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Possible effects of the North Atlantic Oscillation on the strengthening relationship between the East Asian Summer monsoon and ENSO

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ABSTRACT: In contrast to the weakened relationship between the Indian summer monsoon and El Niño–Southern Oscillation (ENSO) since 1970s, the East Asian summer monsoon (EASM) has exhibited a strengthened relationship with ENSO. In this study, observational and numerical evidences manifest that spring NAO may exert notable impacts on the enhancement of the EASM–ENSO relationship. Anomalous spring NAO induces a tripole sea surface temperature anomaly (SSTA) pattern in North Atlantic which persists into ensuring summer. The tripole SSTA excites downstream tele-connections of a distinct Rossby wave train prevailing over the northern Eurasia and a simple Gill-Matsuno-type quadrupole response over western Pacific. The former modulates the blocking highs over the Ural Mountain and the Okhotsk Sea. The latter enhances the linkage between the western Pacific subtropical high and ENSO. The co-effects of the two tele-connection patterns help to strengthen (or weaken) the subtropical Meiyu-Baiu-Changma front, the primary rain-bearing system of the EASM. As such, spring NAO is tied to the strengthened connection between ENSO and the EASM. Copyright © 2011 Royal Meteorological Society

KEY WORDS NAO; summer monsoon; ENSO

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1. Introduction

A number of studies have noticed that inverse relationship between the Indian summer monsoon (ISM) and El Niño–Southern Oscillation (ENSO) has weakened rapidly since the late 1970s (e.g. Webster and Palmer, 1997; Kumar *et al*., 1999; Chang *et al*., 2001). The explanations to such a phenomenon can be classified into three categories. Webster and Palmer (1997) attributed it to the chaotic nature of the ISM. Kumar *et al*. (1999) suggested a southeastward shift in the Walker circulation anomalies associated with ENSO events may lead to a reduced subsidence over the Indian region, thus favouring normal monsoon conditions. Besides that, they also suggested increased surface temperatures over Eurasia in winter and spring may favour the enhanced land-ocean thermal gradient conducive to a strong monsoon. Chang *et al*. (2001) believed the weakened ISM–ENSO relationship is most likely due to the strengthening and pole-ward shift of the jet stream over the North Atlantic, which led to the recent development of a significant correlation between winter time western European surface air temperatures and the ensuing ISM rainfall. This western European winter signal extended eastward over most of northern Eurasia, enhanced the meridional thermal contrast and disrupted the influence of ENSO on the ISM. This point has been further verified by other studies (e.g. Yang *et al*., 2004; Goswami *et al*., 2006).

As the other principal component of the Asian monsoon system, the East Asian summer monsoon (EASM) has many distinct features due to unique tectonic forcing: huge thermal contrasts between the world's largest continent, Eurasia, and the largest ocean basin, the Pacific, and is strongly influenced by the world's highest land feature, the Tibetan Plateau (Ding, 1992; Lau and Yang, 1997; Wang *et al*., 2008a; Wu *et al*., 2009). In contrast to the breakdown of the ISM–ENSO relationship, the EASM exhibits an enhanced relationship with ENSO (Wang *et al*., 2009; Li *et al*., 2010; Ding *et al*., 2010). Wang *et al*. (2008b) attributed such an interdecadal change in EASM–ENSO relationship to increased magnitude and periodicity of ENSO and the strengthened local monsoon–ocean interactions in low latitudes. Since the EASM has complex space and time structures that encompass tropics, subtropics, and mid-latitudes, its

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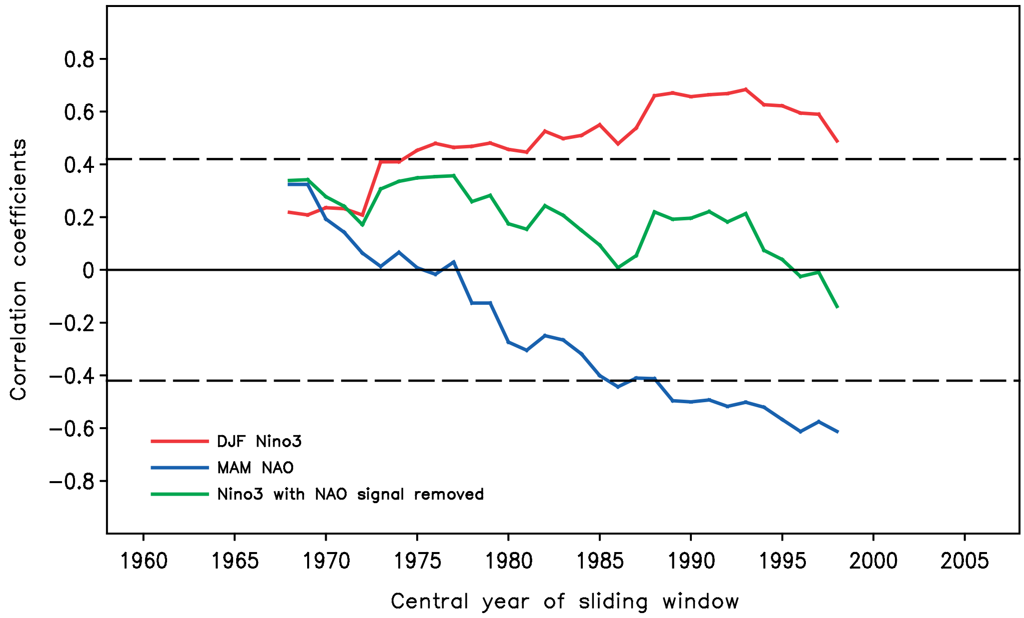

Figure 1. Correlation (based on a 21-year sliding window) between the EASM index (EASMI) and preceding winter (December–February, DJF) Niño 3 SST (red curve), spring (March–May, MAM) NAO index (NAOI) (blue curve), and Niño 3 SST with NAO signal removed (green curve). The horizontal dashed lines denote 95% confidence level based on the Student-*t* test. The NAO signal is removed from the ENSO signal based on linear regression. This figure is available in colour online at wileyonlinelibrary.com/journal/joc

variability is influenced not only by tropical systems (Wu *et al*., 2006; Li *et al*., 2010), but also by systems from mid-high latitudes (i.e. North Atlantic Oscillation or NAO) (e.g. Ding and Wang, 2007; Wu *et al*., 2009, 2010).

The NAO has long been recognized as a major circulation pattern over northern mid-high latitudes influencing weather and climate from eastern North America to Europe (Hurrell, 1995). Recently, NAO has also been found to be able to influence the interannual variations of the EASM through changing the low boundary forcing over North Atlantic and the associated subpolar teleconnections (Wu *et al*., 2009). Nevertheless, it is still not clear whether the NAO–EASM relationship has an inter-decadal change or not in the past decades. If so, how does it change and to what extent does it contribute to the strengthened relationship between the EASM and ENSO? In this paper, we attempt to answer these questions. The main datasets used in this study include: (1) European Centre for Medium-Range Weather Forecasts 40-year reanalysis datasets (ERA-40; Uppala *et al*., 2005) and ERA-interim reanalysis datasets; (2) The Niño 3 sea surface temperature index calculated from the improved Extended Reconstructed sea surface temperature Version 2 (ERSST V2; Smith and Reynolds, 2004); (3) The EASM index (EASMI) is defined by the $U850$ averaged in (22.5 °N–32.5 °N, 110 °E–140 °E) minus $U850$ in (5 °N–15 °N, 90 °E–130 °E), where $U850$ denotes the zonal wind at 850 hPa (Wang *et al*., 2008a); (4) The NAO index used in this study (hereafter NAOI) is defined as the difference in the normalized monthly sea level pressure zonal-averaged over the North Atlantic sector from 80 °W to 30 °E between 35 °N and 65 °N (Li and Wang, 2003).

2. Results

Sliding correlations on a 21-year moving window between the EASMI and preceding winter (December–Feburary, DJF) Niño 3 SST index have become significant since the 1970s, exceeding the 95% confidence level (Figure 1). It indicates an obvious strengthening relationship between the EASM and ENSO. It is interesting to notice that the EASM also exhibits an enhanced relationship with prior spring (March–May, MAM) NAO, their correlation coefficients having been beyond the 95% confidence level since 1985. If NAO signals were removed from the Niño 3 SST anomaly (SSTA), the ENSO–EASM relationship would break down with their correlation coefficients becoming insignificant (Figure 1). Such a breakdown implies that spring NAO might impact on the linkage between the EASM and ENSO.

The correlation between the EASMI and 500 hPa stream function during 1985–2008 (Figure 2) also displays a pronounced dipole pattern over North Atlantic, which is indicative of the strong relationship with NAO. Such a NAO pattern is not clear during 1958–1984. Another striking feature is that in Figure 2(b), an Atlantic-Eurasian wave-train controls the mid-high latitudes north of 40 °N, extending from the North Atlantic to the Okhotsk Sea. Associated with this wave-train pattern, three positive geo-potential height anomaly centres are located at North Atlantic, the Ural Mountains and the Okhotsk Sea. Such a high-latitude tele-connection pattern is not clear during 1958–1984 (Figure 2(a)). The interdecadal changes in circulations over the northern Eurasia indicate that NAO has stronger and further downstream impacts. In addition, large areas of positive correlations prevail over the western Pacific and expand to

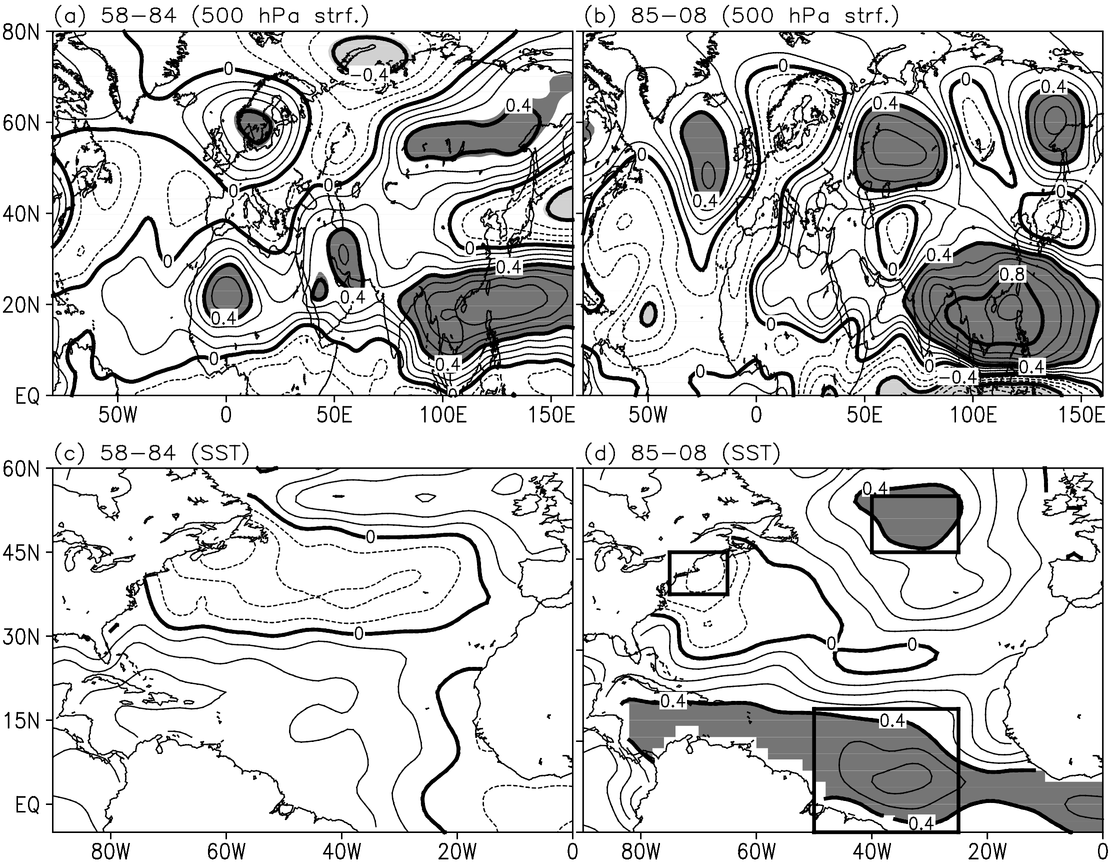

Figure 2. Correlation between the EASMI and summer (June–August, JJA) stream function at 500 hPa for (a) 1958–1984 and (b) 1985–2008, and summer SST for (c) 1958–1984 and (d) 1985–2008. The contours interval is 0.1 and significant (95% level) correlations are shaded (positive: dark, negative: light). A summer tripole SST index (TSSTI) is defined as the difference between the sum of averaged SST in two positive correlation boxes and averaged SST in the negative correlation box (positive domain minus negative domain).

the southern China, Indo-China Peninsular and the Bay of Bengal during 1985–2008 (Figure 2(b)), whereas during 1958–1984, the areas of positive correlations over the western Pacific are relatively smaller and weaker (Figure 2(a)). The expanding of the positive correlation areas over the western Pacific from 1958 to 2008 indicates that western Pacific subtropical high (WPSH) is strengthening and its linkage with NAO-like circulation anomaly is enhanced, too.

Wang *et al*. (2000, 2008a) attributed such a WPSH change to ‘prolonged’ impacts of ENSO or a ‘delayed’ response of the EASM to ENSO. They pointed out the critical role of the interaction between the off-equatorial moist atmospheric Rossby waves and the underlying SSTA in the western Pacific warm pool region. The moist Rossby wave–SST interaction can maintain both the Philippine Sea anticyclone (or WPSH) anomalies and the dipole-like SSTA in the western Pacific during the decaying El Niño. Thus, even if the SSTA disappears during the summer after the peak El Niño, the EASM remains to be affected by the WPSH anomalies significantly. In light of the strengthened linkage between the NAO-like circulation anomalies and the WPSH from 1958 to 2008 (Figure 2(a) and (b)), it is reasonable to speculate spring NAO might also affect the EASM via altering the WPSH.

Due to lack of persistence, the NAO can only prolong its influence through coupled mechanisms that involve low boundary forcing such as SST (Charney and Shukla, 1981; Shukla, 1998). Figure 2(c) and (d) show SST correlation patterns with the EASMI for 1958–1984 and 1985–2008, respectively. A pronounced feature during 1985–2008 is that the EASM is connected to a tripole SSTA pattern over North Atlantic. Previous studies proved that the tripole SSTA is coupled with atmospheric NAO-like anomalies (e.g. Wu *et al*., 2009). To quantitatively depict the tripole pattern during boreal summer, a simple tripole SST index (TSSTI) is defined as the difference between the sum of averaged SST in two positive correlation boxes and averaged SST in the negative correlation box (positive domain minus negative domain). The TSSTI displays a nearly consistent variability with the EASMI during 1985–2008 (not shown), their correlation coefficient reaching −0.64 (beyond 95% confidence level). The tripole SSTA is not detectable during 1958–1984 (Figure 2(c)) and the correlation coefficient between the TSSTI and the EASMI is only −0.2 for the 1958–1984 period.

The enhancement of such a tripole SSTA pattern over North Atlantic may result from the interdecadal change in spring NAO, which is supported by Figure 3. Figure 3 takes the summer TSSTI as a reference and

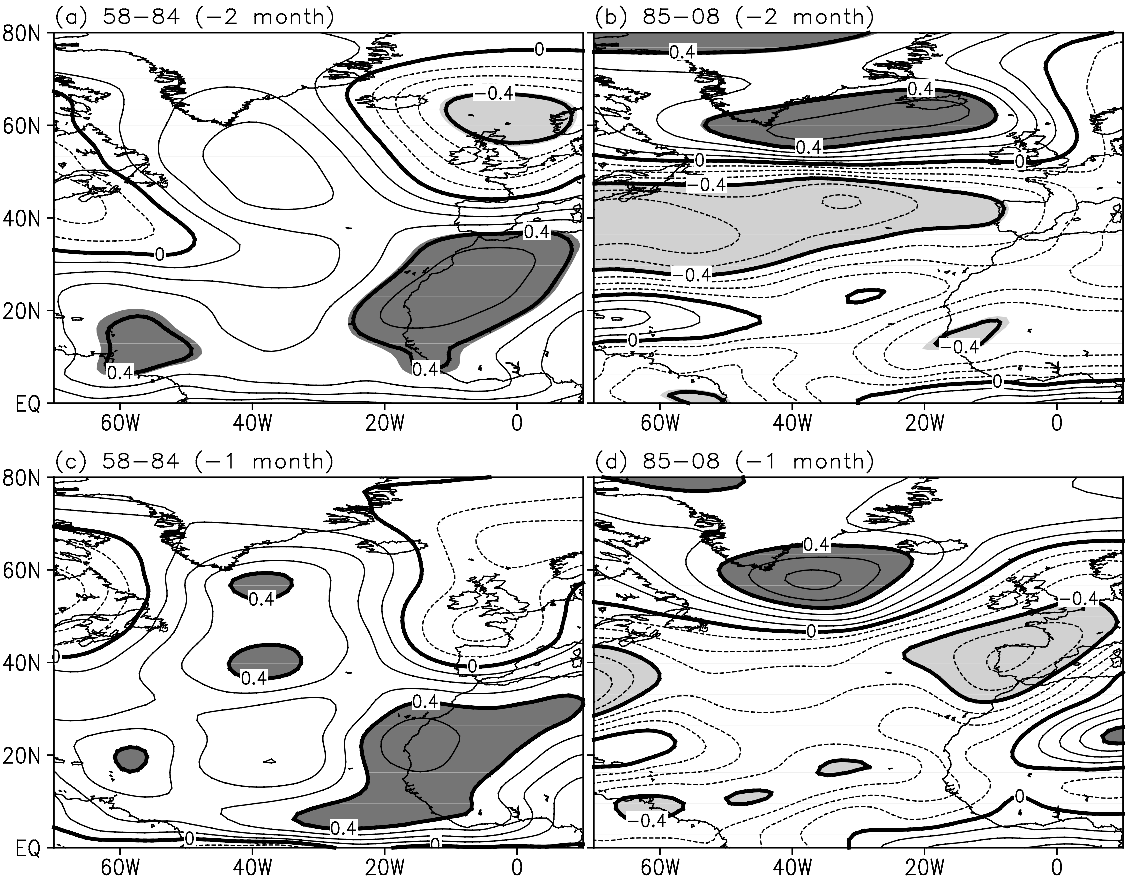

Figure 3. The lead correlation patterns between 500 hPa stream function and the summer TSSTI defined in Figure 2. The TSSTI leads the stream function by −2 months for (a) 1958–1984 and (b) 1985–2008, and −1 month for (c) 1958–1984 and (d) 1985–2008. The dark (light) shaded areas denote significant positive (negative) correlation exceeding 95% confidence level. Note that −2 months correspond to April–June (AMJ), and −1 month corresponds to May–July (MJJ).

computes the lead correlation with 500 hPa stream function for 1958–1984 and 1985–2008. In the earlier period (Figure 3(a) and (c)), NAO-like circulation anomalies are undetectable. In the latter period (Figure 3(b) and (d)), a notable NAO-like circulation anomaly, namely, a meridional dipole pattern, emerges over North Atlantic from −2 month to −1 month. This indicates that tripole SSTA in ensuing summer arises from spring NAO-like circulation anomalies.

How could the atmosphere respond to such a tripole SSTA forcing in summer in North Atlantic? Figure 4 presents 500 hPa zonal winds and stream function anomalies regressed to the summer TSSTI for 1958–1984 and 1985–2008. For the earlier period (Figure 4(a)), the mid-latitude jets are strong and shallow, whereas for the latter period (Figure 4(b)), the mid-latitude jets are weak and wide. This feature is particularly true over the central Eurasia. Associated with such an interdecadal change of jet streams, for the latter period, a pronounced Rossby wave train is excited over the northern Eurasia as responses to the tripole SSTA forcing in North Atlantic. The northern wave train propagates along the subpolar region with two anomalous high value centres over the Ural Mountain and the Okhotsk Sea. Its spatial pattern resembles an inverted East Atlantic Western Russia (EAWR) pattern (Barnston and Livezey, 1987). It raises (or weakens) pressure over these two regions which have important effects on the extra-tropical components of the EASM (e.g. Ding and Sikka, 2006; Wu *et al.*, 2009).

Another notable circulation anomaly associated with the tripole SSTA is the anomalous WPSH over northwestern Pacific (Figure 4(b)). It implies that the tripole SSTA in North Atlantic might also contribute to the WPSH anomalies. Then, what kind of physical mechanism might be responsible for bridging the tripole SSTA and the WPSH anomalies? Kucharski i. (2009) found SSTAs in the tropical Atlantic can influence African and Indian monsoon rainfall and a Gill-Matsuno-type quadrupole response (Matsuno 1966; Gill 1980) is proposed to explain the tele-connection between the tropical Atlantic and the Indian basin. Whether this physical process also works for bridging the tripole SSTA and the WPSH largely depends on whether the tropical component of the tripole SSTA can extend its influence further to East Asia. To answer this question, we perform an idealized numerical experiment with a simplified general circulation model (SGCM) (Hoskins and Simmons, 1975; Lin and Derome, 1996). In the control run, the SGCM is forced by climatological SSTs. In the sensitivity experiments, we superimposed a heating (cooling)

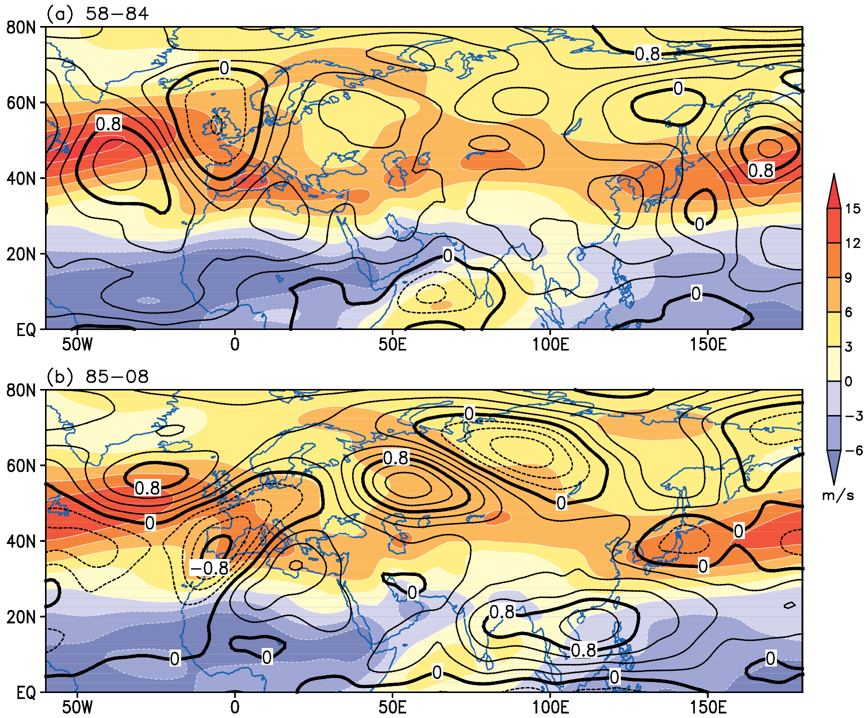

Figure 4. 500 hPa zonal winds (color shadings in units of m/s) and stream function anomalies (contours in units of $10^6 m^2/s$) regressed to the summer TSSTI for (a) 1958–1984 and (b) 1985–2008. The westerly winds are obtained through climatological JJA westerly winds plus westerly anomalies regressed to the TSSTI. This figure is available in colour online at wileyonlinelibrary.com/journal/joc

source in tropical Atlantic (its position centred in the bottom box in Figure 4(d)) on the climatological values to mimic a warm (cold) SSTA in tropical Atlantic during a high (low) TSSTI summer; each source has an elliptical squared cosine distribution in latitude and longitude with a vertically integrated heating rate of 1 K/day. To make the numerical results more robust, the control run was integrated for 12 years and the last 10 years' integration was used to derive a reference state. The two sensitivity tests were integrated for 10 years each. The 10-year integrations were used to construct a 10-member ensemble (arithmetic) mean to reduce the uncertainties arising from differing initial conditions.

Figure 5 presents the SGCM responses to the above tropical Atlantic forcing. The results of the numerical experiments are basically similar with those obtained by Kucharski *et al.* (2009). The atmosphere responds a Gill-Matsuno-type pattern. A warming (cooling) over the tropical Atlantic during a high (low) TSSTI summer induces a surface pressure (SP) gradient extending from the northeast to the southwest over Africa (Figure 5(a)). The vertical structure of the response is baroclinic with a positive (negative) SP and low-level stream function anomaly (Figure 5(a) and (b)) and a negative (positive) high-level stream function anomaly (Figure 5(c)) over western Pacific. This usually favours a strong (weak) WPSH anomaly (e.g. He *et al.*, 2011). Some studies have already pointed out that a strong (weak) WPSH anomaly is usually associated with El Niño (La Niña) events (Wang *et al.*, 2000). Therefore, the tropical component associated with the tripole SSTA tends to strengthen the linkage between the WPSH and ENSO. On the other hand, the anomalously high (low) pressure over the Okhotsk Sea, together with a strengthened (or weakened) and westward extended (or eastward withdrawn) WPSH, would favour an enhanced (or weakened) subtropical Meiyu-Baiu-Changma front, the primary rain-bearing system of the EASM, thus, leading to a strong (weak) EASM (Wang *et al.*, 2008a).

3. Summary and Discussion

Most previous studies focus on the weakened ISM–ENSO relationship, while fewer studies investigate the strengthened EASM–ENSO relationship which is also of great importance. This work investigates contribution of prior spring NAO to the enhanced linkage between the EASM and ENSO from observational and numerical perspectives. The relevant physical processes can be summarized as following: The anomalous spring NAO induces a tripole SSTA pattern in North Atlantic which persists into ensuring summer and excites downstream development of a distinct Rossby wave train prevailing over the northern and a simple Gill-Matsuno-type quadrupole response over western Pacific. The former modulates the blocking highs over the Ural Mountain and the Okhotsk Sea, while the latter enhances the linkage between the WPSH and ENSO. The co-effects of the two tele-connection patterns help to strengthen (or weaken) the subtropical Meiyu-Baiu-Changma front, the primary rain-bearing system of the EASM. As such, spring NAO

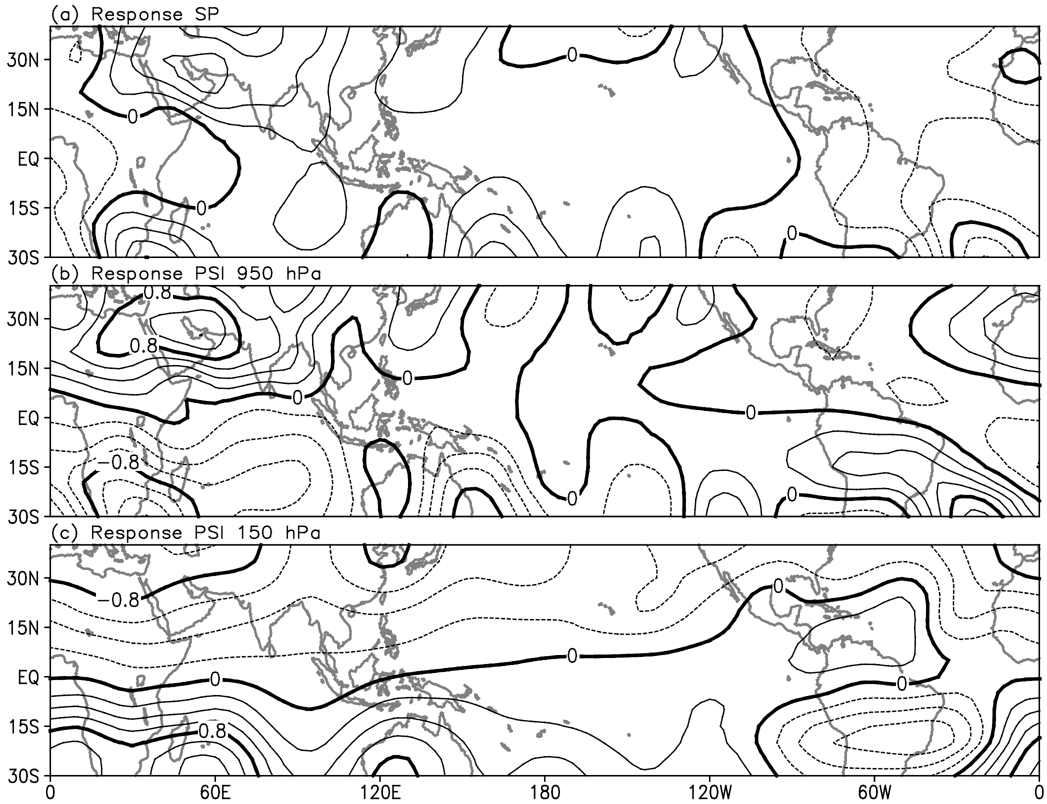

Figure 5. Response to the tropical SSTA in Figure 2(d) of (a) surface pressure (SP), (b) 950 hPa stream function and (c) 150 hPa stream function. Contour intervals are 0.2 hPa in (a), 0.2×10^6 m^2 s^{-1} in (b), and 0.2×10^7 m^2 s^{-1} in (c).

is tied to the strengthened connection between ENSO and the EASM.

This study focuses on the potential roles of the interdecadal change in spring NAO in strengthening the EASM-ENSO relationship. Some previous studies found that ENSO, itself, may exert remote influences on the NAO variability (e.g. Lin *et al*., 2002, 2005), while others believed that occurrences of particular modes of ENSO with those of the NAO seem to occur by chance (e.g. Hurrel, 1996; Rogers, 2000; Zanchettin *et al*., 2008). Therefore, whether the interdecadal change of the NAO arises from ENSO is still an open question.

Some recent papers have reported the influence of the tropical Atlantic SSTs (e.g. Atlantic Niño) on the Indian summer monsoon (Kucharski *et al*., 2007, 2008, 2009; Losada *et al*., 2010). It should be pointed out that many factors may influence the tropical Atlantic SST variability besides the NAO (Latif and Grötzner, 2000; Huang *et al*., 2004; Chang *et al*., 2006; Hu and Huang, 2007). The contribution from spring NAO 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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References

Barnston AG, Livezey RE. 1987. Classification, seasonality and persistence of low-frequency atmospheric circulation patterns. *Monthly Weather Review* **115**: 1083–1126.

Chang CP, Harr P, Ju J. 2001. Possible roles of Atlantic circulations on the weakening Indian monsoon rainfall–ENSO relationship. *Journal of Climate* **14**: 2376–2380.

Chang P, Fang Y, Saravanan R, Ji L, Seidel H. 2006. The cause of the fragile relationship between the Pacific El Niño and the Atlantic Niño. *Nature* **443**: 324–328. DOI:10.1038/nature05053 Letter.

Charney JG, Shukla J. 1981. Predictability of monsoons. In: *Monsoon Dynamics*, Lighthill J, Pearce RP (eds), Cambridge Univ. Press: New York; pp. 99–109.

Ding YH. 1992. Summer monsoon rainfalls in China. *Journal of Meteorological Society, Japan* **70**: 397–421.

Ding YH, Sikka DR. 2006. Synoptic systems and weather. In: *The Asian Monsoon*, Wang B (ed.), Springer-Verlag: New York; 131–201.

Ding Q, Wang B. 2007. Intraseasonal teleconnection between the summer Eurasian wave train and the Indian monsoon. *Journal of Climate* **20**: 3751–3767.

Ding R, Ha K, Li J. 2010. Interdecadal shift in the relationship between the East Asian summer monsoon and the tropical Indian Ocean. *Clim. Dyn* **34**: 1059–1071. DOI:10.1007/s00382-009-0555-2.

Gill AE. 1980. Some simple solutions for heat-induced tropical circulations. *Quarterly Journal of Royal Meteorological Society* **106**: 447–462.

Goswami BN, Madhusoodanan MS, Neema CP, Sengupta D. 2006. A physical mechanism for North Atlantic SST influence on the Indian summer monsoon, *Geophysical Research Letters* **33**: L02706. DOI:10.1029/2005GL024803.

He JH, Lin H, Wu ZW. 2011. Another look at influences of the Madden-Julian Oscillation on the wintertime East Asian weather. *J. Geophys. Res* **116**: D03109. DOI: 10.1029/2010JD014787.

Hoskins BJ, Simmons AJ. 1975. A multi-layer spectral model and the semi-implicit method. *Quarterly Journal of Royal Meteorological Society* **101**: 637–655.

Hu ZZ, Huang B. 2007. Physical processes associated with tropical Atlantic SST gradient: The anomalous evolution in the southeastern ocean. *Journal of Climate* **20**: 3366–3378.

Huang BH, Paul SS, Shukla J. 2004. Intrinsic Ocean–Atmosphere variability of the tropical Atlantic ocean. *Journal of Climate* **17**: 2058–2077.

Hurrell JW. 1995. Decadal trends in the North Atlantic Oscillation: regional temperature and precipitation. *Science* **269**: 676–679.

Hurrell JW. 1996. Influence of variations in extratropical wintertime teleconnections on Northern Hemisphere temperature. *Geophysical Research Letters* **23**: 665–668.

Kucharski F, Bracco A, Yoo JH, Molteni F. 2007. Low-frequency variability of the Indian Monsoon-ENSO relation and the tropical Atlantic: The 'weakening' of the '80s and 90s'. *Journal of Climate* **20**: 4255–4266.

Kucharski F, Bracco A, Yoo JH, Molteni F. 2008. Atlantic forced component of the Indian monsoon interannual variability. *Geophysical Research Letters* **35**: L04706. DOI:10.1029/2007GL033037.

Kucharski F, Bracco A, Yoo JH, Tompkins A, Feudale L, Ruti P, Dell'Aquila A. 2009. A Gill-Matsun-type mechanism explains the tropical Atlantic influence on African and Indian Monsoon Rainfall. *Quarterly Journal of Royal Meteorological Society* **135**: 569–579.

Kumar KK, Rajagopalan B, Cane MA. 1999. On the weakening relationship between Indian monsoon and ENSO. *Science* **284**: 2156–2159.

Latif M, Grötzner A. 2000. The equatorial Atlantic oscillation and its response to ENSO. *Climate Dynamic* **16**: 213–218.

Lau KM, Yang S. 1997. Climatology and interannual variability of the Southeast Asian summer monsoon. *Advances in Atmospheric Sciences* **14**: 141–162.

Li JP, Wang J. 2003. A new North Atlantic Oscillation index and its variability. *Advances in Atmospheric Sciences* **20**: 661–676.

Li JP, Wu ZW, Jiang ZH and He JH. 2010. Can global warming strengthen the East Asian summer monsoon? *Journal of Climate*, DOI:10.1175/2010JCLI3434.1.

Lin H, Derome J. 1996. Changes in predictability associated with the PNA pattern. *Tellus* **48A**: 553–571.

Lin H, Derome J, Greatbatch RJ, Peterson KA, Lu J. 2002. Tropical links of the Arctic Oscillation. *Geophysical Research Letters* **29**: 1943, DOI:10.1029/2002GL015822.

Lin H, Derome J, Brunet G. 2005. Tropical Pacific link to the two dominant patterns of atmospheric variability. *Geophysical Research Letters* **32**: L03801, DOI:10.1029/2004GL021495.

Losada T, Rodríguez-Fonseca B, Polo I, Janicot S, Gervois S, Chauvin F, Ruti P. 2010. Tropical response to the Atlantic Equatorial mode: AGCM multimodel approach. *Climate Dynamic* **35**: 45–52.

Matsuno T. 1966. Quasi-geostrophic motions in the equatorial area. *Journal of Meteorological Society, Japan* **44**: 25–43.

Rogers JC. 2000. The association between the North Atlantic Oscillation and the Southern Oscillation in the Northern Hemisphere. *Monthly Weather Review* **112**: 1999–2015.

Shukla J. 1998. Predictability in the midst of chaos: A scientific basis for climate forecasting. *Science* **282**: 728–731.

Smith TM, Reynolds RW. 2004. Improved Extended Reconstruction of SST (1854–1997). *Journal of Climate* **17**: 2466–2477.

Uppala SM, Kallberg PW, Simmons AJ, Andrae U, da Costa Bechtold V, Fiorino M, Gibson JK, Haseler J, Hernandez A, Kelly GA, Li X, Onogi K, Saarinen S, Sokka N, Allan RP, Andersson E, Arpe K, Balmaseda MA, Beljaars ACM, van de Berg L, Bidlot J, Bormann N, Caires S, Chevallier F, Dethof A, Dragosavac M, Fisher M, Fuentes M, Hagemann S, Hólm E, Hoskins BJ, Isaksen L, Janssen PAEM, Jenne R, McNally AP, Mahfouf J-F, Morcrette J-J, Rayner NA, Saunders RW, Simon P, Sterl A, Trenberth KE, Untch A, Vasiljevic D, Viterbo P, Woollen J. 2005. The ERA-40 re-analysis. *Quart. J. R. Meteorol. Soc* **131**: 2961–3012. doi:10.1256/qj.04.176.

Wang B, Wu R, Fu X. 2000. Pacific-East Asia teleconnection: How does ENSO affect East Asian climate? *Journal of Climate* **13**: 1517–1536.

Wang B, Wu ZW, Li JP, Liu J, Chang CP, Ding YH, Wu GX. 2008a. How to measure the strength of the East Asian summer monsoon? *Journal of Climate* **17**: 4449–4462.

Wang B, Yang J, Zhou T, Wang B. 2008b. Interdecadal Changes in the Major Modes of Asian–Australian Monsoon Variability: Strengthening Relationship with ENSO since the Late 1970s. *Journal of Climate* **21**: 1771–1789.

Wang B, Huang F, Wu ZW, Yang J, Fu X and Kikuchi K. 2009. Multi-Scale Climate Variability of the South China Sea Monsoon: A Review. *Dynamics of Atmospheres and Oceans*, DOI:10.1016/j.dynatmoce.2008.09.004, **47**: 15–37.

Webster PJ, Palmer TN. 1997. The past and the future of El Niño. *Nature* **390**: 562–564.

Wu ZW, Li JP, He JH, Jiang ZH. 2006. Occurrence of droughts and floods during the normal monsoons in the mid- and lower reaches of the Yangtze River. *Geophysical Research Letters* **33**: L05813, DOI:10.1029/2005GL024487.

Wu ZW, Wang B, Li JP, Jin FF. 2009. An empirical seasonal prediction model of the east Asian summer monsoon using ENSO and NAO. *Journal of Geophysical Research* **114**: D18120, DOI:10.1029/2009JD011733.

Wu ZW, Li JP, Jiang ZH, He JH. 2010. Predictable climate dynamics of abnormal East Asian winter monsoon: once-in-a-century snowstorms in 2007/2008 winter. *Climate Dynamics*, DOI:10.1007/s00382-010-0938-4.

Yang S, Lau KM, Yoo SH, Kinter JL, Miyakoda K, Ho CH. 2004. Upstream Subtropical Signals Preceding the Asian Summer Monsoon Circulation. *Journal of Climate* **17**: 4213–4229.

Zanchettin D, Franks SW, Traverso P, Tomasino M. 2008. On ENSO impacts on European wintertime rainfalls and their modulation by the NAO and the Pacific multidecadal variability described through the PDO index. *International Journal of Climatology* 10.1002/joc.1601.

