Parameterization of Organized Tropical Convection

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Mesoscale Processes

Weather

Climate

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Hypothesis

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

Complete description …

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 convective parameterization, excellent success with MJO (NYU Courant Institute; NYU Abu Dhabi Institute)

   • Multiscale Coherent Structure Parameterization (MCSP): Nonlinear slantwise overturning model (Moncrieff 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

Δp

Mesoscale Stratiform Heating

Mesoscale Evaporative Cooling

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

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

\[ F: \text{Buoyancy measured along trajectories} \]
\[ G: \text{Environmental shear} \]

Key approximation valid across scales (i.e., self-similarity):
Convective heating is proportional to vertical Velocity
2\textsuperscript{nd} Baroclinic Organized Momentum Transport

\[ \frac{\partial \bar{u}}{\partial t} + \ldots = - \frac{\partial}{\partial z} \left( \bar{u} \bar{w} \right) = \left( \frac{\partial u}{\partial t} \right)_{\text{convection}} \]
Momentum Transport Parameterization

\[ Q_m(p,t) = \alpha_3 \cos \pi \left( \frac{p_s - p}{p_s - p_t} \right) \]
$Q_m (p, t) = Q_c (p, t) \left[ \alpha_1 \sin \pi \alpha \left( \frac{p_s - p}{p_s - p_t} \right) - \alpha_2 \sin 2\pi \left( \frac{p_s - p}{p_s - p_t} \right) \right]$
Eastward Propagating MJO & Embedded Westward Propagating Meso-Synoptic Systems

Nakazawa (1988)
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 ($\alpha_3 = 1$)

MCSP: 2nd Baroclinic Heating & Momentum Transport ($\alpha_3 = 5$)
Zonal Wind at 200 hPa (15S – 15N)

CAM6 Control

MCSP: 2\textsuperscript{nd} Baroclinic Momentum Transport (\(\alpha_3 = 1\))

MCSP: 2\textsuperscript{nd} Baroclinic Momentum Transport (\(\alpha_3 = 5\))
Zonal Wind at 850hPa: Rossby-Haurwitz Waves (15S-15N)

CAM6 Control

MCSP: 2\textsuperscript{nd} Baroclinic Momentum Transport ($\alpha_3 = 1$)

MCSP: 2\textsuperscript{nd} Baroclinic Momentum Transport ($\alpha_3 = 5$)
Precipitation ‘Amplitude’

CAM6 Control

MCSP: 2\textsuperscript{nd} Baroclinic Heating

MCSP: 2\textsuperscript{nd} Baroclinic Heating & Momentum Transport ($\alpha_3 = 1$)
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: 2\textsuperscript{nd} Baroclinic Momentum Transport ($\alpha_3 = 1$)

MCSP: 2\textsuperscript{nd} Baroclinic Heating
Convective Heating Rate Proportional to Vertical Velocity
(DYNAMO Field Campaign)

Oh et al. (2015)
Model Development Strategy

- **$O(10 \text{ km})$ Grid**
  - Global NWP
  - Next-generation GCM
  - Organized Convection Parameterization

- **$O(1 \text{ km})$ Grid**
  - Cloud-System Resolving Model (CRM)
  - Dynamical Analogs

- **$O(100 \text{ km})$ Grid**
  - Traditional GCM
  - Cumulus Parameterization

- **Multiscale Coherent Structure Parameterization**
  - i) Multiscale Coherent Structure Parameterization
  - ii) Multicloud Parameterization

- **Organized Convection**

- **Tropical Convection**

- **Monsoons**

- **Intraseasonal Variability**

- **InterTropical Convergence Zone**

- **Atmospheric Water Cycle**

- **Slantwise Overturning**

- **Physical and Dynamical Processes**
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


