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Impact of tropical cyclones on flood risk in southeastern China: Spatial patterns, causes and implications

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ABSTRACT

Using flood peaks data from 62 hydrological stations covering a period of 1951–2014 and tropical cyclone (TC) tracks, floods due to TCs were differentiated and relations between occurrences of floods and TCs were investigated. Then, the impact of TCs on the flood magnitude and frequency was evaluated. Results indicated that there was more than one external influencing factor for flood occurrences, i.e. convective precipitation and TC-related heavy precipitation. In general, the landed TC events have a crucial influence on the occurrence of floods in eastern and western parts of Guangdong province. The mountainous topography limits the northward propagation of TC events and hence limits their impact on the occurrence of floods in the northern part. More than 60% of the largest 10 hazardous floods in the northern and eastern parts were attributed to TCs and hence they significantly modified the probability distributions of flood peaks, increasing the location and scale parameters of the generalized extreme value (GEV) probability distribution model. Therefore, development of measures for mitigation of coastal flooding would need to consider the occurrences of TCs.

1. Introduction

Coastal regions of the globe are usually urbanized with denser population and better developed economy (Mori and Takemi, 2016), but these regions are also highly susceptible to natural hazards, such as storm surge and coastal flooding. Tropical cyclones (TCs) are one of the major causes of hazardous hydrological and/or weather extremes in the coastal regions of the world (Hopley and Harvey, 1976; Webster et al., 2005; Igeta et al., 2007; Pielke et al., 2008). These extreme events include floods, landslides, damaging winds, high waves, and storm surges. Intense TCs can cause devastation (Mori and Takemi, 2016) and have therefore aroused worldwide concern (Eliot and Pattiaratchi, 2010). With growing population and infrastructure facilities, coastal urban regions are becoming more vulnerable and are being increasingly threatened by TCs. Seto (2011) projected that in the next few decades, most population increase will take place in the exposed deltas, near estuaries, coastal zones and coastal cities of Asia (and Africa) due to better employment and education opportunities. With increasing urban population and greater financial capital invested in the flood prone coastal zones (Chan et al., 2014), socio-economic trends would amplify the possible consequences of future floods.

Coastal regions in Asia, especially in vulnerable deltas and coastal cities, are home to more than half of the Asian population (Chan et al., 2014). More than 325 million inhabitants are living in the coastal low-lying flood prone areas in East Asia alone (McGranahan et al., 2007). Many of these coastal regions are predicted to be vulnerable due to climate change (e.g. sea-level rise), with millions of people and their economic assets being vulnerable to floods and storms (Ward et al., 2011; Walsh et al., 2012; Chan et al., 2014). Considering the case of China, an agricultural country with the largest population of the world, its coastal regions are mostly economically developed, densely populated, and are frequently hit by landfalling tropical cyclones (TCs). Southeastern China, such as Guangdong province (Zhang et al., 2011a), is a particular case. Guangdong province has a large number of megacities and is major part of the Pearl River Delta. Flash floods, mountainous floods, and water logging are some of the natural disasters that occur in the province (Zhang et al., 2011a). Some of these disasters are mainly the consequences of typhoons or TCs. Statistically speaking, an average of 9 TCs make a landfall in China every year (Yin et al., 2010). When TCs make a landfall in these areas, they cause strong winds, torrential rains, and tidal surges, resulting in serious losses of life and property (Zhou et al., 2004). It is therefore

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important to evaluate the impacts of TCs on flood risk in coastal regions, such as Guangdong province.

Survey of literature shows that previous researches mainly focused on the impact of TCs on extreme precipitation (e.g. Ren et al., 2006). Yin et al. (2010) examined the extent to which TCs are responsible for heavy rainy days (precipitation > 100 mm/d) in coastal Fujian Province. Breña-Naranjo et al. (2015) evaluated the rainfall contribution of tropical depressions, storms and hurricanes across Mexico from 1998 to 2013 using the satellite-derived precipitation dataset TMPA 3B42. Chen et al. (2010) investigated both the synoptic and mesoscale processes responsible for causing heavy rainfall events which produced up to 379.5 mm over southwestern Taiwan on 7 June 2003. Urbanization of coastal regions over the globe and related TC-induced flood risks have aroused increasing concern (Zhang et al., 2008; Muis et al., 2015). Although southeastern China, including Guangdong province, has numerous megacities, such as Hong Kong and Guangzhou, whose economies are highly developed, limited researches have been reported concerning tropical cyclones and flood risk. Yang et al. (2015) investigated climate change trends, impacts on flood events, flood vulnerability and risk, and response strategies in the Pearl River Delta (PRD), a rapidly urbanizing coastal area in southeastern China. However, the study by Yang et al. (2015) was done based on a reanalysis dataset and model projections with results from the literature. No reports are available addressing the impact of TCs on hydrological extremes, based on observed hydrological datasets in southeastern China.

It is widely accepted that evaluation of flood risk and related drivers is crucial for effective risk management (Muis et al., 2015). Further, quantifying the contribution of tropical cyclones to the terrestrial water cycle can help determine the benefits and hazards caused by TCs (e.g. Huang et al., 2011). Therefore, the central issues of this study are (1) "mixtures" of flood peak distributions, (2) regional characteristics of flood magnitudes influenced by TCs, and (3) parameter characteristics of flood peak distributions related to TCs. This study attempted to relate floods to TCs in the coastal region of southeastern China by taking Guangdong province as a case study, evaluate the potential effect of TCs on flood risk. Results of this study would be helpful for mitigation of flood hazards in southeastern China.

2. Study region and data

Guangdong province, involving the Pearl River Delta (PRD) and the lower Pearl River basin, is a highly developed region in China (Fig. 1). The PRD has been the fastest developing region in China since the adoption of so-called "reform and open door" policy in the late 1970s, with a highly dense agglomeration of over 100 towns and cities (Fig. 1). On <0.5% of the country's territory, PRD produces about 20% of the national GDP, attracts about 30% of Foreign Direct Investment, and contributes about 40% of export (therefore, PRD is called the "World Factory") (Zhang et al., 2011a). Guangdong province is located in the way where northwest Pacific subtropical cyclones enter and/or departs from the mainland of Asia with the coastline (except islands) of about 3368 km. Guangdong province is topographically high in north, northwest and northeast parts and is topographically lower in the central and south parts. Precipitation events generally last 2–3 days and even 7–8 days with the largest amount of 100–800 mm. Therefore, the TC-induced rainstorms can easily trigger the occurrence of flash floods and mountainous floods. Hence, evaluation of flood risk under the impact of TCs is crucial for management of flood risk and mitigation of food hazards.

The flood event was defined as the annual maximum daily discharge which is consistent with previous studies (e.g. Zhang et al., 2015a, 2015b; Villarini et al., 2011a). The annual maximum daily discharge with unit of m^3/s was used as the flood peak series. Flood peak data were obtained from the Hydrological Bureau of Guangdong province

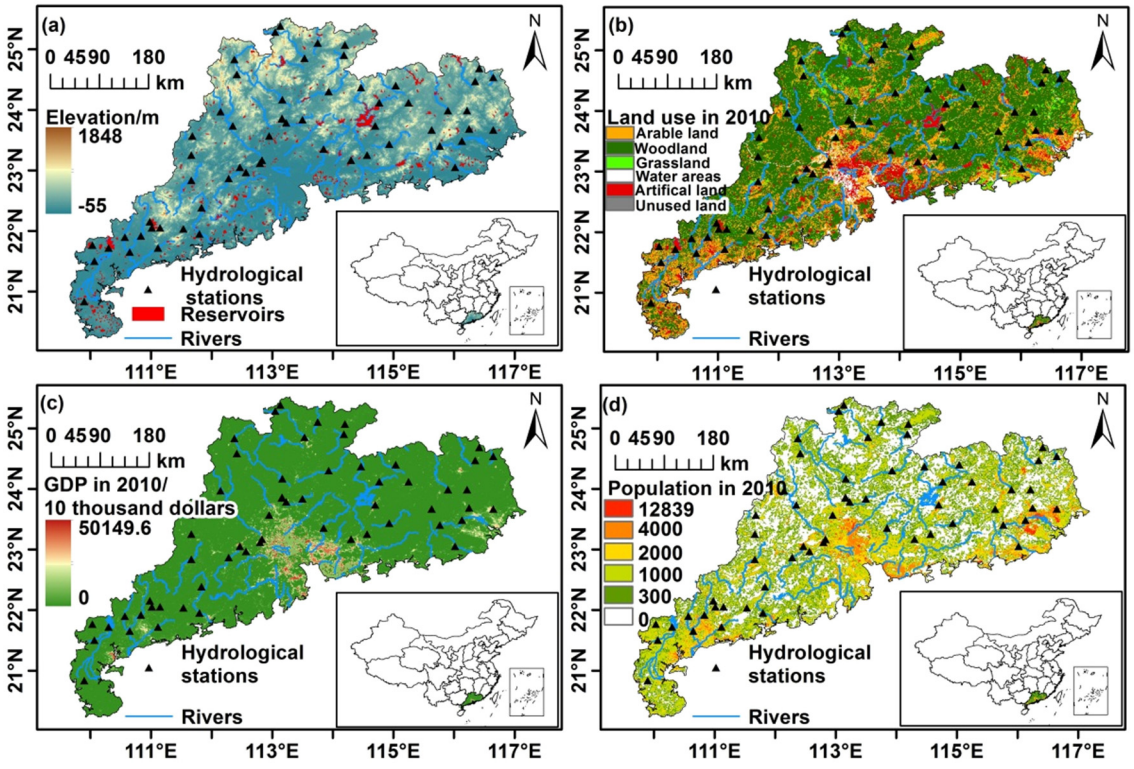

Fig. 1. Location of hydrological stations (a), spatial pattern of land use and land cover (b), Gross Domestic Product (c) and population (d) across Guangdong province.