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Analysis of Heavy Precipitation Event in Northeast China from August 1 to 5, 2023

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Abstract

This study delves into the multiple weather systems and their interaction mechanisms that caused the severe rainfall event in Northeast China in early August 2023. The analysis reveals that the atmospheric circulation in the mid-to-high latitudes of the Eurasian continent exhibited a significant "two troughs and two ridges" structure, with Northeast China located precisely in the peripheral region of the subtropical high, significantly influenced by its marginal airflows. Additionally, the residual circulation of Typhoon "Doksuri" interacting with the subtropical high and upper-level troughs significantly increased the rainfall intensity and duration in the region. In particular, the continuous and powerful transport of the southwest jet provided the necessary moisture and unstable conditions for the generation and development of convective systems. The rainfall event resulted in nearly 40,000 people affected and crop damage covering an area of approximately 4000 hectares, demonstrating the severity of extreme weather. The study emphasizes that strengthening meteorological monitoring and early warning systems, as well as formulating and improving emergency response mechanisms, are crucial for reducing potential disaster losses caused by heavy rainfall. Future research can further explore the interaction mechanisms among weather systems, limitations of data sources, and the connection between long-term trends of heavy rainfall events and global climate change.

Keywords

Heavy Precipitation, Eurasian Circulation, Typhoon Doksuri, Water Vapor Transport, Regional Heavy Rainfall Mechanism

1. Introduction

Precipitation refers to water vapor condensation falling from the atmosphere to the ground, including rain, snow, etc. Strong rainfall requires sufficient water vapor, upward movement, and condensation nuclei. Typhoons often contribute significantly to heavy rain by transporting vast amounts of water vapor. Worldwide, cities utilize techniques like rainwater harvesting and stormwater management to mitigate flooding and promote sustainable water use. In early August 2023, Northeast China, particularly Shulan City in Jilin Province, there experienced severe heavy rainfall. From the evening of August 1st to 15:00 (Beijing time, the same below) on August 4th, the average rainfall in Shulan City reached 111.7 millimeters, with Yongsheng Forest Farm, the center of heavy rainfall, recording a staggering 489.0 millimeters. Additionally, nine weather stations reported rainfall amounts that were 2 to 4 times than their historical extremes. On August 3rd at 19:00, the hourly rainfall intensity in Jinma Town reached 95.7 millimeters, indicating the intense nature of the precipitation. As a result of this heavy rainfall, the Lalin River basin in Yushu City, Changchun, Jilin Province, experienced a catastrophic flood that occurs once in over 50 years. Nearly 40,000 people in eight townships along the river were affected, and the affected area of crops approached 4000 hectares, causing significant human and property losses. This extreme weather event not only had profound impacts on the ecological environment and socio-economic conditions in Northeast China but also presented a new case and challenge for studying weather events.

A recent study reveals that climate change is having progressively serious impacts on global precipitation patterns. Rising temperatures and shifting atmospheric conditions are altering the frequency, intensity, and spatial distribution of rainfall, with potentially grave consequences for ecosystems, agriculture, and water resources worldwide (Irumva et al., 2023). Heavy rainfall, as a global meteorological phenomenon, has been a hot topic in meteorological research due to its causes and impact mechanisms. Multiple studies have explored the dynamic conditions, circulation backgrounds, and interactions with terrain, climate, and other factors of heavy rainfall from different perspectives, providing a scientific basis for a deep understanding of the heavy rainfall process. Chen & Wang (2023) investigated the precipitation, circulation, and dynamic conditions of heavy rainfall in Henan Province, China, in July 2021. The results showed that the dynamic changes in the western Pacific subtropical high typhoons, and the Eurasian trough-ridge structure jointly maintained favorable large-scale circulation backgrounds and water vapor conditions. The vertical structure of low-level convergence and high-level divergence near Zhengzhou, coupled with the topographic blocking and uplift, provided favorable dynamic uplift conditions for heavy rainfall. Qi (2023) constructed weather maps at 850 hPa and 500 hPa, along with relative humidity and precipitation distribution maps, and used synoptic meteorology methods to analyze a heavy precipitation event in North China from August 23 to 24, 2020. The study indicated that the formation of short-term heavy precipitation requires sufficient water vapor and strong upward motion. The precipitation process was influenced by upper-level trough lines, cold vortices, and cold fronts, resulting in severe convective weather in North China. Additionally, Typhoon "Bavi" also affected the precipitation in North China, leading to an increase in maximum precipitation and air humidity. Tan (2022) focused specifically on rainstorm warnings in China and analyzed seasonal variations and regional differences in rainstorm warnings. The study found that rainstorm warnings are more frequent during specific seasons and closely related to regional characteristics. In particular, Henan Province had a significant proportion of red rainstorm warnings in July, which was closely associated with the sudden heavy rainfall event in the province that month. Liu (2022) analyzed a rainfall event that occurred in most parts of China from October 3 to 6, 2021. The results showed that the rainfall was related to the intersection of warm and wet air currents and cold air in central and western China and northeastern regions, forming a regional heavy rainfall process. The low-level jet stream moved from Guizhou and Hunan to the southern part of northeast China, bringing a large amount of water vapor. Abdel-Basset et al. (2015) calculated the adiabatic heating process during a heavy rainfall event in Jeddah, Saudi Arabia, on November 25, 2009, and found that horizontal heat advection was the dominant factor. The vertical advection term offset the adiabatic term, and the contribution of local temperature changes to changes in adiabatic heating was relatively small.

The innovation of this study lies in the combination of real-time case studies and regional specificity analysis. The study focus on a heavy rainfall event in Northeast China in early August 2023, conduct a new case study, deeply analyze its causes and characteristics, and provide a scientific basis for weather forecasting. At the same time, the study pays special attention to the unique climate and circulation conditions in Northeast China, revealing the mechanism of regional heavy rainfall. In the following discussion, we will first review the weather background and meteorological conditions of this heavy rainfall process, then explore its possible influencing factors in detail, and finally discuss some coping strategies for heavy precipitation.

2. Methodology

2.1. Data Sources

China National Climate Center, U.S. NCEP (National Centers for Environmental Prediction), and Japan Meteorological Agency are all important meteorological information release agencies in the world. The meteorological data they release plays an important role in weather forecasting, climate research and other fields. The meteorological data released by China National Climate Center used in this study includes historical climate data and real-time climate prediction data. The meteorological data released by the U.S. NCEP is very extensive, including global and regional weather forecasts, climate monitoring data, marine environmental data, etc. Among them, the reanalysis data of NCEP used in this study has been widely used in the field of global meteorology and climate research. These data sets combine observation data and numerical models to provide meteorological element fields on a global scale, which is of great significance for studying atmospheric circulation, climate change, etc. The Japan Meteorological Agency has a high reputation in early warning of natural disasters such as typhoons, and this study uses its historical typhoon information.

2.2. Research Methodology

As a global meteorological phenomenon, heavy rain has complex and diverse causes and impact mechanisms, which are affected by multiple factors. Synoptic meteorology research method is a scientific method to study the physical nature and laws of weather phenomena and processes. It mainly analyzes the changes of weather through describing various phenomena and processes in the atmosphere, such as fronts, cyclones, and troughs. This method particularly emphasizes the study of weather phenomena and processes that play an important role in weather evolution (Santurette & Georgiev, 2005; Zhu et al., 2007). In this study, the synoptic meteorology method was used to deeply explore the formation conditions, circulation background, and their interactions of heavy rain, providing a scientific basis for us to better understand the heavy rain process.

A robust review methodology was employed to ensure the rigor of this study. Keywords central to the research theme were utilized to search databases such as SpringerLink, Wiley Online Library, Web of Science, Google Scholar, Scopus, and Taylor & Francis Online. Publications were selected based on relevance, quality, and novelty. Both inclusion and exclusion criteria were defined to ensure the studies met our research objectives. The Web of Science database was primarily utilized, supported by other sources. The logic of results organization and discussion is grounded in PRISMA and VOS frameworks (Twagirayezu et al., 2024).

3. Results and Analysis

3.1. Evolution of Atmospheric Circulation

Based on the climate data of the average 500 hPa geopotential height field in the Eurasian region from early August (**Figure 1**), the atmospheric circulation in the mid-to-high latitudes of the Eurasian continent exhibited a prominent "two troughs and two ridges" structure during this period. Specifically, two trough regions were significantly present around the Caspian Sea and in Northeast China, respectively, and this distribution pattern partly shaped the weather conditions in these regions. Meanwhile, most other regions of China were under the control of the subtropical high's broken belt. It is worth noting that in the southeast waters of China, affected by tropical weather systems such as Typhoon Doksuri, a distinct central closed low-pressure area formed at the 500 hPa level. During the weather development from August 1 to 5, the westerly trough and the residual low-pressure circulation system of Typhoon Doksuri jointly affected most areas of Northeast China. This complex interaction resulted in widespread heavy

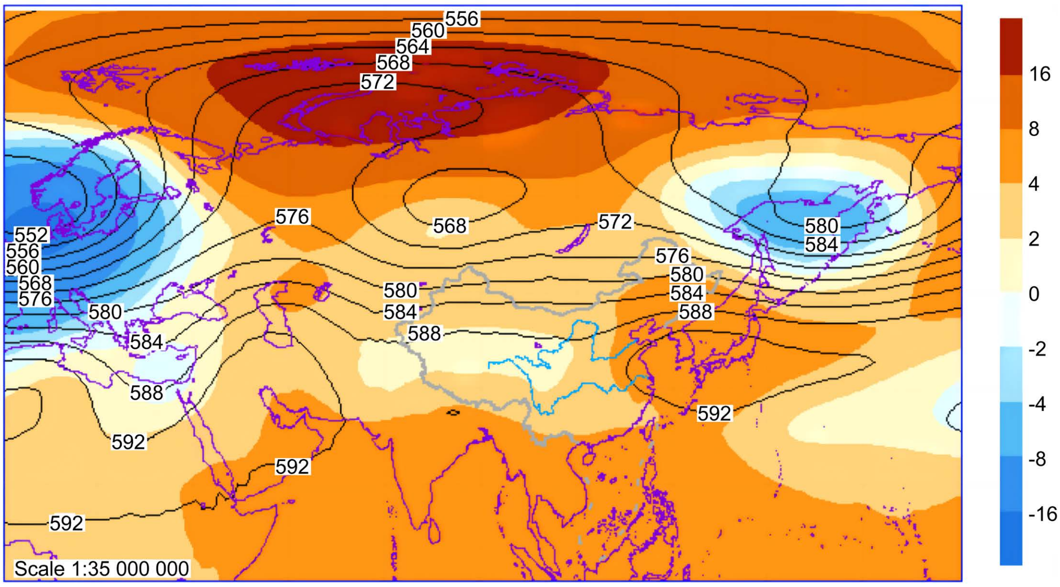

Figure 1. Average 500 hPa geopotential height field in the eurasian region in early August 2023.

rainfall in the region, with some areas experiencing torrential rains.

The interaction between these two weather systems created favorable conditions for the convergence of warm and moist air masses with cold air masses over Northeast China. This dynamic setup triggered the development of convective systems that led to the heavy precipitation. Additionally, the subtropical high's broken belt over most of China modulated the northward flow of moisture, further enhancing the precipitation potential in Northeast China. As a result, the "two troughs and two ridges" circulation pattern, coupled with the influence of Typhoon Doksuri and the subtropical high, significantly contributed to the extreme rainfall event observed in Northeast China during early August.

3.2. Analysis of Weather Systems Influencing Precipitation

During the widespread heavy precipitation event in Northeast China, multiple weather systems played a role, with the residual circulation of Typhoon Doksuri, upper-level troughs, and the subtropical high being the dominant factors. The interaction of these weather systems led to significant changes in meteorological conditions in Northeast China, ultimately triggering the heavy precipitation process.

Typhoon Doksuri is one of the significant typhoons that have affected China in recent years. After weakening into a tropical depression, its residual circulation continued to affect various regions of China, particularly Northeast China. Typhoon Doksuri exhibited strong intensity during its early formation and had a relatively stable path, mainly affecting the southeast coastal areas of China (Figure 2). After landfall, the typhoon moved northward at a relatively fast speed. In Jiangxi and Anhui provinces, where the typhoon passed through, the precipitation did not reach extreme levels. Doksuri weakened into a tropical depression within Anhui Province and further weakened into a residual low-pressure circulation. Due to the interconnection between the subtropical high and the western

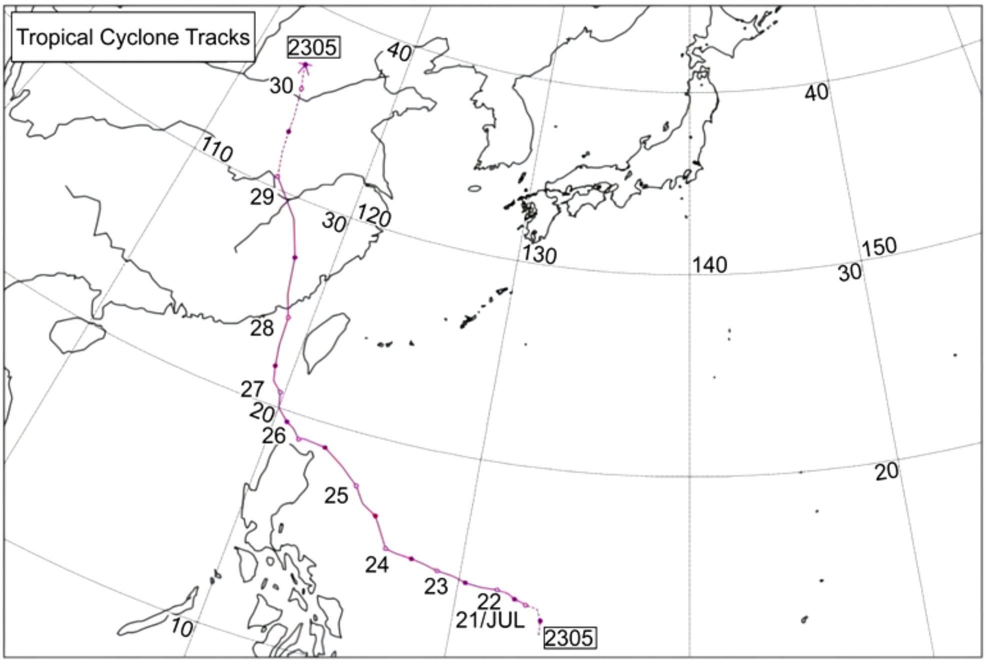

Figure 2. Track map of Typhoon Doksuri.

high-pressure ridge, a "high-pressure dam" was formed. This regional mechanism prolonged the duration of Doksuri's residual circulation in Northeast China, significantly increasing the accumulated rainfall and resulting in heavy rainstorms.

The residual circulation of Typhoon Doksuri, though weakened, retained sufficient moisture and energy to interact with local weather systems. In Northeast China, this interaction occurred in a region already predisposed to precipitation due to the "two troughs and two ridges" circulation pattern. The formation of the "high-pressure dam" acted as a barrier, trapping the residual moisture from Doksuri, leading to prolonged periods of heavy rainfall. The combination of these factors resulted in the extreme precipitation event observed, highlighting the complex interplay between tropical cyclones, atmospheric circulation patterns, and regional weather systems.

Based on the in-depth analysis of the weather situation map at 08:00 on August 3 (Figure 3), the location of Northeast China at the 500 hPa level appears particularly critical. It is situated in the peripheral region of the subtropical high, a powerful pressure system whose edge currents often carry abundant moisture and energy. This specific geographical location makes the region highly susceptible to the influence of these edge currents. When these currents encounter cold air in Northeast China, they create dynamic conditions favorable for precipitation.

Meanwhile, Figure 3 also reveals a significant impact of upper-level troughs on eastern Inner Mongolia and the three northeastern provinces of China. Upper-level troughs are important weather systems in the atmosphere, typically associated with decreasing air pressure and temperature. As these troughs move over the mentioned regions, they enhance atmospheric instability, making vertical air movement more likely. This increased vertical motion facilitates the

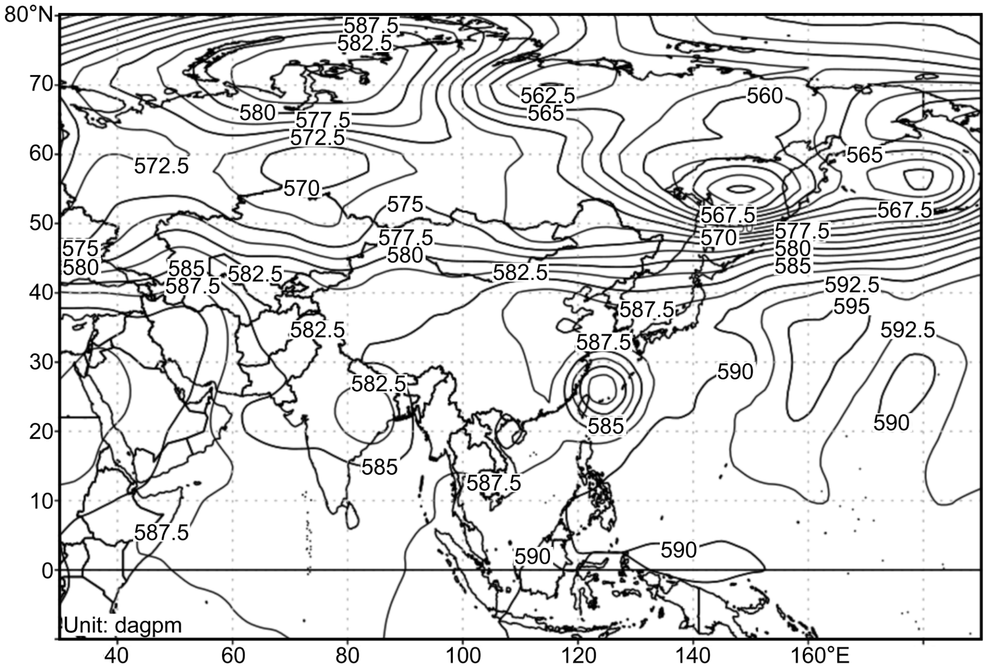

Figure 3. Weather map at 500 hPa at 08:00 on August 3.

transport of moisture and energy from lower to upper levels of the atmosphere, providing favorable conditions for the formation and development of precipitation cloud systems. Furthermore, the presence of upper-level troughs promotes the convergence and lifting of warm and cold air, further intensifying the strength and extent of precipitation.

In the case of Northeast China, the convergence of the subtropical high's edge currents with cold air masses was further augmented by the upper-level troughs. This combined effect led to a significant enhancement in the dynamic lifting processes, triggering the development of intense convective systems. These systems, in turn, released latent heat into the atmosphere, further destabilizing the air column and contributing to the amplification of the precipitation event.

Furthermore, on the weather map at 850 hPa at the same time (**Figure 4**), a distinct low vortex structure can be observed in the northwest of Northeast China. This low vortex is associated with southward-moving cold air that interacts with the low-level warm and moist airflows on the northwest side of the subtropical high. The convergence of these cold and warm air masses not only intensifies atmospheric instability but also provides a rich source of moisture, creating highly favorable conditions for the occurrence and development of precipitation.

The widespread heavy precipitation event in Northeast China was the result of the combined effects of multiple weather systems. The residual circulation of Typhoon Doksuri, upper-level troughs, and the subtropical high interacted at different altitudes and scales, collectively shaping the meteorological environment conducive to precipitation.

This vortex, in conjunction with the subtropical high and upper-level troughs,

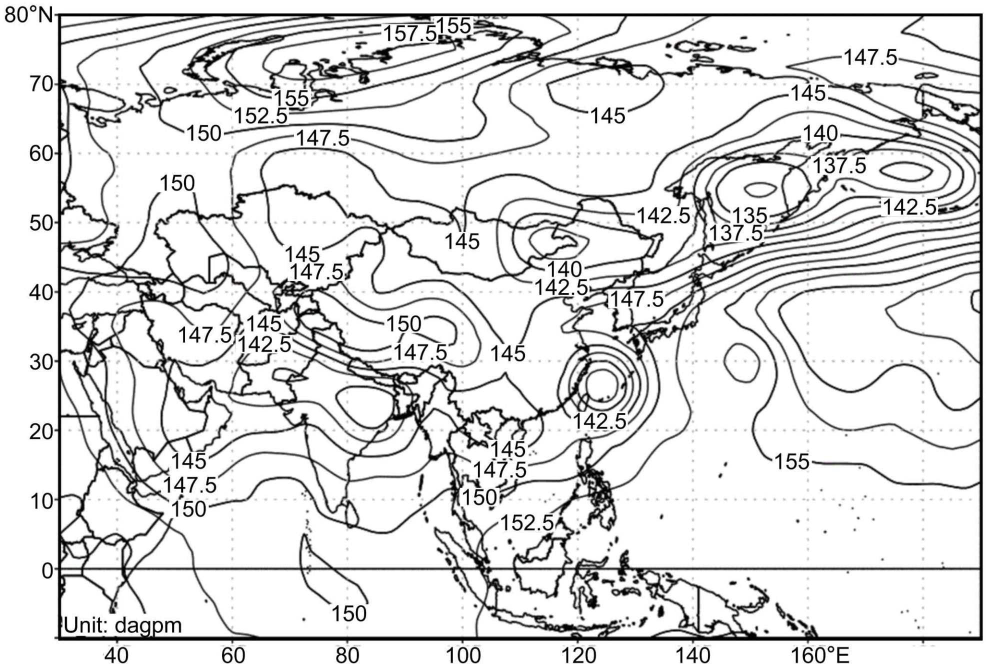

Figure 4. Weather map at 850 hPa at 08:00 on August 3.

created a complex flow pattern that significantly influenced the precipitation event. The vortex drew in cold air from the north, while the subtropical high's edge currents transported warm and moist air from the south. The collision of these opposing air masses led to the formation of convective cells, which released latent heat and further enhanced the precipitation process. In essence, the low vortex acted as a catalyst, intensifying the interactions between the various weather systems and ultimately contributing to the widespread heavy precipitation in Northeast China.

3.3. Analysis of Water Vapor Supply

In addition to the critical factor of the sustained presence of the low vortex shear, another significant underlying cause of the extreme heavy precipitation event in Northeast China was the adequate supply of water vapor. As analyzed in **Figure 5**, the southwest jet on the southeast side of the low vortex played a crucial role in this process. With a central wind speed exceeding 20 m/s, the jet's continuous and powerful transport of water vapor provided strong support for the generation and development of the convective system. Specifically, it not only brought abundant moisture but also provided the necessary unstable conditions for the weather system in the region, both contributing to the formation and intensification of the heavy precipitation event.

The southwest jet's influence was further amplified by the location of Northeast China within the subtropical high's marginal zone. This region is characterized by high moisture content and instability, making it particularly prone to convective activity. The combination of the southwest jet's water vapor transport and the subtropical high's instability created an ideal environment for the development of intense precipitation systems. Furthermore, the persistence of the low vortex shear maintained the vertical motion required for convective updrafts, leading to the sustained release of latent heat and further intensification of the precipitation event.

Figure 6 shows that, influenced by the aforementioned meteorological conditions, most of the precipitable water in the entire atmospheric layer in Northeast

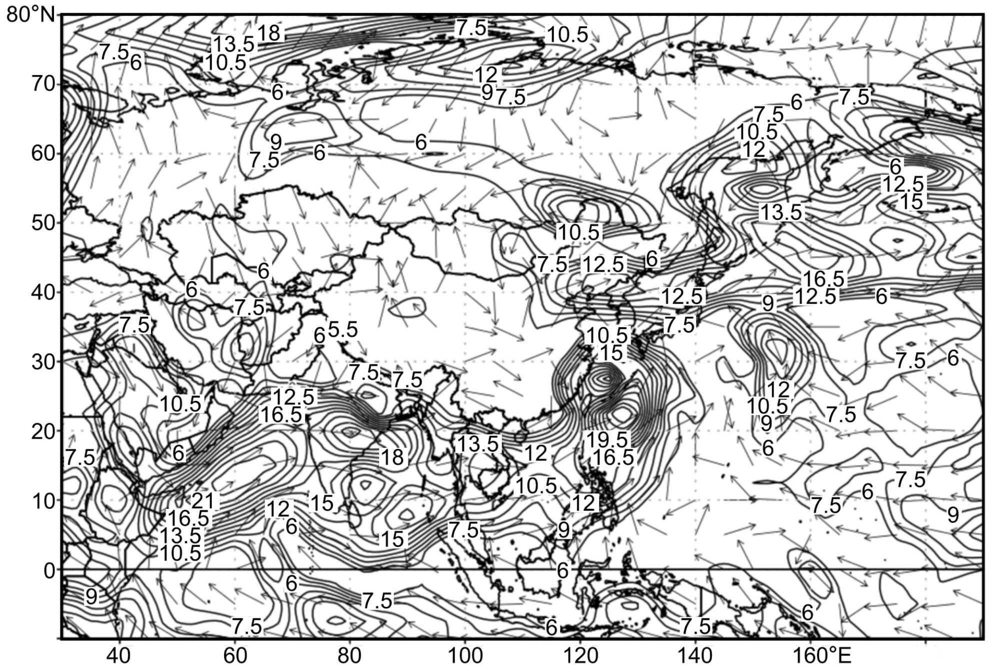

Figure 5. 850 hPa Wind Field at 08:00 on August 3.

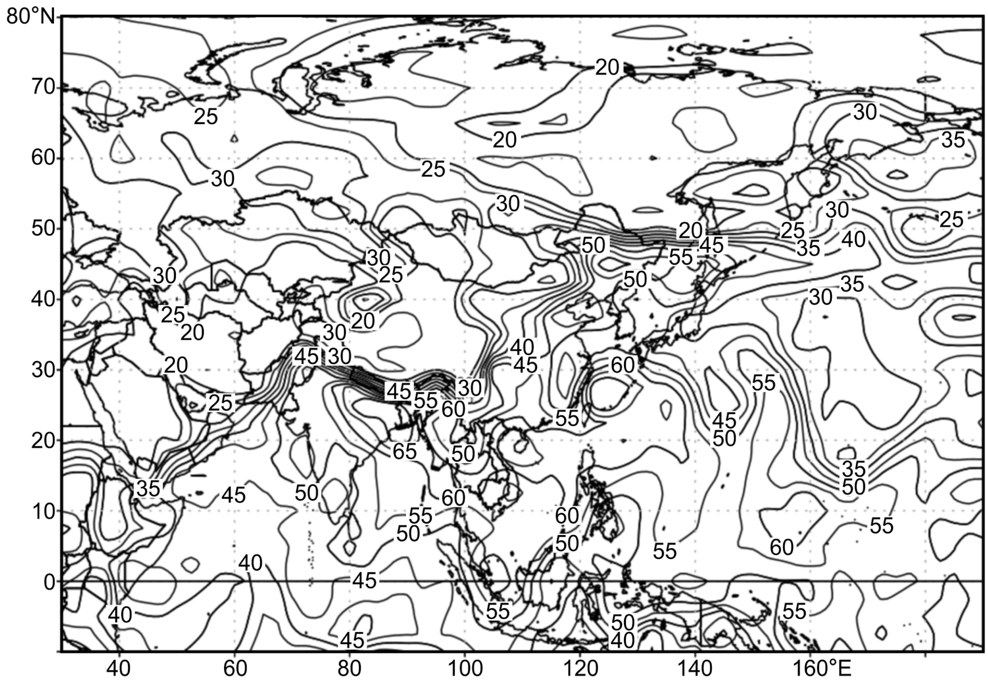

Figure 6. Precipitable Water in the Entire Atmospheric Layer at 08:00 on August 3.

China reached over 50 mm, and some local areas reached or exceeded 65 mm. Such abundant water vapor resources could rapidly condense and precipitate under suitable weather conditions, leading to a large amount of precipitation in a short period. Especially on August 2 and 3, the precipitation intensity in some local areas centered on Jilin Province increased abnormally, forming an extreme heavy precipitation event. According to detailed records, on August 3, the precipitation intensity in some areas even approached or reached 100 mm per hour, fully reflecting the extremity and severity of this precipitation event. Through the analysis of this event, we can clearly see the important roles of the low vortex shear, water vapor supply, and especially the southwest jet in the formation of heavy precipitation.

The ability of the atmosphere to hold such large quantities of moisture indicates the presence of favorable conditions for condensation and precipitation. When coupled with the dynamic lifting mechanisms provided by the low vortex shear and the southwest jet, the high water vapor content led to the rapid and intense release of precipitation. This event highlights the importance of considering both water vapor availability and dynamic processes when assessing the potential for extreme precipitation. Understanding and monitoring these factors is crucial for effective prediction and mitigation of such extreme weather events.

4. Conclusion and Discussion

This study has conducted an in-depth exploration of multiple weather systems and their interaction mechanisms affecting heavy precipitation events in Northeast China through detailed analysis of relevant weather and climate data from early August 2023. The main conclusions of the study are as follows:

Relationship between atmospheric circulation and precipitation: During this period, the mid-to-high latitudes of the Eurasian continent exhibited a significant “two troughs and two ridges” atmospheric circulation structure, with Northeast China located precisely in the peripheral region of the subtropical high, influenced by its marginal airflows. This circulation structure provided favorable dynamic conditions for heavy precipitation in Northeast China.

Impact of the residual circulation of Typhoon Doksuri: As one of the significant typhoons affecting China in recent years, the residual circulation of Typhoon Doksuri continued to have a notable impact on Northeast China even after its weakening. Its interaction with the subtropical high and upper-level troughs contributed to increased precipitation intensity and duration in the region.

Water vapor supply and the formation of heavy precipitation: In addition to the maintenance of the low vortex shear, adequate water vapor supply was a crucial factor in this heavy precipitation event. In particular, the continuous and powerful transport of the southwest jet provided the necessary moisture and unstable conditions for the generation and development of convective systems.

This study also acknowledges the significant impacts of heavy precipitation events on various aspects such as regional ecology, agriculture, and urban operations. Therefore, it is particularly crucial to devise effective strategies to address such extreme weather events. On the one hand, meteorological monitoring and early warning systems should be strengthened to improve the accuracy and timeliness of forecasts; on the other hand, emergency response mechanisms should be formulated and improved to reduce potential disaster losses caused by heavy precipitation.

Meanwhile, this study also has certain limitations. Firstly, further in-depth research may be needed on the interaction mechanisms among various weather systems. Secondly, due to limitations in data sources, such as the lack of radar and satellite meteorological data, there may be other unconsidered influencing factors. Lastly, the long-term trends of heavy precipitation events and their connections with global climate change are also worthy of further exploration. Future research can expand and deepen in these areas.

In light of the extreme precipitation event, coping strategies are crucial. To mitigate losses, communities should enhance early warning systems and disaster preparedness plans. Additionally, infrastructure should be designed to withstand such events, and land use planning should prioritize flood-resistant areas. A comprehensive risk management approach, including insurance mechanisms, is also necessary. Through these strategies, we can better respond to and adapt to the challenges posed by heavy precipitation events.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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