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Invited review

Impact of Arctic Oscillation on the East Asian climate: A review

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ABSTRACT

The Arctic Oscillation (AO), which depicts a most dominant large-scale seesaw between the mid-latitudes and Arctic atmospheric mass, influences climate over Eurasia, North America, eastern Canada, North Africa, and the Middle East, especially during boreal winter. This review, with a special focus on the East Asian region, summarizes the climatic impact of AO. It begins with a description of the spatial structure of AO and the related climatic anomalies. The relationship of winter AO with the simultaneous East Asian winter climate (e.g. the East Asian winter monsoon (EAWM), cold surges/cold waves, and precipitation) and its instability are then followed. It is generally accepted that, through impacting the Siberian high, westerly wind, blocking frequency, Rossby wave activities etc., a positive phase of winter AO is associated with a weaker-than-normal EAWM, warmer conditions in East Asia, less frequency of cold surges/cold waves, increasing (decreasing) of winter precipitation in south (north) parts of East Asia; and vice versa. Notably, the pathways that the winter AO exerts impact are different. Besides, the AO-EAWM and the AO-cold surges/cold wave linkages have spatial and temporal variations. Subsequently, an overview of the inter-seasonal linkages between the East Asian summer monsoon with the preceding spring/winter AO is presented. There is a generally accepted knowledge that a positive spring AO is followed by significant positive summer precipitation anomalies in southern China and western Pacific as well as negative ones in the lower valley of Yangtze River and southern Japan. Finally, this review synthesizes the impact of winter/spring AO on the East Asian spring climate (e.g. dust storm, temperature, and precipitation) and discusses the potential predictive value of AO. The projection of AO and its impact on the East Asian climate in future has been barely explored. We conclude that, along with the long-term observation data, the linkage between AO and the East Asian climate on the sub-seasonal and decadal time scales, how tropical and extratropical forcing modulates the linkage and how the linkage evolves under future warming conditions should be more investigated. Notably, the change of AO during 1990–2013 winters could explain the Eurasian cooling but failed to explain the Arctic warming. In the future, the effect of Ural blocking on Arctic and Eurasian climate and their connection might be a hot topic.

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1. Introduction

Thompson and Wallace (1998) applied the empirical orthogonal function (EOF) to the extended-winter (November–April) sea level pressure (SLP) anomaly field over the domain poleward of 20°N and found that the leading vector of EOF is characterized by opposite pressure anomalies in the Arctic and the mid-latitudes (Fig. 1a). Although the AO resembles the North Atlantic Oscillation (NAO, Rogers, 1981) in many respects, it shows some unique characters in the Polar region and North Pacific. The main differences are 1) the NAO has no center of action in the Pacific, and 2) the AO has a broader center of action over the polar cap, giving it a more zonally symmetric appearance (Thompson et al., 2000). Furthermore, this leading EOF is more strongly coupled to surface air temperature (SAT) fluctuations over the Eurasian continent than the NAO (Thompson and Wallace, 1998; Wang et al., 2005). The correlation coefficients of this leading EOF time series and NAO index with the Eurasian extended-winter SAT anomalies during 1900–1995 are 0.55, 0.23 on the interannual time scale, respectively (Table 2 in Thompson and Wallace, 1998). To distinguish this pattern from the regional NAO, Thompson and Wallace (1998) referred to it as the Arctic Oscillation (AO) and the associated principal component time series as the AO index (Fig. 1b). Since then, the AO has been well-known in scientific community for its role in shaping the climate over the Northern Hemisphere (NH) (Gong et al., 2001; Gong and Ho, 2003; Jeong and Ho, 2005; Shi and Bueh, 2011; Kim and Ahn, 2012; Cui et al., 2013; Xue et al., 2014; Wan and Li, 2015).

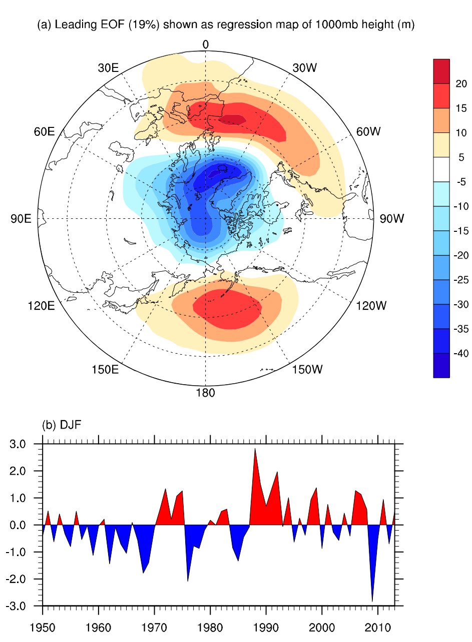

Fig. 1. The AO pattern. (a) Leading pattern of the AO which is defined as the leading mode of EOF analysis of monthly mean 1000 mb height during 1979–2000 period. (b) The principal component time series of the leading EOF during 1950–2013 winter (DJF). Figures and datasets could be downloaded from NOAA Climate Prediction Center on their website at http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/ao.shtml.

The AO is present in both cold and warm seasons, but its amplitude and meridional scale are generally larger during the cold season (Thompson and Wallace, 2000). It is revealed that the positive polarity of winter AO is associated with positive SAT anomalies throughout high latitudes of Eurasia. This SAT anomalies pattern is evident throughout the year except during the boreal summer months (Thompson and Wallace, 2000). Due to the close interannual relationship between the winter AO and Eurasian winter SAT, some studies suggest that the transition of AO from negative phase to its positive phase after the mid-1980s might contribute to interdecadal warming over Eurasia. For example, Thompson and Wallace (2000) pointed out that during 1970–2000 January–March, positive trends in the AO described ~50% of the warming trends over Europe and Asia, ~30% of the warming over the entire Northern Hemisphere, and ~40% of stratospheric cooling. Meanwhile, many previous studies have documented that the climate over Europe and West Asia is also largely dominated by the NAO (Hurrell and Deser, 2009; Luo and Cha, 2012; Luo et al., 2014, 2016a, 2016b). It's very difficult to distinguish the relative effects of NAO and AO over these regions. And it is not the ambition of this review paper to discuss the difference between AO and NAO because it is still a debatable question (Deser, 2000; Ambaum et al., 2001; Wallace and Thompson, 2002). Besides, the various alterations of meteorological parameters over the Atlantic Ocean and Europe associated with NAO have been sufficiently reviewed by Bader et al. (2011). Therefore, the impact of AO over East Asia will be the main focus of this review paper.

East Asia, located in the eastern Asian continent, includes the countries such as China, North Korea, South Korea, Mongolia, and Japan (please see Fig. 6a for geographical position). Driven by the thermal contrast (both in winter and summer) between the Eurasia continent and the Pacific, East Asian monsoons are the dominant climate over East Asia. The East Asian winter monsoon (EAWM) (generally refer to December–January–February) consists of sub-components, such as the Siberian high, Aleutian low, East Asian trough, low-level northerly and high-level East Asian jet stream (Wang and He, 2012; He and Wang, 2013a; He et al., 2013; He, 2015b). The low-level northerly along coastal East Asia brings cold air to the Asian continent, leading to cold climate during winters (Boyle and Chen, 1987; Chang et al., 2006; Li and Wang, 2012b; Li and Wang, 2012a, 2013). Another distinctive component of the Asian climate system is the East Asian summer (generally refer to June–July–August) monsoon (EASM). As the anomalous southerly (lower component of the EASM) are expected to bring more moisture to East Asia, the summer precipitation over East Asia is significant correlated with the EASM (Wang, 2001, 2002). In fact, the EASM can contribute to about 40–50% of the annual total precipitation amount over East Asia (Gong and Wang, 2003).

Given the significant influence of monsoon on East Asian climate, there has been much research effort devoted to better understanding the ingredients of the cause of the East Asian climate variability which shows both the interannual and interdecadal change. The EAWM varies on interannual timescales with strong variability on quasi-2, 4, and 4–7 years and on interdecadal timescales with remarkable cycles of 9–10, 20–30, 40 years and even longer (Ding et al., 2014, 2015). Early studies suggested that the East Asian climate variability could be significantly impacted by the anomalies of global ocean-land-atmospheric interaction such as El Niño-Southern Oscillation (ENSO) (Wang et al., 2000; Chang et al., 2006; He, 2015a), snow cover over the Eurasian continent (Shinoda, 2001; Liu and Yanai, 2002), AO (Gong et al., 2001; Jeong and Ho, 2005; Park et al., 2010), NAO (Luo et al., 2016a, 2016b),