Seasonal predictability of the extreme Pakistani rainfall of 2022 -possible contributions from the northern coastal Arabian Sea temperature-

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1. Introduction

Pakistan and northwestern India experienced extremely wet conditions during June–August (JJA) of 2022 (Fig. 1a). The mean rainfall anomaly in the region 20°N–35°N and 60°E–75°E (hereafter, the Pakistan rainfall (PR) anomaly) was 2.76 mm day-1, i.e., beyond four standard deviations of the year-to-year variations (0.66 mm day-1) in the past 40 years (Fig. 2). A sequence of extreme rainfall events led to severe floods, which killed nearly 1500 people, caused havoc on infrastructure over a wide area, and even reduced crop production by 80–60%. A successful prediction of the extreme flood at least a few months ahead could have helped reduce the socio-economic losses through necessary mitigation measures. Such a research stream is becoming critically important in Pakistan and India, where the frequency of extreme floods is expected to increase due to ongoing global warming3 and the impacts of natural year-to-year climate variability are also becoming more serious.

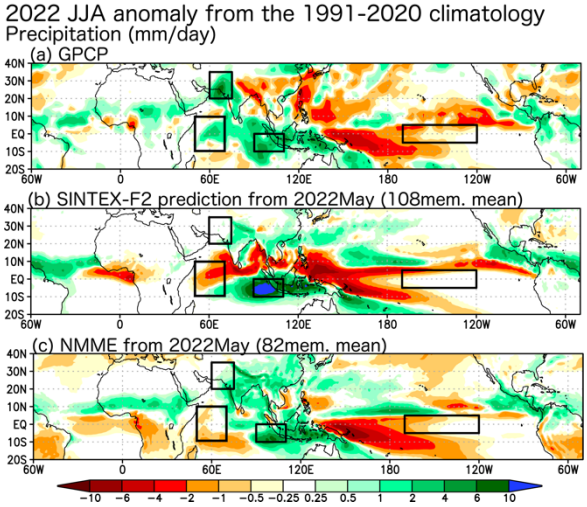

Figure 1. Precipitation anomaly in June–August 2022 (a) Precipitation anomaly from the GPCP observational data averaged in June–August 2022 (mm day-1). The PR, the DMI, and the Niño3.4 regions are shown by black boxes, respectively. (b, c) Same as (a), but for the prediction issued on early May 2022 by the SINTEX-F2 (108-ensemble mean) and the NMME (82-ensemble mean).

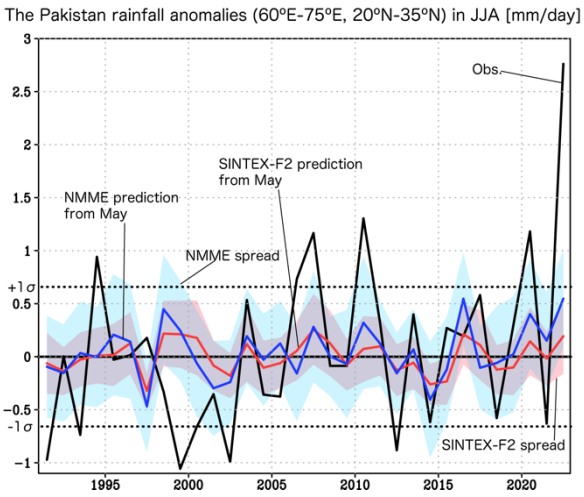

Figure 2. Time series of the June–August average of the Pakistan rainfall anomaly (a) Time series of the June–August average of the PR anomaly from the GPCP observational data (mm day-1; black), the predictions issued on early May by the SINTEX-F2 (108-ensemble mean; red) and the NMME (53-ensemble mean; blue). The pink and light blue shades showed the ensemble spreads of the SINTEX-F2 and the NMME. The standard deviation (σ) from the GPCP data (0.66 mm day-1) is shown by the dashed line. The correlation skills in the 1991–2021 period of the SINTEX-F2 and the NMME prediction from May are shown on the top-left corner.

Unfortunately, the extreme event of summer 2022 was not captured by seasonal prediction systems, such as the Scale Interaction Experiment-Frontier version 2 (SINTEX-F2) climate model and the North American Multi-Model Ensemble (NMME), despite their success in capturing the negative Indian Ocean Dipole and La Niña evolving at the time (Figs. 1 and 3). The present study is to explore the origin of the failure and, hopefully, find potential room for improvement in the seasonal predictions by analyzing the co-variability of intermember anomalies and conducting some numerical experiments with the SINTEX-F2.

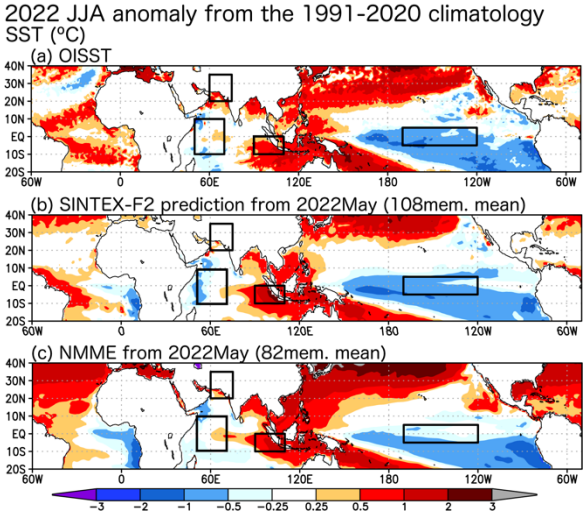

Figure 3. Sea surface temperature (SST) anomaly in June–August 2022 Same as Figure 1, but for the OISSTv2 high-resolution data and the SST predictions (ºC).

2. Numerical experiments

Deep convection over tropical oceans is generally enhanced above a threshold SST around 26–28 °C. Since the observation shows that the absolute SST in the northern coastal Arabian Sea (60°E–75°E, 20°N–30ºN, hereafter referred to NAS) was about 28–29 ºC during the summer of 2022, it is possible that the NAS could locally drive the deep convection and contribute to the PR. To examine the hypothesis, we have conducted two sets of sensitivity experiments starting from early May 2022. The first experiment (NAS_OBS) is a 108-member ensemble prediction in which the model SST in the NAS was strongly nudged to the NOAA OISST V2 High Resolution Dataset from early May until August at a daily time-scale by a coefficient of 2,400 W m−2 K−1 with a linearly tapering 5º buffer zone that extends to 15ºN and 55ºE. The second experiment (NAS_ANOM) is similar to the NAS_OBS, but nudged toward the daily observed SST anomaly of the NOAA OISST V2 High Resolution Dataset (deviation from the daily mean climatology) added to the model predicted daily climatology for the 1991–2020 period. The anomalies in NAS_ANOM are defined as deviations from the mean climatology in the original prediction, while the anomalies in NAS_OBS are defined as deviations from the mean climatology in the 1991-2020 re-forecast experiments in NAS-OBS by 12 members.

In the NAS_ANOM experiment, the number of members predicting the PR anomalies above 1.00 mm day-1 almost tripled, and the ensemble mean prediction (+0.42 mm day-1) was about 220% of that of the original reforecast experiments, capturing about 15% of the observed PR anomalies. The difference in the ensemble means between the original reforecast and the NAS_ANOM was beyond the 99% confidence level on a paired t-test. The enhancement of moisture convergence at 850 hPa over the enhanced positive SST anomalies in the NAS seems to be responsible for this (Fig. 4). The orographic rainfall in the Western Ghats also clearly increased, which could contribute to the target area. In the climatological state, the orographic rainfall in the Western Ghats is large relative to the Pakistan rainfall. When we normalized the rainfall anomalies by the climatological rainfall, the effectiveness of the NAS warming in increasing rainfall over Pakistan and the Western Ghats was comparable. Those features in the NAS_ANOM was enhanced in the NAS_OBS experiment. The ensemble mean prediction (+0.69 mm day-1) captured about 25% of the observed PR anomalies (Fig. 4).

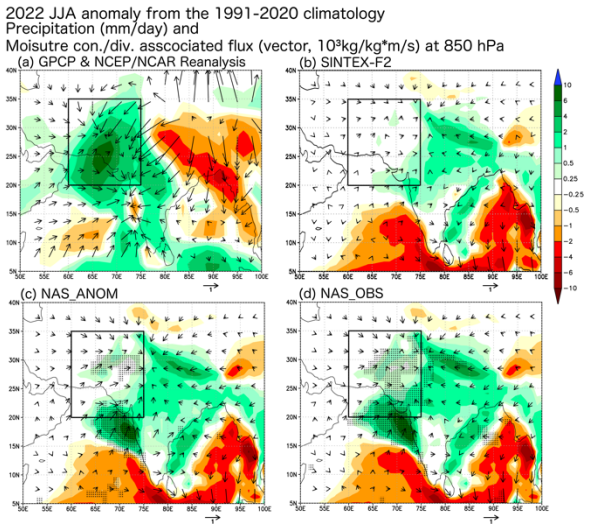

Figure 4. Pakistan precipitation anomaly in June–August 2022 (a, b) Same as Figure 1 (a, b), but for the zoom-in the northern Indian Ocean. The PR region is shown by black boxes. (c, d) Same as (a, b), but for the NAS_ANOM and the NAS_OBS (108-ensemble mean). For (c, d), dotted are area where the differences between the nudging experiment and the original experiment are statistically significant above the 99% significance level.

The above results clearly demonstrate the importance of the positive SST anomaly in the NAS in the successful seasonal prediction of the 2022 summer extreme rainfall in Pakistan [1].

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References

[1] Doi, T., Behera, S.K. & Yamagata, "Seasonal predictability of the extreme Pakistani rainfall of 2022 possible contributions from the northern coastal Arabian Sea temperature", npj Clim Atmos Sci 7, 13 (Jan. 2024).