

Research on the Effect of Topographic Factors on Extreme Rainfall in South China

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Abstract: The extreme rainstorms, along with the flood disasters, have been plaguing south China every summer. The reason for this phenomenon is not only because of its sub-topical monsoon climate, but the specific terrain character in south China also plays a role in the extreme weather. This essay delves into the extreme rainfall events in South China, highlighting the significant role of topographic factors in influencing precipitation patterns. The focus is on understanding how geographical characteristics impact rainfall intensity and subsequently lead to various natural hazards. The analysis employs a combination of historical precipitation data and topographic assessments to explore the forming mechanisms of extreme rainfall, specifically frontal rainstorms and warm-sector torrential rains (WSTRs). The roles are divided into the direct effects and the indirect effects, with the former taking the lead. The direct effects include the uplift of the moist air and the fraction of the ground contributing to the addition of turbulence. As for the indirect roles, key research questions emphasize the influence of low-level jets effects. The data of the precipitation figures comes from ERA5 reanalysis data of ECMWF, and the topography data is excerpted from GEBCO Gridded Bathymetry Data Download. In conclusion, extreme rainfall events are significantly intensified by South China's rugged topography, leading to increased risks of landslides and flooding. It emphasizes the need for improved disaster management strategies and long-term data collection to better understand and mitigate these impacts.

Keywords: Topography, Extreme rainfalls, Southwest China

1. Introduction

In South China, extreme rainfalls are severely influencing people's work and daily life, meanwhile triggering several geological disasters. In order to alleviate the damage caused by extreme rainfalls, it is of great significance to delve into its forming mechanisms. Among all, topography is a crucial factor that contributes to its form, although it has been less frequently discussed in past studies. This essay aims to summarize past surveys on the effect of topography. First, the definition of extreme rainfall is given. Then, according to past surveys, some common conclusions about the extreme rainfalls in different topographic areas, where mostly in south China, are summarized into two categories: direct effect and indirect effect. A few principles are listed which can be applied in all sorts of situations. Third, based on these findings, a further conclusion is drawn on the impact of topography on geological disasters in the region. Finally, some constructive suggestions are given to

reduce the destruction. Understanding how topographical factors contribute to extreme rainfall and associated disasters is one of the most direct ways to mitigate damage. Compared with other factors affecting heavy rainfalls, topographic factors are relatively easy for human beings to change and then reduce the damage of flood disasters.

2. Theory background

South China is in the low latitude region of 104.5 degrees to 117 degrees east longitude and 18 degrees to 26.5 degrees north latitude. Within this area, mountainous region covers 36.6%. Hills occupy 46.5% and the area of plains takes up 16.9%. The distribution of the hills and mountains play significant roles in the precipitation. Because it is located near the sea with a subtropical monsoon climate, the warm and humid air from the sea is brought to the area by the monsoon, forming abundant precipitation, and sometimes even extreme rainfalls. This is one of the most concerning issues within South China for its extremely destructive force. Generally, a day is classified as having an extreme rainstorm when daily precipitation exceeds 50 mm. According to past surveys, 72% of extreme rainfall events occur during the flood season, with 45% taking place between April and June (the first season), and 27% between July and September (the second season) [1]. As for the spatial distribution, the precipitation in South China presents distinctly. Generally, the intensity and frequency of rainfalls decrease from the coast to the interior land, with differences in terrain contributing to the disparity of rainfalls. There are two heavy precipitation zones in the area, one located in the Wuyi Mountains to Nanling Mountains, and the other on the coast of Guangdong.

There are two forming mechanisms of rainfalls, frontal rainstorms and warm-sector torrential rains (WSTRs). The frontal rainstorm forms when the colder air moves south to form a cold front. In this theory, warm air climbs up along the cold front, causing water vapor to condense into raindrops. On the other hand, the formation of WSTRs has almost nothing to do with the front, and it happens when no cold air parcel take control. Low-level water vapor convergence in the boundary layer, intrusion of shallow cold air and low-level jet stream or boundary layer jet stream can trigger convection in the warm zone, causing WSTRs within the areas [2]. Besides, the topographic factors also influence the raining pattern. WSTRs are more harmful for its greater intensity and duration than frontal rainstorms. These events are the primary drivers of flood disasters, and when combined with specific terrain conditions, the resulting floods can be exacerbated, leading to severe and often unimaginable damage.

3. The effect of topographic factors on extreme rainfalls

As shown in Figure 1, the topography of South China is dominated by hills, delta plain, and platform plain. It mainly contains hills below 500m, while the mountains above 1000m are scattered somewhere in western Fujian, northern Guangdong, and western Guangxi. Most of these mountains exhibit a northeast-southwest orientation, and the terrain gradually slopes from northwest to southeast.

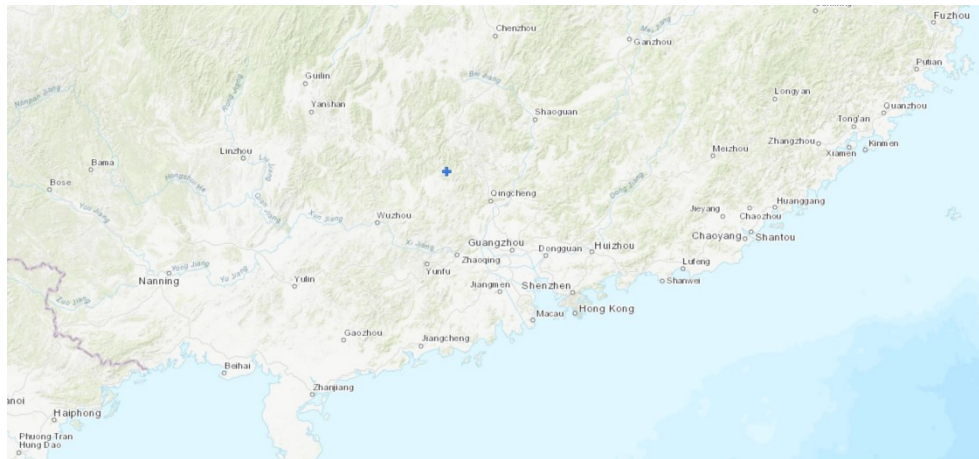


Figure 1: Topographic map in South China

The topographic characters contribute to the different spatial distributions of extreme rainstorms. Generally, the impacts can be divided into the direct effect and the indirect effect.

3.1. The direct effect

Topographic factors influence multiple types of extreme rainstorms, while this essay focuses on the pre-flood heavy rains that cause the most serious disasters. The direct effects are dominant. Firstly, the formation mechanisms for frontal rainstorms and WSTRs differ. For the frontal rainstorm, the mountains block the cold air from the north to the south, which is conducive to the formation and maintenance of the quasi-stationary front in South China, so as to maintain long-term heavy rainfall. For example, the southern part of Guangxi and Guangdong are bounded by Yunkai Mountains, which block the southbound cold air flow and guide the southwest warm and moist air northward, while guiding the eastward warm and dry air westward. These three air currents meet and converge to form heavy precipitation. For WSTRs, the role of the terrain is mainly to lift the warm and moist air from the sea, forming a large amount of rainstorms on the windward slope. At the same time, the trend of mountains in Guangxi is the bell-mouth terrain of southwest to northeast, which is the gradually shrinking valley terrain. As airflow enters this bell-mouth, the contraction of the terrain enhances air convergence. Because of these two reasons, it is inevitable to increase the upward movement of the air, so that the precipitation is larger. In addition, as the terrain in southern China is mostly rugged and hilly, ground friction will cause turbulence to rise, thus increasing rainfall. This condition occurs in both frontal rainstorms and WSTRs.

Regarding the movement and maintenance of storms, past studies indicate that mountains over 1,000 meters can obstruct the movement of cumulonimbus clouds, forcing rain masses to move horizontally or change direction, which prolongs and intensifies the rainfall [3]. For example, in South China, three heavy rainfall centers, namely southeastern Guangxi, southern Guangdong, and Yunkai Mountain are located near mountains of more than 1km [4]. In contrast, South China's coastal topography is low, which allows the low-level jet stream to lift warm and moist air and trigger rainfall, as they flow into the interior land at relatively higher altitudes. Figure 2 shows the spatial distribution of rainfalls in 2006, July 16th along with the terrain characters in South China. The blue area indicate the raining districts, and it follows the directions of the mountains, which is northeast-southwest.

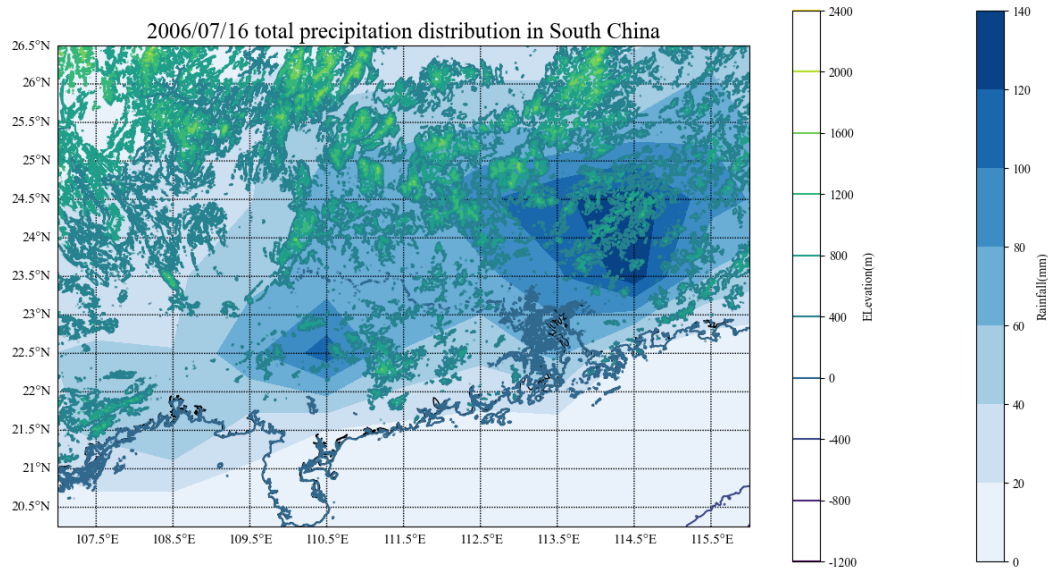


Figure 2: The distribution of the rainfall with the topographic characters in 2006, July 16th

3.2. The indirect effect

According to Du Yu et al., low-level jets (LLJs) play an important role in the formation of heavy rain in warm regions. The LLJs over southern China are classified into two types in early summer, including synoptic-system-related low-level jet (SLLJ) and boundary layer jet stream (BLJ). The former affects frontal rainstorms, while the latter mainly influences the formation of WSTRs with the topographic fluctuation playing an important role in it. When the BLJs meet the higher terrain, it will strengthen the convergence at the coast, thus intensifying the convection and forming heavy rainfall [6]. What's more, the airflow is guided by the terrain. The mountains and hills cause the airflow disturbance to form a vortex, which accelerates and turns the wind speed, as well as makes the BLJs more powerful in transporting water vapor and has a wider influence range. In addition, due to the undulating terrain, the temperature difference between day and night is also different at different altitudes, forming a thermal wind under the action of a strong temperature gradient, so that the wind field will further aggravate the transport of water vapor.

4. Constructive advice for these areas

First of all, the government needs to strengthen the construction of urban drainage systems, especially in low-lying areas that are particularly vulnerable to flooding. This includes not only expanding the capacity of existing drainage infrastructure but also implementing sustainable urban drainage systems (SUDS) that can effectively manage stormwater runoff. Additionally, it is crucial to improve the early warning and detection systems to provide timely alerts about extreme precipitation and typhoons. This proactive approach can help communities prepare for potential disasters, thereby avoiding massive property losses and minimizing the impact of a series of natural disasters that often follow such events.

In areas prone to landslides, a more strategic approach to land management is necessary. Planting more trees and restoring vegetation can significantly strengthen the soil, as roots help to bind the earth and reduce erosion. Moreover, trees play a vital role in absorbing moisture from the soil and atmosphere, which can help mitigate the rise of warm, moist air that contributes to extreme weather conditions. This reforestation effort not only reduces the risk of landslides but also helps to alleviate the urban heat island effect by providing shade and cooling the surrounding environment.

Secondly, for residents, careful consideration of living areas is equally important. It is advisable to avoid low-lying areas that are prone to waterlogging and flooding during heavy rains, as these regions can quickly become hazardous. Similarly, while mountainous areas offer higher elevations, they are vulnerable to mudslides and other geological dangers following intense rainfall. Middle to high-altitude areas are generally more suitable for habitation, as they offer a lower temperature, reduced heat island effect, and a decreased likelihood of flooding. These regions provide a safer living environment, allowing residents to enjoy the benefits of natural landscapes while minimizing the risks associated with extreme weather events. By making informed decisions about where to live, individuals can contribute to their own safety and resilience in the face of climate-related challenges.

5. Conclusion

This essay investigates the complex interplay between extreme rainfalls, topographic features in South China. It highlights how the differently-distributed terrain, characterized by hills and mountainous areas, significantly influences the patterns and intensity of rainfall. The analysis reveals that extreme precipitation events arise chiefly from two mechanisms: frontal rainstorms and warm-sector torrential rains (WSTRs). These phenomena are intensified by the region's geographical characteristics, which facilitate the uplift of warm, moist air, leading to substantial rainfall.

Despite these valuable insights, the research has limitations that warrant attention. A major drawback is the insufficient temporal data concerning rainfall patterns and the long-term geological impacts in the affected regions. Meanwhile, this essay mainly intends to clarify the formation of WSTRs, while other types of extreme rainstorms that also caused millions of treasure losses are neglected, highlighting the need for further study in this area. Besides, other factors contributing to the extreme rainstorms, such as cold pools and mesoscale convective vortices, are not discussed when finding their relations with the topographic factors. factors contributing to extreme rainstorms, such as cold pools and mesoscale convective vortices, were not discussed in relation to their interactions with topographic features.

In summary, to enhance the quality and comprehensiveness of future research on extreme rainfall events and their geological impacts in South China, several improvements and avenues for further investigation can be pursued. A focus on long-term data collection, a broader examination of various storm types, and an exploration of additional meteorological factors, coupled with interdisciplinary collaboration, will enhance understanding of extreme rainfalls and their consequences. This approach ultimately contributing to better risk assessment and disaster management strategies in vulnerable regions.

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