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Possible influence of Asian polar vertex contraction on rainfall deficits in China in autumn

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ABSTRACT

The mechanisms governing variations in autumn precipitation are complicated and influenced by a number factors. This paper analyses the characteristics of autumn precipitation in China and investigates the influence of Asian polar vertex contraction on rainfall deficits in China and relevant mechanisms. Autumn precipitation decreased significantly from 1961 to 2012 in mid- and southern China, and the area of the Asia polar vortex (AAV) has decreased significantly since 1988. Asian polar vertex contraction is found to be an important factor in these autumn rainfall deficits in China through the following mechanism. Asian polar vertex contraction causes anomalously high geopotential heights in East Asia (from 25°N to 55°N) and low heights north of 65°N in the upper and lower troposphere, weakening meridional gradients in geopotential height. In the upper troposphere, the westerly and northerly winds are strengthened over high latitudes and westerly winds and the subtropical westerly jet are weakened over the East Asian mid-latitudes. In the lower troposphere, westerly winds are strengthened over high latitudes, westerly winds are weakened in East Asia and along the southern periphery of the Tibetan Plateau, and northerly winds in mid- and southern China are clearly strengthened. Hence, autumn rainfall decreases in mid- and southern China.

1. Introduction

Precipitation is one of many climate change indicators. Climate change, whether driven by natural or human forcing, can lead to changes in the likelihood or magnitude of extreme weather and climate events, such as drought. According to the IPCC AR5 report (IPCC, 2013), the globally averaged combined land and ocean surface temperature warmed by 0.72 °C over the 1951–2012 period. However, uncertainty concerning global-scale observed trends in drought and/or dryness since the mid-20th century is high. The frequency and intensity of drought have likely increased in the Mediterranean and West Africa and likely decreased in central North America and northwest Australia since 1950. The responses of drought to global warming differ between regions and between

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seasons in a given region. The most recent several decades have seen the emergence of widely recognized "floods in the south and drought in the north" in eastern China during summer. The characteristics and causes of these trends have been investigated extensively. Indeed, autumn drought is also occurring in southern China. Wang et al. (2009) analyzed seasonal trends in six precipitation indices in China during 1961–2007 based on daily observations at 587 stations; they found that precipitation decreased in autumn in eastern China with increasing maximum dry spell duration, implying a drying tendency during the post-rainy season. Li et al. (2014) detected regional meteorological drought events in Southwest China between 1960 and 2010 using the daily composite drought index; they found that regional meteorological drought events in southwest China increased in both frequency and intensity between 1960 and 2010 due primarily to a significant decrease in precipitation over this region. Jiang et al. (2014) reported that the variations of early autumn rainfall amount and number of rain days in the lee side of the Tibetan Plateau increase. Xiao et al. (2016) indicated that the summer and autumn precipitation across Yunnan has significantly decreased over the past 50 years. Wei et al. (2018) indicated that western China autumn precipitation experienced a significant inter-decadal shift around the mid-1980s followed by greatly reduced precipitation. These studies focus predominantly on variations in autumn precipitation in western and southwestern China.

Niu and Li (2008) found that droughts have been dominant over southern China since the 1990s and that autumn precipitation inter-annual variability over southern China is significantly correlated with the autumn western Pacific subtropical high. Autumn precipitation over southern China is positively correlated with July sea surface temperature (SST) in the western and northern Pacific Ocean, whereas a negative correlation occurs over the southern Indian Ocean. Zhang et al. (2011, 2013) demonstrated that the El Niño-Southern Oscillation (ENSO) has a substantial impact on autumn precipitation over China. Jian and Qiao (2012) found two dominant patterns of SST anomalies related to fall drought in southern China. Yang et al. (2017) suggested that SST can impact precipitation over China through a link between the Pacific Decadal Oscillation (PDO) and the decadal variability of the East Asian Summer Monsoon (EASM). Xiao et al. (2016) found that anomalous summer and autumn precipitation over Yunnan were influenced by a lower-atmosphere meridional wind anomaly in eastern China, a cross-equatorial airflow anomaly, a tropical zonal wind anomaly over the Indian Ocean, and the related South Asian and Western Pacific Subtropical Highs, which involve the Indian Ocean SST and the Pacific warm pool. Wei et al. (2018) indicated that the decrease in western China autumn precipitation is related to features including the weakening of warm, wet prevailing southerlies from the oceans to inland China, the weakening of Eurasian patterns, and the southward displacement of the East Asian jet stream. These studies focus mainly on variations in autumn drought characteristics and the influence of oceanic factors.

Huang et al. (2012) analyzed the causes of severe drought in southwestern China between the fall of 2009 and the spring of 2010, finding that both the SST in the Pacific and Indian Oceans and the arctic oscillation (AO) influence drought. The AO, which characterizes the strength of the Arctic vortex, can lead to circulation anomalies over the mid- and high latitudes, which can impact severe drought appreciably. Angell (2006) found that the AO increased clearly with the significant retraction of the Arctic vortex in 1963–2001.

A polar vortex is a persistent, large-scale cyclone of extremely cold air located near either of a planet's geographical poles (Angell, 2006; Wang and Ding, 2009). On Earth, the polar vortices are located in the middle and upper troposphere and the stratosphere (Zhang et al., 2006); they surround the polar highs and lie in the wake of the polar front (Frauenfeld and Davis, 2003). These cold-core, low-pressure areas strengthen in the winter and weaken in the summer due to their reliance upon the temperature differential between the equator and the poles (Gu and Yang, 2006). Important to weather systems in the Arctic region, the Arctic vortex has responded significantly to global warming and sea ice reduction. In general, the area of the Arctic vortex has clearly contracted under global warming (Wang and Ding, 2009; Waugh et al., 2016). The intensity and position of the Arctic vortex have also changed in recent decades. For example, the wintertime Arctic stratospheric polar vortex has weakened (Kim et al., 2014) and shifted persistently towards the Eurasian continent and away from North America over the past three decades (Zhang et al., 2016).

The variability of the Northern Hemisphere stratospheric polar vortex has been linked with tropospheric blocking (Woollings et al., 2010) and has been shown to influence surface climate (Baldwin and Dunkerton, 2001; Thompson et al., 2002; Mitchell et al., 2012). The polar vortex has been also shown to influence variations in climate variables such as precipitation and temperature over China (Huang et al., 2004; Zhang et al., 2006; Wu et al., 2008; Li et al., 2012). However, these studies focus on winter and summer; climate impacts during autumn have not been determined. This paper investigates the relationship between Asian polar vertex contraction and rainfall deficits in China in autumn in order to determine possible mechanisms of influence.

2. Data and methods

The monthly precipitation data used herein, which were measured from 1961 to 2012 at 730 stations in China, were supplied by the China Meteorological Administration. Atmospheric circulation was examined using NCEP/NCAR reanalysis data from the National Center for Environmental Prediction/National Center for Atmospheric Research (Kalnay et al., 1996). A Global Precipitation Climatology Centre (GPCC) monthly precipitation dataset with a 1.0° latitude × 1.0° longitude global grid (Schneider et al., 2011) spanning 1901–present, which was calculated from global station data, was used in the composite analysis.

The Asia polar vortex area (AAV) index was derived from the 74 circulation parameters treated by the Climate Diagnostics and Prediction Division of the China Meteorological Administration National Climate Center. These data were obtained from the website (http://cmdp.ncc.cma.gov.cn/nccdownload/index.php?ChannelID=1). The AAV is defined as the area from 60°E to 150°E and from the North Pole to the isohypse contour line, which indicates the southern boundary of the polar vortex at 500 hPa. The isohypse contour line varies according to the month.

In this study, Mann-Kendall (MK) testing was used to detect long-term trends and abrupt changes. The MK test is a rank-based