Using a case-study approach to improve the MJO in the Hadley Centre model

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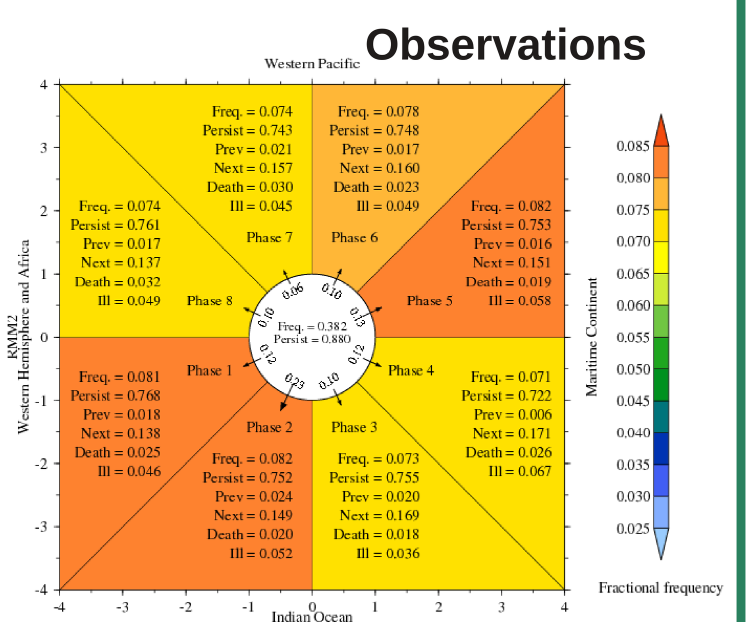
1. Introduction

The Madden-Julian Oscillation (MJO) is the leading mode of intra-seasonal variability in the tropics. It is a quasi-regular, eastward-propagating oscillation between enhanced and suppressed convective conditions, with a period of 30-60 days. This relatively long period makes the MJO is an important source of predictability for extended-range forecasts. Recent studies have found teleconnections between MJO activity and extra-tropical variability, including the North Atlantic Oscillation (Cassou, 2008).

Many current general circulation models (GCMs) display weak sub-seasonal variance in tropical convection, relative to observations (Lin et al., 2006). Even GCMs with adequate variance often fail to simulate the propagation of the MJO.

In its default configuration, the Hadley Centre HadGEM3 atmosphere-only GCM produces approximately half of the observed MJO activity (Figure 1). Particularly large deficiences in MJO activity exist near the Maritime Continent (phases 3 and 4). The "death rate" for strong MJO activity is roughly four times greater in the model than for observations.



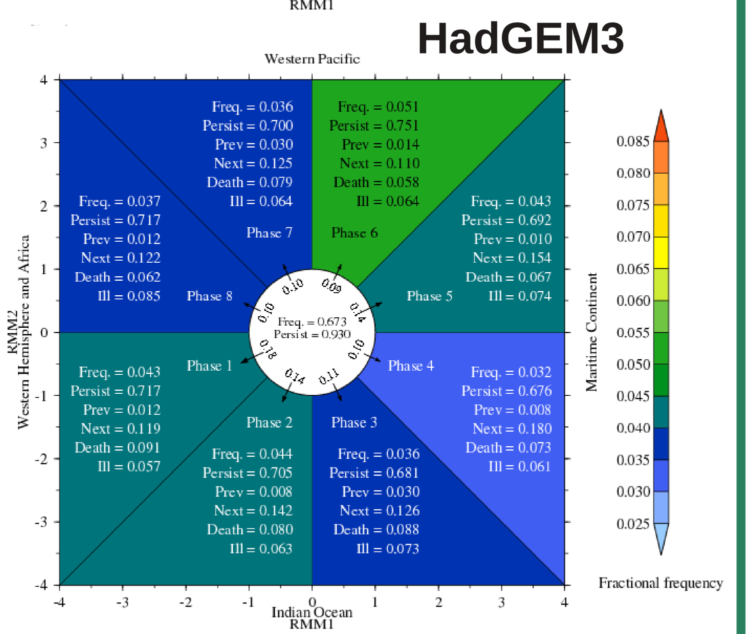


Figure 1. Budgets of MJO activity for observations (1989-2008) and a 20-year HadGEM3 atmosphere-only simulation with repeating climatological SSTs. The budget terms (e.g., "previous phase", "next phase") are the mean day-plus-one probabilities for strong MJO activity in each Wheeler-Hendon phase. The probability and the day-plus-one persistence of no MJO activity are given inside the unit circle.

2. Case-study approach with YoTC/Cascade MJO events

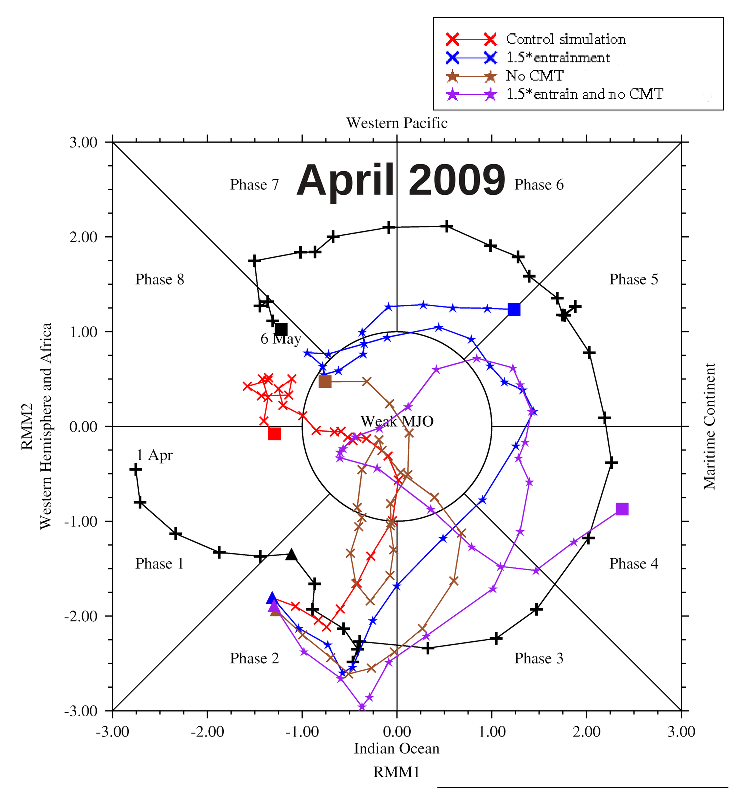
To target improvements for the HadGEM3 MJO, initialized, climate-resolution (1.875º x 1.25º), 30-day hindcasts were performed for two MJO events during the Year of Tropical Convection (YoTC) period: October 2008 and April 2009. These events are also being analyzed at convection-permitting resolutions (4 km) in the NERC Cascade project.

The integrations' trivial expense allowed a wide variety of perturbations to be made, singly, to the HadGEM3 physics parameterizations. Of nearly two dozen perturbations, two substantially improved skill:

- Increasing the **convective entrainment** for mid-level and deep convection by 50% (hereafter **1.5ε**)
- Turning off **the CMT** (convective momentum transport; **NoCMT**)

1.5ε improved OLR and 850 hPa winds, while NoCMT improved 200 hPa winds by not allowing the convection to mix westerly momentum vertically. Combining the changes (**1.5ε+NoCMT**) further improved skill.

Figure 2. MJO phase diagrams for the hindcasts of the (top) April 2009 and (bottom) October 2008 cases. The solid black line shows the observations.



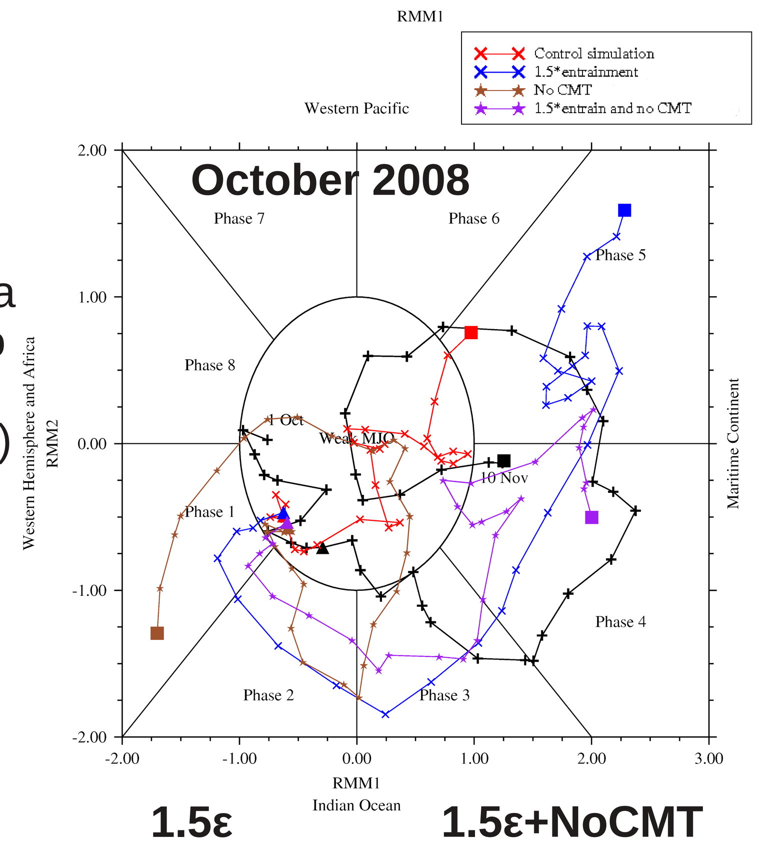
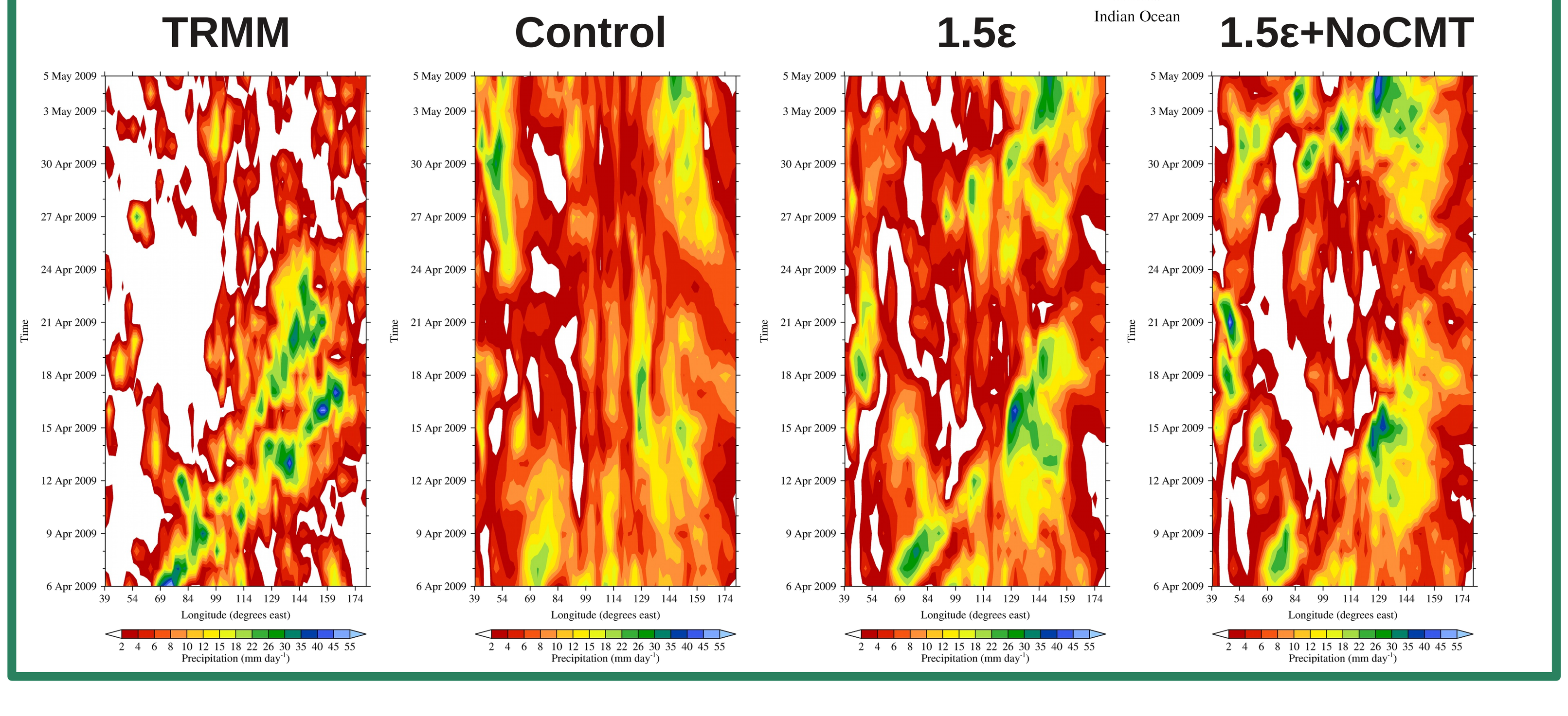


Figure 3. Longitude-time evolution of precipitation for the April 2009 case, latitude-averaged between 5S and 5N. Increasing entrainment concentrates the overly diffuse precipitation in the control simulation.



Conclusions

- The default HadGEM3 produces roughly one-half the observed MJO activity.
- Inexpensive, initialized, climate-resolution hindcasts of well-observed MJO events allowed many changes to physics parameterizations to be tested to target improvements in the MJO.
- Increasing convective entrainment and turning off convective momentum transport improved hindcasts of two YoTC MJO events. The former (latter) improved OLR and U850 (U200).
- Only the increased entrainment consistently improved skill in a wider range of hindcasts.
- In a 20-year climate run, increased entrainment produces near-observed MJO activity.

3. MJO phase 2 hindcasts: Experiment design and results

A further 14 hindcast sets were conducted to confirm improvements from 1.5ε and NoCMT, with 30-day integrations for each MJO in 2000-2009 satisfying:

- Amplitude > 1 in phase 2 on day *n* and phase 6 on day *n+30*
- Amplitude > 1 on all days *n* through *n+30*.

1.5ε results in a stronger, propagating MJO (Fig. 4). NoCMT gives a small mean improvement for 1.0ε and 1.5ε, but also compensating errors among the cases: only three of 14 showed lower RMSE in both RMMs for 1.5ε+NoCMT over 1.5ε. RMSE in RMM phase and amplitude are halved for 1.5ε, with or without CMT (Fig. 5). 1.5ε improves skill in OLR and U850, particularly for RMM2; NoCMT increases variance in U850 and U200, but has little impact on skill.

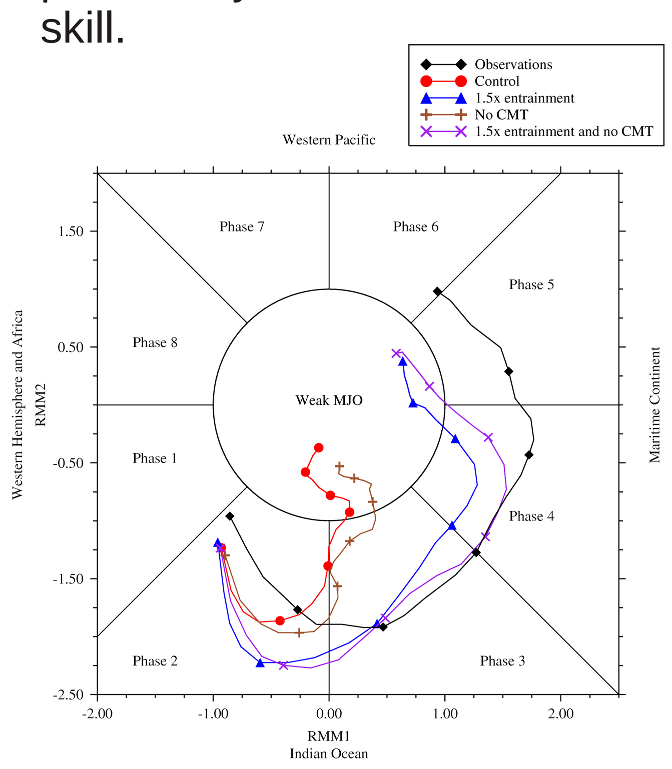


Figure 4. Composite Wheeler/Hendon evolution of all hindcasts initialized in phase 2 and the corresponding observations. Each trace is 30 days, with symbols every five days. The model was initialized from ECMWF analyses, while the observations use NOAA OLR and NCEP winds.

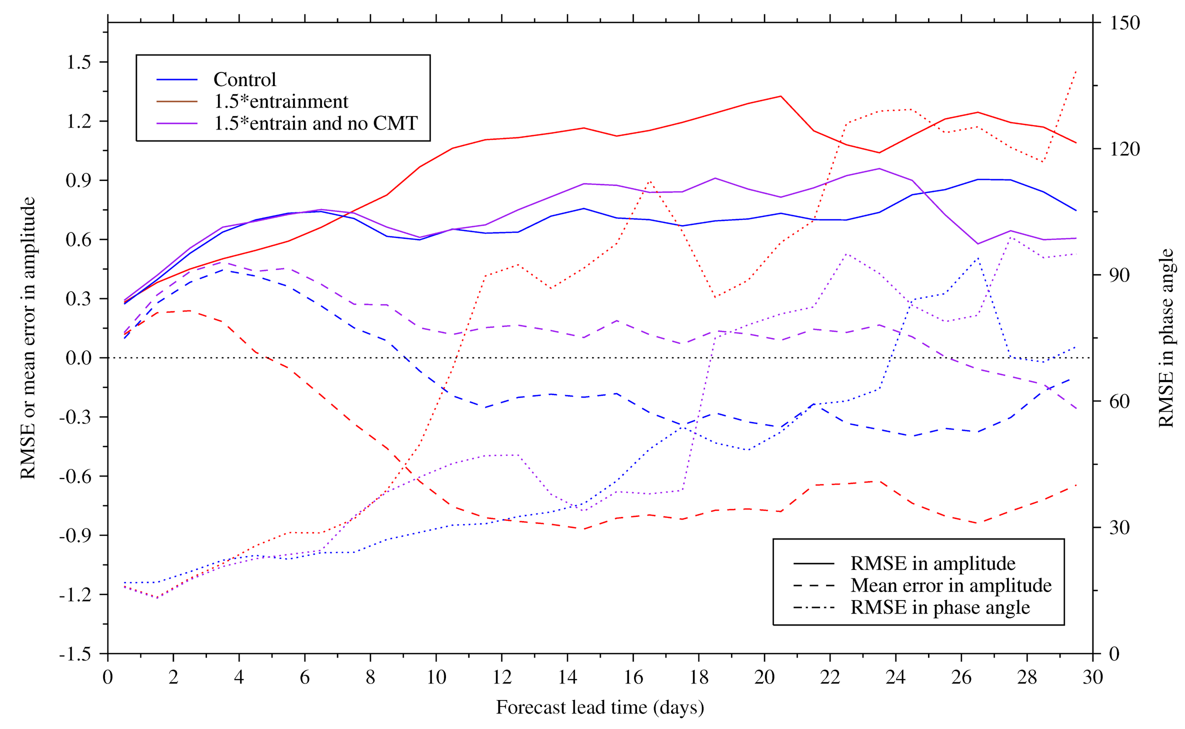


Figure 5. Errors in RMM amplitude and phase angle, with forecast lead time, for each hindcast set. RMSE (solid) and mean error (dashed) are shown for amplitude; the initially high RMSE in the increased entrainment runs is due to an overly strong MJO.

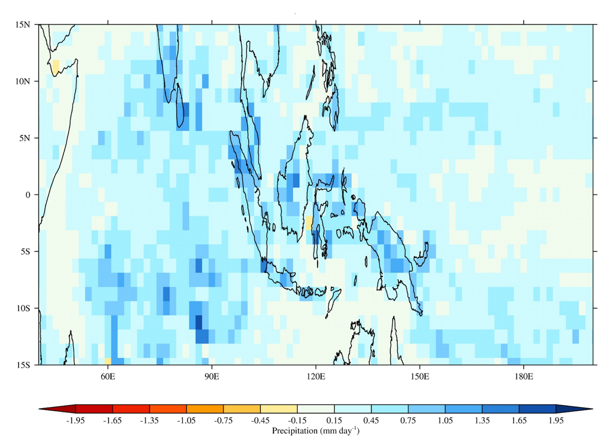


Figure 6. Mean difference in large-scaleprecipitation (mm day) between 1.5ε andcontrol hindcasts over the first three days.

1.5ε increases large-scale precipitation and the large-scale fraction, due to increased detrainment of moisture from convection (Fig. 6).

4. Impact of increased entrainment in a climate integration

As 1.5ε produced a much more substantial impact in the hindcast cases than NoCMT, the 1.5ε change alone was tested in a 20-year atmosphere-only integration with repeating climatological SSTs from the AMIP (1982-2008) period. MJO activity nearly doubles from the 1.0ε HadGEM3 integration (Fig. 1), bringing the model much closer to observations (Fig. 7). MJO propagation is also improved in 1.5ε, although HadGEM3 is still too strongly attracted to the origin in RMM phase space (Fig. 8).

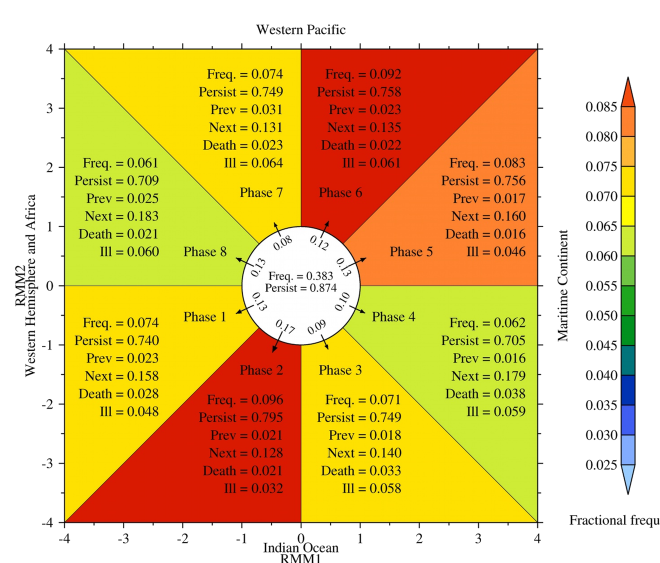


Figure 7. As in Figure 1, but for the HadGEM3 integration with 1.5ε. MJO activity closely resembles observations, while MJO "death" rates are roughly one-quarter those in 1.0ε.

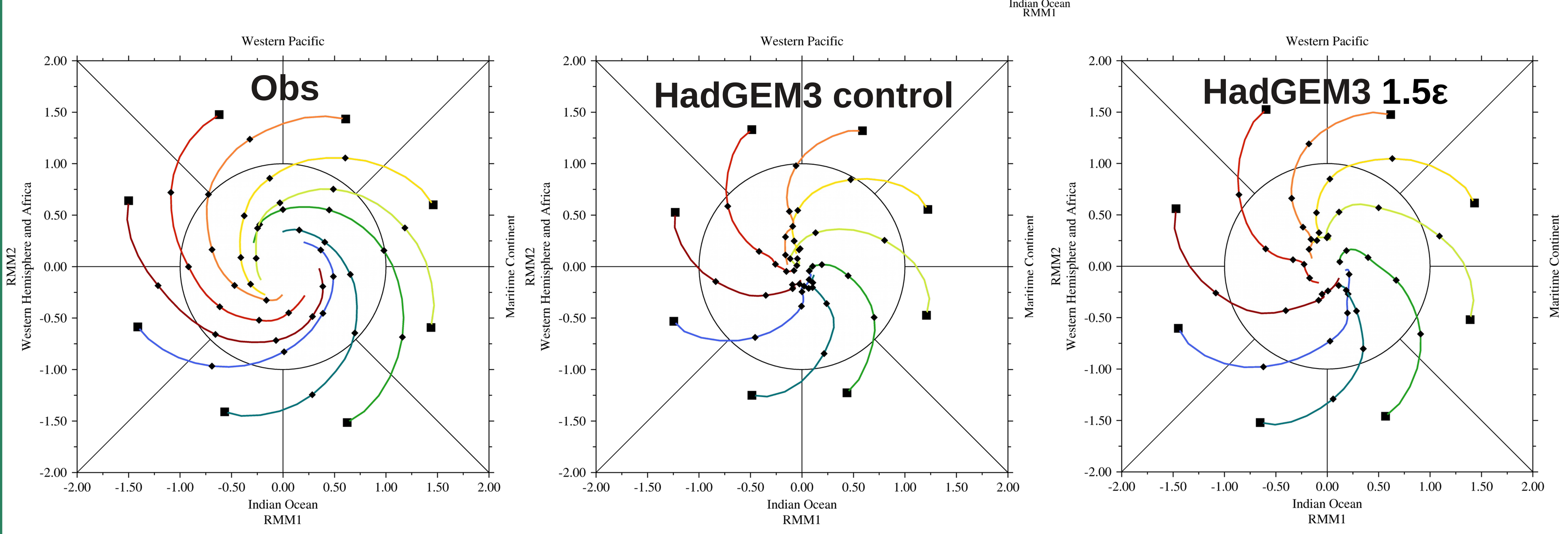


Figure 8. For each Wheeler/Hendon phase, the lag-composite evolution of strong MJO activity. Each trace is 30 days, with symbols spaced every five days. Observations use ERA-Interim winds and NOAA OLR.

References

Cassou, C., 2008: Intraseasonal interaction between the Madden-Julian Oscillation and the North Atlantic Oscillation. *Nature*, **455**, 523-527.
Lin, J-L. et al., 2006: Tropical intraseasonal variability in 14 IPCC AR4 climate models. *J. Climate*, **19**, 2665-2690.
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