3A.5 CONTRIBUTION OF TROPICAL INDO-PACIFIC PRECIPITATION ANOMALY TO SEASONAL DIFFERENCES OF LONG-TERM CHANGES IN TROPICAL CYCLONE GENESIS FREQUENCY OVER THE WESTERN NORTH PACIFIC

Jinhui Ju[1], Doo-Sun R. Park[1,2] *, Dasol Kim[3], Minhee Chang[4], Chang-Kyun Park[5]

[1]BK21 Weather Extremes Education & Research Team, Department of Atmospheric Sciences, Kyungpook National University, Daegu, Republic of Korea
[2]Department of Earth Science Education, Kyungpook National University, Daegu, Republic of Korea
[3]Department of Geography, University of Florida, Gainesville, Florida, USA
[4]Climate and Environmental Research Institute, Korea Institute of Science and Technology, Seoul, Republic of Korea
[5]AVEL Solution Development Team, LG Energy Solution, Seoul, Republic of Korea

1. INTRODUCTION

In recent decades, there has been an abrupt decrease in tropical cyclone genesis frequency (TCGF) over the western North Pacific (WNP) since the mid-1990s (Liu and Chan 2013; Park et al. 2011). The changes have shown seasonality (Chang et al. 2021; Hsu et al. 2014); The TCGF over the WNP significantly decreased only in the late season [October–December (OND)], but not in the other seasons.

The previous study by Chang et al. (2021) proposed that the seasonally different location of climatological convective regions within the Indian Ocean and the western Pacific would be able to explain the seasonality in the long-term changes of the TCGF. They suggested that, according to the “rich-get-richer” mechanism proposed by Chou and Neelin (2004), the precipitation increased with increasing sea surface temperature (SST) in the climatological convective regions. The diabatic heating induced by the positive anomaly of precipitation could affect the large-scale circulations. The enhanced convection would cause the anomalous easterlies to the east. They found that the climatological convective regions are located further west in OND than in the other seasons and discussed that the anomalous easterlies to the east of the climatological convective regions could extend more westward in OND. Furthermore, they also explained that, in OND, the anomalous anticyclonic flow could be induced by the anomalous easterlies and the meridional shear anomalies over the WNP. Consequently, the TCGF decreased significantly only in OND.

In this study, we aim to show that the hypothesis suggested by Chang et al. (2021), which was done based on observations, can be verified based on model experiments. Firstly, we verify if the rich-get-richer mechanism works under the tropical Indo-Pacific warming. Secondly, we confirm if the observed diabatic heating induced by increased precipitation can drive the seasonality in large-scale circulations over the WNP.

2. EXPERIMENTAL DESIGNS

Here, we used two models, the Models for Prediction Across Scales – Atmosphere (MPAS-A) Version 7.3 and the dry Linear Baroclinic Model (LBM). MPAS-A was used to confirm whether the precipitation in the climatological convective regions is enhanced under the tropical SST warming. The model configurations are shown in Table 1. For the control-run simulations (CTRL), we prescribed the climatological SST pattern that was averaged daily from 1982 to 2020. For the uniform SST warming simulations (U-WARM), we added 0.5 °C warm anomaly only for tropics (20°S–20°N) to the climatological SST pattern. To reduce model instability caused by drastic changes in the SST at the boundaries, we applied a buffer zone of 10° toward higher latitude (Figure 1). The SST field was updated daily throughout the simulations in both experiments. Both were conducted as parallel experiments with the same SST pattern prescribed for each year, and ran for a total of 30 years, with the first 5 years excluded from analysis as a spin-up period. Identical initial atmospheric conditions from ERA5 were applied

* *Corresponding author address:* Doo-Sun R. Park, Department of Earth Science Education, Kyungpook National. University, Daegu, Republic of Korea; e-mail: dsrpark@knu.ac.kr

to both experiments.

The experiments for LBM were conducted for each season [January–March (JFM), April–June (AMJ), July–September (JAS), and October–December (OND)]. Each experiment was forced by the diabatic heating calculated from each seasonal precipitation anomaly within the tropical Indo-Pacific Ocean (20°S–20°N, 60°E–150°E), where the climatological convective regions are located (Figure 2), which is our region of main interest. Figure 3 shows seasonal precipitation anomalies, and it is evident that the spatial distributions depicted in Figures 2, 3 are similar. The diabatic heating rate (*H*, *K day*$^{-1}$) is calculated from the precipitation anomalies (*P*, *mm day*$^{-1}$) using the following equation:

$$H = \frac{P \times \rho_w \times L_c}{C_p \times (p_s/g)} \times 10^{-3}\ [K\ day^{-1}]$$

where ρ_w is the average water density (1000 kg m^{-3}), L_c is the average latent heat of condensation (2.265×10^6 J kg^{-1}), C_p is the specific heat of hydrostatic pressure (1004 J kg^{-1} K^{-1}), p_s is the average surface pressure (101325 Pa) and g is the average gravitational acceleration (9.80665 m s^{-2}). The experiments ran for a total of 25 days, and the data later than 15 days are used in this study to exclude a spin-up period. Seasonally averaged atmospheric fields from 1982 to 2020 were used as initial conditions for each experiment.

3. RESULTS

Figures 4 show the seasonal differences in precipitation between CTRL and U-WARM (i.e., U-WARM minus CTRL). In JFM and AMJ, the high precipitation areas are mostly constrained over the Indian Ocean and around the Maritime Continent. It moves further north-east in JAS season. In OND, it moves back west and is over the Philippines and the tropical South Indian Ocean. A comparison of Figures 3 and 4 indicates that while the two are not identical, they exhibit a similarity in terms of the seasonal variability in climatologically high precipitation regions, especially being located further west in OND than in the previous season. Only except for JFM, the pattern correlations between the seasonal mean precipitations and the differences are notable and statistically significant at the 99% confidence level. These results imply that the rich-get-richer mechanism is valid in the tropical Indo-Pacific under the tropical SST warming. In JFM, just like observation (Fig. 3a), the pattern correlation is relatively low compared to the other seasons.

Figure 5 depict the seasonal differences in relative vorticity and horizontal wind at 850-hPa between CTRL and U-WARM (i.e., U-WARM minus CTRL). In JFM and AMJ, there are minor changes in the large-scale flow over the seasonal main development regions (MDR) of TCs, which is similar with the observations (Fig. 6). In JAS, there is a strong anomalous cyclonic flow over the south of the seasonal MDR, which is related to increased precipitation and differs from observed changes. There is still a strong anomalous anticyclone over the north of the MDR, which may offset the anomalous cyclone. In OND, there is an anomalous anticyclone across the seasonal MDR, which is unfavorable for TC development, but the circulation is so week, which could be results of the competition between precipitation in Indian Ocean and in equatorial Pacific.

To clarify the causality between the changes in the precipitation and the large-scale circulation, we implemented the LBM experiment forced by diabatic heating calculated from the observed changes in the precipitations. Our LBM experiments reveal that applying diabatic heating for each season results in distinct modifications in the large-scale circulation over the seasonal MDR region. Figure 7 shows the relative vorticity and the horizontal wind at 850-hPa simulated by the LBM experiments. In JFM, AMJ, and JAS, anomalous easterlies and anticyclonic flows are restricted to the east of 140°E. On the other hand, there are strong anomalous easterlies and anticyclones over the tropical WNP in OND. These results affirm that the diabatic heating induced by the changes in precipitation could modulate the large-scale circulation over the seasonal MDR.

4. DISCUSSIONS

Our model results indicated that just the observed changes in the large-scale environmental factors that can affect TC genesis are simulated in the numerical model. The TC genesis was not captured directly due to a low model resolution of 240 km. A higher resolution requires lots of computational resources, which is beyond our current capabilities. Furthermore, the SST changes observed in the real world are not uniform but La Niña-like SST warming, indicating a warmer SST in western Pacific than in the equatorial or Eastern Pacific. In our study, we assumed the uniform SST warming over tropics to verify that the rich-get-richer mechanism is valid in MPAS-A. Further study will be conducted to investigate the effects of La Niña-like SST warming on the mechanism. Additional LBM experiments forced by differences in precipitation over broader regions including the tropical Indo-Pacific Ocean, and the differences in precipitation simulated in MPAS-A, could provide insight into whether the precipitation anomalies over the Indo-Pacific Ocean would affect the large-scale circulation over the WNP.

5. REFERENCES

Chang, M., D.-S. R. Park, and C.-H. Ho, 2021: Possible Cause of Seasonal Inhomogeneity in Interdecadal Changes of Tropical Cyclone Genesis Frequency over the Western North Pacific. *Journal of Climate*, **34,** 635-642.

Chou, C., and J. D. Neelin, 2004: Mechanisms of Global Warming Impacts on Regional Tropical Precipitation. *Journal of Climate*, **17,** 2688-2701.

Hsu, P.-C., P.-S. Chu, H. Murakami, and X. Zhao, 2014: An Abrupt Decrease in the Late-Season Typhoon Activity over the Western North Pacific. *Journal of Climate*, **27,** 4296-4312.

Huangfu, J., R. Huang, and W. Chen, 2018: Interdecadal variation of tropical cyclone genesis and its relationship to the convective activities over the central Pacific. *Climate Dynamics*, **50,** 1439-1450.

Liu, K. S., and J. C. L. Chan, 2013: Inactive Period of Western North Pacific Tropical Cyclone Activity in 1998–2011. *Journal of Climate*, **26,** 2614-2630.

Park, D.-S. R., C.-H. Ho, J.-H. Kim, and H.-S. Kim, 2011: Strong landfall typhoons in Korea and Japan in a recent decade. *Journal of Geophysical Research: Atmospheres*, **116**.

Table 1. Model configurations for MPAS-A and LBM.

	MPAS-A	LBM
Horizontal spacing	240 km	T42 (64×128)
Vertical levels	55 levels	20 levels
Convection	Grell-Freitas	-
Microphysics	WSM6	-
Land Surface	Noah	-
Boundary and Surface layer	MYNN	-

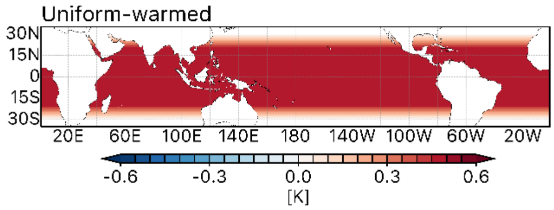

Figure 1. Distribution of sea surface temperature anomaly for U-WARM experiments.

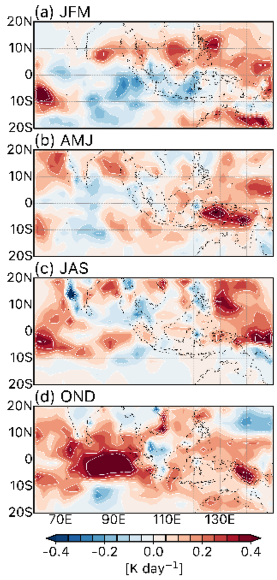

Figure 2. Diabatic heating rate during (a) January to March, (b) April to June, (c) July to September, and (d) October to December.

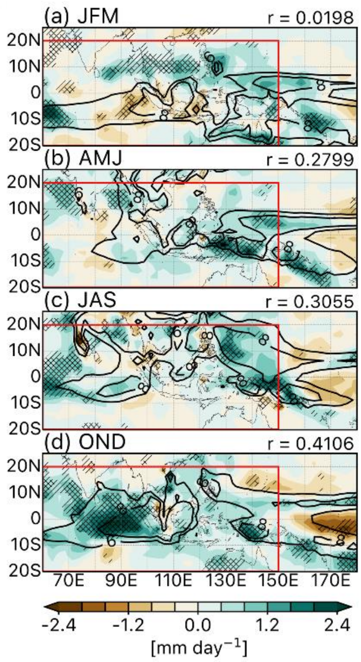

Figure 3. Spatial distribution of interdecadal changes (shadings) in precipitation and seasonal mean precipitation (contours). The red boxes indicate the location of which the climatologically large precipitation is located.

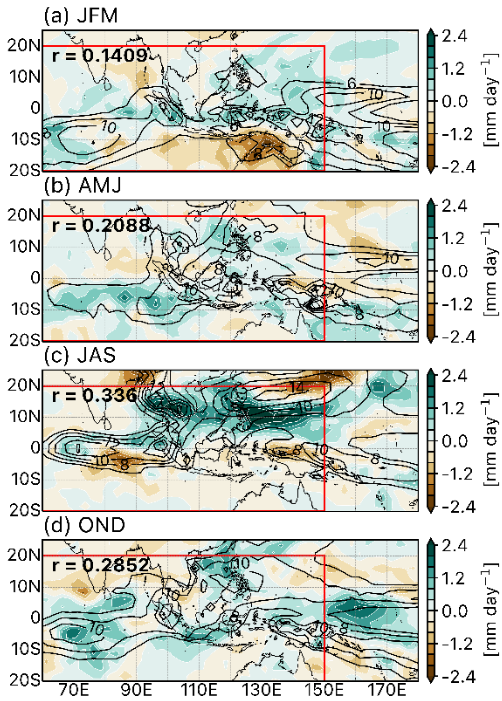

Figure 4. Difference in precipitation between U-WARM and CTRL experiments (U-WARM minus CTRL). The black contours indicate that the climatological mean precipitation simulated in CTRL. The red boxes represent the location of which the observed main precipitation region. The r values in the upper left of red boxes denote the pattern correlation between the CTRL precipitation and the difference.

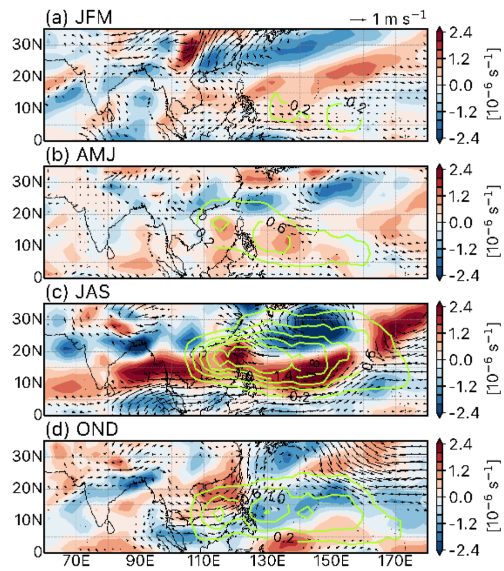

Figure 5. Differences in 850-hPa relative vorticity (10^{-5} s^{-1}; shadings) and horizontal wind (m s^{-1}; vectors) between U-WARM and CTRL (U-WARM minus CTRL). The vectors are plotted when they are significant at the 90% confidence level. The green contours indicate the seasonal main development region based on the JTWC best track data.

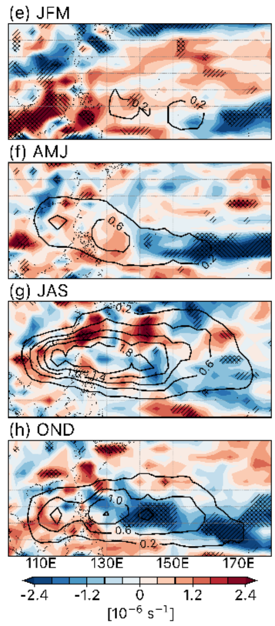

Figure 6. Spatial distribution of interdecadal changes (shadings) in 850-hPa relative vorticity and seasonal mean main development regions (MDR; contours).

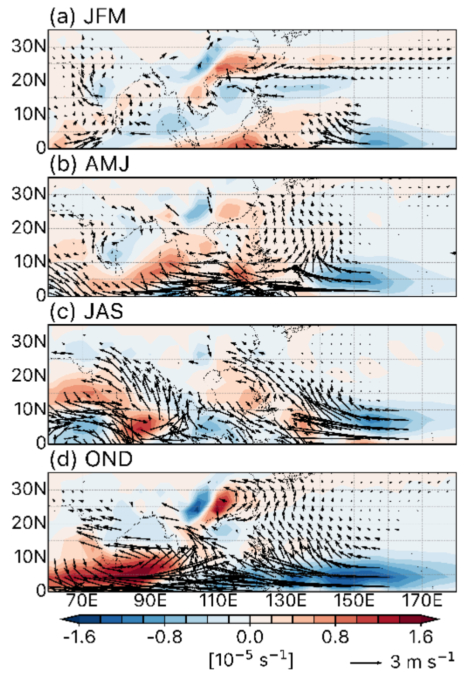

Figure 7. Anomaly of 850-hPa relative vorticity (shadings) and horizontal wind (vectors) simulated by LBM.