Sensitivity of the MJO to SST: A Simulation and Predictability Study of the MJO using the CFS and GFS

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1. Introduction

This study addresses the following two questions: 1) What is the impact of air-sea coupling on the simulation and predictability of the Madden-Julian Oscillation (MJO)? and 2) How sensitive is the predictability of the MJO to forcing by different SST variability. These questions can be viewed in terms of the forecast problem by asking at what lead time should coupled models be used to make forecasts and if a coupled model is not used, what the potential impact on skill is.

2. Model and Experiment Design

a) Model Description

This study investigates the impact of air-sea coupling on the simulation and predictability of tropical intraseasonal variability using the NCEP Climate Forecast System (CFS; Saha et al. 2006). Here, we give a brief description of the model. A more extensive description of the CFS is provided by Saha et al. (2006) and Wang et al. (2005). The CFS is a fully coupled atmosphere-ocean general circulation model used operationally by the NCEP for climate forecasts. It is composed of the NCEP Global Forecast System 2003 (GFS) as the atmospheric component and the Geophysical Fluid Dynamics Laboratory (GFDL) Modular Ocean Model version 3 (MOM3; Pacanowski and Griffies 1998) as the oceanic component. The GFS has a resolution of T62 in the horizontal and 64 layers in the vertical. The ocean model has a quasi-global domain ranging from 74°S to 64°N latitude. It has 40 layers in the vertical and a resolution of 1/3°x1° in the tropics and 1°x1° in the extratropics. The atmosphere and ocean exchange fluxes and sea surface temperatures once per day without flux correction. The sea ice extent is taken as climatology.

b) Simulation Experiments

A series of experiments are conducted to determine the impact of coupled air-sea feedbacks on the simulation of tropical intraseasonal variability in the CFS. These experiments are described in detail in Pegion and Kirtman 2007a. First, a control experiment is used to assess the ability of the CFS to simulate tropical intraseasonal variability. The control experiment is a freely coupled simulation initialized on Jan 1, 1985, and run for 52 years. The initial conditions for the atmosphere are from the NCEP Reanalysis-2 (Kanamitsu et al. 2002). The ocean is initialized from the Global Ocean Data Assimilation System (GODAS).

Second, to determine the impact of air-sea coupling on the simulation of tropical intraseasonal variability, an uncoupled experiment is performed using the atmospheric component of the CFS forced by prescribed, daily SST from the control simulation. The initial conditions are perturbed using atmospheric initial conditions from a different year of the control simulation. If the initial conditions are not perturbed, the control run is reproduced exactly. The uncoupled experiment is run for 32 years with the SSTs from the last 32 years of the control simulation.

c) Predictability Experiments

Since the goal is to estimate the impact of coupled air-sea feedbacks and on the predictability of the MJO and the sensitivity to SST, a series of predictability experiments are performed using both the coupled and uncoupled models. In the case of the uncoupled experiments, experiments are performed with different SST forcing including: “perfect” SST, forecast SST, monthly SST, persisted SST anomalies, and climatological SST.

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The predictability experiments are performed for ten strong (>2s) intraseasonal events selected from the coupled control simulation and the atmospheric initial conditions of these events are perturbed. The events are chosen according to the amplitude of the principal component (PC) time series of an extended empirical orthogonal function (EEOF) analysis of precipitation from the control simulation (Pegion and Kirtman 2007a). It is possible that the phase of the El Niño–Southern Oscillation (ENSO) may affect the propagation of the intraseasonal oscillation (Tam and Lau 2005) and its predictability. Therefore, in an attempt to reduce this impact, the selected events span the phases of the ENSO.

After the events are selected, ensembles are created by perturbing the atmospheric initial conditions to produce nine initial states. The coupled predictability experiments are initialized with the nine atmospheric states and the ocean initial conditions from the control simulation. They evolve with their own SSTs. The coupled predictability experiments by design have different SST evolutions than the control. On the other hand, the uncoupled experiments are initialized with the same nine atmospheric states and are forced by the different SSTs described above. All of the SSTs used to force the uncoupled model are derived from the coupled control simulation. These experiments are described in more detail in Pegion and Kirtman 2007.

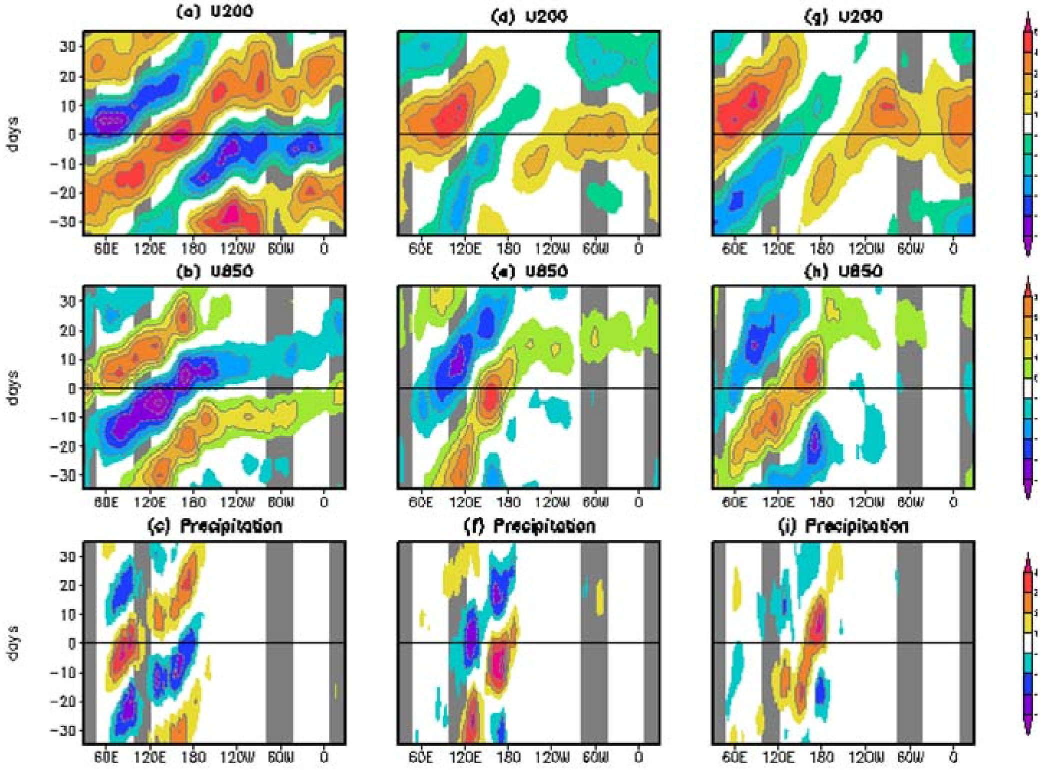

Figure 1 Time-longitude diagram of composite intraseasonal events averaged over 10°S-10°N calculated from observed and reanalysis fields (a,b,c), 30 years of the CFS control simulation (d,e,f), and 30 years of the uncoupled simulation forced with daily SST (g,h,i). Composites are calculated by averaging events with PC timeseries amplitude $>2\sigma$. Twelve (twenty-one) events are averaged to make the observed (CFS) composite and twenty events are averaged to make the uncoupled composite. Time zero represents the average peak amplitude of precipitation. The top panels (a,d,g) are U200 (m/s), the middle panels (b,e,h) are U850 (m/s), and the bottom panels (c,f,i) are precipitation (mm/day).

3. The Impact of Air-Sea Interactions on the Simulation of the MJO

The simulation of the MJO is evaluated, by calculating composite events for U200, U850, and precipitation. Time-longitude diagrams of these composites are shown in Fig 1. In the composites from the coupled control simulation, the basic characteristics of the MJO are evident. There is eastward propagation from the Indian

Ocean into the western Pacific Ocean in both U200 and U850. Additionally, eastward propagation is also evident in precipitation; however it is weak in the Indian Ocean. In the region of enhanced (suppressed) precipitation, the lower level zonal winds are convergent (divergent) and the upper level zonal winds are divergent (convergent), consistent with observations. Also evident is a change in the phase speed once the convection becomes decoupled from the surface and the precipitation ceases near the dateline. The uncoupled model also has many of the characteristics of the observed MJO. There is eastward propagation from the Indian Ocean into the western Pacific Ocean in both U200 and U850. In the region of enhanced (suppressed) precipitation, the lower level zonal winds are convergent (divergent) and the upper level zonal winds are divergent (convergent), consistent with observations. The uncoupled model is also able to simulate the change in phase speed near the dateline. Similar to the coupled simulation, no precipitation anomalies are evident in the Indian Ocean because they remain too far south (~20°S; not shown). The main difference between the coupled and uncoupled composites (Fig 1, middle and right columns) is the organization of the precipitation. The precipitation in the uncoupled simulation is less organized. Although the precipitation propagates eastward from about 150°E to the dateline, it propagates westward near the Maritime Continent at about 120°E. These differences in propagation can be attributed to coupled air-sea interactions.

4. The Sensitivity of MJO Predictability to SST

a) Predictability Metrics

The predictability of intraseasonal precipitation is estimated in terms of the ability of each model to “forecast” the events from the control simulation. For this calculation, we calculate the pattern correlation precipitation anomalies in the Indo-Pacific region (30°S-30°N; 32.5°E-92.5°W) over the nine ensemble members for the ten events between the predictability experiments and the control. The precipitation anomalies are first subject to a 30-day filter in order to remove the high frequency, synoptic variability. In order to apply the filter, 15-days from the control experiment are appended to the beginning of each of the predictability experiments. We also calculate correlations between the ensemble mean of the predictability experiments and the control over all 10 events. The ensemble mean is used in an attempt to reduce the “noise” and isolate any “signal” associated with the intraseasonal oscillation that is common among all ensemble members. Over lead-time, correlations will be reduced as the difference between the predictability experiment and the control simulation becomes larger. The limit of predictability for the correlations is subjectively defined as the time at which correlations fall below 0.5. We use this de-correlation time as a measure of predictability in order to mimic the way in which operational forecasts are verified. These predictability estimates are calculated for the coupled and uncoupled predictability experiments and their results are compared.

b) Predictability Estimates

The predictability estimates based on the ensemble members with the control are presented Fig. 2a as a function of lead-time. These estimates indicate that the coupled model has the longest predictability at about 18 days. The uncoupled model forced with perfect SST, forecast SST, and persisted SST anomalies all perform similarly with predictability estimates around 16-17 days. While most of the SST experiments have correlation coefficients that are very close together out to about 10 days, the monthly and climatological SST experiments both appear to lose skill more rapidly with estimates around 14 days and 9 days respectively. This is likely due to the fact that the initial SSTs for these experiments are out of balance with the initial atmospheric state whereas the other SST sensitivity experiments are initialized with SSTs that are the same as the coupled control run although the SSTs evolve differently. This underscores the importance of the balance between the atmosphere and ocean initial conditions as well as the importance of the initial SST containing the intraseasonal variability in SST.

The predictability estimates based on the correlation of the ensemble mean with the control shows a marked increase in predictability compared with the previous correlations with the exception of the climatological SST and monthly SST experiments (Fig. 2b). Both the forecast SST and perfect SST experiments show increases of about 7-8 days, when the ensemble mean is used. The largest increase as well as the longest predictability is seen in the coupled model, which has predictability estimates of about 36 days when the ensemble mean is used. By comparing the predictability estimates between the coupled and perfect SST experiments, it appears that coupled air-sea interactions provide about 12 days of additional predictability. However, perfect SST is not realistic for an operational forecast. Therefore, if a coupled model is not used, then the potential loss of forecast skill is based on the predictability estimates from the forecast (~13 days less than coupled) or persisted SST anomaly (~16 days less than coupled) cases.

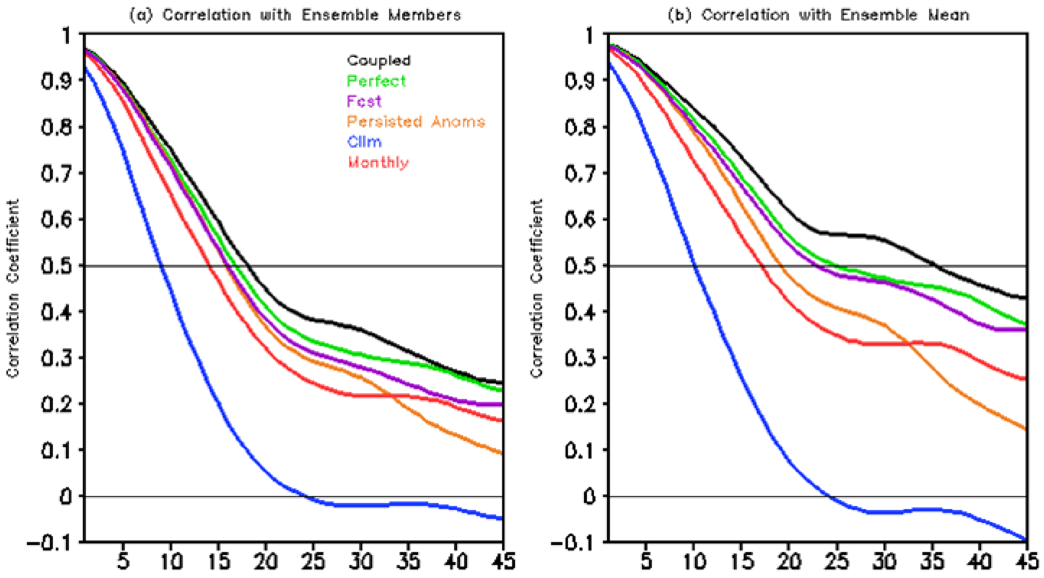

Figure 2 Predictability curves of filtered precipitation in terms of correlations between the ensemble members with the control (a) and correlations of the ensemble mean with the control (b) for the coupled experiment (black), the uncoupled experiment (green), the forecast SST experiment (purple), the persisted SST anomaly experiment (orange), the climatotological SST experiment (blue), and the monthly SST experiment (red).

c) Implications for extended range forecasts

In the previous predictability calculations, the predictability is calculated over the entire Indo-Pacific region. Therefore, it is not possible to ascertain the specific locations that contribute to the "skill" of the forecasts. In this section, we focus on understanding the regions that potentially contribute to the skill of a week-3 forecast. The correlations over the nine ensemble members for all ten events are calculated at each point in the Indo-Pacific region for unfiltered precipitation anomalies averaged over a week-3 forecast. These correlations are calculated for the SST sensitivity experiments (excluding the climatological SST case) and shown in Fig 3. The bottom right panel (Fig 3f) shows the composite precipitation anomalies over all ten events from the control simulation for week-3. This is a composite picture of what the predictability experiments are trying to forecast. It is assumed that the "skill" in the predictability "forecasts" should be primarily due to the MJO-related precipitation. In general, the predictability experiments show skill in the region of positive precipitation anomalies with correlations exceeding 0.5. However, the region of highest correlations in all the experiments is located in the central Pacific Ocean with correlations exceeding 0.7. This indicates that ENSO may contribute strongly to forecast skill for week-3. In comparing the correlation maps for the different SST experiments, it is clear that degrading the SSTs produces a reduction in skill in the central Pacific and in the Indian Ocean for a week-3 forecast. Similar results are also seen for a week-4 forecast (not shown), although the correlations are weaker.

5. Conclusions

This study investigates the impact of coupled air-sea interactions on the simulation and predictability of the MJO and further attempts to understand the sensitivity of the predictability of the MJO to different SST variability. These questions are addressed by performing both simulation experiments and perfect model predictability experiments using the CFS. The main of conclusions of this work are:

1. The CFS and GFS are able to simulate some of the major characteristics of the MJO, but there are deficiencies.
2. There is potential to improve forecasts of the MJO by using ensembles and a coupled model for week-2 and beyond. The loss of potential skill by not using a coupled model is approximately 18 days.
3. Forecasts for the MJO need to be initialized with atmospheric and oceanic initial conditions that contain intraseasonal variability and are in balance with each other.
4. There is potential skill for lead times of up to 4-weeks even without intraseasonal filtering. This skill comes from both ENSO and the MJO.

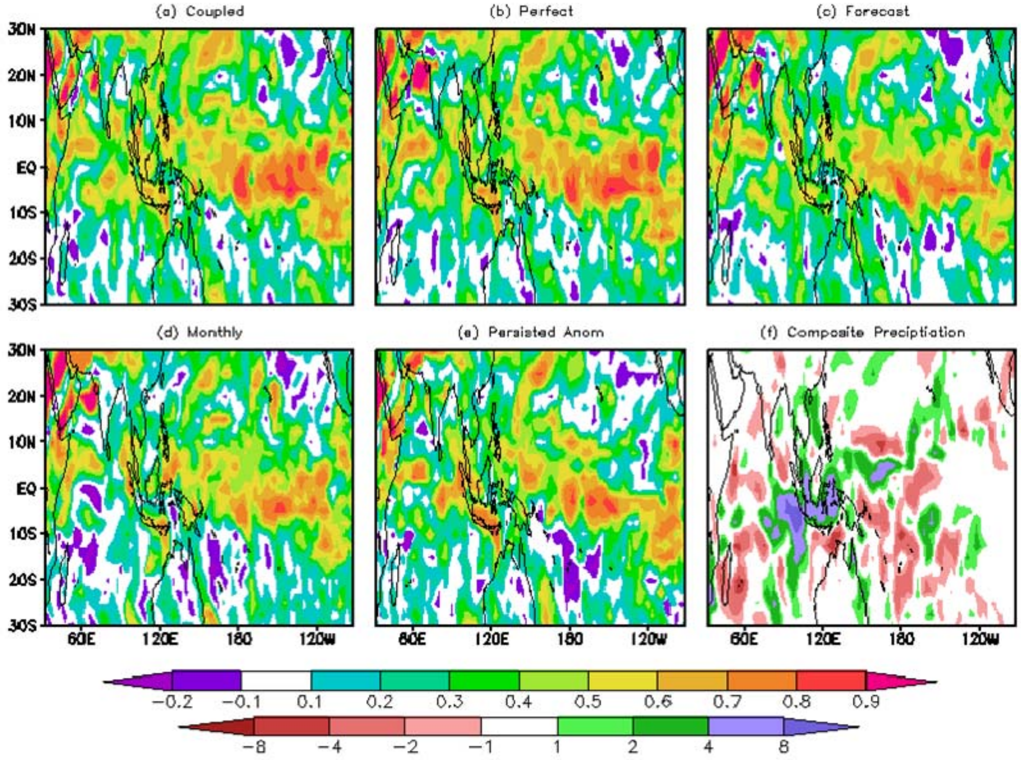

Figure 3 Correlation of unfiltered precipitation for a week-3 forecast calculated over the nine ensemble member for each of the ten events for the (a) coupled, (b) perfect SST, (c) forecast SST, (d) monthly SST, and (e) persisted SST experiments. The bottom right panel (f) shows the composite precipitation (mm/day) over all events from the control simulation for a week-3 forecast.

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