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

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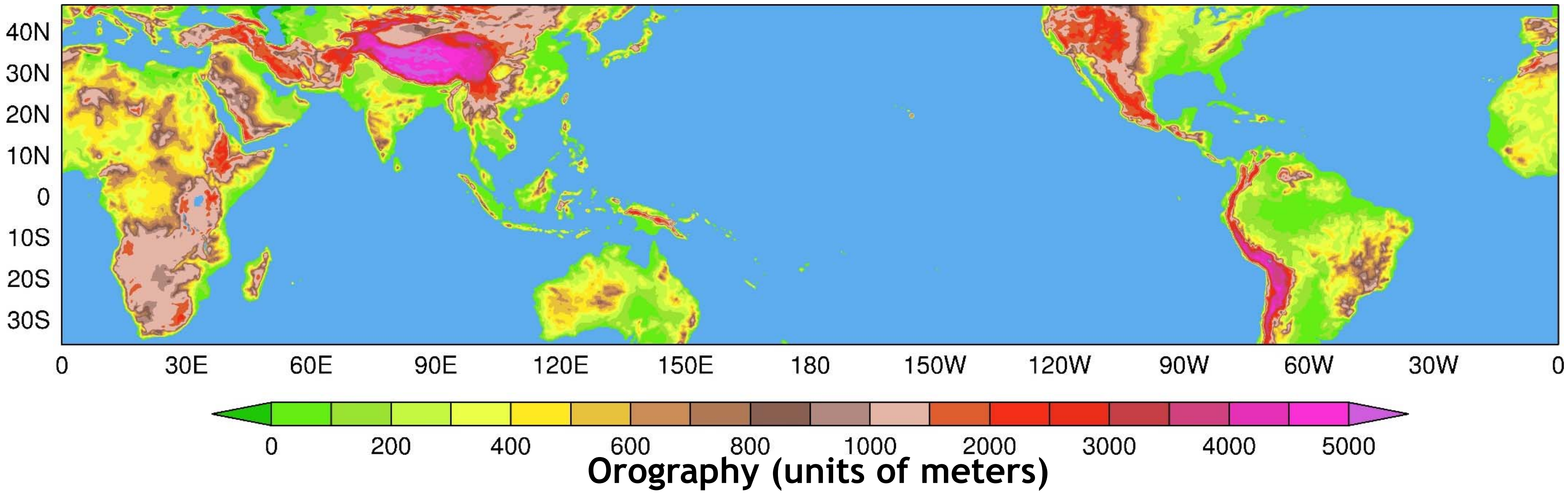
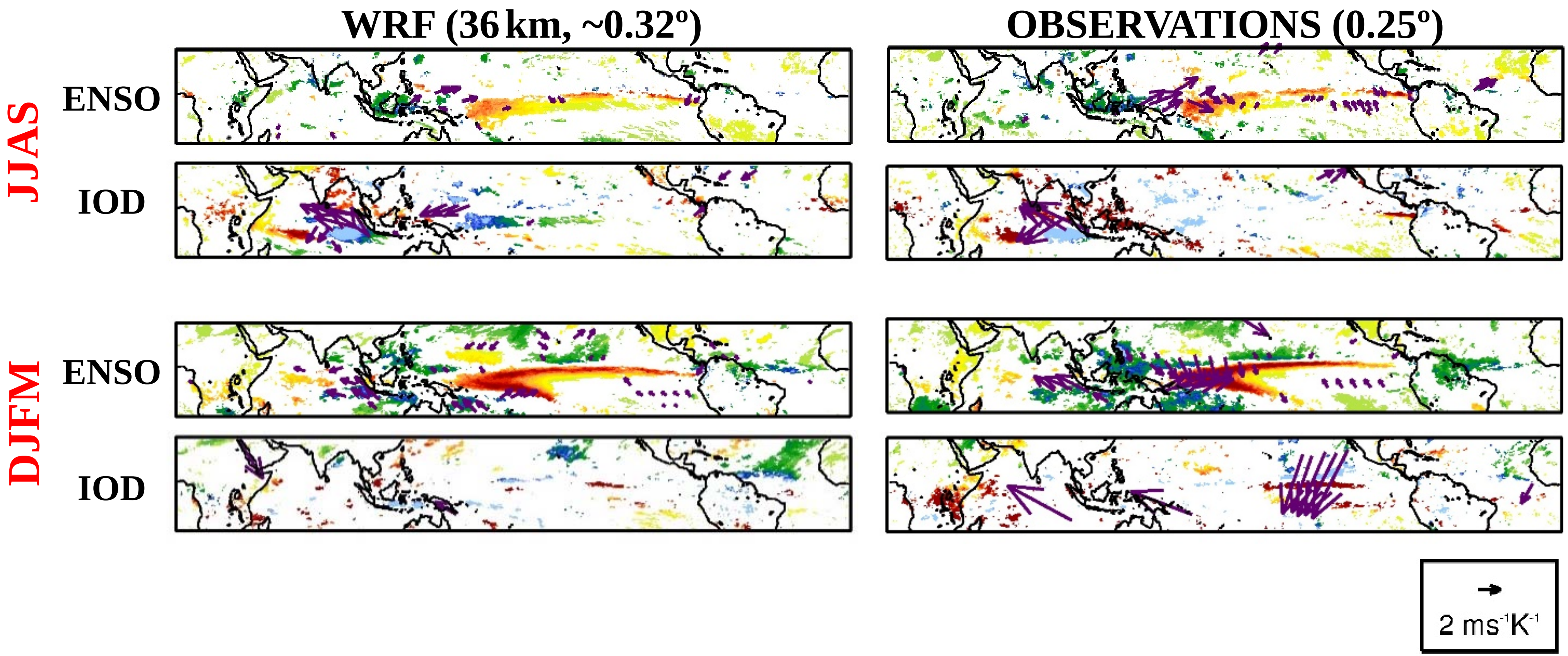
WRF DOWNSCALING EXPERIMENT: 27-YEARS @ 36km



- **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)

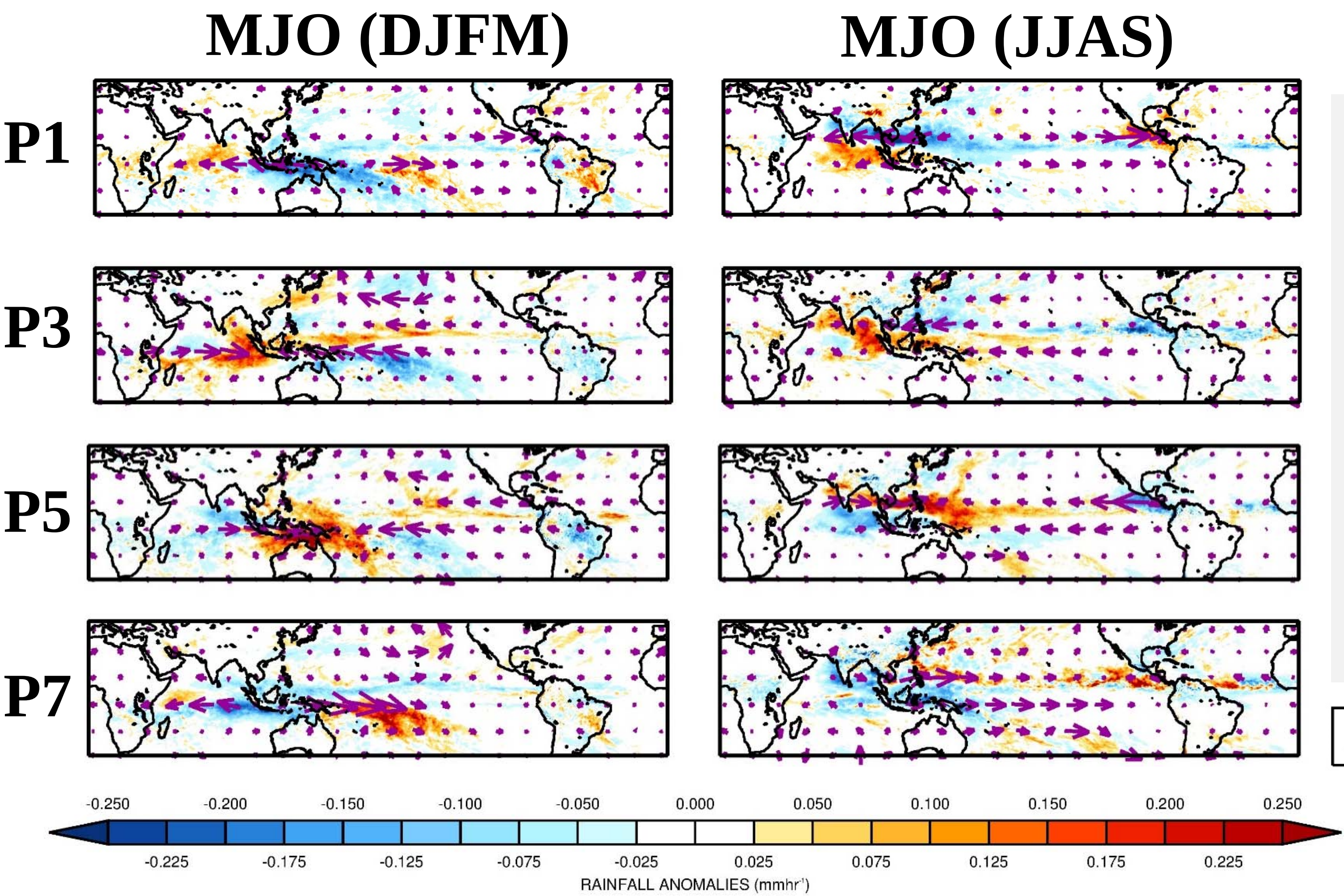
Inter-Annual Variations (IAV)

- 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.

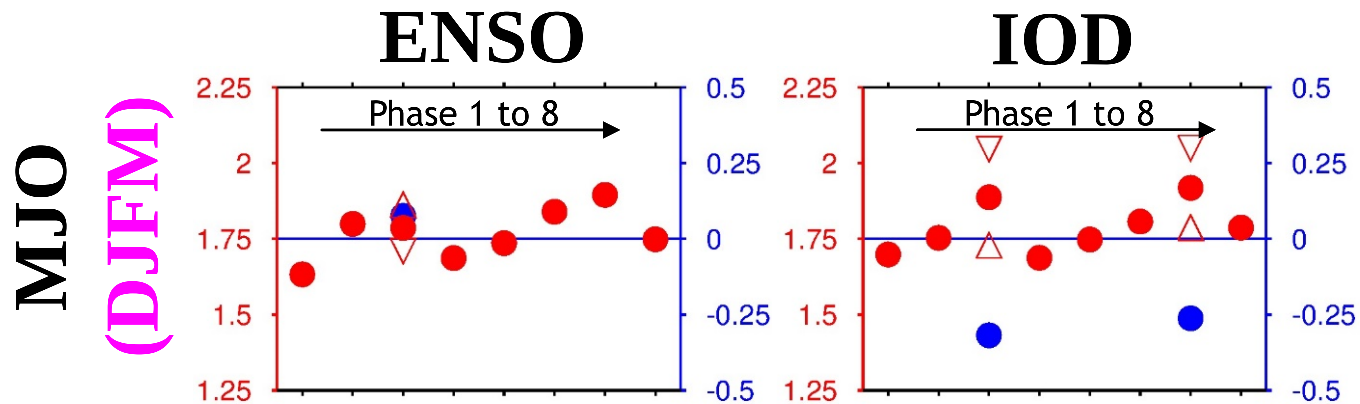


Model composites by model's RMM index
1 Apr 1988 – 31 Mar 2015

Attention on Maritime Continent region

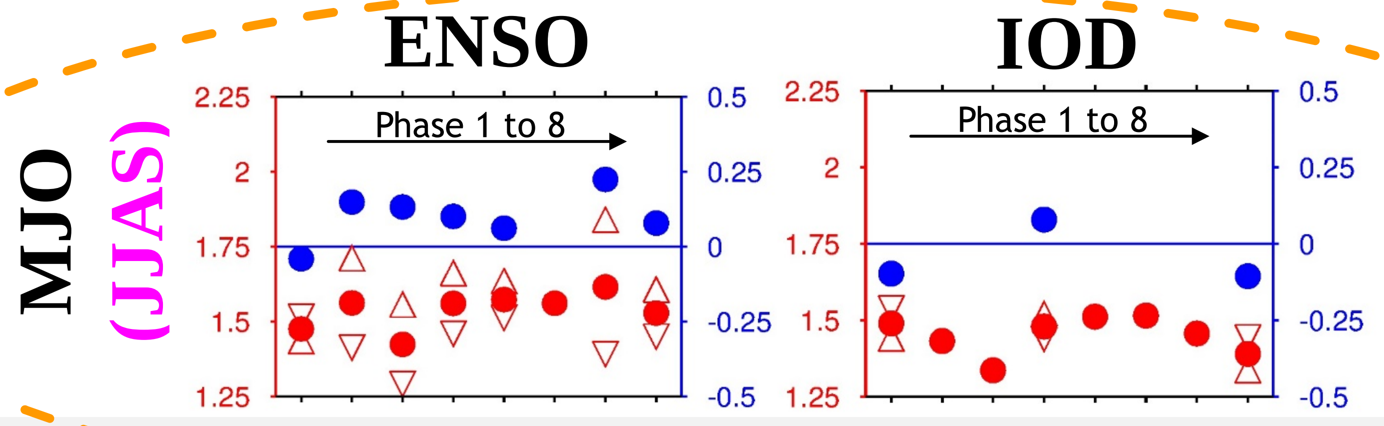
MJO-IAV INTERACTIONS - <u>GLOBAL</u>

- **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.



Upward (Downward) triangle: associated anomaly for +1(-1) K or +0.5 (-0.5) K change in the ENSO or IOD index respectively.

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

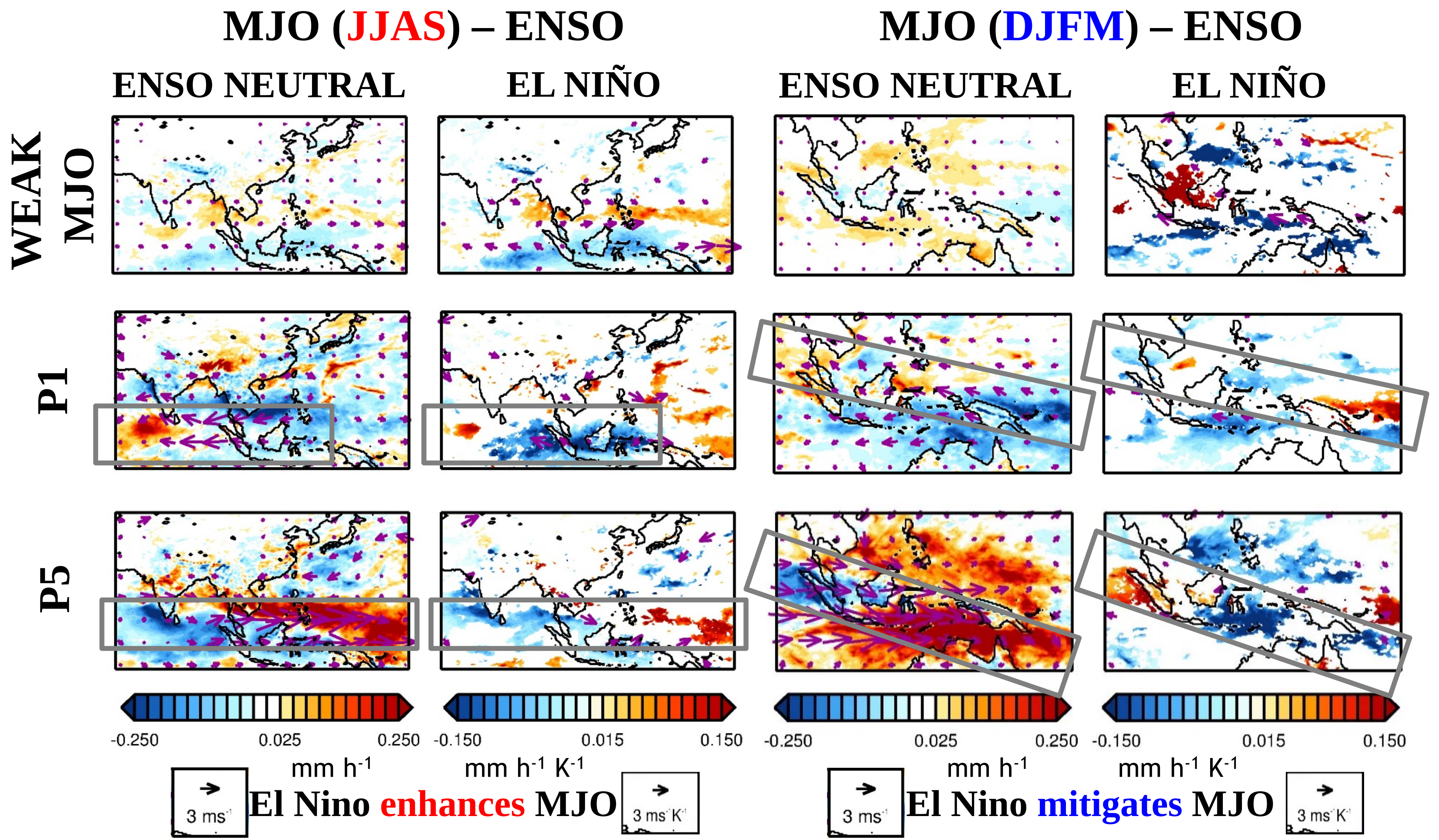


≥3 phases should be significant (at 90% level)

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

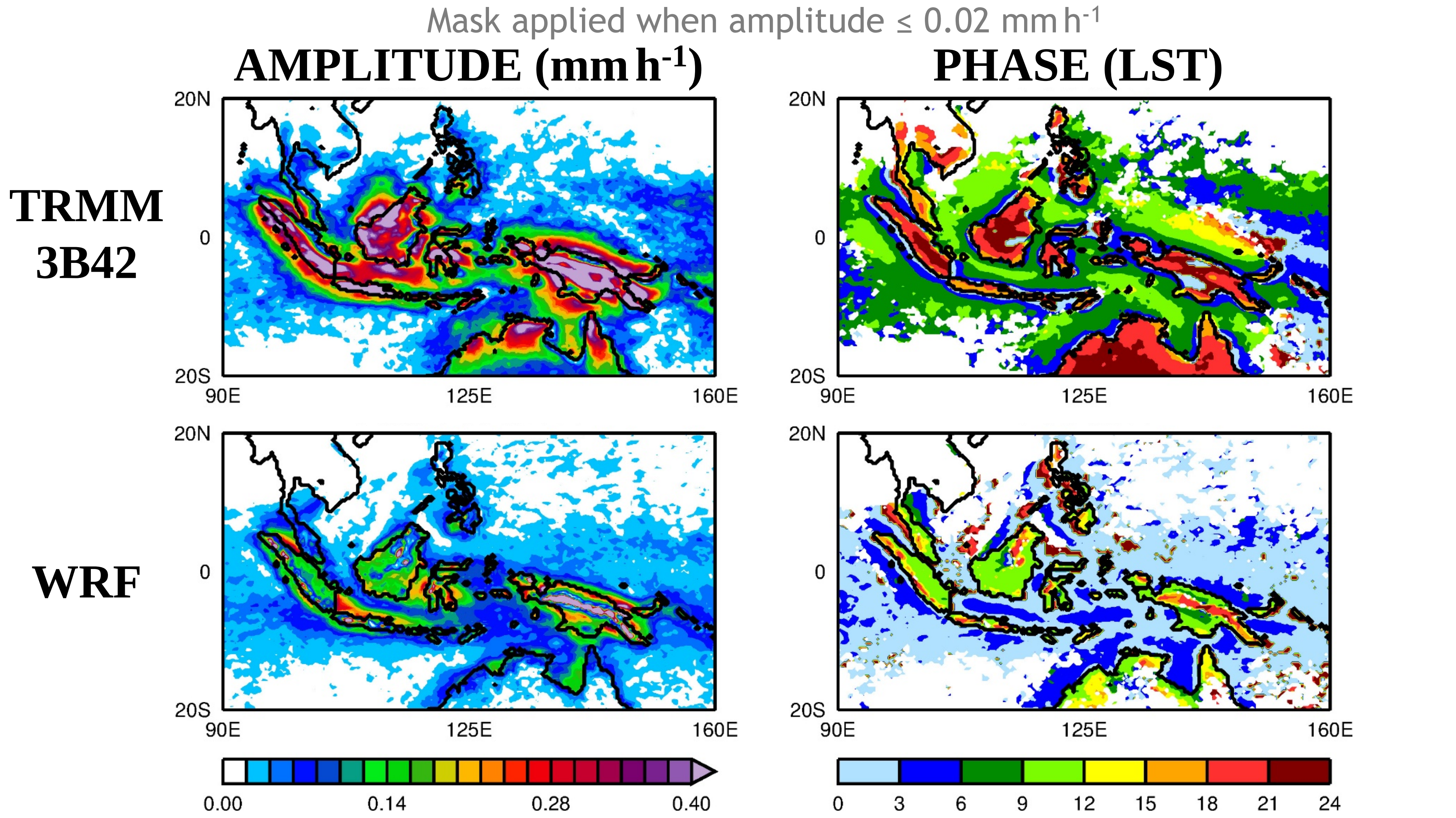
MJO-ENSO INTERACTIONS – **REGIONAL** (MC)

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



PRECIPITATION DIURNAL CYCLE (DJFM 1998-2015)

- 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).



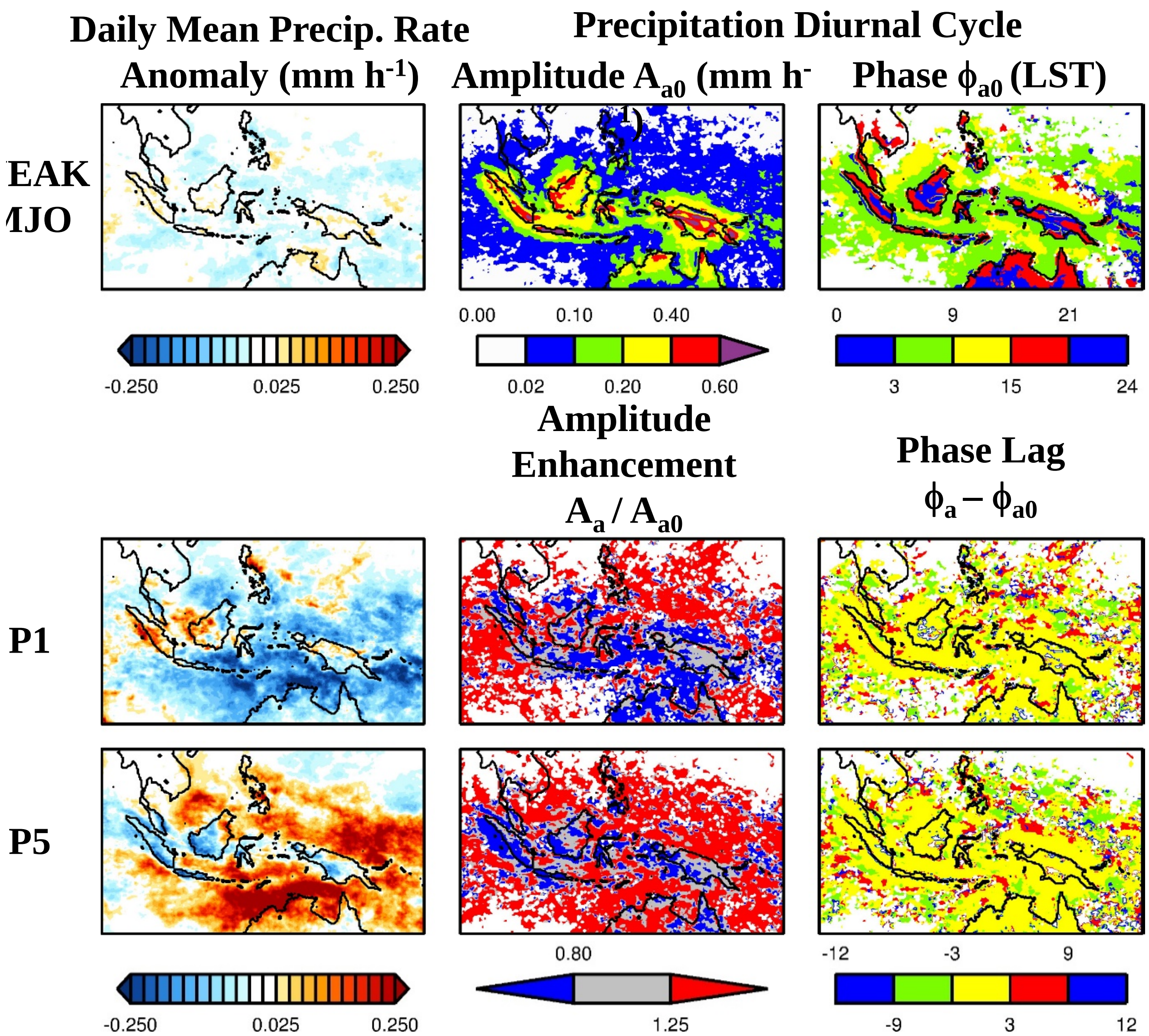
ENSO-MJO-Diurnal Cycle INTERACTIONS

- **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).

Regression intercept denotes neutral ENSO.

Phase (ϕ) 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. **ϕ virtually invariant** to MJO phase.

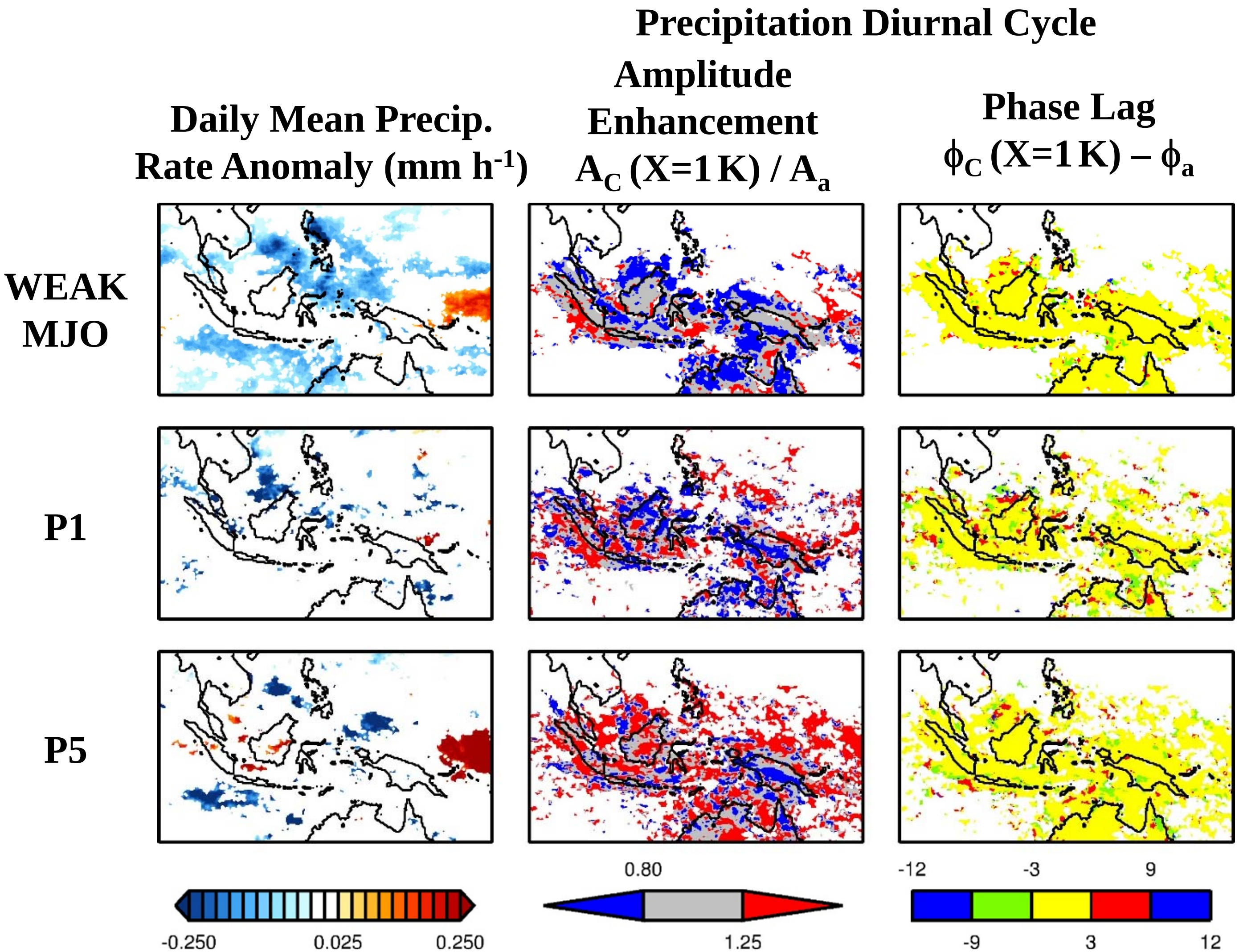


ENSO-MJO-Diurnal Cycle INTERACTIONS

- **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**.

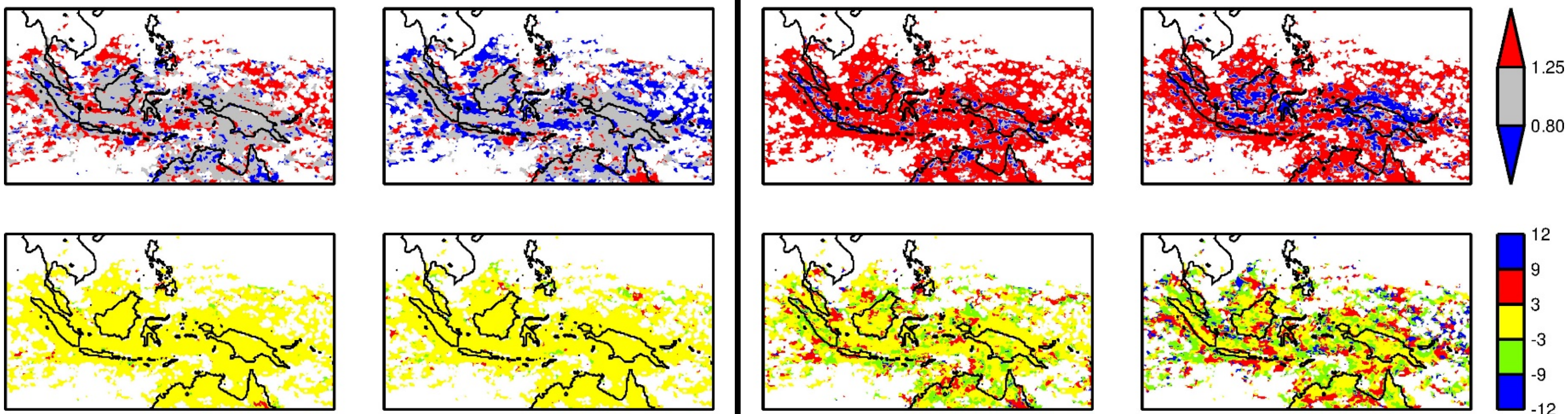


ENSO-MJO-Diurnal Cycle INTERACTIONS

- **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 **weak and strong El Nino**.
- **Weak El Niño and La Niña** are practically **anti-symmetric** in their influence on diurnal cycle amplitude with little change in the phase. For s**trong 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.

MJO phase 4

	ENSO INDEX X = +0.5K	ENSO INDEX X = -0.5K	ENSO INDEX X = +3K	ENSO INDEX X = -3K
Amplitude Enhancement $A_C(X) / A_a$				
Phase Lag $\phi_C(X) - \phi_a$				



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

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