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Severe weather disasters in China linked to solar activity during 1-1825 Common Era

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Abstract

Historical records truthfully document human life and environment associated with climate changes. We quantify official historical records of China dating back last 2000 years to examine the disasters due to anomalous temperatures of cold or hot, irregular precipitations of wet or dry, and floods in inland/coastal or Northern/Southern areas in four seasons that possibly linked to solar activities during 1-1825 CE (Common Era). It is found that the proportion of disaster years is positively associated with the time periods, and therefore, both the cases with high and low solar activity (HSA and LSA) leading are under study. Statistical results show that extreme cold weather occurs particularly in the Winter and Spring during LSA periods. Irregularities precipitations, including heavy rain/hail/snow and severe drought are significantly frequent during LSA periods, while floods on inland and coastal river basins tend to occur more frequently in LSA and HSA periods, respectively. The disasters owing to irregularities precipitations and floods frequently happen in Summer and Autumn, which suggests that the irregular precipitations could cause the floods. All the disasters occur significantly in the Northern China, which suggests the climate boundary of the Qinling–Huaihe Line along at about 33°N being essential. In total, all the disasters due to the anomalously cold temperatures, irregular precipitations, and floods tend to occur during the LSA periods.

Keywords: Solar activity, Severe weather, Climate change, Temperature, Precipitation, Flood

Keypoints

1. Historical records of natural disasters due to severe weather in China during the last 2000 years are converted into digital data and quantitatively examined.
2. Natural disasters owing to temperature anomalies, precipitation irregularities, and floods occur preferentially in China during low solar activity periods.
3. Inland and coastal floods tend to occur during low and high solar activity periods, respectively.

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Introduction

Climate makes history (Hsu 2012), and vice versa history records climate. Scientists have examined the relationship between long-term variations in solar activity and global climate, and have found that changes in the solar irradiance are important for climate changes (Reid 1987; Rind 2002; Friis-Christensen and Lassen 1991; Lassen and Friis-Christensen 1995; Lean et al. 1995; Tinsley 1996; Mann et al. 1998). In general, reduced solar irradiance could lower global temperature (Eddy, 1976), increase the global low cloud cover (Svensmark and Friis-Christensen 1997; Carslaw et al. 2002), and affect precipitation (Verschuren et al. 2000; Kniveton and Todd 2001). These indicate solar inputs, including electromagnetic waves, particle radiations, interplanetary magnetic fields, etc., and their associated effects, which are termed solar activities, into the climate system can cause temperature anomalies, precipitation irregularities, and floods.

Historical records faithfully document human life and environmental changes in the past. China has long historical records, which continuously document severe natural disasters and anomalies over the approximately 4000 years up to 1911 CE (Common Era, equivalent to Anno Domini, AD) (Song 1992). In fact, historical records in China have been well documented since the Han dynasty from 206 BC (Before Christ) to 220 AD). Therefore, the primary purpose of this paper is to investigate disasters related to temperature anomalies, precipitation irregularities, and floods in various locations and four seasons during low and high solar activity periods for the last 2000 years in China. Here, sunspot history records mainly refer to the solar activity (Pang and Yau 2002).

Data processes

To see if severe weather disasters owing to temperature anomalies, precipitation irregularities, and floods are associated with solar activities, long term records on sunspots, meteorology, and hydrology are required. A review of many sunspot history records from China, Japan, and Korea, together with cosmogenic, carbon-14 (Stiuver and Braziunas 1989), as well as beryllium-10 (Pang and Yau 2002) data confirm that before 1600 CE there were 6 solar activity time-periods with relatively low solar activity: 332–365 CE (Fourth-Century Minimum), and 462–526 CE (Fifth-Century Minimum), 580–820 CE (Medieval Minimum), 980–1070 CE (Oort Minimum), 1280–1350 CE (Wolf Minimum), and 1410–1590 CE (Sporer Minimum) (Pang and Yau 2002; Usoskin et al. 2003; Knudsen et al. 2009; Steinhilber et al. 2012). Meanwhile, Steinhilber et al. (2012) found Second-Century Minimum appearing during 107–203 CE. After 1600 CE, with the invention of the telescope, observations revealed that very few sunspots were seen during 1645–1715 CE (Maunder Minimum) and 1795–1825 CE (Dalton Minimum). To avoid the possible influence of anthropogenic greenhouse gases and other industrial effects (Kelly and Wigley 1990), as well as human-induced climate changes and natural internal climate changes in the most recent 200 years, we focus on the anomalies and disasters observed during 1–1825 CE. Therefore, if considering the Minimum as a low solar activity (LSA) and the period between two adjacent minima as a high solar activity (HSA), in total, there are an 8-LSA-to-HSA (LSA-leading) cycle during 107-1794 and an 8 HSA-to-LSA (HSA-leading) cycle during 204-1825. The LSA-leading and HSA-leading cycles are constructed by dropping the final LSA period of Dalton Minimum and the first LSA period of Second-Century Minimum during 107-1825, respectively (Table 1). A statistical investigation of a variety of disasters during the HSA-leading and LSA-leading cycles could help confirm the possible association between disasters and solar activities.

For climate data, we refer to an almanac/chronology (Song 1992) that summarizes severe natural disasters and anomalies occurred in China spanning the approximately 4000 years up to 1911 CE. These are mainly taken from 25 Chinese historical books, and cross checked by general historical records, important county annals, ancient medical books, ancient irrigation books, and other historical texts. The accuracy or reliability of the 25 Chinese historical books as official dynastic histories is warranted by the head/life of history officers and double checked by their successive dynasties (Sima 1961). The first volume (i.e., book) of the 25 official dynastic histories is the Records of the Grand Historian, also known by its Chinese name Shiji, completed around 94 BC in Han dynasty, and therefore, we focus on disasters after Christ. In Song (1992), the disasters and anomalies therein are classified into many items, which are grouped into 9 categories: astronomy including sunspot, geology, seismology, meteorology, hydrology, ocean, plant, animal, and human. Each event listing includes the original

Table 1 List of the Nine Minimums and the 8 LSA- and 8 HSA-leading Cycles

Minimums	Cycle	LSA-to-HSA (CE) LSA-leading (Series LH)		Cycle	HSA-to-LSA (CE) HSA-leading (Series HL)	
Second-Century	1	107–203	204–331			
Fourth-Century	2	332–365	366–461	1	204–331	332–365
Fifth-Century	3	462–526	527–579	2	366–461	462–526
Medieval	4	580–820	821–979	3	527–579	580–820
Oort	5	980–1070	1071–1279	4	821–979	980–1070
Wolf	6	1280–1350	1351–1409	5	1071–1279	1280–1350
Sporer	7	1410–1590	1591–1644	6	1351–1409	1410–1590
Maunder	8	1645–1715	1716–1794	7	1591–1644	1645–1715
Dalton				8	1716–1794	1795–1825
Total Duration (years)		851	837		837	785

statements in the 25 Chinese historical books as well as the lunar month and year of the occurrence in terms of the Gregorian calendar and the Chinese imperial era, the location of the historical prefecture (together with the corresponding current province), the human and animal casualties, property and environmental damage, the size of the area affected, the duration, and the original document source.

Here, the categories of disasters associated with severe weather events of temperature anomalies, precipitation irregularities, and floods response to the solar activity are examined in detail. To investigate temperature anomaly related disasters, events associated with items of severely cold winters, cool equinoxes/summers, frosty/icy plants, frozen wells/lakes/rivers, harsh hot summers, and warm equinoxes/winters are quantified. To study disasters owing to precipitation irregularities, events in items of torrential rain, heavy snow, heavy hail, and severe drought events are extracted from the meteorology and hydrology category. Meanwhile, floods in 9 river basins are isolated from the hydrology category. In general, severe disasters, especially involving loss of life, and/or remarkable and enormous anomalies are recorded in the documents. Therefore, we convert qualitative historical records into quantitative data by marking years with disasters by "1" and those without by "0" as well as denote the associated location of river basins or current provinces and lunar month accordingly (Fig. 1).

Since years with and without disasters have been denote by "1" and "0", respectively, we compute the proportion for each item in the time period during the HSA or LSA, where the proportion is the number of disaster years divided by the number of years in the study time period. Note that items under the same category of cold, hot, precipitation, inland flood, or coastal flood could happen in the same year. When two or more disasters happen in the same year, the subtotal or total will be simply counted by "1" in the year. Hence, the subtotal or total proportion would not be the same as the summation of the individual proportions.

Disasters during high and low solar activity periods

Maunder Minimum (1645–1715 CE) is the lowest solar activity period in recent 2000 years (Eddy 1976; Usoskin et al. 2003, 2007), which allows us to quickly test if

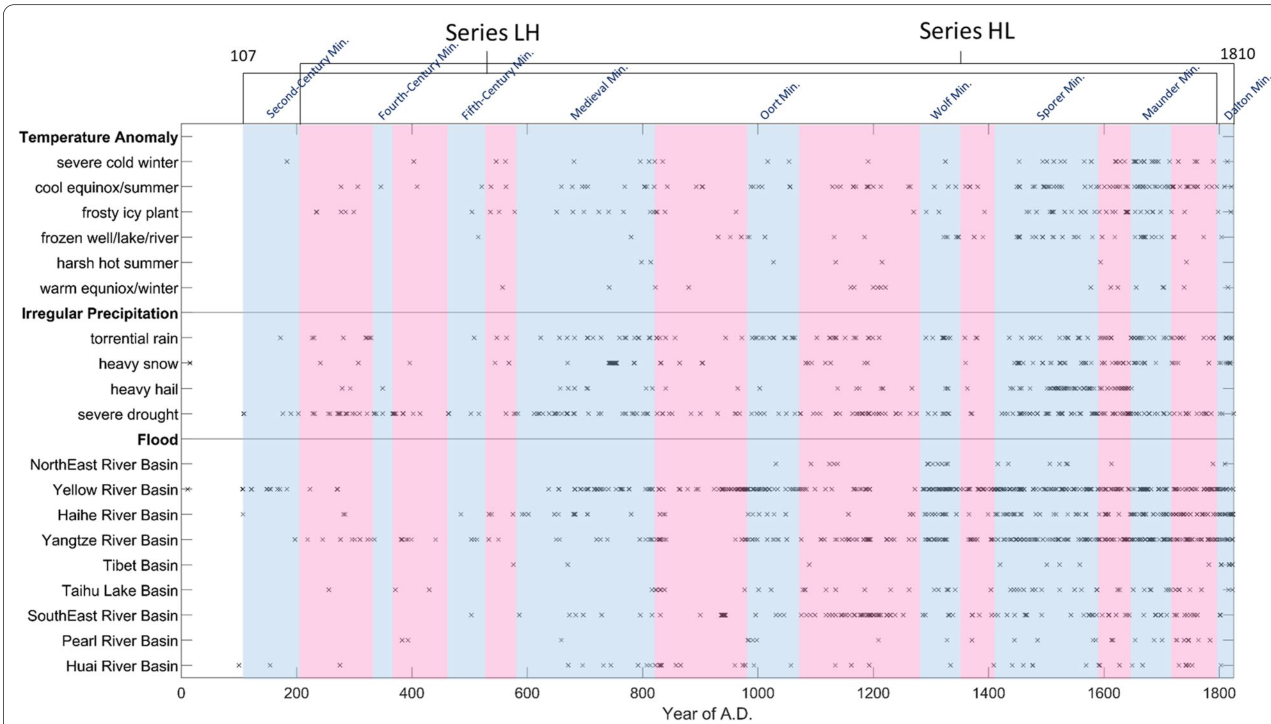

Fig. 1 Temperature anomalies, precipitation irregularities, and flood disasters occurring in China from 1 to 1825 CE. Nine LSA periods: 107–203 CE (Second-Century Minimum), 332–365 CE (Fourth-Century Minimum), 462–526 CE (Fifth-Century Minimum), 580–820 CE (Medieval Minimum), 980-1070 CE (Oort Minimum), 1280–1350 CE (Wolf Minimum), 1410–1590 CE (Sporer Minimum), 1645–1715 CE (Maunder Minimum) and 1795–1825 CE (Dalton Minimum). Red and Blue denote HSA and LSA periods, respectively. The temperature (top panel), precipitation (middle panel), and floods (bottom panel) are classified as cold and hot, wet and dry, as well as inland and coast, respectively. The cross symbols denote the disasters isolated from [Song 1992]. Table 2 shows the associated statistical results in detail

Maunder minimum results in a significantly high frequency of disasters comparing to the other study years. The proportions of disaster years associated with temperature anomalies during the 71 year Maunder Minimum period (number of years with disasters/71) and the 1754 (=1825-71) reference years are 0.4648 and 0.1186, respectively. Similarly, the proportion during the Maunder Minimum period and the reference years are 0.6056 and 0.2360, respectively, owing to irregular precipitations, as well as 0.8310 and 0.3312, respectively, related to floods. Disasters due to the cold temperatures occur much more often than those the hot ones during the Maunder Minimum period (Fig. 1). Therefore, the significant large odds (Klotz and Johnson 1983) of temperature anomalies as 3.92 (=0.4648/0.1186), precipitation irregularities as 2.57 (=0.6056/0.2360), and floods as 2.51 (=0.8310/0.3312) suggest that in China, the unusual cold, irregular precipitation, and floods occur more frequently during Maunder Minimum. In fact, the results for Maunder Minimum motivate the study of disasters linked to the HSA and LSA periods during 107–1825 considering long-term change in number of disasters.

Disasters seem yielding a tendency that is less and more frequent in the earlier and later years, respectively (Fig. 1). In spite of the tendency, the proportions of disasters related to temperatures, precipitations, and floods are generally greater during the LSA period than those during the HSA period in either the LSA-leading or the HSA-leading cycle (Figs. 2 and 3). Moreover, the two figures reveal that proportions of disasters due to the severely cold winter, cool equinox/summer, frosty/icy plant, and frozen well/lake/river in the LSA are all greater than those in the HSA. Conversely, proportions of the harsh hot summer and warm equinox/winter in the LSA periods are both smaller than those in the HSA periods. These results imply that the weather tends to be cold and hot during the LSA and HSA periods, respectively. The subtotal of the proportions also show that the cold and hot weather disasters appear more likely in the LSA and HSA periods, respectively. In general, disasters related to temperature anomalies occur more frequently in the LSA periods.

The disasters due to the irregular precipitation events of both the wet (torrential rain, heavy snow, and heavy hail) and dry (severe drought) occur more often in the LSA periods (Figs. 2 and 3). These results indicate that the precipitation becomes more irregular in the LSA than does in the HSA periods. On the other hand, the proportions of the flood events seem to vary a lot more in their locations (Figs. 4 and 5). However, Figs. 2 and 3 show that the proportions are greater in the inland and coastal river basins during the LSA and HSA periods, respectively. In total, the floods tend to occur in the LSA period. The results in Figs. 2 and 3 strongly suggest that the overall severe weather disasters occur more frequently in the LSA period than in the HSA period in either the LSA-leading or HSA-leading cycle.

It might be of doubt that the historical weather records would be fewer in the older past (Figs. 1, 2a, and 3a). To investigate for the possible temporal variation in the recording frequency during the time periods under study, we employ Page's test (Page 1963) to see if the proportion of disaster years is increasing with the time period during HSA and LSA, respectively. Note that there are 19 ($=n$) different disasters related to the temperature anomaly, irregular precipitation or flood regions. Moreover, for each disaster under investigation, proportions of disaster years are computed under 8 and 9 ($=k$) time cycles in the two periods of HSA and LSA, respectively. For the jth disaster under study, the k proportions of disaster years are arranged from the smallest to the largest and the ranks are assigned from 1 to k accordingly, as denoted by R_{ij}, $i=1, 2, \ldots, k$, $j=1, 2, \ldots, n$. Let R_i be the sum of ranks, $R_{i1}, R_{i2}, \ldots, R_{in}$, or $R_i = \sum_{j=1}^{n} R_{ij}$. The statistic in Page's test is then obtained as $L = \sum_{i=1}^{k} iR_i$ for measuring the positive association between the time period and proportion of disaster years. Therefore, under the significance level of 0.05, the monotonic increasing trend in the k proportions of disaster years is favored if

$$T = \frac{12L - 3nk(k+1)^2}{\sqrt{nk^2(k^2-1)(k+1)}}$$

is greater than 1.645. Note that $T=7.651$ and 8.050 for HSA and LSA periods, respectively, are both larger than 1.645. Page's tests then suggest that the proportion of disaster years is positively associated with the time periods under study. This may be caused by the growth of the Chinese population (Lee et al. 2008) and temporal changes in the detectability of disaster on historical books. Hence, to make a reasonable inference about the link between the severe weather and solar activity, a comparison of proportions of disaster years in the LSA and HSA should consider both the cases with HSA-leading (8 cycles of HSA–LSA) and LSA-leading (8 cycles of LSA–HSA).

To confirm whether severe weather disasters due to temperature anomalies, precipitation irregularities or floods are related to solar activity, 90% confidence intervals (CIs) for the differences between the proportions in the LSA and HSA periods are then constructed (Agresti 1996) for the cases with HSA-leading and LSA-leading, respectively. The 90% CI for the true difference between the two proportions is then given by

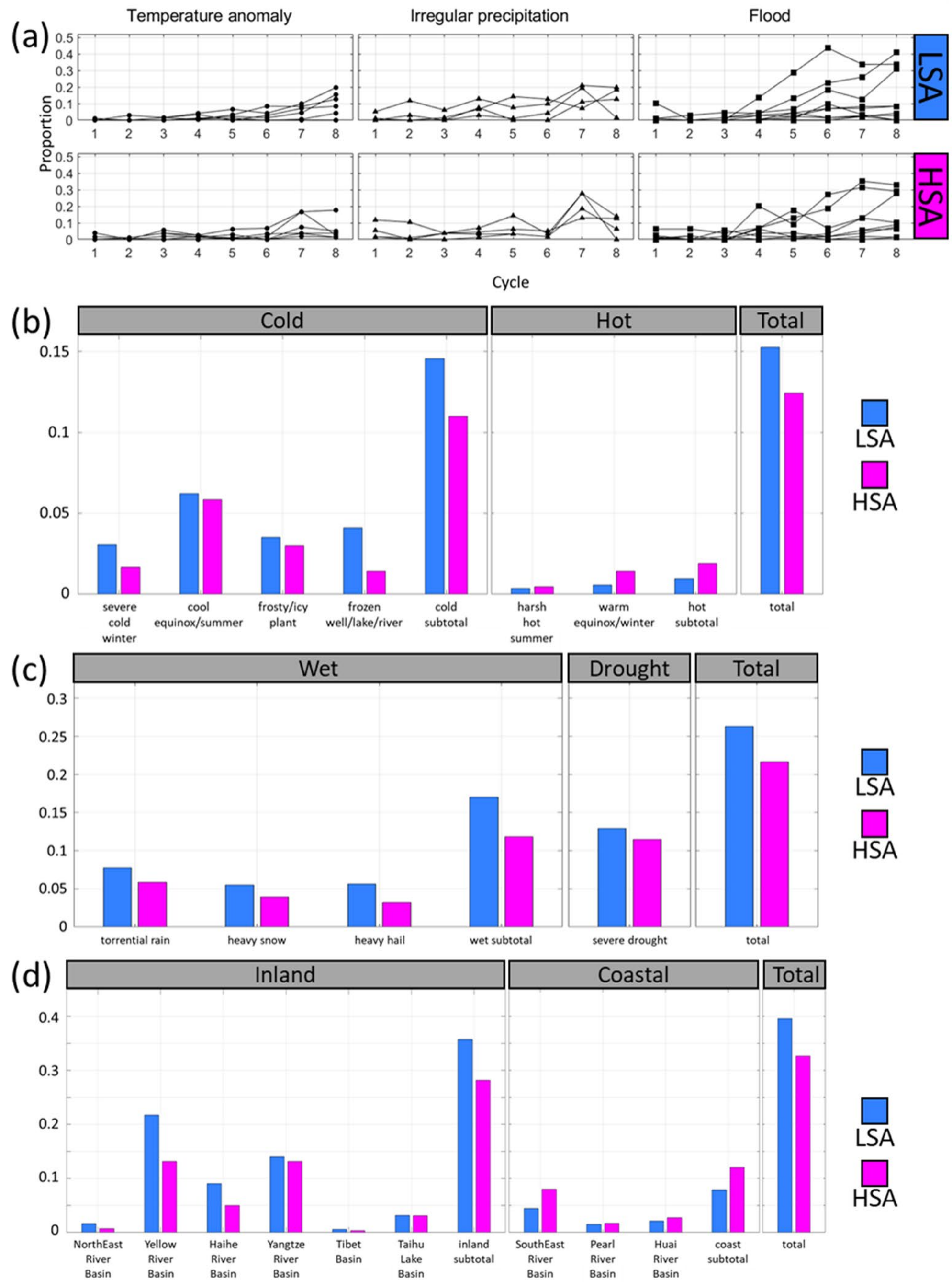

Fig. 2 Proportion trends and proportion comparisons of disasters in 8 LSA-leading cycles. Red and blue denote HSA and LSA periods, respectively. **a** Proportion trends, **b** temperature anomalies, **c** precipitation irregularities, and **d** floods

$$\left[P_L - P_H - 1.645\sqrt{\frac{P_L(1-P_L)}{N_L} + \frac{P_H(1-P_H)}{N_H}}, P_L - P_H + 1.645\sqrt{\frac{P_L(1-P_L)}{N_L} + \frac{P_H(1-P_H)}{N_H}}\right],$$

where P_L and P_H are the proportions in LSA and HSA periods, respectively. In the LSA-leading case, the numbers of years involved in the LSA and HSA periods are $N_L = 785$ and $N_H = 837$, while in the HSA-leading case, the numbers of years involved in the LSA and HSA periods are $N_L = 851$ and $N_H = 837$, respectively.

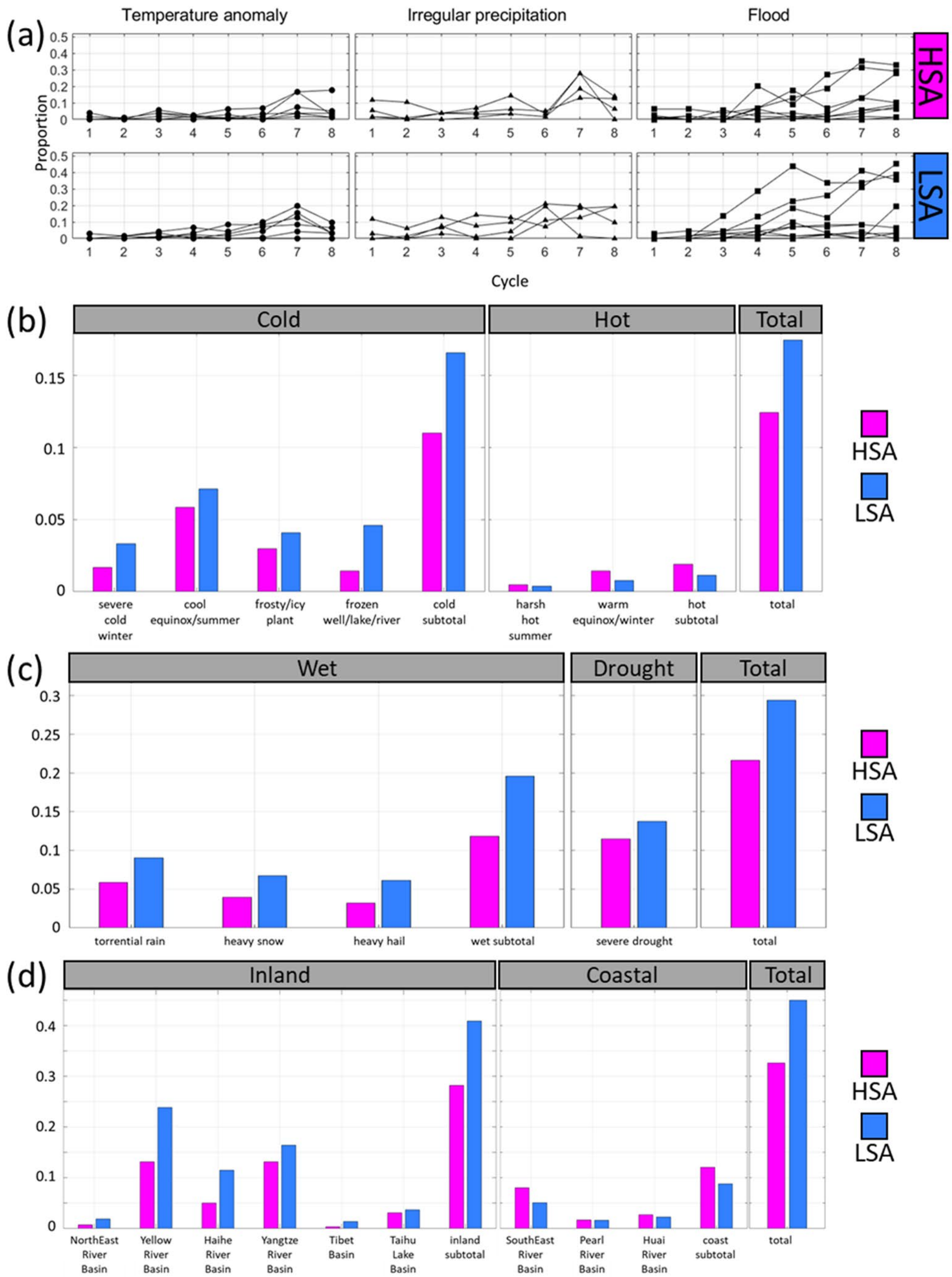

Fig. 3 Proportion trends and proportion comparisons of disasters in the 8 HSA-leading cycles. **a** Proportion trends, **b** temperature anomalies, **c** precipitation irregularities, and **d** floods

Both the 90% CIs under the cases with LSA-leading and HSA-leading are given in Table 2. The CI at 90% level provides a possible range for the difference between two proportions. Therefore, when the 90% CI includes 0, the data do not provide significant evidence at level 0.10 for different proportions (i.e., the proportion-difference is not significant) (Klotz and Johnson 1983).

The 90% CIs in the upper panel of Table 2, [0.009, 0.056] in the LSA-leading and [0.028, 0.073] in the HSA-leading cycles, show that recorded disasters related to total temperature anomalies occur more frequently during the LSA than during the HSA periods. Moreover, for disasters related to cold temperature anomalies, the differences of the proportions between the two periods yield

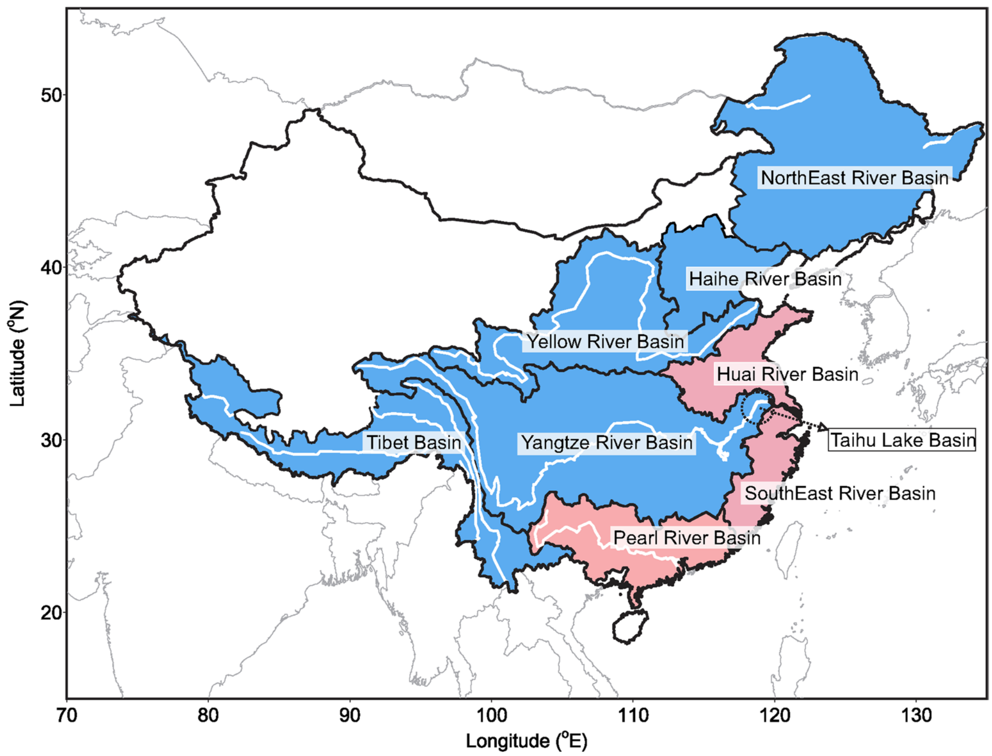

Fig. 4 Nine river basins of China. Red and blue colors indicate that more frequent flooding occurred during the HSA and LSA periods, respectively, for 204–1825 CE. See also the bottom panels in Fig. 1 and Table 2

a 90% CI of [0.015, 0.0057] in the LSA-leading and [0.034, 0.078] in the HSA-leading. In particular, the proportion-differences for the disasters of frozen wells/lakes/rivers occurring in the winter periods are all positive, while those for the cool equinoxes/summers, which might be due to seasonal effects, are not significant, since the 90% CIs of [− 0.011, 0.019] and [− 0.003, 0.029] include zero (Klotz and Johnson 1983). For the disasters related to hot temperature anomalies, namely, the harsh hot summers and warm equinoxes/winters, the proportions during the LSA periods are smaller than those during the HSA periods. The 90% CIs [− 0.015, − 0.002] and [− 0.013, − 001] of warm equinox/winter in the two leading cycles as well as the 90% CI of the subtotal of the hot [− 0.017, − 0.002] in the LSA-leading cycle are significant. The 90% CI of the subtotal of the hot [− 0.015, 0.001] includes zero in the HSA-leading cycle, but does not in the LSA-leading cycle, which indicates that the proportion-differences for the disasters of the hot are not significant. The proportions of the subtotal of cold and the total of temperature anomalies being significant in both LSA- and HSA-leading cycles confirms that the climate tends to be colder and disasters due to temperature anomalies occurs more frequently during the LSA periods.

All the disasters related to the irregular precipitation events occur significantly more frequent during LSA periods than HSA periods, except the severe drought with 90% CI [− 0.006, 0.035] in the LSA-leading cycle (see the middle panel of Table 2). The proportions of the subtotal of wets and the total of precipitation irregularities being significant indicates that the climate tends to be wet and disasters owing to irregular precipitations is more likely to occur during the LSA periods.

Based on the hydrology records in China, the flood regions can be classified into 9 river basins as shown in Fig. 4. Table 2 shows that for the floods in the 6 inland river basins, the proportions during the LSA periods are greater than those during the HSA periods. By contrast, for the floods in the 3 coastal river basins, the proportions during the HSA periods are greater than those during the LSA periods. The 90% CIs for the differences of proportions for the floods in Northeast River Basin, Yellow River Basin, and Haihe River Basin as well as the subtotal of the inland basins are all positive, which confirms that inland floors are more likely to occur during the LSA periods. Notice that Haihe River Basin in Northern China, in fact, locates at both inland and coastal areas.

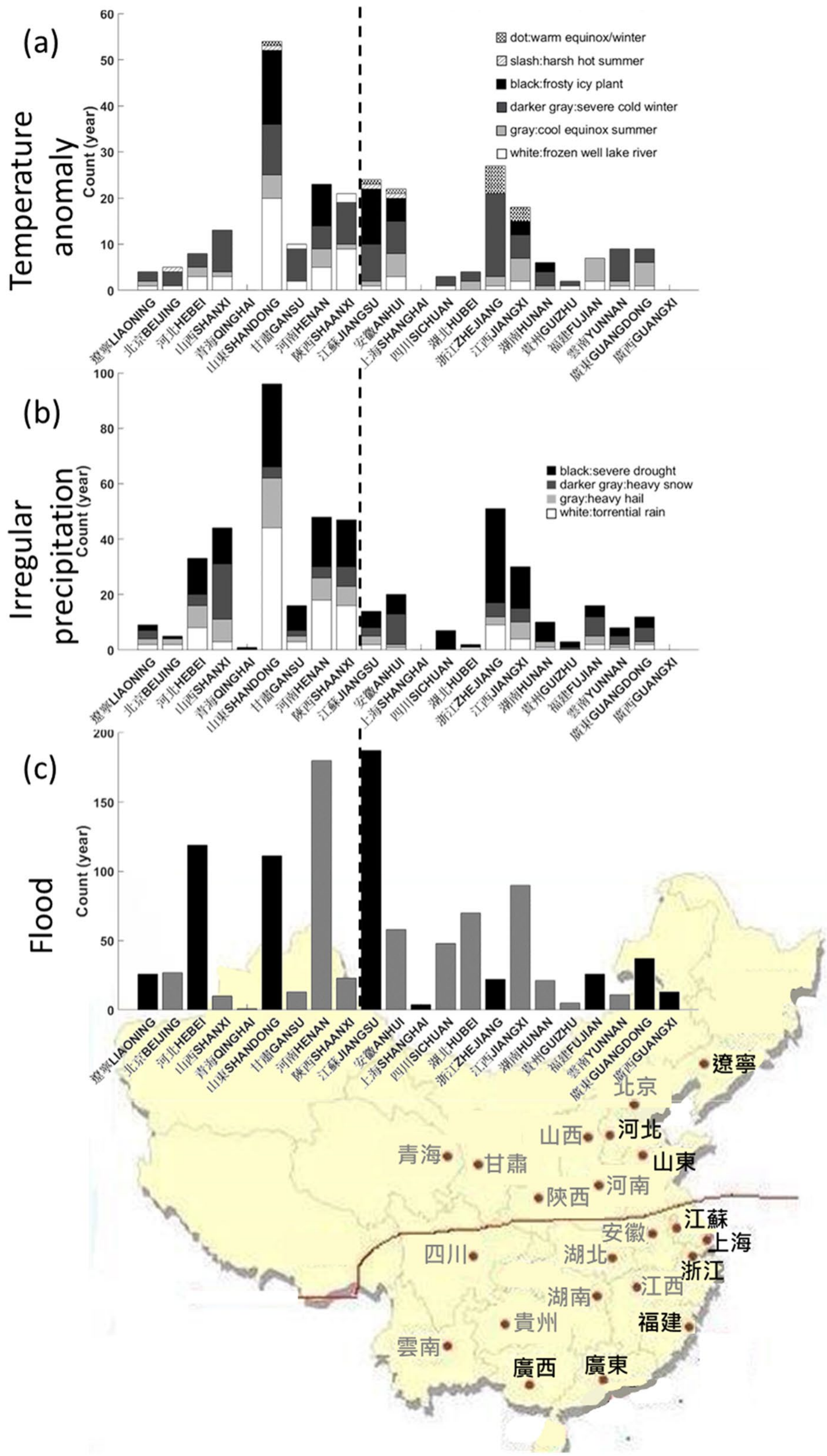

Fig. 5 Counts of the disasters caused by anomalous temperatures, irregular precipitations, and floods in the 22 provinces. The dashed lines in **a**–**c** stand for the Qinling–Huaihe Line

Table 2 Proportion and confidence interval of the severe weather disaster

Item	8 LSA-HSA periods (Series LH)				8 HSA-LSA periods (Series HL)			
	PL	PH	LB	UB	PL	PH	LB	UB
Anomalous temperature								
Severe cold winter	0.0306	0.0167	**0.004**	**0.023**	0.0331	0.0167	**0.006**	**0.026**
Cool equinox/summer	0.0623	0.0585	− 0.011	0.019	0.0713	0.0585	− 0.003	0.029
Frosty/icy plant	0.0353	0.0299	− 0.006	0.016	0.0408	0.0299	− 0.001	0.023
# Frozen well/lake/river	0.0411	0.0143	**0.017**	**0.037**	0.0459	0.0143	**0.021**	**0.042**
Subtotal of the cold	0.1457	0.1099	**0.015**	**0.057**	0.1656	0.1099	**0.034**	**0.078**
Harsh hot summer	0.0035	0.0048	− 0.005	0.003	0.0038	0.0048	− 0.005	0.003
Warm equinox/winter	0.0059	0.0143	**− 0.015**	**− 0.002**	0.0076	0.0143	**− 0.013**	**− 0.001**
Subtotal of the hot	0.0094	0.0191	**− 0.017**	**− 0.002**	0.0115	0.0191	− 0.015	0.001
Total of the temperature	0.1528	0.1243	**0.009**	**0.056**	0.1745	0.1243	**0.028**	**0.073**
Irregular precipitation								
Torrential rain	0.0776	0.0585	**0.003**	**0.035**	0.0866	0.0585	**0.015**	**0.049**
Heavy snow	0.0552	0.0394	**0.003**	**0.029**	0.0675	0.0394	**0.014**	**0.042**
Heavy hail	0.0564	0.0323	**0.011**	**0.037**	0.0611	0.0323	**0.015**	**0.042**
Subtotal of the wet	0.1704	0.1183	**0.030**	**0.074**	0.1962	0.1183	**0.055**	**0.101**
Severe drought	0.1293	0.1147	− 0.006	0.035	0.1376	0.1147	**0.002**	**0.034**
Total of the precipitation	0.2632	0.2162	**0.020**	**0.074**	0.2943	0.2162	**0.050**	**0.106**
Flood								
NorthEast River Basin	0.0165	0.0072	**0.003**	**0.016**	0.0191	0.0072	**0.005**	**0.019**
Yellow River Basin	0.2174	0.1314	**0.063**	**0.109**	0.2382	0.1314	**0.082**	**0.131**
Haihe River Basin	0.0905	0.0502	**0.024**	**0.056**	0.1146	0.0502	**0.047**	**0.082**
Yangtze River Basin	0.1398	0.1314	− 0.013	0.030	0.1643	0.1314	**0.010**	**0.055**
Tibet Basin	0.0059	0.0036	− 0.002	0.007	0.0140	0.0036	**0.004**	**0.016**
Taihu Lake Basin	0.0317	0.0311	− 0.010	0.012	0.0369	0.0311	− 0.006	0.017
Subtotal of the inland	0.3572	0.2820	**0.046**	**0.104**	0.4089	0.2820	**0.097**	**0.157**
South East River Basin	0.0447	0.0800	**− 0.055**	**− 0.016**	0.0510	0.0800	**− 0.045**	**− 0.013**
Pearl River Basin	0.0153	0.0167	− 0.009	0.006	0.0166	0.0167	− 0.008	0.008
Huai River Basin	0.0212	0.0275	− 0.016	0.003	0.0229	0.0275	− 0.015	0.005
Subtotal of the coastal	0.0787	0.1207	**− 0.061**	**− 0.023**	0.0879	0.1207	**− 0.052**	**− 0.013**
Total of the flood	0.3960	0.3262	**0.040**	**0.100**	0.4497	0.3262	**0.093**	**0.154**
Total of the disaster	0.6178	0.4839	**0.094**	**0.174**	0.6021	0.5134	**0.046**	**0.131**

[#] bold numbers denote the differences of proportions being significant in the LSA and HSA period, respectively. *Series LH* LSA leading cycles. *Series HL* HSA leading cycles

On the other hand, the negative upper bound in the 90% CI shown in Table 2 implies that the coastal flooding occurs more often in HSA periods, where the significant difference may be due to the flood in the Southeast River Basin. The differences in proportion for the subtotal of the coastal floods are all negative, which strongly suggests that coastal floods occur more frequently during the HSA periods. Notice that the Taihu Lake Basin is at the downstream end of the Yangtze River, where is very close to the coast, which might result in the insignificance of the proportion difference. In general, the inland and coastal floods tend to occur during the LSA and HSA periods, respectively.

Regional and seasonal variations of disasters

We examine the disasters in various geographic locations during the LSA and HSA periods. Locations of the disasters are denoted by the 22 current provinces, which are subdivided into 4 areas of northern versus southern area by the climate boundary of the Qinling–Huaihe Line (dark brown curve in Fig. 5) at about 33°N and coastal (black characters/bars) versus inland provinces (gray characters/bars). The geography of the Qinling–Huaihe Line (i.e., Qinling Mountains–Huaihe River line) makes the obvious differences between north and south of China in climate, water system, vegetation, transportation, diet, etc. (Gao et al. 2019). Thus, the Qinling–Huaihe Line is the recognized geographical boundary between north and south China (Liu et al. 2020).

Table 3 Proportion and confidence interval of the anomalous temperature and irregular precipitation in various locations

Item	P_L	P_H	LB	UB
Anomalous temperature				
Northern Inland	0.0476	0.0299	**0.006**	**0.030**
Northern Coastal	0.0454	0.0239	**0.010**	**0.033**
Southern Inland	0.0340	0.0311	**0.002**	**0.023**
Southern Coastal	0.0351	0.0227	− 0.008	0.014
Subtotal	0.1528	0.1243	**0.009**	**0.056**
Irregular precipitation				
Northern Inland	0.1223	0.0526	**0.052**	**0.088**
Northern Coastal	0.1083	0.0454	**0.046**	**0.080**
Southern Inland	0.0497	0.0430	− 0.007	0.020
Southern Coastal	0.0561	0.0502	− 0.008	0.020
Subtotal	0.2632	0.2162	**0.020**	**0.074**
Flood				
Northern Inland	0.1610	0.0908	**0.050**	**0.091**
Northern Coastal	0.1395	0.0812	**0.039**	**0.078**
Southern Inland	0.1395	0.1063	**0.013**	**0.054**
Southern Coastal	0.1281	0.1434	− 0.037	0.006
Subtotal	0.3960	0.3262	**0.040**	**0.100**

Bold numbers denote the differences of proportions being significant at level 0.10 (i.e., the 90% confidence interval)

Figures 5a–c illustrates frequencies of the disasters associated with temperature anomalies, precipitation irregularities, and floods in each province, respectively. The proportions of disasters are further examined in the northern inland, northern coastal, southern inland, and southern coastal areas. Table 3 depicts that for each disaster in the area, the proportion during the LSA period is larger than that during the HSA periods, except the flood in the southern coastal area. The 90% CIs show that the disasters in the northern areas occur significantly in the LSA period. In contrast, most of the disasters in the southern areas do not show the significant difference between the LSA and HSA periods. This indicates that the climate boundary of the Qinling–Huaihe Line along at about 33°N could be important for severe weathers in China. Meanwhile, although it is not statistically significant due to [− 0.037, 0.006] including zero, in the southern area, the proportion of floods of 14.34% in the HSA period is larger than that of 12.81% in the LSA, which indicates the flood tends to occur in the southern coastal area during the HSA period that agrees with results of the river basin in Table 2 and Fig. 4. These agreements suggest that in the southern coastal area, the coastal effect of the East Asian summer monsoon contributing to more floods in the HSA periods than the LSA periods (Rao et al. 2015) is essential. Nevertheless, the 90% CIs of the three subtotals show that in whole China, the disasters occur significantly in the LSA period.

To examine how the disasters in different seasons respond to solar activities, we further classify seasons as: Spring (February ~ April; lunar month 1–3; green sectors), Summer (May–July; lunar month 4–6; magenta sectors), Autumn (August–October; lunar month 7–9; yellow sectors), and Winter (November–January; lunar month 10–12; blue sectors), and compute the percentage of the disaster in various seasons during LSA and HSA period. Here, we define the percentage of disasters as the number of disaster years in a certain season during the LSA or HSA period being derived by the total number of disaster years. Figure 6 displays that in each season, the percentage of disasters associated with the anomalous temperatures, irregular precipitations, and floods during the LSA period is larger than that during the HSA period, except the disaster associated with anomalous temperatures in Autumn. The disasters owing to temperature anomalies frequently (63%) occur in Winter (29 = (21 + 8)%) and Spring (34(= 18 + 16)%) during the entire study period, which indicates that the weather tends to be cold during the LSA period. On the other hand, the disasters due to irregular precipitations (68(= (23 + 19) + (16 + 10))%) and floods

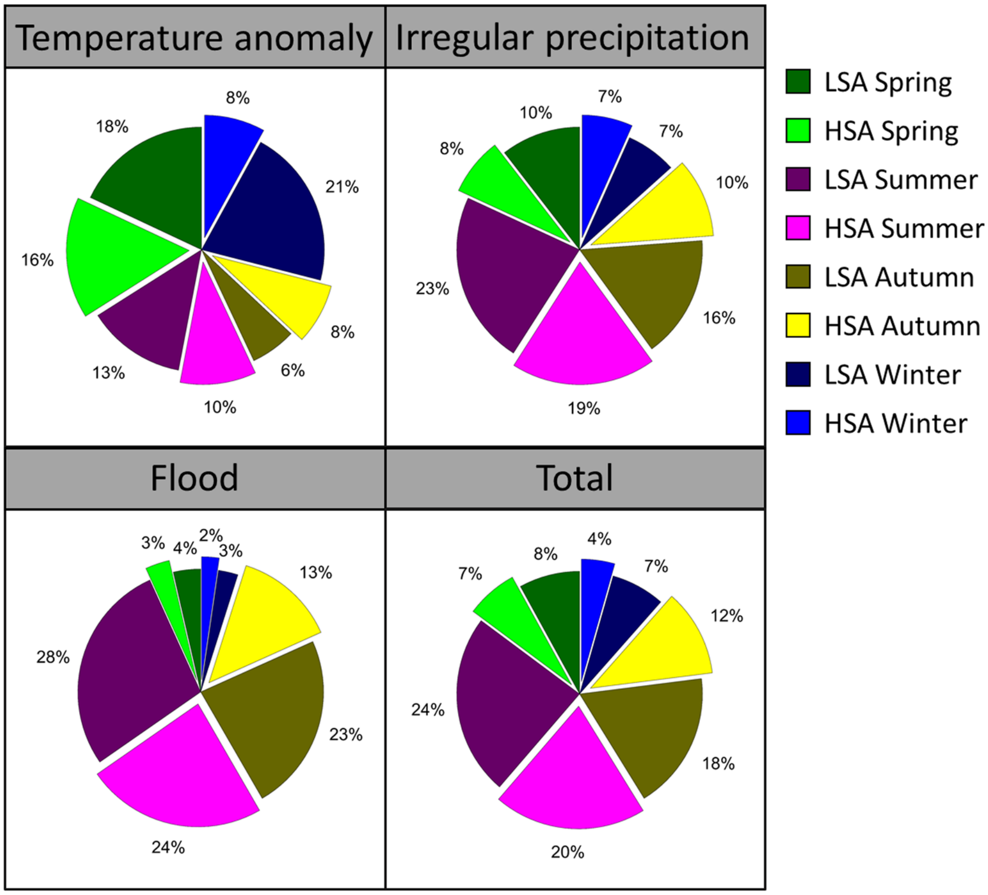

Fig. 6 Percentage of the disasters caused by anomalous temperatures, irregular precipitations, and floods in the four seasons during the HSA (light color with explode pies) and LSA (heavy color pies) periods

(88(=(28 + 24) + (23 + 13))% happen in Summer and Autumn, which suggests that the irregular precipitations most likely result in the floods. The percentage of the overall shows that in China, 74(=(24 + 20) + (19 + 11))% of the disasters occur in Summer and Autumn, and regardless the season, the disasters frequently occur in the LSA period.

Discussion and conclusion

The proportion of disaster years is positively (increased) associated with the time periods (Figs. 1, 2a, and 3a), while Page's tests confirm that the proportion of disaster years is positively associated with the time periods under study. Therefore, to make a reasonable inference about the link between the severe weather and solar activity, both the cases with HSA-leading and LSA-leading are taken into consideration. The agreements of results of the two leading cycles will be used to confirm whether severe weather disasters in China link to solar activity.

The relationship between the long-term changes in solar activity and climatic changes have been studied by many scientists. Reduced solar activity could lower global temperature, increase the global low cloud cover, and affect precipitation. Figures 2 and 3 show that in China, the weather tends to be cold, to precipitate irregularly, and to have more floods during the low solar activity. Tables 2 and 3 show that disasters owing to irregular precipitations, anomalous temperatures, and floods frequently occur during the low solar activity. By contrast, all great civilizations, such as the prosperity of the Sumerian, the pyramids in Egypt, the Roman Empire, were built in the period when solar activity was high, and Earth's temperatures were warm (Eddy 1976). Therefore, we might treat disaster and civilization as antonyms that the periods for great civilizations when the solar activity was high and Earth's temperatures were warm, which yield a small number of disasters.

Table 4 Proportion and confidence interval of the anomalous temperature and irregular precipitation in LSA and HSA during 1645–1825 (1645–1794)CE

LSA: 102 years, HSA: 79 years				
1645–1825CE	P_L	P_H	**LB**	**UB**
Anomalous Temperature	0.4020	0.2785	**0.034**	**0.213**
Irregular Precipitation	0.4118	0.3038	**0.017**	**0.199**
Flood	0.8529	0.7342	**0.041**	**0.197**
Total	0.9804	0.8101	**0.111**	**0.229**
LSA: 71 years, HSA: 79 years				
1645–1794CE	P_L	P_H	**LB**	**UB**
Anomalous Temperature	0.4468	0.2785	**0.087**	**0.286**
Irregular Precipitation	0.4085	0.3038	**0.005**	**0.205**
Flood	0.8310	0.7342	**0.011**	**0.182**
Total	0.9718	0.8101	**0.100**	**0.224**

Bold numbers denote the differences of proportions being significant at level 0.10 (i.e., the 90% confidence interval)

Table 3 shows that the proportions of disasters caused by the anomalous temperature, irregular precipitation, and flood during the LSA periods are greater than those during the HSA periods, except the southern coastal area. The exception in Table 3 agrees well with Table 2 and Fig. 4 that the floods in the southern coastal reiver basins and area tend to occur in the HSA period, which indicate that the coastal effect of the East Asian summer monsoon in southern China being essential. On the other hand, the 90% CIs for the location study in Table 3 confirm that the disasters of severe weather significantly occur during the LSA periods, except the Southern China area. These indicate that the climate boundary of the Qinling–Huaihe Line could be essential.

Figures 2, 3, and 6 together with Table 2 show that the disasters owing to torrential rain and heavy hail mainly occur in Summer and Autumn, and those due to the heavy snow prominently happen in Winter and Spring during the LSA periods. Although the disasters associated with severe drought occur frequently in Summer during the HSA periods, in general, the irregular precipitation disasters in any season frequently appear during the LSA periods. This indicates in China that the solar activity effect overpowers the seasonal one, and confirms that the weather tends to be wet during the LSA periods. Regardless the location and the solar activity, the floods frequently occur in Summer and Autumn, which suggests that torrential rain is the most probable causal of the floods.

Since the difference in solar activity is more significant after 1600 CE, with the invention of the telescope, it would be essential to carry out the examination of fractions and statistical significance for the period of 1645–1825 (Maunder Minimum: 1645–1715, the 8th HSA: 1716–1794, Dalton Minimum: 1795–1825). The 90% CIs in Table 4 once again confirm that the disasters owing to anomalous temperatures, irregular precipitations, and floods occur significantly during the LSA period.

In conclusion, results of statistical analyses demonstrate that in China, the climate tends to be colder and experience more irregular precipitations during the low solar activity period. The results also show that the inland and coastal floods occur more often during the low and high solar activity period, respectively (Additional file 1).

Supplementary Information

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Additional file 1. The disasters in occurrence year, lunar month, area (province), and season during 1-1825 Common Era.

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Authors' contributions
All authors read and approved the final manuscript.

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Availability of data and materials
All the digitized data of temperature anomaly, precipitation irregularity, and flood disaster years are available from Ionospheric Radio Science Laboratory (IRSL), Graduate Institute of Space Science, National Central University (NCU) website (http://tiger.ss.ncu.edu.tw:6578/s/7QMck2Ewb43NMJg).

Declarations

Competing interests
The authors declare that they have no competing interests.

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