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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

1 in coastal regions of southeast China were influenced by more than one climate
2 index; (2) Agricultural floods of different time scales were subject to different
3 degrees of correlations with climate indices. Remarkably, climate indices that were
4 significantly correlated with agricultural floods were usually temporally enhancing.
5 Relations between ENSO and agricultural floods across China were statistically
6 strong with good persistency. Thus, ENSO can be taken as a suitable predictor for
7 flood-affected and flood-destroyed crop areas across China. However, AMO cannot
8 be taken as the predictor for flood-affected and flood-destroyed crop areas in China;
9 (3) The combined influence of climate indices on flood-affected and flood-destroyed
10 crop areas across China did not have a firm spatiotemporal pattern. However,
11 specific groups of climate indices can have definitive impacts on flood-affected and
12 flood-destroyed crop areas over specific regions. Findings of this study can help
13 predict flood-affected and flood-destroyed crop areas across provinces of China, and
14 hence plan and manage agricultural activities in China.

15
16 **Key words:** Climate indices; Flood hazards; Agricultural loss; Stability analysis

17 18 **1. Introduction**

19 As a result of emission of greenhouse gas, global warming is alleged to be
20 accelerating the global hydrological cycle (Allen and Ingram, 2002; Alan et al.,
21 2003). This acceleration is altering spatiotemporal patterns of precipitation and
22 hence increased occurrences of extremes (Easterling et al., 2000; Dore, 2005) and in

1 turn increased occurrences of floods and droughts in many regions of the world (e.g.
2 Easterling et al., 2000; Mirza, 2002). There is a general belief that extreme flood
3 events will occur more frequently due to the change in climate, particularly in the
4 backdrop of warming climate and increasing land use (Reynard et al., 2001;
5 Posthumu et al., 2008; Das et al., 2013).

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

21 China has the largest population in the world and its arable land accounts for 7%
22 of the world arable land, and meets the food demand of 22% of the global population

1 (Piao et al., 2010). It is expected that in the next twenty years, 30%-50% more food
2 would be required to support the fast growing population (Zhang et al., 2013).
3 However, frequent floods and droughts greatly limit the development of agriculture in
4 China. Xu et al. (2013) indicated that the impact of flood catastrophes on grain
5 production in China was quite serious, and high or very high risk of flood catastrophes
6 concentrated in central and eastern regions. For a majority of major grain producing
7 provinces, the probability of 10% reduction in grain output is more than 90%, given
8 the one-hundred-year flood disaster (Xu et al., 2013). Climate change adds a
9 significant degree of uncertainty to projections of agricultural output in China. Zhang
10 et al. (2013) identified different regional responses of precipitation extremes to
11 increasing temperature across China. Under the influence of increasing temperature,
12 precipitation is intensifying in southeastern China. The responses of changes in weak
13 precipitation extremes to climate warming are comparatively complicated and diverse.
14 Nevertheless it can be confirmed that increasing temperature tends to trigger the
15 intensification of precipitation (Zhang et al., 2013a). Alterations of precipitation
16 regime greatly increase the risks of floods and droughts across China (Zhang et al.,
17 2011). Furthermore, future decades are expected to witness higher risks of floods. Li
18 et al. (2015) indicated that during 2021-2050 and 2071-2100, there would be less
19 co-occurrence of consecutive wet and dry days, and more joint extreme heavy
20 precipitation events, implying less risk of co-occurrence of floods and droughts in the
21 same year but higher risk of floods in China.

22 Relations between ENSO and flood hazards have been well evidenced (Pasquini

1 and Depetris, 2010; Räsänen and Kummu, 2013; Zaroug et al., 2014). Bouwer et al.
2 (2008) analyzed relations between annual mean, maximum streamflow and the North
3 Atlantic Oscillation (NAO), the Arctic Oscillation (AO), the frequency of west
4 circulation (FWC) and south sea level pressure difference (SLPD), indicating that
5 the annual maximum streamflow was subject to larger sensitivity to changes of
6 climate indices. Delgado et al. (Delgado et al., 2012) developed models using
7 discrete wavelet transform (DWT) to analyze the impacts of ENSO and PDO on
8 flood variations of the Mekong River, suggesting that the sea surface temperature of
9 the Pacific and monsoon activities can be taken as the predictors for flood changes in
10 the lower Mekong River basin. Impacts of ENSO, NAO, IOD, PDO and AMO on
11 East Asian monsoon have also been well studied (Wang et al., 2009; Zhang et al.,
12 2014; Xiao et al., 2015), particularly on precipitation changes in China (e.g. Zhang et
13 al., 2013b; Ouyang et al., 2014). However, studies have mainly focused on the
14 impacts of ENSO and related climate indices, such as the North Atlantic Oscillation
15 (NAO), on precipitation changes in China and have indirectly investigated the risk of
16 floods and droughts under influence of climate indices. No reports are however
17 available pertaining to the impacts of climate indices on agricultural flood hazards. It
18 should be noted here that the understanding of impacts of floods on agriculture is
19 important for management of agricultural activities and food security. The objectives
20 of this study therefore are: (1) to investigate influence of ENSO, NAO, IOD (Indian
21 Ocean Dipole), PDO (Pacific Decadal Oscillation) and AMO (Atlantic Multidecadal
22 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

1 NOAA (Climate Prediction Center of National Oceanic and Atmospheric
2 Administration) at
3 <http://www.cpc.ncep.noaa.gov/products/analysismonitoring/ensostuff/ensoyears.shtml>.
4 NAO is defined as a meridional dipole in atmospheric pressure with centers of
5 action near the Azores and Iceland. A high NAO index is associated with stronger
6 than average westerlies in the North Atlantic mid-latitudes, while the opposite is true
7 for negative values of the index (Moore et al., 2013). The NAO index is calculated
8 by applying rotated principal component analysis, and here the values for the NAO
9 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
10 ocean-atmosphere coupling phenomenon and is quantified by Dipole Mode Index
11 (DMI), being defined as the temperature anomaly between the western equatorial
12 Indian Ocean and the southeastern equatorial Indian Ocean. The IOD data covering
13 the period of 1950-2013 were obtained from Japan Agency for Marine-Earth Science
14 and Technology at [http://www.jamstec.go.jp/frsgc/research/d1/iod/iod/dipole_mode_](http://www.jamstec.go.jp/frsgc/research/d1/iod/iod/dipole_mode_index.html)
15 [index.html](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
16 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)
17 is a mode of variability occurring in the North Atlantic Ocean that has its principal
18 expression in the sea surface temperature (SST) field. The AMO data were obtained
19 from NOAA at <http://www.esrl.noaa.gov/psd/data/timeseries/AMO/>. The values of
20 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., 2014. 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 Functions (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 year as the time interval.

3.3 Difference between flood-destroyed and flood-affected crop areas under the influence of warm and cold episodes of climate indices

To understand the influence of warm and cold episodes of climate indices, changing properties of flood-destroyed and flood-affected crop areas were analyzed during the warm and cold episodes of climate indices. In so doing, the flood-destroyed and flood-affected crop area series corresponding to warm and cold episodes, respectively, of the ENSO, NAO, IOD, PDO and AMO events were extracted and analyzed using the Student t test technique. The significance of the relations between flood-destroyed and flood-affected crop areas and related cold and warm episodes of climate indices was tested at 95% confidence level. Besides, the influence of one or more climate indices on the changes in flood-destroyed and flood-affected crop areas was analyzed. Specifically, the time intervals characterized by: (1) the warm and cold episodes of PDO and AMO; and (2) the warm and cold episodes of ENSO, NAO and IOD, were extracted and the flood-destroyed and flood-affected crop areas during these time intervals were analyzed and relations were determined using the Student t test. The significance of correlation was tested at 95% confidence level.

1

2 **4. Results and discussion**

3 4.1 Influence of climate indices on spatial and temporal patterns of flood-destroyed 4 and flood-affected crop areas

5 It can be seen from Fig. 3 that 6 modes can be chosen for further analysis with
6 the total explained variance of 70% and 72%, respectively, for the flood-affected
7 crop area and the flood-destroyed crop area. After the seventh rank, the changes of
8 eigenvalue are flattened and no evident changes can be identified. After deciding the
9 number of modes, correlation relations between climate indices and temporal modes
10 were analyzed (Fig. 4). The climate index with a suffix of ‘_0’ and ‘_1’ denote the
11 climate index with 0- and 1-year ahead of the occurrence of flood-affected crop areas
12 or flood-destroyed crop areas, respectively (Fig. 4). It can be observed from Fig. 4
13 that significant negative correlations can be observed between IOD and PC1 of the
14 flood-affected crop area of the next year; and significant positive correlations
15 between ENSO and PC1 of the flood-affected area of the next year. NAO also has
16 significant positive correlation with PC2 of the flood-affected crop area of the next
17 year. Thus, IOD, ENSO and NAO usually caused flood-induced agriculture losses in
18 the next year. However, significant positive correlations can be identified between
19 PDO and PC4 of the flood-affected crop area of the same year and the next year.
20 Significant negative correlation can be observed between ENSO and PC4 of the
21 flood-affected crop area of the next year. AMO and ENSO have significant negative
22 correlations with PC4 of the flood-affected crop area in the same year and the next

1 year and PDO has significant negative correlation with PC5 of the flood-affected
2 crop area in the next year. A different picture emerges for correlations between
3 climate indices and the flood-destroyed crop area (the lower panel of Fig. 4). PDO
4 exhibits a significant negative correlation PC2 of the flood-destroyed crop area, and
5 PDO and ENSO have significant negative and positive correlations with PC4 and
6 PC5, respectively, of the flood-destroyed crop area. Besides, significant negative
7 correlations can be found between PDO and PC4 of the flood-destroyed crop area of
8 the same year. The PC6 variations are heavily influenced by more than one climate
9 index. AMO has a significant positive correlation with PC6 of the flood-destroyed
10 crop area of the same year, and PDO and IOD have significant positive correlations
11 with PC6 of the flood-destroyed crop area of the next year. However, ENSO has a
12 significant negative correlation with PC6 of the flood-destroyed crop area of the next
13 year.

14 Figs. 4 and 5 combine to show the influence of climate indices considered in this
15 study on the flood-induced agricultural loss across China. It can be observed from
16 Figs. 4 and 5 that warm phases of IOD (ENSO) can lead to increased (decreased)
17 flood-affected crop areas in northwest and southwest China (EOF1 in Fig. 5).
18 Flood-affected crop areas in northeast and east China increased during the warm
19 phase of NAO (EOF2 in Fig. 5). The flood-affected crop area increased in northwest
20 and central China under the influence of warm phase of PDO during the same year
21 and one-year earlier. However, warm phases of ENSO can trigger decreased
22 flood-affected crop area in northwest and central China (EOF4 in Fig. 5). In

1 northeast China and also in the coastal regions of south China, the flood-affected
2 crop area had an increasing tendency due to the warm phase of PDO of the previous
3 year (EOF5 in Fig. 5). Changes in the flood-affected crop area in the provinces in
4 east and south China are influenced by more than one climate index, e.g. warm phase
5 of PDO of the same year and the previous year and warm phase of NAO in the
6 previous year tended to cause an increase in the flood-affected crop areas; and the
7 warm phase of AMO of the previous year and also the warm phase of ENSO of the
8 same year tended to trigger a decrease in the flood-affected crop area.

9 Spatial patterns of flood-destroyed crop areas due to the influence of different
10 climate indices show different pictures when compared to those of the flood-affected
11 crop areas (Figs. 4, 5 and 6). Figs. 4 and 6 indicate an increase in the flood-affected
12 crop area during the warm phase of PDO of the previous year in northeast China and
13 also in the coastal regions of south China (EOF2 in Fig. 6). Warm phases of PDO of
14 the very year and the previous year and cold phase of ENSO of the previous year
15 tended to trigger an increase in the flood-destroyed crop areas in central China and
16 also in the coastal provinces of east China (EOF4 in Fig. 6). Under the influence of
17 warm phase of PDO and cold phase of ENSO during the previous year, an increase
18 in the flood-destroyed crop areas was observed in northeast and central China and a
19 decrease in the flood-destroyed crop area in the eastern parts of central China (EOF5
20 in Fig. 6). Changes in the flood-destroyed crop area in east China and also in the
21 coastal regions of south China are influenced by more than one climate index: an
22 increase in the flood-destroyed crop area can be observed under the influence of

1 warm phase of AMO of the same year and warm phases of PDO and IOD of the
2 previous years. However, the warm phase of ENSO of the previous year tends to
3 cause a decrease in the flood-destroyed crop areas (EOF6 in Fig. 6). Changes in
4 flood-affected and flood-destroyed crop areas should be attributed to different
5 magnitudes of flood events under the influence of different climate indices, and also
6 to topographical features of different regions. Provinces in the central and coastal
7 regions of east and south China are mostly low-lying areas and are sensitive to flood
8 inundation. Besides, rainstorms in central and south China are becoming frequent
9 (e.g. Zhang et al., 2011) and they have the potential to trigger more frequent and
10 serious floods. These results provide a scientific reference for the management of
11 agricultural activities based on occurrences of different climate indices.

12

13 4.2 Constancy of the influence of climate indices on flood-induced crop area changes

14 Temporal variations of ENSO, NAO, IOD, PDO and AMO are evident for various
15 time scales from decades to hundreds of years. Besides, spatial ranges under these
16 climate indices are also wide. Spatial and temporal patterns of the influence of
17 above-mentioned climate indices on flood-induced agricultural losses are shifting.
18 Correlations between temporal modes of REOF and flood-affected and
19 flood-destroyed crop areas were analyzed with a moving time window of 5 years. In
20 so doing, the moving correlation results shed light on the constancy of influences of
21 climate indices on flood-affected and flood-destroyed crop areas across China.

22 Fig. 7 demonstrates moving correlation coefficients between climate indices and
23 flood-affected crop areas of the next year. The climate indices with a year ahead of

1 the occurrence of flood-affected crop areas are denoted as ENSO_1, NAO_1, IOD_1,
2 PDO_1, and AMO_1. Fig. 7 indicates consistent positive and negative correlations
3 between ENSO_1, PC1 and PC4, and particularly the correlation between ENSO_1
4 and PC1 is persistently steady. Meanwhile, increasingly stronger correlation can be
5 detected between ENSO_1 and PC4. As for NAO_1, weakening correlations can be
6 observed between NAO_1 and PC1, relatively steady correlation relations between
7 PC2 and NAO_1, and increasingly stronger correlation between NAO_1 and PC6.
8 The influence of IOD on the flood-affected and flood-damaged crop areas is
9 different when compared to ENSO, and NAO_1. Enhancing correlations can be
10 identified between IOD_1 and PC1 and weakening correlations between IOD_1 and
11 PC2-PC6; while weakening correlations can be observed between IOD_1 and PC1,
12 and PC2 and PC6. Negative correlations between IOD_1 and PC3 before 1971 shift
13 to positive correlations after 1971 and constantly positive and negative correlation
14 are kept between IOD_1, PC4 and PC5. Correlations between AMO_1 and all the
15 PCs of the flood-affected crop areas are largely unsteady and positive correlations
16 shift to negative correlations between AMO_1 and PC1, PC3, PC4 and PC6,
17 respectively.

18 Moving correlation coefficients between the PCs of the flood-affected crop areas
19 and climate indices of the same year, denoted as ENSO_0, NAO_0, IOD_0, PDO_0
20 and AMO_0, are illustrated in Fig. 8. When compared to correlations between
21 flood-affected crop areas and climate indices with one year ahead, correlations
22 between flood-affected crop areas and climate indices of the same year are weaker. It

1 can be depicted from Fig. 8 that the influence of ENSO_0 on PC1 is weakening and
2 the influence of ENSO_0 on PC6 is enhancing. Correlations between NAO_0 and
3 PC1 shift from positive to positive and negative correlations between NAO_0 and
4 PC3 are weakening, and correlations between NAO_0 and PC6 are enhancing.
5 Correlations between other climate indices, such as IOD_0, PDO_0, AMO_0, and
6 PCs of flood-affected crop areas are weak or unsteady and are characterized by shifts
7 from positive/negative to negative/positive correlations. No confirmative or fixed
8 correlation patterns can be detected. Thus, the occurrences of ENSO, NAO, IOD,
9 AMO and NAO usually have evident influences on the occurrences of floods and
10 hence the flood-affected crop areas in subsequent years.

11 Figs. 9 and 10 demonstrate correlations between climate indices and
12 REOF-based PCs of flood-destroyed crop areas. Fig. 9 shows strong correlations
13 between ENSO and PC3, PC4 of the subsequent years and the correlations are steady.
14 Besides, enhancing correlations are observed between ENSO and PC3. However,
15 weak correlations are detected between NAO, IOD and PCs of the flood-destroyed
16 crop areas across China and these correlations are relatively unsteady. PDO and
17 AMO have strong influences on the flood-destroyed crop areas of the subsequent
18 years. Specifically, significant negative correlations are observed between PDO and
19 PC2, PC4 and PC5 of the subsequent years and correlations between PDO, AMO
20 and PC2, PC4 are enhancing. However, correlations between AMO and PC1, PC5
21 shift from positive correlations to negative correlations. Comparatively, weaker and
22 relatively unsteady correlation relations can be observed between changes in climate

indices and PCs of flood-damaged crop areas of the same year. Relatively weak negative, positive and negative correlations are found between ENSO_0 and PC3, PC4 and PC6, respectively. Shifts from weak negative correlations to weak positive correlations are found between NAO_0 and PC1 and PC5. Besides, weak correlations and positive correlations vs. negative correlations shifts are found between PDO_0, AMO_0 and REOF-based PCs of food-damaged crop areas.

In summary, Figs. 4, 7-10 indicate strong correlations between REOF-based PCs of flood-affected crop areas and climate indices except AMO, and correlations tend to be enhancing, e.g., correlations between IOD_1, ENSO_1 and PC1, NAO_1 and PC2, PDO_0, PDO_1, ENSO_1 and PC4, PDO_1 and PC5 in Figs. 4, 7-8. These results help provide insights into the prediction of flood-affected crop areas. Similar spatial and temporal patterns of correlations between flood-destroyed crop areas and climate indices are found when compared to those between flood-affected crop areas and climate indices, e.g. correlations between PDO_1 and PC2, PDO_1, ENSO_1 and PC4 (Figs. 4, 9-10). However, correlations between flood-destroyed and climate indices are relatively weaker and unsteady in comparison with those between flood-affected crop areas and climate indices (Figs. 7-10), which should be attributed to alleviate the flood-induced influence on agriculture in China by mitigation of flood hazard (Zhang et al., 2012, 2015). Enhanced mitigation of flood hazards greatly reduces flood-destroyed crop areas in China. Consistency and stability of the influences that ENSO, NAO and IOD have on flood-affected crop areas are higher than those PDO and AMO have. Furthermore, the influence of ENSO on flood-affected and flood-destroyed crop areas is more evident than other climate indices considered in this study.

4.3 Influence of cold and warm phases of climate indices on flood-affected and flood-destroyed crop areas across China

Differences in changes in flood-affected and flood destroyed area under the influence of cold and warm episodes of climate indices were analyzed. The differences were defined as: flood-affected crop areas during cold episodes-flood-affected crop areas during warm episodes)/flood-affected crop areas during warm episodes (Fig. 11); flood-destroyed crop areas during cold episodes-flood-destroyed crop areas during warm episodes)/flood-destroyed crop areas during warm episodes (Fig. 12). Besides, combined influences of all the climate indices considered in this study on flood-affected and flood-destroyed crop areas were investigated. The significance of analysis was tested using the Student t test technique at 95% confidence level.

Fig. 11 illustrates the spatial distribution of differences in flood-affected crop areas due to warm and cold episodes of climate indices, i.e. ENSO, NAO, IOD, PDO and AMO. It can be observed from Fig. 11 that more flood-affected crop areas are detected in 15 provinces of China under the influence of cold episodes of ENSO when compared to those under warm episodes of ENSO. Specifically, increasing magnitude of flood-affected crop areas due to cold episodes of ENSO is higher in Shanxi, Shannxi, Hubei and Jiangxi provinces, reaching 70.7%, 76.9%, 76.5% and 75.4%, respectively. Locations of these provinces can be seen in Fig. 1. However, a decrease in flood-affected crop areas is identified under the influence of cold ENSO episodes in the coastal provinces except Zhejiang province, and the largest

1 decreasing magnitude of 30.8% of flood-affected crop areas can be found in Jilin
2 province, and the decreasing magnitude of flood-affected areas of other coastal
3 provinces ranges lower than 20%. The difference in flood-affected crop areas due to
4 cold and warm ENSO episodes is not statistically significant at 95% confidence level
5 (Fig. 7a). Flood-affected crop areas decrease significantly under the influence of cold
6 NAO episodes in all provinces, except Hebei, Shanxi and Shandong provinces (Fig.
7 7b). Statistically significant difference between flood-affected crop areas during cold
8 NAO episodes and during warm NAO episodes is detected in 14 provinces and these
9 provinces are concentrated in central and southwest China. Specifically, the largest
10 decreasing magnitude of flood-affected crop areas due to cold NAO episodes is
11 observed in Yunnan, Sichuan, Guizhou and Guangxi provinces, and the decreasing
12 magnitude reaches 67.9%, 68.6%, 70.2% and 64.3%, respectively. Note also that
13 flood-affected crop areas due to cold NAO episodes are evidently larger than those
14 due to warm NAO episodes, being 361% and 70.6%, respectively (Fig. 11b).
15 Comparatively, the difference in flood-affected crop areas under warm and cold IOD
16 episodes is smaller than those under ENSO, NAO, PDO and AMO. Increased
17 flood-affected crop areas under cold IOD episode can be found in 15 provinces and
18 these provinces are mainly in eastern China and also Sichuan and Gansu provinces
19 in central China. Cold IOD episodes trigger a decrease in flood-affected crop areas
20 in western and southern China (Fig. 11c). The largest difference between
21 flood-affected crop areas during cold NAO episodes and those during warm NAO
22 episodes is observed mainly in Hebei and Ningxia, being +57.8% and -67.1%,

1 respectively (Fig. 11c). Similar spatial patterns of flood-affected crop areas can be
2 found for PDO when compared to NAO so no detailed discussion will be presented
3 here (Fig. 11d). As for AMO, flood-affected crop areas during cold AMO episodes
4 are larger than those during warm AMO episodes and can be observed mainly in
5 northeastern China, in the coastal regions of south China and also in central China.
6 The difference between flood-affected crop areas during cold and warm AMO
7 episodes, respectively, is the largest in Heilongjiang and Hebei provinces, being
8 +87.0% and -62.6%, respectively (Fig. 11e).

9 Changes in flood-destroyed crop areas due to warm and cold climate episodes,
10 i.e., ENSO, NAO, IOD, PDO and AMO, are presented in Fig. 12. In comparison
11 with Fig. 11, the difference in flood-destroyed crop areas due to cold and warm
12 climate episodes and spatial patterns thereof are similar to flood-affected crop areas
13 (Figs. 11-12). Fig. 12a shows that flood-destroyed crop areas increased during cold
14 ENSO events when compared to warm ENSO events in 17 provinces and these
15 provinces are found mainly in central, western and southwestern China. Specifically,
16 the increasing magnitude of flood-destroyed crop areas is the largest in Jiangxi,
17 Hebei and Shannxi provinces, reaching 70.7%, 92.9% and 90.7%, respectively (Fig.
18 12a). When it comes to NAO, provinces dominated by increase or decrease of
19 flood-destroyed crop areas due to cold or warm NAO episodes are similar in spatial
20 distributions with different increasing or decreasing magnitudes. Particularly, the
21 flood-destroyed crop areas due to warm NAO episodes are similar to those due to
22 cold NAO events (Fig. 12b). Besides, when compared to flood-destroyed crop areas

1 due to warm IOD events, more evident increase can be found in flood-destroyed
2 crop areas under cold IOD events in all the coastal provinces and the nearby
3 provinces, however the opposite is found in western China. The increasing
4 magnitude is evidently larger than the decreasing magnitude of flood-destroyed crop
5 areas due to cold IOD regimes, being +93.6% and -44.6%, respectively (Fig. 12c).
6 The spatial distribution and related changing magnitudes of flood-destroyed crop
7 areas due to warm or cold PDO and AMO events are similar to those due to IOD
8 (Figs. 11d, 11e; Figs. 12d, 12e). Influences of individual climate indices in terms of
9 warm and/or cold episodes on changes of flood-destroyed crop areas are distinctly
10 different (Figs. 11, 12), implying that crop areas or agriculture in a region can be
11 impacted by more than one climate index. Hence, investigation of combined
12 influences of various climate indices will be considerable value. Thus, comparison is
13 done to anatomize differentiations in changes of flood-destroyed and flood-affected
14 crop areas due to nexus of warm and cold episodes of ENSO, NAO, IOD and PDO,
15 AMO, such as cold ENSO event/cold PDO event ~ cold ENSO event/warm PDO
16 event (Figs. 13-14).

17 Fig. 13 illustrates changes in flood-affected crop areas under the combined
18 influence of ENSO, NAO, IOD and PDO, AMO across China. It can be observed
19 from Fig. 13 that a decrease in flood-affected crop areas is detected during cold PDO
20 events in central, northeast and western China. However, no confirmed impacts can be
21 found from cold or warm ENSO events. Besides, a decrease of flood-affected crop
22 areas can be identified during cold NAO and cold PDO regimes in most provinces of
23 China (Fig. 11b, 11d), however, an increase in flood-affected crop areas can be

1 observed during cold NAO and PDO events in northeast, northwest and south China,
2 and it is particularly true for northeast China where an increase in flood-affected crop
3 areas is significant at 95% confidence level. The nexus of warm NAO events and cold
4 PDO events causes an evident decrease of flood-affected crop areas in east and
5 northeast China. Moreover, when compared to flood-affected crop areas under the
6 combined influence of cold PDO and warm IOD events, a decrease of crop areas can
7 be expected under the combined influence of warm PDO and warm IOD events in
8 south and northeast China. Comparatively, cold IOD and cold PDO events can
9 combine to trigger a decrease in flood-affected crop areas in most provinces of China,
10 except Hebei, Shandong and Liaoning provinces, and a significant decrease in crop
11 areas can be detected in Gansu, Sichuan, Yunnan, Guizhou, Hunan, Jiangxi and
12 Zhejiang provinces. Nevertheless, a substantial increase of flood-affected crop areas
13 can be found in all the coastal provinces during cold AMO and cold ENSO events and
14 the opposite results can be obtained for the remaining provinces. An increase in
15 flood-affected crop areas in almost all provinces except Hebei and Shandong can be
16 detected during cold AMO but warm ENSO events. The flood-affected crop areas are
17 decreasing in northeast China during cold AMO and cold NAO regimes. Besides, cold
18 AMO and warm NAO combine to cause an increase in flood-affected crop areas in
19 northeast north and east China. Warm AMO events, whether cold or warm IOD events,
20 can cause an increase in flood-affected crop areas in most of the provinces and mainly
21 in south and northeast China (Fig. 13).

22 Changes in flood-affected crop areas under the combined influence of ENSO,
23 NAO, IOD and PDO, AMO across China are demonstrated in Fig. 14. Figs. 13 and 14
24 indicate similar spatial patterns of flood-affected and flood-destroyed crop areas under
25 the combined influence of climate indices. It can be seen from Fig. 14 that an evident

1 increase in flood-destroyed crop areas is detected in Shandong, Anhui, Jiangxi and
2 Fujian provinces during cold PDO and NAO events. Besides, Fig. 14 shows more
3 evident impacts of AMO, ENSO, NAO and IOD on flood-destroyed crop areas when
4 compared to the impacts of these climate indices on flood-affected crop areas. Besides,
5 cold AMO and cold ENSO regimes tend to trigger an apparent decrease of
6 flood-destroyed crop areas in southwest China. Furthermore, an evident decrease in
7 flood-destroyed crop areas can be depicted during cold AMO and cold NAO events in
8 the coastal provinces in east China, implying that higher frequency of floods can be
9 expected during warm AMO and cold NAO periods in the coastal provinces. The
10 influence of single climate index on flood-affected and flood-destroyed crop areas is
11 greatly altered by the influence of other climate indices or the combined influence of
12 more than one climate index (Figs. 11-14). It should be noted here that the combined
13 influence of joint climate indices on flood-affected and flood-destroyed crop areas is
14 uneven in the spatial distribution without clear and apparently confirmative spatial
15 patterns. However, coherency in the combined influence of climate indices on
16 flood-affected and flood-destroyed crop areas can help predict flood-affected and
17 flood-destroyed crop areas based on the occurrence of climate indices in different
18 parts of China.

20 **5. Conclusions**

21 Temporal and spatial modes of flood-destroyed and flood-affected crop areas of
22 26 provinces of China are obtained, based on the REOF-based decomposition.
23 Influences of climate indices, ENSO, NAO, IOD, PDO and AMO, on flood-affected
24 and flood-destroyed crop areas are analyzed. The following conclusions are drawn

1 from this study:

2 (1) Warm IOD and PDO events of the previous year tend to cause an increase in
3 flood-affected crop areas of the subsequent year in northwest China and warm PDO
4 phases tend to trigger an increase in flood-affected crop areas of the same year in
5 northwest China. However, warm ENSO events have the potential to cause a
6 decrease in flood-affected crop areas of its next year in southwest China.
7 Flood-affected crop areas in northeast and south China tend to increase under the
8 influence of warm PDO of the previous years. Furthermore, warm NAO episodes
9 usually cause an increase in flood-affected crop areas of the subsequent years in
10 northeast and east China. Similar spatial and temporal patterns can be found for the
11 influence of climate indices on flood-destroyed crop areas when compared to
12 flood-affected crop areas. Flood-destroyed crop areas in northeast and south China
13 tend to increase due to the warm PDO events of the previous years, and
14 flood-destroyed crop areas in central China have the potential to increase due to the
15 occurrence of warm PDO events of the same and previous years and also cold ENSO
16 events of the previous years. Notably, flood-destroyed and flood-affected crop areas
17 in the coastal provinces of China are both influenced by multiple climate indices.

18 (2) Changes in flood-affected and flood-destroyed crop areas at different time scales
19 are subject to different degrees of correlation with climate indices. Remarkably,
20 climate indices which have significant correlation relations with flood-affected and
21 flood-destroyed crop areas usually exhibit temporally enhancing and persistent
22 correlations with flood-destroyed and flood-affected crop areas. This finding is

1 meaningful for the prediction of flood-destroyed and flood-affected crop areas across
2 China. Amongst five climate indices considered in this study, ENSO regimes usually
3 have significant correlations with flood-affected and flood-destroyed crop areas and
4 these relations tend to be enhancing in recent years with a substantial degree of
5 correlation. This suggests that ENSO can be taken as an ideal predictor for
6 flood-affected and flood-destroyed crop areas in China.

7 (3) Influences of individual climate indices and combined influences of groups of
8 climate indices on flood-affected and flood-destroyed crop areas are similar in both
9 space and time. Cold NAO and cold PDO regimes can likely trigger a decrease of
10 agricultural floods in most provinces of China; on the contrary, cold ENSO regimes
11 and cold IOD events can probably cause an increase of agricultural flood hazards.
12 Furthermore, cold AMO events can lead to an increase in agricultural flood hazards
13 in northeast China and the coastal regions of southeast China. This result should
14 arouse considerable concern for the mitigation of agricultural flood hazards and also
15 planning and management of agricultural activities.

16 (4) Combined influences of climate indices on flood-affected and flood-destroyed
17 crop areas across China are not subject to confirmative spatiotemporal patterns.
18 Significant influences of PDO and NAO events on agricultural floods are identified
19 mainly in the coastal provinces of southeast China and in central China. Cold PDO
20 and cold IOD events influence flood-affected and flood-destroyed crop areas in
21 central and south central China. However, cold AMO and cold NAO tend to
22 influence flood-affected and flood-destroyed crop areas in coastal provinces of east

China. Results of this study provide a picture for the prediction of flood-affected and flood-destroyed crop areas under the influence of different climate indices, particularly the five climate indices considered in this study.

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Fig. 1 Long-term average flood-affected, flood-destroyed crop areas and the percentage of flood-destroyed crop areas to flood-affected crop areas across 26 provinces of China. The provinces marked by capital letter are: A: Hebei; B: Shanxi; C: Inner Mongolia; D: Liaoning; E: Jilin; F: Heilongjiang; G: Jiangsu; H: Zhejiang; I: Anhui; J: Fujian; K: Jiangxi; L: Shandong; M: Henan; N: Hubei; O: Hunan; P: Guangdong; Q: Guangxi; R: Sichuan; S: Guizhou; T: Yunnan; U: Tibet; V: Shanxi; W: Gansu; X: Qinghai; Y: Ningxia; and Z: Xinjiang.

Fig. 2 Temporal variations of cold and warm episodes of the ENSO, NAO, IOD, PDO and AMO events during 1951-2013

Fig. 3 REOF eigenvalues and accumulative explained variance of the anomaly series of the flood-affected and flood-destroyed crop areas across China. The numbers lining along the curves denote the accumulated explained variance. The bars along with the curves denote the upper and lower limits of the 95% confidence level.

Fig. 4 Pearson correlation coefficients between REOFs-based temporal modes and climate indices. The 0 and 1 behind the short line after the climate indices denotes 0- and 1-year time lag before the flood-affected and flood-destroyed crop area series. The correlation coefficient being larger than or equaling 0.25 is significant at 95% confidence level. PC1 denotes the first principle component and the same denotation for PC2, PC3 and so on.

Fig. 5 REOFs-based spatial patterns of flood-affected crop areas across China

Fig. 6 REOFs-based spatial patterns of flood-destroyed crop areas across China

Fig. 7 Correlations between REOFs-based temporal modes of flood-affected crop areas and climate indices with one year ahead across China

Fig. 8 Correlations between REOFs-based temporal modes of flood-affected crop areas and climate indices of the same year across China

Fig. 9 Correlations between REOFs-based temporal modes of flood-destroyed crop areas and climate indices with one year ahead across China

Fig. 10 Correlations between REOFs-based temporal modes of flood-destroyed crop areas and climate indices of the same year across China

Fig. 11 Percentage of flood-affected crop areas during the cold episodes to those during warm episodes, i.e. (flood-affected crop areas during cold episodes-flood-affected crop areas during warm episodes)/flood-affected crop areas during warm episodes. The significance level of the student t test is 0.05. The filled triangles with black points denote significant trends.

Fig. 12 Percentage of the flood-destroyed crop areas during cold episodes to those during warm episodes, i.e. (flood-destroyed crop areas during cold episodes-flood-destroyed crop areas during warm episodes)/flood-destroyed crop areas during warm episodes. The significance level of the student t test is 0.05. The filled triangles with black points denote significant trends.

Fig. 13 Changes in the flood-affected crop areas under the combined influence of ENSO, NAO, IOD and PDO, AMO across China. Regions with black points indicate significant changes, and gray points not significant changes.

Fig. 14 Changes in flood-destroyed crop areas under the combined influence of ENSO, NAO, IOD and PDO, AMO across China. Regions with black points indicate significant changes, and gray points not significant changes.