Long-term Meridional Variation of Lifetime Maximum Intensity of Tropical Cyclone over the Western North Pacific

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1. INTRODUCTION

Kossin (2014) revealed a significant poleward migration of the global mean location of the lifetime maximum intensity (LMI) and an apparent northward trend of the LMI latitudes in the western North Pacific (WNP) after the 1980s. They suggested that global LMI location poleward migration is potentially linked to the tropical expansion associated with global warming. Many previous studies have analyzed the factors deriving the global poleward migration of LMI locations. They suggest that the variability in the TC frequency and the poleward migration of their genesis locations are the dominant factors driving the poleward migration. In this study, we considered the effect of TC track pattern on the long-term trend of LMI latitude. By classifying the track patterns in WNP, we calculated and estimated the effect of TC patterns on the mean of LMI latitude. We defined the effect of TC track pattern as 'TRACK CHANGE' and the contribution of in-pattern changes as 'PURE CHANGE' in the variation of the annual mean of LMI latitude.

2. DATA and METHOD

The TC best-track data was obtained from the Joint Typhoon Warning (JTWC) Center. We used only the TC with a maximum sustained wind speed greater than 34 knots. The analysis period is 1948–2021, June–October (JJASO). We used the monthly mean SST data, with a horizontal resolution of 2°×2°, was from the National Oceanic and Atmospheric Administration (NOAA) Extended Reconstructed SST version 5.

We quantitively estimated these two effects (track change and pure change) using the method suggested by Kim et al. (2022). At first, we classified the TC tracks over the WNP into seven track patterns using the Fuzzy C-means clustering method (FCM). The ϕ_{LMI} for each TC is equal to the sum of the climatological mean for each pattern($\overline{\overline{\phi_{LMI}}}^{C_k}$) and its anomaly ($\Delta^{C_k}\phi_{LMI}$), as follows,

$$\phi_{LMI} = \overline{\overline{\phi_{LMI}}}^{C_k} + \Delta^{C_k}\phi_{LMI}$$

Using this formula, the anomaly latitude of TC LMI in WNP ($\Delta^{WNP}\phi_{LMI}$) can be expressed as follows:

$$\Delta^{WNP}\phi_{LMI} = \overline{\phi_{LMI}}^{WNP} - \overline{\overline{\phi_{LMI}}}^{WNP} = \frac{1}{N_{WNP}}\sum_{i=1}^{N_{WNP}}\left(\phi_{LMI_i} - \overline{\overline{\phi_{LMI}}}^{WNP}\right)$$

$$= \frac{1}{N_{WNP}}\sum_{k=1}^{7}\sum_{j=1}^{N_{C_k}}\left(\left(\overline{\overline{\phi_{LMI}}}^{C_k} + \Delta^{C_k}\phi_{LMI_j}\right) - \overline{\overline{\phi_{LMI}}}^{WNP}\right)$$

Here, N_{WNP} is the basin-wind annual TC frequency in WNP, N_{C_k} is the annual TC frequency for each track pattern, $\overline{\phi_{WNP}}^{WNP}$ is the annual mean latitude of TC LMI in WNP. Note that the double bar denotes the climatological mean, and the single bar indicates the annual mean in the equations of this study. Because $\overline{\overline{\phi_{LMI}}}^{C_k}$ is a non-variant value for each pattern, $\sum_{j=1}^{N_{C_k}}\overline{\overline{\phi_{LMI}}}^{C_k}$ become $N_{C_k}\overline{\overline{\phi_{LMI}}}^{C_k}$. Thus, Eq.2 can be modified as follows:

$$\Delta^{WNP}\phi_{LMI} = \frac{1}{N_{WNP}}\sum_{k=1}^{7}N_{C_k}\left(\overline{\overline{\phi_{LMI}}}^{C_k} - \overline{\overline{\phi_{LMI}}}^{WNP}\right) + \frac{1}{N_{WNP}}\sum_{k=1}^{7}\sum_{j=1}^{N_{C_k}}\Delta^{C_k}\phi_{LMI_j}$$

Finally, $\Delta^{WNP}\phi_{LMI}$ can be divided into two terms. The first term is a weighted average of $\overline{\overline{\phi_{LMI}}}^{C_k}$ using the annual TC counts in each track pattern. The increase (decrease) of TCs in the pattern that has a higher $\overline{\overline{\phi_{LMI}}}^{C_k}$ leads to a larger (smaller) value of this term. Thus, this term represents the effect of the TRACK CHANGE. The second term is the basin wide annual mean of the anomalies of ϕ_{LMI} within each pattern ($\Delta^{C_k}\phi_{LMI}$). It represents the effect of the PURE CHANGE, independent of the track change.

3. RESULTS

Figure 1 illustrates the time series of PURE CHANGE, and TRACK CHANGE during the analysis period. The correlation coefficients for TRC and PRC with the $\overline{\phi_{LMI}}^{WNP}$ are 0.76 and 0.64, respectively, all of which are statistically significant at more than 99% confidence level, while the correlation coefficient between TRACK CHANGE and PRC is nearly zero (r=0.01). These results indicate that the TRACK CHANGE and PURE CHANGE independently and almost equally contribute to the inter-annual variation of the $\overline{\phi_{LMI}}^{WNP}$. The linear trends for TRACK CHANGE and PURE CHANGE are -0.02° and 0.24° per decade, respectively. Only the PURE CHANGE has a significant slope comparable to the $\overline{\phi_{LMI}}^{WNP}$. Therefore, it can be suggested that the PURE CHANGE is the dominant factor of the long-term trend of LMI poleward migration.

To analyze the relationship with global warming, we illustrate the correlation between SST and $\overline{\phi_{LMI}}^{WNP}$, PURE CHANGE, and TRACK CHANGE (Figure 2). As shown in Figure2, PURE CHANGE contributing the

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LMI poleward migration strongly linked with local SST warming.

4. CONCLUSION

In this study, we evaluated the effect of inter-pattern and intra-pattern changes in the long-term trends of $\overline{\phi_{LMI}}^{WNP}$ over the WNP using the seven TC track patterns classified by the Fuzzy c-mean clustering method. Because each TC track pattern has a different climatological mean of ϕ_{LMI}, the proportions of TCs for the track patterns induce the changes in $\overline{\phi_{LMI}}^{WNP}$. The variation of ϕ_{LMI} within each TC track pattern also cause the changes in ϕ_{LMI}. In the long-term change of $\overline{\phi_{LMI}}^{WNP}$, the PURE CHANGE more significantly contributes rather than TRACK CHANGE. The analysis with the SST suggested that the PURE CHANGE was strongly related to the SST warming. Therefore, the LMI poleward trend may continue due to global warming.

5. REFRENCES

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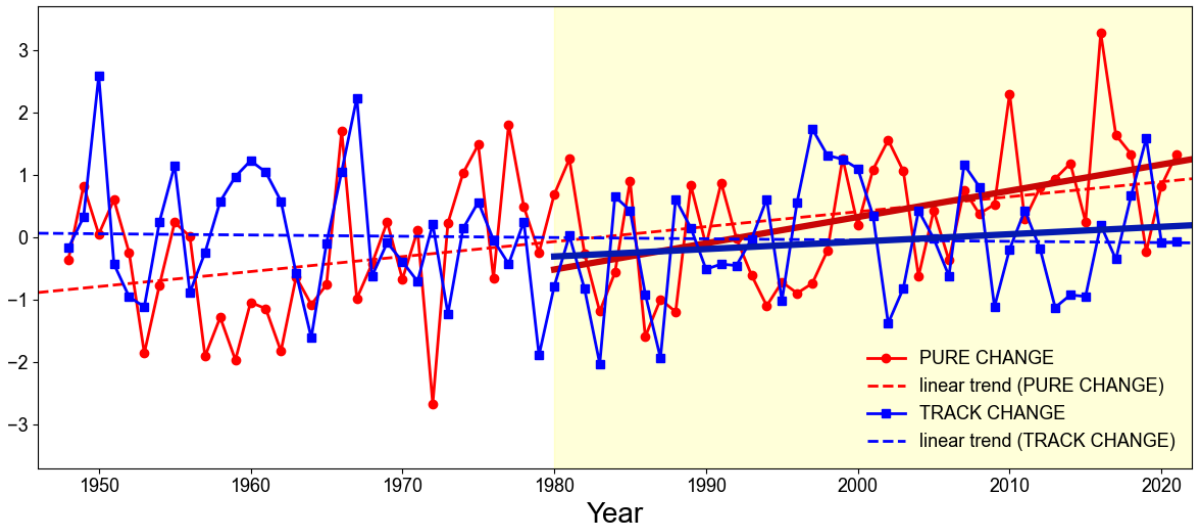

Figure1 Time series of TRACK CHANGE(blue), and PURE CHANGE(red). Dashes lines represent the linear trends for each time series.

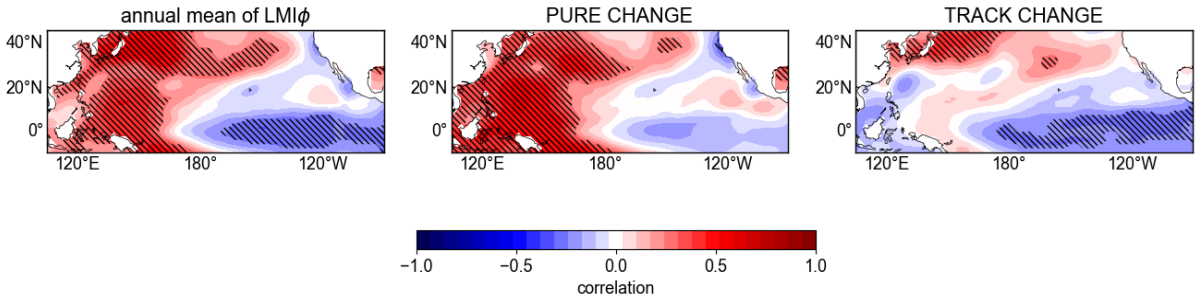

Figure 2. Correlation map of SST on annual mean of LMI latitude(a), PURE CHANGE(b), and TRACK CHANGE(c).