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Research article

Economic sector loss from influential tropical cyclones and relationship to associated rainfall and wind speed in China

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ABSTRACT

Tropical cyclones caused significant national economic losses in China in recent decades. For alleviating these hydro-meteorological disasters, the spatiotemporal distributions of losses per economic sector and the associated rainfall and wind patterns of such influential tropical cyclones (ITCs) were estimated for China. Based on multiple reference databases and socio-economic data, ITCs losses for major economic sectors have been deduced. The obtained information plays an important role in the projection of sector losses of future ITCs affecting China. The total economic losses have been split into five major sector loss categories, comprising agriculture, industry, construction, transport, and business & others. About 37% of the total loss occurred in the industrial sector, occupying the largest proportion. High values were primarily distributed in the urban agglomerations of the Pearl River and Yangtze River deltas and along the mainland coast of the Taiwan Strait, with over 1 billion CNY per year. Significant upward trends are found in all of sectors except in agriculture, which shows a decreasing tendency for the period of 1984–2014. The years with the highest losses occurred in the mid-1990s, mid-2000s, and early 2010s, consistently affecting all sectors in all regions along the mainland coast. The southern part of China was most frequently affected by ITCs, with increasing trends in sector losses for most areas. The relationships between wind speed, rainfall and sector losses can be presented in the form of an exponential function. The results show that rainfall is more positively correlated with ITCs losses than wind speed. Here, the industry sector shows the largest correlation coefficient and highest growth rate, whereas the construction sector shows the lowest. In future, research should pay more attention on impacts of heavy rainfall triggered by ITCs in China.

1. Introduction

Tropical cyclones can cause considerable amounts of damage by exposing economic assets to strong winds and excessive rainfall. The major categories of damage include structural property damage, destroyed machinery and equipment, as well as business interruption. Global economic losses from tropical cyclones are estimated to range at about $26 billion annually (Mendelsohn et al., 2012). As one of the most cyclone-prone countries in the world, China experiences an average of seven land-falling tropical cyclones per year since 1949, currently ranking higher than any other country in cyclone frequency (Hurricane Research Division, 2015). Between 1984 and 2015, some 249 out of 817 tropical cyclones generated in the western North Pacific and the South China Sea caused significant economic losses in mainland China incl. Hainan (hereafter incl. in China). In an average year, such tropical cyclones cause 44.2 billion CNY of normalized direct economic losses (Wang et al., 2016). On average, of all the various types of hydro-meteorological disasters to affect China, the direct economic losses and

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number of fatalities attributable to tropical cyclones account for 18.3% and 50.2% of the total, respectively (China Meteorological Administration, 2016a). In our study, the loss-producing tropical cyclones are defined as Influential Tropical Cyclones (ITCs).

For a country experiencing rapid economic growth, natural disasters may result in serious economic losses, which can severely affect China's economic growth. The 22 provinces that have been affected by ITCs (Wang et al., 2016) are also the most economically dynamic areas in China, with large populations and industry, high capital, and strong productivity. Heavy economic losses are inevitable in these areas, especially when heavy rain and high wind speed occur. For example, the 2014 ITC named "Rammasun", which is considered to be the strongest and most severe ITC to make landfall in China since the record taking began in 1949, affected > 10.4 thousand square kilometers of crops, as well as numerous commercial properties and vehicles. Additionally, many factories suspended operations due to heavy rains and high winds. At least 73 people died caused by the ITC, and 44.7 billion CNY worth of direct economic losses occurred in China. Each sector plays an important role in the Chinese economy, and because of their individual contributions, various degrees of influence from the same disaster result in different losses for each sector. For Guangxi, the loss in the agriculture sector is estimated at 10.7 billion CNY, which accounted for 76.8% of the total 14 billion CNY lost in the whole province (China Meteorological Administration, 2016b).

A considerable amount of research on overall economic losses caused by ITCs has already been examined (Pielke et al., 2008; Nordhaus, 2010; Schmidt et al., 2010; Mohleji and Pielke Jr, 2014; Estrada et al., 2015; Fischer et al., 2015; Wang et al., 2016), but very little research has focused on analyzing different sector losses at national scale. Agriculture is regarded as one of the main components of sustainable development, which has become a consensus in the international community (Brundtland, 1985). Strong variations in food supply always receive widespread attention, leading to sector studies focusing mainly on agriculture, such as estimating crop damage area or yield losses (Iizumi et al., 2008; Chen and McCarl, 2009; Masutomi et al., 2012; Blanc and Strobl, 2016). Only few studies on agricultural ITC damage exist in China. These mainly rely on post-disaster investigation data (Li et al., 2006; Wang et al., 2010; Du et al., 2015; Boschetti et al., 2015). One reason for this could be the absence of detailed sector loss data in existing Chinese databases, resulting in studies of agricultural economic impacts that are primarily concerned with individual ITC events. Additionally most of these studies only provide some qualitative descriptions, such as economic policy and response measures. Concomitant with economic development is rapid urbanization. Industry and service sectors occupy prominent, special positions in the national economy. Hence, more attention should be paid to sector disaster impacts in China.

Although it remains uncertain whether a relationship between ITCs and global warming exists, future projections based on theory and high-resolution dynamical models consistently indicate that global warming may increase the global averaged intensity of ITCs by 2–11% at the end of the twenty-first century (Knutson et al., 2010). Therefore, increases in economic loss due to ITCs under global warming are of considerable concern, not only to the scientific community and public but also to insurance and reinsurance companies. To understand these changes, it is necessary to develop a model for estimating damage due to ITCs, but as the relationship between loss and ITCs intensifies, factors like rainfall, wind speed, and underlying surface regimes become more complex and difficult to model. Previous studies established an exponential relationship between precipitation, wind speed and loss from tropical cyclones (Huang and Wang, 2015; Kim et al., 2015; Basharat et al., 2016; Murnane and Elsner, 2012). Most recently, Yu et al. (2017) developed a potential hazard index for estimating tropical cyclone losses based on accumulated daily precipitation and wind speed in China.

In this study, the spatiotemporal distributions of losses per economic sector and the associated rainfall and wind patterns of influential tropical cyclones are estimated for China. This is done to alleviate the hydro-meteorological disasters in China. For this it is essential to gain a general understanding of the spatial distribution of economic sector losses and how losses have changed over the past few decades in China. Using this information, we further explore the relationships among sector losses and the associated rainfall and wind speed factors at county level. The sector loss results are especially important in the field of disaster risk reduction.

2. Data and methods

2.1. Data

2.1.1. Socioeconomic data

Direct economic losses caused by ITCs were compiled from the Tropical Cyclone Disasters Databank of the National Climate Center (1984–1999), the Yearbook of Natural Disaster in China (2005–2015), the China Climate Impact Assessment Reports (1991–2015) of the China Meteorological Administration (CMA), and the Economic Losses National Survey at county level (China Meteorological Administration, 2001, 2016a, 2016b). These databases all follow the same guideline, *i.e.* the Classification of Tropical Cyclones Standardization [GB/T19201-2006], which was established by the CMA (Chinese Standardization Administration Committee, 2006). Due to this guideline, the data derived from the different sources mentioned above are homogeneous.

Gross Domestic Product (GDP) and its sector composition from 1984 to 2014 were drawn from the provincial statistical yearbook at county level. Data on the consumer price index (CPI) and total household wealth at the provincial level were obtained from the China Statistical Yearbooks (1984–2014) of the National Bureau of Statistics (2015).

2.1.2. ITC tracks

The data used in this study comprises the best-track dataset for tropical cyclones that occurred in the Northwest Pacific, and was derived from the Shanghai Typhoon Institute of the CMA. These data included maximum 2-minute sustained wind speed, minimum sea surface pressure, and individual tropical cyclone 6-hour track point locations. All ITC track lines affecting China from 1984 to 2014 are shown in Fig. 1.

2.1.3. Weather

Daily rainfall data from meteorological stations at the county level, along with the detailed metadata covering all provinces and counties of China for the period 1984–2014, were used in this study. The data was provided by the National Meteorological Information Center of CMA. Measurements at all climate stations were made using the same standards and instrumentation, ensuring consistency in data quality (Liu et al., 2005).

2.2. Methods

2.2.1. Sector economic losses from influential tropical cyclones

ITCs frequently bring heavy rainfall, strong winds, and high storm surges, resulting in economic losses in affected areas. In general the destruction differs depending mainly on the ITC intensity or its size. However, an ITC over land will begin to weaken rapidly usually after just a few hours because of a lack in moisture and heat sources otherwise provided by ocean. Rainfall may occur in a large area, ranging from hundreds of meters to hundreds of kilometers, while the heaviest rainfall is mainly concentrated within a 50 km radius from the storm center. Based on Lonfat and Marks Jr (2004) and Matyas (2005) the maximum rainfall decreases significantly at roughly a distance of 35–50 km from the center. The areas affected by gale-force winds mainly extend to an approximate radius of 50 km from the center (Bureau of Meteorology, 1977; Hill and Lackmann, 2009; McCloskey et al., 2013; Mahala et al., 2015). Thus, in this paper, a 50 km buffer