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Modulation of the Tibetan Plateau Snow Cover on the ENSO Teleconnection: From the East Asian Summer Monsoon Perspective

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Seasonal prediction of the EASM is a challenging issue.

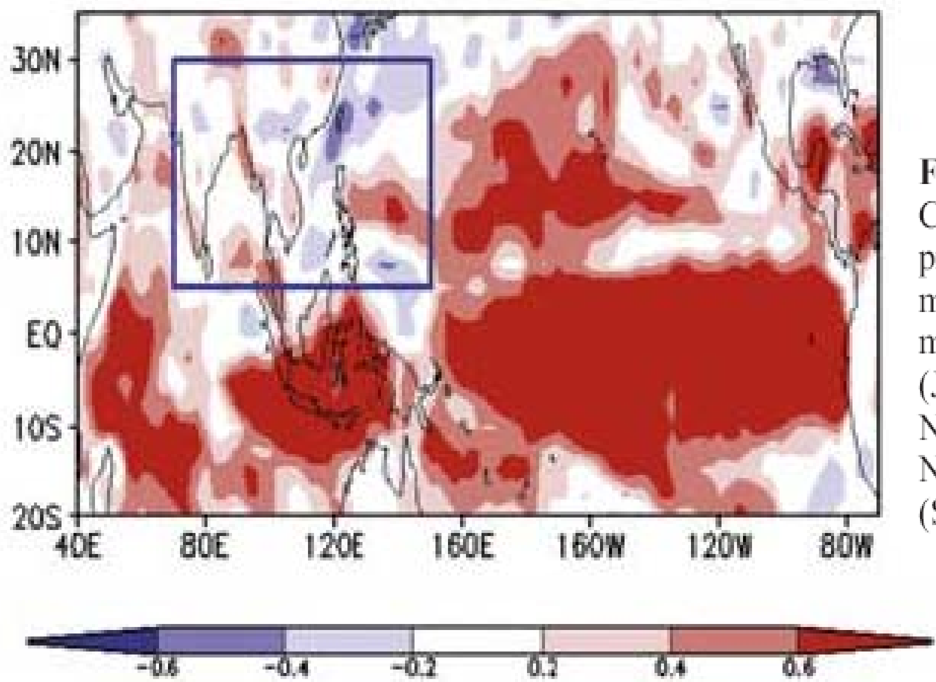
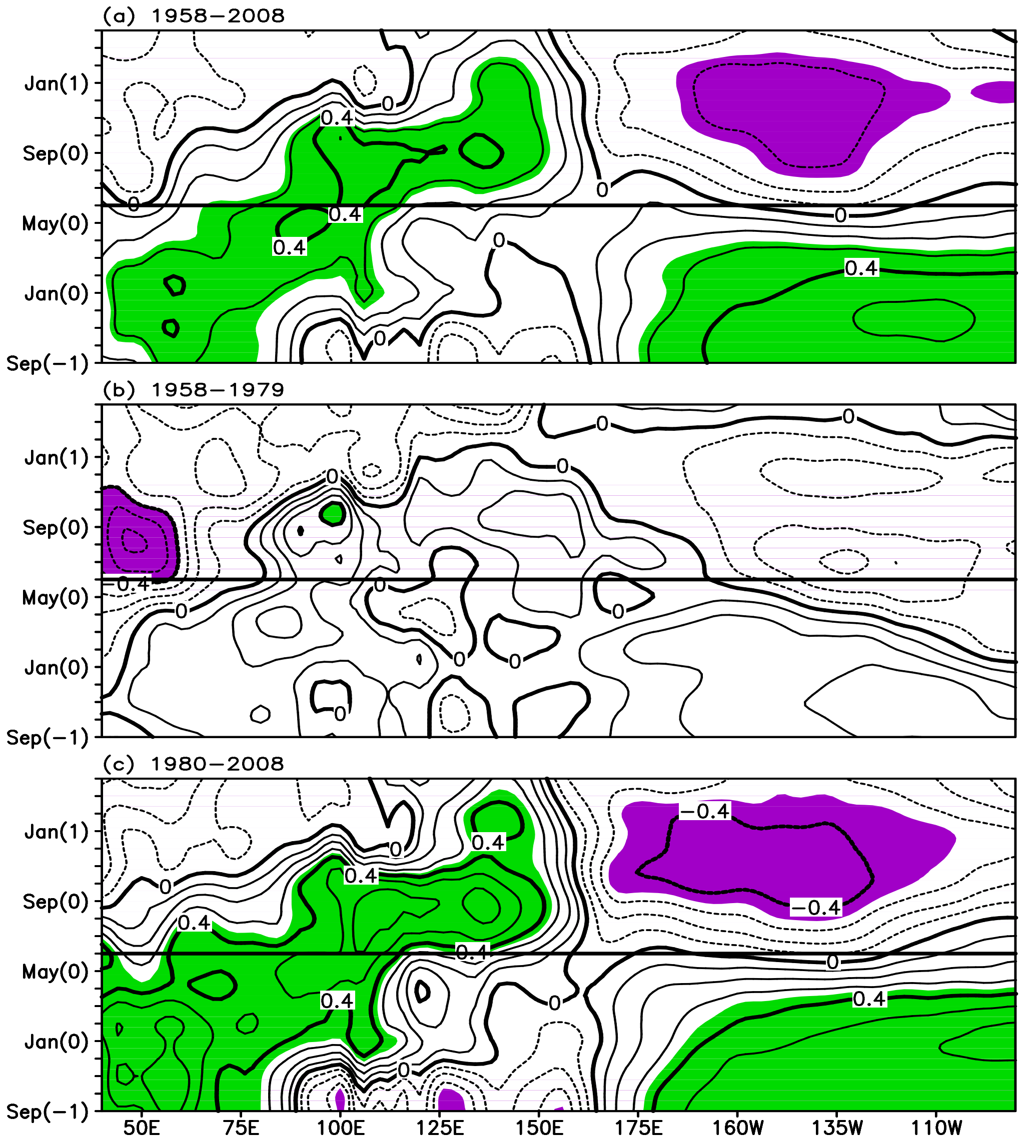


Figure 1. Correlation coefficients between the observed CMAP (1979–1999) and the simulated June–August precipitation anomalies made by five-model multi-ensemble mean. The five models are National Center for Environmental Prediction (NCEP), Japan Meteorological Agency (JMA), Center for Ocean-Land-Atmosphere (COLA), National Aeronautical Space Agency (NASA), and Seoul National University/Korean Meteorological Administration (SNU/KMA).

(*Geophys. Res. Lett.*, Wang et al., 2005)

The relationship between the EASM and ENSO is not stable and exhibits considerable interdecadal differences.



(Wang et al. 2009; Li et al. 2010)

The lead-lag correlation coefficients between the EASM index and the SST anomalies averaged between -5° S and 5° N from Sep(-1) to Apr(1). The bold horizontal line indicates Jul(0) where the simultaneous correlations are shown. The green (purple) shaded are significantly positive (negative) correlation areas exceeding 95% confidence level.

Therefore, understanding the interdecadal modulation of the ENSO teleconnection may facilitate the practical seasonal to decadal prediction of the EASM.

Many factors can modulate the ENSO behaviors on the decadal to interdecadal time scales.

- **Gershunov and Barnett (1998) found that the North Pacific Oscillation (NPO) exerts a modulating effect not only on the North American climate anomalies but also ENSO teleconnections.**
- **Yeh et al. (2009) proposed that a flattening of the thermocline in the equatorial Pacific can increase the occurrences of the central Pacific El Niño and in turn lead to the decadal changes in the associated atmospheric teleconnection patterns.**
- **Wu et al. (2011) suggested that the North Atlantic Oscillation (NAO) may also modify the ENSO influences as well as its linkage with the EASM.**

How about Tibetan Plateau snow cover (TPSC)?

- To what extent can the TPSC modulate the ENSO teleconnection and in turn modify the ENSO-EASM relationship?
- What kind of physical mechanism is responsible for such modulation?

Summer climatology and standard deviation (STD) of the year-to-year variability of the TPSC.

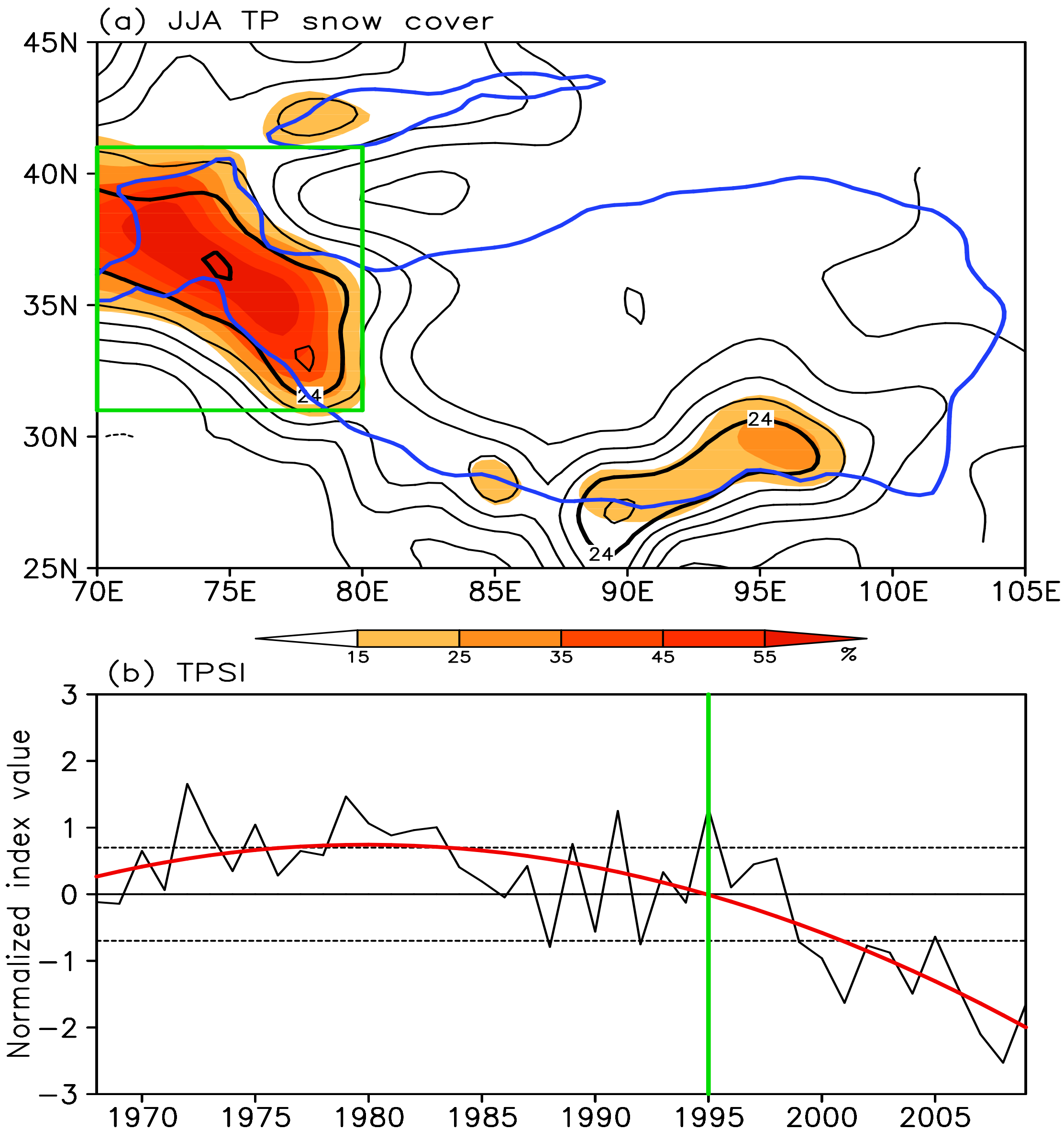


Fig. 1 (a) Long-term average (contours) and standard deviations (color shadings) of the Tibetan Plateau (TP) snow cover (TPSC) during summer (June-July-August, JJA) for the period 1968-2009. The unit of the TPSC is %. The areas included by the blue curves are 3000 meters above sea level. (b) The normalized TPSC index (TPSI) time series (black curve) defined by the TPSC averaged in the green-boxed area in (a). The red curve indicates the third-order polynomial fit. The dashed lines denote 0.7 (-0.7) standard deviations of the normalized TPSI.

Interdecadal changes in the TPSC and ENSO-EASM relationship

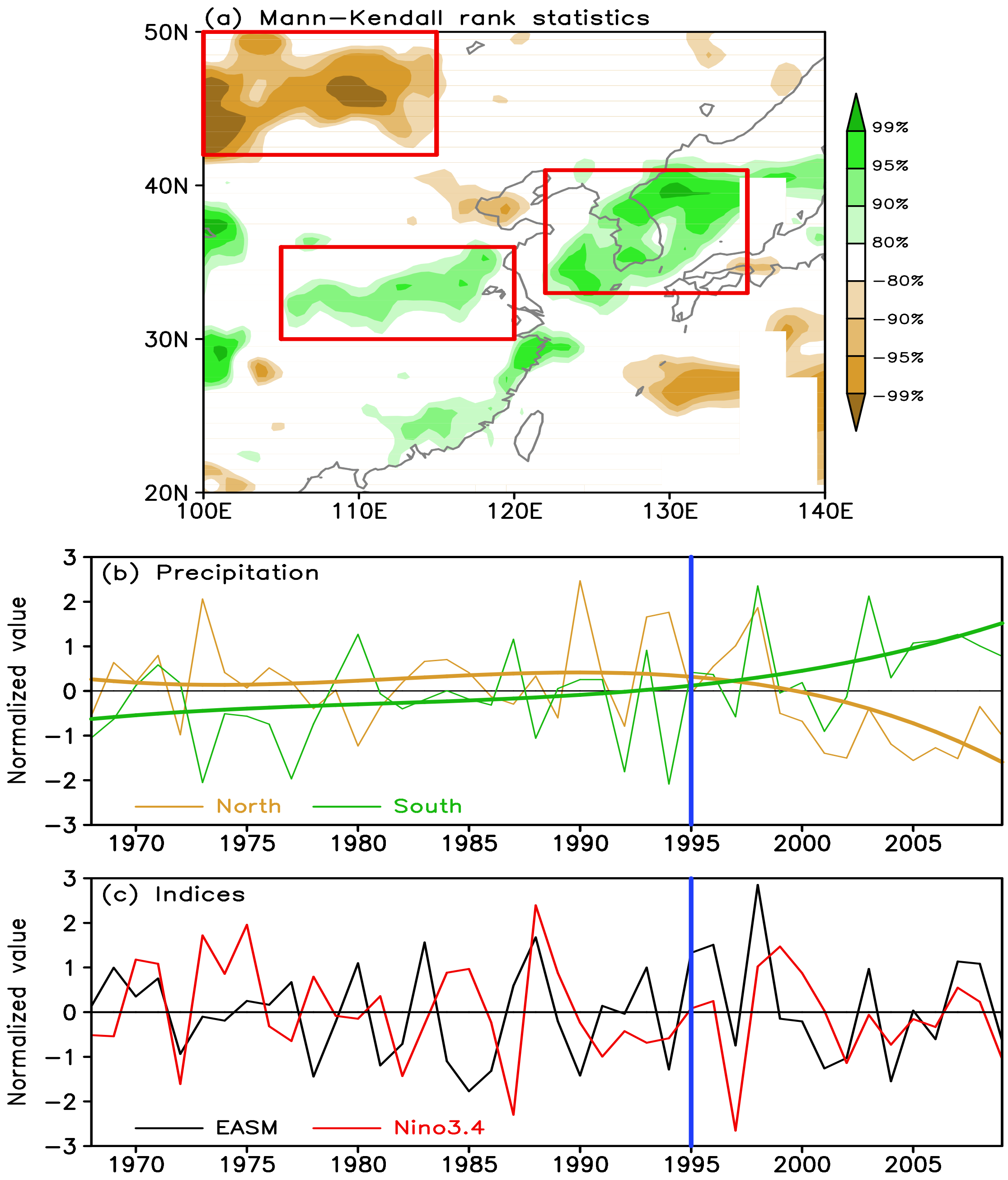


Fig. 2 (a) Mann-Kendall statistical significance of the linear trends in JJA precipitation over East Asia. (b) Time series of the normalized precipitation anomalies averaged over the northern (represented by the upper red box in (a); thin brown curve) and the southern (represented by the two lower red boxes in (a); thin green curve) East Asia. The thick curves indicate the third-order polynomial fits. (c) Time series of the normalized East Asian summer monsoon (EASM) and JJA Niño 3.4 indices for the 1968–2009 period.

Before 1995: Corr.=-0.04

After 1995: Corr.=-0.53

Interdecadal changes in the TPSC and ENSO-EASM relationship

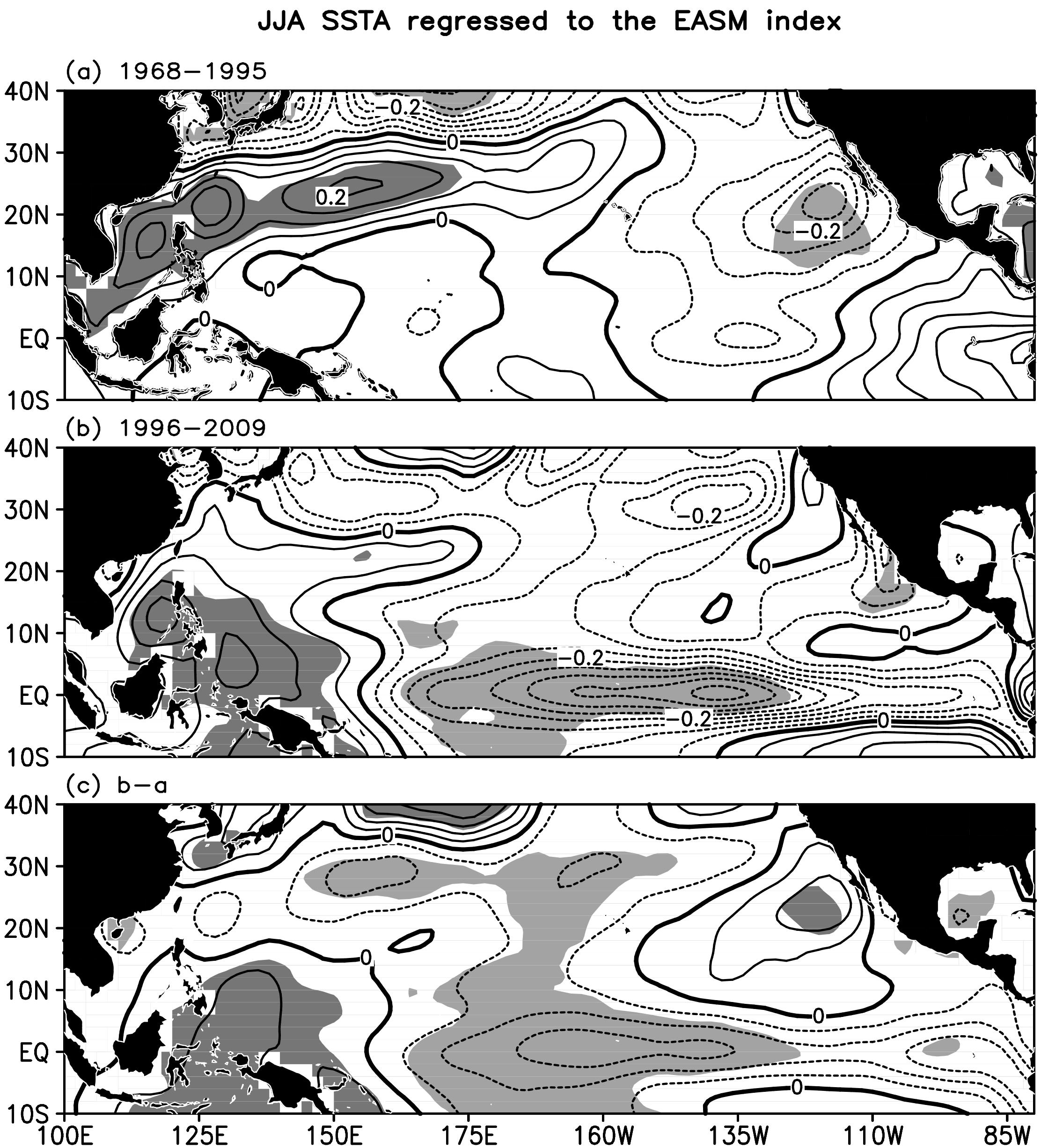


Fig. 3 The JJA sea surface temperature anomaly (SSTA) (contours in units of ° C) pattern regressed to the EASM index for the (a) 1968-1995 and (b) 1996-2009 period. (c) b-a. The dark (light) areas exceed the 95% confidence level.

All these indicate an enhanced linkage between the EASM and ENSO since 1995.

The TPSC Modulation

Table 1. Classification of summers based on phases of ENSO and the TPSC [a]

	Excessive TPSC	Reduced TPSC
El Niño	**1972 (–0.94), 1977 (0.67), 1982 (–0.71),** 1991 (0.14)	**2002 (–1.03), 2004 (–1.55), 2009 (–0.63)**
La Niña	1970 (0.35), 1973 (–0.1), 1975 (0.25), **1978 (–1.45),** 1989 (–0.2), **1.98 (2.85)**	**1988 (1.68),** 1999 (–0.15), 2000 (–0.21), **2007 (1.13)**

[a] Numbers in the brackets are the normalized EASM index values of the corresponding JJA.

The TPSC does show modulating effects on the ENSO teleconnections!

Interdecadal changes in the three-dimensional circulation structures associated with the EASM

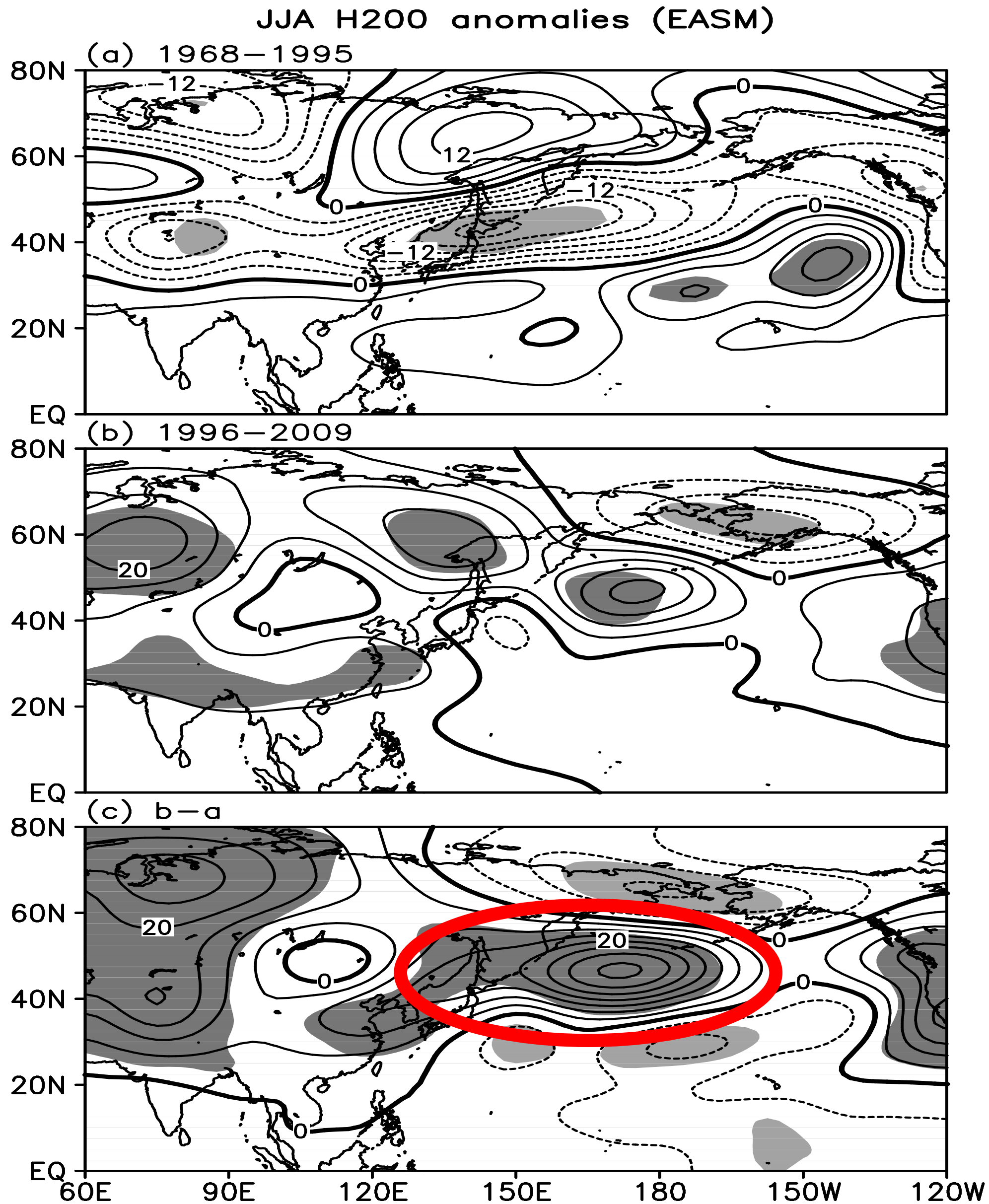


Fig. 4 The JJA 200-hPa geopotential height (H200) anomalies regressed to the EASM index for the (a) 1968-1995 and (b) 1996-2009 period. (c) b-a. The dark (light) areas exceed the 95% confidence level.

For the latter epoch, significant H200 anomalies expand from the North Pacific to the extratropical eastern Eurasian continental areas, with two positive centers located over the Okhotsk and the region northwest of the Tibetan Plateau, respectively.

Interdecadal changes in the three-dimensional circulation structures associated with the EASM

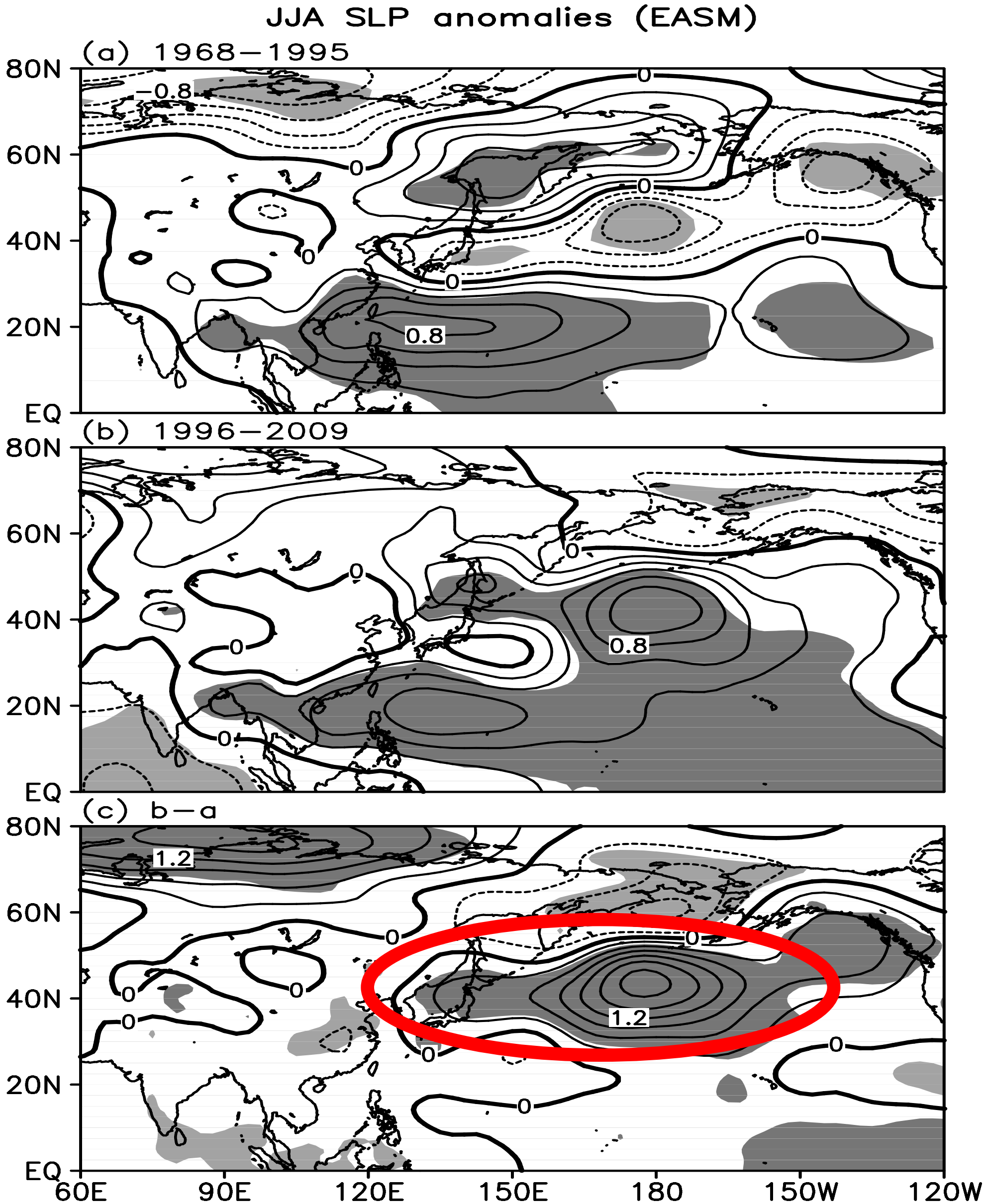


Fig. 5 The JJA sea level pressure (SLP) anomalies anomalies regressed to the EASM index for the (a) 1968-1995 and (b) 1996-2009 period. (c) b-a. The dark (light) areas exceed the 95% confidence level.

A barotropic structure over the North Pacific.

A baroclinic structure can be interpreted as atmospheric responses to the ENSO-related diabatic forcing of which the maximum heating area is located near the 300-hPa level (Lin 2009; Wu et al. 2011).

ENSO-related teleconnection patterns during the two epochs

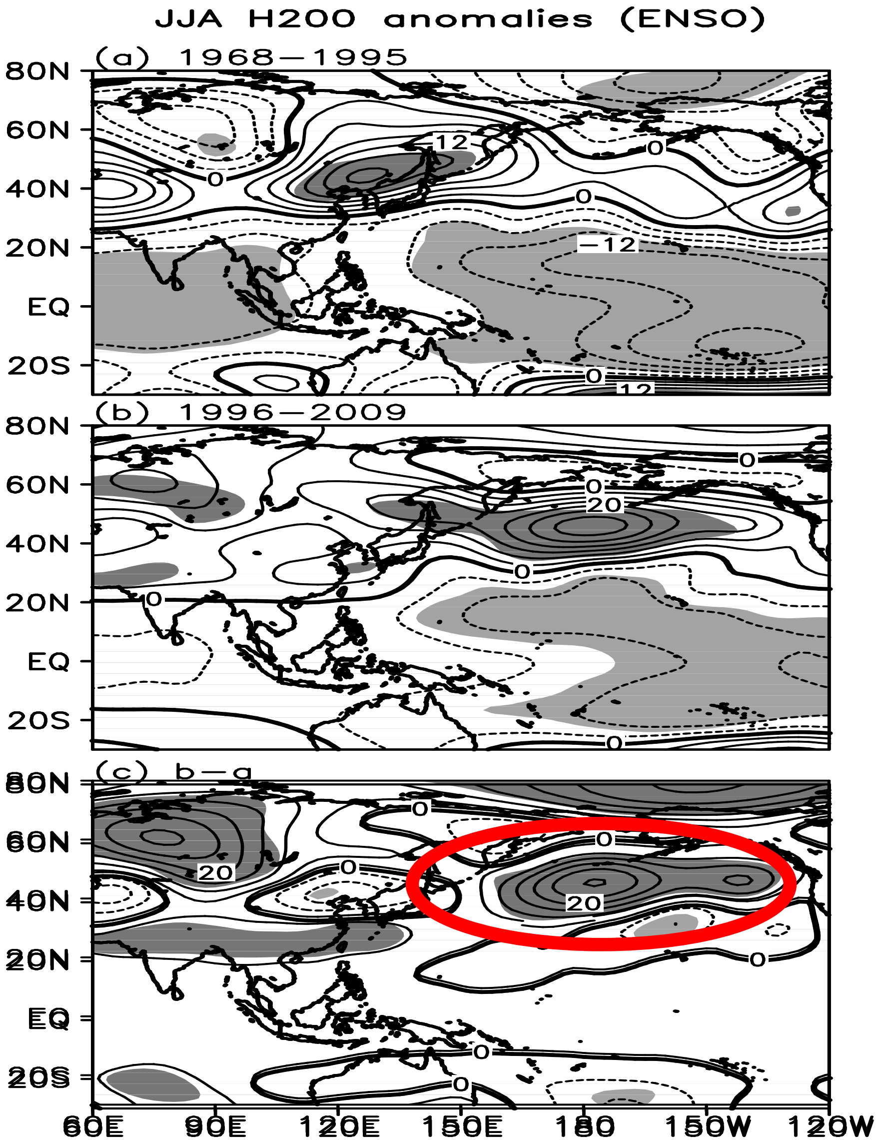


Fig. 6 The same as Figs. 4, except for the Niño 3.4 index. For comparison purpose, the sign of the Nino3.4 index is reversed.

The notable difference is that the extratropical Rossby wave response during the latter epoch is stronger and more obvious over East Asia (Figs. 6b and 6c) than that during the earlier epoch (Fig. 6a).

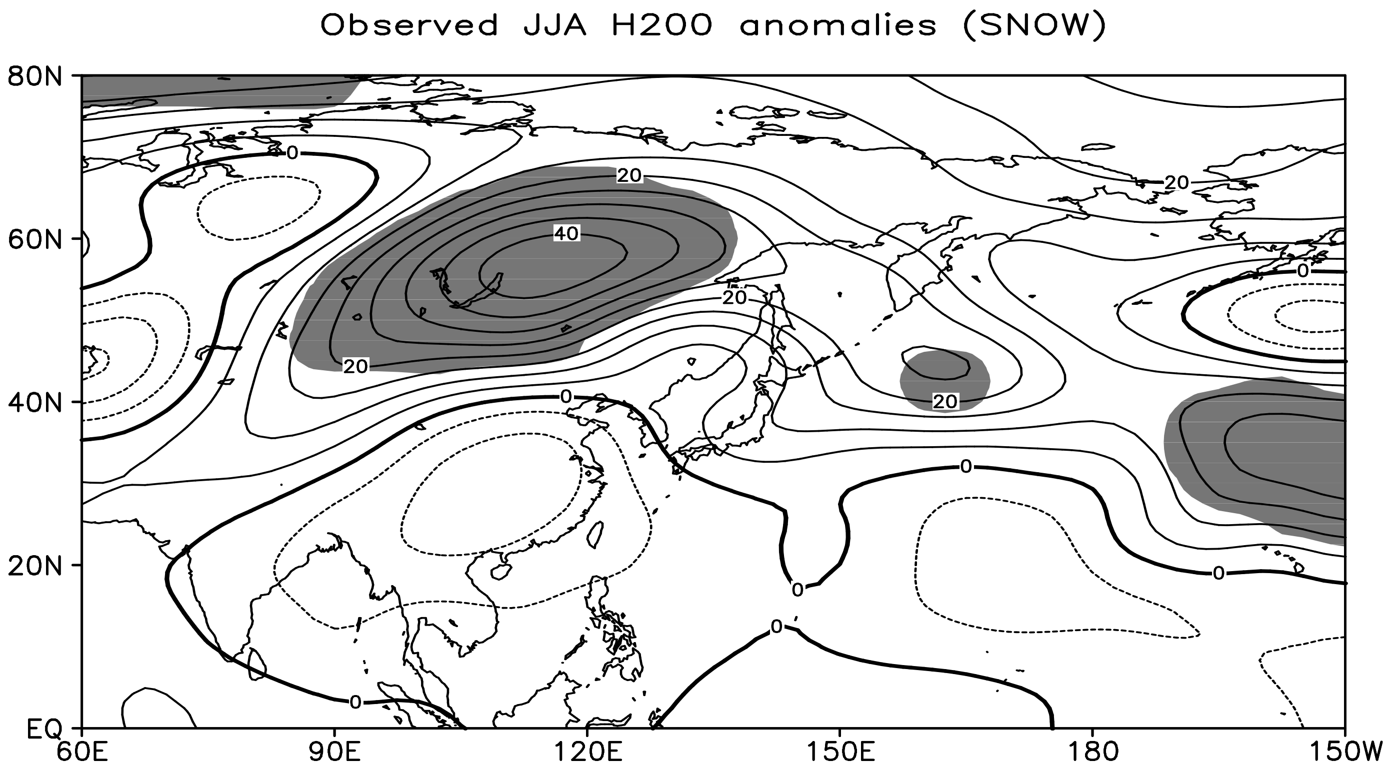


Fig. 7 H200 composite differences between the reduced and excessive TPSC JJA (reduced minus excessive). A reduced (excessive) TPSC JJA refers to that of a TSCI value greater (less) than 0.7 (-0.7) times standard deviation.

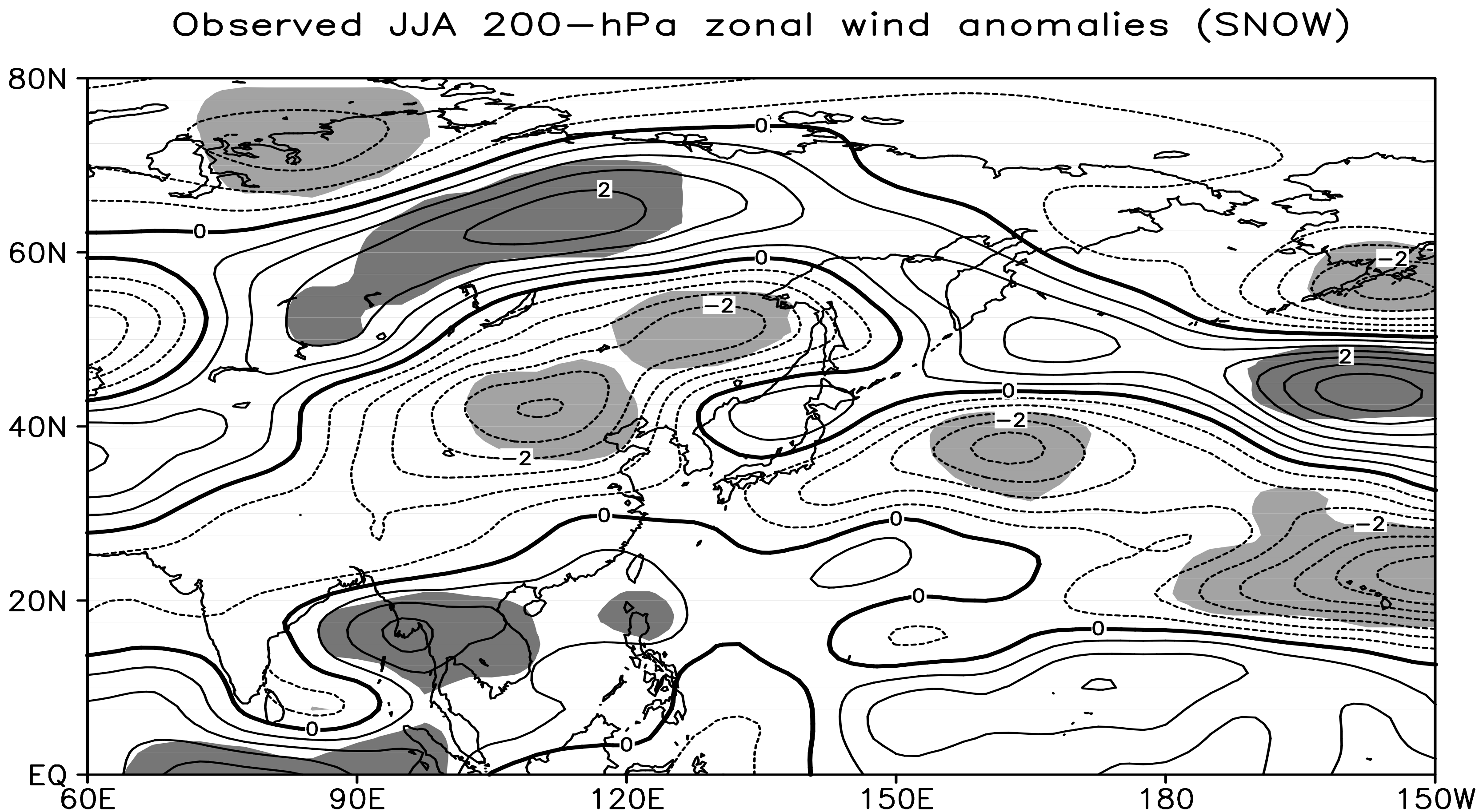


Fig. 8 Same as Fig. 7, except for the 200-hPa zonal wind anomalies.

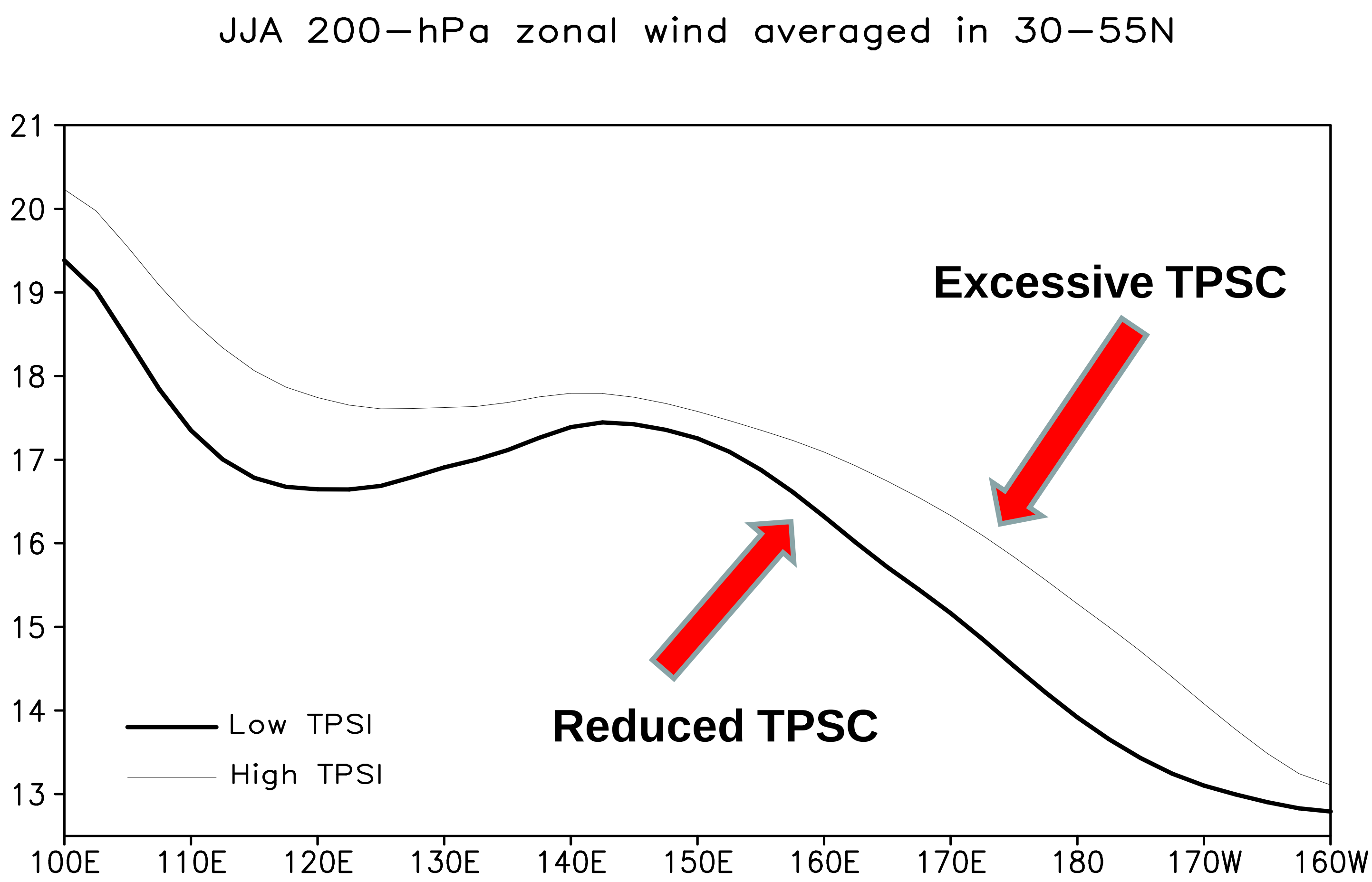


Fig. 9 JJA composite 200-hPa zonal winds averaged between 30° -55° N. The thin and thick curves indicate the high and low TPSI JJA, respectively. 16 m/s 17m/s

Speculation?

Reduced TPSC

Decrease the jet stream over northeastern Asia and the North Pacific.

Favor a more westward development of the Rossby wave response associated with ENSO.

Enhance the linkage between the EASM and ENSO.

Numerical experiments

- **To further verify the above speculation, we conducted numerical experiments with the SGCM.**
- **Under the same ENSO forcing (a La Niña-related forcing here), we performed the experiments with a reduced TPSC anomaly, and excessive TPSC anomaly and no TPSC anomaly, respectively.**
- **Three perturbed experiments were integrated for 3700 days. The last 3600-day integrations were used to construct an ensemble (arithmetic) mean. Note that the result is not sensitive to the selection of initial condition, since the analysis is conducted for the period after the climate equilibrium is reached.**

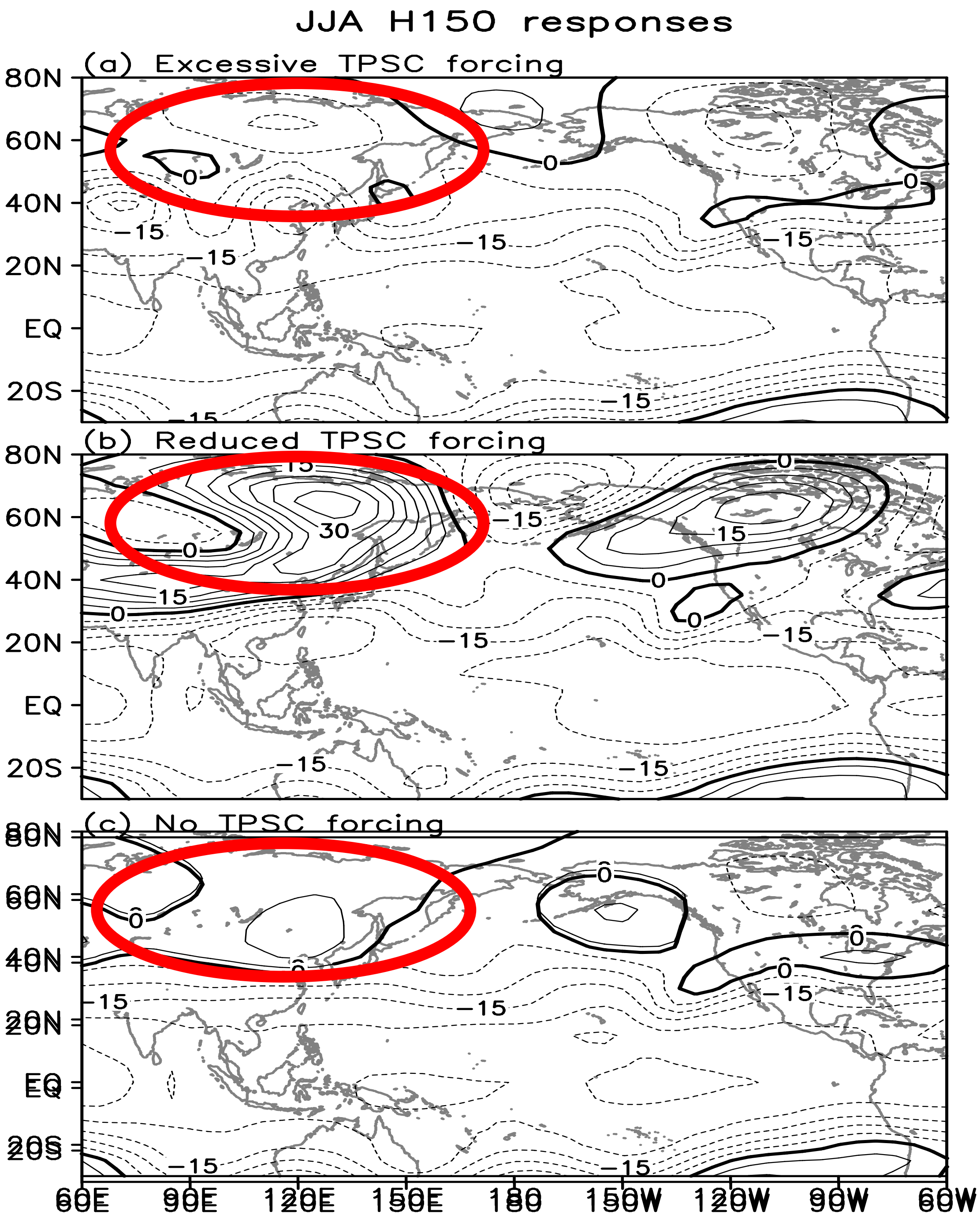


Fig. 10 The SGCM H150 responses (contours in units of gpm) to La Nina with (a) an excessive TPSC, (b) an reduced TPSC, and (c) no TPSC anomaly forcing in summer.

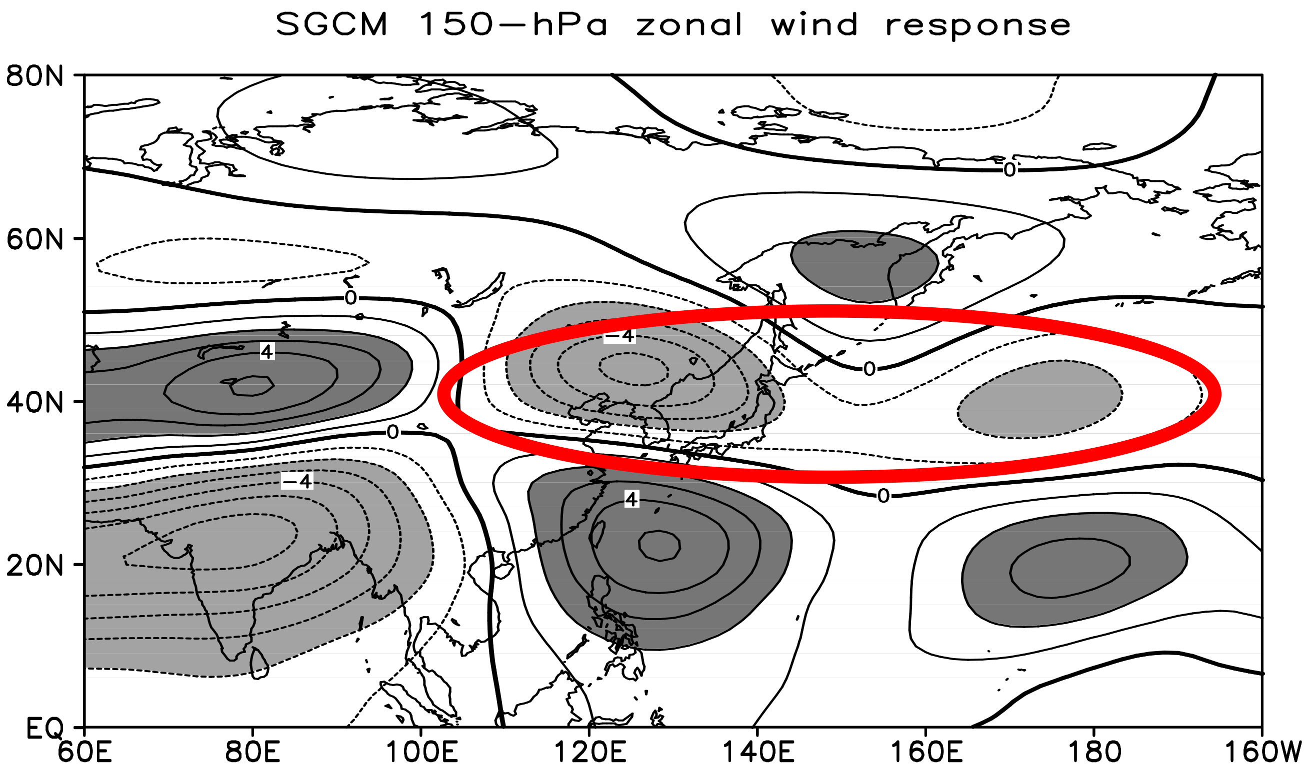


Fig. 11 150-hPa zonal wind responses in the SGCM regarding a reduced and excessive TPSC forcing in summer (reduced minus excessive).

Theoretical analysis

- For the steady forcing of ENSO, the amplitude of the Rossby wave response meets the following relationship (e.g., Hoskins and Yang 2000; Lin 2009):

$$A = \frac{1}{\sqrt{(\omega_k + kU)^2 + \alpha^2}}$$

Where w_k is the wave frequency (which is a function of k according to the dispersion relationship), k the wavenumber, U the basic state zonal wind, and α the damping.

The parameters used in this study include: k=6 (equivalent to a typical ENSO forcing scale), $\beta = 2.2 \times 10^{-11} m^{-1} s^{-1}$ $H = 200m$ $\alpha = (10day)^{-1}$
According to the aforementioned observational results that U is around 16 m/s for the reduced TPSC summers and 17 m/s for the excessive TPSC summers.
We computed the amplitude factor A, respectively. Results show during a low TPSI summer, A is around 8 for Rossby wave mode n=1 and 6.8 for mode n=2. During a high TPSI summer, A is around 7 for Rossby wave mode n=1 and 5.5 for mode n=2.

Theoretical analysis

- A in a low TPSI summer is greater than that in a high TPSI summer. It indicates that the Rossby wave gyre in a reduced TPSC summer has larger amplitudes, which favors a more westward development. This result theoretically proves that the TPSC can modulate ENSO teleconnections through changing the background zonal mean flows.

Conclusion

- **The TPSC does show modulating effects on the ENSO teleconnections and in turn modify the ENSO–EASM relationship.**
- **Numerical and theoretical evidences confirm that the enhanced relationship between ENSO and the EASM is likely or partly due to the fact that the Rossby wave response to the ENSO diabatic forcing is stronger in a reduced TPSC summer.**
- **The contribution from the TPSC provides another physical background to understand the strengthened EASM-ENSO relationship and to predict the long-term variations of the EASM.**

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ABSTRACT

The East Asian summer monsoon (EASM) may exhibit rather large variability between years characterized by the same ENSO phase. Such inconsistency reduces the EASM predictability based on ENSO. Results in this study show that the Tibetan Plateau snow cover (TPSC) exerts a modulating effect on ENSO teleconnections and ENSO significantly correlates with the EASM only during the reduced TPSC summers. Three-dimensional circulation structures are examined to manifest that the typical ENSO signals in reduced TPSC summers tend to be stronger than in excessive TPSC summers. Numerical and theoretical evidences indicate that the anomalously reduced TPSC can force positive geopotential height anomalies at the upper troposphere and weaken the jet streams across eastern Asia and northwestern Pacific. Governed by such basic state zonal flows, the extratropical Rossby wave response to the ENSO forcing usually has a larger amplitude and pronounced westward development. In such case, ENSO extends its influences to eastern Asia and enhances its connection with the EASM.

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Thank you!

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谢谢！