Relationship between sea surface temperature anomalies over tropical Atlantic in late spring and East Asian summer monsoon

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Introduction

- The climate in Northeast Asia, including the Korean peninsula, China, and Japan, is strongly affected by the East Asian Summer Monsoon system (EASM) and its variation can cause extreme events such as droughts and floods, leading to regional socio-economic consequences.
- Several recent studies have newly suggested that Tropical Atlantic SST (TASST) itself can affect the climate variability in the Northern Hemisphere during subsequent seasons (Sun et al. 2009; Ham et al. 2013a, b, 2017; Ham and Kug 2015)
- Based on these aforementioned studies, TASST generally persists from the preceding spring through the following summer due to the oceanic thermal memory, and its signal can be transmitted to the western Pacific through teleconnections
- However, most existing studies merely focused on the relationship between the EASM and the SST tripole in the North Atlantic rather than TASST. Therefore in this study, we examine the remote impact of springtime TASST on the subsequent EASM variability.

Data and method

- Atmospheric Variables (monthly mean air temperature, u,v wind, geopotential height) : MERRA Reanalysis data (1.25°×1.25°)
- Precipitation : GPCP, Korea Weather Station data (monthly mean)
- Sea Surface Temperature : HadISST (1°×1°)
- Nino3.4 Index : NOAA CPC
- Reversed Wang and Fan index (EASMI) (Wang et al., 2008)
  U850 (22.5°~32.5°N, 110°~140°E) - U850 (5°~15°N, 90°~130°E)
- May TASST : Area averaging the SST anomalies over the region (25°S–25°N, 84°W–0°)

Result

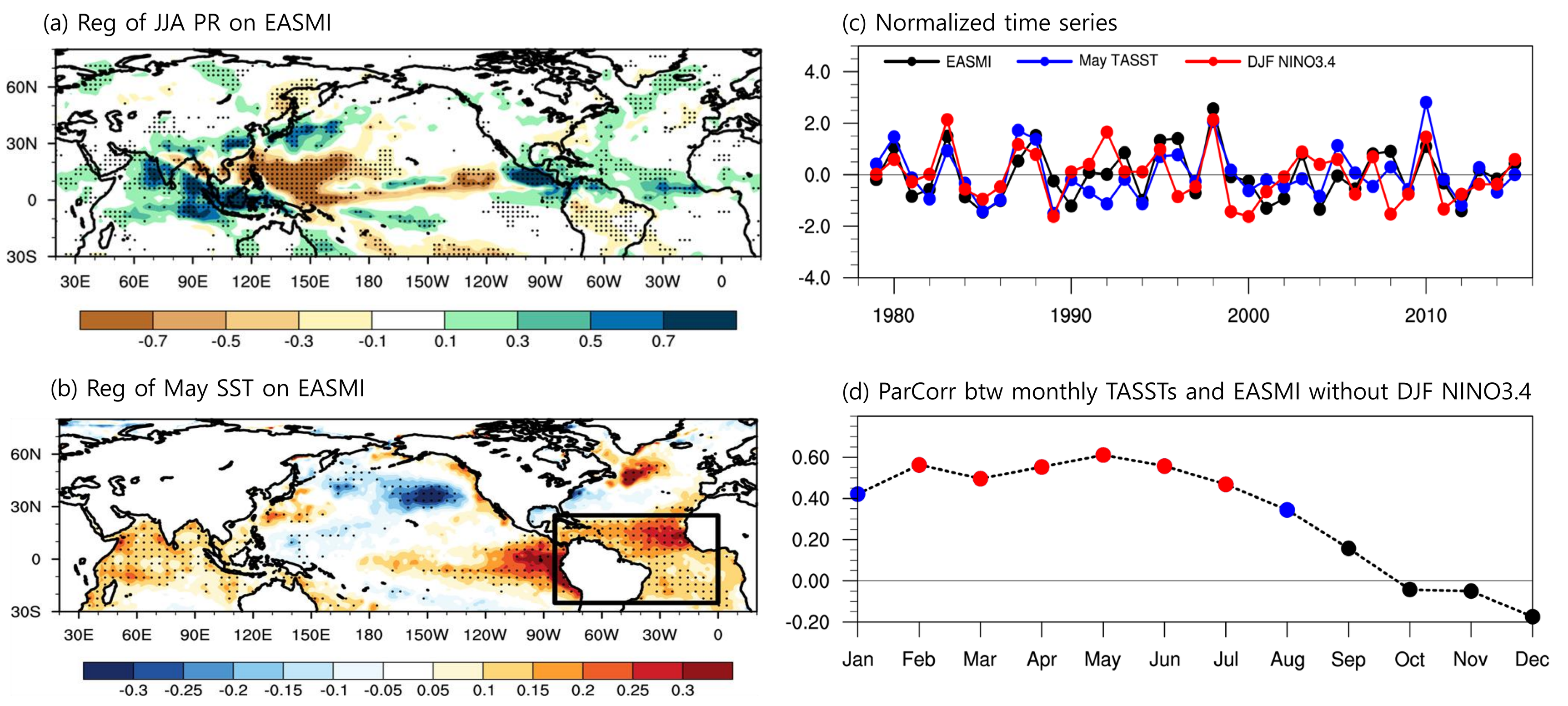


Fig. 1 (a) Regression map of the summer (JJA) precipitation anomaly (Unit: mm/day) on the East Asian Summer Monsoon index (EASMI). **(b)** Regression map of the May SST anomaly (Unit: °C) on the EASMI. **(c)** Time series of the normalized EASMI, May TASST, and DJF Nino3.4. **(d)** Partial correlation coefficients between monthly TASSTs and the EASMI after excluding the effect of the preceding DJF Nino3.4. The dots in (a, b) indicate the areas where the correlation coefficients are significant at the 90% confidence level. The blue (red) dots in (d) denote that the correlations are significant at the 95% (99%) confidence level

- Positive (negative) precipitation anomalies appear in the tropical Atlantic and Indian Oceans (the Okhotsk Sea and vicinity of the Nino3.4 region) (Fig. 1a). The positive precipitation anomalies over the tropical Atlantic during boreal summer are closely associated with the strengthened Atlantic ITCZ, and are known to be affected by TASST anomalies during the preceding spring. This implies that the EASM could be predicted by the preceding spring SST over the tropical Atlantic.
- The significant positive SST anomalies associated with the EASMI are located over the Atlantic with the maximum centered in the north tropical Atlantic (black rectangle in Fig. 1b), suggesting that the EASM variability may be controlled by the long-lived TASST.
- Normalized EASMI, May TASST, and DJF Nino3.4 indices significantly covariate over the analysis period with a correlation coefficient of 0.72 (0.54) between the EASMI and May TASST (DJF Nino3.4), which is significant at the 99% confidence level (Fig. 1c).
- To isolate the unique contribution of May TASST to the EASM, independent of the preceding DJF Nino3.4, we performed partial correlation analysis excluding the effect of the preceding DJF Nino3.4. The result show that EASMI is significantly correlated with the monthly TASSTs from February to July. (Fig. 1d)
- These statistical results suggest that May TASST can potentially affect the EASM with 1-month time lag.

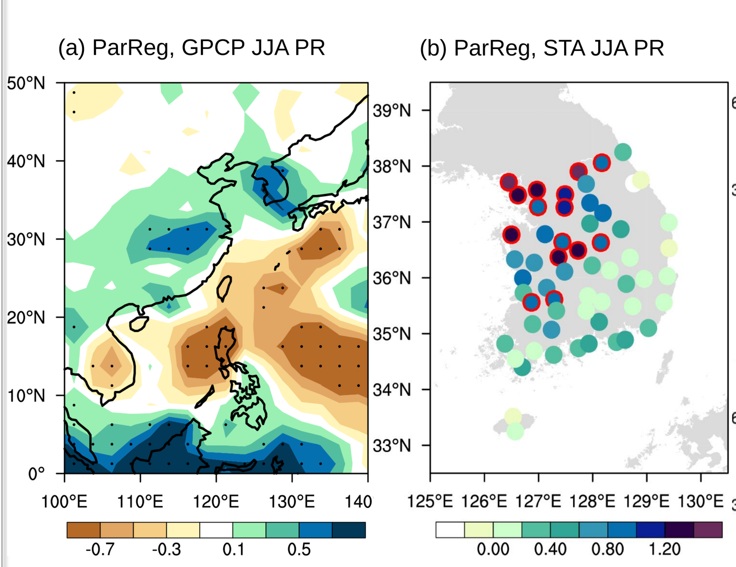


Fig. 2 Partial regression maps of the summer precipitation anomalies (Unit: mm/day) on May TASST after excluding the effect of the preceding DJF Nino3.4; (**a**) and (**b**) are from GPCP and 59 weather station data maintained by the Korea Meteorological Administration, respectively. The dots in (**a**) and the red circles in (**b**) indicate the areas where the correlation coefficients are significant at the 90% confidence level

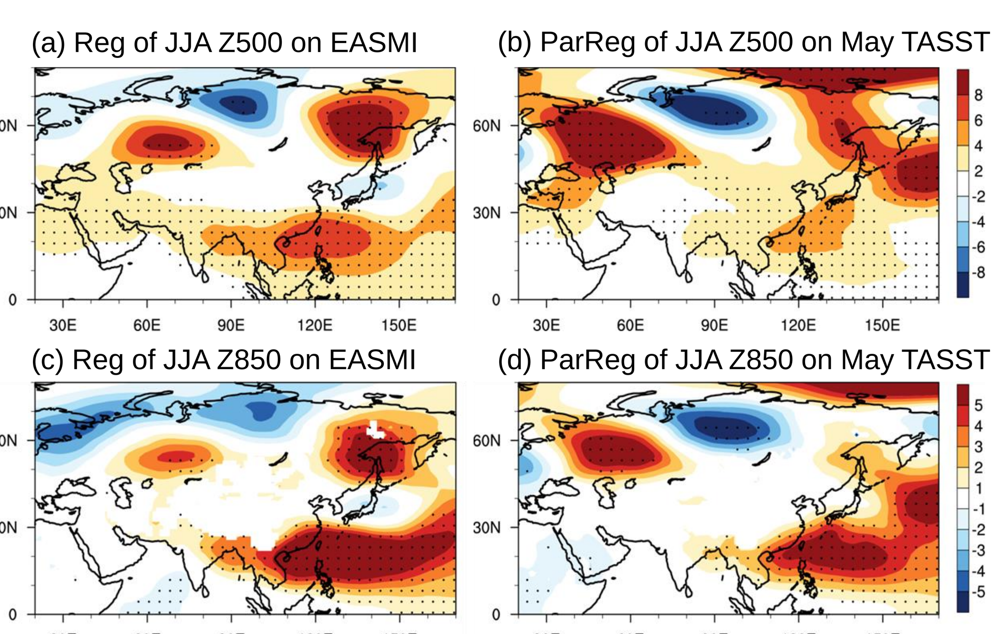


Fig. 3 Regression maps of the summer geopotential height anomalies (Unit: gpm) at (**a**) 500-hPa and (**c**) 850-hPa on the EASMI. Partial regression maps of the summer geopotential height anomalies (Unit: gpm) at (**b**) 500-hPa and (**d**) 850-hPa on May TASST after excluding the effect of the preceding DJF Nino3.4. The dots indicate the areas where the correlation coefficients are significant at the 90% confidence level

- The pattern of the GPCP precipitation anomalies associated with May TASST yields the meridional tripole pattern and the positive (negative) precipitation anomalies are located over the subtropical frontal area and Maritime Continent (western North Pacific) (Fig. 2a).
- In the Eurasian Continent, a wave-like pattern is clearly seen, especially in the upper (not shown) and middle troposphere (Fig. 3a). This pattern exhibits a quasi-barotropic structure with positive (negative) geopotential anomalies in the Ural Mountains and the Okhotsk Sea (central Europe and Siberia, particularly to the northwest of Lake Baikal).
- In addition to the zonal wave-train pattern, a Pacific-Japan teleconnection pattern extending from south to north is found along the coastal region of East Asia.
- Similarly, the 1-month lag responses of JJA circulation to the preceding May TASST, excluding the effect of the preceding DJF Nino3.4 (Fig. 3b and d) closely resemble the summer monsoon system over East Asia

Table. 1 Correlation coefficients among the EASMI, May TASST, DJF Nino3.4, AM NAO, Expansion Coefficients (EC) of the first coupled SVD modes for May SST (SST EC1), and for summer precipitation (PR EC1), for the period 1979-2015. The values in parentheses indicate the partial correlation coefficient between May TASST (preceding DJF Nino3.4) and the EASMI after excluding the effect of the preceding DJF Nino3.4 (May TASST)

	May TASST	DJF Nino3.4	AM NAO	SST EC1	PR EC1
EASMI	0.72** (0.61**)	0.54** (0.28*)	-0.43**	0.65**	0.92**
May TASST		0.52**	-0.46**	0.88**	0.70**
DJF Nino3.4			-0.01	0.64**	0.55**
AM NAO				-0.37*	-0.39*
SST EC1					0.68**

- The linkage between the EASMI and the preceding May TASST is evident for the period 1979–2015. It is also apparent that the EASMI has a close relationship with SST EC1 and with PR EC1 which is significant at the 99% confidence level.
- Although April–May (AM) NAO and DJF Nino3.4 are well known to affect the EASM through teleconnections (Ogi et al. 2003; Sung et al. 2006), these two indices show relatively low correlations with the EASMI.
- Furthermore, the partial correlation coefficient between May TASST (preceding DJF Nino3.4) and the EASMI after excluding the effect of the preceding DJF Nino3.4 (May TASST) is significant at the 99% (90%) confidence level.
- This indicates that TASST itself strongly affects the EASM variability, and that the connection between the EASM and the preceding DJF Nino3.4 is strongly determined by May TASST.

Possible Mechanism

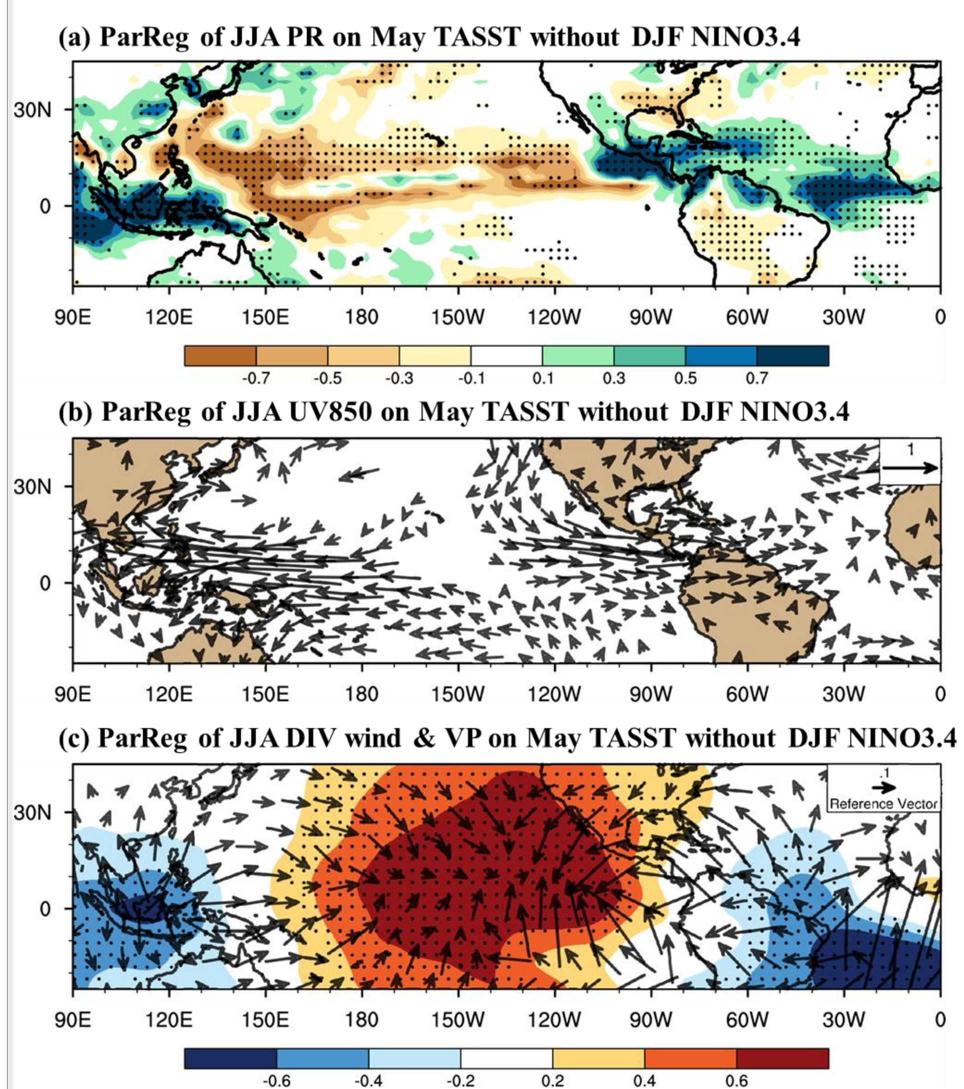


Fig. 4 Partial regression maps of (**a**) summer precipitation (Unit: mm/day, shading), (**b**) horizontal wind anomalies at 850-hPa (Unit: m/s, vector), and (**c**) divergent winds (Unit: m/s, vector), and 300-hPa velocity potential (Unit: 10^6 m^2/s, shading) on May TASST after excluding the effect of the preceding DJF Nino3.4. The dots in (**a**) and (**c**) indicate the areas where the correlation coefficients are significant at the 90% confidence level. Only vectors statistically significant at the 90% confidence level are shown in (**b**)

- The positive precipitation anomaly response to May TASST appears over the north tropical Atlantic where the ITCZ is located. This positive precipitation anomaly in the off-equatorial Atlantic (i.e., enhanced Atlantic ITCZ) can **induce a Gill-type Rossby wave response over the subtropical eastern Pacific**, with an anomalous low-level cyclonic circulation (Fig. 4b) and westward extension of the downward branch of the Pacific Walker circulation (Fig. 4c).
- At the same time, the **descending branch of Pacific Walker circulation** is simultaneously accompanied by anomalous upper-level convergence and **low-level divergence in the CP region** and this low-level divergence causes an **equatorial easterly wind anomaly** in the western CP region
- The equatorial easterly wind anomaly **enhances the equatorial upwelling**, resulting in a negative SST anomaly, which not only decreases the precipitation (Fig. 4a; weakened Pacific ITCZ) but also **produces anomalous low-level anticyclonic circulation over the western North Pacific** as a Gill-type atmospheric response.
- This anticyclonic circulation over the western North Pacific resulting in the **enhanced rainfall over Korea, China and Japan.**

- The associated baroclinic wave response (low-level cyclonic circulation and upper-level anticyclonic circulation anomalies) increases the precipitation over the eastern Pacific ITCZ region, which in turn **produces another Gill-type Rossby wave response over the eastern North Pacific** (145°W–105°W; Fig. 5a)
- These wave responses near the subtropical westerly jet region (Fig. 5a) produce RWS. **The perturbed Rossby wave in turn propagates eastward from the eastern Pacific to the Okhotsk Sea** along the jet stream waveguide.
- This pattern closely resembles the regression maps shown in Fig. 3, indicating the quasi-barotropic structure.

↓

The **anomalous anticyclonic circulation with barotropic structure over the Okhotsk Sea** can transport cold air to lower latitudes.

- This cold air mass can be combined with the warm and humid air mass induced by the anomalous Philippine high, **causing the enhanced subtropical frontal rainfall over the Korea, China and Japan** (Yim et al. 2014; Oh et al. 2018).

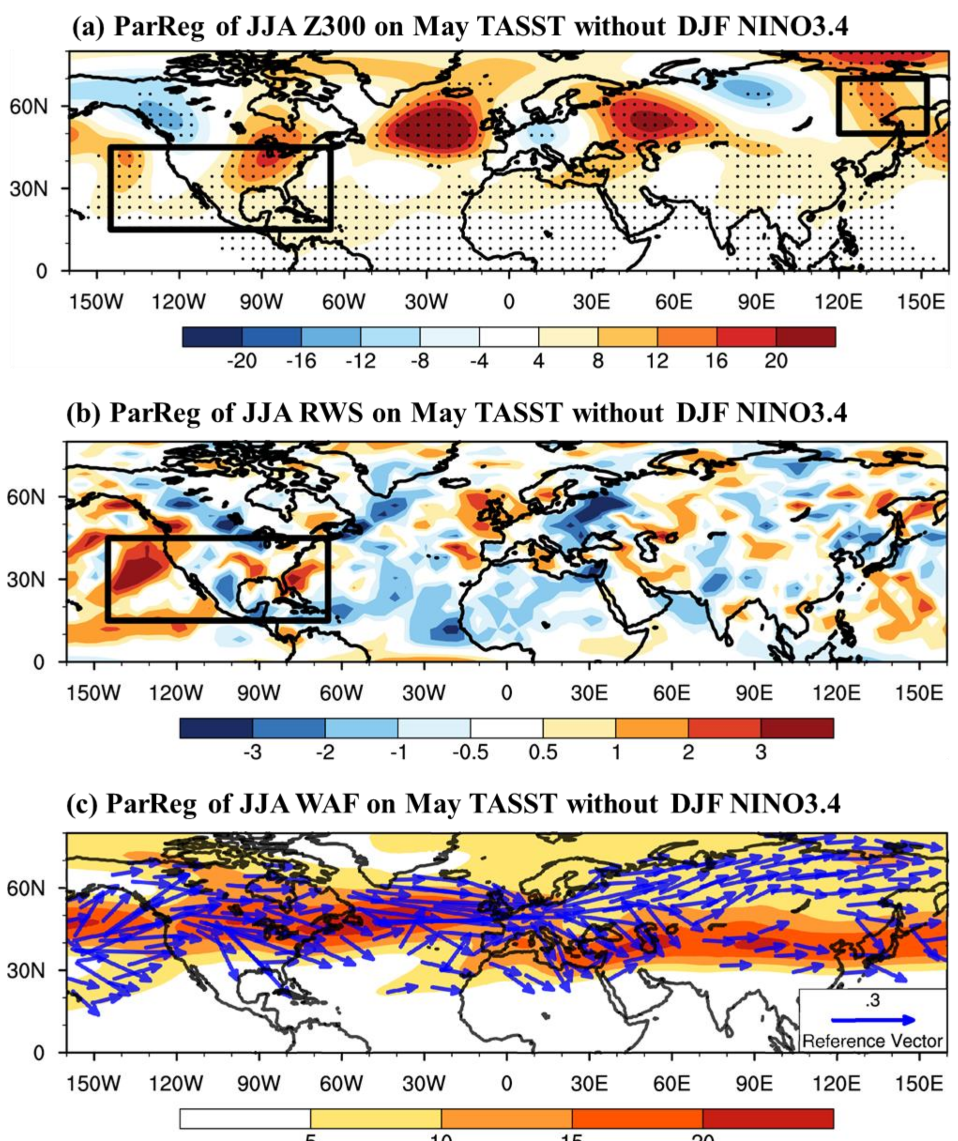


Fig. 5 Partial regression maps of **a** 300 hPa geopotential height anomaly (Unit: gpm), **b** Rossby wave source (RWS; Unit: $1×10^{-11}$ s^{-2}), and **c** associated wave activity flux (WAF; Unit: m^2/s^2) on May TASST after excluding the effect of the preceding DJF Nino3.4. The dots in (**a**) indicate the areas where the correlation coefficients are significant at the 90% confidence level. The black rectangles in (**a**) and (**b**) represent the region where the Gill-type response index is defined. Shading in (**c**) denotes the climatological 300 hPa zonal wind (Unit: m/s) during boreal summer

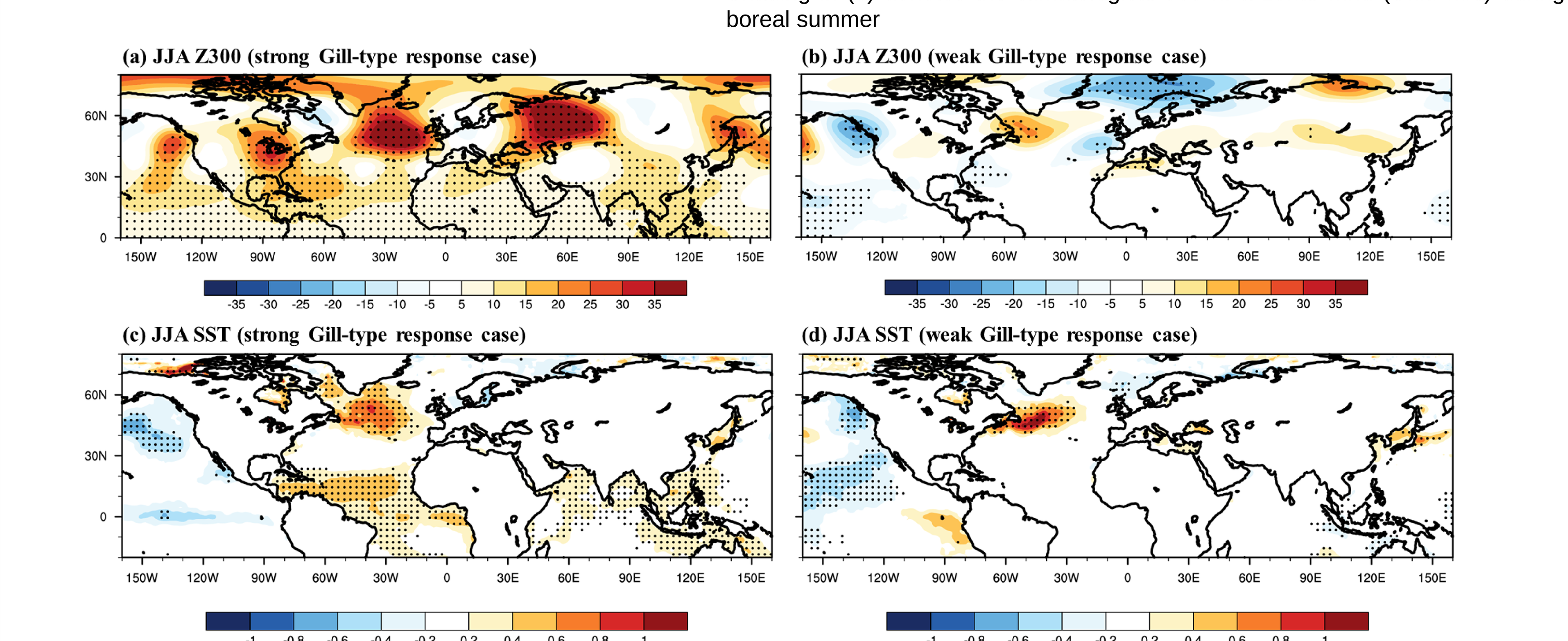
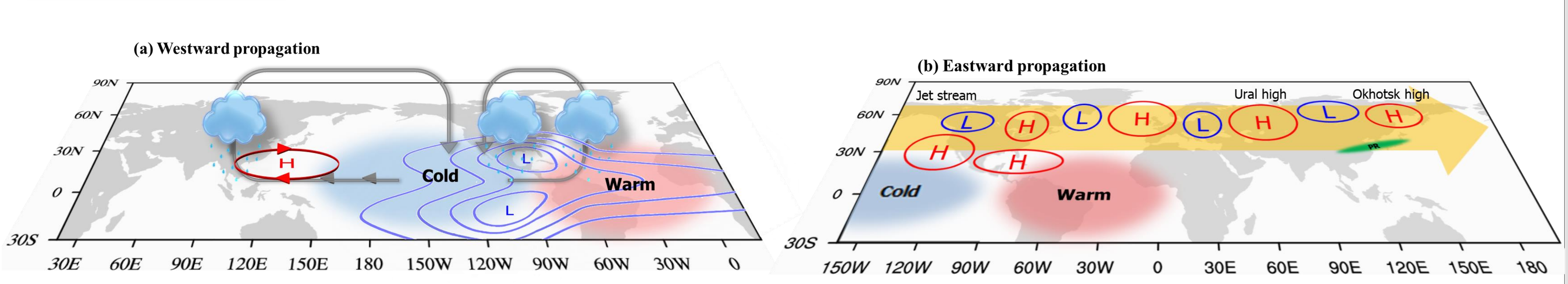


Fig. 6 Composites of JJA 300-hPa geopotential height (**a**, **b**) and SST (**c**, **d**) anomalies for strong and weak Gill-type response cases. The dots indicate the areas where the correlation coefficients are significant at the 90% confidence level based on the two-tailed student's *t* test

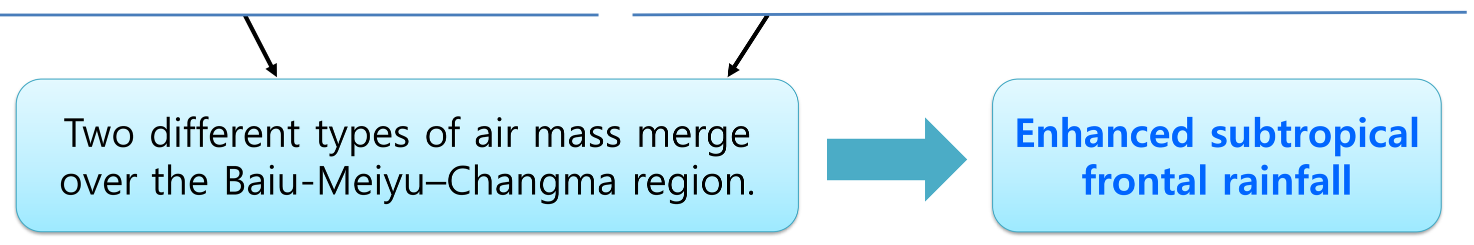
- JJA 300hPa geopotential height for strong case, the Rossby wave train with the strong Okhotsk high develops during JJA, while when the Gill-type response is weak, the Rossby waves may not propagate far from their source.
- TASST (subpolar SST) warming only appears in the case of the strong Gill-type response (both cases) during the boreal summer season, while there is no significant signal over the tropical Atlantic in the weak Gill-type response case.
- This suggests that the Gill-type response derived from May TASST plays some role in modulating both Rossby wave propagation and the Okhotsk high.

Summary



Positive TASST in late Spring → Strengthen off-equatorial Atlantic ITCZ → Induce Gill-type response → Westward extension of descending branch of Walker circulation → Anomalous low-level divergence in the western CP region → Equatorial easterly wind anomaly → Equatorial upwelling → Negative SST anomaly → Low-level anticyclones over the Philippine Sea → Bring warm and humid air to higher latitudes

Positive TASST in late Spring → Gill-type atmospheric response → Produce Rossby Wave Sources near the subtropical westerly jet region → Rossby wave propagates eastward → Anomalous tropospheric anticyclone with barotropic structure over the Okhotsk Sea → Transport cold air to lower latitudes



Reference
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