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The Remote Responses of Early Summer Cold Vortex Precipitation in Northeastern China to the precedent Sea Surface Temperatures

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ABSTRACT

Based on the daily precipitation data of Northeastern China (NEC), this research study utilized the monthly mean geopotential height field and vertical velocity field data obtained by NCEP/NCAR reanalysis. In addition, the monthly mean SST (sea surface temperature) data obtained by NOAA reconstruction, along with the calculations of NEC precipitation generated on the occurrence date of the annual early summer (June) northeast cold vortex (NECV) (hereinafter referred to as the cold vortex precipitation) were used to analyze the variation characteristics of cold vortex precipitation. The aim of this study was to explain the physical mechanism of the previous SST factors which had influenced the cold vortex precipitation through the force of atmospheric circulations, from the perspective of a statistical analysis. Finally, sensitivity tests of the AM2.1 atmospheric circulation model were conducted to verify the statistical analysis results. The results revealed that since 1961 there had been a significant increase trend in the early summer cold vortex precipitation. The relationships between the NEC early summer cold vortex precipitation and the previous SST were divided into three periods. During the period ranging from 1961 to 1979 (hereinafter referred to as Phase 1), a NAT anomaly positive phase during March to May resulted in the blocking highs of the Ural Mountains and the Sea of Okhotsk becoming strengthened ("dual blocking pattern") in the early summer, which in turn led to increased early summer cold vortex precipitation. During the period ranging from 1980 to 2000 (hereinafter referred to as Phase 2), a higher Kuroshio SST in April to May stimulated an EU-like teleconnection pattern in the early summer over Eastern Asia. As a result, the cold vortex precipitation in early summer was reduced. After 2001 (hereinafter referred to as Phase 3), the NAT anomaly negative phase during March to May induced strengthened blocking patterns on the northwestern side of Lake Baikal in the early summer, which was accompanied by a strengthened northeastern cold vortex (a pattern of "higher in the north, lower in the south"). Also, an upward vertical velocity anomaly appeared over the NEC, which resulted in increased early summer cold vortex precipitation. The sensitivity tests of this study's numerical model reproduced the force effects of the Kuroshio SST in Phase 2, and the NAT in Phase 3 on the EU-like teleconnection pattern, and the pattern of "higher in the north, lower in the south". These findings further corroborated the aforementioned results.

1. Introduction

The NEC is one of China's largest commercial grain bases and agricultural production areas, and is expected to be the source of the country's greatest development potential. Summer is the main growth season of the NEC crops, as well as the season with the most

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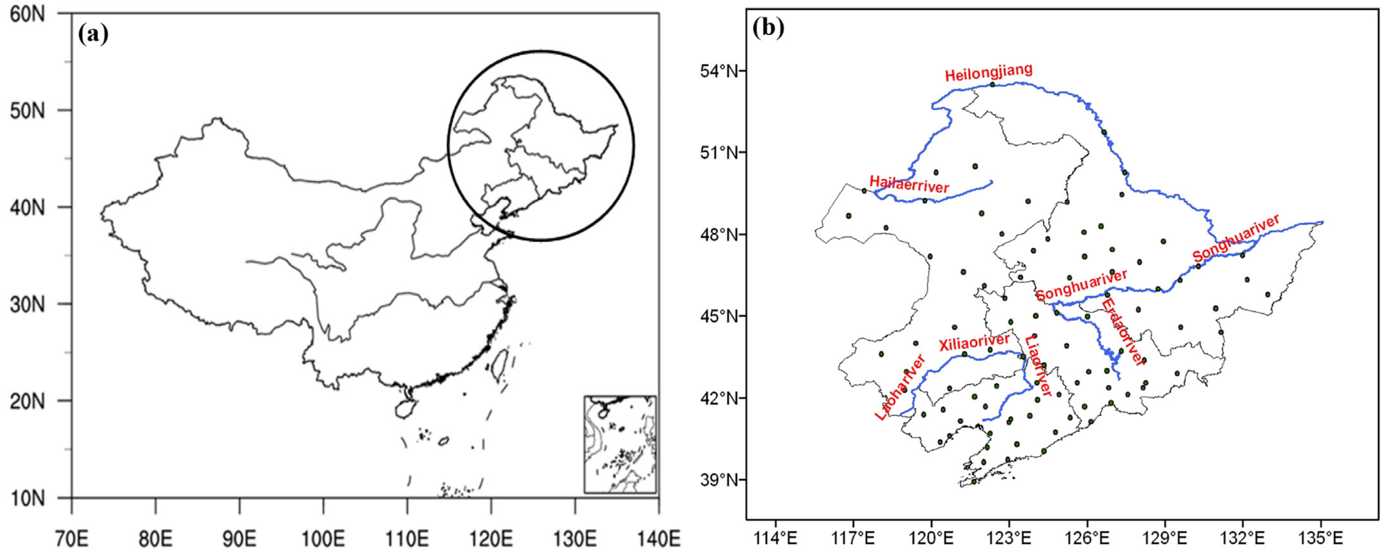

(a) (b)

Fig. 1. (a) Location of NEC; and (b) Distribution of the 94 selected stations in the NEC.

concentrated yearly precipitation. The amount and distribution of the summer precipitation are among the important factors affecting the grain yields of the NEC. Therefore, it is of great significance for China's grain production safety to study the NEC's summer precipitation. In addition, studies on regarding the NEC's summer precipitation are helpful in the prevention and reduction of natural disasters.

The influence systems of the precipitation in the NEC in early (June) and midsummer (July and August) months differ considerably. The early summer precipitation is mainly affected by the northeast cold vortex. Meanwhile, the midsummer precipitation is influenced by the East Asian summer monsoons (Shen, 2011). As a result, when analyzing the NEC summer precipitation, it is necessary to analyze the early summer and midsummer separately. The present study mainly focused on the early summer precipitation. The previous research studies regarding the early summer precipitation patterns of the NEC were mainly based on the relationship between the early summer precipitation and the northeast cold vortex (Li et al., 2014; Fang et al., 2016). The northeast cold vortex (NECV) is not only an important part of a mid- to-high-altitude atmospheric circulation in Eastern Asia, but also a particularly important weather system of the NEC. For example, the frequency of the activities related to the NECV may cause flood, drought or chill damages in the NEC (Sun and An, 2001; Sun et al., 2002; Wang et al., 2007). The continuous activities of the NECV are important symbols of the abnormal continuity and adjustments of the mid- to high-latitude atmospheric circulations in the northern hemisphere (Liu et al., 2002). Previously, studies have been carried out regarding the influences of the NECV on climate conditions. For example, Hu et al. (2011) pointed out that, under the control of the local persistent NECV, increased local precipitation could be caused during the spring and summer months. He et al. (2006a) held that the frequent occurrences of cold vortex systems would essentially bring cold and rainy weather, and even flood disasters, to the NEC during the summer seasons.

Considering the significant role of the NECV on the early summer precipitation of NEC, it is very important to predict the NECV precipitation according to the previous abnormal signals of the external forces in the area, considering their significant roles in the early summer precipitation of the NEC. For the previous predictions of the NECV, Liu et al. (2002) and He et al. (2006b) discovered that the previous North Pacific oscillations (NPO), along with the previous North Pacific SST anomalies, had close relationships with the anomalies of the NECV. Shen et al. used a similar-year method to accurately predict the NECV of the case years. However, the past predictions of the NECV were mainly characterized by the monthly or seasonal average 500 hPa height field, while the influences of the NECV system are known to be a synoptic-scale process. Therefore, in order to ensure more accurate and reasonable data regarding the NECV activities, future research should be based on the atmospheric circulations or meteorological elements of the daily time scale for the characterization process. In order to address these issues, this study adopted a NECV objective recognition method based on a daily synoptic chart, in which the NEC's accumulated precipitation (cold vortex precipitation) during the annual early summer cold vortex days were taken as the research objects. Then, the responses of the NECV precipitation to the previous global SST anomaly signals and physical mechanisms were analyzed in order to provide theoretical support for the forecasting of NEC early summer cold vortex precipitation.

2. Materials and methods

2.1. Data sources

The data used in this study included the daily precipitation data of China's northeastern region (Heilongjiang, Jilin, Liaoning, and eastern Inner Mongolia) from 1961 to 2012, which were provided by the National Meteorological Information Center. Then, by processing of the values absent in the measurements, a total of 94 stations in the northeastern region were finally selected. The monthly average 500 hPa potential height field data of the NCEP/NCAR were reanalyzed. Also, the monthly mean SST data were reconstructed using NOAA. The circle shown in Fig. 1a denotes the geographical location of the NEC. Fig. 1b shows the spatial distribution of the selected 94 meteorological stations.

2.2. Research methods

In this research study, correlation analysis and other statistical analysis methods were used to analyze the relationship between the cold vortex precipitation in early summer and the previous SST and simultaneous circulation. Meanwhile, sensitivity tests were designed based on the AM2.1 global atmospheric model in order to verify the conclusions obtained by the statistical analysis.