Seasonal predictability of tropical cyclone frequency over the western North Pacific by a large-ensemble climate model

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1. Introduction

In Japan, South Korea, Taiwan, the Philippines, and other southeast Asian coastal regions, tropical cyclones (TCs) are the most costly and deadly of natural disasters. A successful prediction of the TC frequency in a season at least a few months ahead could help reduce the socio-economic losses through necessary mitigation measures and can benefit a range of industries, including insurance, agriculture, and tourism. Such a research stream is becoming critically important in the low-latitude northwestern Pacific, where the typhoon intensity is expected to increase due to ongoing global warming3 and the impacts of the natural year-to-year variability are also expected to be more serious.

The current status of some models used to predict seasonal TC activity shows good levels of skill before the start of the climatological periods of peak typhoon activity. However, we believe that there remains room for improvement. To the best of our knowledge, an exploration of how to reduce the large uncertainty of seasonal prediction of TC activity by a large-ensemble climate model has not yet been presented, thus it is the focus of this study. In this study, we have analyzed the reforecast outputs by the 108-ensemble-member SINTEX-F2 seasonal prediction system from the nine initialized dates (1st–9th) May and August of 1982–2022 to find predictable events, explore the origin of the success, and, hopefully, find potential room for improvement in the seasonal predictions by analyzing the co-variability of the inter-ensemble member anomalies. Although the spatial resolution of our system (T106) is relatively coarser than that of the other operational systems, the 108-member system has an advantage in finding a predictable signal against unpredictable atmospheric noise on a seasonal timescale and possible co-variability patterns influencing predictions of TC frequency. Besides, the reforecast period in this study (1982–2022) is much longer than the 16-year period 2003–2018 in the previous work (Klotzbach et al. 2019).

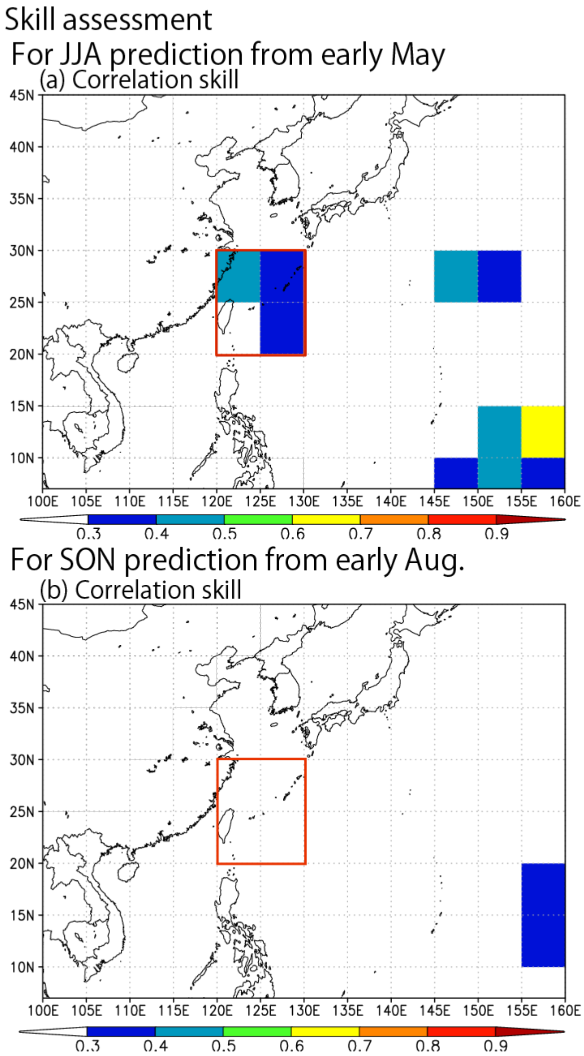

Figure 1. Correlation skill for prediction of TC frequency anomalies in JJA issued in early May by the 1982–2022 reforecast experiments by the SINTEX-F2 system (108-ensemble mean). Areas where the values are statistically significant above the 95% significance level are shaded. The target region (120°E–130°E and 20°N–30°N) is shown by a red box. (b) Same as (a), but for SON issued in early August.

2. Results

We assessed the prediction skills for the JJA prediction issued in early May: the correlation skill of the ensemble-mean prediction. Although the skills were limited, the correlation skill was statistically significant above the 95% significance level around Okinawa and Taiwan (Fig. 1a), which includes the Japanese Exclusive Economic

Zone. Therefore, we would like to focus on that region (120ºE–130ºE and 20ºN–30ºN). The SON prediction issued in early August was further challenging relative to JJA (Fig. 1b) and could not find the predictable area. As shown in the time series of TC frequency anomalies in JJA over the target area (Fig. 2), the TC active (quiescent) summers in 2018 and 1994 (1983 and 1998) were well predicted. Interestingly, the signals, the ensemble-mean predictions, were relatively strong for the four well-predicted summers. When the signal is relatively strong for the coming TC season, we could add information that the prediction is relatively reliable although the sample size was limited to discuss the statistical skill scores.

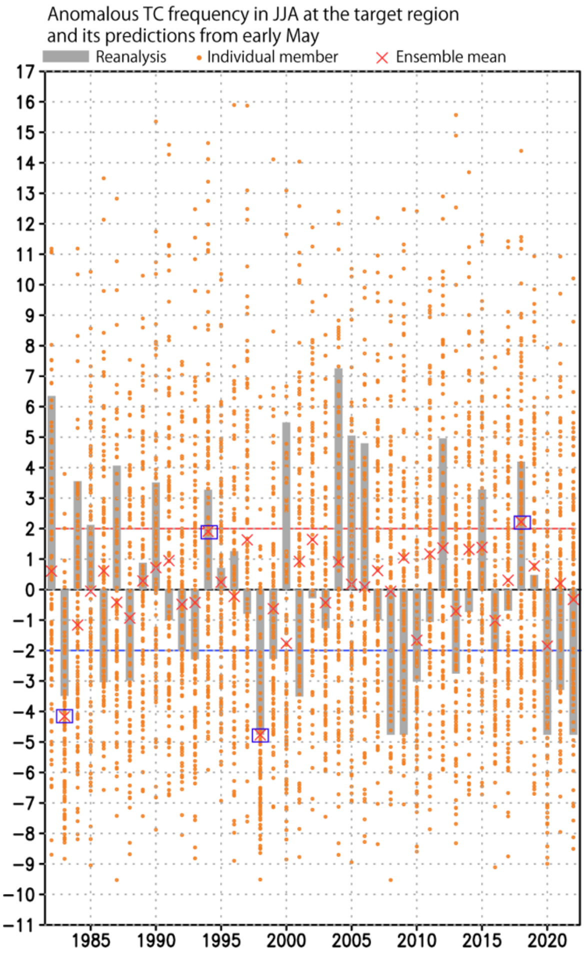

Figure 2. Time series of TC frequency anomalies in JJA averaged over 120°E-130°E and 20°N-30°N; shown by a red box in Figure 2a from the JRA55 reanalysis data (gray bar), the prediction issued on early May of each year by the SINTEX-F2 system (red cross: 108-ensemble mean; orange dot: each ensemble member). The unit of the y-axis is tropical cyclone frequency, i.e. counted TCs. We have highlighted the ensemble mean of 2018, 1994, 1983 and 1998 by blue boxes.

18 TCs were observed over the western North Pacific in JJA 2018, which was ranked the second most active summer since 1979. The model successfully predicted the positive anomalies in the target area (Figs. 3a, b). The model correctly predicted the evolution of a positive IOD, a CP El Niño, and a positive PMM at the time (Figs. 3d, e). The inter-ensemble correlation between the TC frequency anomalies in the target region and them in the other areas could indicate the TC frequency anomalies in the target region had no linear relationship with the TC frequency anomalies in the other regions (Fig. 4c). Interestingly, the prediction of the TC frequency anomalies in the target region was significantly linked with the prediction of the positive IOD, particularly the eastern pole (Fig. 3c): ensemble members that predicted stronger positive IOD tend to predict higher TC frequency in the target region. Although the differences among ensemble members due to large atmospheric internal variability have been considered to be unpredictable noise, the inter-ensemble correlation analyses could support that the teleconnection from the positive IOD commonly appears in ensemble members to some extent.

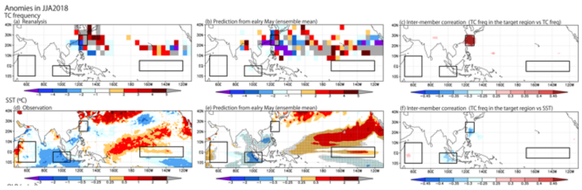

Figure 3. TC frequency anomalies in JJA 2018 from the JRA55 reanalysis data in 5°×5° grid. **(b)** Same as **(a)**, but for the prediction issued in early May 2018 by the SINTEX-F2 system (108-ensemble mean). **(c)** Inter-ensemble member correlation in the 108-member prediction between the TC frequency anomalies in the target area (120°E-130°E and 20°N-30°N) and the TC frequency anomalies for JJA of 2018 issued in early May 2018 by the SINTEX-F2. Values above 0.25, which are statistically significant above the 99% significance level, are shaded. (**d, e, f**) Same as (a, b, c), but for SST (°C). Dotted in (e) are area where the signal-to-noise ratio is above 1. In all panels, the target area, the Dipole Mode Index (DMI, the SST anomaly difference between the western pole off East Africa (50°E–70°E, 10°S–10°N) and the eastern pole off Sumatra (90°E–110°E, 10°S–Equator) and the Niño3.4 (170°W–120°W, 5°S–5°N) regions are shown by black boxes, respectively.

The correlation between the eastern pole of the DMI and the TC frequency anomalies around Okinawa and Taiwan for JJA of 1982–2022 was positive in the observational and reanalysis datasets, which was statistically significant above the 90% significance level (Fig. 4a). This is in agreement with a previous work22. The relationships were also well captured by the seasonal prediction system

(Fig. 4b).

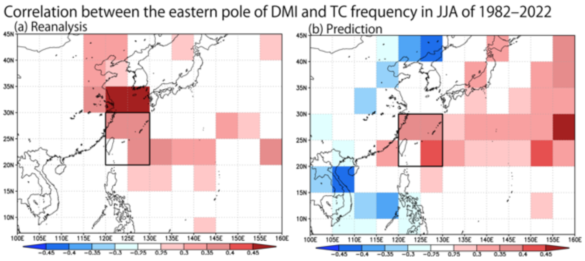

Figure 4. Correlation map between the eastern pole of DMI from the observation and the TC frequency anomalies in JJA of 1982–2022 from the JRA55 reanalysis data in 5°×5° grid. **(b)** Same as **(a)**, but for the prediction issued in early May by the SINTEX-F2 system (108-ensemble mean). In all panels, the target area is shown by a black box. Values above 0.25, which are statistically significant above the 90% significance level, are shaded.

We found that a positive IOD played a key role in the seasonal predictability of the 2018 summer TC frequency around Okinawa and Taiwan by the dynamical prediction system. The 108-member system had an advantage in finding the predictable signal against the large unpredictable noise and the possible IOD teleconnection via the inter-member co-variability analyses. By reducing the uncertainty of the IOD prediction, we could reduce the uncertainty of the TC frequency prediction around Okinawa and Taiwan and increase the signal. The IOD contributions to the predictability were also seen in the correlation analyses in 1982–2022 and some case studies in 1994 and 1998.

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