Intraseasonal SST-precipitation relationship and its variability over the tropical summer monsoon region, as in observations and the Climate Forecast System v2

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The SST-precipitation relationship in the intraseasonal variability (ISV) over the Asian monsoon region is examined using recent satellite data and simulations from a state of the art coupled model, the Climate Forecast System version 2 (CFSv2). Results from the study demonstrates the presence of a spatial variability in the atmospheric convective response to the SST, with a quicker response over the Arabian Sea (~5 days) and a slower response over the Bay of Bengal and the South China Sea (~12 days). Though the response to the SST anomalies in destabilizing the lower atmospheric column is similar across the basins, the presence of a relatively strong surface convergence over the Arabian Sea accelerates the vertical upward motion of moist air, resulting in a relatively faster response in the local precipitation anomalies.

CFSv2 is found to exhibit reasonable skill in simulating the coherent patterns in northward propagating monsoon intraseasonal anomalies, consistent with observed ISV characteristics. With respect to the observations, the air-sea coupling and the spatial variability is well simulated in the model. However, there is an aggravation of the ISV over the Arabian Sea, leading to a stronger SST-precipitation correlation in the model ($r=0.7$) in comparison with the observations ($r=0.4$). Such an overestimation of the SST-precipitation relationship might contribute to the bias in the precipitation over the region. This could be due to a systematic bias in the mixed layer depth in the model, leading to an amplification of the SST anomalies and the resultant ISV. As simulating the ISV accurately is important for predicting the active/break spells of the monsoon, it is argued that a prime focus should be on improving the mixed layer scheme of the ocean model. Model sensitivity experiments are carried out and presented to substantiate the results obtained.

1 Introduction

A major aspect of the Asian monsoon variability, usually playing the decisive role on the agriculture and economy, is its intraseasonal variability (ISV), which manifests as active and break spells of precipitation. The ISV has a large zonal extent extending from the Arabian Sea to the South China Sea and even to the western North Pacific [1]. Studies based on observations [2,3,4] and numerical experiments [5] have indicated significant roles of intraseasonal SST in influencing the monsoon ISV.

However, these studies have not delved into the spatial variability of the SST-precipitation relationship and the differences in the ocean-atmosphere interaction over these regions in contributing to this variability. Understanding the SST-precipitation relationship, its spatial variability and the ocean-atmosphere processes involved in it is crucial for evaluating and rectifying model forecasts, and hence, our first objective. The present study also aim to examine the fidelity of a state of the art model, the CFSv2, in reproducing the monsoon ISV, as many of the earlier models including those in the IPCC AR4 array had significant issues in simulating the salient features of the ISV over the tropics.

2 Data, Model and Methods

The 3-day running mean SST and precipitation based on the TRMM Microwave Imager (TMI), and sea surface winds from the QuikSCAT scatterometer, on a ~0.25° grid are used. The surface fluxes are obtained from the TropFlux project.

The model used is the Climate Forecast System (CFSv2), a fully coupled ocean–land–atmosphere–sea ice model from NCEP. The atmospheric component of CFSv2 is the Global Forecast System with a resolution of T126 (~0.9° grid) in the horizontal and 64 sigma-pressure hybrid layers in the vertical. The ocean component is the GFDL MOM4p0 with a horizontal resolution of 0.25°-0.5°, with 40 layers in the vertical. CFSv2 was run for 100 years, with the initial conditions and mixing ratios of time varying forcing agents set for the current decade, so that the model climate is comparable with the observed climate from the satellite data.

Anomalies are obtained for all variables by removing the seasonal means and band pass filtered for 10-90 days to retain the ISV over the Asian monsoon region, during June-September. For testing our hypothesis on the role of model systematic bias in modulating the ISV, ensembles of short integrations for the summer monsoon were performed by adding temperature anomalies on the top levels of the ocean, and changing the mixed layer characteristics.

3 Results and Discussion

CFSv2 demonstrates high skill in reproducing the spatial distribution of the observed mean monsoon precipitation, along with its interannual variability, simulating which has been a conundrum for many of the recent climate models (Fig. 1 and Table 1). The intraseasonal SST-precipitation relationship appears to show a spatial variability over the Asian monsoon region, both in the observations and the CFSv2 model. Over the Arabian Sea (AS), SST leads precipitation by ~5 days, whereas over the Bay of Bengal (BoB) and the South China Sea (SCS)
the response is slow, with an SST lead over precipitation by ~12 days (Fig. 2). The reason for the spatial variability is hypothesized as follows. Though the AS, BoB and SCS exhibit similar ISV features and though the response to the SST anomalies in destabilizing the lower atmospheric column is similar, the relatively stronger (weaker) surface convergence over the AS (BoB and SCS) accelerates (decelerates) the uplift of the moist air, resulting in a relatively faster (slower) response in the local precipitation anomalies.

With respect to the observations, the ocean-atmosphere coupling and the spatial variability in the ISV is well simulated in the model. However, there is an overestimation in the intraseasonal anomalies, leading to a stronger SST-precipitation correlation in the model ($r=0.7$) in comparison to the observations ($r=0.4$). Such an amplification of the SST-precipitation relationship might lead to the precipitation bias over the Arabian Sea, in the model. To assess whether the overestimation of the ISV is due to a mismatch between the coupling variables or fine tuning in the model, the anomalies are quantitatively evaluated for their contribution with respect to the increased intraseasonal anomalies. The intensified latent heat flux anomalies in the model are comparable to the amplified surface wind anomalies and the increased SST anomalies are found to be comparable to the simulated net surface flux anomalies. Since there is no apparent mismatch across the coupling variables, it is reasonable to assume that the dynamical processes involved in the intraseasonal air-sea coupling are fairly well simulated in the model.

This leads to an investigation on whether the systematic bias in the mixed layer depth in the model could attribute to the amplification of the ISV over the region. Model sensitivity experiments, with and without the bias, shows that improving the Arabian Sea bias in the model could possibly improve the summer monsoon ISV [6].

### References