Coupled impacts of the diurnal cycle of sea surface temperature on the Madden-Julian Oscillation

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Typical 5-day winter weather forecast in Boston
prediction skill (Vitart et al. 2007; Fu et al. 2013), the effect of ensemble average on both predictability and prediction skill is also investigated.

First, we examine the predictability using ensemble mean and individual ensemble members. To estimate predictability using ensemble mean, the bivariate correlation coefficient $\text{ACC}(t)$ between one ensemble member (considered as "truth") and the ensemble mean calculated from the rest of ensemble members is computed. Predictability is assessed by the average of $\text{ACC}(t)$ for each of the ensemble subsamples.

Figure 2a shows the predictability of total MJOs, irrespective of the initial MJO amplitude, as a function of forecast lead time from 0 to 32 days for both VarEPS and CFSv2 hindcasts. Similar to Rashid et al. (2011), predictability remains around 0.6 at 32-day lead time in CFSv2 and even higher in VarEPS. The dashed line in Fig. 2a represents the predictability measured using individual ensemble. This is calculated by the $\text{ACC}(t)$ between one ensemble member and the rest of ensemble members and then averaged over the subsamples. The predictability of individual ensembles is lower than that of the ensemble mean.

The prediction skill is far below the predictability (Fig. 2b). The ensemble mean prediction skill (solid line), defined as the forecast lead day when the $\text{ACC}$ is 0.5, is about 27 days in VarEPS and 21 days in CFSv2, similar to the skill explored in recent studies for each system (Vitart 2014; Wang et al. 2014). The mean prediction skill of ensemble members is 3–5 days lower than that of the ensemble mean. The enhancement of skill in ensemble mean over individual ensembles is greater in VarEPS (5 days) than in CFSv2 (3 days), probably due to the slightly larger number of ensemble members or the smaller ensemble spread and error ratio. This issue will be explored later in this section. It is obvious that the MJO prediction skill has been gradually increased in each forecasting system compared to its previous version and the skill is now higher than that of statistical models (Maharaj and Wheeler 2005; Seo et al. 2009; Kang and Kim 2010; Rashid et al. 2011). However, the gap between the predictability and prediction skill still remains about 10 days.

Previous studies have demonstrated that the prediction skill depends strongly on the initial MJO amplitude (Lin et al. 2008; Agudelo et al. 2009; Kang and Kim 2010; Rashid et al. 2011; Zhang and van den Dool 2012; Wang et al. 2014). Figure 3 compares the prediction skill $\text{ACC}(t)$ for forecasts initialized with strong and weak/non MJO cases in two hindcasts. It clearly shows that forecasts initialized with strong MJO (solid line) possess greater prediction skill compared to those initialized with weak/non MJO (dashed line) in both models, probably due to the disorganized anomalies in the initial condition in the weak/non MJO. In CFSv2, the prediction skill of the MJO is greater by about 4–5 days.
- Planetary-scale ($k=1$ to $3$), eastward-propagating ($\sim5\text{ms}^{-1}$), equatorially-trapped, baroclinic oscillations
  - *Active*: deep convection, heavy precipitation, westerly wind, cool SST, weak diurnal SST
  - *Suppressed*: weak convection, strong insolation, easterly wind, warm SST, strong diurnal SST

- Many aspects of the MJOs remain poorly simulated and predicted:
  - Initiation and intensity of MJO convection in the equatorial Indian Ocean
  - Role of the upper-ocean variability and air-sea interactions
DYNAMO (Dynamics of MJO): Multi-national field experiment

DYNAMO Field Experiment (October 2011 – March 2012)

R/V R. Revelle

R/V S. Kanya

R/V B. Jaya-III

Sounding Network

Courtesy of C. Zhang
Three MJOs during DYNAMO

TRMM_3B42RT Precipitation [mm/hr]

Average Lat: 10°S - 10°N

Moorings
Revelle
Mirai

MJO2
MJO3

NSA

P3
FF

Mirai
Revelle

Manus
Addu

Courtesy of C. Zhang

RMM1
RMM2

Western Pacific
Maritime Continent
Indian Ocean

West Hem. and Africa
My contribution to the DYNAMO project

Process modeling: the role of “oceanic process” in the initiation and maintenance of MJO convection

Oceanic process, barrier layer, shear driven mixing, diurnal variation in the upper ocean stratification, and mixing-layer entrainment, controls the upper ocean heat content, SST and thus air-sea flux and the MJO convection.

*Focus of this study:
Diurnal cycle of the upper ocean temperature

Why diurnal cycle?
Diurnal cycle enhances the daily mean and intraseasonal SST

I-D KPP modeling study (Bernie et al. 2005)

Forcing frequency 3h vs 24h

Vertical resolution: 1m vs 10m
How does it impact the MJO convection?

*Stronger and more coherent MJO*

A coupled GCM study (Bernie et al. 2008)

Daily coupled

Lagged composites of convective precipitation

No studies exist that examined “physical process” for the diurnal SST cycle — MJO connection.
Regional coupled modeling study: SCOAR model

- **SCOAR 1**: RSM-ROMS  
  - Seo et al. 2007

- **SCOAR 2**: WRF-ROMS  
  - Seo et al. 2014

- An input-output based coupler; portable, flexible, expandable

- Circum-equatorial tropical disturbances are allowed to interact with high-resolution oceanic process

- 40 km O-A resolutions & matching mask

- Deep & shallow convection and PBL schemes for MJO simulation
MJO diagnostics from the 5-yr baseline SCOAR simulation
Wavenumber-frequency spectra of symmetric component of OLR and U10m

• SCOAR reproduces reasonably the observed level of power at MJO $\kappa$-$\omega$ band.
• Interactive SST acts to straighten the MJO.
• Have some trust in model and its credibility for MJO simulation!
Observed diurnal warm layer during DYNAMO

- Diurnal warm layer thickness of ~1 to 5 m
- >0.1°C temperature difference across the diurnal warm layer
SCOAR model configuration
to better capture this observed thin diurnal warm layer

- **Need extremely high vertical resolution**
  - Total 55 levels;
  - 5 levels in the upper 1-m (dz=20cm)
  - 15 levels in the upper 15 m (dz=1m)

- Experimental configuration:
  - 5 Coupled 1-month-long runs with various coupling frequency (CF):
    - CF1, CF3, CF6, CF24

![Graph showing temperature 6 hourly composite anomalies](image)
diurnal SST amplitude (dSST) prior to the MJO2 convection

- Enhanced dSST (>1 °C) in regions of weak wind speed (<4 ms⁻¹)
- CF1 represents about 56% of the observed dSST.
- Higher CF leads to greater dSST
Warmer upper ocean temperature before convection

- Stronger diurnal variation helps achieve higher (>0.1°C) SST on a diurnal basis.

<table>
<thead>
<tr>
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<th>Suppressed phase</th>
</tr>
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<tbody>
<tr>
<td>Mean T</td>
<td>dSST</td>
</tr>
<tr>
<td>CF1</td>
<td>29.8 0.6</td>
</tr>
<tr>
<td>CF3</td>
<td>29.7 0.4</td>
</tr>
<tr>
<td>CF6</td>
<td>29.7 0.3</td>
</tr>
<tr>
<td>CF24</td>
<td>29.7 0.0</td>
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The higher diurnal SST, the stronger moistening of the atmosphere

Latent heat flux (a) LH at NSA region (73-80.5 °E 0.7°S-7°N)

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<th>Suppressed phase</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Mean LH</td>
<td>dLH</td>
<td></td>
</tr>
<tr>
<td>OAFux</td>
<td>95.9</td>
<td>N/A</td>
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</tr>
<tr>
<td>CF1</td>
<td>103.8</td>
<td>30.2</td>
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</tr>
<tr>
<td>CF3</td>
<td>99</td>
<td>24.6</td>
<td></td>
</tr>
<tr>
<td>CF6</td>
<td>98</td>
<td>21.1</td>
<td></td>
</tr>
<tr>
<td>CF24</td>
<td>97.7</td>
<td>30.2</td>
<td></td>
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Stronger moistening of the atmosphere with diurnal SST.
Diurnal moistening is maximized by the diurnal SST

Hourly composites of \( \textbf{LH} = \rho L C_H W_{10} (q_s - q_a) \)

- Without diurnal SST peak in the afternoon, LH peaks in the morning following \( W_{10} \).
- \( q_s \) (SST) plays a leading role in maximizing the moistening effect of the troposphere.

What is the consequence on the MJO convection?
**Precipitation intensity response to diurnal SST**

10S-10N mean precipitation rates

(a) 3B42 Rain  
(b) CF1  
(c) CF6  
(d) CF24  
(e) Rain at NSA average of 73-80.5°E, 0.7°S-17°N

- MJO2 rainfall event on Nov. 24 with the eastward propagation at 5 ms⁻¹.
- Models: qualitatively consistent intraseasonal evolution of rainfall.
- Higher dSST and dLH leads to higher rainfall!

**Why does it rain more with the stronger diurnal SST?**
Column-integrated moist static energy (MSE) budget

\[
\langle m_t \rangle = -\langle v_h \cdot \nabla m \rangle - \langle \omega m_p \rangle + (LH + SH) + \langle LW + SW \rangle
\]

\[m = c_p T + gz + Lq\]

MSE budget terms prior to the convection

Recharge of MSE

Dominant role by LH+SH for MSE recharge
Column-integrated moist static energy (MSE) budget

\[
\langle m_t \rangle = \langle v_h \cdot \nabla m \rangle - \langle \omega m_p \rangle + (LH + SH) + \langle LW + SW \rangle
\]

\[m = c_p T + gz + Lq\]

Maloney 2009

**MSE budget terms prior to the convection**

**MSE budget terms during the convection**

Vertical advection is a dominant export term

LH+SH, and LW + SW source of MSE
Diurnal moistening of the lower troposphere

\[
\langle -\omega m_p \rangle = -\left(\langle \omega m_p \rangle + \langle \omega' m'_p \rangle \right)
\]

(a) \(-\omega m_p\) suppressed phase

- The daily mean advection
  - Exports MSE by the mean convective downdrafts
  - No obvious proportionality to dSST

- Diurnal moistening
  - A source of MSE
  - A clear proportionality to dSST

- Drying by mean convective downdrafts

- Moistening by diurnal vertical motion (~diurnal congestus)
Summary (1)

1. SCOAR regional coupled modeling for the MJO
   - EW channel configuration
   - Specific combination of WRF deep & shallow convection and PBL schemes for MJO simulation
     - Modified ZM deep and UW shallow convection & PBL schemes
   - Higher (especially in the ocean) horizontal resolution: 40 km
   - High vertical resolution (~1 m in the top 15 m)
   - Hourly model coupling

2. SCOAR2 supports significant eastward propagating convectively coupled disturbances in the MJO $\kappa$-$\omega$ band
   - True regardless of coupling
   - Coupling enhances the intraseasonal power and coherence
3. Diurnal SST variability prior to the deep convection
   - raises the time-mean SST and LH: via diurnal rectified effect
   - enhances the diurnal moistening: via coincident diurnal peaks of LH & SST

4. Further sensitivity experiments (not really discussed today) suggest
   - the first mechanism dominates and more efficiently expedites the recharge of the MSE.
   - But the diurnal moistening is a non-negligible process
     - cancel out the drying effect by the convective downdrafts.
5. Precipitation amount scales quasi-linearly with pre-convection diurnal SST

- LH+SH feedback over higher SST instrumental in stronger convection intensity (Arnold et al. 2013)

- Consistent with previous studies: an improved representation of diurnally evolving SST as a potential predictability source of MJO.
Thanks for listening,
and
Seo, Subramanian, Miller and Cavanaugh, 2014:
Coupled impacts of the diurnal cycle of sea surface temperature on the Madden-Julian Oscillation. J. Climate, doi: http://dx.doi.org/10.1175/JCLI-D-14-00141.1