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Limitations of BCC_CSM's ability to predict summer precipitation over East Asia and the Northwestern Pacific

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ABSTRACT

This study examines the ability of the Beijing Climate Center Climate System Model (BCC_CSM) to predict the meridional pattern of summer precipitation over East Asia-Northwest Pacific (EA-NWP) and its East Asia-Pacific (EAP) teleconnection. The differences of summer precipitation modes of the empirical orthogonal function and the bias of atmospheric circulations over EA-NWP are analyzed to determine the reason for the precipitation prediction errors. Results indicate that the BCC_CSM could not reproduce the positive-negative-positive meridional tripole pattern from south to north that differs markedly from that observed over the last 20 years. This failure can be attributed to the bias of the BCC_CSM hindcasts of the summer EAP teleconnection and the low predictability of 500 hPa at the mid-high latitude lobe of the EAP. Meanwhile, the BCC_CSM hindcasts' deficiencies of atmospheric responses to SST anomalies over the Indonesia maritime continent (IMC) resulted in opposite and geographically shifted geopotential anomalies at 500 hPa as well as wind and vorticity anomalies at 850 hPa, rendering the BCC_CSM unable to correctly reproduce the EAP teleconnection pattern. Understanding these two problems will help further improve BCC_CSM's summer precipitation forecasting ability over EA-NWP.

1. Introduction

It has been shown in many studies that East Asia, especially the East China region experiences a seasonal climatic variability that is largely affected by East Asian monsoon system. Summer precipitation in this region is mainly influenced by the East Asian Summer Monsoon (EASM) and has significant interannual variability, leading to severe weather and climate events, such as floods and droughts, especially in the eastern China, Japan and Korea (Ding et al., 2008; Huang et al., 1998; Min et al., 2003). As East Asian region covers vast land that is composed of complex terrain (Kan et al., 2015) with unique topographic features, which results in high seasonal variability of EASM (Ding and Chan, 2005; Huang et al., 2012), therefore precipitation over East Asia changes dramatically from one region to the other in different seasons. Therefore, studies pertaining to the diagnosis and prediction of summer precipitation over East Asia (SPEA) are of great scientific interest and deserve more attention.

Recently, SPEA has exhibited dominant modes of anomalous precipitation, switching from a meridional tripole pattern to a dipole pattern on annual and interdecadal scales (Huang et al., 2012). This characteristic of SPEA is closely related to atmospheric anomalies in the middle to upper troposphere over East Asia, particularly wind convergence and divergence, water vapor transport and vertical motion, all of which have meridional structures (Nitta and Hu, 1996; Zhou et al., 2013). In addition, Nitta (1987) and Huang (1987) showed that the thermal state in the tropical Western Pacific and convective activity near the Philippines significantly affected the interannual variability of the EASM, which caused a teleconnection pattern of summer circulation anomalies across the tropical and mid-latitude Northwestern Pacific. This teleconnection over the Northern Hemisphere has been called the East Asia-Pacific (EAP) teleconnection, and its teleconnection over Pacific and Japan has been called the Pacific-Japan (PJ) teleconnection (Huang, 1987; Nitta, 1987). Kosaka et al. (2012) and Huang (2004) demonstrated that the EAP (PJ) teleconnection pattern was able to modulate the meridional pattern of SPEA by affecting the Northwestern Pacific Subtropical High (PASH). Therefore, the EAP teleconnection is anticipated to be a crucial component that could influence the seasonal predictability of summer precipitation over the East Asia and Northwestern Pacific (EA-NWP).

The Beijing Climate Center (BCC) has recently developed a new global climate system model called the BCC Climate System Model (BCC_CSM) (Wu et al., 2013). A previous study on the performance of

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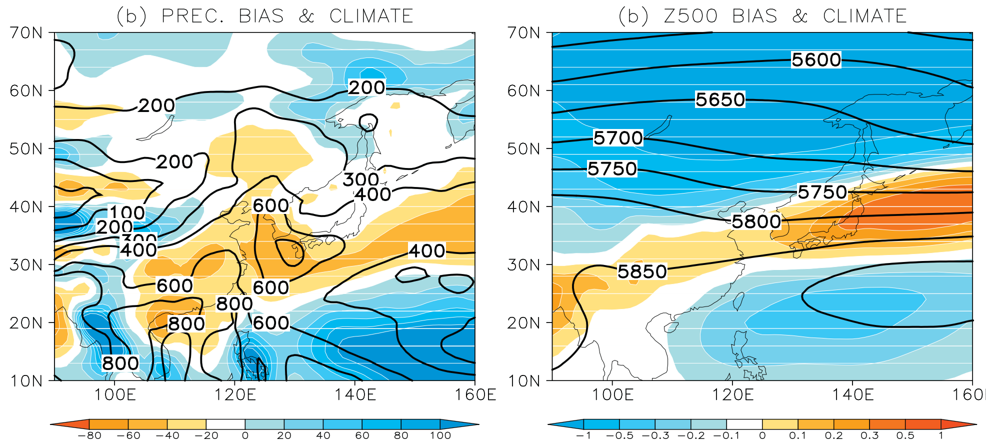

Fig. 1. Observed climatology (contour, units: mm for precipitation and gpm for Z500) and relative bias of BCC_CSM hindcasts minus observations (shade, units: %) for (a) summer precipitation and (b) Z500.

the BCC_CSM (Liu et al., 2015) indicates that this model has a reasonable ability to estimate certain aspects of the climatology and spatiotemporal variability of South and Southeast Asian summer monsoon system. Nevertheless, the model exhibited errors in the forecasts over the tropical eastern equatorial Indian Ocean and the Western North Pacific (Gong et al., 2015; Kosaka et al., 2012).

In this paper we focus on the BCC_CSM's ability and limitations in predicting summer precipitation, especially, the meridional mode of local precipitation anomalies over the EA-NWP. Moreover we also analyze model's ability in reproducing EAP teleconnection patterns by looking at the interactions between the atmospheric anomalies and sea surface temperature (SST). Mainly the following two questions are addressed: (1) whether BCC_CSM is able to reproduce the meridional patterns over EA-NWP and (2) whether the model's inability to correctly reproduce the spatial characteristics of precipitation anomalies could be attributed to its inability to capture the EAP teleconnection pattern. Answering these two questions could help improve BCC_CSM's summer precipitation forecasting ability over EA-NWP, especially over middle to high latitude areas. Understanding the reason of BCC_CSM's summer precipitation forecasting bias could also aid in proposing dynamic-statistic combined scheme to improve the model's skill for summer precipitation prediction (Fan et al., 2012; Feng et al., 2013; Li et al., 2001; Wan et al., 2012; Wang et al., 2015).

Section 2 provides a brief introduction to the data used in this study and an overview of the BCC_CSM. The BCC_CSM's bias in the climatology and the leading mode of summer precipitation over EA-NWP is presented in Section 3. The reasons underlying BCC_CSM's inability to produce the EAP teleconnection pattern are analyzed in Section 4. Meanwhile, the attribution of BCC_CSM's inability to reproduce EAP teleconnection is given in Section 5. Finally, Section 6 includes a brief summary and discussion of the study's main findings.

2. Model and data

The BCC_CSM employed in this study is a global ocean-land-ice-atmosphere coupled model. The atmospheric component of the model is the BCC Atmospheric General Model with a T106 horizontal resolution and 26 hybrid sigma/pressure layers in the vertical direction (Wu et al., 2013). BCC_CSM based seasonal hindcasts experiments were conducted for the period 1991 to 2013 in which data from 1991 to 2010 were selected for analysis in this study. To get a two decades dataset, just like the normal climate state from 1981 to 2010, years from 2011 to 2013 were left out. For each year, the hindcasts were initiated on the first day of March and included a 13-month forecast integration. The initial atmospheric conditions are obtained from the four-times daily air temperature, winds, and surface pressure fields of the National Centers for Environmental Prediction (NCEP) Reanalysis, and the initial oceanic conditions are from the sea temperature of the NCEP Global Oceanic Data Assimilation System. The reanalysis data are used to initialize the model by a nudging method, which operates from the late 1980s to the end of 2013 (Liu et al., 2015). In the seasonal hindcast experiment, 24 members participated in the ensemble forecast, which was produced by a lagged average forecasting with a combination of different atmospheric and oceanic initial conditions at the end of the month prior to the beginning of the hindcasts (Liu et al., 2015). The BCC_CSM's precipitation hindcasts from 1991 to 2013 were used to obtain the yearly summer (June to August) cumulative precipitation for the EA-NWP region (10–70°N, 90–160°E).

The observational and reanalysis datasets used in this study include the following: 1) The Global Precipitation Climatology Project (GPCP) monthly precipitation observation dataset from 1991 to 2010 (Adler et al., 2003), which was used for validation; 2) The monthly NCEP atmospheric circulation in terms of the geopotential height, wind, and surface pressure from 1991 to 2010 (Masao et al., 2002); and 3) The extended reconstructed monthly SST from 1991 to 2010 produced by the National Oceanic and Atmospheric Administration (NOAA) (Smith et al., 2008).

To align the horizontal resolution of the datasets, the model hindcasts, the observational datasets and the reanalysis datasets (except for SST) were interpolated to a horizontal resolution of 1° × 1° over EA-NWP. The climatology was evaluated as the seasonal mean from June to August (JJA) (accumulation of precipitation) for the years 1991 to 2010. A Student's *t*-test was used to assess the statistical significance of the differences between positive and negative composites (Wilks, 2011).

3. The BCC_CSM's bias in the climatology and the leading mode of summer precipitation over EA-NWP

In Fig. 1(a), observed climatology of summer precipitation increased from the north to south, from inland region to oceanic region, with high-value centers distributed in tropical regions. This distribution feature is associated with the observed climatology of 500 hPa Geopotential height in Fig. 1 (b). Meanwhile, precipitation for 1991–2010 is overestimated over the tropical WNP and the Western Indo-China Peninsula, whereas it is underestimated over the Mei-yu/Changma/Baiu area, including Southeastern China, Northwestern WNP, Korea and parts of Japan (Fig. 1. a). Moreover, the precipitation is also underestimated over the northeastern part of East Asia, the northern Bay of Bengal and the Maritime Continent (not shown). The bias in the 500 hPa geopotential height over EA-NWP is also analyzed to determine the reason for the precipitation prediction bias over the EA-NWP. The BCC_CSM's summer average of 500 hPa geopotential height for 1991–2010 is weaker than the observations over the subtropical WNP