CrossMark

Tropical Atlantic-Korea teleconnection pattern during boreal summer season

Yoo-Geun Ham[1] · Yoshimitsu Chikamoto[2] · Jong-Seong Kug[3] · Masahide Kimoto[4] ·
Takashi Mochizuki[5]

Abstract The remote impact of tropical Atlantic sea surface temperature (SST) variability on Korean summer precipitation is examined based on observational data analysis along with the idealized and hindcast model experiments. Observations show a significant correlation (i.e. 0.64) between Korean precipitation anomalies (averaged over 120–130°E, 35–40°N) and the tropical Atlantic SST index (averaged over 60°W–20°E, 30°S–30°N) during the June–July–August (JJA) season for the 1979–2010 period. Our observational analysis and partial-data assimilation experiments using the coupled general circulation model demonstrate that tropical Atlantic SST warming induces the equatorial low-level easterly over the western Pacific through a reorganization of the global Walker Circulation, causing a decreased precipitation over the off-equatorial western Pacific. As a Gill-type response to this diabatic forcing, an anomalous low-level anticyclonic circulation appears over the Philippine Sea, which transports wet air from the tropics to East Asia through low-level southerly, resulting an enhanced precipitation in the Korean peninsula.

Multi-model hindcast experiments also show that predictive skills of Korean summer precipitation are improved by utilizing predictions of tropical Atlantic SST anomalies as a predictor for Korean precipitation anomalies.

1 Introduction

The East Asian summer rainfall (i.e., East Asian Summer Monsoon, EASM), including rainfall anomalies over Korea, Japan, and China, has received wide attention because of its vast agricultural and economic influence on populations throughout East Asia (Ding 1994; Lau et al. 2001; Ding et al. 2004; Chang 2004; Yancheva et al. 2007). On one hand, efforts have been devoted to revealing the climatological evolution of the EASM, including its onset or seasonal progression from a regional perspective (Ding 1994; Webster et al. 1998; Zhang et al. 2004). However, there are many studies regarding interannual variation of the EASM that examine the effect of El Niño Southern Oscillation (ENSO; Huang and Wu 1989; Wu et al. 2010), Indian Ocean sea surface temperature (SST; Kosaka et al. 2013), the temperature anomaly over the Tibetan Plateau (Yeh and Gao 1979; Murakami and Ding 1982; Luo and Yanai 1984; Ding 1992; Lau et al. 2006), the Indian summer monsoon (Wang et al. 2001), or the Western North Pacific summer monsoon (WNPSM; Huang and Sun 1992; Kwon et al. 2005).

In particular, the role of tropical Pacific SST on the interannual variability of the EASM has been widely examined because of its possible usage as a predictor of the East Asian summer rainfall (Huang and Wu 1989; Liu and Ding

✉ Yoo-Geun Ham
ygham@jnu.ac.kr

1   Faculty of Earth Systems and Environmental Sciences, Chonnam National University, 77 Yongbong-ro, Buk-gu, Gwangju 500-757, Republic of Korea

2   International Pacific Research Center, University of Hawaii at Manoa, Honolulu, USA

3   School of Earth Science and Engineering, Pohang University of Science and Technology, Pohang, South Korea

4   Atmosphere and Ocean Research Institute, University of Tokyo, Kashiwa, Japan

5   Japan Agency for Marine-Earth Science and Technology, Yokohama, Japan

1992; Chang et al. 2000). Huang and Wu (1989) found that El Niño causes drought over southern and northern China and flooding in central China during its developing phase whereas this relationship is reversed during the decaying phase. The ENSO-related teleconnection over the China is mostly determined by the southward extension of the North Pacific Subtropical High (Wang et al. 2000; Kwon et al. 2005). In particular, the high-pressure anomalies in a lower troposphere over the Philippine Sea tend to enhance the EASM (Huang and Sun 1992). As a result, dry WNPSM is linked to the negative precipitation anomalies over the off-equatorial western Pacific that can induce the low-level high-pressure anomaly through a Gill-type response (Gill 1980).

High-pressure anomalies over the Philippine Sea also can be modulated by SST anomalies that are less relevant to the ENSO. For example, Huang and Sun (1992), using the Atmospheric General Circulation Model (AGCM) experiment, found that convective activity over the off-equatorial western Pacific, which excites the WNPSM, is mainly induced by the western Pacific warm pool SST (Su et al. 2001). On the other hand, Xie et al. (2009) proposed that Indian Ocean warming can generate a boundary layer frictional convergence over the equatorial western Pacific, which leads to frictional divergence and resultant negative precipitation anomalies over the subtropical western Pacific. In addition, Shen and Lau (1995) found a link between Indian Ocean SST warming and the wet EASM that has a 6-month lag-time through a tropical biennial oscillation (TBO)-like teleconnection. Using the AGCM, Ahmed and Kucharski (2012) showed that the Indian Ocean warming may increase precipitation over south Asia and reduce precipitation in East Asia.

There are also studies that focus on summer rainfall over Japan (Ninomiya and Akiyama 1992; Kosaka and Naka-mura 2006), or the Korean peninsula (Kwon et al. 2005). The rainy season over the Korean peninsula is called 'Changma', which has primary rainy period with onset and withdraws around 20–25 June, and 20–25 July, respectively (Ho and Kang 1998; Seo et al. 2011). It has been reported that Changma exhibits delicate evolution and variabilities due to its complex mechanisms. Seo et al. (2011) mentioned that Changma is affected by five different air masses; the tropical North Pacific air mass, cold Okhotsk sea air mass, tropical monsoon air mass related to the intertropical convergence zone (ITCZ), the tropical continental air mass over North China, and intermittently polar continental air mass. There were many previous studies to investigate Changma characteristics including evolution, amount, and intensity (Ho et al. 2003; Kim et al. 2006; Yoon et al. 2006; Kim and Shu 2008; Choi et al. 2016), however, only few of them is focused on the relationship of the Changma with the tropical SST variability, and particularly with the

ENSO. For example, Kang (1998) quantifies the relationship between Korean precipitation and ENSO; the correlation coefficient between summer (averaged from June to August) Korean rainfall and ENSO is marginal (Ahn et al. 1997; Cha et al. 1999). Recently, Son et al. (2014, 2015) found that the relationship between Korean climate variability and ENSO has strong intra-seasonal variation. Therefore, the statistical relationship between them is not clear based on seasonal-mean basis (Ham et al. 2016).

Among the tropical oceans, the Atlantic impacts on the Changma have less attention because of its long distance or the small geographic size of the Korean peninsula compared to the large-scale forcing. Recently, some studies have pointed out that the tropical Atlantic SST variability also plays an important role for global climate variability like ENSO (Rodríguez-Fonseca et al. 2009; Ding et al. 2012; Ham et al. 2013a, b; Keenlyside et al. 2013; Polo et al. 2015; Chikamoto et al. 2012, 2015) and/or the Indian monsoon (Kucharski et al. 2008). In line with those findings, this study first reports that there is a strong positive relationship between the tropical Atlantic SST anomalies and rainfall anomalies over the Korean peninsula during the boreal summer season.

In "Sect. 2", the observations and model output used in this study are described. In Sect. "3", the tropical Atlantic-Korea teleconnection pattern and possible dynamical mechanism are introduced. Section "4" shows results using partial assimilation experiments based on the coupled model MIROC3.2 m. Section "5" describes the predictability of Korean precipitation using multi-model hindcast experiments used in the APEC Climate Center multi-model ensemble (APCC MME; Jeong et al. 2012) and WCRP CHFP-SHFP projects (Osman et al. 2015) to support the observational findings. Section "6" presents a summary and discussion.

2 Data and models

2.1 Observational data

The Global Precipitation Climatology Project (GPCP) monthly-mean precipitation data during 1979–2010 is used as the observed precipitation data (Adler et al. 2003). The observed SST data during 1979–2010 are taken from the NOAA Extended Reconstructed Sea Surface Temperatures version 3 (ERSST V3b, Smith et al. 2008). The 850 hPa zonal and meridional wind data from 1979 to 2010 are obtained from the ERA-Interim (Berrisford et al. 2011). In addition to the reanalysis output, the precipitation variability over the Korea Peninsula is obtained based on the station data; the monthly precipitation data from 86 stations on the Korea Peninsula, including South and North Korea,

were provided by the Korea Meteorological Administration (Ham et al. 2016). The anomaly is defined as a deviation from the climatology during 1979–2010, and the observed linear trend is also removed before analysis.

2.2 The partial assimilation experiments using MIROC3.2m coupled model

Two partial assimilation experiments using the coupled atmosphere–ocean general circulation model MIROC3.2m (K-1 Model Developers 2004) are analyzed: the Atlantic (ATL) and equatorial Pacific (eqPAC) runs. The atmospheric component of the MIROC3.2 has a T42 spectral resolution with 20 vertical levels on a sigma coordinate system. The ocean component has a horizontal resolution of 1.4° in longitude and 0.56–1.4° in latitude with 44 vertical levels. No flux corrections for the heat, water, or momentum fluxes are applied. In addition to prescribing natural and anthropogenic radiative forcings (observed and following the A1B-type emission scenario in Nakicenovic et al. 2000), the observed three-dimensional oceanic temperature and salinity anomalies are assimilated from the surface to a depth of 700 m during 1945–2009 (Ishii and Kimoto 2009) in either the ATL (50°S–60°N over the Atlantic) or eqPAC (10°S–10°N over the Pacific) runs. These partial assimilation experiments each consist of 10-member ensembles, and we utilized the output from 1979 to 2009. The ATL partial assimilation experiment is beneficial for separating the observed variability induced by the Atlantic SST from that over the other regions while maintaining the atmosphere–ocean interaction processes over the Pacific and Indian Oceans (Ham et al. 2013a). Details regarding this partial assimilation experiment are given in Chikamoto et al. (2015, 2016), and note that the simulated linear trend is also removed before analysis.

2.3 The hindcast experiments

Twenty sets of hindcast experiments are utilized to examine the role of Atlantic variability in the forecast skill of Korean summer precipitation. Eleven sets of hindcast experiments are gathered from the APEC Climate Center (APCC) Multi-Model Ensemble (MME) (Jeong et al. 2012), and nine sets of hindcast experiments are obtained from the World Climate Research Programme (WCRP) Climate Historical Forecast Project (WCRP CHFP, Osman et al. 2015). All hindcast experiments begin on May 1st, and we utilized the JJA-averaged forecasted value (i.e., the averaged value from 2 to 4 month lead forecast). The longest forecast period is 1979–2010 for Japan Meteorological Agency (JMA) Meteorological Research Institute (MRI) in WCRP CHFP, and the shortest forecast period is 1996–2009 for GloSea5 in WCRP

CHFP. The number of ensemble members also varies from 5 to 20. Details regarding the hindcast experiments are given in Table 1.

3 Observed relationship between Korean precipitation and tropical Atlantic SST

To quantify the global distribution of the SST anomalies associated with the Korean precipitation during the boreal summer season, we made correlation maps between JJA-mean precipitation and SST anomalies and the Korean summer precipitation index (precipitation anomalies averaged over 120–130°E, 35–40°N) for the 1979–2010 period (Fig. 1). It is found that the summer Korean precipitation index has a significant positive correlation with precipitation anomalies over the Korean peninsula, the Maritime Continent, and the eastern Australia but slightly negative correlations with those over south of Korea/Japan and subtropical southeastern Asia. In contrast to the precipitation correlation, SST anomalies over the tropical western Pacific and the Indian Ocean regions are weakly correlated to the summer Korean precipitation

Table 1 Descriptions of the hindcast experiments that participated in the APCC MME system and WCRP_CHFP, including model name, forecast period, and number of ensemble members

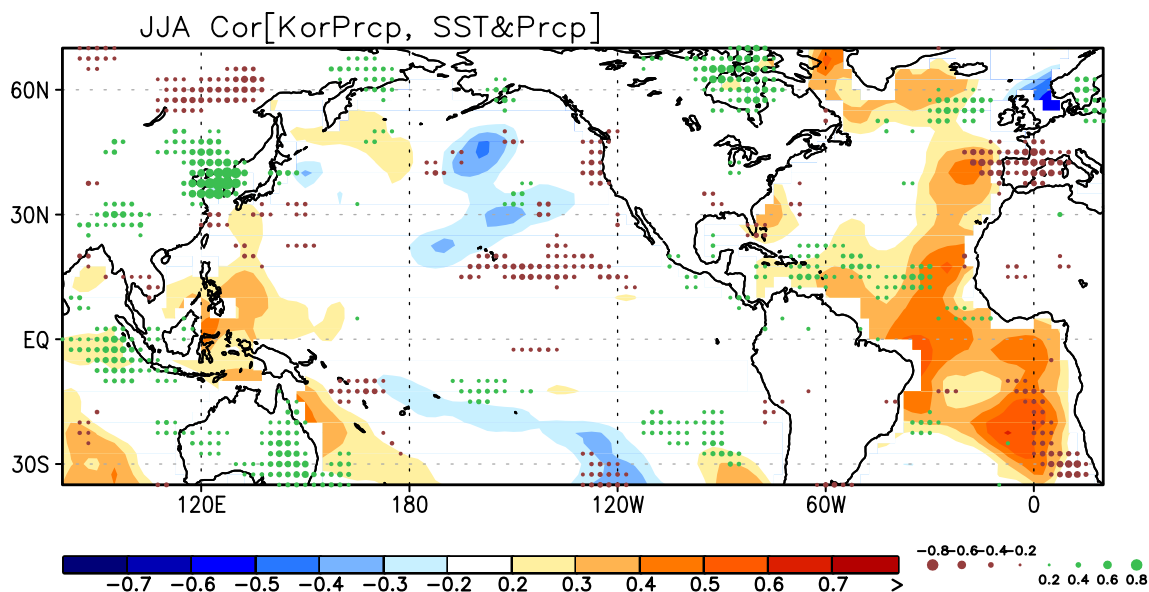| Model name	Number in Fig. 9	Period	Ensemble #
APCC			
COLA	19	82–02	10
CWB	9	83–05	10
CANCM3	13	81–10	10
CANCM4	11	81–10	10
HMC	6	81–10	10
IRI	15	79–05	24
MGO	16	79–04	6
NASA/GMAO	5	82–12	11
CFS v1	14	82–09	20
PNU	20	80–12	5
POAMA-2	8	80–11	30
WCRP_CHFP			
ARPEGE	17	79–07	11
CFSv2	18	81–07	7
CMAM	12	79–08	10
ECMWF-S4	3	81–10	15
GloSea5	1	96–09	12
JMA MRI	7	79–10	10
L85GlSea4	4	89–09	9
MIROC5	10	79–09	8
MPI-ECM-CR	2	82–11	9

Fig. 1 Correlation maps of June–July–August (JJA)-mean precipitation (*dotted*) and SST anomalies (*shaded*) with respect to the Korean precipitation index (JJA-mean precipitation anomalies averaged over 120–130°E, 35–40°N) for the 1979–2010 period. Correlation coefficient of 0.34 corresponds to statistical confidence at the 95% with 30 degrees of freedom based on the two-sided Student's *t* test

index. This weak correlation between Korean precipitation and the Indo-Pacific SST anomalies during the boreal summer is consistent with previous studies (Kang et al. 1999; Son et al. 2014).

However, there is a much clearer relationship between the Korean summer precipitation and Atlantic SST anomalies. In particular, the Korean precipitation index is highly correlated with the tropical Atlantic SST anomalies within 30°S–30°N (with a correlation coefficient >0.5). Associated with this higher SST correlation, positive correlations of precipitation anomalies are particularly observed over the off-equatorial northern Atlantic, indicating a strengthened Atlantic Inter-Tropical Convergence Zone (ITCZ). These results suggest a remote impact of the tropical Atlantic on Korean summer precipitation variability. This strong teleconnection between the tropical Atlantic SST and Korean precipitation is unique because previous studies show the weak relationship between the Korean precipitation and ENSO and therefore they presume that Korean summer precipitation is independent to the tropical SST anomalies. However, a clear correlation between the tropical Atlantic SST and Korean precipitation means that Korean precipitation during the boreal summer season can also be controlled by large-scale tropical SST forcing, which can be relatively well predicted (Ham et al. 2012, 2014).

To quantify the relationship between the tropical Atlantic SST and Korean precipitation, we define the Tropical Atlantic SST (TAtlSST) index as the SST anomalies averaged over 60°W–20°E, 30°S–30°N. A scatter diagram

between the JJA TAtlSST and the JJA Korean precipitation indices clearly shows a strong positive correlation (Fig. 2a; the correlation coefficient is 0.64, which is above the 99% confidence level). Note that this relationship is still significant over 99% confidence level when a station-based observations over the Korean peninsula is used. Also, it is worthwhile to note that this relationship becomes stronger after 1980s, implying that there is strong inter-decadal variation in the relationship between the TAtlSST and the Korean precipitation (not shown). The correlation coefficient between these indices is strongest during JJA compared to other seasons (Fig. 2b). We can also find significant correlations during the early and late summer [i.e., May–June–July (MJJ) and July–August–September (JAS)], indicating a robust relationship during the overall summer season. The correlation is relatively weak but significant at the 95% confidence level during the February–March–April (FMA) season. During the boreal fall and winter seasons, the relationship becomes insignificant.

To investigate the dynamical mechanism of the tropical Atlantic-Korea relationship, we made regression maps of SST, precipitation, and 850 hPa wind-vector anomalies using the TAtlSST index during JJA (Fig. 3). Associated with positive SST anomalies over the tropical Atlantic, we find increased precipitation in the northern tropical Atlantic (0°–20°N). In the equatorial Pacific, precipitation anomalies show a zonal gradient: negative over the central Pacific and positive over the Maritime Continent. This equatorial zonal gradient is consistent with weak La Niña-like SST anomalies. The equatorial easterly associated with this
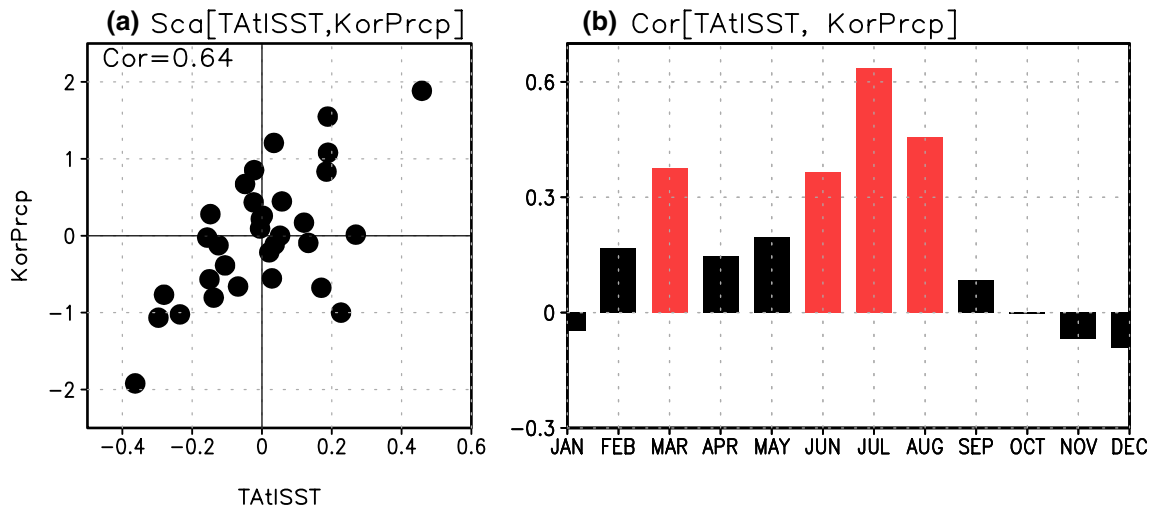
Fig. 2 a Scatter diagram between the tropical Atlantic SST and Korean precipitation indices during the JJA. **b** Correlation coefficients between the SST anomalies over the tropical Atlantic and Korean precipitation index as a function of each calendar month (3-month averages, plotted as the central month). The *red bars* indicate statistical significance at the 95% confidence level
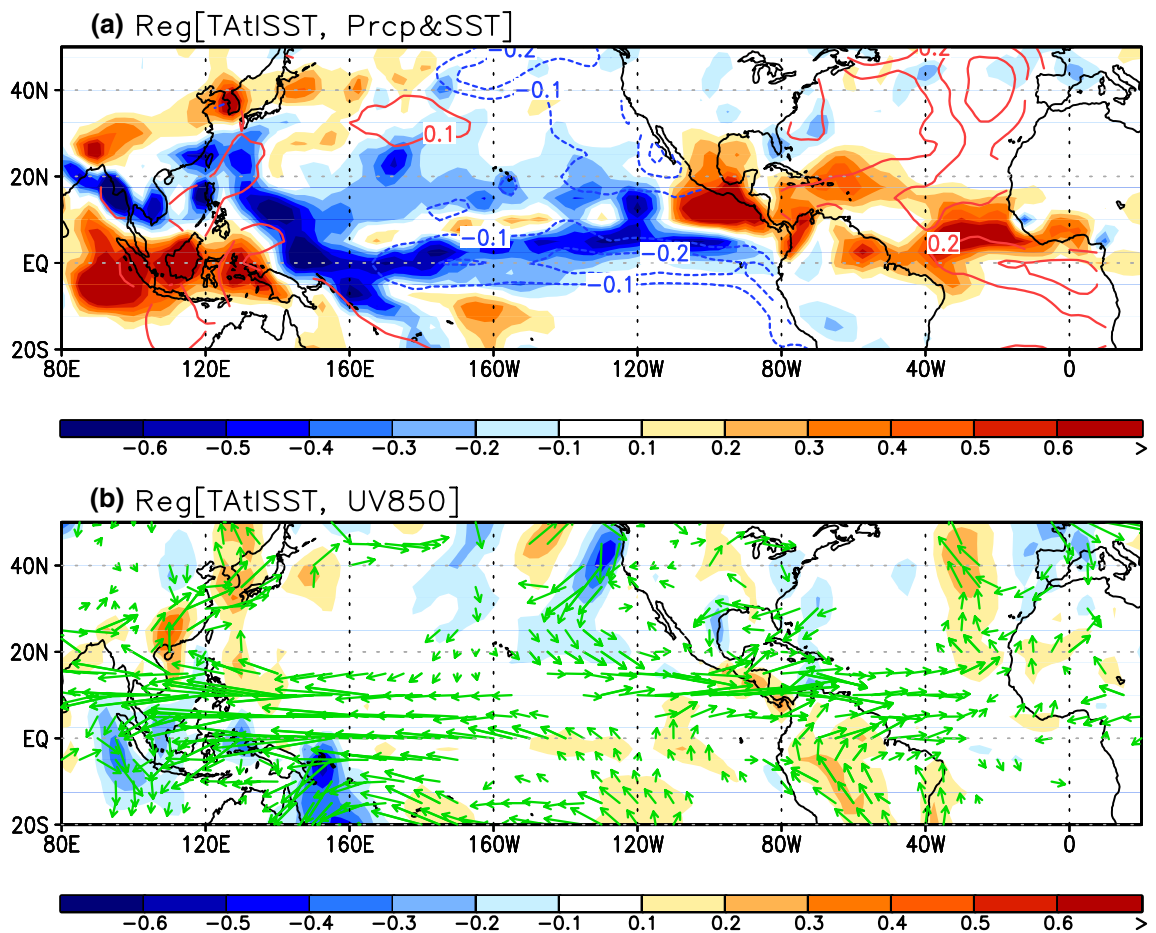

Fig. 3 Regression maps of SST (contour, °C), precipitation (*shaded*, mm/day), and horizontal wind anomalies at 850 hPa (*vector*, m/s) onto the TAtlSST index during JJA. The *color* in *panel b* denotes the 850 hPa meridional velocity (m/s)

weak La Nina SST anomalies is clear over the central-western Pacific. The negative precipitation anomalies over the western Pacific is extended to the subtropical region up to 25°N, as the easterly can generate the frictional low-level divergence over the subtropical western Pacific (Xie et al. 2009).

Cyclonic flow over the far eastern Pacific and anticyclonic flow over the northern western-central Pacific are clear (Ham et al. 2013a, b). As part of the anticyclonic flow over the northern western-central Pacific around 120°–180°E, 5°–40°N, low-level wind anomalies exhibit southerly along the east-coast of the China. Simultaneously, because the Korean peninsula is at the northwestern edge of this anticyclonic circulation, it is also dominated by low-level southwesterly. Then, southerly winds over the Korean peninsula may lead to positive meridional moisture advection, which can be directly linked to an increase in precipitation (Son et al. 2015), thus affirming the remote impact of the tropical Atlantic on Korean precipitation variability.

Two pathways from the Atlantic to the Korean peninsula are possible. First, the tropical Atlantic SST warming may induce negative precipitation anomalies over the equatorial western-central Pacific by modulating the zonal Walker Circulation (Hong et al. 2013; McGregor et al. 2014; Chikamoto et al. 2015; Li et al. 2015). Subsequently, the negative diabatic heating anomalies related to the reduced convective activities generates the anticyclonic flow over the subtropical western Pacific (120–180°E, 5–40°N), which induce positive moisture advection, resulting in an increase in precipitation over the Korean peninsula. The second pathway emphasizes a westward propagating atmospheric signal along the Inter-tropical Convergence Zone (ITCZ). Ham et al. (2013a) argued that the North Tropical Atlantic (NTA) warming can induces the low-level cyclonic flow over the eastern Pacific as a Gill-type response, then the northerly over the western-part of this cyclone generates the decreased precipitation over the off-equatorial central-eastern Pacific (see Fig. 1). Finally, the decreased precipitation, a proxy of the negative diabatic heating anomalies, induces the low-level anticyclonic flow over the subtropical western-central Pacific. In both pathways, the anticyclonic flow over the north-western Pacific (120–180°E, 5–40°N) is key to understand the Atlantic-Korea teleconnection pattern. The only differing views are as to whether this anticyclonic flow over the north-western Pacific is induced by the modulation of the zonal Walker Circulation (McGregor et al. 2014; Chikamoto et al. 2015) or by the westward propagating precipitation signal along the ITCZ (Ham et al. 2013a, b), and both pathways consistently argues that the reduced convective activities and resultant low-level anticyclonic flow over the north-western Pacific.

One can ask why the impact of large-scale Atlantic forcing on East Asia is localized. For example, the impact of the

TAtlSST on East Asia is clear over Korea but unclear over Japan. One of possible reasons is that the low-level southerly regressed onto the TAtlSST is systematically stronger over Korea, while it is weaker over Japan. As shown in the shading of Fig. 3b, the low-level wind regressed onto the TAtlSST index is between 0.3 and 0.4 m/s/K over Korea, while it is <0.1 m/s/K over Japan, even though there is southerly in both countries. This means that the intensity of the low-level southerly, which leads the moisture flux convergence and the resultant increase in precipitation, is systematically stronger over Korea. In addition to this, the southerly wind anomalies are closely linked with precipitation variability over Korean rather than Japan. In fact, a correlation coefficient between the meridonal wind at 850 hPa and the precipitation during JJA season is about 0.7 over the Korean peninsula but <0.3 over Japan.

As mentioned earlier, the overall positive relationship between the JJA Korean precipitation and JJA TAtlSST anomalies is quite robust. However, there are some exceptions, such that TAtlSST warming is not associated with the wet summer over the Korean peninsula. According to Fig. 2a, for example, there are few years for which the Korean precipitation anomaly is negative even with TAtlSST warming. To further investigate what disturbs the overall positive Tropical Atlantic SST-Korean precipitation relationship, Fig. 4 shows the composite SST, precipitation, and 850 hPa wind vector anomalies during TAtlSST warming with and without positive Korean precipitation. Note that TAtlSST warming is defined as years when the TAtlSST is >0.5 standard deviation (std), and the Korean precipitation anomalies is greater than 1 std. The number of each composite is four (i.e., 1987, 1996, 1998, and 2003 for KorPrcp >1 std with TAtlSST warming, and 1988, 1989, 2008, and 2010 for KorPrcp <1 std with TAtlSST warming). The systematic differences between two composite cases (i.e., the TAtlSST warming composite when the Korean precipitation is >1 std and TAtlSST warming composite when Korean precipitation is <1 std) could identify the tropical Atlantic SST impact on Korean precipitation more clearly.

In both cases, the equatorial easterly winds over the western Pacific is clearly shown. In addition, the precipitation anomalies tend to be positive over the Maritime Continent but negative over the western Pacific. This means that the equatorial Pacific precipitation response to the TAtlSST warming is quite robust. However, the peak locations of negative precipitation anomalies over the western Pacific are different between the two cases, which implies that the detailed precipitation structure over the western Pacific is key to controlling the strength of the tropical Atlantic-Korea connection. When the negative precipitation anomalies over the western Pacific are located over the subtropical area between 10–25°N,
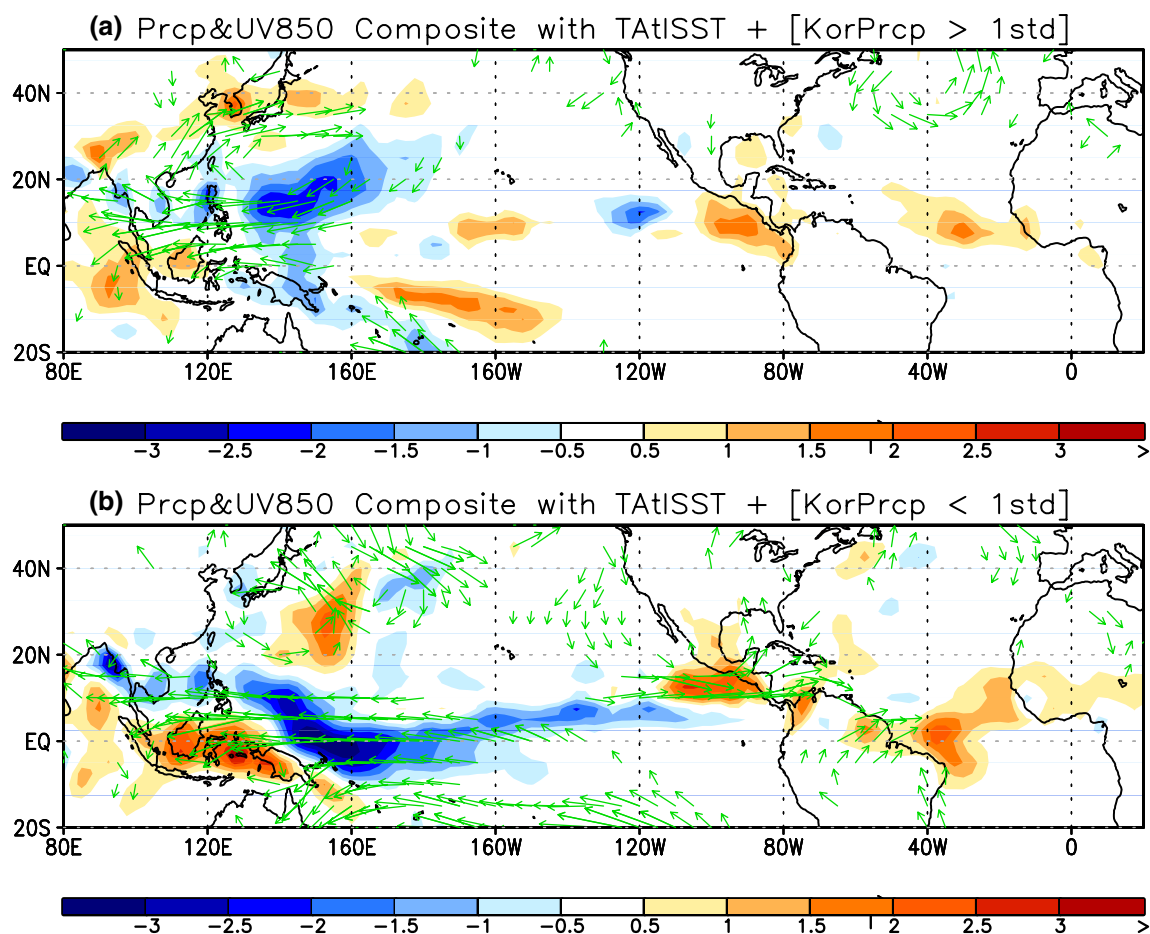
Fig. 4 Composite maps of precipitation (*shaded*, mm/day) and horizontal wind anomalies at 850 hPa (*vector*, m/s) during the warm phase of the TAtlSST index (<0.5 std) with, **a** stronger and **b** weaker Korean precipitation (i.e., the Korean precipitation index is larger and smaller than 1 std, respectively)

TAtlSST warming can lead to an increase in Korean precipitation (Fig. 4a). As a Gill-type response due to this negative precipitation anomaly, the anticyclonic flow is shown southeast of the Korean peninsula, which leads to southerly winds over Korea. Also, the La Nina-like response over the equatorial Pacific is significantly weakened, which is consistent with a weak relationship between ENSO and Korean precipitation variability as reported by previous studies. On the other hand, in the case when there are negative precipitation anomalies over the equatorial western Pacific (Fig. 4b), the precipitation anomalies over the Korean peninsula are unclear or slightly negative. As discussed in Sect. "6" later, this is a common feature during a La Niña year that is linked to the weak relationship between ENSO and Korean precipitation during boreal summer season.

4 Partial assimilation experiments using the MIROC3.2 coupled model

In this section, the effect of the tropical Atlantic SST on Korean precipitation during the boreal summer will be supported by the partial assimilation experiments using the MIROC3.2 coupled model (Chikamoto et al. 2015). The partial assimilation experiments denote a long-term integration of the coupled model by assimilating observed temperature and salinity anomalies only over the Atlantic (50°S–60°N over the Atlantic, ATL experiment) or the tropical Pacific between 10°S–10°N (eqPAC experiment). In the ATL experiment, global climate variability that follows the observed fluctuations clearly originates from the Atlantic variability.

To examine how well the assimilation run captures the observed precipitation variability, Fig. 5 shows the correlation skill between the observed and ensemble-mean precipitation anomalies during the JJA season in the ATL and eqPAC experiments from 1979 to 2009. In the ATL
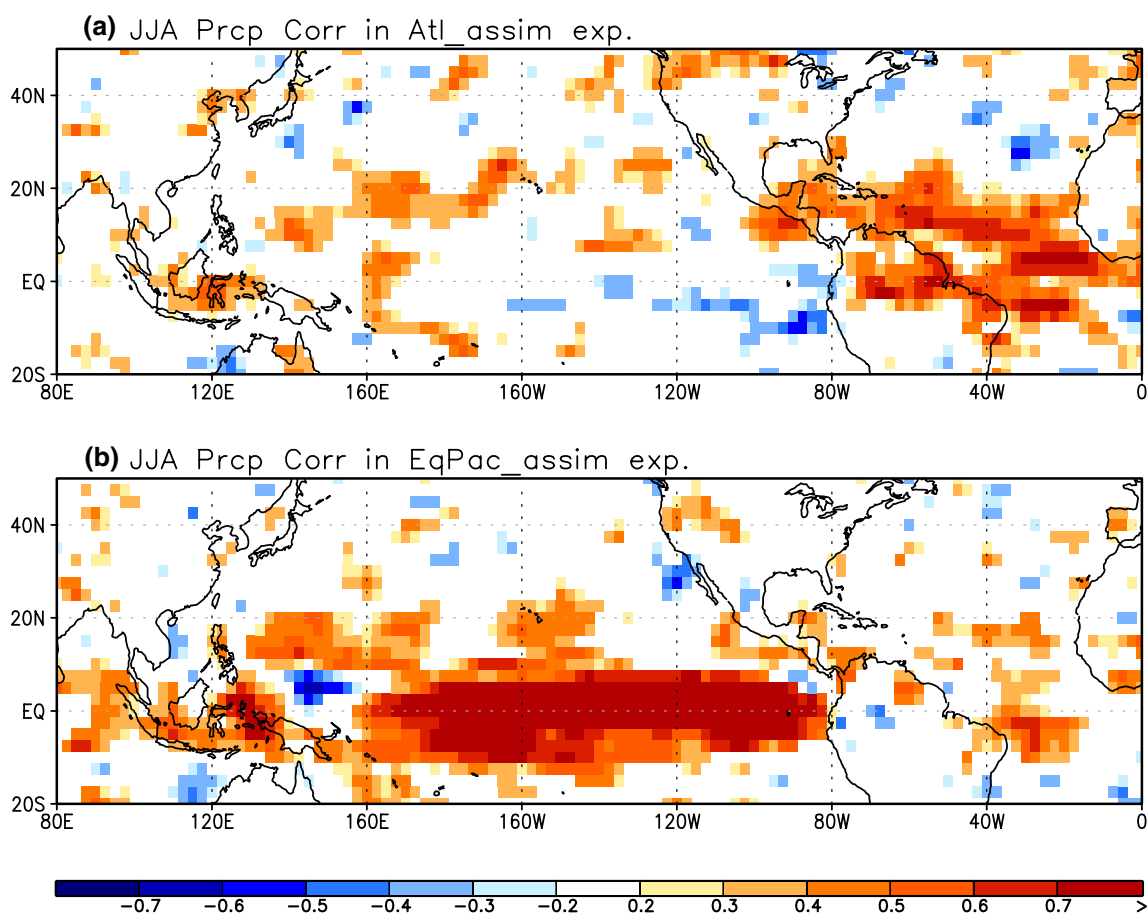
Fig. 5 Correlation skill between the observation and 10-member-ensemble averaged precipitation anomalies during the JJA season in the, **a** Atlantic-partial-assimilation and **b** equatorial Pacific-partial-assimilation experiments. The correlation value over 90% confidence level is only *shaded*

experiment, it is quite expected that the correlation skill is systematically higher over the Atlantic compared to other areas due to the observed oceanic information (Fig. 5a). In particular, the correlation over the tropical Atlantic is higher than that over the mid-latitudes, which is evidence that the precipitation anomalies over the tropical Atlantic can be strongly controlled by local SST anomalies. Outside of the Atlantic, there are also several regions with positive correlation coefficients through the atmospheric teleconnection patterns originating from the Atlantic. We can find some positive correlations over the Maritime Continent, tropical and subtropical western Pacific, and the Korean peninsula. The correlation coefficient over Korea (i.e., precipitation anomalies averaged over 120–130°E, 35–40°N) is 0.34, which is significant over 95% confidence level. This clearly denotes that the observed Korean precipitation is simulated in the climate model to some extent through Atlantic-induced teleconnections. Note that this correlation coefficient is high as the correlation skill of the precipitation anomalies over Korea predicted by a state-of-the-art

seasonal forecast system. We will discuss this point in more detail in the next section.

In the eqPAC experiment, the correlation coefficient of precipitation anomalies over the tropical Pacific is superior to that of other regions due to the prescribed oceanic information. In particular, the correlation coefficient over the equatorial central-eastern Pacific exceeds 0.7, which implies successful simulation of the observed ENSO-related precipitation variability. In addition to the equatorial central-eastern Pacific, the correlation coefficients over the Maritime Continent and the off-equatorial western Pacific between 10–20°N are also systematically higher than other areas. However, it is interesting that the correlation coefficient over the Korean peninsula (0.17) is very weak.

The robust contribution of Atlantic Ocean to JJA Korean precipitation is also illustrated by a probability distribution function (PDF) of the correlation coefficient between observed and the simulated Korean precipitations in each partial experiment (Fig. 6). To obtain the PDF of the correlation coefficient, we utilized the bootstrap method (Efron

Fig. 6 The probability distribution function (PDF) of the correlation coefficient between the observed and simulated JJA Korean precipitation in the Atlantic-partial-assimilation (*red*) and equatorial Pacific-partial-assimilation (*black*) experiments. The PDF of the correlation is based on 30 randomly selected target years among all hindcast years, allowing overlap of the selected years. The correlation coefficients of the all-member-ensemble average value in the Atlantic-partial-assimilation and tropical Pacific-partial-assimilation are shown as the *red* and *black* vertical lines, respectively
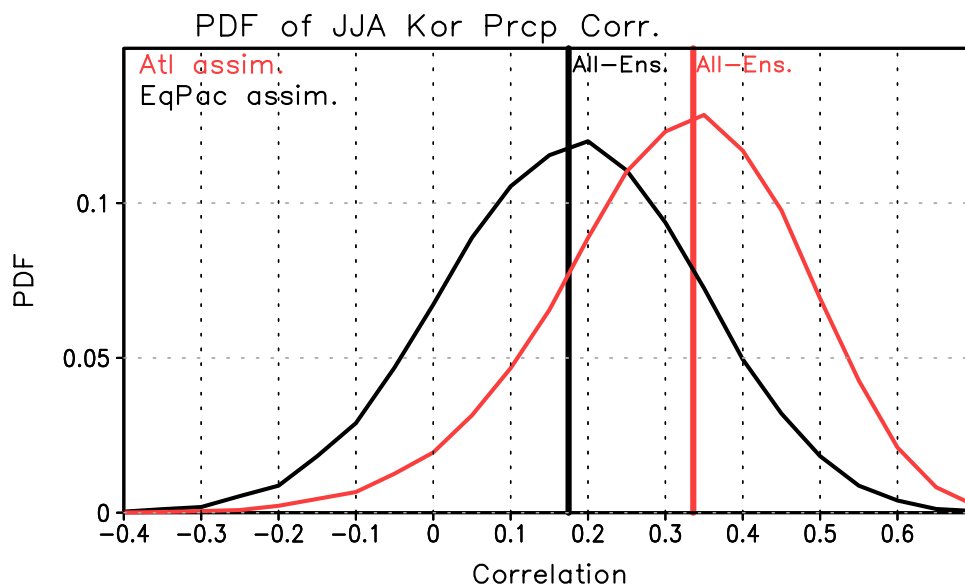
1982; Yeh et al. 2009), which randomly selects 30 target years among all hindcast years allowing overlap and then constructs an ensemble-averaged predicted value to calculate the correlation skill for each partial experiment. This process is repeated 10,000 times to obtain the PDF. Note that the correlation coefficient with all-member-ensembles is also denoted as the red and black line. In the eqPAC experiment, the PDF shows its peak probability at a correlation coefficient of 0.2 with a 5% probability is around correlation of −0.05 to 0.4. In the ATL experiment, the PDF of the correlation shows that the Korean precipitation variability is better simulated than the eqPAC experiment. For example, the peak probability of the correlation coefficient is 0.35, and the 5% probability in the Atlantic-assimilation experiment occurs around the correlation of 0.1 and 0.55, which is systematically higher than that in the eqPAC experiment. Consistently, the correlation coefficients of the 10-member-ensembles are 0.17 in the eqPAC experiment but 0.34 in the ATL experiment. This comparison supports our observational analysis that the Atlantic SST variability, rather than that of the tropical Pacific, plays an important role in simulating the observed Korean summer precipitation variability.

To examine the impacts of tropical Pacific and Atlantic SST on Korean precipitation variability, we made composite precipitation maps of the observation data, ATL experiment, and eqPAC experiment when the JJA Korean precipitation anomalies in each experiment were greater than one standard deviation (Fig. 7). In the observation, the positive precipitation anomalies over Korea during the boreal summer season are related to negative precipitation anomalies over the subtropical western Pacific and positive precipitation anomalies over the Maritime Continent. In addition,

positive precipitation anomalies over the equatorial Atlantic are clearly shown. Those features are captured well in the ATL experiment. For example, we can find the negative precipitation anomalies over the off-equatorial western Pacific, which is similar to the observed pattern when the TAtlSST warming co-occurs with the positive Korean precipitation anomalies (i.e., Fig. 4a). Additionally, the positive precipitation anomalies over the Maritime Continent and the equatorial Atlantic are also well simulated. The La Niña-like signal over the equatorial eastern Pacific might be due to the Atlantic-induced equatorial easterly winds over the equatorial western Pacific.

However, the composited precipitation anomalies of the eqPAC experiment shows a different pattern compared to the observed. For example, the increase in Korean precipitation accompanies the positive precipitation anomalies over the equatorial eastern Pacific and the negative anomalies over the western Maritime Continent, which is inconsistent with the observations. This means the Korean precipitation variability in the eqPAC experiment is related to that over the equatorial eastern Pacific. And, this excessive relationship between the equatorial eastern Pacific and the Korean precipitation can be the reason of low-correlation skill as this relationship was not clear in the observation.

Lastly, to examine the detailed structure of the simulated teleconnection patterns induced by the tropical Atlantic SST anomalies in the ATL experiment, Fig. 8 shows the regression maps of ensemble-mean anomalies for SST, precipitation, and wind vectors at 850 hPa associated with the TAtlSST index in the ATL experiment. The precipitation increase over the tropical Atlantic is shown due to the local SST increase. In addition, increased precipitation over the Maritime Continent and
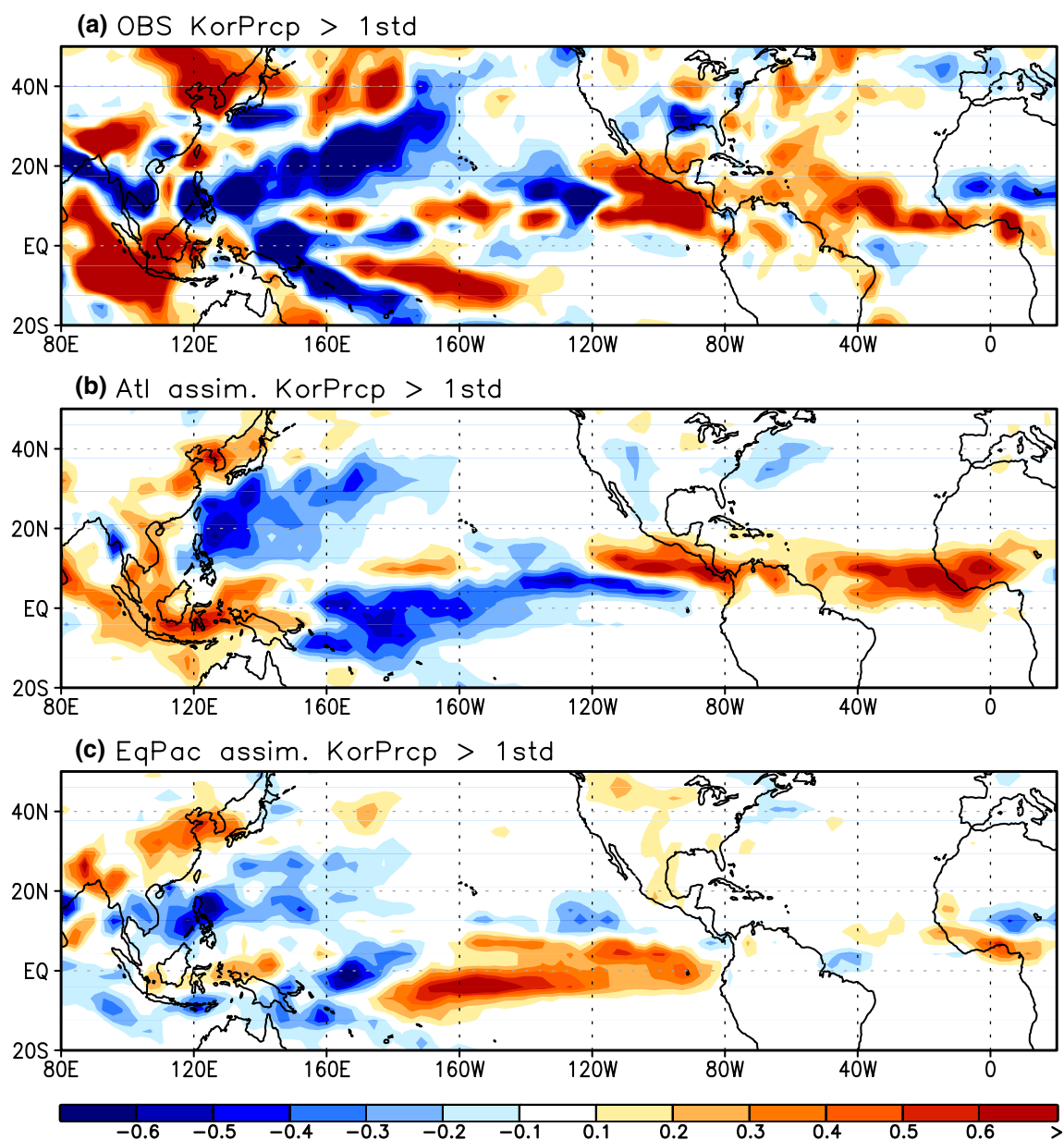
Fig. 7 The composite JJA precipitation maps of the, **a** observation, **b** Atlantic-partial-assimilation experiment, and **c** equatorial Pacific-partial-assimilation experiment

decreased precipitation over the subtropical western Pacific are also clear, which is consistent with the observations. Along with the negative precipitation anomalies over the subtropical western Pacific, the anticyclonic circulation over the western North Pacific clearly leads to southerly winds over the Korean peninsula, which result in increased precipitation there. This means that the TAtlSST warming affects the negative precipitation over the subtropical western Pacific, which, in turn, induces the southerly over Korea and the enhanced precipitation through the Atlantic-Korean atmospheric teleconnection as simulated by the ATL experiment.

Nevertheless, there are still some discrepancies in the tropical Atlantic impacts between the observations and the Atlantic partial assimilation experiment (Figs. 3, 8). For example, whereas the observed TAtlSST warming is associated with weak negative precipitation anomalies over the equatorial central-eastern Pacific, the simulated TAtlSST warming exhibits weak positive precipitation anomalies. This difference is mainly due to the equatorial SST conditions: weak La Niña signals in the observation but weak El Niño in the ATL experiment. In addition to the equatorial Pacific SST patterns, the surface easterly over the equatorial western Pacific is shifted too far to the west in the ATL
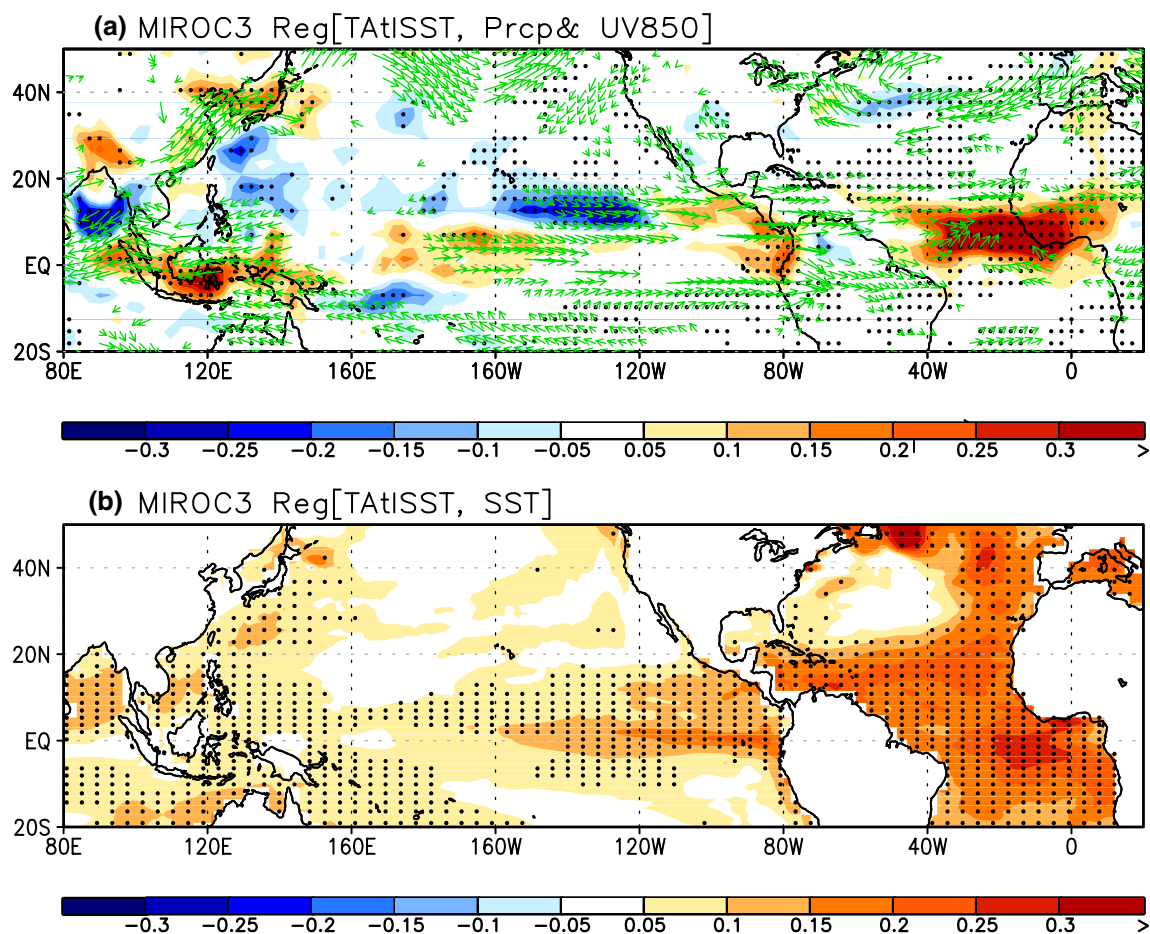
Fig. 8 Regression maps of ensemble-mean anomalies for, **a** precipitation (*shaded*) and wind vectors at 850 hPa (*vector*) and **b** SST with the TAtlSST index in the Atlantic-assimilation simulation

experiment compared to the observations, which weakens the upwelling oceanic Kelvin waves to the lead the La Nina signal. It is interesting to note that impact of the tropical Atlantic on Korean precipitation is simulated well in the ATL experiment even though the SST anomalies over the equatorial central-eastern Pacific is opposite between the observations and the model simulation, implying that the response of the equatorial eastern Pacific to the TAtlSST anomalies plays a minor role for linking the tropical Atlantic SST to Korean precipitation. Instead, the precipitation response over the off-equatorial western Pacific is likely to be crucial to determine the TAtlSST-related response over the Korea.

One can be curious how the inevitable model error, including the errors simulating teleconnection between the tropics and the mid-latitude. For example, the negative precipitation response to the tropical Atlantic SST over the western Pacific is too weak in the ATL experiment (Fig. 8) compared to the observations (Fig. 3). Also, the response of the equatorial eastern Pacific to the Atlantic SST anomalies is even opposite as mentioned above. However, at least,

it is found that the model simulation captures the response over the western Pacific by given Atlantic diabatic heating and the observed Korean precipitation variability to some extent (Fig. 6). This means that the MIROC3.2m at least has ability to simulate the teleconnection pattern between the tropical Atlantic and the Korean precipitation. Further studies using multi-model approach will be helpful to obtain more robust relationship of Atlantic-Korean teleconnection.

5 Hindcast experiments

In this section, the effect of tropical Atlantic SST on Korean precipitation is investigated using 20 sets of hindcast experiments using state-of-the-art atmosphere–ocean coupled GCMs. To quantify the relationship between the TAtlSST and Korean precipitation in the hindcast experiments, Fig. 9a shows the correlation coefficient between the TAtlSST and Korean precipitation indices during the JJA season. Among the 20 sets of hindcast experiments,
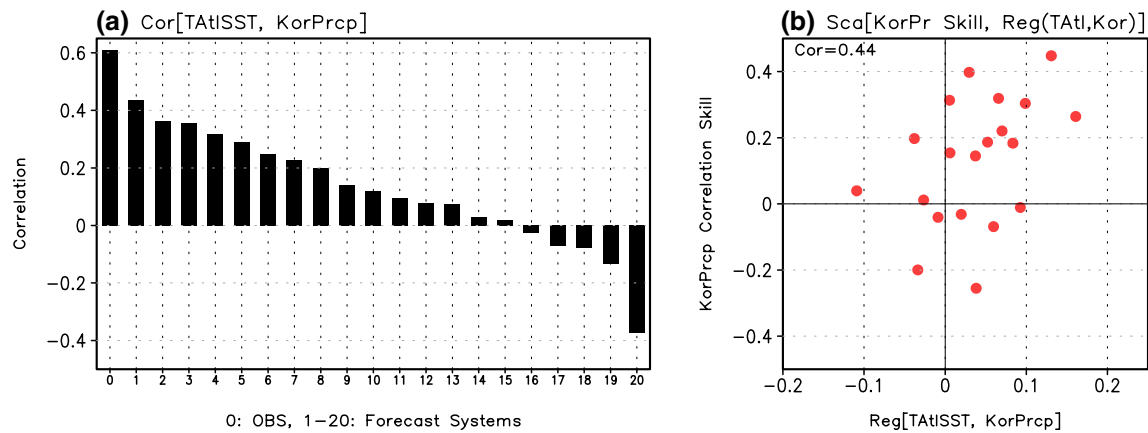
Fig. 9 a The correlation coefficient between TAtlSST and Korean precipitation during the JJA season in each hindcast experiment. *Bar graph* with respect to the number 0 on the *x-axis* denotes the correlation between observed TAtlSST and Korean precipitation. Correlations between model-produced TAtlSST and Korean precipitation are shown with respect to the number 1 through 20, which represents the individual hindcast experiments. **b** A scatter diagram of the forecast skill of Korean precipitation and the regression coefficients between TAtlSST and Korean precipitation indices during the JJA season

15 models simulate a positive TAtlSST-Korean precipitation relationship, which is consistent with the observation, while five of them simulate a negative relationship. The observed correlation is about 0.6, and all hindcast experiments underestimate this observed relationship.

Figure 9b shows a scatter diagram between the forecast skill of Korean precipitation and the regression coefficient between the TAtlSST and Korean precipitation during the JJA season. The correlation skill of Korean precipitation during the JJA season varies from −0.25 to 0.44. The best performance model (i.e. correlation skill of 0.44) well simulates the overall teleconnection pattern associated with the TAtlSST index (not shown). For example, the pattern correlation between the observed and the simulated TAtlSST-related precipitation anomalies over the tropical regions (80°E–0°W, 10°S–25°N) is 0.74 for the best performance model, while that is only 0.42 in the worst performance model. Also, note that the third hindcast correlation skill among all forecast systems is 0.32, which is similar to the correlation skill of Korean precipitation in the Atlantic partial-assimilation experiments.

It is clear that there is a positive linkage between the forecast skill of Korean precipitation and the tropical Atlantic-Korea relationship. This implies that the models, which simulate a stronger tropical Atlantic-Korea relationship, tend to be better in predicting Korean precipitation than the others. As all hindcast experiments underestimate the tropical Atlantic-Korea relationship, this implies that a model with a realistic tropical Atlantic-Korea relationship in the hindcast experiments have skillful prediction of Korean precipitation during the boreal summer season. Conversely, a model with low prediction skill of Korean precipitation has a systematically weaker tropical Atlantic-Korea relationship than the observed.

To further emphasize the relationship between the tropical Atlantic SST anomalies and the predictive skill of Korean precipitation during the boreal summer season, a simple linear regression model is formulated using the predicted TAtlSST as a single predictor. That is, the predictor variable of the statistical model is the forecasted JJA TAtlSST anomaly using a dynamical forecast system, and the predictand variable is the JJA Korean precipitation anomaly. The statistical relationship of the linear regression model is calculated using the predicted TAtlSST and the observed Korean precipitation data. To assess the real prediction skill, we applied the one-leave-out cross validation method by excluding the observed value of the target year during the statistical training. Figure 10 shows a scatter diagram between the correlation skill of the JJA Korean precipitation produced by the dynamical forecast system and the correlation skill of statistically predicted JJA Korean precipitation using linear regression models. It is surprising that the correlation skill of the statistically predicted Korean precipitation varies between 0.02 and 0.67, which is generally higher than the original model output. This denotes that the tropical Atlantic SST can be successfully utilized as a predictor for Korean precipitation by improving their relationship. In addition, the TAtlSST-induced teleconnection pattern has not yet been successfully simulated in the operational seasonal forecast system, and there is much room for improvement of current seasonal prediction skill over Korea through a successful simulation for the tropics-induced teleconnection patterns.
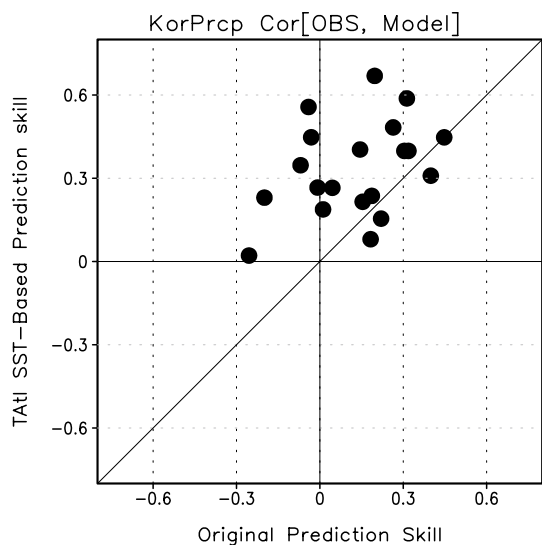
Fig. 10 A scatter diagram of the correlation skill of the JJA Korean precipitation produced by the dynamical forecast system (*x-axis*) and the correlation skill of statistically predicted JJA Korean precipitation using linear regression models (*y-axis*)

6 Summary and discussions

This study shows that warming of the tropical Atlantic SST contributes to increasing precipitation over the Korean peninsula during the boreal summer season. The correlation coefficient between the JJA TAtlSST index (i.e., SST anomalies averaged over 60°W–20°E, 30°S–30°N) and the JJA Korean precipitation (i.e., precipitation anomalies over 120–130°E, 35–40°N) for the 1979–2010 period is 0.64, which is statistically significant at the 99% confidence level. Tropical Atlantic SST warming can induce surface easterly wind anomalies over the Maritime Continent through modulation of the zonal Walker Circulation, generating low-level wind divergence and suppressed precipitation over the subtropical western Pacific. As a Gill-type response, the decreased precipitation anomalies over the subtropical western Pacific induce anticyclonic circulation over the Philippine Sea, which leads to anomalous surface southerly over the Korean peninsula. This low-level southerly effectively transports wet air from the lower latitudes to the Korean peninsula, therefore contributing to the enhanced precipitation.

Observational findings are supported by the partial assimilation experiment using the MIROC3.2m coupled climate model. Even though the observed ocean temperature anomalies are prescribed only over the Atlantic (50°S–60°N), the model simulation captures the observed precipitation variability over the Maritime Continent, tropical western Pacific, and Korean peninsula to some extent, which support the observed Atlantic-induced teleconnection patterns. Consistent with the observational analysis, the model experiment also demonstrates that tropical Atlantic SST warming accompanies the low-level southerly winds over the Korean peninsula as a part of anticyclonic flow over the Philippine Sea. These observational and model results indicate a robust connection between tropical Atlantic SST warming and enhanced Korean summer precipitation.

The impact of tropical Atlantic SST anomalies on Korean precipitation anomalies is shown using the 20 sets of hindcast experiments that participated in APCC MME and WCRP CHFP. It is likely that this tropical Atlantic-Korea relationship plays some roles in the prediction skill of Korean precipitation during the boreal summer season. That is, models with a stronger relationship between TAtlSST and Korean precipitation have the higher predictive skills of Korean precipitation. This implies that TAtlSST is a critical predictor of Korean precipitation. To further emphasize this point, a linear regression model was formulated using predicted TAtlSST anomalies as the single predictor. The predicted Korean precipitation using the linear regression model exhibits superior forecast skills to the original Korean precipitation anomalies produced in the hindcast experiments. This indicates that seasonal forecast skill of Korean precipitation in the current operational system would be enhanced by improving the TAtlSST-induced teleconnection.

One may wonder why the relationship between the ENSO and Korean precipitation is not clear, even though the atmospheric response over the western Pacific during the ENSO is known to be stronger than that during TAtlSST warming. To examine this point, Fig. 11 shows the precipitation, SST, and the 850 hPa wind vector anomalies regressed onto the Niño3.4 index (i.e., SST anomalies over the 170–120°W, 5°S–5°N). Note that we multiplied the regressed maps by negative one to plot the response during the La Niña for easy comparison with the regression map of TAtlSST warming (Fig. 3). At first glance, the spatial distribution of the negative precipitation response over the tropical Pacific between 20°S–20°N during La Niña is similar to that during TAtlSST warming. In addition to the response over the tropical Pacific, the overall precipitation increase over the Maritime Continent and the tropical Atlantic is also similar. However, over the subtropical western Pacific between 20–30°N, the precipitation anomalies during La Niña exhibits positive values, while those during TAtlSST warming are still negative.

Similarly, the low-level wind anomalies during La Niña are also quite similar to those during TAtlSST warming within 20°S–20°N, while those over the subtropical western Pacific north of 20°N are quite different. For example, cyclonic flow is dominant over the subtropical western Pacific during La Niña, while anticyclonic flow is robust during TAtlSST warming. Therefore, during La Niña, the
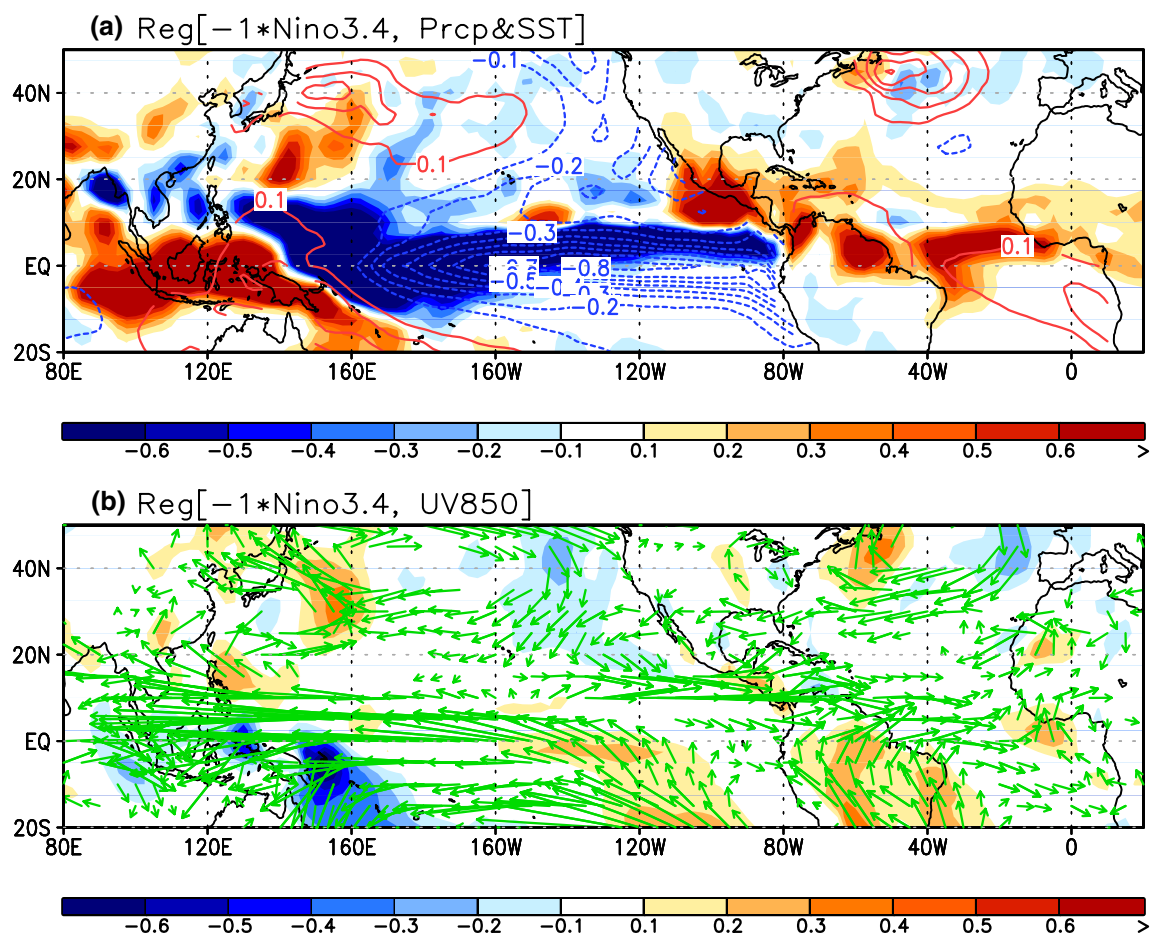
Fig. 11 Regression maps of **a** SST (*contour*), precipitation (*shaded*), and **b** horizontal (*vector*) and meridional wind anomalies at 850 hPa (*shaded*) with respect to the Niño3.4 index during the JJA season. Note that we multiplied the regressed map by negative one to *plot* the response during La Niña

low-level easterly is clear over the Korean peninsula, while the southerly wind is significant during TAtlSST warming. Because the southerly is not clear over the Korean peninsula during the La Niña, there may be weak moisture advection, therefore, the precipitation anomalies over the Korean peninsula are not significant during La Niña. The Linear Baroclinic Model (LBM) experiment confirms this point that the positive diabatic heating over the subtropical western Pacific between 20–30°N is responsible for the easterly wind over Korea, as a part of the Gill-type cyclonic response over the south of the Korean peninsula (not shown). This is distinguished from the robust negative precipitation anomalies over the subtropical western Pacific during TAtlSST warming, which lead to southerly winds over Korea as a part of the anticyclonic flow over the western Pacific.

Based on this study, the following issues are worth investigating in future studies to broaden our understanding of the role of tropical Atlantic SST on Korean climate variability. (1) Is there decadal modulation of the relationship between the TAtlSST and Korean precipitation? If there is, is it connected to global warming? (2) What determines the variation in the relationship between the TAtlSST and Korean precipitation in climate models? How does it affect the seasonal forecast skill over Korea? (3) What is the impact of TAtlSST warming on the East Asian climate as a whole?

Many previous studies focus on the tropical Pacific SST impacts on climate variability over China (Ding and Chan 2005) and Japan (Kosaka and Nakamura 2006) but not over Korea because no clear connection between the tropical SST variability and Korean precipitation during the boreal summer season was reported in previous studies. Therefore, we hope that the clear relationship between the tropical Atlantic SST and Korean precipitation in this study will encourage further research on climate variability over the Korean peninsula. Furthermore, we hope that this will lead to innovative improvement of the seasonal forecast skill over Korea during the boreal summer season.

References

Adler RF et al (2003) The version-2 global precipitation climatology project (GPCP) monthly precipitation analysis (1979-present). J hydrometeorol 4:1147–1167

Ahmed T & Kucharski F (2012) The Influence of Indian Ocean Warming and Soil Moisture Change on the Asian Summer Monsoon

Ahn J, Ryu J, Cho E, Park J, Ryoo S (1997) A study of correlations between air-temperature and precipitation in Korea and SST over the tropical Pacific. J Korean Meteorol Soc 33:487–495

Berrisford P et al (2011) Atmospheric conservation properties in ERA-Interim. Q J R Meteorolog Soc 137:1381–1399

Cha E, Jhun J, Chung H (1999) A study on characteristics of climate in South Korea for El Niño/La Niña years. J Korean Meteorol Soc 35:98–117

Chang C-P (2004) East Asian Monsoon, vol. 2. World Scientific, Hackensack

Chang C, Zhang Y, Li T (2000) Interannual and interdecadal variations of the East Asian summer monsoon and tropical Pacific SSTs. Part I: roles of the subtropical ridge. J Clim 13:4310–4325

Chikamoto Y, Kimoto M, Watanabe M, Ishii M, Mochizuki T (2012) Relationship between the Pacific and Atlantic stepwise climate change during the 1990s. Geophys Res Lett 39:L21710

Chikamoto Y et al (2015) Skilful multi-year predictions of tropical trans-basin climate variability. Nat Commun. doi:10.1038/ncomms7869

Chikamoto Y, Modhizuki T, Timmermann A, Kimoto M, & Watanabem M (2016) Potential tropical Atlantic impacts on Pacfic decadal climate trends. Geophys Res Lett 43(13):7143–7151

Choi JW, Cha Y, & Kim HD (2016) Interdecadal variation of precipitation days in August in the Korean Peninsula. Dyn Atmos Oceans. doi:10.1016/j.dynatmoce.2016

Developers KM (2004) KI coupled GCM (MIROC) description. *KI Technical Report*, 1.

Ding Y (1992) Effects of Qinghai-Xizang (Tibetan) Plateau on the circulation features over the plateau and its surrounding areas. Adv Atmos Sci 9:112–130

Ding Y (1994) Monsoons over China Kluwer Academic Publisher Dordrecht Boston London 419

Ding Y, & Chan JCL (2005) The East Asian summer monsoon: an overview. Meteor Atmos Phys 89:177–182

Ding YH, Li CY, & Liu YJ (2004) Overview of the South China Seas monsoon experiment. Adv Atmos Sci 21:343–360

Efron B (1982) The Jackknife, the Bootstrap, and Other Resampling Plans 1–92. Society for Industrial and Applied Mathematics, philadelphia

Gill AE (1980) Some simple solutions for heat-induced tropical circulation. Q J R Meteorolog Soc 106:447–462

Ham Y-G, Kang I-S, Kim D, Kug J-S (2012) El-Nino Southern Oscillation simulated and predicted in SNU coupled GCMs. ClDy 38:2227–2242

Ham Y-G, Kug J-S, Park J-Y, Jin F-F (2013a) Sea surface temperature in the north tropical Atlantic as a trigger for El Niño/Southern Oscillation events. Nat Geosci 6:112–116

Ham YG, Kug JS, Park JY (2013b) Two distinct roles of Atlantic SSTs in ENSO variability: north tropical Atlantic SST and Atlantic Niño. GeoRL 40:4012–4017

Ham Y-G, Schubert SD, & Rienecker MM (2014) An assessment of the skill of GEOS-5 seasonal forecasts

Ham Y-G, Kug J-S, Yeh S-W, Kwon M (2016) Impact of two distinct teleconnection patterns induced by western Central Pacific SST anomalies on Korean temperature variability during the early boreal summer. J Clim 29:743–759

Ho C-H, Lee J-Y, Ahn M-H, Lee H-S (2003) A sudden change in summer rainfall characteristics in Korea during the late 1970s. Int J Climatol 23:117–128

Hong S, Kang I-S, Choi I, Ham Y-G (2013) Climate responses in the tropical Pacific associated with Atlantic warming in recent decades. Asia Pac J Atmos Sci 49:209–217

Huang R, Sun F (1992) Impacts of the tropical western Pacific on the East Asian summer monsoon. J Meteor Soc Jpn 70:243–256

Huang R, Wu Y (1989) The influence of ENSO on the summer climate change in China and its mechanism. Adv Atmos Sci 6:21–32

Ishii M, Kimoto M (2009) Reevaluation of historical ocean heat content variations with time-varying XBT and MBT depth bias corrections. J Oceanogr 65(3):287–299

Jeong H-I et al (2012) Assessment of the APCC coupled MME suite in predicting the distinctive climate impacts of two flavors of ENSO during boreal winter. Clim Dyn 39:475–493

Kang I-S (1998) Relationship between El-Nino and Korean climate variability. J Korean Meteorol Soc 34:390–396

Kang I, An S, & Jin F (1999) Roles of thermal advective processes in the SST anomalies of ENSO appearing in NCEP ocean assimilation data. Submitted to. *ClDy*.

Keenlyside NS, Ding H, Latif M (2013) Potential of equatorial Atlantic variability to enhance El Niño prediction. Geophys Res Lett 40:2278–2283

Kim C-S, & Shu M-S (2008) Change-point in the recent (1976–2005) precipitation over South Korea. Atmosphere 18:110–120

Kim J-H., Ho C-H, Lee M-H, Jeong J-H, & Chen D (2006) Large increase in heavy rainfall associated with tropical cyclone landfalls in Korea after the late 1970s. Geophys Res Lett 33:L18706

Kosaka Y, Nakamura H (2006) Structure and dynamics of the summertime Pacific–Japan teleconnection pattern. Q J R Meteorolog Soc 132:2009–2030

Kosaka Y, Xie S-P, Lau N-C, Vecchi GA (2013) Origin of seasonal predictability for summer climate over the Northwestern Pacific. Proc Nat Acad Sci USA 110:7574–7579

Kucharski F, Bracco A, Yoo J, & Molteni F (2008) Atlantic forced component of the Indian monsoon interannual variability. Geophys Res Lett 35.

Kwon, M, Jhun BJG, Wang SI, & Kug JS (2005) Decadal change in relationship between east Asian and WNP summer monsoons. Geophys Res Lett. doi:10.1029/2005GL023026

Lau K, Weng H, & Einaudi F (2001) Recurrent Interannual Climate Modes and Teleconnection Linking North America Warm Season Precipitation Anomalies to Asia Summer Monsoon Variability.

Lau K, Kim M, Kim K (2006) Asian summer monsoon anomalies induced by aerosol direct forcing: the role of the Tibetan Plateau. Clim Dyn 26:855–864

Li X, Xie S-P, Gille ST, & Yoo C (2015) Atlantic-induced pan-tropical climate change over the past three decades. Nat Clim Change. doi:10.1038/nclimate2840

Liu Y, & Ding YH (1992) Influence of El Nin~o on weather and Climate in China. Acta Meteor Sin 6:117–131

Luo H, Yanai M (1984) The large-scale circulation and heat sources over the Tibetan Plateau and surrounding areas during the

early summer of 1979. Part II: heat and moisture budgets. Mon Weather Rev 112:966–989

McGregor S, Timmermann A, Stuecker MF, England MH, Merrifield M, Jin F-F, Chikamoto Y (2014) Recent Walker circulation strengthening and Pacific cooling amplified by Atlantic warming. Nat Clim Change 4:888–892

Murakami T, Ding Y-H (1982) Wind and temperature changes over Eurasia during the early summer of 1979. J Meteor Soc Jpn 60:183–196

Nakicenovic N et al (2000) Special report on emissions scenarios: a special report of Working Group III of the Intergovernmental Panel on Climate Change (No. PNNL-SA-39650). Pacific Northwest National Laboratory, Richland, WA (US), Environmental Molecular Sciences Laboratory (US)

Ninomiya K, Akiyama T (1992) Multi-scale features of Baiu, the summer monsoon over Japan and East Asia. J Meteorol Soc Jpn 70(1B):467–495

Osman M, Vera C, Doblas-Reyes F, 2015: Predictability of the tropospheric circulation in the Southern Hemisphere from CHFP models. Clim Dyn, 1–12

Polo I, Martin-Rey M, Rodriguez-Fonseca B, Kucharski F, Mechoso CR (2015) Processes in the Pacific La Niña onset triggered by the Atlantic Niño. ClDy 44:115–131

Rodríguez-Fonseca B, Polo I, García-Serrano J, Losada T, Mohino E, Mechoso CR, & Kucharski F (2009) Are Atlantic Niños enhancing Pacific ENSO events in recent decades? Geophys Res Lett. doi:10.1029/2009GL040048.

Seo K-H, Son J-H, & Lee J-Y (2011) A new look at Changma. Atmos Korean Meteor Soc 21:109–121

Shen S, Lau K-M (1995) Biennial oscillation associated with the East Asian summer monsoon and tropical sea surface temperatures. J Meteorol Soc Jpn 73:105–124

Smith TM, Reynolds RW, Peterson TC, Lawrimore J (2008) Improvements to NOAA's historical merged land–ocean surface temperature analysis (1880–2006). J Clim 21:2283–2296

Son H-Y, Park J-Y, Kug J-S, Yoo J, Kim C-H (2014) Winter precipitation variability over Korean Peninsula associated with ENSO. Clim Dyn 42:3171–3186

Son H-Y, Park J-Y, & Kug J-S (2015) Precipitation variability in September over the Korean Peninsula during ENSO developing phase. ClDy. doi:10.1007/s00382-015-2776-x

Su H, Neelin JD, Chou C (2001) Tropical teleconnection and local response to SST anomalies during the 1997–1998 El Nino. J Geophys Res 106:20025–20043

Wang B, Wu R, Fu X (2000) Pacific-East Asian teleconnection: how does ENSO affect East Asian climate? J Clim 13:1517–1536

Wang B, Wu R, Lau K (2001) Interannual variability of the Asian summer monsoon: contrasts between the Indian and the Western North Pacific-East Asian Monsoons*. J Clim 14:4073–4090

Webster PJ, Magana VO, Palmer T, Shukla J, Tomas R, Yanai M, Yasunari T (1998) Monsoons: Processes, predictability, and the prospects for prediction. J Geophys Res 103:14451–14510

Wu B, Li T, Zhou T (2010) Relative contributions of the Indian Ocean and local SST anomalies to the maintenance of the western north Pacific anomalous anticyclone during the El Niño Decaying Summer*. J Clim 23:2974–2986

Xie S-P, Hu K, Hafner J, Tokinaga H, Du Y, Huang G, Sampe T (2009) Indian Ocean capacitor effect on Indo-western Pacific climate during the summer following El Niño. J Clim 22:730–747

Yancheva G et al (2007) Influence of the intertropical convergence zone on the East Asian monsoon. Nature 445:74–77

Yeh T, Gao Y (1979) Qinghai-Xizang Plateau Meteorology. Science Press, Beijing

Yeh SW, Kug JS, Dewitte B, Kwon MH, Kirtman BP, Jin FF (2009) El Niño in a changing climate. Nature 461(7263):511–514

Yoon, H.-J., Kim H-J, & Yoon I-H (2006) On the study of the seasonality precipitation over South Korea. J Korean Earth Sci Soc 27:149–158

Zhang Z, Chan JC, Ding Y (2004) Characteristics, evolution and mechanisms of the summer monsoon onset over Southeast Asia. Int J Climatol 24:1461–1482