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Moisture sources of extreme summer precipitation events in North Xinjiang and their relationship with atmospheric circulation

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Abstract

In this study, the daily observational precipitation data and NCEP reanalysis data during 1951−2014, Euler and Lagrangian method were used to investigate the moisture sources of summer extreme precipitation events in North Xinjiang. The results show that water vapor at low and upper levels of most summer heavy rain (more than 50 mm d^{-1} and less than 100 mm d^{-1}) in North Xinjiang are mainly transported by westerly circulation from the North Atlantic Ocean and the Eurasian continent. However, rainstorms of more than 100 mm d^{-1}, which are rarely observed, are dominated by vertically integrated moisture from the North Atlantic, Arctic Oceans, and the Eurasian continent, in addition to low-level moisture from the Indian Ocean. Among these sources, the anomalous low-level moisture from the Indian Ocean, which is closely associated with stronger meridional circulation, is considered to be more important with respect to rainstorms. On the days prior to rainstorm days, stronger meridional circulation leads to an anomalous pressure gradient force, which can transport low-level moisture from the Indian Ocean along the eastern periphery of the Tibetan Plateau to North Xinjiang. Furthermore, moisture from the North Atlantic, Arctic Oceans, the Eurasian continent, and the Indian Ocean converge together to influence rainstorm development in this region.

Keywords: North Xinjiang; Moisture sources; Extreme precipitation events; Lagrangian trajectory model; Indian Ocean

1. Introduction

North Xinjiang (NX) is located in the western part of northwestern China, where precipitation is scarce. This region is far from ocean, and the movement of water vapor is blocked by the Tibetan Plateau and Tienshan Mountains (Fig. 1, Feng and Fu, 2013). In recent years, global warming has impacted the water cycle over land and has led to regional moisture variations. Many studies have been conducted to better understand the moisture variations in Xinjiang and the nearby arid area. In this respect, researchers have determined that certain indicators—annual precipitation and soil moisture levels—relate to moisture conditions, as these have been increasing over recent decades in the inland lake area of Xinjiang and the nearby arid area (Jiang et al., 2005; Feng et al., 2007; Su and Wang, 2007; Chen et al., 2011). Evidence suggests that, since the mid-1980s, the climate and environment of Xinjiang have been undergoing a shift from a warm-dry to a warm-wet regime (Shi et al., 2007). Both the intensity and path of water vapor transport play important roles in regional moisture variations, so it is important to analyze the moisture sources of precipitation to gain an understanding of Xinjiang's warm wet regime in the context of global warming.

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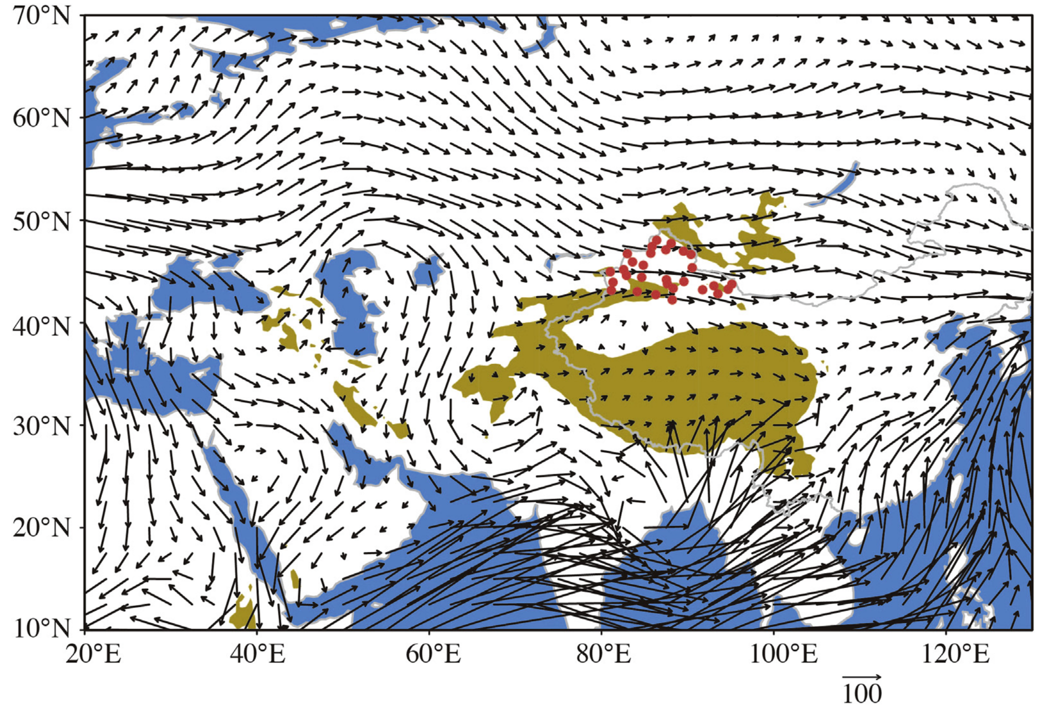

Fig. 1. Climatological water vapor fluxes during 1971−2000 (arrows, unit: kg m^{-1} s^{-1}). Yellow shadings indicate areas of terrain above 2000 m (above sea level); red dots indicate locations of 29 national meteorological stations in North Xinjiang.

Previous studies have suggested that the climatological water vapor influencing Xinjiang and the nearby arid area primarily originates from the west (Yatagai, 2003; Huang et al., 2013). Huang et al. (2015) analyzed summer precipitation and its association with moisture and atmospheric circulation within the Tarim Basin and found that variations in anomalous summer precipitation have been dominated by water vapor originating from the south and east, and that anomalous water vapor fluxes are closely related with the circum global teleconnection (CGT) and the meridional teleconnection pattern around 50°−80°E. However, the moisture sources of precipitation in NX have not been understood clearly.

Additionally, most studies on water vapor transport have focused on climatological rather than precipitation events, and to date no attempts have been made to understand the moisture sources of extreme precipitation events with differing intensities in NX. Globally, the frequency and intensity of extreme precipitation events have shown noticeable increasing trends in relation to global warming (Easterling et al., 2000a, 2000b; Goswami et al., 2006). As NX is located in both arid and semiarid regions, only a relatively few days of precipitation are required to contribute most of the typical summer precipitation. The total annual precipitation in this region is less than 400 mm, with most occurring during summer. As such, extreme precipitation events in this region cause enormous variations in summer precipitation levels. Yang (2003) argues that in the 1980s the climate in Xinjiang shifted from a warm-dry to a warm-wet regime, based on the increased frequency of extreme precipitation events. The focus of this study, therefore, is to analyze the moisture sources of summer extreme precipitation events in NX.

2. Data and methods

The daily precipitation data from the China Ground Daily Climate Dataset Version 3.0 (obtained from 824 national meteorological stations) was used to analyze extreme precipitation events. This dataset covers the period from January 1, 1951 to December 12, 2014, and its quality and uniformity are maintained by the National Meteorological Information Center. Precipitation at 29 stations falls mainly during the summer time (June−August) in NX were used. In this respect, the analysis focuses on water vapor transport during 1951−2014 for two precipitation scenarios: 1) heavy rain days as Case 1 (daily precipitation more than 50 mm $d^{-1}$and less than 100 mm d^{-1}, $n = 45$ d), and 2) rainstorm days as Case 2 (daily precipitation more than 100 mm d^{-1}, $n = 2$ d). In addition, daily and monthly geopotential height, winds, vertical velocity, and specific humidity at various pressure levels for 1951−2014 were obtained from the National Center for Environmental Prediction-National Center for Atmospheric Research (NCEP-NCAR) reanalysis (Kalnay et al., 1996).

To evaluate the impacts of water vapor transportion on precipitation in NX, the vertically integrated horizontal water vapor fluxes were calculated by the following equation:

$$\vec{Q} = \frac{1}{g} \int_{300\text{hPa}}^{p_s} q\vec{V}dp \quad (1)$$