The Madden-Julian Oscillation in General Circulation Models

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Goals

-evaluate the ability of the AMIP and CMIP models to simulate the boreal winter
Madden-Julian Oscillation
  -propagation
  -mechanisms
  -vertical structure
  -role of air-sea interaction

-relationship between mean state error and the MJO
Daily Data (November-March)

-NCEP-NCAR Reanalysis
-CPC Merged Analysis of Precipitation (CMAP)
-Advanced Very High Resolution Radiometer OLR

-20 AMIP Models (1979/80-1994/95)
-9 Coupled Models (9-19 winters)
Analysis

1) MJO Index
   - intraseasonal variability of the 200hPa tropical zonal mean zonal wind
   - used to identify years of strong MJO variability

2) EOF analysis of 20-100 day bandpass filtered AVHRR OLR during years of strong MJO vari-
   ability
   - isolate propagation characteristics of MJO convection

3) Project the 20-100 day bandpass filtered OLR from the observations (1979/80-1994/95) and
   models onto the observed EOF’s to obtain PC’s

4) For each model identify years when the simulated lead/lag behavior of the PC’s is consistent
   with observations

5) For these years, linear regression of PC time series against 20-100 day bandpass filtered OLR,
   rainfall, winds etc. to evaluate observed/simulated spatio-temporal evolution of the MJO. All re-
   gressions have been scaled by a 1 standard deviation perturbation of the PC to return actual units
The 200hPa zonal mean zonal wind MJO index

Based on EOF analysis of 20-100 day filtered OLR, characteristics of the lead-lag relationship of the 2 leading PC’s are also given, including the maximum positive correlation, and the time lag (L’n’; days) at which it occurred. Blue (red) labelling is from the analysis of 10 (7) winters of data.
Characteristics of the two leading EOF’s/PC’s using seven winters of 20-100 day filtered OLR

a) EOF-1 16.2%

b) EOF-2 14.6%

c) % Variance (EOF-1 + EOF-2)

d) PC-2 leads PC-1 by 12 days, R=0.83
Lead-lag relationship between PC-1 and PC-2
-colored lines: individual winters
-thick solid black line: average over all winters
-thick dashed black line: average of winters in observed phase-space

a) AVHRR OLR

b) ECHAM4/HOPE OLR

c) Maximum R vs. time lag
Lag 0 regression of PC-1 and PC-2 with filtered OLR

AVHRR OLR

a) EOF-1

b) EOF-1

c) EOF-2

d) EOF-2

ECHAM4/HOPE
Day of maximum convection

AVHRR OLR

a) EOF-1

b) EOF-1

c) EOF-2
d) EOF-2

ECHAM4/HOPE

Day of maximum convection
Lagged linear regression using PC-1 (5°N-5°S)

Observations

a) AVHRR OLR

b) OLR

c) CMAP Rainfall w/OLR

d) Rainfall w/OLR

ECHAM4/HOPE
Lagged linear regression using PC-1 (5ºN-5ºS)

Observations and NCEP/NCAR Reanalysis

a) SST and ground temperature w/OLR

b) SST and ground temperature w/OLR

c) Surface zonal wind w/OLR

d) Surface zonal wind w/OLR

ECHAM4/HOPE

Observations and NCEP/NCAR Reanalysis

a) SST and ground temperature w/OLR

b) SST and ground temperature w/OLR

c) Surface zonal wind w/OLR

d) Surface zonal wind w/OLR

Lagged linear regression using PC-1 (5ºN-5ºS)
Lagged linear regression using PC-1 (5°N-5°S)

Observations and NCEP/NCAR Reanalysis

a) Latent heat flux w/OLR

b) Latent heat flux w/OLR

c) Sea-level pressure w/OLR
d) Sea-level pressure w/OLR

ECHAM4/HOPE

Legend:

-12.5 -10 -7.5 -5 -2.5 0 2.5 5 7.5 10 12.5

-1.25 -1 -0.75 -0.5 -0.25 0 0.25 0.5 0.75 1 1.25
Lagged linear regression using PC-1 (5°N-5°S)

Observations and NCEP/NCAR Reanalysis

a) 1000hPa Divergence w/OLR

b) 1000hPa Divergence w/OLR

c) 1000hPa Specific humidity w/OLR

d) 1000hPa Specific humidity w/OLR

ECHAM4/HOPE
Lagged linear regression using PC-1 (5°N-5°S)

NCEP/NCAR Reanalysis

a) Divergence 125°E

b) Divergence 125°E

c) Specific humidity 125°E

d) Specific humidity 127.5°E
Table 1: Observed, reanalyzed, and AMIP Model MJO-eastward characteristics. Given are the standard deviations of PC-1 and PC-2, the maximum positive correlation, R, the time lag (days) at which it occurred, and the fraction of years for which the PC’s had a lead-lag relationship consistent with the observations. Shaded models used the same atmospheric component in their coupled integration (see Table 2).

<table>
<thead>
<tr>
<th>Model</th>
<th>PC-1</th>
<th>PC-2</th>
<th>R</th>
<th>Lag (days) PC-2 leads PC-1 (positive)</th>
<th>#Years Eastward/Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVHRR</td>
<td>211.3</td>
<td>205.6</td>
<td>0.67</td>
<td>12</td>
<td>16/16</td>
</tr>
<tr>
<td>NCEP/NCAR</td>
<td>119.4</td>
<td>103.4</td>
<td>0.60</td>
<td>12</td>
<td>14/16</td>
</tr>
<tr>
<td>CCCMA</td>
<td>105.8</td>
<td>102.3</td>
<td>0.41</td>
<td>12</td>
<td>8/16</td>
</tr>
<tr>
<td>CCSR</td>
<td>109.7</td>
<td>91.0</td>
<td>0.41</td>
<td>12</td>
<td>10/16</td>
</tr>
<tr>
<td>CNRM</td>
<td>161.8</td>
<td>141.1</td>
<td>0.57</td>
<td>14</td>
<td>12/16</td>
</tr>
<tr>
<td>COLA</td>
<td>104.0</td>
<td>77.9</td>
<td>0.30</td>
<td>25</td>
<td>7/16</td>
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<tr>
<td>DNM</td>
<td>73.7</td>
<td>70.3</td>
<td>0.42</td>
<td>17</td>
<td>5/16</td>
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<tr>
<td>ECHAM4</td>
<td>221.2</td>
<td>232.2</td>
<td>0.43</td>
<td>12</td>
<td>11/16</td>
</tr>
<tr>
<td>ECMWF (T63)</td>
<td>100.7</td>
<td>97.5</td>
<td>0.42</td>
<td>19</td>
<td>4/16</td>
</tr>
<tr>
<td>ECMWF (T159)</td>
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<td>84.8</td>
<td>0.58</td>
<td>21</td>
<td>4/16</td>
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<tr>
<td>GFDL</td>
<td>107.1</td>
<td>79.7</td>
<td>0.28</td>
<td>14</td>
<td>6/16</td>
</tr>
<tr>
<td>GFDL/DERF</td>
<td>158.4</td>
<td>186.4</td>
<td>0.41</td>
<td>12</td>
<td>13/16</td>
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<tr>
<td>GISS (A170)</td>
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<td>36.2</td>
<td>0.27</td>
<td>20</td>
<td>3/16</td>
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<tr>
<td>GISS (Model II)</td>
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<td>59.2</td>
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<tr>
<td>HADAM3 (L58)</td>
<td>125.4</td>
<td>99.0</td>
<td>0.42</td>
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<tr>
<td>HADAM2 (AMIP I)</td>
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<td>137.9</td>
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<tr>
<td>JMA</td>
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<td>159.3</td>
<td>0.35</td>
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<tr>
<td>MRI</td>
<td>185.0</td>
<td>159.6</td>
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<tr>
<td>NCAR CAM2</td>
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<td>97.2</td>
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<tr>
<td>NCAR CCM3</td>
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<td>82.8</td>
<td>0.37</td>
<td>16</td>
<td>7/16</td>
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<tr>
<td>NCEP (T42)</td>
<td>111.0</td>
<td>103.1</td>
<td>0.46</td>
<td>11</td>
<td>8/16</td>
</tr>
<tr>
<td>NCEP (T62)</td>
<td>102.7</td>
<td>96.1</td>
<td>0.41</td>
<td>21</td>
<td>7/16</td>
</tr>
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Table 2: Observed, reanalyzed, and coupled model MJO-eastward characteristics. Given are the standard deviations of PC-1 and PC-2, the maximum positive correlation, R, the time lag (days) at which it occurred, and the fraction of years for which the PC’s had a lead-lag relationship consistent with the observations. Shaded models used the same atmospheric component in their AMIP integration (see Table 1).

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<td>119.4</td>
<td>103.4</td>
<td>0.60</td>
<td>12</td>
<td>14/16</td>
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<tr>
<td>CSIRO</td>
<td>143.6</td>
<td>165.7</td>
<td>0.49</td>
<td>16</td>
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<td>ECHAM4.6/HOPE (ECHO-G)</td>
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<td>267.1</td>
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<td>ECHAM4/OPYC3</td>
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<td>19/19</td>
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<td>GFDL R30</td>
<td>221.4</td>
<td>198.9</td>
<td>0.48</td>
<td>10</td>
<td>16/19</td>
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<tr>
<td>HADCM3 (L30)</td>
<td>105.5</td>
<td>99.8</td>
<td>0.51</td>
<td>8</td>
<td>14/19</td>
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<td>IAP/LASG GOALS</td>
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<td>132.8</td>
<td>0.47</td>
<td>10</td>
<td>7/9</td>
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<tr>
<td>NCAR CCSM2</td>
<td>103.6</td>
<td>119.8</td>
<td>0.40</td>
<td>16</td>
<td>5/9</td>
</tr>
<tr>
<td>NCAR PCM</td>
<td>109.4</td>
<td>94.9</td>
<td>0.42</td>
<td>15</td>
<td>10/15</td>
</tr>
</tbody>
</table>
MJO OLR propagation vs. the 850hPa wind climatology (Nov.-Mar.)

Observations (1979/80-1994/95)

a) AVHRR OLR

b) OLR

c) NCEP/NCAR 850hPa wind climatology

d) 850hPa wind climatology

ECHAM4/HOPE
MJO OLR propagation vs. the 850hPa wind climatology (Nov.-Mar.)

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**MJO OLR propagation vs. the 850hPa wind climatology (Nov.-Mar.)**


- **a) AVHRR OLR**
- **b) OLR**
- **c) NCEP/NCAR 850hPa wind climatology**
- **d) 850hPa wind climatology**

**ECHAM4/OPA8.1**
MJO OLR propagation vs. the 850hPa wind climatology (Nov.-Mar.)

Observations (1979/80-1994/95)

a) AVHRR OLR

b) OLR

c) NCEP/NCAR 850hPa wind climatology

d) 850hPa wind climatology
Results

1) The MJO is a very stringent test of a model's ability to simulate tropical variability.

2) The models still fail to represent the intraseasonal dominance of the large-scale circulation.

3) Within a family of models, ocean-atmosphere coupling leads to an improved lead/lag structure of the MJO.

4) The ECHAM family of models produces a realistic representation of the MJO, though some problems exist (e.g., latent heat flux relation to MJO convection, details of the vertical structure).
Results (con’t)

5) The propagation of convection into the western/central Pacific tends to be limited by systematic error of the lower-tropospheric zonal wind (e.g., eastward propagation impeded in presence of easterly winds)

6) For the other models a more comprehensive diagnosis of the MJO mechanism will require daily data:
   - latent heat flux
   - winds (standard pressure levels)
   - vertical velocity (standard pressure levels)
   - specific humidity (standard pressure levels)
   - diabatic heating profiles (pressure or model levels?)