Can coupled models perform better in the simulation of sub-seasonal evolution of the western North Pacific subtropical high than atmospheric models in boreal summer?

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This study examines the climatological sub-seasonal evolution of the western North Pacific subtropical high (WNPSH) in boreal summer using observation and multiple state-of-the-art climate models, which has not been focused by previous research. The two sub-seasonal shifts in boreal summer are analyzed, one from June to July (J–J) and another from July to August (J–A). In observation, the WNPSH consistently retreats eastward and jumps northward (weakens) from June to August. Driven by observed sea surface temperature (SST), the multi-models ensemble (MME) of atmospheric general circulation models (AGCMs) that participated in the Coupled Model Intercomparison Project Phase 5 (CMIP5) can reproduce the weakening of WNPSH from June to July, but fail to simulate the weakening from July to August. This may be due to the sub-seasonal variation of local SST increasing from June to July but decreasing from July to August. Compared with AGCMs simulation, CMIP5 coupled models MME largely improve the sub-seasonal variation of the WNPSH and associated precipitation change. Thus, it is argued that coupled models should be adopted in studies of the WNPSH on sub-seasonal timescales.

KEYWORDS
AGCM, climatology, CMIP5, coupled model, sub-seasonal evolution, western Pacific subtropical high

1 | INTRODUCTION

Climate models are useful tools in climate research. It is necessary to evaluate the performance of climate models before using climate model experiments to investigate specific scientific problems. With respect to the western North Pacific subtropical high (WNPSH), an essential part of the East Asian summer monsoon system, much work has been done to explore the performance of climate models on simulation of WNPSH, especially on inter-annual timescale. For instance, He and Zhou (2014) examined the two inter-annual variability modes of the WNPSH simulated by 28 CMIP5 AGCMs. Liu et al. (2014) argued that CMIP5 coupled models underestimated mean intensity of the WNPSH. Kim et al. (2016) discussed the inter-model differences of WNPSH simulated by CMIP5 models on inter-annual timescale.

In addition to inter-annual variations, WNPSH in boreal summer also has notable characteristics on sub-seasonal variations (e.g., Ren et al., 2013; Dong, 2016; Dong et al., 2017a; 2017b; Xue et al., 2018). Before exploring WNPSH using climate model numerical experiments, the performance of climate models on simulation of WNPSH on sub-seasonal timescale should be examined. Although the sub-seasonal variation of the Asian summer monsoon in multi-models has been investigated (e.g., Lin et al., 2008), whether the CMIP5 models can reasonably reproduce the sub-seasonal evolution of the WNPSH has not been mentioned by most previous research. The WNPSH experiences sub-seasonal eastward
and northward shifts from June to August, leading to different stages of the rainy season in eastern China (early summer, late summer) (e.g., Li and Zhou, 2011; Ye and Lu, 2011; Xue et al., 2018). In our earlier work, we investigated the sub-seasonal evolution of the WNPSH simulated by CMIP5 AGCMs and argued that most models can reproduce the northward jump of the WNPSH, but have difficulties in simulating the eastward retreat of the WNPSH from July to August (Dong et al., 2017b). In this study, we will further investigate the performance of CMIP5 models in simulating the sub-seasonal evolution of the WNPSH in boreal summer. We intend to answer the following two questions:

1. To what extent can the CMIP5 AGCMs and coupled models reproduce sub-seasonal evolution of the WNPSH from June to August?
2. Whether coupled models have better performance than AGCMs? Why?

2 | DATA, MODELS, AND METHODS

The following datasets are adopted to evaluate the performances of CMIP5 models:

1. Monthly mean sea surface temperatures provided by the National Oceanic and Atmospheric Administration of the United States (NOAA Extended Reconstructed Sea Surface Temperature, ERSST V5) with horizontal resolution of $2 \times 2^\circ$ (Huang et al., 2017).
2. Monthly mean atmospheric reanalysis from the National Centers for Environmental Prediction–U.S. Department of Energy (NCEP–DOE) Atmospheric Model Intercomparison Project (AMIP) II Reanalysis with horizontal resolution of $2.5 \times 2.5^\circ$ (Kanamitsu et al., 2002).
3. Monthly mean precipitation dataset from the Global Precipitation Climatology Project (GPCP) with horizontal resolution of $2.5 \times 2.5^\circ$ (Adler et al., 2003).

Besides the observation and reanalysis data, output from 27 atmospheric models and 34 coupled models of CMIP5 are adopted in this study (Table 1) (Taylor et al., 2012). In the Atmospheric Model Intercomparison Project–type experiments (AMIP), AGCMs are driven by observed SST and sea ice from 1979 to 2008. The coupled simulation adopted in this study is the historical simulation using climate models or earth system models from 1900 to 2005. The MME results are shown to examine the averaged performance of CMIP5 models. The time period used in this study is 1979–2005 for the observation data, AMIP and CMIP historical experimental data.

To quantitatively measure the zonal displacement of WNPSH, an index is adopted as in Lu (2002), which is calculated as regional averaged (10°–30°N, 110°–150°E) geopotential height on 850 hPa (Z850). The inter-monthly difference is then calculated to measure the sub-seasonal variation (SSV) of WNPSH. Hereafter it is denoted as SSV index. Positive (negative) SSV index denotes WNPSH experiences westward extension (eastward retreat) from month to month. The westward extension (eastward retreat) is associated with the strengthening (weakening) of WNPSH.

3 | RESULTS

3.1 | Observation and AGCMs simulation

In observation, the precipitation change shows a significant tri-pole pattern from June to July (Figure 1a). Precipitation increases significantly (exceed 95% Student’s t-test) over the Philippine Sea, most part of the north and northeast China and the Korean Peninsula. Between the two positive precipitation centers there is a significantly negative precipitation change zonal belt along 30°N. The AMIP MME can reproduce the three precipitation centers with much smaller magnitude in the negative center and the northern positive center (Figure 1c). With respect to the WNPSH, from June to July it retreats eastward and jumps northward in observation. Measured by the SSV index, the WNPSH weakens (retreats eastward) from June to July (Figure 2a). The AMIP MME can reproduce the weakening of WNPSH (10°–30°N, 110°–150°E) from June to July with overestimated magnitude.

From July to August in observation (Figure 1d), the northern positive center of precipitation (around 20°–30°N, 130°E) moves northeastward to the Sea of Okhotsk (around 30°N–40°, 150°E). The other two precipitation anomaly centers over ocean both move northward with the seasonal evolution of the general circulation. Precipitation in most of the Mainland China decreases from July to August. The pattern of precipitation change can be poorly reproduced by AMIP MME (Figure 1f). Particularly, the precipitation increase center along 20°N over western North Pacific region is largely underestimated in AMIP MME. Meanwhile, WNPSH still retreats eastward in observation, which is associated with the precipitation increase along the western edge of WNPSH. In AMIP MME however, the WNPSH also weakens around 20°N, but intensifies around 40°N to the northern flank of the WPSH (Figure 1f), which is opposite to observation. The inconsistent shift of geopotential height in different latitudes make the WNPSH looks more like a changing in shape instead of strengthening in Figure 1f. The change of WNPSH over 10°–30°N is revealed by Figure 3d. It can be seen from SSV index that 16 out of 27 AGCMs wrongly simulate a strengthening of WPSH from July to August (Figure 3d).

3.2 | Coupled models simulation

According to previous studies, air–sea interaction is very important to climate simulation in East Asia and western North Pacific region (Wang et al., 2005; Zou and Zhou,
### Table 1: Detailed information of the 34 CMIP5 coupled models and 27 CMIP5 AGCMs used in this study

| Model ID | Atmospheric resolution (lon × lat) | Originating group(s), country |
|----------|------------------------------------|-----------------------------|
| **34 CMIP5 coupled models** | | |
| 1 ACCESS1-0 | 1.875 × 1.241° | CSIRO-Bureau of Meteorology (BOM), Australia |
| 2 ACCESS1-3 | 1.875 × 1.268° | CSIRO-BOM, Australia |
| 3 BCC_CSM1-1 | 2.81 × 2.81° | Beijing Climate Center (BCC), China Meteorological Administration (CMA), China |
| 4 BCC-CSM1-1-M | 1.25 × 1.25° | BCC, CMA, China |
| 5 BNU-ESM | 2.81 × 2.81° | Global Change And Earth System Science, Beijing Normal University (BNU), China |
| 6 CanESM2 | 2.81 × 2.81° | Canadian Centre for Climate Modelling and Analysis (CCCMA), Canada |
| 7 CCSM4 | 1.25 × 0.9375° | National Center For Atmospheric Research (NCAR), United States |
| 8 CESM1-BGC | 1.25 × 0.9375° | National Science Foundation (NSF)/DOE NCAR, United States |
| 9 CESM1-CAM5 | 1.25 × 0.9375° | NSF/DOE NCAR, United States |
| 10 CESM1-CAM5-1-FV2 | 1.25 × 0.9375° | NSF/DOE NCAR, United States |
| 11 CMCC-CMS | 1.875 × 1.875° | Centro EuroMediterraneo sui Cambiamenti Climatici (CMCC), Italy |
| 12 CNRM-CM5 | 1.875 × 1.875° | CNRM, Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique (CERFACS), France |
| 13 CSIRO Mk3-6-0 | 1.875 × 1.875° | CSIRO-Queensland Climate Change Centre of Excellence, Australia |
| 14 FGOALS-g2 | 2.81 × 3° | State Key Laboratory of Numerical Modeling for Atmospheric Sciences And Geophysical Fluid Dynamics (LASG), Institute of Atmospheric Physics (IAP), Chinese Academy of Sciences (CAS), China |
| 15 FGOALS-s2 | 2.81 × 1.67° | LASG, IAP, CAS, China |
| 16 GFDL-CM3 | 2.5 × 2° | NOAA/Geophysical Fluid Dynamics Laboratory (GFDL), United States |
| 17 GFDL-ESM2G | 2.5 × 2° | NOAA GFDL, United States |
| 18 GFDL-ESM2M | 2.5 × 2° | NOAA GFDL, United States |
| 19 GISS-E2-H | 2.5 × 2° | NASA/GISS, United States |
| 20 GISS-E2-H-CC | 2.5 × 2° | NASA/GISS, United States |
| 21 GISS-E2-R | 2.5 × 2° | NASA/GISS, Unites States |
| 22 GISS-E2-R-CC | 2.5 × 2° | NASA/GISS, United States |
| 23 HadGEM2-AO | 1.875 × 1.241° | National Institute of Meteorological Research, South Korea |
| 24 INMCM4 | 2 × 1.5° | INM, Russia |
| 25 IPSL-CM5A-LR | 3.75 × 1.875° | L’Institut Pierre-Simon Laplace (IPSL), France |
| 26 IPSL-CM5A-MR | 2.5 × 1.259° | IPSL, France |
| 27 IPSL-CM5B-LR | 3.75 × 1.875° | IPSL, France |
| 28 MIROC5 | 1.41 × 1.41° | Model for Interdisciplinary Research on Climate (MIROC), Japan |
| 29 MIROC-ESM | 2.81 × 2.81° | MIROC, Japan |
| 30 MIROC-ESM-CHEM | 2.81 × 2.81° | MIROC, Japan |
| 31 MPI-ESM-LR | 1.875 × 1.875° | Max Planck Institute for Meteorology (MPI-M), Germany |
| 32 MPI-ESM-MR | 1.875 × 1.875° | MPI-M, Germany |
| 33 MRI-CGCM3 | 1.125 × 1.125° | Meteorological Research Institute (MRI), Japan |
| 34 NorESM1-M | 2.5 × 1.875° | Norwegian Climate Centre (NCC), Norway |
| **27 CMIP5 AGCMs** | | |
| 1 ACCESS1-0 | 1.875 × 1.241° | CSIRO-BOM, Australia |
| 2 BCC_CSM1-1 | 2.81 × 2.81° | BCC, CMA, China |
| 3 BCC-CSM1-1-M | 1.25 × 1.25° | BCC, CMA, China |
| 4 BNU-ESM | 2.81 × 2.81° | Global Change And Earth System Science, Beijing Normal University (BNU), China |
| 5 CanAM4 | 2.81 × 2.81° | CCCMA, Canada |
| 6 CCSM4 | 1.25 × 0.9375° | NCAR, United States |
| 7 CMCC-CM | 0.75 × 0.75° | CMCC, Italy |
| 8 CNRM-CM5 | 1.406 × 1.406° | CNRM, Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique (CERFACS), France |
| 9 CSIRO Mk3-6-0 | 1.875 × 1.875° | CSIRO-Queensland Climate Change Centre of Excellence, Australia |
| 10 FGOALS-g2 | 2.81 × 3° | LASG, IAP, CAS, China |
| 11 FGOALS-s2 | 2.81 × 1.67° | LASG, IAP, CAS, China |
| 12 GFDL-CM3 | 2.5 × 2° | NOAA GFDL, United States |
| 13 GFDL-HIRAM-C180 | 0.5 × 0.5° | NOAA GFDL, United States |
Thus, besides AMIP-type simulation, we also examined coupled simulation in 37 CMIP5 models. It is notable that compared with AMIP simulation; coupled models largely improve the performance on sub-seasonal evolution of WNPSH in boreal summer. From June to July, although AMIP MME can reproduce the eastward retreat of WNPSH, the magnitude is overestimated (Figure 2a). In coupled models MME, the magnitude of WNPSH weakening from June to July is more comparable to observation (Figure 2a).

With respect to the second shift from July to August, compared with AMIP MME in which WNPSH wrongly strengthens, coupled models MME can reproduce the weakening of WNPSH reasonably (Figures 1e,f and 2a).

TABLE 1 (Continued)

| Model ID    | Atmospheric resolution (lon × lat) | Originating group(s), country |
|-------------|-----------------------------------|------------------------------|
| 14 GFDL-HIRAM-C360 | 0.25 × 0.25°  | NOAA GFDL, United States    |
| 15 GISS-E2-R       | 2.5 × 2°       | NASA/GISS, United States    |
| 16 HadGEM2-A       | 1.875 × 1.241° | MOHC, UK                    |
| 17 INMCM4          | 2 × 1.5°       | INM, Russia                 |
| 18 IPSL-CM5A-LR    | 3.75 × 1.875°  | IPSL, France                |
| 19 IPSL-CM5A-MR    | 2.5 × 1.259°   | IPSL, France                |
| 20 IPSL-CM5B-LR    | 3.75 × 1.875°  | IPSL, France                |
| 21 MIROCS          | 1.41 × 1.41°   | MIROC, Japan                |
| 22 MPI-ESM-LR      | 1.875 × 1.875° | MPI-M, Germany              |
| 23 MPI-ESM-MR      | 1.875 × 1.875° | MPI-M, Germany              |
| 24 MRI-AGCM3-2H    | 0.6 × 0.6°     | MRI, Germany                |
| 25 MRI-AGCM3-2S    | 0.2 × 0.2°     | MRI, Japan                  |
| 26 MRI-CGCM3       | 1.125 × 1.125° | MRI, Japan                  |
| 27 NorESM1-M       | 2.5 × 1.875°   | NCC, Norway                 |

(a) (b) (c)

FIGURE 1 Climatological difference between (a–c) July and June (d–f, August and July) of the precipitation (shaded, units: mm/day) and wind field on 850 hPa (vectors, units: m/s) in (a, d) observation, (b, e) historical (coupled models, CM) multi-model ensemble (MME) and (c, f) atmospheric models (AM) MME. Climatological 1,520 gpm contour lines in observation (1,505 gpm in CM MME and 1,500 in AM MME) are shown to denote the WNPSH in June (black), July (red), and August (blue), respectively. The gray oblique lines denote the area where the precipitation differences reach 95% significant test. As for the circulation, we only draw the wind vector when both the \( u \) and \( v \) components exceed 95% significant test. The Student’s \( t \)-test method are used to calculate the statistically significant.
Considering the performance of each model, only six models cannot reproduce the weakening from July to August (Figure 3c). Associated with WNPSH simulation improvement, the magnitude of precipitation increase from July to August in western North Pacific region (110°–150°E, 10°–30°N) can also be improved in coupled MME (Figure 2e). The increasing precipitation region over the northern part of the South China Sea and east to Philippine in observation can be reasonably reproduced in coupled MME, while in AMIP MME it shows decreasing (Figure 1d,f).

**FIGURE 2**  (a) Inter-month difference of climatological Z850 (unit: gpm) averaged over (10°–30°N, 110°–150°E) (SSV) in observation (OBS, black), AM MME (red), and CM MME (blue). (b) Same as (a) but for precipitation (unit: mm/day) averaged over the same area (10°–30°N, 110°–150°E). The letter “Y” indicates that the difference value exceed 95% significant test. The Student’s t-test method are used to calculate the statistically significant

**FIGURE 3** Relationship between area-averaged precipitation inter-month difference (10°–30°N, 110°–150°E) and area-averaged Z850 inter-month difference (10°–30°N, 110°–150°E). (a, b) Difference between July and June, (c, d) difference between August and July, (a, c) CM simulation, (b, d) AM simulation. Red circle is OBS and green circle is MME. Numbers represent the models shown in Table 1
3.3 Relationship between precipitation and WNPSH simulation

The prominent positive precipitation center in western North Pacific region exists both from June to July and July to August. Meanwhile the WNPSH retreats eastward in the two shifts (June-to-July and July-to-August). To explore whether precipitation change in the western North Pacific region is associated with the movement of WNPSH, Figure 3 shows the climatological precipitation change and SSV index of WNPSH in each model along with observation. It can be seen that the precipitation change is negatively associated with the SSV index. That is, stronger (weaker) retreat of the WNPSH is always associated with larger (smaller) local precipitation increase, both from June to July and from July to August. The reason is that anticyclonic circulation always prevails over the region covered by WNPSH. When WNPSH retreats eastward the associated circulation changes to cyclonic and prefers more precipitation to occur. The stronger (weaker) WNPSH retreats, the larger (smaller) region cyclonic circulation anomaly dominate which can be favorable for more (less) precipitation increase.

Figure 3 shows that compared with AMIP-type simulation MME, coupled models MME are closer to observation. For July to August, with air–sea interaction unconsidered, the AMIP MME cannot reproduce the eastward retreat of the WNPSH from July to August. We note that there are still 11 AGCMs that can reproduce the weakening of WNPSH with different magnitude (Figure 3d). It should be kept in mind that the precipitation increase cannot guarantee weakening of the WNPSH because there are several AGCMs that cannot reproduce the WNPSH weakening even though the precipitation increase is reasonably reproduced.

3.4 Why AGCMs MME cannot reproduce eastward retreat from July to August?

From the previous subsection, it is revealed that the precipitation change is associated with the movement of the WNPSH. From July to August, AMIP models underestimate the precipitation increase, which is related to the wrongly simulated strengthening of the WNPSH. With respect to the coupled models, the better performance of the precipitation change simulation is intimately associated with the largely improved simulation of WNPSH movement. Why can the eastward retreat of the WNPSH from June to July be reproduced rather than the shift from July to August in atmospheric-alone models? Note that in AMIP experiments, AGCMs are driven by observed SST, without adding the complexity of air–sea feedbacks in the climate system (Taylor et al., 2012). Thus in AMIP-type experiments, warm (cold) local SST will lead to more (less) local precipitation over tropical areas. However, the atmospheric feedback cannot be ignored in WNPSH region (Zou and Zhou, 2013; Lin et al., 2016). Worth noting is that the process explained here applied only to tropical areas. The mid-latitude atmospheric circulation can be influenced by remote tropical SST anomaly via “atmospheric bridge” (Lau, 1997; Alexander et al., 2002). In mid-latitude, the precipitation may be affected by atmospheric circulation which is influenced by remote SST anomaly rather than local SST anomaly.

Figure 4a shows the observed SST and precipitation change from June to July. It can be noted that the observed precipitation increase from June to July in WNP region is associated with local oceanic warming. Driven by observed SST, this sub-seasonal SST warming can induce more moisture evaporation, which leads to more precipitation in AGCMs. Thus, even without air–sea interaction in AMIP experiments, AGCMs can reproduce the precipitation increase from June to July. In another words, from June to July, the SST affects atmosphere more than atmosphere affects the SST.

Figure 4b shows the observed SST and precipitation change from July to August. Different from Figure 4a, the local precipitation increase and local SST decrease, implying that atmospheric process may play a leading role. When atmosphere affect SST more than SST affect atmosphere, the precipitation increasing can induce more cloud and less shortwave radiation, which leads to local SST cooling (Wang et al., 2005). AMIP experiments cannot reproduce this atmospheric feedback process in its design. In AGCMs,
the observed negative SST anomaly will force to a wrongly negative precipitation anomaly (as Figure 1f shown). In coupled models, although the SST simulation has bias compared with observation that is used in AMIP-type experiments, with air–sea interaction considered, the real physical process can be reflected and the simulated precipitation increase can be improved. It should also be noted that the precipitation increase over WNP region may result from other factors rather than the local SST change because in nine AMIP models, although the observed SST cools from July to August, the precipitation still increases. Besides the local air–sea interaction factor, the atmospheric variations over WNP region may be affected by remote forcing from the equatorial central-eastern Pacific through wind–moist enthalpy advection–convection feedback (Wu et al., 2017) and tropical Indian Ocean through a baroclinic Kelvin wave (Xie et al., 2009; Wu et al., 2010). For example, in response to positive SST anomaly and related positive precipitation anomaly over the equatorial central-eastern Pacific, twin Rossby wave cyclonic anomalies are induced to the west. The northern branch of the twin cyclonic anomalies advects dry and low moist enthalpy air into the tropical western North Pacific, which suppresses local convection. The suppressed convection further suppressed precipitation.

In order to explain that why there are also nine AMIP models can simulate the eastward retreat from July to August, we chose four best AGCM models (ACCESS1-0, CCSM4, HadGEM2-A, and MPI-ESM-MR, model ID are 1, 6, 16, and 23) and four worst AGCM models (bcc-csm1-1, CSIRO-Mk3-6-0, FGOALS-s2, and GFDL-HIRAM-C180, model ID are 2, 9, 11, and 13) for comparing. Deriving from Figure 3d, the best models are largely different from the worst model in reproducing the inter-month differences of Z850 and precipitation. From July to August, the Z850 decrease (increase) and precipitation increase (decrease) in the best (worst) models. Firstly, we compare the climatology of these two kinds of models. The climatological JJA mean Z850, u and v components of wind at 850 hPa (UV850) and precipitation are shown in Figure 5a,b. The best models reproduce a better climatology than the worst model. The southwest winds in the worst models are stronger than the observation (Figure 5a). The stronger southwest winds transport more moist air to 120°–150°E, making more precipitation over that region (Figure 5b). Second, the correlation coefficients between SST anomalies and precipitation anomalies are shown in Figure 5c. In the WNP regions, the SST and precipitation anomalies are negatively correlated in the observation and positively correlated in AMIP models. Positive correlation means the SST affect atmosphere more than atmosphere affect SST (Wang et al., 2005; Lin et al., 2016). The best models reveal negative correlation or small positive correlation over some small areas. In these areas, the precipitation may be affected by remote SST rather than local SST. Better revealing the SST–precipitation correlation may lead to better reproducing the inter-month differences in the best models.

From Figure 1f, we can see that from July to August, the AGCM-simulated WNPSH also weakens around 20°N, but intensifies around 40°N to the northern flunk of the WNPSH. This WNPSH intensification can be explained by the subtropical jet response to the Kuroshio and Oyashio Extension (KOE) SST. Higher KOE SST (e.g., Figure 4) intensifies WNPSH by shifting the jet poleward (Matsumura et al., 2015; 2016; Matsumura and Horinouchi, 2016). Thus, AGCM models may overestimate the atmospheric response to SST forcing because of no air–sea coupling. Indeed, in all months (June, July, August), the WNPSH ridge in AGCMs is located to the north of that in observations and coupled models (Figure 1). The jet response to KOE SST is weaker in early summer but stronger in late summer (Nakamura and Miyama, 2014), which could account for the reproducibility of the WNPSH difference between early and late summer in AGCM models.

4 CONCLUSIONS

The climatological sub-seasonal evolution of the WNPSH and associated precipitation change in WNP region in boreal summer has been examined using observation, AMIP-type simulation from 27 AGCMs and historical simulation from 34 coupled models participated in CMIP5. Our results can answer the two questions raised in the Introduction. CMIP5 AGCMs MME can reproduce the weakening (eastward retreat) of WNPSH from June to July, but fails to simulate the weakening from July to August. This may be due to the sub-seasonal variation of local SST increasing from June to July but decreasing from July to August, causing the local precipitation increase from June to July to be reasonably reproduced, but not from July to August. The reasonably reproduced precipitation increase prefers the weakening of WNPSH from June to July. From July to August, due to the local ocean cooling, the precipitation increase is largely underestimated, which is unfavorable for the eastward retreat of WNPSH. Thus, although the weakening of WNPSH from June to July can be reproduced in AMIP-type simulation, it is not to say that air–sea interaction is unimportant.

Compared with AGCMs simulation, CMIP5 coupled models can largely improve the sub-seasonal variation of the WNPSH and associated precipitation change. From June to July, although AMIP MME can reproduce the eastward retreat of WNPSH, the overestimated magnitude can be improved in coupled models MME. From July to August, compared with the AMIP MME in which WNPSH wrongly strengthens, coupled models MME can reproduce the weakening of WNPSH reasonably. The associated precipitation increase in WNP region can also be improved in coupled...
models. Thus in the sub-seasonal evolution of WNPSH simulation air–sea interaction is essential and should be considered.

ACKNOWLEDGMENTS
We acknowledge the Editor and two anonymous reviewers for the constructive comments and suggestions to improve the quality of the manuscript. We thank Dr. Sherry Ryan for her help in revising the grammar of this manuscript. The efforts from all the modeling groups, the PCMDI and the World Climate Research Programme’s Working Group on Coupled Modelling (WGCM) in making available the CMIP multi-model datasets were acknowledged. This work was jointly supported by the National Natural Science Foundation of China (Grant Nos. 41706028 and 41606027) and the China Postdoctoral Science Foundation (Grant No. 2015M571095).

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How to cite this article: Lin R, Dong X, Fan F. Can coupled models perform better in the simulation of sub-seasonal evolution of the western North Pacific subtropical high than atmospheric models in boreal summer? Atmos Sci Lett. 2018;19:e862. https://doi.org/10.1002/asl.862