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Tropical cyclones in high-resolution Global Climate Models (GCMs) over the Bay of Bengal

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Introduction

Tropical cyclones (TCs) in the Bay of Bengal exhibit distinct bimodal characteristics during the pre-monsoon (April-May) and post-monsoon (October-December) seasons than other ocean basins of the world. The Genesis Potential Index (GPI) is a product of four large-scale climatological variables (absolute vorticity, inverse of vertical wind shear, relative humidity and maximum tropical cyclone potential intensity) associated with the TC genesis in observations (Camargo *et al.* 2007). As a prerequisite of using GCMs to evaluate the effect of global warming on TC activity in the Bay of Bengal, it is crucial to assess the reliability of the model to simulate accurately TC activity in the present. In this study, TC activity over the Bay of Bengal using multi-ensemble GCMs in the PRIMAVERA project at high resolution (25km) is examined in the present (1950-2014) climate. We use GPI to study the large-scale environmental conditions associated with the seasonal cycle of TC frequency in the models.

TC frequency in observations and models

We average the GPI and its components in the Maximum Development Region (MDR) (5°–15°N and 80°–95°E) which contains 80% of the TC genesis locations in the Bay of Bengal (Li *et al.* 2013) . In observations, the climatological monthly cyclone frequency is estimated using the IBTrACS data and the climatological GPI and its components are calculated using the ERA5 reanalysis data. Although the CNRM-CM6.1 (atmosphere-only) model struggles to reproduce the observed frequency and intensity of TCs, the model can capture the bimodal characteristics of the seasonal cycle of cyclones over the BoB during the pre-monsoon and post-monsoon seasons (Figure 1). However, the difference in cyclone frequency between the pre-monsoon and post-monsoon seasons is reduced in the this model compared to the observations. GPI is able to capture the seasonal variation of the TC frequency over the Bay of Bengal in both the observations and the model.

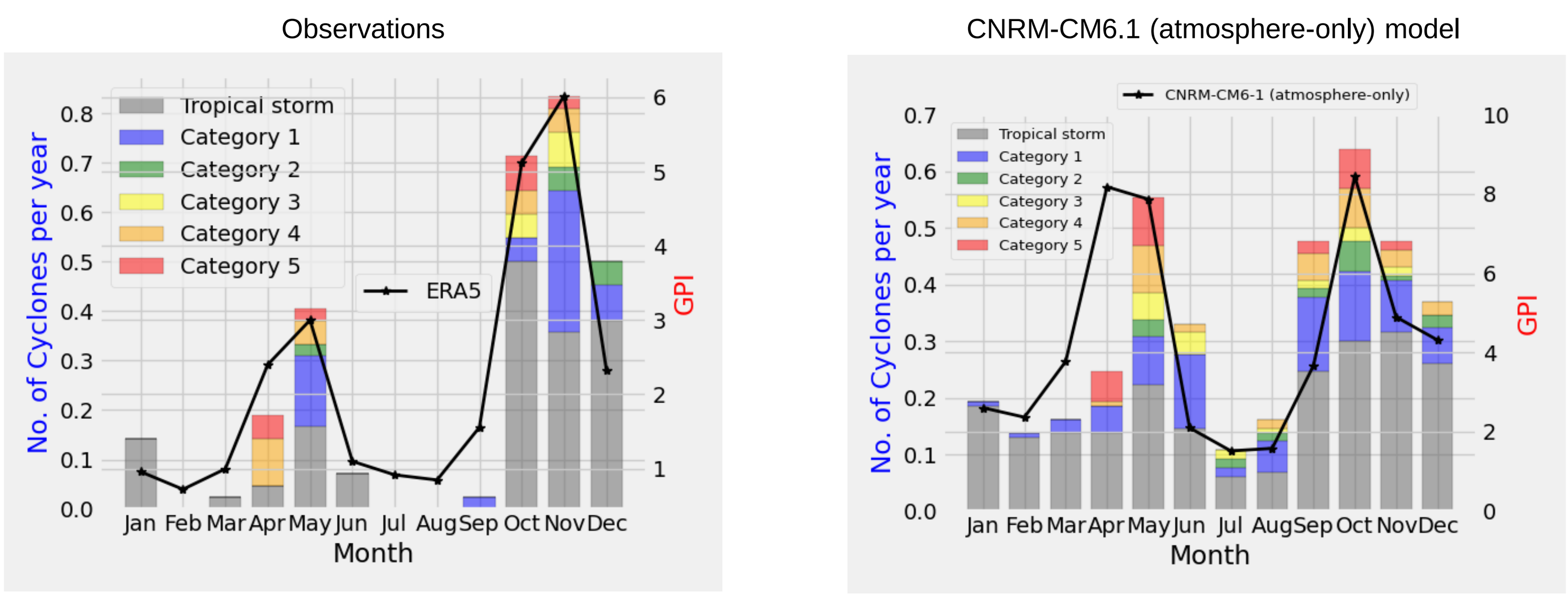

Figure 1: Seasonal cycles of the number of cyclones per year (bars) and GPI (black solid curve) in the BoB for the observations (left) and CNRM-CM6.1 atmosphere-only model (right) in PRIMAVERA in the present climate (1950-2014). The left and right vertical axes are for the number of cyclones per year and GPI values respectively.

Contributions of large-scale environments in GPI to model biases

We analyse the monthly relative contribution of each term in GPI to the total GPI bias for the CNRM-CM6.1 (atmosphere-only) model, with ERA5 taken as reference (Figure 2). In the pre-monsoon season, the RH term (green bars) contributes the most (and positively) to the GPI bias in CNRM-CM6.1 and might increase the TC frequency in the model. We also see that a negative RH bias in the post-monsoon which could be linked to a decreasing TC frequency. Due to the increase of RH term in the pre-monsoon and a decrease in the post-monsoon, it is possible therefore that this model produces almost the same magnitude of GPI during the pre-monsoon and post-monsoon seasons. In the post-monsoon season, the windshear term (blue bars) contributes significantly and positively to the GPI bias.

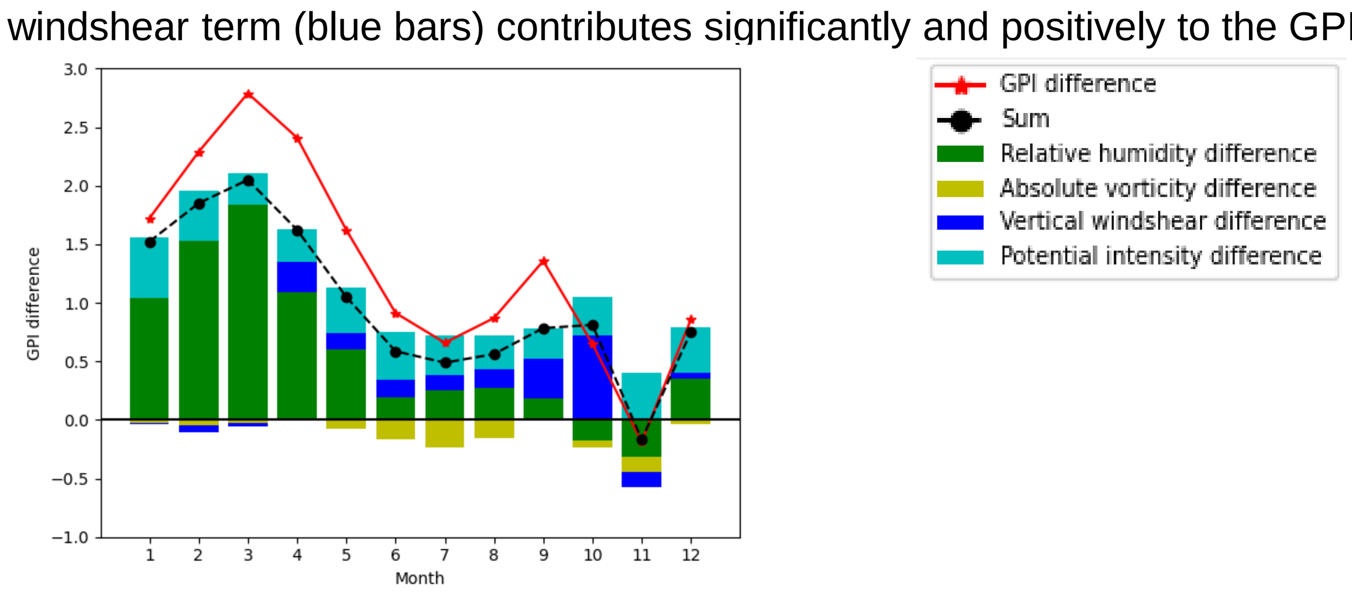

Figure 2: The climatological monthly contribution of the relative difference of each term in GPI to the model biases and their sum for the CNRM-CM6.1 (atmosphere-only) model in the Bay of Bengal. Different colour bars correspond to different environmental variable terms in the GPI. The black dashed line is the sum of the biases of the four terms in GPI and the red solid line is the actual GPI bias (relative difference) in the model.

Model bias in RH term during the pre-monsoon

In the Maximum Development Region over the Bay of Bengal, both the positive RH (at 600 hPa) bias and positive precipitation bias are observed during the pre-monsoon season for the CNRM-CM6.1 model (Figure 3). There is a convergence of low-level wind wind over the same region which coincides with the area of positive precipitation anomaly in the model during this season. We suggest that the pre-monsoon positive relative humidity bias is caused by the early onset of monsoon because the model has a positive rainfall bias over the Bay of Bengal.

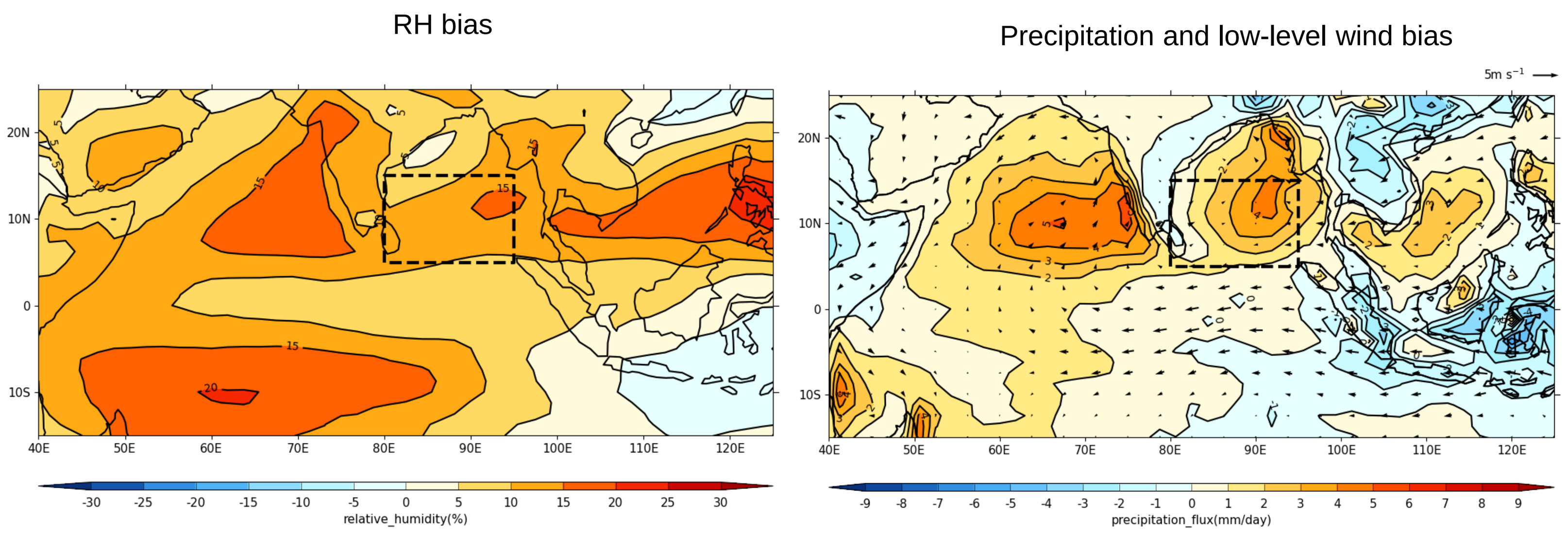

Figure 3: Spatial distributions of model biases in the 600hPa RH (left) and 850 hPa wind (vectors) and precipitation (contours) (right) in CNRM-CM6.1 (atmosphere-only) during the pre-monsoon season.

Model bias in windshear term during the post-monsoon

In the Maximum Development Region over the Bay of Bengal, there is a negative bias in the magnitude of the actual vertical windshear between 200 and 850 hPa level (inverse of GPI windshear term) in the CNRM-CM6.1 model (Figure 4). There is a westerly upper-level (200 hPa) wind bias over the same region. If we compare the wind vector at this level between the reanalysis and the model bias, it is clear that the ERA5 easterlies at the upper level are weaker in the model, so we get a westerly bias in the BoB box.

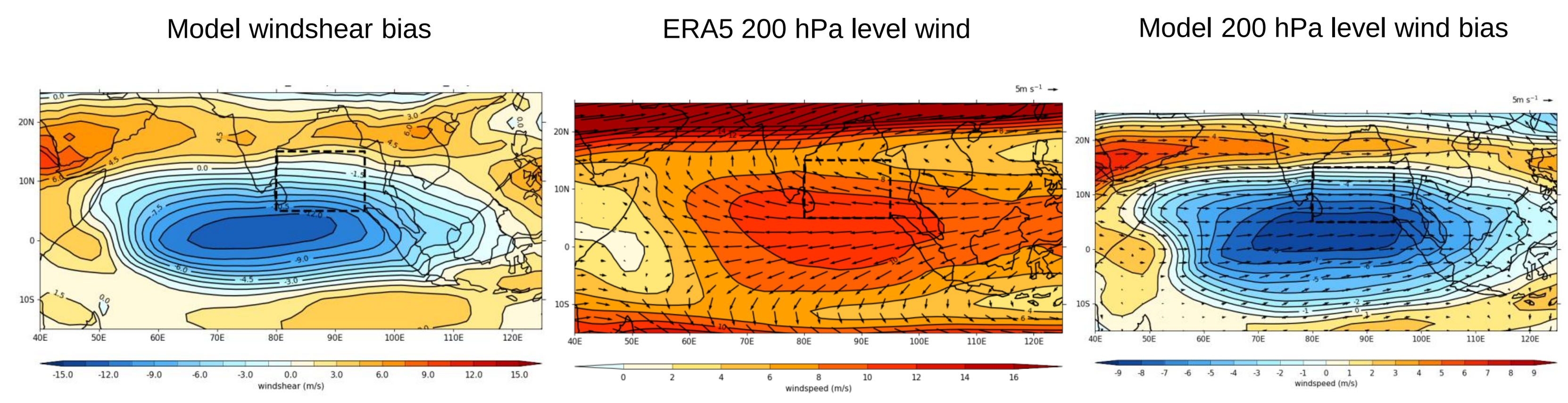

Figure 4: Spatial distributions of CNRM-CM6.1 model bias in the magnitude of the actual vertical wind shear between 200 and 850 hPa (left), ERA5 reanalysis upper-level (200 hPa) winds (middle) and CNRM-CM6.1 model bias in the upper level (200 hPa) winds (right) during the post-monsoon season. For windshear, the contours represent the magnitude of the vertical wind shear bias in the model (left). For 200 hPa winds, The contours represent the magnitude of the windspeeds at 200 hPa (middle and right).

Summary

- CNRM-CM6.1 model can capture the observed double peaks in TC frequency during pre-monsoon and post-monsoon. GPI has the capability to predict the seasonal variation of TC frequency in both the model and observations.
- The relative humidity term in GPI contributes the most to the model bias during the pre-monsoon season. This might be caused by an early onset on monsoon in model.
- The windshear term contributes the most to the model bias during the post-monsoon season for the CNRM-CM6.1 model. The easterlies in the upper level gets weaker in the model compared to the observation which causes a negative windshear bias in the model.

References

1. Camargo, S. J., Emanuel, K. A. and Sobel, A. H. (2007), Use of a genesis potential index to diagnose ENSO effects on TC genesis, *J. Climate*, **20**, pp. 4819-4834.
2. Li, Z., W. Yu, T. Li, V. S.N. Murty, and F. Tangang (2013), Bimodal character of cyclone climatology in the Bay of Bengal modulated by monsoon seasonal cycle. *J. Climate*, 26 (3), pp. 1033-1046.

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