Diabatic Processes in the Madden-Julian Oscillation

Steve Woolnough

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Outline

1. Motivation and Introduction

2. The GASS-MJOTF “Vertical Structure and Physical Process in the MJO Project”
   — A Global Modelling Project

3. Cascade MJO simulations
   — MJO simulations in a convection permitting model

4. Summary
Motivation

• The Madden-Julian Oscillation is the leading mode of sub-seasonal tropical variability, with global impacts
  • Modulates local weather, including monsoon systems
  • Teleconnections to extratropics
  • Role in the onset of El Niño events
• However
  • Generally poor simulation in climate models (Lin et al, 2006; Hung et al. 2013) and until recently extended range prediction systems (e.g. Waliser 2011)
  • No clear consensus on the relative importance of key physical processes in determining the initiation, maintenance and propagation of the MJO
The role of diabatic heating in the MJO

- The interaction between the convection and the large-scale dynamics are fundamental to the MJO, but the details of the diabatic processes are key to understanding the details of the MJO propagation characteristics including e.g. –
  - role of stratiform heating (e.g. Chang and Lim, 1988; Fu and Wang 2009)
  - role of shallow heating (e.g. Wu 2003, Li et al 2009)
  - role of moistening by shallow convection (e.g. Woolnough et al. 2010)
  - sensitivity of convection to environmental humidity (e.g. Hannah and Maloney 2011)
  - cloud (e.g. Lee et al. 2001; Raymond 2001) and clear-sky (e.g. Bony and Emanuel 2005) radiative effects
The vertical profile of heating

- The primary influence of the vertical profile of the diabatic heating is through the vertical modes of the waves it excites. This can impact the characteristics of the Madden-Julian Oscillation.
  - Directly, through the phase speed of the modes excited (e.g., Chang and Lim 1988) and in the energetics of the waves (e.g., Mu and Zhang 2006).
  - Indirectly through the role of the vertical profile of convergence in determining the moisture convergence (e.g., Benedict et al. 2013).
• Broad agreement between reanalysis products showing strongly tilted structure
• Large differences between satellite retrievals with varying degrees of tilt and vertical distribution (and even mean) heating

Some uncertainty in the variations in diabatic heating associated with the MJO

MJO composite heating anomalies from re-analysis products (top row) and satellite retrievals (bottom row), Jiang et al (2009, 2011).
Response to heating – Moisture Convergence

Moisture Convergence
Moisture Convergence - Heating
Difference

ERA-I

FIXED
FIXED
FULL
FULL-FIXED

TRAIN

Run 981 TCMC
Run 981 TCMC Anom (TCMC-TCH)
Run 983 TCMC Anom (TCMC-TCH)
Run 983-981 TCMC Diff

Run 984 TCMC
Run 984 TCMC Anom (TCMC-TCH)
Run 986 TCMC Anom (TCMC-TCH)
Run 986-984 TCMC Diff

James Taylor, PhD Thesis
Response to heating – Energetics

Eddy APE Generation

Conversion of EAPE to EKE

ERA-I

FULL

FIXED

TRAIN

James Taylor, PhD Thesis
The GASS-MJOTF Diabatic Heating Project

• The combination of
  • the critical role of the detail of diabatic process in MJO theories,
  • the relatively poor simulation of the MJO in GCMs,
  • the availability of new “observations” of diabatic heating

prompted the (then YOTC) MJO Task Force in collaboration with GASS to develop the “Vertical Structure and Physical Process of the MJO - Global Model Evaluation” Project

Petch et al., 2011: A Global Model Intercomparison of the Physical Processes Associated with the Madden-Julian Oscillation. GEWEX News, August.


Klingaman et al., 2014: Vertical structure and physical processes of the Madden–Julian Oscillation: Linking hindcast fidelity to simulated diabatic heating and moistening. JGR submitted

Xavier et al., 2014: Vertical structure and physical processes of the Madden-Julian Oscillation: Biases and uncertainties at short range. JGR nearly submitted

http://climate.ncas.ac.uk/pmwiki/MJO_Diabatic_Hindcast/index.php/Main/HomePage
The GASS-MJOTF Diabatic Heating Project

**Time step / 2 – Day Physics Errors**

**Daily / Weekly Forecast Errors**

**Long-Term Climate Simulation Errors**

GASS-like process study

AMIP-like intercomparison

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<th>Experiment</th>
<th>Output Data</th>
<th>Science Focus</th>
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</thead>
<tbody>
<tr>
<td>II. 2 day hindcasts YoTC MJO cases E&amp;F * Prince Xavier Jon Petch</td>
<td>Detailed time step data on model grid for Indo-Pacific domain (11 models)</td>
<td>Evaluation of model physics during different MJO phases</td>
</tr>
<tr>
<td>III. 20 day hindcasts YoYC MJO cases E&amp;F * Nick Klingaman Steve Woolnough</td>
<td>Global 3 hourly Including vertical profiles of tendencies (14 models)</td>
<td>MJO hindcast skill Lead time dependent evolution of diabatic processes</td>
</tr>
</tbody>
</table>
Summary

• Range of MJO fidelity across all three components

• No clear link between the vertical profile of diabatic heating and the fidelity of the simulations of the MJO

• Little correlation between a model’s ability to predict the MJO and its ability to simulate MJO variability in a free running climate simulation

• A reliable representation of the moistening profile, particularly at low and mid-levels during the transition between suppressed and active convection, may be critical to simulating the MJO in these models.
20-day hindcast "skill"

Bi-variate correlation of hindcast and observed RMM1 and RMM2 for 20091010 to 20100215
Non-radiative diabatic heating profiles

- Lines shown 4 precipitation quartiles and < 1 mm/day
- Wide range of vertical heating profiles between models
- Increasingly top heavy for increasing precipitation rate
- No relationship between model hindcast skill and
  - Shape of profile
  - Change in profile with precipitation rate
Non-radiative diabatic heating profiles

Fraction of Heating above 550hPa, for Q4 and difference with Q2, Q1
Humidity Tendencies from Physics

• Very different detailed structure
• Better models tend to have net-moistening or zero tendency for 2\textsuperscript{nd} quartile at low-levels
• Less good models tend to have drying at low levels for 2\textsuperscript{nd} quartile
Total Moistening Rates (Physics + Dynamics)

- Very different detailed structure
- Better models tend to have net-moistening or zero tendency for 2nd quartile at low-levels
- Less good models tend to have drying at low levels for 2nd quartile
- Clearer distinction when looking at total tendency and transition from net moistening to drying
Total Moistening Rates with precipitation rate

- Higher-skill models show smooth transition from low-level moistening at low precipitation rates to mid-level and then upper-level moistening at heavier precipitation rates.

- Lower skill models tend to have very weak signal or sharp switch.
Simulation of the MJO in a cloud resolving model

- Part of a larger NERC funded project *Cascade* to perform large domain convection permitting simulations of tropical convection
  - 14000x4000km domain over Indian Ocean and West Pacific
  - YoTC case D
  - Forced at boundaries by ECMWF YoTC analysis
  - Range of resolutions from 1.5km to 40km
  - Comparison of simulations with explicit convection and parametrized convection
  - Sensitivity to vertical mixing in explicit convection simulations

Holloway et al., 2013: The effects of explicit versus parameterized convection on the MJO in a large-domain high-resolution tropical case study. Part I: Characterization of large-scale organization and propagation. *J. Atmos. Sci.*

... Part II: Processes leading to differences in MJO development; *in preparation*
# Cascade MJO Simulations

<table>
<thead>
<tr>
<th></th>
<th>4 km 2Dsmag</th>
<th>4 km 3Dsmag</th>
<th>12 km 2Dsmag</th>
<th>12 km 3Dsmag</th>
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<th>40 km</th>
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Explicit vs Parametrized Convection

- Parametrized Convection Simulations fail to capture eastward propagation
- 3 of four explicit convection simulations capture propagation but
  - 4km 2Dsmag loses organization very quickly
  - 12km simulations have very over active convection
Vertical Heating Profiles

- 12km model has large variations in heating profile with heating increasing above 4km and decreasing below (relatively) with increasing precip

- 4km model has less marked increase in top-heaviness with increasing precipitation and relative reduction in heating occurs between surface and 2km

Normalized heating profiles as a function of precipitation, Yellows ~ 20mm/day, Light blues ~ 10mm/day
Vertical Heating Profiles

Difference between normalized heating rates between 4-12km and 0-4km with precipitation contours

• 12km strongly tied and collocated with maximum precipitation
• 4km maximum “top-heaviness” seems to lag maximum heating slightly

Generation of APE

• 4km (orange) has much larger generation of APE than 12km (green)
• ~ 50% of this change due to changes in the correlation between Q,T between 800-300hPa
• ~35% due to increased variance in Q
Conclusions

• GASS/MJOTF physical process project found no clear link between diabatic heating profiles and MJO performance

• Clear differences between diabatic heating profiles in Cascade simulations but differences in many other things as well and certainly not as trivial as “top heaviness” of heating

• GASS/MJOTF across all components found links between evolution of moisture field during the transition phase and MJO simulation

• YoTC has provided an excellent focus for studying the MJO

• Data from the GASS/MJOTF project can be applied to a wide number of interests and is available for download from

  https://earthsystemcog.org/projects/gass-yotc-mip
## GASS/MJOTF Project Data Archive


The archive contains
- Prognostic variables, cloud variables
- Surface and top of the atmosphere fluxes, near surface variables, integrated water paths
- Tendencies from individual model parametrization schemes
- And for 2 day experiments some parametrization diagnostics

<table>
<thead>
<tr>
<th>Number of Models</th>
<th>Data domain</th>
<th>Data Resolution</th>
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<td>2 day</td>
<td>10°N-10°S 60°E-180°E</td>
<td>Model Grid</td>
<td>Model Grid</td>
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This data could be analyzed for a wide variety of processes and phenomena.