MJO modeling and Prediction

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RMM index based on Leading PCs of Combined EOF (OLR, U850, U200)

Phase diagram (RMM1, RMM2) : Nov1979-Apr1980

Composite: OLR & U850
The Madden-Julian Oscillation and its teleconnections (Lin et al. 2006)
Intraseasonal and Interannual Variations: EOF (OBS)

**EOF 1st Mode**

- **EOF 1st mode of ISO activity (13.79%)**
- **EOF 1st mode of Summer mean prcp (28.30%)**

**Time coefficient of 1st mode**

- Corr : ISO Activity & NINO34 = 0.887
- Corr : ISO Activity & Summ. Mean Prcp = 0.867
Predictand: RMM index

Real-time Multivariate MJO index (RMM):

The PCs of combined EOFs (Equatorially averaged OLR, U850, U200)

(Wheeler and Hendon 04)

- EV of Combined EOF

1. Annual cycle removed;
2. Interannual variability (ENSO) removed:
   - Regression pattern of each variable against NINO3.4
   - Mean of previous 120 days

- PCs: RMM1 and RMM2

1. Annual cycle removed;
2. Interannual variability (ENSO) removed:
   - Regression pattern of each variable against NINO3.4
   - Mean of previous 120 days
Madden & Julian Oscillation (MJO) index

RMM index based on Leading PCs of Combined EOF (OLR, U850, U200)

Phase diagram (RMM1, RMM2) : Nov1979-Apr1980

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RMM index based on Leading PCs of Combined EOF (OLR, U850, U200)
Forecast skills of RMM index (Kang and Kim, J. Climate 2010)

### Correlation 0.5 at (day)

<table>
<thead>
<tr>
<th></th>
<th>RMM1</th>
<th>RMM2</th>
</tr>
</thead>
<tbody>
<tr>
<td>DYN (CGCM)</td>
<td>19-20</td>
<td>16-17</td>
</tr>
<tr>
<td>DYN (AGCM)</td>
<td>19-20</td>
<td>16-17</td>
</tr>
<tr>
<td>STAT (MREG)</td>
<td>16-17</td>
<td>14-15</td>
</tr>
</tbody>
</table>
Issues on MJO prediction

1. Model Improvement
   - Convective parameterization

2. Initialization of the model
Climate models **STILL** have problem in simulation of MJO.
Resolution impact with same physics

TRMM: Satellite data (Precipitation)
MJO simulation

200hPa VP (20-70 day filter) : 1999yr
**MJO Variance** (eastward wavenumber 1-6, periods 30-70 days)

IPCC AR4 models

poor!

Convection scheme

: represent model diversity in MJO variability

(Lin et al. 2006)

SNUAGCM

(Lin et al. 2008)
Physics of cumulus parameterization

Cumulus ensemble (A-S) type

- Cloud Top 1 (LNB)
- Cloud Top 2
- Cloud Top 3

Entrainment rate: $\varepsilon = f(T_{CB}, q_{CB}, \overline{T}, \overline{q})$

Cloud structure: $T_c, q_c = f(T_{CB}, q_{CB}, \overline{T}, \overline{q}, \varepsilon)$

Cloud Base (LCL)

- All types of clouds coexists
  - Cumulus ensemble

- Cloud top/entrainment rate
  - Deterministic, insensitive to environment

Bulk type

- Cloud Top
- $w_c = 0$

Entrainment rate: $\varepsilon = f(T_c, q_c, w_c, \overline{T}, \overline{q})$

Cloud structure:
- $T_c, q_c = f(T_{CB}, q_{CB}, \varepsilon, \overline{T}, \overline{q})$
- $w_c = f(T_c, q_c, \varepsilon, \overline{T}, \overline{q})$

Cloud Base (LCL)

- Cloud is homogeneous in horizontal space
  - Bulk model

- more suitable for high resolution model

*similar approach: ECMWF, MPI, UKMO
Practical representation of cumulus ensemble

**Bulk method**
(Kim and Kang 2011, Clim Dyn.)

**Bottom-oriented / Bulk**

In-cloud vertical velocity

\[
\frac{1}{2} \frac{\partial w_u^2}{\partial z} = aB - b\varepsilon w_u^2
\]

- **Buoyancy**
- **Entrainment rate**

- *a=1/6, b=2*

**Entrainment rate**

\[
\varepsilon = C_\varepsilon \frac{aB}{w_u^2}
\]

- Gregory (2001)

Environmental RH effect

Bechtold et al. (2009)

**Detrainment rate**

\[
\delta = \varepsilon + \frac{1}{z_t - z}
\]

- *Above max. buoyancy (linear decrease to zero)*

Cloud top determination

- **depends on Environment**

Surface

Cloud Base (LCL)

Cloud structure

Entrainment rate: \(\varepsilon\)

Cloud Top
Relative humidity

Unit: %
Lag-correlation diagram (U850, 20-100day filtered)

- Reference point: 155-160°E, 5°N-5°S averaged

- NCEP

- Bulk

- RAS

Reference point: 155-160°E, 5°N-5°S averaged
A Mechanism of Northward Propagation of ISO during boreal summer: 
Cumulus Momentum Mixing

(Kang et al., GRL, 2010)
1st mode of EEOF (GPCP, 1997-2005)
Schematic diagram - mechanism

- Easterly mean flow
- Secondary circulation
- Westerly mean flow
- Coriolis force
- CMT forcing
- Momentum mixing
MJO Modeling

1. MJO simulation (eastward propagation)
   - Cumulus convection properly interacting with large-scale environment
   - Cloud-Radiation interaction

2. Summer ISO (northward propagation)
   - Large vertical shear of mean zonal wind
   - Cumulus momentum mixing
Issues on MJO prediction

1. Model Improvement
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2. Initialization of the model
Dynamical MJO prediction system with CGCM

**V1 Prediction System**
- **Atmospheric initial condition**
  - NCEP - Replace
- **Oceanic initial condition**
  - from OGCM run
    - Wind-stress forcing
    - SST (OISST) Nudging
- **Ocean-Atmosphere coupled model**
  - CGCM V.1
    - SNU AGCM + MOM2.2

**Improvement**
- **Observation data**
  - NCEP → ERA40
- **Initialization method**
  - Replace → Nudging

**V2 Prediction System**
- **CGCM V.2**
  - revised SNU AGCM + MOM2.2
  - Cumulus Momentum Transport
  - Diurnal air-sea coupling
  - Tokioka constraint (alpha=0.1)
  - Reduced auto-conversion time scale (tau=9600s → 3200s)

**Procedure**
- **Initialization**
- **Model integration**
Summary of prediction system improvement

Correlation skill of RMM index

<table>
<thead>
<tr>
<th>Initialization</th>
<th>Red (V2 System)</th>
<th>Blue</th>
<th>Green</th>
<th>Black (V1 System)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nudging (rescaling time: 6 hour)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Replace ERA40</td>
<td></td>
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<tr>
<td>Replace NCEP</td>
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<thead>
<tr>
<th>Observation</th>
<th>ERA40</th>
<th>ERA40</th>
<th>NCEP</th>
<th>NCEP</th>
</tr>
</thead>
</table>

<table>
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<tr>
<th>Model</th>
<th>CGCM V.2</th>
<th>CGCM V.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initialized variable</td>
<td>3-dimensional U,V,T,q</td>
<td></td>
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<tr>
<td>Surface pressure (Ps)</td>
<td></td>
<td></td>
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<table>
<thead>
<tr>
<th>Ensemble member</th>
<th>1</th>
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</table>

| Prediction period | 1981.11.6-2000.2.24 (Total: 437 cases) |
Empirical Singular Vector for optimal perturbations (Kug et al, 2009)

1. Define Initial (X) & final (Y) variables with forecast data
   (1) Select optimal time: 10 days → Time-lag between X & Y: 10 days
   (2) Initial variable (X): 925hpa moisture
       Final variable (Y): U850, U200, VP200 at 10-day after
   (3) Calculate anomaly
       - Subtract daily climatology & previous 120 day mean
       - Divide by standard deviation of each variables
   (4) X: PC time series of EOF 5 modes of initial variable
       Y: PC time series of combined EOF 5 modes of final variable

2. Formulate the Empirical Operator (L)
   Linear inverse modeling (L\text{linear})
   \[
   Y = L \cdot X \\
   L = YX^T (XX^T)^{-1}
   \]

3. Find fast growing perturbation using SVD
   \[ L_{\text{linear}} = USV^T \]
   Fast growing perturbations:
   → Right singular vectors whose singular value is maxima
# Correlation skill 2 ensemble members

## Graph
![Graph showing correlation skill over forecast lead days for ESV, CNTL1, and CNTL2.](image)

## Table

<table>
<thead>
<tr>
<th>Number of ensemble member</th>
<th>ESV (RED)</th>
<th>CNTL1 (BLUE)</th>
<th>CNTL2 (BLACK)</th>
</tr>
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<tbody>
<tr>
<td>Observations</td>
<td>ERA40</td>
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<td>Model</td>
<td>CGCM V.2</td>
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<tr>
<th>Ensemble member Description</th>
<th>1&lt;sup&gt;st&lt;/sup&gt;</th>
<th>2&lt;sup&gt;nd&lt;/sup&gt;</th>
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<tbody>
<tr>
<td></td>
<td>ERA40 Nudging +</td>
<td>ERA40 Nudging +</td>
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<tr>
<td></td>
<td>Positive ESV pert.</td>
<td>Negative ESV pert.</td>
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<tr>
<td></td>
<td>Nudging - on time</td>
<td>Replace - on time</td>
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<td>Nudging - on time</td>
<td>Nudging - 6 hour lag</td>
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Correlation skill improvement of ESV prediction is robust during unpredictable phase of CNTL prediction
Prediction Skill of Summer ISO

Bivariate Correlation for RMM index

MAY to OCT 1989-2008

ENS MEAN
ENS1
ENS2

Number of phase for serial integration

<table>
<thead>
<tr>
<th>Phase</th>
<th>Pha1</th>
<th>Pha2</th>
<th>Pha3</th>
<th>Pha4</th>
<th>Pha5</th>
<th>Pha6</th>
<th>Pha7</th>
<th>Pha8</th>
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<td>40</td>
<td>38</td>
<td>33</td>
<td>32</td>
<td>31</td>
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</table>

Prediction skill depends on start phase
Thank you
Propagation of MJO in summer

<table>
<thead>
<tr>
<th>Phase1</th>
<th>Phase2</th>
<th>Phase3</th>
<th>Phase4</th>
<th>Phase5</th>
<th>Phase6</th>
<th>Phase7</th>
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<tr>
<td>52</td>
<td>54</td>
<td>36</td>
<td>47</td>
<td>47</td>
<td>40</td>
<td>44</td>
<td>40</td>
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- **Phase2**
- **1 lead day**
- **5 lead day**
- **10 lead day**
- **15 lead day**
- **20 lead day**
Propagation of MJO in summer

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<th>Phase</th>
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1 lead day

5 lead day

10 lead day

15 lead day

20 lead day
Experimental Design

- **45 Days Integration**
  - 1 MAY
  - 11 MAY
  - Whole Summer
  - 21 OCT

- **Serial Integration**
  - * Advantage
  - ➔ Evenly include all convective stages of ISO

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<tr>
<th>Period</th>
<th>Ensemble</th>
<th>Integration</th>
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<tr>
<td>1989-2008</td>
<td>2</td>
<td>45 days</td>
</tr>
<tr>
<td>5.1~10.21</td>
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</table>

- 18 cases/year x 20 years * 2
  = 720 cases

**ENS 1**
- 9 NUDG
- 9 NUDGING
- 45 prediction

**ENS 2**
- 8 NUDG
- 8 NUDGING
- 1 prediction
- 45 prediction

**ENS Mean**

ENS Mean
Intraseasonal and Interannual Variations: EOF (AGCM)

Time-series of 1st mode
Intraseasonal and Interannual Variations: EOF (CGCM)

Time-series of 1st mode

Content:
- CES CGCM EOF 1ST MODE
  - ISO Activity (11.04%)
  - Summer Mean PRCP (24.56%)

Graphs showing spatial and temporal variations with color-coded fields and line graphs.