Multi-Scale Interactions in a High-Resolution Tropical-Belt WRF Experiment and TRMM Observations

Ricardo FONSECA\textsuperscript{1,4}, Tieh-Yong KOH\textsuperscript{2,4}, Chee-Kiat TEO\textsuperscript{3,4}

\textsuperscript{1}Lulea University of Technology, Sweden
\textsuperscript{2}Singapore University of Social Sciences, Singapore
\textsuperscript{3}Centre for Climate Research Singapore, Singapore
\textsuperscript{4}Nanyang Technological University, Singapore
WRF DOWNSCALING EXPERIMENT: 27-YEARS @ 36km

- **Downscale CFSR** (reanalysis data) over 27 years (Apr 1988 - Mar 2015)
- **Continuous runs of 1 full year** (1 Apr - 31 Mar) after 1-month spin-up (discarded)
- **Arakawa C-grid**: 36 km x 36 km; 37 levels; 2-min time-steps; 3 hourly diagnostics
- **Modified Betts-Miller-Janjic** adjustment & **Precipitating Convective Cloud** schemes correct for deep convective rainfall and cloud cover biases
- **Radiation call every 10 min** (5 time-steps), which means every 2.5° westward migration of the zenith sun (~7.7 grid-boxes)
- **Interactive sea surface skin layer** damped to diurnally varying SSTs (linearly interpolated in time from 6-hrly CFSR data)
- **Grid nudging on mid-tropospheric q** (water budget constraint) & **stratospheric u, v, θ’** (QBO)
Inter-Annual Variations (IAV)

- Observations: TRMM 3B42 for rainfall, QuikSCAT for 10-m wind
- The monthly means of these variables are regressed linearly against modelled/observed monthly ENSO and IOD indices over Dec 1988 - Sep 2009
- Regression coefficients shown are statistically significant at 90% confidence level
Madden-Julian Oscillation (MJO)

- WRF simulates well the MJO for both monsoon seasons.
- Maritime Continent (MC) in WET phase of MJO in P3.
- Maritime Continent (MC) in Dry phase of MJO in P7.
MJO-IAV INTERACTIONS - GLOBAL

- For each MJO phase, we regress the amplitude of the RMM index (daily, 5-day moving average) against IAV indices (daily, 150-day moving average) from the model output.
- Regression intercept (red circle, left axis) → IAV-neutral state.
- Regression coefficient (blue circle, right axis, zero-line) → anomaly per Kelvin increment in IAV index.

ENSO IOD

MJO (DJFM)

Phase 1 to 8

- ENSO: DJFM: ENSO & IOD have no overall significant impact on RMM amplitude.
- IOD: ENSO IOD

MJO (JJAS)

Phase 1 to 8

- El Niño (La Niña) mostly enhances (weakens) RMM amplitude; IOD effects are phase-dependent.

≥3 phases should be significant (at 90% level)
MJO-ENSO INTERACTIONS - REGIONAL (MC)

- For each MJO phase, we regress daily rainfall and 850mb-wind anomalies from climatology against ENSO index (150-day moving average of daily series).

**MJO (JJAS) – ENSO**

**ENSO NEUTRAL**

**EL NIÑO**

**WEAK MJO**

**P1**

**P5**

**MJO (DJFM) – ENSO**

**ENSO NEUTRAL**

**EL NIÑO**

El Nino enhances MJO

El Nino mitigates MJO
WRF model does not simulate well the precipitation diurnal cycle: amplitude is underestimated and phase shifted earlier by ∼6 h over sea and ∼9 h over land.

Explicit convection is necessary to achieve a closer match in the phase of the average diurnal cycle, but the synoptic and sub-seasonal variations are degraded severely (no better than a random forecast).

Mask applied when amplitude ≤ 0.02 mm h⁻¹
For each MJO phase in DJFM, we regress 3-h TRMM precipitation rate anomalies against daily ENSO index (150-day moving average of daily series).

Regression intercept denotes neutral ENSO. Phase (\( \phi \)) masked out when amplitude does not exceed 0.02 mm h\(^{-1}\).

Diurnal cycles over land & coastal seas have larger amplitude coinciding with rain-enhancing influence of MJO is over the locality. \( \phi \) virtually invariant to MJO phase.
ENS0-MJO-Diurnal Cycle INTERACTIONS

➢ For each MJO phase in DJFM, we regress 3-h TRMM precipitation rate anomalies against daily ENSO index (150-day moving average of daily series).

➢ Regressed daily mean precipitation rate anomaly and amplitude enhancement / phase lag (with respect to regression intercept) for a moderate El Nino (ENSO index of +1 K).

Only regression coefficients statistically significant at 95% are shown. Phase only plotted if amplitude of regression intercept exceeds 0.06 mm h⁻¹.

Moderate El Niño conditions in Maritime Continent accentuate the influence of MJO on diurnal cycle amplitude with phase largely unchanged.
For each MJO phase in DJFM, we regress 3-h TRMM precipitation rate anomalies against daily ENSO index (150-day moving average of daily series).

Regression of daily mean precipitation rate anomaly and amplitude enhancement / phase lag (with respect to regression intercept) for weak and strong El Niño.

Weak El Niño and La Niña are practically anti-symmetric in their influence on diurnal cycle amplitude with little change in the phase. For strong ENSO events, non-linearity in amplitude and phase sets in with amplitude more enhanced than suppressed and significant phase lag for all MJO phases & weak MJO periods.

<table>
<thead>
<tr>
<th>MJO phase 4</th>
<th>ENSO INDEX X = +0.5 K</th>
<th>ENSO INDEX X = -0.5 K</th>
<th>ENSO INDEX X = +3 K</th>
<th>ENSO INDEX X = -3 K</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Amplitude Enhancement</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$A_C(X) / A_a$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Phase Lag</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\phi_C(X) - \phi_a$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
SUMMARY

- We succeeded in correcting for previous model rainfall biases: a modified BMJ scheme and a Precipitating Convective Cloud (PCC) scheme yield good rainfall for the global tropics in all monsoon and inter-monsoon seasons.

- WRF is able to reproduce the tropical variability associated with IAVs and MJO. However, WRF does not capture well the precipitation diurnal cycle in Maritime Continent.

- MJO’s global amplitude is significantly enhanced by ENSO in JJAS. But regional interactions on Maritime Continent are noted in both seasons: El Nino enhances MJO impacts in JJAS but mitigates MJO impacts in DJFM; the converse is true for La Nina.

- In DJFM over Maritime Continent, moderate El Niño enhances MJO’s influence on diurnal cycle amplitudes with little change in phase; moderate La Nina has an anti-symmetric influence. Non-linear influence on amplitude and changes in the phase manifest in strong ENSO.

REFERENCES

