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Flood-induced agricultural loss across China and impacts from climate indices

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ABSTRACT

Province-wide data on flood-destroyed and flood-affected crop areas across China covering a period of 1960–2013 were analyzed in this study for investigating their relations with climate indices, such as ENSO, NAO, IOD, PDO and AMO. Results indicated that: (1) agricultural flooding in northeast and south China tended to enhance under the influence of warm PDO and warm IOD events of the previous years. However, agricultural flooding in southwest China tended to decrease as a result of warm ENSO events of the previous years. Agricultural floods in coastal regions of southeast China were influenced by more than one climate index; (2) Agricultural floods of different time scales were subject to different degrees of correlations with climate indices. Remarkably, climate indices that were significantly correlated with agricultural floods were usually temporally enhancing. Relations between ENSO and agricultural floods across China were statistically strong with good persistency. Thus, ENSO can be taken as a suitable predictor for flood-affected and flood-destroyed crop areas across China. However, AMO cannot be taken as the predictor for flood-affected and flood-destroyed crop areas in China; (3) The combined influence of climate indices on flood-affected and flood-destroyed crop areas across China did not have a firm spatiotemporal pattern. However, specific groups of climate indices can have definitive impacts on flood-affected and flood-destroyed crop areas over specific regions. Findings of this study can help predict flood-affected and flood-destroyed crop areas across provinces of China, and hence plan and manage agricultural activities in China.

1. Introduction

As a result of emission of greenhouse gas, global warming is alleged to be accelerating the global hydrological cycle (Allen and Ingram, 2002; Alan et al., 2003). This acceleration is altering spatiotemporal patterns of precipitation and hence increased occurrences of extremes (Easterling et al., 2000; Dore, 2005) and in turn increased occurrences of floods and droughts in many regions of the world (e.g. Easterling et al., 2000; Mirza, 2002). There is a general belief that extreme flood events will occur more frequently due to the change in climate, particularly in the backdrop of warming climate and increasing land use (Reynard et al., 2001; Posthumu et al., 2008; Das et al., 2013).

In recent years, climate change and impacts thereof on human society, particularly on agriculture and food security, have received an unprecedented importance (e.g., Schmidhuber and Tubiello, 2007; MacDonald, 2010) because of the concern for the role of availability, accessibility and security of food, energy and water in the stability and sustainability of society. Chau et al. (2013) analyzed impacts of floods on agriculture in Vietnam using GIS, and results indicated that the 1:10, 1:20 and 1:100 year floods led, respectively, to 27%, 31%, and 33% of the arable land inundation. Since the exact loss of agricultural production will depend upon a number of factors, including crop variety, stage of plant development, length of flooding period and level of inundation, Posthumu et al. (2008) indicated that recent changes in agricultural and flood defense policies create new opportunities for involving rural land use, in particular agriculture, in flood risk management. Xu et al. (2013) also indicated that flood catastrophe risk assessment is the key step to the steady development of agriculture in the backdrop of climate change. Meanwhile, it is an important scientific issue that needs to be addressed for agricultural risk assessment.

China has the largest population in the world and its arable land accounts for 7% of the world arable land, and meets the food demand of 22% of the global population (Piao et al., 2010). It is expected that in the next twenty years, 30%–50% more food would be required to support the fast growing population (F. Zhang et al., 2013; Q. Zhang et al., 2013a,b). However, frequent floods and droughts greatly limit the development of agriculture in China. Xu et al. (2013) indicated that the impact of flood catastrophes on grain production in China was quite

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serious, and high or very high risk of flood catastrophes concentrated in central and eastern regions. For a majority of major grain producing provinces, the probability of 10% reduction in grain output is more than 90%, given the one-hundred-year flood disaster (Xu et al., 2013). Climate change adds a significant degree of uncertainty to projections of agricultural output in China. F. Zhang et al. (2013), Q. Zhang et al. (2013a,b) identified different regional responses of precipitation extremes to increasing temperature across China. Under the influence of increasing temperature, precipitation is intensifying in southeastern China. The responses of changes in weak precipitation extremes to climate warming are comparatively complicated and diverse. Nevertheless it can be confirmed that increasing temperature tends to trigger the intensification of precipitation (F. Zhang et al., 2013). Alterations of precipitation regime greatly increase the risks of floods and droughts across China (Zhang et al., 2011). Furthermore, future decades are expected to witness higher risks of floods. Li et al. (2015) indicated that during 2021–2050 and 2071–2100, there would be less co-occurrence of consecutive wet and dry days, and more joint extreme heavy precipitation events, implying less risk of co-occurrence of floods and droughts in the same year but higher risk of floods in China.

Relations between ENSO and flood hazards have been well evidenced (Pasquini and Depetris, 2010; Räsänen and Kummu, 2013; Zaroug et al., 2014). Bouwer et al. (2008) analyzed relations between annual mean, maximum streamflow and the North Atlantic Oscillation (NAO), the Arctic Oscillation (AO), the frequency of west circulation (FWC) and south sea level pressure difference (SLPD), indicating that the annual maximum streamflow was subject to larger sensitivity to changes of climate indices. Delgado et al. (2012) developed models using discrete wavelet transform (DWT) to analyze the impacts of ENSO and PDO on flood variations of the Mekong River, suggesting that the sea surface temperature of the Pacific and monsoon activities can be taken as the predictors for flood changes in the lower Mekong River basin. Impacts of ENSO, NAO, IOD, PDO and AMO on East Asian monsoon have also been well studied (Wang et al., 2009; Zhang et al., 2014; Xiao et al., 2015), particularly on precipitation changes in China (e.g. Q. Zhang et al., 2013a; Ouyang et al., 2014). However, studies have mainly focused on the impacts of ENSO and related climate indices, such as the North Atlantic Oscillation (NAO), on precipitation changes in China and have indirectly investigated the risk of floods and droughts under influence of climate indices. No reports are however available pertaining to the impacts of climate indices on agricultural flood hazards. It should be noted here that the understanding of impacts of floods on agriculture is important for management of agricultural activities and food security. The objectives of this study therefore are: (1) to investigate influence of ENSO, NAO, IOD (Indian Ocean Dipole), PDO (Pacific Decadal Oscillation) and AMO (Atlantic Multidecadal Oscillation) during warm or cold episodes on agricultural flood hazards in China; and (2) to analyze possible mechanisms behind the influence of ENSO, NAO, IOD, PDO and AMO on agricultural floods across China. This study can help understand flood-destroyed and flood-affected agricultural crop areas and impacts of climate indices on agriculture in China.

2. Data

Data on flood-destroyed and flood-affected crop areas from 26 provinces covering a period of 1960–2013 were collected from the Agriculture Department of China via http://202.127.42.157/moazzys/zaiqing.aspx and were analyzed in this study (Fig. 1) (Zhang et al., 2012). Missing data, if any, during 1967–1969 were handled using the long-term annual mean values. The flood-destroyed and flood-affected crop areas were defined, respectively, as crop areas with agricultural loss exceeding 30% and 10% of agricultural production. These thresholds are ascertained by the ministry of agriculture of the People's Republic of China at http://202.127.42.157/moazzys/zaiqing.aspx, which are used to distinguish the loss degree caused by flood disasters to agriculture. This concept of flood-destroyed and flood-affected crop areas can well mirror the negative influence of flood hazards on agricultural production. Fig. 1 indicates that flood-induced agricultural loss is observed mainly in the coastal regions and south, southeast and central parts of China with high flood-destroyed crop area/flood-affected crop area percentage above 45%. ENSO in this study refers to the SST in the Niño 3.4 zone (5°N–5°S, 120–170°W). The ENSO data during the period of 1950-2013 were obtained from NOAA (Climate Prediction Center of National Oceanic and Atmospheric Administration) at http://www.cpc.ncep.noaa.gov/products/analysismonitoring/ensostuff/ensoyears.shtml. NAO is defined as a meridional dipole in atmospheric pressure with centers of action near the Azores and Iceland. A high NAO index is associated with stronger than average westerlies in the North Atlantic mid-latitudes, while the opposite is true for negative values of the index (Moore et al., 2013). The NAO index is calculated by applying rotated principal component analysis, and here the values for the NAO index are taken from the Climate Prediction Center of NOAA (http://www.cpc.ncep.noaa.gov/products/precip/CWlink/pna/nao.shtml). IOD is a kind of ocean-atmosphere coupling phenomenon and is quantified by Dipole Mode Index (DMI), being defined as the temperature anomaly between the western equatorial Indian Ocean and the southeastern equatorial Indian Ocean. The IOD data covering the period of 1950–2013 were obtained from Japan Agency for Marine-Earth Science and Technology at http://www.jamstec.go.jp/frsgc/research/d1/iod/iod/dipole_mode_ index.html. PDO is the SST anomalies in the Pacific north to 20°N. The PDO data covering the period of 1950–2013 were extracted from NOAA at http://www.esrl. noaa.gov/psd/data/correlation/pdo.data. The Atlantic Multidecadal Oscillation (AMO) is a mode of variability occurring in the North Atlantic Ocean that has its principal expression in the sea surface temperature (SST) field. The AMO data were obtained from NOAA at http://www.esrl.noaa.gov/psd/data/timeseries/AMO/. The values of climate index obtained from http://www.esrl.noaa.gov/psd/data/climateindices/list/ are monthly atmospheric and ocean time series. Monthly atmospheric and ocean time series (climate index) were aggregate by averaged over the year, which is refer to Villarini et al. (2012) and Xiao et al. (2015). The annual variations with warm and cold episodes of ENSO, NAO, IOD, PDO and AMO are displayed in Fig. 2.

3. Methodology

3.1. Spatial decomposition of flood-affected and flood-destroyed crop areas

The flood-destroyed and flood-affected crop area data exhibit nonlinear, inter-correlative and multi-dimensional features. To reduce the dimension and also to avoid inter-correlation, the Rotated Empirical Orthogonal Function (REOF) method (Hannachi et al., 2007) was used to analyze the spatial patterns and also the principle components (PC) of flood-destroyed and flood-affected crop areas across China. The REOF technique was introduced in details in Hannachi et al. (2007) and was used in the decomposition of seasonal precipitation changes into spatial patterns and associated temporal patterns (Xiao et al., 2015). Here, further introduction of the REOF technique is not provided to avoid redundancy.

3.2. Correlation between climate indices and flood-destroyed and flood-affected crop areas

Correlation between climate indices and flood-destroyed and flood-affected crop areas was done using the Pearson correlation analysis technique. It should be noted here that climate indices influence flood-destroyed and flood-affected crop areas in the same year or in subsequent years. Thus, correlations between climate indices and flood-destroyed and flood-affected crop areas were done with 0- and 1-year time lag. Correlation analysis was done with 1951 as the starting time point and 5 years as the time interval.