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Downscaling and Disaggregating NAO-conflict Nexus in Pre-industrial Europe

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Abstract: Recently, the desiccation effect of the North Atlantic Oscillation (NAO) is found to be positively correlated with violent conflict in pre-industrial Europe, with agricultural shrinkage and its subsequent economic shocks to be their causal link. However, it remains unexplored whether the correlation persists if the study period is extended backward in time, a different definition of violent conflict is applied, or the relationship is examined at lower geographic levels. In this study, we based on 835 internal disturbance incidents in Europe during 1049–1800 to conduct long-temporal and multi-scalar examination on the NAO-conflict nexus. 'Time-series' and 'panel data' disaggregation approaches, together with Granger Causality, Multiple Regression, and Survival Analyses were applied to verify the nexus quantitatively. Results show that the positive NAO-conflict correlation was significant at the continent and physiographic zone levels. During the positive NAO phases, the annual probability of internal disturbance outbreak increased by 70.0% in the southern Europe and the Mediterranean, a zone most affected by the NAO-induced desiccation effect. Yet, the NAO-conflict correlation was rather inconsistent when it was downscaled to the sub-regional level. Moreover, the NAO-conflict correlation was inflated under the time-series approach, while the panel data approach demonstrated the region-specific nature of the NAO forcing more clearly. The associated implications in examining climate-conflict nexus are discussed. Our findings may be crucial in examining violent conflict in the northwestern Africa, a highly agricultural region affected by the NAO.

Keywords: climate change; North Atlantic Oscillation (NAO); violent conflict; internal disturbance; Europe

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1 Introduction

North Atlantic Oscillation (NAO) is a large-scale meridional oscillation of atmospheric mass between the sub-tropical anticyclone near the Azores and the sub-polar low pressure system near Iceland, which is the regional manifestation of the Artic Oscillation (Hurrell, 2003; Chu *et al.*, 2008). Depending on where the balance of atmospheric mass lies, the NAO is either in a 'high' state (mass balance over the Azores, positive NAO) or 'low' state (mass balance over Iceland, negative NAO). This mass balance acts as a pressure corridor that influences the direction, magnitude and speed of westerlies across the Atlantic Ocean from North America to Europe, and thereby, winter temperatures and the balance of precipitation and evaporation over both continents (Hurrell, 1995; Hurrell and van Loon, 1997). During a high NAO winter, the axis of maximum moisture transport shifts to a more southwest-to-northeast orientation across the Atlantic and extends much farther to the north and east onto northern Europe and Scandinavia (Hurrell and van Loon, 1997). Together with the

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associated anti-cyclonic circulation and cloud cover reduction (Trigo *et al*., 2002), there is less precipitation over the southern Europe and the entire Mediterranean sector (Hurrell and van Loon, 1997; Trouet *et al*., 2009). Turkey also becomes significantly drier. This is the easternmost limit of the NAO influence on the Mediterranean, which extends from Portugal and Morocco to the eastern Turkey (Cullen and deMenocal, 2000). The NAO regime over the Mediterranean modulates growing season climate over Europe through controlling winter precipitation that initializes the soil moisture states that subsequently interact with temperature. A positive phase of the NAO tends to generate the possibility of a hot and dry summer (or even heat and drought waves) (Wang *et al*., 2011). Additionally, as reflected by annual river discharge and reservoir storages, the NAO-induced reduction of freshwater supply not only happens in winter, but also lasts for the whole year (Cullen and deMenocal, 2000). The synthesis of heat stress and water strain during the growing season is detrimental to agricultural production.

In pre-industrial era, as the vast majority of households in Europe were rural and derived most of their income from agricultural activity (Zhang *et al*., 2011a; Pei *et al*., 2013; 2014; 2015), climate-induced agricultural shrinkage and its subsequent economic shocks could result in social instability there. For instance, the negative effect of cooling on social stability in pre-industrial Europe has been demonstrated by both quantitative analysis (Zhang *et al*., 2007a; Tol and Wagner, 2010; Zhang *et al*., 2011a; Pei *et al*., 2013; 2014) and qualitative interpretation (Büntgen *et al*., 2011; Fraser, 2011; Büntgen *et al*., 2013). On the other hand, drought appears as the common stressor in disrupting socio-political order throughout history (Pei and Zhang, 2014; Zhang *et al*., 2015). Along with the above rubric, Lee *et al*. (2013) took a first step towards identifying the correlation between the NAO and violent conflict in pre-industrial Europe. It was found that the multi-decadal desiccation effect of the NAO is positively correlated with violent conflict in Europe, particularly in southern Europe and the Mediterranean, where the NAO is an imperative determinant of climate (Hurrell and van Loon, 1997; Trigo *et al*., 2002; Trouet *et al*., 2009). Their result is also the first demonstration that the NAO affected social stability in pre-industrial society. Still, the following issues should be resolved to further substantiate the correlation.

First, it has been suggested that violence in the world, especially in the western regions, has declined in both the long and short run as a result of change in the cultural and material milieu (Pinker, 2011). In the analysis of Lee *et al*. (2013), the study time began at the year of 1400. If the study is extended backward in time, will the NAO-conflict correlation be affected by the above phenomenon?

Second, different types of conflict may have different sensitivity to climate change. For instance, in historical agrarian China, the outbreak of internal disturbance is found to be more sensitive to cooling (Zhang *et al*., 2005; 2006; Zhang *et al*., 2007b). In the study of Lee *et al*. (2013), violent conflict was broadly defined as violence that meets Richardson′s Magnitude 1.5 or higher criterion (32+ deaths) (Brecke, 1999), and both interstate war and internal disturbance were pooled together for data analysis. If conflict is further specified as a particular type of violence, does the NAO-conflict correlation persist?

Third, climate and human society interact over a tremendous range of spatial scales. Much of the current debate on cause and effect, vulnerability, and marginality stems from uncritical or unconscious efforts to transfer experience, conclusion, and insight across scales (Clark, 1985). So far, the effect of the NAO in triggering violent conflict has only been demonstrated at the continent, i.e., the whole of Europe, and physiographic zone levels, i.e., the desiccated and non-desiccated zones in Europe (Fig. 1). Can the NAO-conflict correlation be downscaled to lower geographic levels?

This study is designed to address the above issues, with the aim of further assessing the validity of the NAO-conflict link in pre-industrial Europe in long-temporal and multi-scalar manner.

2 Materials and Methods

2.1 Study area and study period

The political boundary of the current European Continent was adopted as our area of interest for this study. Our study period started at the year of 1049, using the entire span of our available data. As the climate-war relationship is found to be much weaker in the modern world than in pre-industrial times (Tol and Wagner,

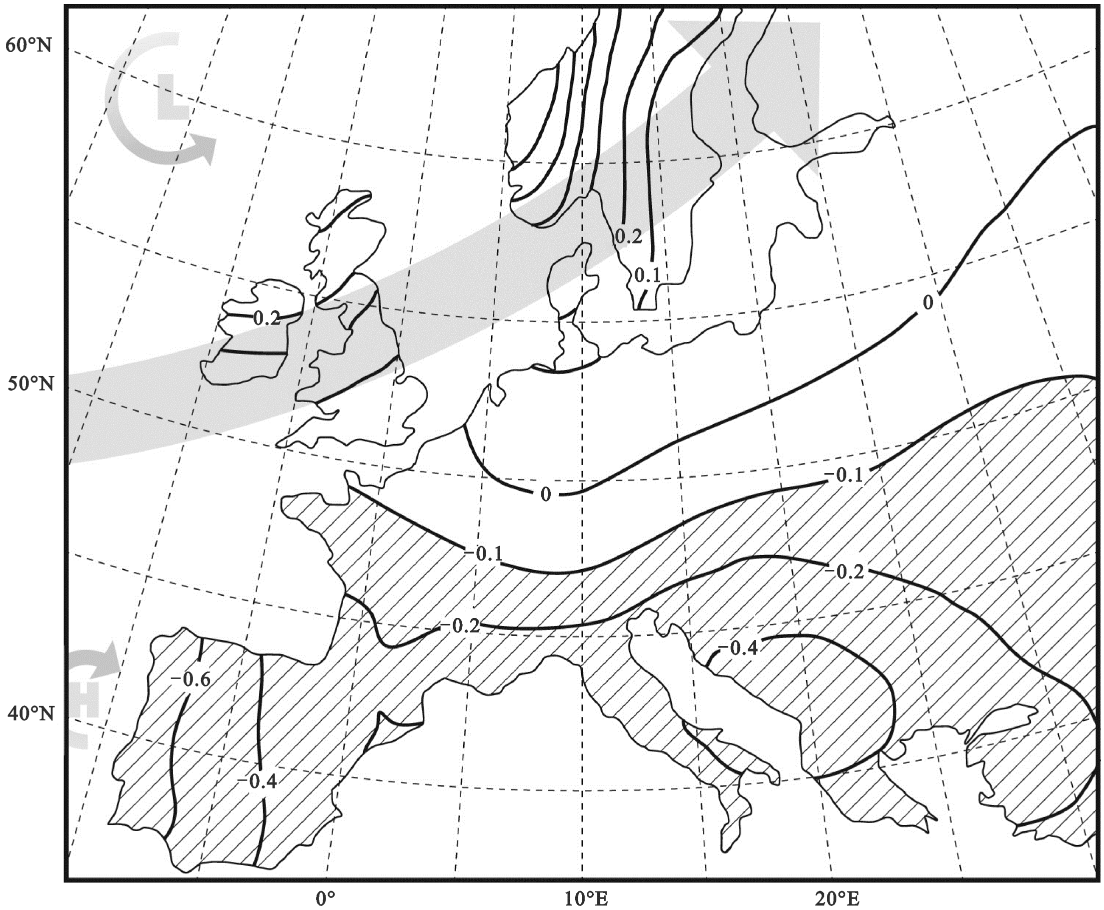

Fig. 1 Map showing location of desiccated zone and non-desiccated zone in Europe. Two physiographic zones were delineated according to changes in precipitation corresponding to the deviation of the North Atlantic Oscillation (NAO) index computed over winters (December–March) in 1900–1994 (Hurrell and van Loon, 1997). Grey shaded arrow indicates the position of the Jet Stream during the positive phase of the NAO. When the NAO index increases by a unit, the area in which precipitation reduces ≥ 0.1 mm/day was delineated as the desiccated zone (shaded part), while the remaining area was delineated as the non-desiccated zone (un-shaded part)

2010; Lee *et al*., 2013), the study time span was cut off at 1800 to allow us to focus on pre-industrial Europe. A total of 835 internal disturbance incidents in Europe were recorded in the study period. All of them were included in our data analysis.

2.2 Data

2.2.1 NAO index

Our NAO index is obtained from the study of Trouet *et al*. (2009) (Fig. 2a). Their NAO index is based on decadal variations in a speleothem-based precipitation proxy from Scotland and a tree-ring based drought proxy from Morocco. The two proxies locate at the centers of opposing poles of NAO-driven precipitation regimes. Their differences (Scotland minus Morocco) give the NAO index, covering the period of 1049−1995. The index can be downloaded from the World Data Center for Paleoclimatology (http://www.ncdc.noaa.gov/paleo/pubs/trouet2009/trouet2009.html). We also compared the NAO index of Trouet *et al*. (2009) with NAO reconstructions of Glueck and Stockton (2001) and Cook *et al*. (2002). The correlations were calculated for the period of 1429−1983 in which the three datasets overlapped. As Trouet *et al*. (2009) shows the multi-decadal variability of the NAO, to achieve comparability, NAO reconstructions of Glueck and Stockton (2001) and Cook *et al*. (2002) were smoothed with a 30-year Butterworth low-pass filter prior to the correlation analysis, with n = 555. The associated correlations were 0.437 and 0.548, respectively. Both of them were strongly significant (P < 0.01), thus confirming the reliability of dataset in Trouet *et al*. (2009).

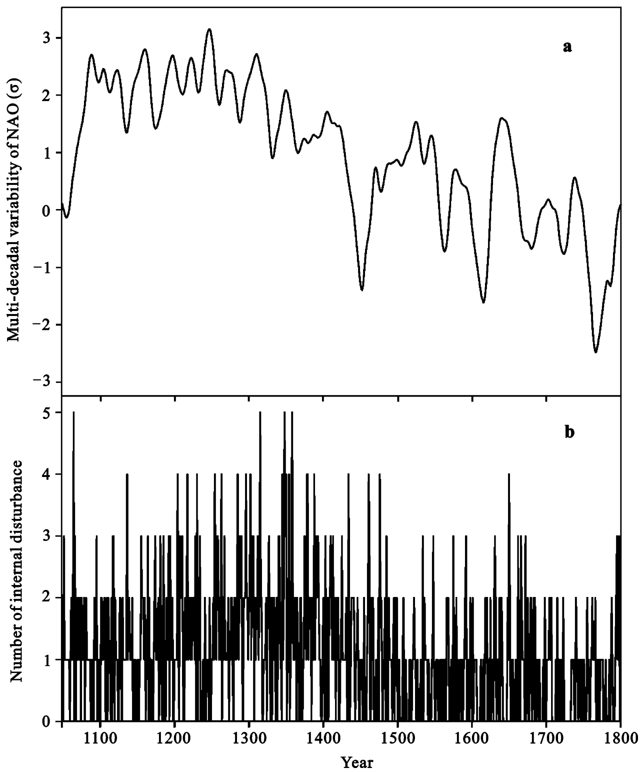

Fig. 2 Comparison of North Atlantic Oscillation (NAO) and internal disturbance in Europe during 1049–1800. (a) Multi-decadal variability of NAO (σ), (b) number of internal disturbances

2.2.2 Violent conflict (internal disturbance) and its geographic delineation

To test whether the NAO-conflict correlation persists when violent conflict is defined as a particular type of violence, violent conflict was limited to internal disturbance in this study. Our internal disturbance data were obtained from Sorokin (1937). It includes most of the recorded internal disturbances of importance (i.e., with the use of available weapons between organized groups within a zone of sovereignty) that have taken place in the life history of Europe over the past millennium. Internal disturbance includes: 1) political disturbance, the main objective of which is a change of the existing political regime; 2) socio-economic disturbance, directed toward a modification of the existing social and economic order; 3) national and separatist disturbance, the main objective is national independence, autonomy, the elimination of disfranchisements, or the achievement of some other privileges and advantages; 4) religious disturbance; 5) others.

Only incidents which violated the existing social order and laws of the period and of the society in which they occurred were classified as internal disturbance. Alternatively, social disturbance of purely or mainly international character (wars between various countries or the revolt of a conquered country against its victorious foreign invaders, for instance, the riots of the French communes against English invaders during the Hundred Years′ War and the wars of Louis XI with the Dukes of Burgundy after the evaporation of the fealty) was excluded. We counted internal disturbance incidents according to their year of onset, which were aggregated to form annual data series (Fig. 2b).

Although some publications contain warfare data for Europe over extended periods (Luard, 1986; Brecke, 1999; Kohn, 1999), in terms of the internal disturbance record, Sorokin (1937)′s dataset are believed to be the most comprehensive one. We have also cross-checked Sorokin (1937)′s record with the original historical document as far as we can, and no error is found. According to Sorokin (1937), Europe was divided into the following sub-regions: France, Germany and Austria, England, Italy, Spain, the Low Countries, Byzantium, Poland and Lithuania, and Russia. The historical boundary of the above regions is given in Table 1. The geographic location of internal disturbance was also categorized accordingly.

In this study, we assessed the internal disturbance created by NAO-induced climatic and environmental change upon the desiccated zone and non-desiccated zone in Europe, respectively. In line with Lee *et al.* (2013), the two physiographic zones were delineated according to change in precipitation corresponding to the deviation of the NAO index computed over winters (December–March) during 1900–1994 (Hurrell and van Loon, 1997). When the NAO index increases by a unit, the area in which precipitation reduces $\geq$ 0.1 mm/day was delineated as the desiccated zone, while the remaining area was delineated as the non-desiccated zone (Fig. 1). However, Byzantium and Germany and Austria occupied both the desiccated and non-desiccated zones in Europe. When the NAO-conflict relationship in the two zones was compared, Byzantium, and Germany and Austria were deliberately excluded to avoid biased estimates. In this study, the desiccated zone in Europe contains France, Italy, and Spain, while the non-desiccated zone contains England, Poland and Lithuania, Russia, and the Low Countries.

Table 1 Historical political boundary of various sub-regions in Europe during 1049–1800 (based on Sorokin, 1937)

Sub-region	Description
France	Prior to its unification and emergence, territories included are those which later composed France. After its establishment, territories included are those which belonged to France at any given period
Italy	Prior to its unification and emergence, territories included are those which later composed Italy. After its establishment, territories included are those which belonged to Italy at any given period
Spain	Within Iberian Peninsula, exclusive of Portugal
England	Before establishment of United Kingdom of Great Britain, England is considered within England Proper, without Wales, Scotland, and Ireland. For subsequent periods it is taken within territory and population which composed Great Britain at any given period. Colonies and overseas dominions are excluded
Poland and Lithuania	They are taken within territory that belonged to them. Temporary dynastic liaisons of Poland with Hungary and Bohemia are disregarded. After division of Poland in 1795, disturbances in previous Polish territories are considered within territories of countries that divided Poland
The Low Countries	Within contemporary Holland and Belgium
Russia	Within territory subject to Grand Dukes of Kiev, then to Grand Dukes of Vladimir and of Moscow, Moscovy Czars and to Emperors of Russia. Galicia and Western Russia, which became subject to Lithuania and Poland since 13th and 14th centuries respectively, are excluded
Byzantium	Within its proper limits and omitting possessions in western Europe
Germany and Austria	Varying territory and population of central Europe which belonged to, or was under power of, German kings and German arch-chancellors. Roughly it embraces territory of Holy Roman Empire

2.3 Methods

2.3.1 Data disaggregation approaches and statistical analyses

To move beyond a simple explanation of conflict derived from data aggregated over a large area, the spatial disaggregation of the climate-conflict nexus is emphasized in climate-conflict research. So far, the disaggregation has been managed in two ways. In the first, the study area is boiled down to some sub-regions and their climate-conflict correlation compared (in time-series, hereafter referred to as ′time-series approach′) (Zhang *et al*., 2005; 2006; Zhang *et al*., 2007a; 2007b; Bai and Kung, 2011; Lee *et al*., 2013). In the second, the study area is boiled down to different sub-regions, then all of the sub-regions are pooled together to estimate the climate-conflict correlation, with those unobserved factors pertinent to the inter-regional variation of the climate-conflict nexus controlled by location-specific constants (in panel data, hereafter referred to as ′panel data approach′) (Anderson *et al*., 2013; Jia, 2013; Kung and Ma, 2014). Both of the above disaggregation approaches were applied in this study.

To examine quantitatively the NAO-conflict relationship, Granger Causality Analysis (Granger, 1988), Multiple Regression Analysis (de Vaus, 2002), and Survival Analysis (including Kaplan-Meier Procedure and Cox Regression Analysis) (Kleinbaum, 1996) were applied. The minimum level of significance was chosen to be 0.1.

2.3.2 Control variables

We employed control variables in our statistical analyses to cater for possible endogenous factors, unmeasured heterogeneity, and temporal fluctuations in the underlying conflict propensity:

Social development. We included calendar year (*Year*) to account for mean shifts in violent conflict and the change of relationship between climate and violent conflict over time (Tol and Wagner, 2010; Hsiang *et al*., 2011). In addition, we included a trend break to control for the conflict suppression effect engendered by the start of the Reformation in 1517 (Tol and Wagner, 2010). It was represented by an additive constant during 1500−1800 (*Reform*).

Weather. Cold and dry weather could induce economic hardship and contribute to human migration, which subsequently triggered conflict onset (Brázdil *et al*., 2005). To focus on the multi-decadal effect of the NAO on internal disturbance in pre-industrial Europe, we controlled the short-term impact of weather on conflict risk by adding the inter-annual growth (i.e., the proportional change since the previous year) of temperature ($Temp$ and $Temp_{t-1}$) and precipitation ($Precip$ and $Precip_{t-1}$) as explanatory variables (Buhaug, 2010). Our weather variables were derived from tree ring-based reconstructions of summer temperature anomalies (℃) and summer total precipitation (mm) for the central

Europe (Büntgen *et al*., 2011), covering the northeastern France, the northeastern Germany, and the southeastern Germany.

Empire and war are strongly interrelated, and Eckhardt (1990) demonstrated a correlation between empire growth and war. On the other hand, the number of violent conflicts may be positively correlated with the number of states (Hsiang *et al*., 2011). Lee *et al*. (2013) employed the total empire size and the total state number in Europe as control variables to prevent the above effect from distorting their results. However, in this study, we studied only internal disturbance, while the above effect is more relevant to interstate war. Therefore, we did not follow the above practice here.

The link from the NAO to internal disturbance can be described as: positive NAO causes drought, then poor harvest, economic hardship, and eventually internal disturbance. However, when the NAO-conflict nexus was examined in this study, we did not control the effect of agricultural production and food price on internal disturbance. This is because those factors themselves are affected by climate variation. If they are included as control variables, it will cause either the signal in the climate variable of interest to be inappropriately absorbed by the control variable or the estimate to be biased because populations differ in unobserved ways that become artificially correlated with climate when the control variable is included (Hsiang *et al*., 2013).

3 Results and Analyses

To start with, we validated the causality between the NAO and internal disturbance using Granger Causality Analysis. The causal relationship between variables is confirmed only if the cause precedes the effect in time and the causal series contains special information that could better explain and forecast the series being caused (Granger, 1988). Before Granger Causality Analysis, an Augmented Dickey-Fuller test was adopted to check the stationarity of data. Any non-stationary data were subjected to first- or second-level differencing. Then regressions were run by controlling the number of lags to identify the causal relation (Table 2). Our Granger Causality Analysis results show that all null hypotheses about the NAO and internal disturbance in the whole of Europe (with Byzantium, and Germany and Austria included ($P < 0.01$) or excluded ($P < 0.01$) and the desiccated zone in Europe ($P < 0.01$) were rejected (Table 3), implying that the causal relationship between the NAO and internal disturbance is statistically valid.

Then, we proceeded to estimate the effect of NAO on internal disturbance using Multiple Regression Analysis. Table 4 shows the results from a number of regression models. In models 1, 2, 3, and 4, we regressed our annual internal disturbance time series on the NAO and all of the control variables. The NAO effect on internal disturbance was robust to the inclusion of the control variables in the regressions. At the continent level, we detected a significant increase in internal disturbance associated with higher NAO values for the whole of Europe, regardless whether Byzantium and Germany and Austria were included ($P < 0.05$) or excluded ($P < 0.05$). This implies that the NAO-conflict association throughout the whole of Europe is not driven by the inclusion/exclusion of the two sub-regions in the sample. At the physiographic zone level, the NAO influence was significant in the desiccated zone in Europe ($P < 0.1$), while not significant in the non-desiccated zone in Europe ($P > 0.1$). This reveals that the NAO-induced environmental changes and the associated societal impact were regionalized and varied across the physiographic zones in the European continent.

Recent violence may trigger the outbreak of a new conflict (Buhaug, 2010). This phenomenon may result in auto-correlated errors in statistical analysis. In models 1a, 2a, 3a, and 4a (Table 4), we added the number of internal disturbances in the previous two years

Table 2 Augmented Dickey-Fuller test and time lag for Granger Causality Analysis in Table 3

Time series	P	Lag
NAO	0.000	5
Internal disturbance in Europe	0.000	8
Internal disturbance in Europe (exclude Byzantium and Germany and Austria)	0.000	1
Internal disturbance in desiccated zone in Europe	0.000	3

Table 3 Granger causality of NAO-conflict relationship in Europe

Causal linkage (null hypothesis)	F
NAO does not Granger-cause internal disturbance in Europe	3.474***
NAO does not Granger-cause internal disturbance in Europe (exclude Byzantium and Germany and Austria)	24.116***
NAO does not Granger-cause internal disturbance in desiccated zone in Europe	8.737***

Note: ***: $P < 0.01$

Table 4 NAO-conflict correlation in Europe based on annual time series data

Internal disturbance	Europe		Europe (exclude Byzantium and Germany and Austria)		Desiccated zone		Non-desiccated zone	
	Model 1	Model 1a	Model 2	Model 2a	Model 3	Model 3a	Model 4	Model 4a
Constant	0.836 (0.531)	0.916^{*} (0.540)	0.134 (0.507)	0.245 (0.516)	0.298 (0.349)	0.369 (0.356)	–0.164 (0.360)	–0.111 (0.367)
NAO	0.098^{**} (0.046)	0.078^{*} (0.046)	0.106^{**} (0.044)	0.087^{*} (0.044)	0.057^{*} (0.030)	0.053^{*} (0.031)	0.048 (0.031)	0.043 (0.031)
Year	0.027 (0.037)	0.016 (0.037)	0.065^{*} (0.035)	0.052 (0.036)	0.024 (0.024)	0.020 (0.024)	0.041 (0.025)	0.036 (0.025)
Reform	-0.525^{***} (0.141)	-0.454^{***} (0.143)	-0.531^{***} (0.135)	-0.462^{***} (0.138)	-0.311^{***} (0.093)	-0.305^{***} (0.094)	-0.220^{**} (0.095)	-0.201^{**} (0.096)
Temp	-0.106^{*} (0.063)	–0.095 (0.063)	–0.091 (0.060)	–0.083 (0.060)	0.008 (0.041)	0.009 (0.041)	-0.098^{**} (0.042)	-0.094^{**} (0.043)
$Temp_{t-1}$	0.009 (0.062)	0.021 (0.062)	0.025 (0.060)	0.035 (0.060)	–0.025 (0.041)	–0.022 (0.041)	0.050 (0.042)	0.054 (0.042)
Precip	–0.060 (0.109)	–0.059 (0.109)	0.006 (0.105)	0.004 (0.105)	0.042 (0.072)	0.041 (0.072)	–0.036 (0.074)	–0.033 (0.074)
$Precip_{t-1}$	0.028 (0.109)	0.011 (0.109)	–0.014 (0.105)	–0.026 (0.105)	–0.097 (0.072)	–0.101 (0.072)	0.084 (0.074)	0.074 (0.074)
$Disturb_{t-1}$	–	0.015 (0.037)	–	0.027 (0.037)	–	–0.045 (0.037)	–	0.000 (0.037)
$Disturb_{t-2}$	–	0.091^{**} (0.037)	–	0.082^{**} (0.037)	–	0.044 (0.037)	–	0.066^{*} (0.037)
R^2_{adj}	0.073	0.078	0.051	0.055	0.051	0.052	0.013	0.014
n	752	750	752	750	752	750	752	750
β(NAO)	0.115	0.091	0.131	0.108	0.103	0.094	0.086	0.076

Notes: *Year* stands for calendar year; *Reform* stands for reformation trend break; *Temp* and $Temp_{t-1}$ represent temperature in this and the last year; *Precip* and $Precip_{t-1}$ represent precipitation in this and the last year; $Disturb_{t-1}$ and $Disturb_{t-2}$ represent internal disturbance in the last and two years ago; R^2_{adj} stands for adjusted R^2; *n* stands for sample size; β(NAO) stands for standardized beta of NAO. Standard errors are in parentheses. ***: $P < 0.01$, **: $P < 0.05$, *: $P < 0.1$

($Disturb_{t-1}$ and $Disturb_{t-2}$) as explanatory variables to control for the auto-correlated errors (Tol and Wagner, 2010). Although the NAO effect on internal disturbance was estimated to be weaker, it still had a statistically significant effect on the whole of Europe (with Byzantium and Germany and Austria included ($P < 0.1$) or excluded ($P < 0.1$)) and the desiccated zone in Europe ($P < 0.1$) in the expected direction. This indicates that our results were not driven by any autoregressive disturbances.

We also decoupled our annual internal disturbance time series to region panel data to replicate our regression analysis (Table 5). In models 5 and 6, with the same set of control variables as shown in Table 4 (i.e., models 1, 2, 3, and 4), we still observed the effect of the NAO oscillation on the whole of Europe with Byzantium and Germany and Austria included ($P < 0.05$) or excluded ($P < 0.05$). In models 5a and 6a, we added region-specific constants (fixed-effect) with estimated standard errors clustered by sub-region. The correlation persisted with Byzantium and Germany and Austria included ($P < 0.05$) or excluded ($P < 0.05$), implying that the NAO-conflict correlation was robust to different data disaggregation approaches. In model 6b, we replaced the region-specific constants with the desiccation dummy (i.e., the desiccated zone versus the non-desiccated zone in Europe) and produced the same result regarding the risk of violence engendered by the NAO ($P < 0.05$). This shows that the positive association between the NAO and internal disturbance was robust, no matter the fixed effect was controlled at the sub-region or physiographic zone levels.

We proceeded to examine internal disturbance (i.e., years with internal disturbance regardless the number of disturbance incidents) at the physiographic zone level with Survival Analysis. The concept of threshold was applied by creating the binary versions of the NAO using threshold values, with the annual probability of internal disturbance outbreak between positive and negative NAO phases (threshold value of the NAO index is

Table 5 NAO-conflict correlation in Europe based on sub-region panel data

Internal disturbance	Europe		Europe (exclude Byzantium and Germany and Austria)			Desiccated zone		Non-desiccated zone	
	Model 5	Model 5a	Model 6	Model 6a	Model 6b	Model 7	Model 7a	Model 8	Model 8a
Constant	0.062 (0.065)	0.064 (0.066)	0.019 (0.074)	–0.000 (0.075)	0.005 (0.074)	0.099 (0.120)	0.081 (0.120)	–0.041 (0.093)	–0.046 (0.093)
NAO	0.010* (0.006)	0.011** (0.006)	0.015** (0.006)	0.015** (0.006)	0.015** (0.006)	0.019* (0.010)	0.019* (0.010)	0.012 (0.008)	0.012 (0.008)
Year	0.006 (0.004)	0.004 (0.004)	0.009* (0.005)	0.009* (0.005)	0.009* (0.005)	0.008 (0.008)	0.008 (0.008)	0.010 (0.006)	0.010 (0.006)
Reform	–0.064*** (0.018)	–0.065*** (0.017)	–0.076*** (0.020)	–0.076*** (0.020)	–0.076*** (0.020)	–0.104*** (0.032)	–0.104*** (0.032)	–0.055** (0.025)	–0.055** (0.024)
Temp	–0.012 (0.008)	–0.013 (0.008)	–0.013 (0.009)	–0.013 (0.009)	–0.013 (0.009)	0.003 (0.014)	0.003 (0.014)	–0.025** (0.011)	–0.025** (0.011)
$Temp_{t-1}$	0.002 (0.008)	0.001 (0.008)	0.004 (0.009)	0.004 (0.009)	0.004 (0.009)	–0.008 (0.014)	–0.008 (0.014)	0.013 (0.011)	0.013 (0.011)
Precip	–0.008 (0.013)	–0.007 (0.013)	0.001 (0.015)	0.001 (0.015)	0.001 (0.015)	0.014 (0.025)	0.014 (0.025)	–0.009 (0.019)	–0.009 (0.019)
$Precip_{t-1}$	0.002 (0.013)	0.003 (0.013)	–0.002 (0.015)	–0.002 (0.015)	–0.002 (0.015)	–0.032 (0.025)	–0.032 (0.025)	0.021 (0.019)	0.021 (0.019)
Region-specific constants	No	Yes	No	Yes	No	No	Yes	No	Yes
Desiccation dummy	No	No	No	No	Yes	–	–	–	–
R^2_{adj}	0.006	0.017	0.007	0.014	0.009	0.016	0.018	0.003	0.011
n	6368	6368	5264	5264	5264	2256	2256	3008	3008
β(NAO)	0.035	0.038	0.050	0.050	0.050	0.059	0.059	0.042	0.042

Notes: *Year* stands for calendar year; *Reform* stands for reformation trend break; *Temp* and $Temp_{t-1}$ represent temperature in this and the last year; *Precip* and $Precip_{t-1}$ represent precipitation in this and the last year; $Disturb_{t-1}$ and $Disturb_{t-2}$ represent internal disturbance in the last and two years ago; *Region-specific constants* are for controlling variation among sub-regions; *Desiccation dummy* is for controlling variation among physiographic zones; R^2_{adj} stands for adjusted R^2; *n* stands for sample size; β(NAO) stands for standardized beta of NAO. Standard errors are in parentheses. ***: $P < 0.01$, **: $P < 0.05$, *: $P < 0.1$

set at 0) and between strong and weak NAO phases (threshold value of the NAO index is set at 2) compared. Via Kaplan-Meier Procedure, the disparity of social response to the NAO between the desiccated zone and the non-desiccated zone in Europe was demonstrated to be statistically significant. In the desiccated zone, the annual probability of internal disturbance outbreak was significantly higher than that in the non-desiccated zone during the positive NAO ($P < 0.01$) and the strong NAO ($P < 0.01$) phases (Table 6). This further justifies our delineation of Europe into the desiccated and non-desiccated zones when examining the NAO-conflict nexus. We also applied Cox Regression Analysis with region- specific constants to model the internal disturbance period to the NAO. Statistical results confirm that the NAO produced strong and significant impact in the desiccated zone in Europe, where the annual probability of internal disturbance outbreak increased by 70.0% during the positive NAO phases (against the phases in which the NAO index < 0; $P < 0.01$), while the probability increased by 48.2% in the strong NAO phases (against the phases in which the NAO index < 2; $P < 0.01$) (Table 7).

We further scaled down our statistical analysis from the physiographic zone level to the sub-region level to learn whether the correlation persisted in individual sub-regions or not. Via Cox Regression Analysis, within the desiccated zone in Europe, the NAO-conflict correla-

Table 6 Kaplan-Meier Procedure for showing regional variation in Europe in response to NAO ($n = 5264$)

	Desiccated zone	Non-desiccated zone	χ^2
Positive NAO	1.60	1.09	11.174***
Strong NAO	1.46	1.18	12.589***

Notes: periods marked by internal disturbance are equivalent to years with internal disturbance, regardless of the number of disturbance incidents. The row 'positive NAO' states the ratio of the annual probability of internal disturbance outbreak in positive NAO phases in comparison to negative NAO phases; the row 'strong NAO' states the percentage change of the annual probability of internal disturbance outbreak when the NAO switches from weak to strong phases. ***: $P < 0.01$

Table 7 Cox Regression Analysis for periods marked by internal disturbance in Europe

	Europe		Europe (exclude Byzantium and Germany and Austria)		Desiccated zone		Non-desiccated zone	
	Percentage change (%)	Wald	Percentage change (%)	Wald	Percentage change (%)	Wald	Percentage change (%)	Wald
Positive NAO	39.3^{***}	12.068	36.3^{***}	9.625	70.0^{***}	11.756	13.7	0.955
Strong NAO	29.2^{***}	11.133	30.9^{***}	10.864	48.2^{***}	11.688	15.9	1.614
n	6368		5264		2256		3008	

Notes: periods marked by internal disturbance are equivalent to years with internal disturbance, regardless of the number of disturbance incidents. The row 'positive NAO' states the percentage change of the annual probability of internal disturbance outbreak when the NAO switches from negative to positive phases; the row 'strong NAO' states the percentage change of the annual probability of internal disturbance outbreak when the NAO switches from weak to strong phases. All models include region-specific constants. ***: $P < 0.01$

tion was strongly significant for Italy and Spain. The annual probability of internal disturbance outbreak in Italy and Spain increased by 146.8% ($P < 0.01$) and 123.2% ($P < 0.01$) during the positive NAO phases, respectively. For Germany and Austria, which occupied both the desiccated and the non-desiccated zones in Europe, the probability also increased significantly by 88.4% ($P < 0.1$). In the strong NAO phase, the probability in Italy and Spain increased by 67.1% ($P < 0.01$) and 68.2% ($P < 0.05$), respectively. In short, the NAO was not necessary in an extreme mode its effect on the social stability of some sub-regions in the desiccated zone was apparent. However, some sub-regions in the non-desiccated zone in Europe were also adversely affected when the NAO became unusually strongly positive, as the probability of internal disturbance outbreak in Russia and the Low Countries increased by 41.4% ($P < 0.1$) and 63.1% ($P < 0.1$) in the strong NAO phases, respectively (Table 8). The social stability of France, which is located in the desiccated zone in Europe, should have been affected by the NAO. However, the effect of positive and strong NAO on internal disturbance was not statistically significant (Table 8).

An examination of the effect of disaggregation in mediating the NAO-conflict correlation for both Multiple Regression Analysis and Cox Regression Analysis demonstrates that statistically significant correlation can be obtained at the continent and physiographic zone levels with the time-series and panel data approaches (Tables 4, 5, 7). However, we found that the correlation was inflated under the time-series approach, in which the standardized coefficients of NAO (β(NAO)) in all the regression models were higher than those under the panel data approach. In addition, the biggest β(NAO) was found in Europe (with Byzantium and Germany and Austria excluded) under the time-series approach, while the biggest β(NAO) was found in the desiccated zone in Europe under the panel data approach (Tables 4, 5). For

Table 8 Cox Regression Analysis for periods marked by internal disturbance in various sub-regions in Europe

Physiographic zone	Sub-region	Positive NAO		Strong NAO	
		Percentage change (%)	Wald	Percentage change (%)	Wald
Desiccated zone	France	1.8	0.006	12.6	0.309
	Italy	146.8^{***}	9.477	67.1^{***}	7.545
	Spain	123.2^{***}	6.834	68.2^{**}	6.550
Non-desiccated zone	England	–19.4	0.782	–32.0	2.029
	Poland and Lithuania	40.4	1.236	4.0	0.000
	Russia	22.6	0.806	41.4^{*}	3.328
	The Low Countries	29.0	0.688	63.1^{*}	3.910
Others	Byzantium	–65.5	1.070	–39.2	1.100
	Germany and Austria	88.4^{*}	3.468	40.8	1.939

Notes: data time span for the internal disturbance onset in Byzantium is from 1049 to 1400 (n = 352), while that for the remaining sub-regions in Europe is from 1049 to 1800 (n = 752). The periods marked by internal disturbance are equivalent to years with internal disturbance, regardless of the number of disturbance incidents. The column 'positive NAO' states the percentage change of the annual probability of internal disturbance outbreak when the NAO switches from negative to positive phases; the column 'strong NAO' states the percentage change of the annual probability of internal disturbance outbreak when the NAO switches from weak to strong phases. ***: $P < 0.01$, **: $P < 0.05$, *: $P < 0.1$

Cox Regression Analysis, in which panel data were used, the associated statistical results also show that the NAO oscillation produced the strongest risk for violence in the desiccated zone in Europe (Table 7). These findings reveal that the panel data approach performs better than the time-series approach in demonstrating the region-specific nature of NAO forcing. Furthermore, when the NAO-conflict nexus was examined at lower geographic levels, the spatial discrepancy of the nexus became more apparent. In other words, when the geographic units at lower geographic levels were combined or pooled up to estimate the NAO-conflict correlation at higher geographic levels, the discrepancy was masked, no matter the time-series approach or panel data approach was employed (Tables 4, 5, 7).

4 Discussion

The long-temporal and multi-scalar NAO-conflict relationship in pre-industrial Europe was verified by a battery of statistical models. Also, different data disaggregation approaches were applied. The positive NAO-conflict correlation was statistically robust. In the study of Lee *et al*. (2013), the study time span began at the year of 1400; violent conflict was broadly defined as violence that meets Richardson's Magnitude 1.5 or higher criterion (32+ deaths) (Brecke, 1999); and both interstate war and internal disturbance were pooled together for data analysis. In this study, the study time span is extended backward from the year 1400 to 1049 and violent conflict is specified as internal disturbance. We still found the correlation at the continent and at the physiographic zone levels. This further substantiates the NAO-conflict relationship. During the positive NAO phases, the annual probability of internal disturbance outbreak increased by 70.0% in southern Europe and the Mediterranean, a zone most affected by the NAO-induced desiccation effect. However, when we took a step forward by scaling down the relationship between the NAO and internal disturbance, we found that the multi-decadal NAO variability did not uniformly drive up the risk of conflict among the sub-regions within the zone. For Italy and Spain, the annual probability of internal disturbance outbreak increased by 146.8% and 123.2% during the positive NAO phases. In contrast, for France, social stability was not responsive to the NAO. There are two possible explanations for this regional variation.

First, we have a disparity in the geographic levels of the variables concerned. Despite the rapid advancement in high-resolution paleo-climate reconstructions since the mid-1990s, most of the paleo-climate reconstructions of extant periods are global or hemispheric averages in which spatially diverse climate signals are masked. Our NAO index is one of these. The use of global/hemispheric paleo-climate reconstructions (i.e., NAO) may not satisfactorily account for any social phenomenon in the sub-regions in Europe (i.e., internal disturbance), because the variables concerned are aggregated at different geographic levels (Clark, 1985; Schumm, 1991; Gibson *et al*., 2000). This problem may apply to this study. The problem could be solved only if high-resolution regional NAO reconstructions over extant period are available.

Second is the role played by human societies in buffering against climatic forcing. In the pre-industrial era, most human societies were dependent on biological resources. Long-term worsening of climate conditions would have contributed to a gradual build-up of resource strain, resulting in human crisis in general at the hemispheric/continent levels. However, in some places and in some instances, the tension could be buffered by political, socio-economic, and technological institutions. Crisis occurs only if the tension exceeds the buffering capacity of human society (in terms of migration, economic change, innovation, trade, peaceful resource redistribution, and so on) for a significantly long period. In regions where population pressure and/or agricultural dependence on climate were lower, the climate-crisis relationship was weaker and less apparent (Zhang *et al*., 2007a; 2011a). As the socio-economic context (population pressure, agricultural dependency, *etc*.) that characterizes institutional capacity to adapt to social pressure varies across places, the societal impact brought about by global climate change (including NAO) could be geographically diversified. In some regions, climate change has been a driving force of violent conflicts; in other regions, the climate has played an important supporting role. At the same time, there are also regions where the effect of climate change is secondary (Catto and Catto, 2004).

We can not determine here whether the varying NAO-conflict relationship at the sub-region level is caused by the disparity of geographic levels of the variables concerned, the diversity of socio-economic contexts across the sub-regions in Europe, or their combination. The relative importance of the above factors will be examined in future work.

We found significant NAO-conflict correlation at the continent and physiographic zone levels in both time-series and panel data disaggregation approaches. Yet, the correlation was inflated under the time-series approach, while the panel data approach demonstrated the region-specific nature of the NAO forcing more clearly. The inflation of the correlation may be attributable to the aggregation of data into regional time-series, which reduces both the sample size and number of null cases (i.e., units without conflict). On the other hand, the better performance of the panel data approach in capturing the regionalization of the NAO-conflict nexus reveals the importance or even necessity of applying location-specific constants to control for any unobserved local determinants of the historical climate-conflict nexus in large-N studies (Anderson *et al*., 2013; Jia, 2013; Kung and Ma, 2014). A related issue is about the size of spatial units of observation in examining the climate-conflict nexus. In the study of Lee *et al*. (2013) of the NAO-conflict association, the authors divided Europe into two physiographic zones. In this study, further disaggregation was made by dividing Europe into nine sub-regions. At the moment, subject to the dearth of high spatial resolution climate, conflict, and socio-economic data, further disaggregation of the climate-conflict nexus in pre-industrial Europe may not be an option. Moreover, it remains questionable to assign the potential causes of a conflict to conditions within extremely sub-divided spatial units, since many factors located beyond that spatial unit may affect the likelihood of violent conflict in a region.

Apart from the disaggregation approach, our findings also reveal that the manner in which the study area is delimited also matters in climate-conflict research. For instance, France, Italy and Spain are subject to the NAO-induced desiccation effect. If the study area in this research was delimited to Italy or Spain or both of them, we could obtain a rather strong NAO-conflict correlation. However, if the study area was delimited to France only, the NAO-conflict relationship could not be detected. That is to say, there is always a potential for producing misleading findings as a result of an ill-defined study area. Given that the risk analyses of conflict need to include null cases (Buhaug and Rød, 2006), it is necessary for us to include France as part of our spatial domain. On the other hand, when compared with the scope of temperature forcing, the area for NAO is more regionalized. This raises another issue, should the regions in the non-desiccated zone in Europe (i.e., those regions not subject to the NAO-induced desiccation effect) be treated as null cases or not. We do not have any definite answer at the moment. As the inclusion or exclusion of the regions in the non-desiccated zone had a significant effect on estimating the effect of NAO oscillation on violent conflict risk (Tables 4, 5, 7), this issue should be explored further in future work.

Positive NAO caused desiccation in the southern Europe and the Mediterranean, and its subsequent agricultural shrinkage and economic shocks resulted in violent conflicts there (Lee *et al*., 2013). This study further demonstrates that the NAO-conflict correlation held regardless of the length of study time span and definition of violent conflict that was applied. We do not imply that climate change is the only cause of violent conflict or that mediating factors are unimportant. This is revealed by the spatial discrepancy of the NAO-conflict relationship at the sub-region level. Besides, each conflict contains unique elements, features that are impossible to separate and measure across space and time (Buhaug and Rød, 2006). As emphasized by Hsiang and Burke (2014), conflict has many causal and mediating factors, and we identify NAO as one of those factors because it exerts a measurable effect on conflict, holding these other factors fixed. Our standpoint could be epitomized by the analogy of Cane *et al*. (2014), 'drunkenness may increase traffic accidents, but not all traffic accidents involve drunk drivers and not all drunk drivers have traffic accident'.

The importance of spatial scale in interpreting the climate-conflict nexus is also highlighted in this study. From the physical point of view, all the processes have their characteristic spatial scales and application conditions. Each spatial scale has its own laws and is described by equations that are limited by the corresponding conditions (Korotayev *et al*., 2006). At the continental and hemispheric levels, climate change was the ultimate cause, and climate-driven economic downturn was the direct cause, of large-scale human crisis in pre-industrial society (Zhang *et al*., 2011a). We also find that positive NAO was significant in increasing the overall probability of violent conflict outbreak at the continent and physiographic zone levels. But at the sub-regional level, the importance of the NAO varied across space, indicating that the local determinants of conflict and contextual events could significantly mediate or even overshadow the climate-conflict nexus. When the climate-conflict relationship is examined at lower geographic levels, more place-specific factors should be taken into consideration.

To date, the societal impact of NAO is under-researched in academia. A first step has been taken towards identifying the positive correlation between the NAO and violent conflict (Lee *et al*., 2013). In the future, the impact of the desiccation effect brought about by positive NAO on historic societies at various geographic levels which were highly dependent on agriculture should be systematically investigated. On the other hand, our findings highlight the possible constraints of scaling down the climate-conflict nexus, which are overlooked in recent large-N studies that explore the climatic impact upon pre-industrial societies. Examining the climate-conflict relationship without consideration of specific locations of violence across a large region hides a myriad of contextual conditions (O′Loughlin *et al*., 2012). Attention should be paid when the relationship (or more broadly climate-man relationship) is explored at lower geographic levels.

We wish to make a final observation about the generalizability of our results. Societies have changed in recent centuries, e.g., the rise of the modern state, large-scale international trade, industrialization, and the reader should be cautious when making general statements from the reported findings. Still, there remain locations where the state of economic development is near that of pre-industrial society, in which the climate-conflict link is still relevant (Hsiang and Burke, 2014). Concerning Africa, most of the countries there are underdeveloped or developing. They are supported by weather-sensitive agro-pastoral production systems and are characterized by inadequate capacity, economic strength, and institutional capability, and most importantly, by rapid population growth (IPCC, 2013). Nearly half of the major food-insecure regions in the world are located in Africa (Lobell *et al*., 2008). The vulnerability of Africa to climate change has been demonstrated by the devastating effect of the various prolonged drought in the last century, while some African countries, e.g., Sudan, have already experienced demographic crisis brought by climate-induced violent conflict (UNEP, 2007). Also, recent empirical large-N studies have demonstrated the effect of precipitation variability in triggering civil war and various types of violent conflict in Africa (Miguel *et al*., 2004; Hendrix and Glaser, 2007; Hendrix and Salehyan, 2012; Raleigh and Kniveton, 2012). It should be noted that the desiccation effect brought about by positive NAO affects both the southern Europe and the Mediterranean and northwestern Africa (Scaife *et al*., 2008; Trouet *et al*., 2009; Vicente-Serrano *et al*., 2011). Given that the northwestern Africa is highly vulnerable to climatic or environmental change, the possible impact brought by the NAO variability upon violent conflict in the region should be systematically investigated.

5 Conclusions

Based on 835 internal disturbance incidents in Europe during 1049–1800, we conducted long-temporal and multi-scalar examination on the NAO-conflict nexus to address the unexplored issues of the nexus. Time-series and panel data disaggregation approaches together with Granger Causality, Multiple Regression, and Survival Analyses were applied to verify the nexus quantitatively. Results show that the positive NAO-conflict correlation was significant at the continent and physiographic zone levels. During the positive NAO phases, the annual probability of internal disturbance outbreak increased by 70.0% in the southern Europe and the Mediterranean, a zone most affected by the NAO-induced desiccation effect. While the NAO-conflict correlation was rather inconsistent when it was downscaled to the sub-regional level. Moreover, the NAO-conflict correlation was inflated under the time-series approach, while the panel data approach demonstrated the region-specific nature of the NAO forcing more clearly. The associated implications in examining climate-conflict nexus are discussed. This study contributes to the climate-conflict literature by examining the climate-conflict nexus in a multi-scalar perspective (i.e., across geographic levels) and comparing the disaggregation methods of the climate-conflict nexus (i.e., time-series approach versus panel data approach) in a single study. Our findings may be crucial in examining violent conflict in the northwestern Africa, a highly agricultural region affected by the NAO.

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