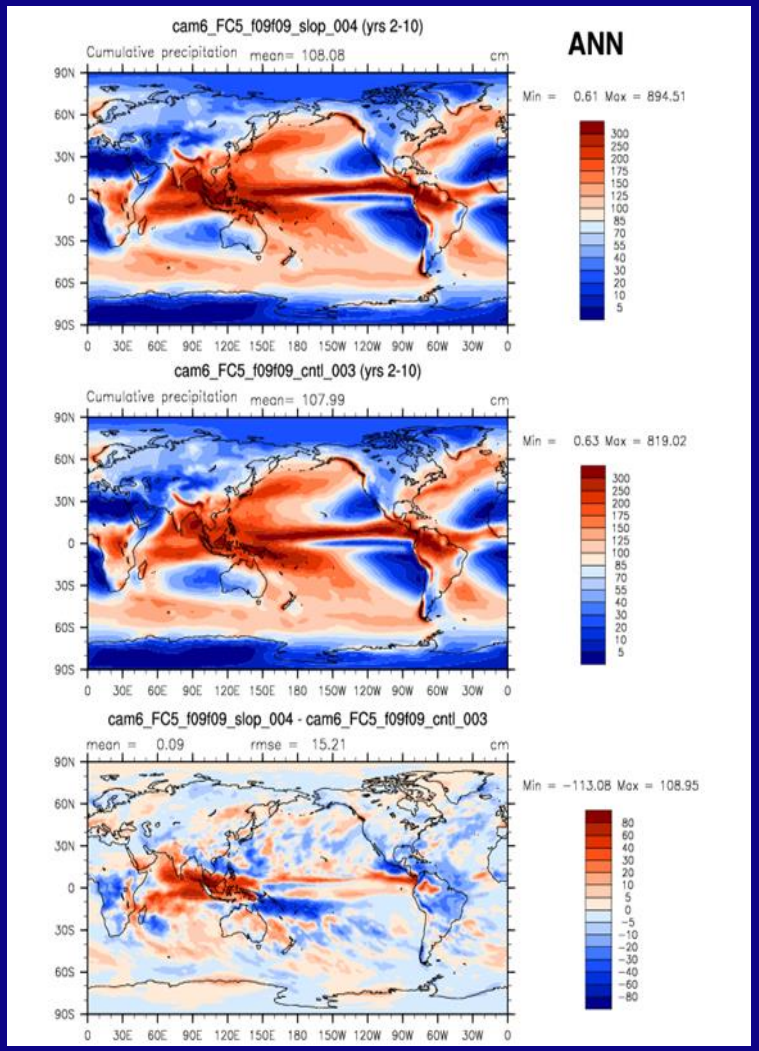
MCSP: 2nd Baroclinic Momentum Transport $\alpha_3 = 1$

CAM6 Control

MCSP – CAM6



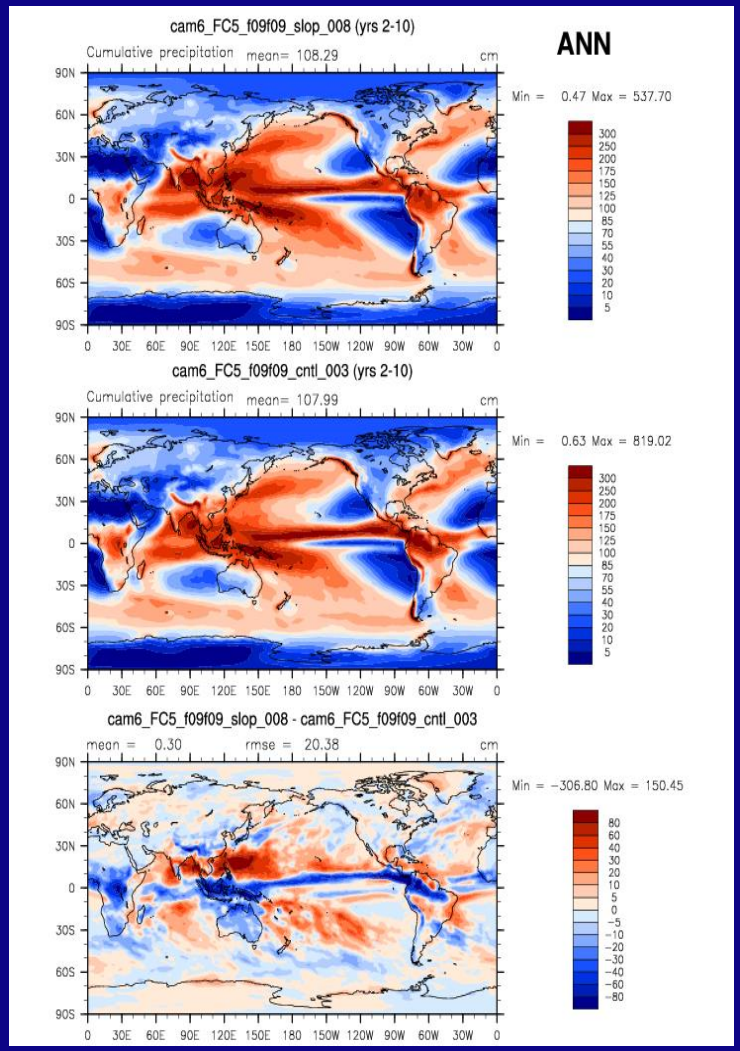
Cumulative Precipitation Pattern



MCSP

CAM6

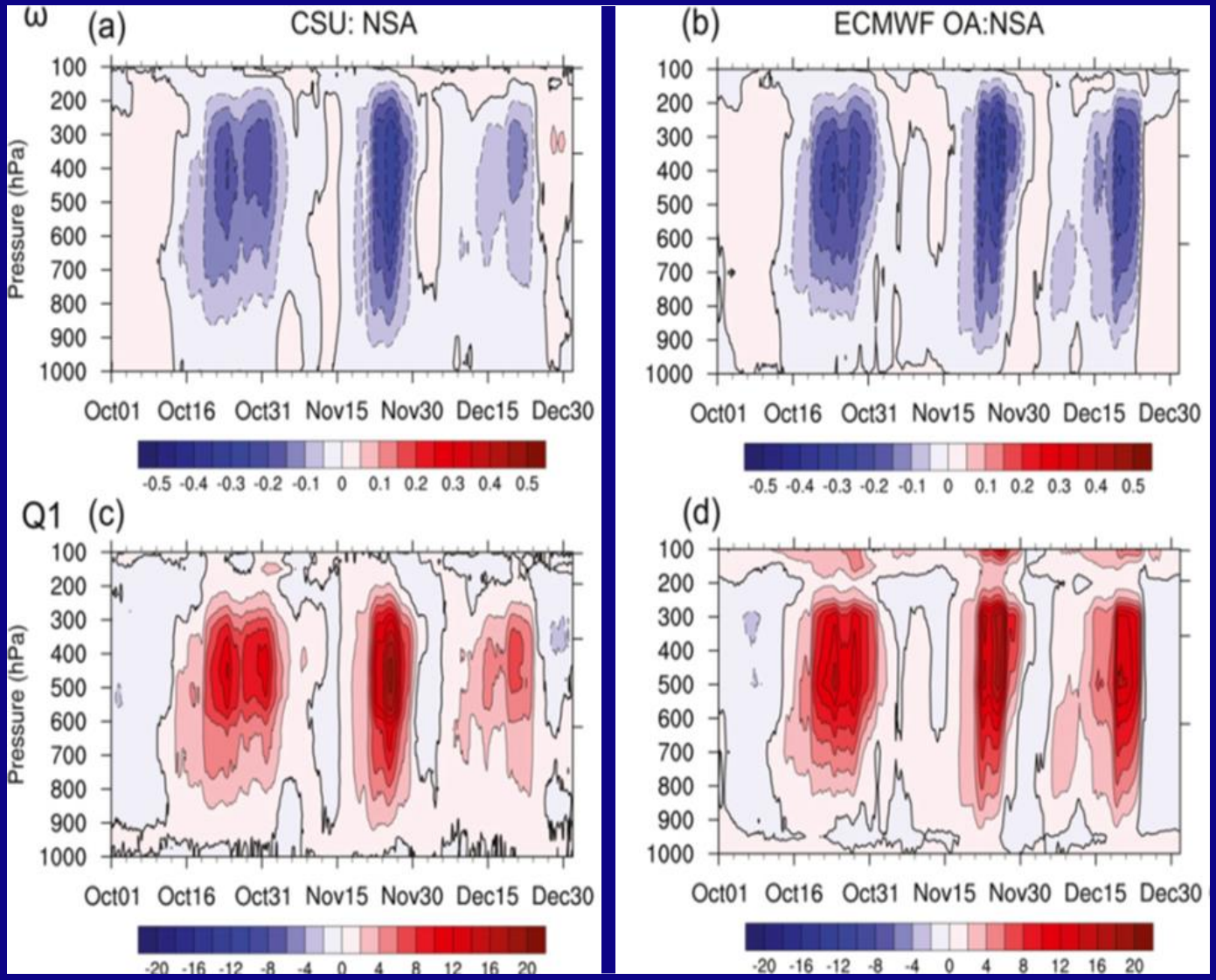
MCSP – CAM6



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

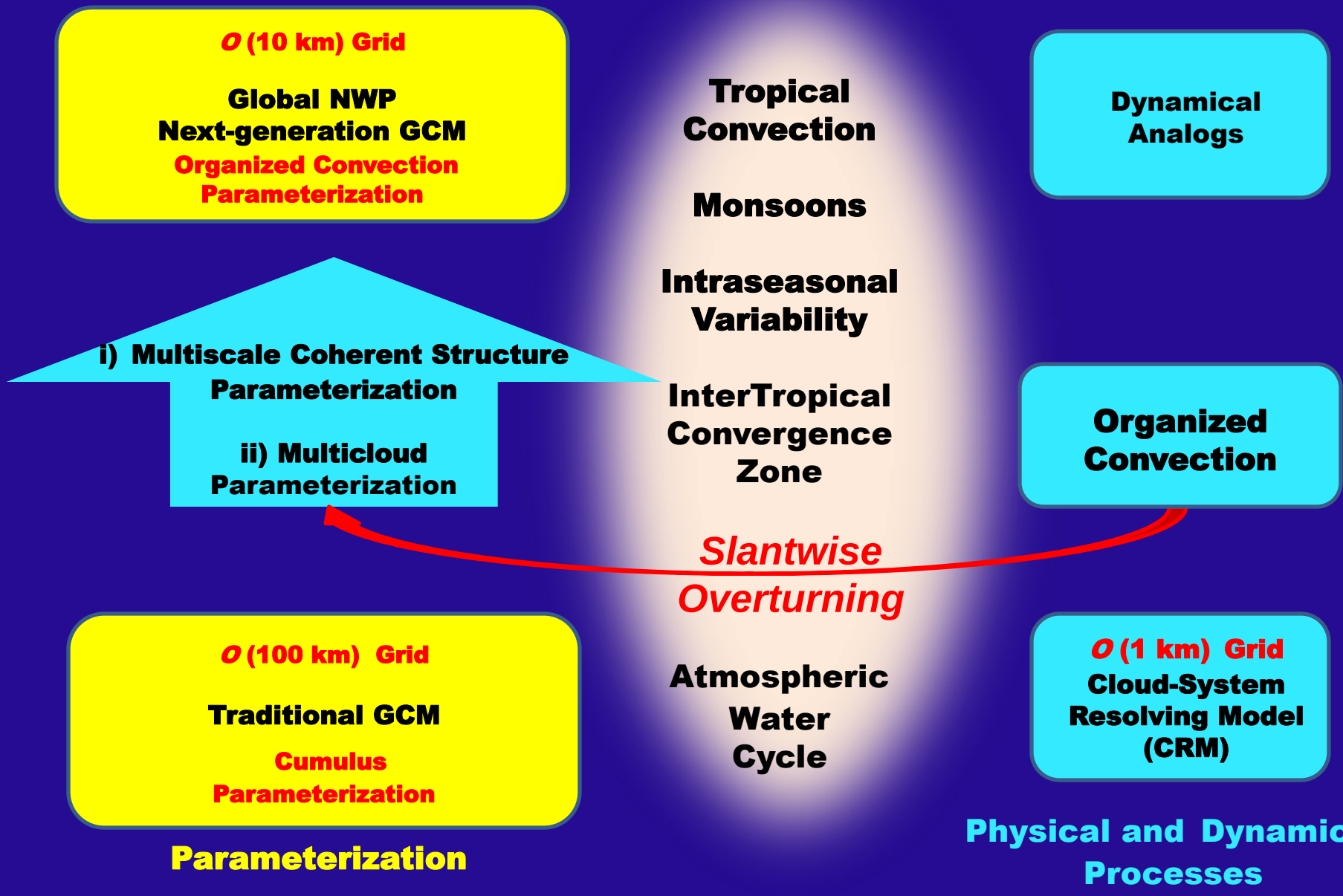
MCSP: 2nd Baroclinic Heating

Convective Heating Rate Proportional to Vertical Velocity (DYNAMO Field Campaign)



Oh et al. (2015)

Model Development Strategy



Summary

- **Multiscale Coherent Structure Parameterization (MCSP), with Slantwise Overturning as the transport module, efficiently adds organized convection to contemporary convective parameterization**

- **Proof of hypothesis: The existence of large-scale coherent response to 2nd baroclinic heating & baroclinic momentum transport in Indian Ocean, Maritime Continent and Tropical Western Pacific regions, i.e., hot spots of global teleconnection**

- **Large-scale features in Indian Ocean, Tropical Pacific, SPCZ, ITCZ are consistent with the TRMM observations**

- **The cross-scale self-similarity of squall lines, MCSs, tropical superclusters and MJO stems from convective heating being proportional to the vertical velocity**

- **The multiscale coherent structure paradigm implies the existence of new scale-selection mechanisms for organized convection at meso- and synoptic-scales**

- **A few lines of code, MCSP is useable in long climate simulations**

- **Much more to be done, e.g.,**
  - **-- CAM6**
  - **-- Collaborate with multicloud parameterization research**
  - **-- Analysis of the 9 km ECMWF IFS *2nd Virtual Global Field Campaign* (YOTC was 25 km)**

References

- 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.

- Miyakawa, T., Y. N. Takayabu, T. Nasuno, H. Miura, M. Satoh, and M.W. Moncrieff, 2012: Convective momentum transport by rainbands within a Madden-Julian oscillation in a global nonhydrostatic model. J. Atmos. Sci., 69, 1317-1338, doi: 10.1175/JAS-D-11-024.1.

- Moncrieff, M.W., and Coauthors, 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.

- 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, PM Ruti Eds.), WMO-No. 1156, ISBN 978-92-63-11156-2, Geneva.

- Moncrieff, M.W., C. Liu, and P. Bogenschutz., 2016: Simulation , analytic models, and dynamical-based parameterization of organized moist convection coupled to equatorial waves. *J. Atmos. Sci.*, conditionally accepted.

- Oh, J-H, X. Jiang, D. E. Waliser, M.W. Moncrieff, R.H. Johnson, and P. Ciesielski, 2015: Momentum Budget Analysis of Westerly Wind Events Associated with the Madden–Julian Oscillation during DYNAMO. J. Atmos. Sci., 72, 3780–3799, doi: http://dx.doi.org/10.1175/JAS-D-15-0044.1

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