Supplementary Materials:

Climate Change and the Pattern of the Hot Spots of War in Ancient China

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1. Categorization of War

Agri-nomadic conflict and rebellion are the most important types of war in Chinese history and have been widely concerned in our group's previous studies. In this research, these two kinds of war are defined as follows:

Agri-nomadic conflict: Agri-nomadic conflict is defined as the conflict between agriculturalists and pastoralists. Nomads lived in the steppe or forest–steppe in North, West, Northeast, and Northwest China and mainly relied on pasture husbandry. Two sides of initiation were involved: the Han Chinese governments launching military campaigns toward the frontier and nomadic tribes or regimes invading the agricultural empires. There were 1390 conflicts all over the study period.

Rebellion: Any battle that contained the meaning of 'anti' can be considered a rebellion. It usually broke out during the middle or late period of a dynasty, or during a disintegration era when people changed their loyalty frequently (e.g., rebel generals jumped to the enemies). It accounted for the largest proportion of all battle records (more than a half), with 2861 battles in 1–1911 CE. Its preconditions include:

(1) Rebels aim to fight against the ruler, the government, or any existing social order,
(2) Rebels are originally under the control of the central government, and
(3) Both sides have clear affiliations.

The rebels can be:

(1) Generals, military governors, and civil officials,
(2) Local or regional powers, such as chieftains, lords, and vassals,
(3) Peasants, civilians, citizens, soldiers, and others who are in the lower class, and
(4) Ethnic minorities under the reign of an empire.

2. Mann–Kendall Trend Test (M–K Test)

The M–K test is a non-parametric test used to analyze whether data are consistently increasing or decreasing over time [1,2]. The null hypothesis of this test is that no monotonic trend resides in the series, whereas the alternative hypothesis is that a trend exists, which can be positive, negative, or non-null. In this study, this test was performed on every location with data as an independent bin time-series test. The bin value for the first time period (e.g., annual unit was set in this study) was compared with the counterpart for the second. The result is +1 (positive trend) when the first is smaller than the second; by contrast, if the result is –1 (negative trend), then the first is larger than the second. The result is 0 (no trend) if the two values are tied. The results for each pair of intervals were compared and computed. The expected sum is 0, which indicates that no trend exists in the values through time. If the observed sum is significantly different from the expected one, the p-value must be small. The more positive (negative) the z-score and the smaller the p-value, the more significant the increased (decreased) trend when the z-score is larger than 1.96 (smaller than –1.96) and the p-value is smaller than 0.05 [3].

3. N–S Confrontations in Ancient China

In Table S2a, five of the eight N–S confrontations within China Proper (located to the south of the Great Wall and the east of the Tibetan Plateau) occurred in cold and disruptive periods, namely, Three Kingdoms (C1), Southern and Northern Dynasties (C2), Five Dynasties and Ten Kingdoms (C3), Southern Song versus Jin (C4), and Southern Ming versus Qing (C6), with three exceptions: the wars between Eastern Jin and nomadic regimes (Sixteen Kingdoms) during a warm interval (W2), Southern Song versus Jin as well as Mongols/Yuan in W5, and the Taiping Kingdom of Heaven versus Qing in a cold phase (C7), which was a short chaotic period within a united era. As the temporal scale of wet/dry stages (multi-centennial) was longer than that of temperature cycles (multi-decadal), N–S confrontations occurred in all stages (regardless of united or disintegrated age, Table S2b). According to the duration of the N–S confrontation(s) in each interval, confrontations in dry conditions were longer. The abovementioned first (321–440 CE) and second (1206–1262 CE) exceptions that actually occurred in D1 and D2 respectively, can be explained. Thus, N–S confrontations usually appeared under cold and/or dry climate.

4. Modifiable Areal Unit Problem (MAUP)

Battle coordinates in imperial China from 1 to 1911 CE were aggregated within the grids formed by 50, 100, and 200 km for the length of each cell, and the results are presented in Figure S1. Notably, different sizes and configurations of spatial units may generate different patterns and affect the analyses, and what is significant on one spatial scale may not be significant on another [4]. This issue where correlation coefficients tend to increase with the level of geographic aggregation was noted by Gehlke and Biehl [5] and was formally described as the Modifiable Areal Unit Problem (MAUP) by Openshaw [6]. In Figure S1, the pattern of the frequency/density of war (i.e., battle number counted in cells) becomes coarser with increasing cell size (i.e., areal units are artificially modified), but we still do not know what size is suitable for the data and the subject (i.e., the hot spot of war) in our research.

The MAUP seems unavoidable; however, its errors can be reduced. One method is to compare the statistical outputs by separately using these three aggregation methods. In this study, the Global Moran's *I* statistic was employed to decide whether spatial autocorrelation or the spatial cluster effect of war existed. The results are listed in Table S3. Evidently, under any circumstance, wars were clustered in space due to the consistent positiveness of all Moran's *I* values, which increased as the cell size increased (e.g., for all war during warm intervals, 50 km: 0.226 < 100 km: 0.508 < 200 km: 0.664). This confirmed that the effect of the MAUP in spatial autocorrelation was certain [7]. Additionally, the variances were incomparable, since the order of magnitude, as a whole, varied among 50, 100, and 200 km. Nevertheless, the *z*-scores were not the same as the values of Moran's *I* and variances when increasing the cell size, which means that their relationship (i.e., *z*-score and cell size) was not linear. Except for rebellion in dry conditions under the 50 km aggregation scheme (*z*-score = 29.2), which was larger than the other two counterparts, the *z*-scores under the 100 km scheme were the largest. From 50 to 200 km, they increased and then drastically dropped, implying that our choice in this research (i.e., 100 × 100 km as the cell size) was reasonable, to some extent.

References

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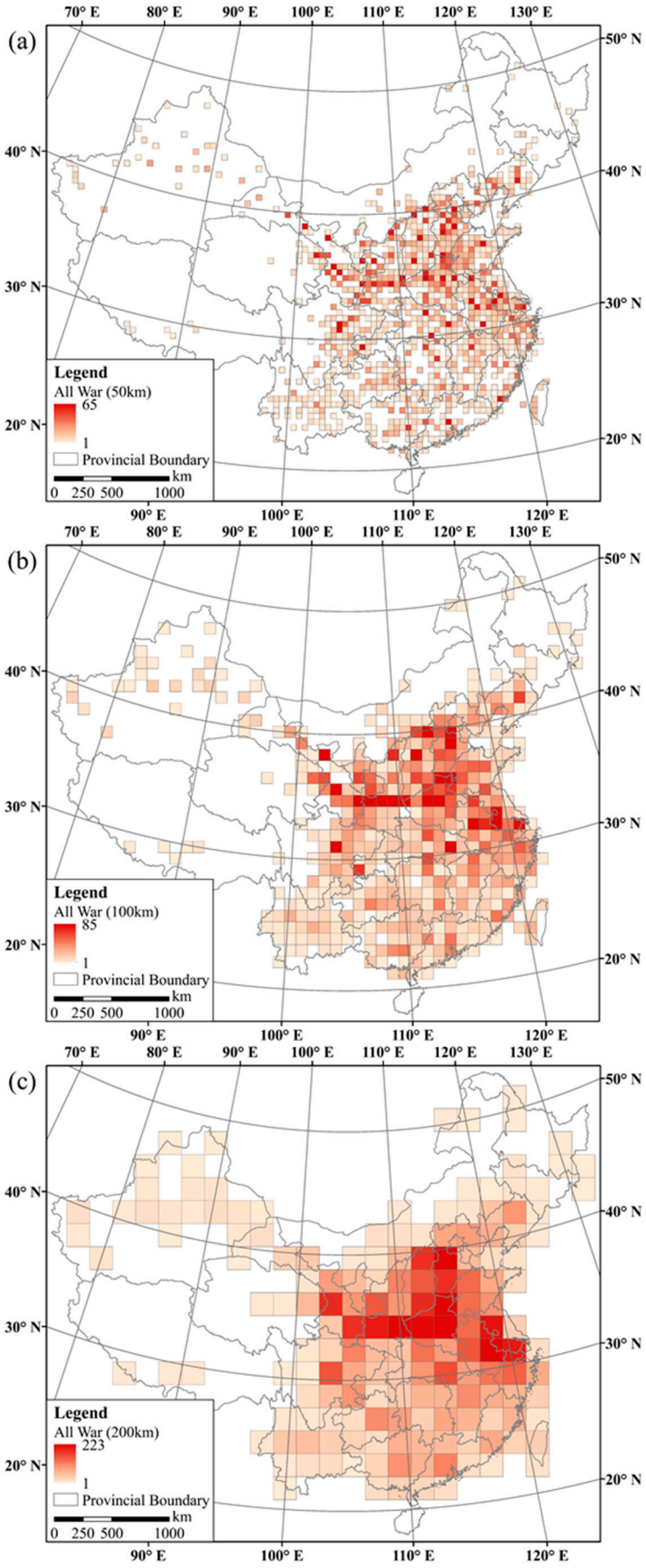

Figure S1. Comparisons of battle number counted within the grids of (**a**) 50 km, (**b**) 100 km, and (**c**) 200 km for each side of a cell.

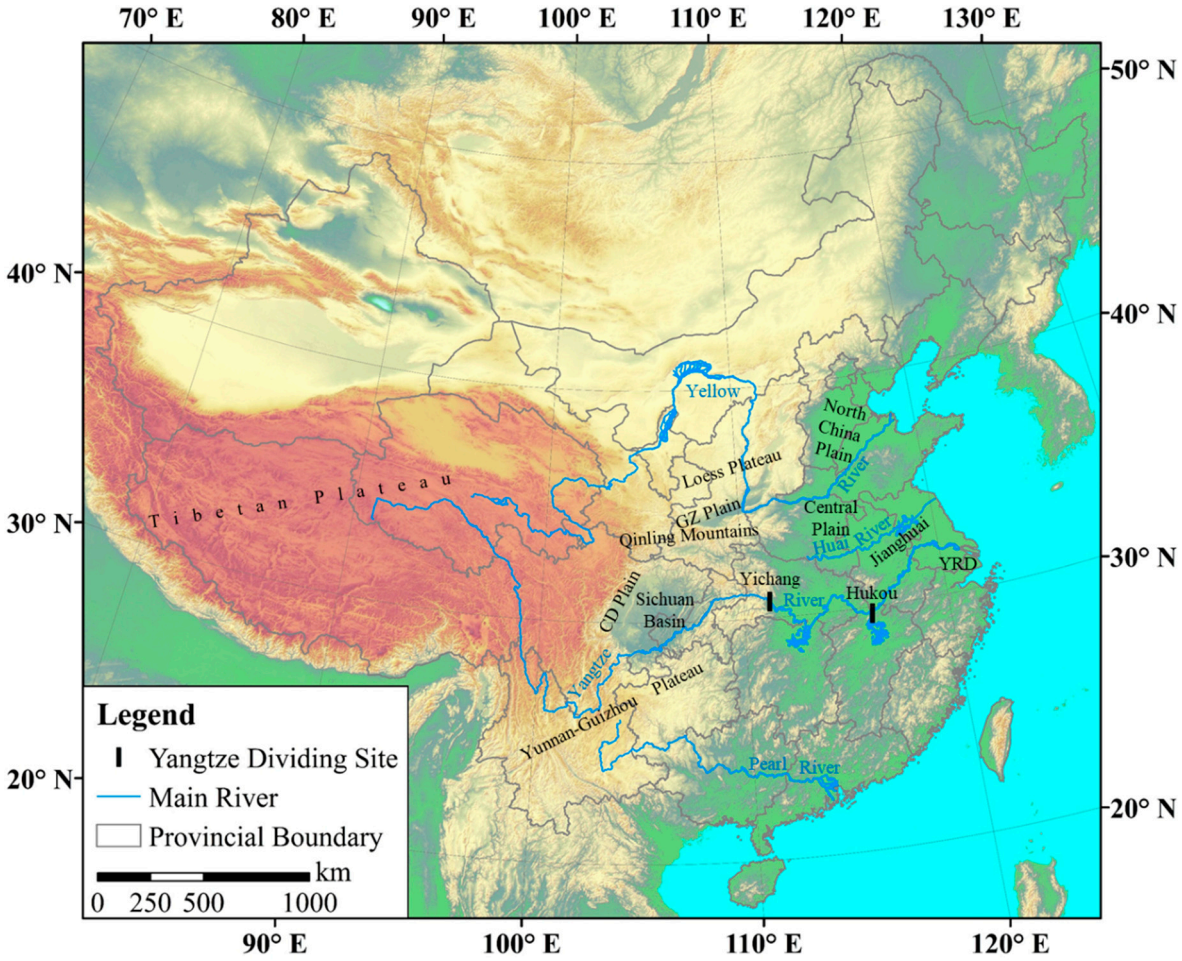

Figure S2. Geographical features of China mentioned in the main text. Note: main rivers are marked in blue; landforms, regions, and other place names are labeled in black; black bars represent the dividing sites of the upper and middle reaches (Yichang) as well as the middle and lower reaches (Hukou) of the Yangtze River; abbreviations--CD Plain: Chengdu Plain; GZ Plain: Guanzhong Plain; YRD: Yangtze River Delta. The base map is a digital topographic map (without actual elevation value but shown in RGB bands) that can be downloaded from CHGIS Datasets (version 4) in Center for Historical Geographical Studies of Fudan University (http://yugong.fudan.edu.cn/views/chgis_download.php)

Table S1. History of China in the study period.

<table>
<tr><th>Southern China</th><th colspan="2">Northern China</th></tr>
<tr><td colspan="3">Western Han 202 BCE–8 CE</td></tr>
<tr><td colspan="3">Xin 9–23</td></tr>
<tr><td colspan="3">Eastern Han 25–220</td></tr>
<tr><td colspan="3">Three Kingdoms 220–280
Shu 221–263
Wu 222–280
Wei 220–266</td></tr>
<tr><td colspan="3">Western Jin 266–316</td></tr>
<tr><td>Eastern Jin 317–420</td><td colspan="2">Sixteen Kingdoms 304–439</td></tr>
<tr><td colspan="3">Southern and Northern Dynasties 420–589
Liu Song 420–479
Xiao Qi 479–502
Xiao Liang 502–557
Southern Chen 557–589
Northern Wei 386–534
Western Wei 535–557 Eastern Wei 534–550
Northern Zhou 557–581 Northern Qi 550–577</td></tr>
<tr><td colspan="3">Sui 581–618</td></tr>
<tr><td colspan="3">Tang 618–907 (Wu Zhou 690–705)</td></tr>
<tr><td colspan="2">Five Dynasties and Ten Kingdoms 907–960</td><td rowspan="2">Liao 907–1125</td></tr>
<tr><td rowspan="2">Northern Song 960–1127</td><td rowspan="2">Western Xia
1038–1227</td></tr>
<tr><td>Jin 1115–1234</td></tr>
<tr><td>Southern Song 1127–1279</td><td colspan="2"></td></tr>
<tr><td colspan="3">Yuan 1271–1368</td></tr>
<tr><td colspan="3">Ming 1368–1644</td></tr>
<tr><td>Southern Ming 1644–1683</td><td colspan="2"></td></tr>
<tr><td colspan="3">Qing 1636–1911</td></tr>
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Table S2a. N–S confrontation within China Proper during warm and cold phase, 5–1911 CE.

Year	Warm/ Cold	Mainly united (U) or disintegrated (D)?	Whether N–S confrontation (Y/N)?	If N–S confrontation exists, when?
5–125	W1	U	N	
126–320	C1	D	Y	Three Kingdoms
321–440	W2	D	Y	Eastern Jin versus nomadic regimes
441–595	C2	D	Y	Southern and Northern Dynasties
596–765	W3	U	N	
766–950	C3	D	Y	Five Dynasties and Ten Kingdoms
951–1120	W4	U	N	
1121–1205	C4	D	Y	Southern Song versus Jin
1206–1330	W5	D	Y	Southern Song versus Jin and Mongols/Yuan
1331–1490	C5	U	N	
1491–1615	W6	U	N	
1616–1705	C6	D	Y	Southern Ming versus Qing
1706–1790	W7	U	N	
1791–1911	C7	U	Y	Taiping Kingdom of Heaven versus Qing

Table S2b. N–S confrontation within China Proper during wet and dry phase, 1–1911 CE.

Year	Wet/ Dry	Mainly united or disintegrated?	Whether N–S confrontation?	If N–S confrontation exists, when?	Confrontation Period	Span (Years)
1–249	W1	U	Y	Three Kingdoms	220–249	30
250–685	D1	D	Y	Three Kingdoms	250–280	304
				Eastern Jin versus nomadic regimes	317–420	
				Southern and Northern Dynasties	420–589	
686–1041	W2	U	Y	Five Dynasties and Ten Kingdoms	907–960	54
1042–1262	D2	D	Y	Southern Song versus Jin and Mongols	1127–1262	136
1263–1483	W3	U	Y	Southern Song versus Yuan	1263–1279	17
1484–1911	D3	U	Y	Southern Ming versus Qing	1644–1683	54
				Taiping Kingdom of Heaven versus Qing	1851–1864	

Table S3. The Global Moran's *I* for different categories of war and climatic stages based on the grids of 50, 100, and 200 km.

	50 km				100 km				200 km			
	Moran's *I*	**Variance**	***z*-score**	***n***	**Moran's *I***	**Variance**	***z*-score**	***n***	**Moran's *I***	**Variance**	***z*-score**	***n***
All War–Warm	0.22599	0.00010	23.18048	5270	0.50834	0.00038	26.07392	1333	0.66352	0.00144	17.54537	352
All War–Cold	0.28824	0.00008	31.92299	6141	0.58829	0.00032	32.79335	1575	0.73778	0.00124	20.99649	414
All War–Wet	0.21365	0.00009	22.91542	5655	0.48712	0.00034	26.49520	1452	0.57919	0.00125	16.47594	374
All War–Dry	0.28076	0.00008	31.07370	6141	0.57926	0.00032	32.26557	1575	0.75847	0.00125	21.50071	414
Agri-Nomadic Conflict–Warm	0.20679	0.00012	18.83315	4080	0.47137	0.00047	21.70074	1040	0.54967	0.00185	12.87827	260
Agri-Nomadic Conflict–Cold	0.13650	0.00014	11.57263	3510	0.41640	0.00057	17.54251	891	0.51062	0.00213	11.16511	238
Agri-Nomadic Conflict–Wet	0.19599	0.00009	20.27325	4758	0.37324	0.00032	20.85525	1209	0.27981	0.00079	10.07964	320
Agri-Nomadic Conflict–Dry	0.18241	0.00013	15.91519	3795	0.49127	0.00052	21.61649	980	0.61213	0.00206	13.58923	252
Rebellion–Warm	0.19058	0.00010	19.39874	5208	0.42235	0.00039	21.44139	1302	0.59521	0.00155	15.21250	336
Rebellion–Cold	0.28200	0.00009	29.33298	5427	0.57246	0.00037	29.99591	1394	0.71795	0.00145	18.95045	357
Rebellion–Wet	0.18006	0.00010	18.33958	5208	0.45726	0.00039	23.18050	1302	0.64962	0.00154	16.62853	336
Rebellion–Dry	0.28055	0.00009	29.20612	5427	0.54164	0.00036	28.43578	1394	0.71114	0.00145	18.74741	357

Note: all values are significant at the 0.01 level.