Chapter 26

Decadal Change of East Asian Summer Monsoon: Contributions of Internal Variability and External Forcing

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The East Asian Summer Monsoon (EASM) has a complex structure and multi-timescale variability, which ranges from intraseasonal, interannual to inter-decadal variability. In the community of East Asian monsoon studies, a stronger summer monsoon is defined as a northward penetration of surface monsoon circulation along with northward shift of monsoon rainband (Zhou *et al.* 2009). The interannual variability of EASM, its link to western North Pacific summer monsoon and their associations with El Niño/Southern Oscillation (ENSO) activities have been reviewed by Zhou *et al.* (2011), Ha *et al.* (2012), and recently updated by Hsu *et al.* (2014), and Zhou *et al.* (2014).

In addition to interannual variability, the EASM also exhibits considerable variability on inter-decadal time scales. For example, since the late 1970s, the EASM circulation has exhibited a weakening tendency. Following the weakened monsoon circulation, there was a trend toward increasing drought in North China but excessive rainfall in South China along the Yangtze River valley. This weakening tendency of EASM from the late 1970s to the end of the 20^{th} century has been of great concern to the climate research community (see Zhou *et al.* 2009 for a review). However, recent studies found that the EASM circulation has been recovering since the early 1990s, although the strength of EASM is still weaker than that averaged over the period of 1965–1980. Associated with the recovery of EASM circulation, the monsoon rain belt has a tendency of moving northward to 30°–35°N along eastern China (Liu *et al.* 2012). Thus how to understand the earlier and recent decadal changes of EASM has been of great concern to both greater society and climate research community. Although up to now it is difficult to get a consensus on the mechanisms of the observed monsoon changes, there are increasing evidences supporting that the monsoon changes over East Asia were driven by both internal variability such as the Pacific Decadal Oscillation (PDO)/Inter-decadal Pacific Oscillation (IPO) and external forcing agents such as greenhouse gases and anthropogenic aerosols. In this paper, a review of our current understanding of the issue is given. In addition to inter-decadal change, the interannual variability of East Asian summer monsoon also exhibits inter-decadal variations (Yun *et al.* 2009; Song and Zhou 2015). The progresses in this field are also reviewed.

1. The Forcing of IPO/PDO to EASM at Interdecadal Time Scale During the 20th Century

Data diagnosis has revealed that the weakening tendency of the EASM since the late 1970s is not a local phenomenon; rather it is a regional manifestation of global land monsoon changes. The rain gauge data over the land has shown a similar decreasing trend in the total precipitation amount accumulated in the global (mainly northern hemisphere) land monsoon domains

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(Zhou *et al.* 2008a). To understand the mechanisms, numerical experiments with AGCMs forced by historical sea surface temperature (SST) variation are done. The results show that the observed weakening tendency of both global land monsoon precipitation and EASM circulation during 1950–2000 are reasonably reproduced by the models (Zhou *et al.* 2008b; Li *et al.* 2010). Both changes are driven by interdecadal changes of tropical ocean SST, which is a tropical lobe of the natural variability mode of PDO/IPO (Zhou *et al.* 2008b; Li *et al.* 2010). The phase transition of PDO/IPO from negative to positive phases around 1976/1977 has led to warming of Tropical Ocean which favors a weakened monsoon circulation through reducing the large-scale land-sea thermal contrast (Li *et al.* 2010).

The forcing of PDO/IPO to EASM is more evident if we extend our analysis from the 2nd half to the end of the 20th century. A weaker monsoon circulation is associated with deficient precipitation and thus more droughts in northern China. Qian and Zhou (2014) analyzed the dry-wet changes in northern China for the period of 1900–2010 on the basis of self-calibrated Palmer drought severity index (PDSI) data. The ensemble empirical mode decomposition method is used to detect multidecadal variability. A transition from significant wetting to significant drying is detected around 1959/60. Approximately 70% of the drying trend during 1960–90 originates from 50–70-yr multidecadal variability related to PDO phase changes (Fig. 1). The PDSI in northern China is significantly negatively correlated with the PDO index, particularly at the 50–70-yr time scale. This kind of significant negative correlation relationship is stable during 1900–2010.

How does PDO/IPO impact the EASM? In addition to the weakened land–sea thermal contrast in East Asia mechanism from a negative to a positive PDO phase proposed by Li *et al.* (2010), the Pacific–Japan/East Asian-Pacific pattern like teleconnection is highlighted by Qian and Zhou (2014). Composite differences between two positive PDO phases (1922–45 and 1977–2002) and one negative PDO phase (1946–76) for summer exhibit an anomalous Pacific–Japan/East Asian–Pacific pattern like teleconnection, which develops locally in response to the PDO-associated warm SST anomalies in the tropical Indo-Pacific Ocean and meridionally extends from the tropical western Pacific to northern China along the East Asian coast. Northern China is dominated by an anomalous high pressure system at mid–low levels and an anticyclone at 850 hPa, which are favorable for dry conditions (Qian and Zhou 2014).

The recent recovery of EASM circulation is also driven by PDO/IPO related tropical SST anomalies. The phase transition of PDO/IPO from positive to negative phases has led to a SST cooling in the tropical eastern Pacific (Liu *et al.* 2012). This kind of SST cooling is regarded as mega-ENSO signals and has been suggested as one driving mechanisms for the recent enhancement of global monsoon (Wang *et al.* 2012; Lin *et al.* 2014). The strengthening EASM since the early 1990s is linked to the inter-decadal change of land-sea thermal contrast, which is mainly dominated by positive SLP anomalies over the western Pacific and "warmer land-colder ocean" thermal contrast change (Liu *et al.* 2012). Numerical modeling study based on SST-driven AGCM simulation indicates that the shift of PDO/IPO from positive to negative phase induces a warming over the Lake Baikal and a weakened subtropical westerly jet, which further lead to an increase of summer rainfall along the Huang-Huai River valley (32°–36°N, 110°–121°E) while a decrease along the Yangtze River valley (28°–31°N, 110°–121°E) during 2000–2008 in comparison to 1979–1999. These precipitation anomalies also indicate a recovery of EASM in the recent decade (Zhu *et al.* 2011). All this evidence indicates that the recent recovery of EASM is dominated by natural variability mode and may not be related to anthropogenic forcing agents, although climate

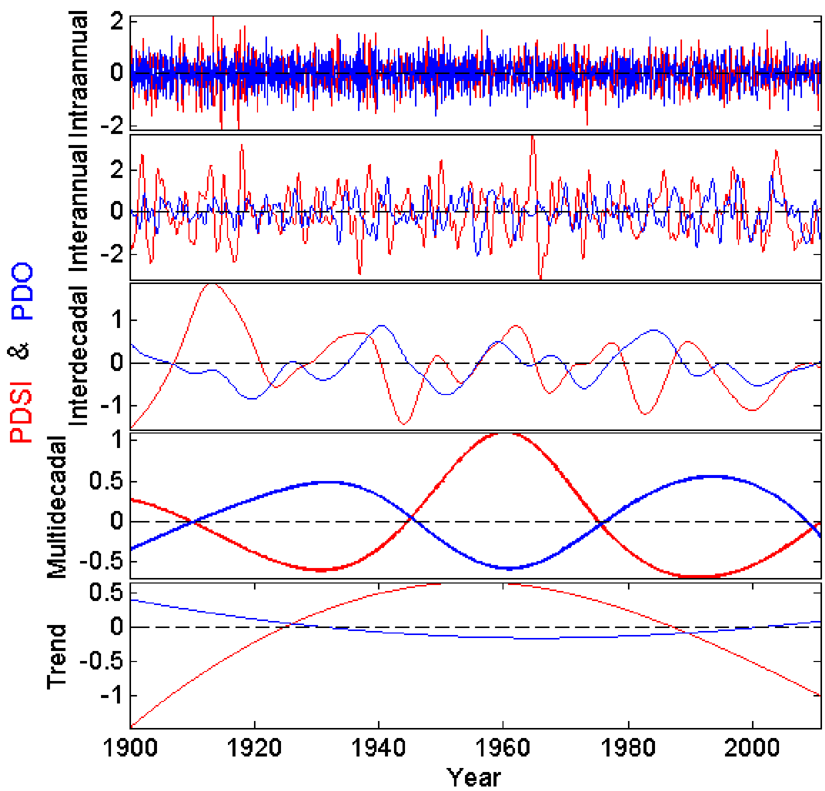

Fig. 1. Decompositions of monthly NC-PDSI (red) and PDO index (blue) during 1900–2010 into ?ve major time scales determined using the EEMD filter. In the last subpanel, the nonlinear trends of NC-PDSI and PDO have been both subtracted by their mean values to facilitate comparison. (After Qian and Zhou 2014.)

model simulations indicate that the anthropogenic greenhouses gases emission would favor an enhancement of summer monsoon circulation (Kitoh *et al.* 2013; Song *et al.* 2014).

The decadal scale recovery of EASM associated with the transition of the PDO/IPO from a positive to a negative phase provides a large-scale background for the stronger summer monsoon in 2012. Nothern China including Beijing (∼39°52′N, 116°28′E) experienced severe flooding in the summer of 2012. During 21–22 July, Beijing received a regionally averaged total precipitation of 190.3 mm, and the center of the rainfall event received 460.0 mm; the observations of 11 stations broke the historical records (Fig. 2). The flood affected area in Beijing was about 16,000 km^2, and the affected population was estimated at 1.9 million with 77 people dead. The direct economic loss is over 10 billion Chinese RMB (Zhou *et al.* 2013).

The occurrence of the 2012 flood in the context of a multi-decadal drying tendency has received great attention. Following the recovery of EASM associated with PDO/IPO phase transition in recent years, whether this kind of extreme events would occur more frequently in the near future deserves special attention and further study.

2. The Anthropogenic Forcings to EASM at Inter-decadal Time Scale

Through analyzing the long-term changes in Baiu rainfall during 1901–2009, it is found that there is no significant trend in the entire Baiu

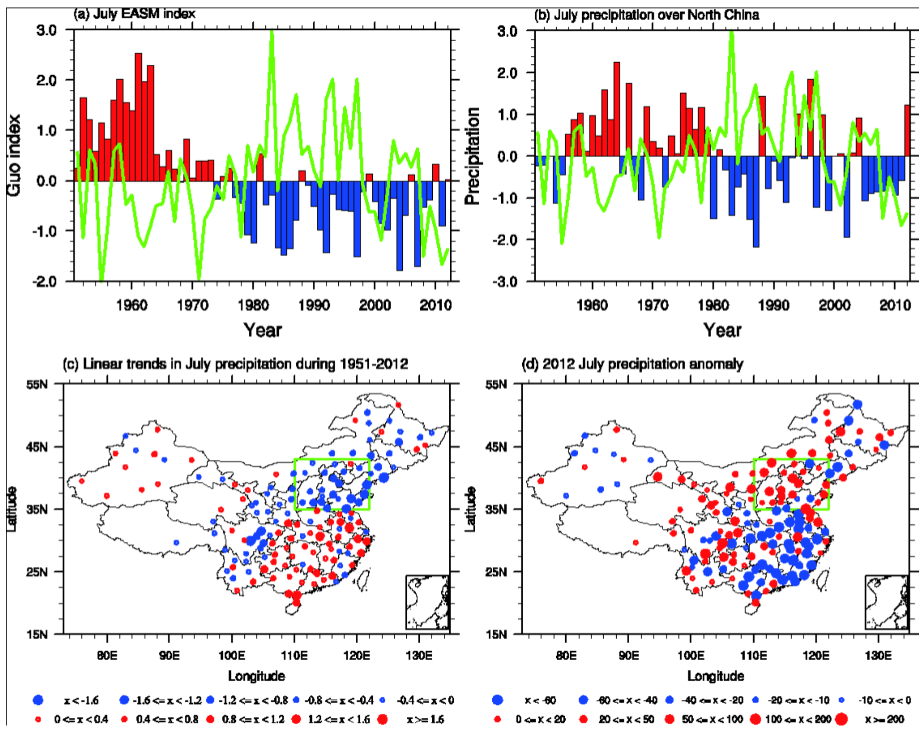

Fig. 2. (a) Normalized Jul EASM index derived from NCEP/NCAR reanalysis based on Guo (1983). The green line indicates the PDO index derived from http://jisao.washington.edu/pdo/PDO.latest. (b) Normalized Jul precipitation amount averaged over North China (35°N–43°N, 110°E–122°E; 23 stations included; dimensionless). The green line indicates the PDO. (c) Linear trends of July precipitation during 1951–2011 (mm yr-1; the absolute values of anomolies larger than 0.4 are statically significant at the 5% level), the green box indicates the North China region (35°N–43°N, 110°E–122°E). (d) Anomalies of July precipitation in 2012 relative to 1981–2010. (After Zhou *et al.* 2013.)

season over all regions, which indicates that the external forcing's influence on the Baiu is small (Endo 2011). However, the heavy precipitation has increased during the last century, indicative of the external forcing's effect (Fujibe *et al.* 2006). Along the Yangtze River valley, the summer precipitation during the whole 20^{th} century also shows no significant trends (Zhou *et al.* 2009). The decadal/interdecadal change is more evident during the 2^{nd} half of the 20^{th} century (Zhang and Zhou 2011). Previous studies suggested that the anthropogenic changes of atmospheric composition, including greenhouse gases (GHG) and aerosol, may also impact the EASM during the 2^{nd} half of the 20^{th} century (see Zhou *et al.* 2009 for a review). For example, using an atmospheric model, Menon *et al.* (2002) found that the "southern-flood-northern-drought" precipitation pattern, one important feature of the EASM weakening, can be reproduced when the observed black carbon is also considered. The influence of sulphate aerosol on the precipitation structure was investigated by Qian *et al.* (2009). Based on observation and model simulation, they found that decreased light rainfall events in China during 1956–2005 are partly due to the increased anthropogenic aerosols, since they increase the cloud droplet number concentration and reduce droplet sizes.

But the effect of aerosol in inter-decadal EASM change is contested by many modeling studies. For example, there is evidence demonstrating that the specified anthropogenic aerosol forcing recommended by CMIP project failed in reproducing the observed features of monsoon changes (Li *et al.* 2007; Li *et al.* 2010).

The discrepancy of previous studies may partly be related to model limitations. The performances of climate models have generally improved in the past 5 years. In the latest Coupled Model Intercomparison Program phase 5 (CMIP5), there are different external forcing historical simulations, which allows investigation of the different influences of the external forcings in the EASM. Song *et al.* (2014) used 17 CMIP5 models and investigated the response of the EASM to these external forcings during the second half of the 20th century. The different forcing runs from the multi-model ensemble (MME) are analyzed to investigate their contributions to the declining trend of the EASM (Fig. 3). The positive trends of SLP over northern China and negative trends of SLP over the northwestern Pacific (NWP) are seen in both the observation and the all-forcing run (Fig. 3a, b). The

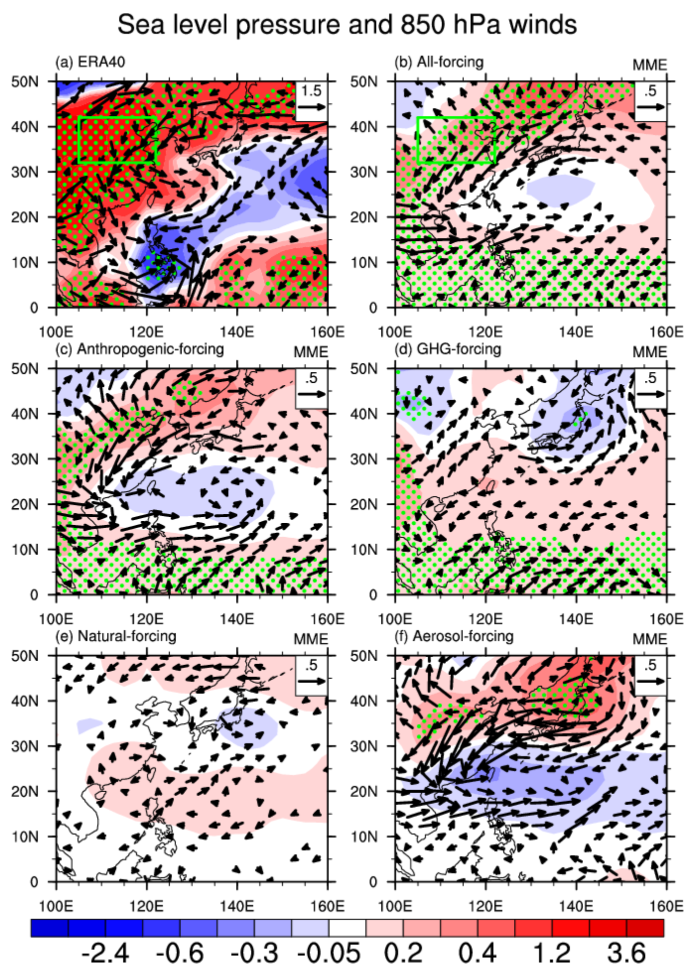

Fig. 3. The linear trends of SLP (shaded; hPa (44 year)$^{-1}$) and 850 hPa winds (vectors; m s^{-1} (44 year)$^{-1}$) in JJA during 1958–2001. (a) Observations (SLP and 850 hPa winds from ERA40); (b) all-forcing run; (c) anthropogenic-forcing run; (d) GHG-forcing run; (e) natural-forcing run; (f) aerosol-forcing run from MME. The green box in (a) and (b) is northern China (32°N–42°N, 105°E–122°E). The dotted areas indicate that the precipitation trends are statistically significant at the 10% level. The MME is constructed by using 35 realizations from 17 CMIP5 models. (After Song *et al.* 2014.)

anthropogenic-forcing dominates the responses in the all-forcing (Fig. 3c). In contrast, the anti-cyclone and southerly winds dominate eastern China in the GHG-forcing runs (Fig. 3d). The response of SLP in the aerosol-forcing run features a meridional dipole pattern, with positive anomalies over northern China and negative anomalies over southern China (Fig. 3f). Given that the anthropogenic aerosol loading over East Asia is larger than elsewhere (Wang *et al.* 2013), the surface cooling over the East Asian continent is the strongest. Hence, the surface cooling over eastern China weakens the land-sea thermal contrast and further induces the positive SLP trends over northern China, leading to a weakening trend of the EASM.

However, we should note that the decreasing trend of the EASM under external forcing is far weaker than in the observation. This discrepancy indicates that the internal variability mode of PDO/IPO may play a dominant role in the monsoon weakening as previously suggested (Li *et al.* 2010) and recently re-emphasized (Yu *et al.* 2015), while the aerosol forcing plays a secondary or complementary role. It should also be noted that the PDO/IPO are natural modes, even if climate models are able to simulate the PDO/IPO reasonably well, their temporal phases are not reasonably reproduced because models are not initialized. The external forcings may also impact the phase of PDO/IPO (Dong *et al.* 2014a). This poses a challenge for the reproduction of the observed EASM changes.

In summary, the anthropogenic emission of aerosol does contribute to but is not a dominant factor for the weakening tendency of the EASM since the late 1970s to the end of the 20th century.

3. Inter-decadal Shift of EASM Interannual Variability

Interannual variability features of the EASM also exhibit inter-decadal variations. Lee *et al.* (2014) examined the change in principal mode of the EASM precipitation (Fig. 4). It is found that during 1979–1993 the first EOF mode is related with ENSO, showing negative correlation to Nino3.4, whereas during 1994–2009 the western North Pacific summer

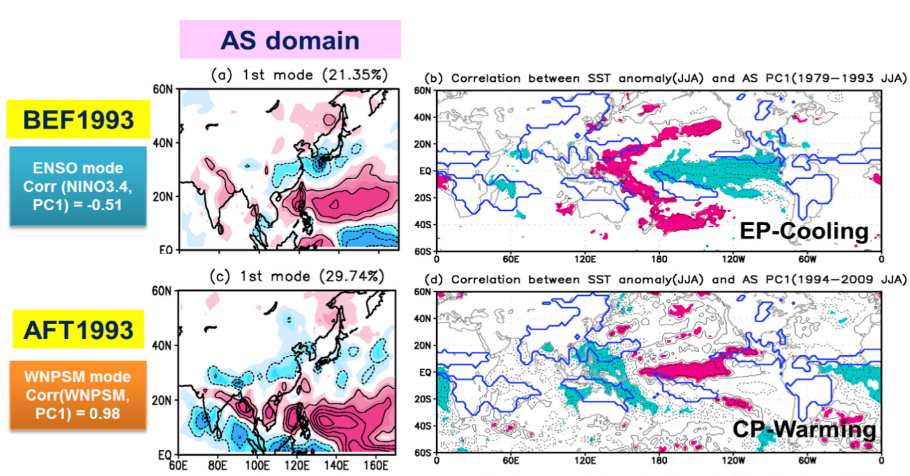

Fig. 4. Spatial patterns of first EOF mode of summer (JJA) precipitation over the Asian summer (AS) domain during (a) 1979–1993 and (b) 1994–2009. Distributions of simultaneous correlation coefficients between the time series of PC1 and JJA SST anomalies during (c) 1979–1993 and (d) 1994–2009. Shading area in (c) and (d) denote regions significant at the 95% confidence level. (After Lee *et al.* 2014).

monsoon (WNPSM)-related variability is dominant, with a very significant correlation with WNPSH index. Consequently, the result indicates that this WNPSM-related variability is related to central-Pacific (CP)-type ENSO than the eastern-Pacific (EP) type ENSO. In fact, Kwon *et al.* (2005) have discovered the decadal change over East Asian summer monsoon (EASM) around 1993/1994. The decadal change has been largely explained by three factors: changes in mean circulation (Kwon *et al.* 2007), interannual variability and its ENSO relationship (Kwon *et al.* 2005; Yim *et al.* 2008), and the climatological intraseasonal oscillation (Kim *et al.* 2011). The increasing role of CP-type ENSO on the NH summer monsoon may be caused by the increasing frequency of CP-type ENSO (Yeh *et al.* 2009). Model experiments show that the CP warming after 1993 causes a more active response vertically than the EP cooling before 1993 does, leading to a stronger ascending motion over the warming region. The CP warming induces the enhanced anticyclonic anomaly over the WNP (WNPSH). It confirms that the CP-type ENSO is related to the dominant WNPSM-related variability.

The interdecadal change after the late 1970s is also found in the monsoonal NPISO (northward propagation of intraseasonal oscillation)-ENSO relationship (Yun *et al.* 2010). The preceding winter ENSO affects the early summer NPISO activity before the late 1970s, while a stronger NPISO–ENSO in the preceding winter relationship appears during the later summer after the late 1970s. The altered NPISO-ENSO relationship has been explained by a strengthening of tropical atmospheric bridge process involving the Walker circulation and Rossby wave propagation.

Recently, Song and Zhou (2015) found that EASM-ENSO relationship exhibits significant decadal variation during the entire 20th century, which is modulated by the phase shift of IPO. The IPO modulates the EASM–ENSO relationship through the western North Pacific subtropical high (WNPSH). Compared to negative IPO phases, the warmer East China Sea in positive IPO phases weakens the WNPSH, inducing more precipitation. The Kelvin wave–induced interannual divergence suppresses more mean-state precipitation and leads to a stronger WPAC. This mechanism has been supported by diagnosis of both reanalysis data and the long-term pre-industrial control simulation of coupled models.

In addition, decadal changes of the interannual variability features of the EASM are also witnessed in the Pacific-Japan pattern (Chen and Zhou 2014), the connection between the western North Pacific Subtropical High and tropical SST (He and Zhou 2015), and the tropospheric temperature meridional gradient over East Asia (Zhang and Zhou 2015).

4. Concluding Remarks

The East Asian summer monsoon circulation has exhibited robust inter-decadal variations, with a weakening phase in the 2nd half of the 20th century and a recovery in recent decades. Both data diagnosis and numerical modeling have presented evidences that the weakening tendency of the EASM in the 2nd half of the 20th century and the recovery of the EASM in recent decades are dominated by the phase transitions of IPO/PDO, suggesting that it is primarily a natural variability mode. The driving of IPO/PDO to the EASM is more evident if we examine their relationship in the whole 20th century. Analysis of CMIP5 models that have conducted different external forcing historical climate simulations shows that the specified aerosol forcing resulted in a weakened EASM circulation, while the greenhouse gases (GHGs) favor an enhanced summer monsoon circulation. Thus both the GHG and aerosol forcings have significant impacts on the EASM changes. But the simulated weakening trend of CMIP5 multi-model ensemble is far weaker than the observation partly due to the limitation of the models in reproducing the temporal phases of IPO/PDO in this kind of uninitialized simulation, suggesting that the anthropogenic forcing agents can contribute to but cannot dominate the long-term changes of summer monsoon. In addition to long-term changes, the EASM also exhibits inter-decadal shift of interannual variability mode. The suggested mechanisms include changes in mean circulation, interannual variability and its ENSO relationship, and the climatological intraseasonal oscillation.

In addition to PDO/IPO, the Atlantic multidecadal oscillation (AMO) has been suggested as effective SST signal that influence the East Asian summer monsoon (Lu *et al.* 2006; Gu *et al.* 2009), although up to now there is no consensus on the mechanisms. Based on the experiments of coupled models, Lu *et al.* (2006) suggested a "non-local mechanism" where the positive AMO phase leads to a stronger East Asian summer monsoons through coupled atmosphere-ocean feedbacks in the western Pacific and Indian Oceans and tropospheric temperature changes over Eurasia in response to the imposed AMO-related SST anomaly forcing in the Atlantic. Traditionally, the PDO/IPO and AMO are regarded as two independent natural variability modes, recent studies such as Dong and Zhou (2014) suggested that the AMO may also drive the phase change of PDO/IPO. How the AMO drives the PDO/IPO in phase transition is a new issue calling for further study.

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References

Chen, X., and T. Zhou, 2014: Relative role of tropical SST forcing in the 1990s periodicity change of the Pacific-Japan pattern interannual variability. *Journal of Geophysical Research — Atmospheres*, **119**, 13043–13066.

Dong, L., T. Zhou and X. Chen, 2014: Changes of Pacific Decadal Variability in the twentieth century driven by internal variability, greenhouse gases and aerosols. *Geophys. Res. Lett.*, **41**, doi:10.1002/2014GL062269.

Dong, L., and T. Zhou 2014: The formation of the recent cooling in the eastern tropical Pacific Ocean and the associated climate impacts: A competition of global warming, IPO, and AMO, *J. Geophys. Res. Atmos.*, **119**, 11272–11287, doi:10.1002/2013JD021395.

Endo, H., 2011: Long-term changes of seasonal progress in Baiu rainfall using 109 years (1901–2009) daily station data. *SOLA*, **7**: 5–8.

Fujibe, F., N. Yamazaki, and K. Kobayashi, 2006: Long-term changes of heavy precipitation and dry weather in Japan (1901–2004). *Journal of the Meteorological Society of Japan*, **84**(6): 1033–1046.

Gu, W., C. Y. Li, X. Wang, and W. Zhou, 2009: Linkage between Mei-Yu precipitation and North Atlantic SST on the decadal timescale. *Adv. Atmos. Sci.*, **26**(1), 101–108, doi:10.1007/s00376-009-0101-5.

Ha, K.-J., K.-Y. Heo, S.-S. Lee, K.-S. Yun, and J.-G. Jhun, 2012: Variability in the East Asian Monsoon: a review. *Meterol. Appl.*, **19**, 200–215.

He, C., and T. Zhou, 2015: Decadal change of the connection between summer western North Pacific Subtropical High and tropical SST in the early 1990s. *Atmospheric Science Letters*, **16**, 253–259.

Hsu, H. H., T. Zhou, and J. Matsumoto, 2014: East Asian, Indochina and Western North Pacific Summer Monsoon–An update. *Asia-Pacific Journal of Atmospheric Sciences*, **50**(1), 45–68.

Kim, W., J.-G. Jhun, K.-J. Ha, and M. Kimoto, 2011: Decadal changes in climatological intraseasonal fluctuation of subseasonal evolution of summer precipitation over the Korean Peninsula in the mid-1990s. *Adv. Atm. Sci.*, **28**, 591–600.

Kitoh, A., H. Endo, K. Krishna Kumar, I. F. A. Cavalcanti, P. Goswami, and T. Zhou, 2013: Monsoons in a changing world: A regional perspective in a global context. *J. Geophys. Res. Atmos.*, **118**, doi:10.1002/jgrd.50258

Kwon, M. H., J.-G. Jhun, B. Wang, S.-I. An, and J.-S. Kug, 2005: Decadal change in relationship between East Asian and WNP summer monsoons. *Geophys. Res. Lett.*, **32**, L16709.

Kwon, M., J.-G. Jhun, and K.-J. Ha, 2007: Decadal change in East Asian summer monsoon circulation in the mid-1990s. *Geophys. Res. Lett.*, **34**, L21706, doi:10.1029/2007GL031977.

Lee, E.-J., K.-J. Ha, and J.-G. Jhun, 2014: Interdecadal changes in interannual variability of the global monsoon precipitation and interrelationships among its subcomponents. *Climate Dynamics*, **42**(9), 2585–2601, DOI 10.1007/s00382-013-1762-4.

Li, H., A. Dai, T. Zhou, and J. Lu, 2010: Responses of East Asian summer monsoon to historical SST and atmospheric forcing during 1950–2000. *Climate Dynamics*, **34**, 501–514, DOI 10.1007/s00382-008-0482-7.

Li, L., B. Wang, and T. Zhou, 2007: Contributions of natural and anthropogenic forcings to the summer cooling over eastern China: An AGCM study. *Geophys. Res. Lett.*, **34**, L18807, doi:10.1029/2007GL030541.

Lin, R., T. Zhou, and Y. Qian, 2014: Evaluation of global monsoon precipitation changes based on five reanalysis datasets, *Journal of Climate*, **27**(3), 1271–1289.

Liu, H., T. Zhou, Y. Zhu, and Y. Lin, 2012: The strengthening East Asia summer monsoon since the early 1990s. *Chinese Science Bulletin*, **57**, 1553–1558, doi:10.1007/s11434-012-4991-8.

Lu, R., B. Dong, and H. Ding, 2006: Impact of the Atlantic Multidecadal oscillation on the Asian summer monsoon. *Geophys. Res. Lett.*, **33**, L24701, doi:10.1029/2006GL027655.

Menon, S., J. Hansen, L. Nazarenko, and Y. Luo, 2002: Climate effects of black carbon aerosols in China and India, *Science*, **297**, 2250–2253.

Qian, C., and T. Zhou, 2014: Multidecadal variability of North China aridity and its relationship to PDO during 1900–2010, *Journal of Climate*, **27**(3), 1210–1222, doi: http://dx.doi.org/10.1175/JCLI-D-13-00235.1.

Qian, Y., D. Gong, J. Fan, L. Leung, R. Bennartz, D. Chen, and W. Wang (2009). Heavy pollution suppresses light rain in China: observations and modeling. *J. Geophys. Res.*, **114**, D00K02. doi:10.1029/2008JD011575.

Song, F., T. Zhou, and Y. Qian, 2014: Responses of East Asian summer monsoon to natural and anthropogenic forcings in the 17 latest CMIP5 models, *Geophys. Res. Lett.*, **41**, doi: 10.1002/2013GL058705.

Song, F., and T. Zhou, 2015: The crucial role of internal variability in modulating the decadal variation of the East Asian summer monsoon-ENSO relationship during the 20th century, *Journal of Climate*, **28**, 7093–7107.

Wang, B., J. Liu, H. J. Kim, P. J. Webster, and S. Y. Yim, 2012: Recent Change of the Global Monsoon Precipitation (1979–2008). *Clim Dyn.*, **39**, 1123–1135, DOI 10.1007/s00382-011-1266-z

Wang, T., H. Wang, H. Ottera, Y. Gao, L. Suo, T. Furevik, and L. Yu, 2013: Anthropogenic forcing of precipitation pattern in Eastern China in late 1970s. *Atmos. Chem. Phys.*, **13**, 12,433–12,450, doi:10.5194/acp-13-12433-2013.

Yeh, S.-W., J.-S. Kug, B. Dewitte, M.-H. Kwon, B. P. Kirtman, and F.-F. Jin, 2009: El Niño in a changing climate. *Nature*, **461**, 511–514.

Yim, S.-Y., J.-G. Jhun, and S.-W. Yeh, 2008: Decadal change in the relationship between east Asian–western North Pacific summer monsoons and ENSO in the mid-1990s, *Geophys. Res. Lett.*, **35**, L20711, doi:10.1029/2008GL035751.

Yu, L., T. Furevik, O. H. Otterå, and Y. Gao, 2015: Modulation of the Pacific Decadal Oscillation on the summer precipitation over East China: A comparison of observations to 600-yr control run of Bergen Climate Model. *Clim. Dyn.*, **44**(1): 475–494.

Yun, K.-S., K.-H. Seo, and K.-J. Ha, 2010: Interdecadal change in the relationship between ENSO and the intraseasonal oscillation in East Asia. *J. Climate*, **23**, 3599–3612.

Zhang, L., and T. Zhou, 2011: An assessment of monsoon precipitation changes during 1901–2001, *Climate Dynamics*, **37**, 279–296.

Zhang, L., and T. Zhou, 2015: Decadal change of East Asian summer tropospheric temperature meridional gradient around the early 1990s. *Science China: Earth Science*, **58**(9), 1609–1622.

Zhou, T., L. Zhang, and H. Li, 2008a: Changes in global land monsoon area and total rainfall accumulation over the last half century, *Geophys. Res. Lett.*, doi:10.1029/2008GL034881.

Zhou, T., R. Yu, H. Li, and B. Wang, 2008b: Ocean Forcing to Changes in global monsoon precipitation over the recent half-century, *Journal of Climate*, **21**(15), 3833–3852.

Zhou, T., D. Gong, J. Li, B. Li, 2009: Detecting and understanding the multi-decadal variability of the East Asian Summer Monsoon? Recent progress and state of affairs. *Meteorologische Zeitschrift*, 18(4), 455–467.

Zhou, T., H.-H. Hsu, and J. Matsuno, 2011: Summer monsoons in East Asia, Indochina, and the western North Pacific, in *The Global Monsoon System: Research and Forecast (2nd Edition)*, edited by Chih-Pei Chang *et al.* World Scientific. pp. 43–72.

Zhou, T., F. Song, R. Lin, X. Chen and X. Chen, 2013: The 2012 North China floods: Explaining an extreme rainfall event in the context of a long-term drying tendency [in Explaining Extreme Events of 2012 from a Climate Perspective]. *Bulletin of the American Meteorological Society*, **94**(9), S49–S51.

Zhou T., B. Wu, and L. Dong, 2014: Advances in Research of ENSO Changes and the associated Impacts on Asia-Pacific Climate, *Asia-Pacific Journal of Atmospheric Sciences*, **50**(4), 405–422.

Zhu, Y. L., H. J. Wang, and W. Zhou, 2011: Recent changes in the summer precipitation pattern in East China. *Clim. Dynam.*, **36**, 1463–1473.