Weather Effects on Social Movements: Evidence from Washington, D.C., and New York City, 1960–95

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ABSTRACT

Scholars have been taking the impact of weather on social movements for granted for some time, despite a lack of supporting empirical evidence. This paper takes the topic more seriously, analyzing more than 7000 social movement events and 36 years of weather records in Washington, D.C., and New York City (1960–95). Here, ''good weather'' is defined as midrange temperature and little to no precipitation. This paper uses negative binomial regression models to predict the number of social movements per day and finds social movements are more likely to happen on good days than bad, with seasonal patterns controlled for. Results from logistic regression models indicate violence occurs more frequently at social movement events when it is warmer. Most interestingly, the effect of weather is more salient when there are more political opportunities and resources available. This paper discusses the implications and suggests future research on weather and social movement studies.

1. Introduction

There is little disagreement that weather affects social life, especially outdoor activities. Extensive social science studies focus on weather's social consequences in the following areas: depression and suicide (Howarth and Hoffman 1984); outdoor recreation and tourism (Bélanger et al. 2009; Gómez Martín 2005; Tucker and Gilliland 2007); transportation (Cools et al. 2010); crime (Butke and Sheridan 2010; Ranson 2014); productivity (Lee et al. 2014); consumption and purchase behaviors (Busse et al. 2015); and finance, especially stock markets (Goetzmann et al. 2015). Recently, weather's effect on politics, specifically on voter turnout and election results, has attracted attention from political scientists (Artés 2014; Gomez et al. 2007; Persson et al. 2014). Simply stated, meteorological factors have significant social and political consequences. They can have immediate and direct effects, such as affecting transportation. Alternatively, the effects can be indirect by influencing emotions or behavioral dispositions: weather conditions may inspire people to make certain stock market or consumption decisions.

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Social movements might well be added to the above list of weather–human interactions. Social movement events, such as marches, strikes, and sit-ins, often take place outdoors and can last for hours, days, or even weeks. Therefore, it is reasonable to think social movements are sensitive to meteorological factors. While sparse, there is some work in the area. Existing meteorology–social movement studies tend to focus on long-term climate dynamics and contentious politics (Gleick 2014; Hsiang et al. 2013), arguing extreme climatic changes and disasters could lead to famines and social unrest (Jia 2014). Regarding short-term weather conditions and social unrest, Anderson (1989), Anderson et al. (1995), and other scholars have connected hot weather to violence, but they only discuss violence as general aggressive behavior, without extending their arguments to violence in social movements (Raleigh et al. 2014). Short-term weather conditions such as daily precipitation have been employed as instrumental variables to reveal other social processes in social movements (Madestam et al. 2013). Some recent works have briefly touched on the relationship between social movements and weather, by noting the seasonal rise and fall of movements (Myers 2010). For example, in their work on youth riots in Belfast, Jarman and O'Halloran (2001, p. 2) say the riots ''flared again as the warmer weather arrived.'' Jain (2010) notes a seasonal fluctuation in

South African protests whereby the intolerable living conditions in winter generate more protests.

However, preliminary findings on weather and social movements are inconclusive, and some arguments are contradictory. Some argue nice weather encourages participation (Jarman and O'Halloran 2001), while others find bad weather results in social unrest (Jain 2010). Given the dissension, we need more empirical investigations to understand the effect of meteorology on social movements, especially as such mobilizations occur in most countries around the globe.

Nice weather is often anecdotally related to social movements. Many famous social movements are related to springtime: the ''Arab Spring,'' the ''Prague Spring,'' the ''Croatian Spring,'' the ''Beijing Spring,'' the ''Seoul Spring,'' and the ''Maple Spring.'' To these we might add ''Mai 68'' in France, the Tiananmen Square protests in Beijing (April–June 1989), the Wild Lily student movement (March 1990), and the Sunflower student movement in Taipei (March–April 2014). The timing of these events suggests desirable weather encourages protest.

These cases inspire the author to ask the following questions: Is there a relationship between weather and social movements? If so, what is the nature of this relationship? This paper plans to answer these questions and to achieve a better understanding of weather's social consequences and the mechanisms influencing social movements. The answers to these questions also have practical implications for the movement mobilizers and activists as well as the antimovement parties (e.g., police, administrations, and corporations) in helping them to decide when, where, and how to act effectively and wisely.

This paper defines good weather as constituting mid-level temperatures (i.e., comfortable) and little or no precipitation. Under this definition, social movement events are speculated to be more likely to happen during good weather, and this effect should remain significant with seasonal patterns controlled for. The paper also links resource mobilization theory and political opportunity theory (McCarthy and Zald 1977; Meyer 2004; Jenkins 1983; Tarrow 2011) to the discussion of the weather effects. The speculation is that weather matters more when there are more political opportunities and resources for mobilization are available, considering social movement activists have more options in such circumstances.

Though these arguments seem plausible, substantial evidence is needed. This paper analyzes the Dynamics of Collective Action (DoCA) data and Global Historical Climatology Network Daily data (GHCN-Daily), focusing on New York City and Washington, D.C., during the 36-yr period of 1960–95, inclusive. The analysis uses weather to predict the likelihood of social movement occurrence and the likelihood of violence in those events. The results support the initial hypotheses discussed above: moderate temperature and less precipitation are found to be associated with more movements; violence happens more when the temperature is higher, which agrees with previous studies on temperature and its positive correlation with aggressive behaviors; and finally, weather's influence on social movements is conditioned by political opportunity context. This interaction effect confirms the validity of previous social movement studies on political opportunities and sources, showing that given different constraints, people's tolerance levels of weather conditions differ. The paper concludes by discussing the implications of the author's findings and suggesting possibilities for future research.

2. Weather, social movements, and political openness

a. Weather and its direct effects on social movements

Various studies confirm the common sense argument that good weather enlivens outdoor activities (Gómez Martín 2005; Tucker and Gilliland 2007), while bad weather discourages them because of the discomfort ensuing from extreme temperatures, precipitation, the wind, and so on. For example, Bélanger et al. (2009) find adolescents have relatively lower physical activity levels in the winter than in the spring or fall. Lin (2009) finds both objective and perceived thermal comfort levels have an influence on the number of people who gather in public spaces. As many social movements hold outdoor events, such as demonstrations or protests in public spaces, it is reasonable to think good weather will encourage them and bad weather will discourage them. Hence, hypothesis 1 states that weather conditions affect the likelihood of social movement occurrence.

In an article discussing riots and seasonal effects, Myers (2010, p. 300) argues that, ''quite simply, rioting is an outdoor activity and far less comfortable for participants in the winter months. Each year we expect to observe a lull in rioting during the winter and a peak during the summer.'' Yet Myers does not test the effect of weather and seasonal patterns in the same model; he simply assumes what he observed as seasonal patterns are the result of weather changes. Therefore, he concludes that ''rioting would wax and wane with seasonal changes in weather'' (p. 306).

Although weather conditions and seasons certainly correlate, they are distinct factors and work through different mechanisms. Plenty of seasonal dynamics are unrelated to weather. These include holidays' impacts on business, tourism, and politics (Blee and Currier 2006; Harvey et al. 1997); religious rituals and events

(Kurzman 1998); national holidays; historical memorial dates; and school timetables' impact on student networks and mobilizations—these are not necessarily affected by weather. Therefore, we need to control the effects of seasonal patterns to correctly identify weather's effects on social movements.

A seasonal pattern should be expected in a social movement's activeness; after introducing weather variables into the models, seasonal effects should be weakened but not completely cancelled by weather. However, weather matters too. Hence, hypothesis 1.1 states that social movements are more likely to happen in good weather with seasonal patterns controlled.

b. *Weather and movement-friendly context*

Using weather as an instrument variable, we can also investigate when movement participants are more sensitive to weather conditions. Therefore, this study connects its weather–social movement analysis with resource mobilization theory and political opportunity theory. This linking is appropriate, as both are commonly used in social movement studies more generally (McCarthy and Zald 1977; Meyer 2004; Jenkins 1983; Tarrow 2011). In social movement studies, resources refer to monetary, material, human, and socio-organizational support available for movement activists and participants (McCarthy and Zald 1977; Jenkins 1983); later theorizations add media support, moral and ideological resources, and other forms of resources to the concept of "resource." When speaking of political opportunities, social movement scholars usually refer to the conditions that encourage movements to happen and facilitate their success. The conditions include the access to political participation, the availability of coalitions, divides among the elites, weakening of state power or other antimovement authorities, and so on (Tarrow 2011).

Political opportunities and resources are often used to explain the success or failure of specific social movements or social movement organizations; they could also explain the long-term cyclic rise and fall of social movements in general as there are historical variations in resources and opportunities. This study adopts the latter approach, focusing on long-term historical contextual differences. During some historical periods and contexts, society is in a movement-friendly mode or has greater "political openness" (Meyer 2004). At such times, the general public holds a more positive opinion of social movements; sympathetic citizens can more easily be converted into participants (Oegema and Klandermans 1994). Given the positive public opinion, governments and authorities tend to be more tolerant. During such movement-friendly periods, activists can afford to defer or reschedule a planned activity when encountering undesirable weather—people are not going to become hostile to their efforts in the short term. Moreover, a movement-friendly context could encourage more nonurgent social movements, which are more sensitive to weather conditions. These forces altogether enhance the weather's effects on social movements. In contrast, during times of fewer political opportunities when mobilizing social movements is harder, the possibility of bad weather will become less important when deciding the timing of an event. Hence, hypothesis 1.2 states that, during times with abundant political opportunities, weather matters more.

Most behavior and criminology studies find temperature to be positively correlated with aggressiveness (Anderson 1989; Anderson et al. 1995; Butke and Sheridan 2010; Myers 2010). However, the relationship between temperature and aggressiveness might not be linear. If hypothesis 1.1 is true (movement activeness is correlated to midrange temperatures), violence may have a similar association with thermal comfort, instead of temperature alone. Therefore, the study tests temperature's linear effects, as well as its quadratic effects, to determine which better explain aggressiveness and violent behavior in social movements. The following three hypotheses relate to this analytic turn:

- Hypothesis 2: Weather conditions affect the likelihood of social movement violence.
- Hypothesis 2.1: Movement violence happens more frequently when the temperature is higher.
- Hypothesis 2.2: Movement violence happens more frequently when the temperature is in the midrange and less often when it is warmer/cooler.

3. Data and methods

a. *GHCN-Daily data: Daily temperature and precipitation*

This analysis employs the GHCN-Daily dataset provided by the National Oceanic and Atmospheric Administration's National Climatic Data Center (Menne et al. 2012). Data for Washington, D.C., are retrieved from the Ronald Reagan Washington National Airport station (station code GHCND: USW00013743); data for New York City are retrieved from Central Park Obs Belvedere Tower station (station code GHCND: USW00094728). These two stations provide the longest and most complete daily weather records among the multiple local stations.

Given the research purpose, the main independent variables should measure how desirable or comfortable the weather is. Ideally, a measure of overall weather desirability/comfort will be a comprehensive combination of temperature, precipitation, wind, weather types, cloud coverage, humidity, and so on. Constructing such an overall measure is not feasible, however, because of the unavailability of data on key variables used in the mainstream thermal comfort and weather comfort measurements. Experts agree the following variables contribute to an overall comfort level: air temperature, radiant temperature, air velocity, water vapor pressure in ambient air, the individual's heat production, and his/her clothing adaptation (Fanger 1970; Nicol and Humphreys 2002; Parsons 2014). Also, precipitation, types of weather (especially extreme weather conditions), and specific microsettings such as buildings, streets, and crowds (of special relevance to the subject of social movements) work unitedly to affect people's perception of weather desirability.

GHCN-Daily provides complete records of temperature (daily maximum and daily minimum) and precipitation (daily total), but for variables such as wind speed, peak wind speed, evaporation, and weather type, there are many missing records.[1] In addition to data problems for these objective measures, there is a severe data problem for the subjective measure of weather desirability. It is impossible to contact all the participants listed in the DoCA dataset (explained at greater length in the next section), interview them, and ask about their perceptions of the weather on a specific date, using, for example, the seven-point scale of subjective assessment of thermal comfort (see Parsons 2014), their clothing adaptation behaviors, or their individual physical health conditions.

Therefore, the research adopts a straightforward way to measure weather desirability by defining good weather as comprising two elements: desirable temperature and no/little precipitation. Under this definition, social movement events have a higher likelihood to occur when the temperature is moderate and the precipitation is low to nil. As most social movement events happen during the daytime, the daily maximum temperature is used to represent that day's temperature. For the measure of precipitation, the study uses daily total precipitation.[2] Using statistical modeling, it standardizes the temperature term and applies the logarithmically transformed precipitation term to reduce skewness.

b. Social movement data: DoCA

As noted above, this research employs the dataset of the DoCA project (McAdam et al. 2009). The DoCA dataset contains information on more than 23 000 social movement events from 1960 to 1995. DoCA compiles information retrieved from major American newspapers into a quantitative database. It provides a wide range of variables, including the location of the event, starting and ending dates, the extent of participation measured in ordinal levels, primary and secondary claims, primary and additional forms of actions, policing and arrests, and use of violence.

Washington, D.C. [observations (obs) of events = 1602, obs of days = 13 149], and New York City[3] (obs of events = 5945, obs of days = 13 149) were selected as focal locations for two reasons. First, studying a relatively small area within the same country makes the story simple: we can assume the climatic, cultural, and political differences between the two cities are minimal, given their geographical proximity. Second, the more than 23 000 events in DoCA data are scattered throughout 1000 cities and towns all over the United States. Most of the locations only have a few dozen social movement events, with a handful of cities seeing more than 100. In contrast, New York City and Washington, D.C., have witnessed more than 1000 social movement events. Excluding those locations with too few social movement observations avoids estimation bias. The two cities also have the most complete weather records for the period 1960–95; other locations often have incomplete weather history on key variables. In sum, these two cities have the best data availability for both independent and dependent variables.

The following variables in the DoCA data are selected into the models. First, location and event starting date[4] constitute the identifier for merging with the weather records. The location is used as a control variable in both the event likelihood and the violence likelihood models. With the original date information, it is easy to retrieve the year, month, and day of the week to construct time controls. The time controls are dummy variables: for months, January is the reference category, and there are 11 dummies; for day of the week, Sunday serves as the reference group. The

[1] For instance, the New York Central Park Obs Belvedere Tower station, one of the earliest weather record stations, has the most complete data since 1876 to the present, but it only recorded evaporation data for 13 years (1948–59); for the average daily wind speed (AWND), the Central Park station only began recording on 1 January 1984. These and other similar problems limit the choice of variables.

[2] Hourly precipitation would be ideal if we could match it with hourly social movement dynamics. However, the DoCA data do not provide an hourly record of how lively a movement is on a particular day; in fact, there is no such database available in the field of social movements or contentious politics.

[3] Categories of "The Bronx," "Brooklyn," "Manhattan," "Queens," and "Staten Island" were recoded into the category of "New York City."

[4] More than 91% of the events in DoCA only last for one day. Therefore, the starting date is treated as equivalent to the "event day"; the study does not focus on the weather dynamics for multiple-day events (only 9% of total observations).

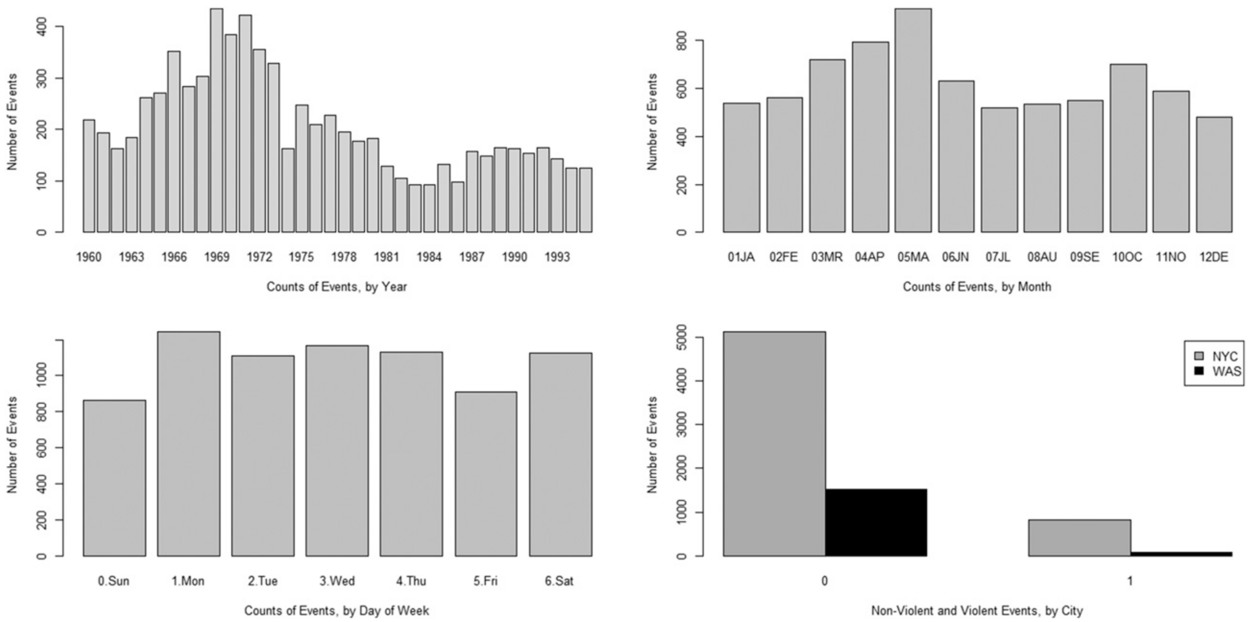

FIG. 1. Bar graphs show count of events by year, month, and day of week and violent/nonviolent events by city.

year variable is used to construct a control variable that links to the political opportunity measure (further discussed in the next section). The occurrence of violence is a binary variable (yes = 1, no = 0) for each event entry. When multiple events occurred on the same date, the total number of events is calculated; this becomes the dependent variable for the statistical models predicting the likelihood of events. The bar plots of the number of social movement observations by the different variables appear in Fig. 1.

In Fig. 1, we see a clear pattern: the 1960s and 1970s are marked by more social movement incidents than the 1980s and 1990s. If we divide the 36 years into two halves, 1960–77 and 1978–95, the first half contains 66% of the cases. Though this is only a rough observation, this considerable gap suggests that of the two time periods, the first offered more political opportunities, better resources, and a higher level of "political openness" than the second.

Hypothesis 1.2, then, can be operationalized by testing the interaction effect between the period dummy variable (0 = 1960–77 inclusive; 1 = 1978–95 inclusive) and the weather indicators. If there are no interactions and weather works similarly across the two periods, the abundance of political opportunities/resources does not matter; if there is interaction effect and weather has a greater impact during the first period, hypothesis 1.2 is supported.

c. *Weather and movement occurrence: NBR models*

The total count of events happening on the same day in the same city is treated as the dependent variable to test hypothesis 1. The number of events is a count variable with overdispersion [mean = 0.287, standard deviation (SD) = 0.704], which suggests the use of a negative binomial modeling method (Long and Freese 2006). Of the total 26 298 days (13 149 dates for two cities), 79.7% (20 965 dates) have zero events, which implies the problem of excessive zeroes. However, the study opts for negative binomial regression (NBR) instead of the zero-inflated negative binomial method (Allison 2012) for the following reasons. First, no certain dates are intrinsically immune to social movements. Hence, there is no theoretical justification to predict "structural zeros." Second, model comparison procedures show the differences between the two modeling methods in estimates and model-fit parameters [Akaike information criterion (AIC), Bayesian information criterion (BIC), and AIC with a correction for finite sample sizes (AICc)] are trivial.[5] The findings and conclusions will not be affected no matter which method is employed.

The independent variables are the daily maximum temperature in degrees Celsius and total precipitation in millimeters. Several other control variables were introduced to the NBR models, including location (Washington, D.C., versus New York City), day of the week, month, and the first versus second half of the time range. With the weather, event location, and day of the week included, model 1 sets a baseline to predict the likelihood of event occurrence. Model 2 adds weather

[5] Detailed information is available from the author upon request.

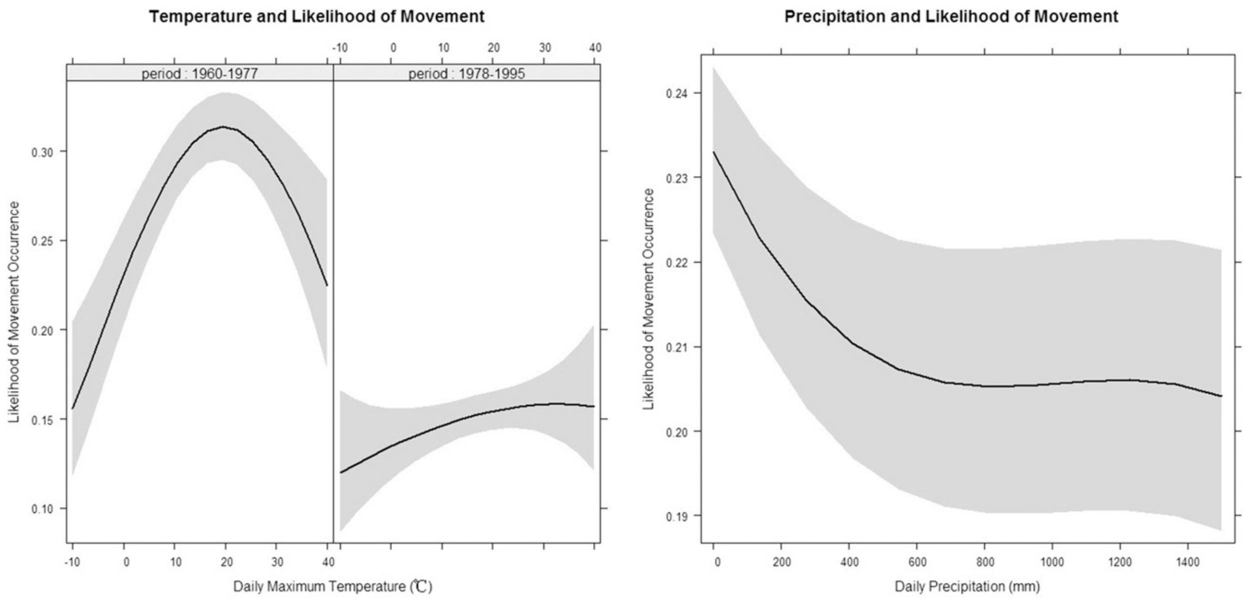

FIG. 2. Fitted values of event occurrence by daily maximum (left) temperature (°C) and (right) precipitation (mm) and time range based on the model from Table 2. Except for the focal predictors, all other variables are set to the typical values: mean values for interval-ratio variables and proportions for categorical variables.

effect to seasonal patterns, testing hypothesis 1.1. Models 3 and 4 test hypothesis 1.2: model 3 has the period dummy variable, and model 4 adds the period-weather interaction effects. Details of the negative binomial models appear in Table 2 and Fig. 2.

d. *Weather and movement violence: Logistic regression models*

Logistic modeling is adopted to test hypothesis 2 since the dependent variable is movement violence, a dummy variable representing whether violence occurs or not in a particular event. The total number of cases of complete information on all variables is 7542.

Similar to the negative binomial models, the event location, day of the week, month, and period dummies are added to models as control variables. Previous studies suggest temperature and violent behaviors tend to have a linear relationship, and the preceding discussion suggests the possibility that middle-level temperatures may provoke more social movements. Therefore, both linear and quadratic terms of temperature are tested to determine the better predictor (hypotheses 2.1 and 2.2). Details of the logistic regression models can be found in Table 3 and Fig. 3.

4. Results

Table 1 displays the AIC values of all models fitted in this analysis. It shows why the models in Tables 2 and 3 are chosen as final models. NBR model 1 serves as a baseline model with only control variables and no focal predictors included; NBR models 2 and 3 compare temperature and its quadratic terms and find the quadratic terms of temperature to be preferable, suggesting temperature's effect on social movement shows a quadratic curve. Based on model 3, model 4 adds the period dummy variable; model 5 includes the temperature by period interaction term; and model 6 includes the precipitation by period interaction term. The AIC value shows model 5 is preferable over model 6; moreover, the insignificant estimates of the precipitation by the period interaction term in NBR model 6 indicate that only temperature interacts with periods. Precipitation's effect does not show variations across time. The final negative binomial model (NBR model 5) appears in Table 2. Similarly, comparison across models decides the final model for logistic regressions to be the logistic regression model 3, with its details displayed in Table 3.

As the final negative binomial model in Table 2 shows, the estimates and odds ratios agree with most of the expectations. First, the odds ratio 0.268 for Washington, D.C., reflects the fewer social movements in Washington, D.C. (obs = 1602), than in New York City (obs = 5945) during 1960–95. Second, weekdays are more active than weekends, with all other factors considered; Sunday (the reference group) and Friday appear to be the least active days in the week, with Monday and Saturday being the relatively active days. Monday may

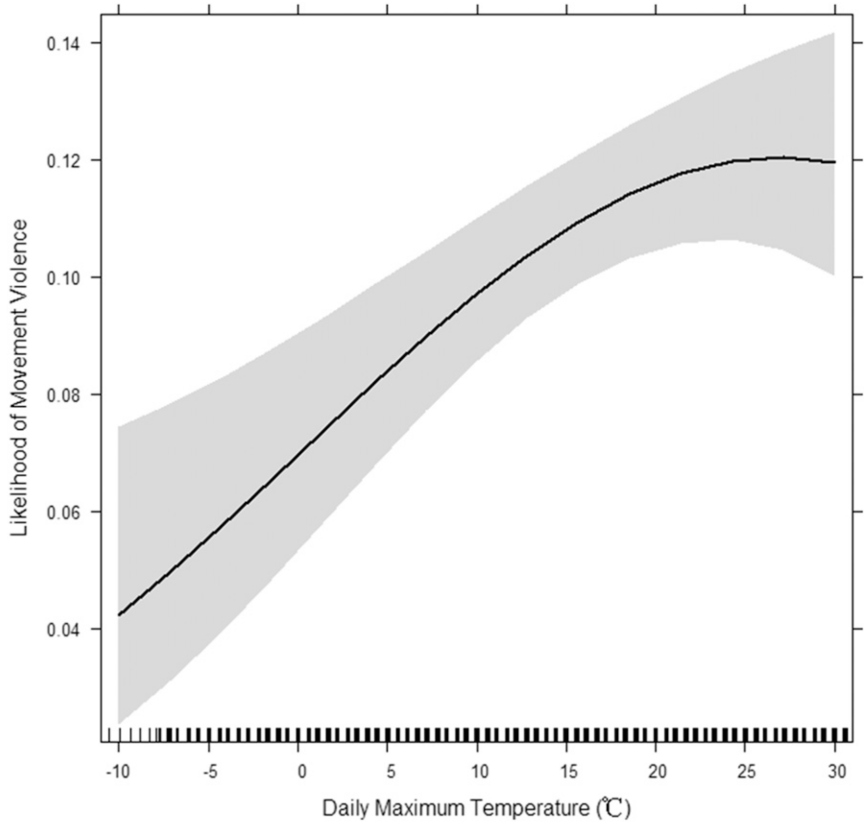

FIG. 3. Fitted values of violence by temperature (°C) based on the model from Table 3. Except for the focal predictor, all other variables are set to the typical values: mean values for interval-ratio variables and proportions for categorical variables.

seem surprising, as it is part of the traditional work week, yet people may use this day to start to mobilize school, colleague, or union networks, or to initiate legal procedures, lobbying, and negotiations. Saturday's activeness during the weekend is more understandable; it is the first day off after a traditional work week; people can activate their friends, family, or church network and use the free time for an event. On Fridays, people are often ready for resting and relaxing and tend to wrap things up instead of initiating new activities. Sundays often feature religious activities. These facts related to Fridays and Sundays may dampen enthusiasm for social protest.

The month dummy variables also yield interesting patterns. With weather variables being considered, some seasonal fluctuations still exist. December is the least active month for movements, suggesting a holiday effect; March, April, and May are the most active months. While not as inactive as December, June shows a significant dwindling of activity. From June to December, October and November stand out a bit for their lesser activity. In sum, in a year, we see a very active spring, a mildly active fall, and a dead summer and winter. Since weather cannot fully explain the seasonal patterns, some alternative explanations are needed here.

The period dummy variables confirm the finding in Fig. 1: the 1960–77 period is a more active era for

TABLE 1. AIC values for model selection. Bold font indicates the preferred models for the binomial and logistical regressions.

Negative binomial models	AIC values
M1: Controls only	33 525.7
M2: M1 + temperature + precipitation	33 522.45
M3: M2 + temperature's quadratic term	33 515.04
M4: M3 + period dummy (1978–95)	32 995.02
M5: M4 + period × temperature quadratic interaction	**32 992.74**
M6: M5 + period ×precipitation interaction	32 994.59
Logistic regression models	AIC values
M1: Controls only	5379.652
M2: M1 + temperature + precipitation	5377.916
M3: M2 + temperature's quadratic term	**5376.632**
M4: M3 + period dummy (1978–95)	5378.631

social movements than 1978–95. This difference in the level of activeness reflects the late-twentieth-century's social movement history in the United States: the peak of such movements came in the 1960s and 1970s, and after that, social movements became less active. Even more interesting is the significant period–temperature interaction: this corroborates hypothesis 1.2 and suggests the effect of weather changes significantly over time.

A clearer pattern emerges in Fig. 2's fitted value graph of weather indicators' effects on the dependent variable. Figure 2 sets all other variables at typical values and focuses on the effect of temperature, precipitation, and time periods on the likelihood of social movements. The left panel of Fig. 2 looks at the temperature by period interaction effects. If weather's role is stable across time, we should expect both curves to have a similar shape even with different intercepts on the graph; however, the graph shows a curve for the first half of the time range and a nearly flat line for the second half. For the years of 1960–77, social movements are more likely to happen when the maximum temperature is around 20°C; the likelihood decreases when it gets warmer or cooler. For instance, the likelihood at 20°C is 0.32 and the likelihood of social movements is 0.16 at −10°C; the former is twice the latter estimate. However, as we can see from the right graph, the temperature is almost irrelevant in predicting occurrence. This difference indicates social movements' sensitivity to weather condition varies dramatically across the two time periods.

The final logistic regression models shown in Table 3 analyze the contributors to violence in social movements. The logistic model indicates temperature is positively correlated with the possibility of violence. Even though the final model uses a quadratic term for temperature, Fig. 3 shows that given a reasonable temperature range (up to 40°C), temperature and violence are positively associated. As Fig. 3 shows, when the temperature (daily maximum) reaches 25°C or higher, the likelihood of violence occurring in a social movement is about 0.12; when the temperature is 0°C, the likelihood becomes about 0.07. Therefore, violence is 71% more likely in the former situation than the latter. This finding supports the traditional view that warmer weather encourages violent behavior (Anderson 1989; Anderson et al. 1995).

5. Conclusions and discussion

This analysis based on data from New York City and Washington, D.C., for 1960–95 provides supportive empirical evidence for the research hypotheses about weather's impact on social movements. Movements are more likely to happen on days where the air temperature is moderate and there is little or no precipitation. Social movements tend to be more violent when it is warmer. An interesting finding is that weather's impact on movement occurrence changes over time. In the first half of the 36 years, 1960–77, when social movements were generally more active, they were also more sensitive to weather conditions. In contrast, in the second half, 1978–95, when social movements were less active, events seem to have been somewhat indifferent to weather conditions.[6]

This research has several implications for social movement studies. Scholars have been studying the social aspects of movements for years, including grievances and other emotions (Goodwin et al. 2000); resources and organizations (Soule et al. 1999; Jenkins 1983); mobilization and networks (Gould 1991); tactics and repertoires (Taylor and Van Dyke 2004); framing and identity (Benford and Snow 2000; Polletta and Jasper 2001); and, more recently, new technologies, especially the Internet and social media (Brym et al. 2014; Lim 2012). Set against such weighty considerations, weather seems a factor too obvious and too simple to be considered. Yet, the natural and physical environments of social movements need more critical attention. Social movements happen in certain natural and physical settings; they are embedded in and affected by certain environments. All parties involved in social movements, including mobilizers, participants, onlookers, and

[6] An anonymous reviewer raised a valid concern about whether the marginal distributions of various forms of collective actions differ across the two periods of 1960–77 and 1978–95. After all, if the forms of actions are associated with the two periods, and if forms of actions are associated with sensitivity to weather conditions, the discovered "period–weather" interaction in this paper might be spurious, and the actual interaction should be "form of action–weather." If that is the case, the finding in this paper only reflects that American's preference of certain forms of collective actions changed from the 1960s to the 1990s, and the author's suggested explanation could be no more than an ad hoc explanation for the United States during 1960–95. The author investigated the contingency table of periods and forms of actions given by the DoCA data. The investigation shows the event distributions during the two periods does not challenge the main arguments here. Both periods featured with certain forms of collective actions: "picketing" and "civil disobedience" occurred more during 1960–77 and "rally/demonstration" and "lawsuit/legal maneuver" occurred more during 1978–95. Both periods have some outstanding numbers of "indoor" and "outdoor" (which are presumably more sensitive to weather conditions) activities. Even if the forms of action make a difference, the opposite effects cancel each other, and the author has reason to believe that does not challenge the main argument. More details are available from the author upon request. The author appreciates the anonymous reviewer pointing this out.

TABLE 2. Event likelihood: Estimates from the final NBR model. Temperature (°C) is standardized; precipitation (mm) is used with logarithmic transformation. CI is confidence interval.

	Final model			
	Coefficient	Odds ratio	95% CI	Std. error
Intercept	−0.756[a]	0.470	−0.907 to −0.606	0.076
Location (New York as reference)				
Washington, D.C.	−1.315[a]	0.268	−1.378 to −1.253	0.032
Day of week (Sunday as reference)				
Monday	0.384[a]	1.468	0.281 to 0.487	0.053
Tuesday	0.266[a]	1.305	0.162 to 0.371	0.053
Wednesday	0.312[a]	1.367	0.209 to 0.416	0.053
Thursday	0.273[a]	1.314	0.169 to 0.378	0.053
Friday	0.041	1.042	−0.067 to 0.150	0.056
Saturday	0.258[a]	1.295	0.154 to 0.363	0.054
Month (January as reference)				
February	0.064	1.066	−0.075 to 0.203	0.071
March	0.155[b]	1.168	0.015 to 0.296	0.071
April	0.237[c]	1.267	0.084 to 0.391	0.078
May	0.338[a]	1.401	0.173 to 0.503	0.084
June	0.017	1.017	−0.169 to 0.202	0.094
July	−0.201[b]	0.818	−0.400 to −0.001	0.101
August	−0.175	0.839	−0.370 to 0.021	0.099
September	−0.156	0.855	−0.336 to 0.024	0.092
October	0.053	1.055	−0.107 to 0.214	0.082
November	−0.038	0.963	−0.188 to 0.113	0.076
December	−0.183[b]	0.833	−0.326 to −0.039	0.073
Daily maximum temperature				
Temperature	7.431	1687.716	−2.543 to 17.396	5.088
Temperature^2	−13.939[a]	0.000	−20.616 to −7.310	3.41
Daily total precipitation	−0.018[b]	0.982	−0.033 to −0.004	0.007
Period (1960–77 as reference)				
1978–95	−0.646[a]	0.524	−0.702 to −0.590	0.028
Temperature × period (1960–77 as reference)				
Temperature × 1978–95	0.686	1.986	−8.679 to 10.058	4.771
Temperature^2 × 1978–95	11.294[b]	80350.470	1.962 to 20.585	4.743
Observations	26 298			
Pseudo − R^2	$R^2_{CS} = 0.106$			
	$R^2_N = 0.206$			
	$D = 0.124$			
AIC	32 992.742			
Theta	0.9373			

[a] $p < 0.001$
[b] $p < 0.05$
[c] $p < 0.01$

governments and police, consider the weather when making decisions about participation, mobilization, logistics (including equipment, transportation arrangements, supplies, etc.), strategies, and forms of action, including policing/antipolicing actions. Confirming weather's impact on social movements and quantitatively measuring the effect sizes is helpful to fully understand the decisions and actions.

What is more, the contextual characteristics could interact with other social mechanisms. For example, Gould (1991) and Zhao (1998) show how urban geographic patterns and spatial structures affect the way movement mobilization networks work. Similarly, the present research suggests movements' sensitivity to weather conditions varies across different political opportunity contexts; movement activists are "picky" about the weather when there are more political opportunities and resources; when society tolerates, even welcomes, movements; and when they have more options.

The use of weather as an instrumental variable looks at societal mechanisms in a new way, thereby adding to longstanding debates in social movement studies on the validity of coupling political opportunity with social movements. For example, Goodwin and Jasper (1999,

TABLE 3. Violence likelihood: Estimates from the logistic regression model. Temperature (°C) is standardized; precipitation (mm) is used with logarithmic transformation. CI is confidence interval.

	Final model			
	Coefficient	Odds ratio	95% CI	Std. error
Intercept	−1.634[a]	0.195	−2.047 to −1.234	0.207
Location (New York as reference)				
Washington, D.C.	−1.162[a]	0.313	−1.410 to −0.927	0.123
Day of week (Sunday as reference)				
Monday	−0.081	0.923	−0.356 to 0.197	0.141
Tuesday	0.025	1.025	−0.251 to 0.302	0.141
Wednesday	0.028	1.028	−0.244 to 0.302	0.139
Thursday	0.008	1.008	−0.267 to 0.285	0.141
Friday	0.195	1.215	−0.085 to 0.477	0.143
Saturday	−0.031	0.969	−0.309 to 0.248	0.142
Month (January as reference)				
February	−0.284	0.753	−0.693 to 0.123	0.208
March	−0.619[b]	0.538	−1.038 to −0.201	0.213
April	−0.076	0.927	−0.486 to 0.344	0.211
May	−0.251	0.778	−0.691 to 0.197	0.226
June	−0.519[c]	0.595	−1.026 to −0.008	0.259
July	0.111	1.118	−0.403 to 0.631	0.264
August	−0.151	0.859	−0.671 to 0.373	0.266
September	−0.078	0.925	−0.554 to 0.404	0.244
October	−0.048	0.953	−0.474 to 0.387	0.22
November	−0.567[c]	0.567	−1.013 to −0.123	0.227
December	−0.032	0.968	−0.436 to 0.372	0.206
Daily maximum temperature				
Temperature	0.151[c]	1.163	2.160 to 27.659	6.503
Temperature quadratic term	−0.080[d]	0.923	−15.439 to 0.588	4.087
Daily total precipitation	−0.016	0.984	−0.055 to 0.023	0.02
Observations	7542			
Pseudo $-$ R^2	$R^2_{CS} = 0.024$ $R^2_N = 0.047$ $D = 0.023$			
AIC	5376.632			

[a] $p < 0.001$
[b] $p < 0.01$
[c] $p < 0.05$
[d] $p < 0.1$

p. 135) argue, "Because it [political opportunity structure] is often coupled with writing that suggests movements flourish during favorable or expanding opportunities and fade in times of less favorable or declining opportunities, the collective scholarship runs the risk of turning an important analytical advance into a mere tautology." In this research, however, the author finds evidence suggesting political opportunity theory is not "mere tautology." There is not only a difference in the number of events but also a difference in people's behavioral dispositions across the periods of 1960–77 and 1978–95. That is to say, the author does not tautologically label the 1960s and 1970s as having high political openness, having more political opportunities, or being movement friendly solely because there are more movements, or the other way around. Instead, from the way activists deal with weather, the analysis finds activists likely enjoyed more options when mobilizing collective actions during 1960–77 than the other 18 years. This finding, made possible by employing weather's impact as an instrumental variable, corroborates the political opportunity and resource mobilization theories.

We also need to keep in mind that people from both the promovement camp (mobilizers, participants, supporters, sympathizers) and antimovement camp (governments, employers, policing forces) do not simply passively respond to weather conditions. Actors strategically make their moves based on the information available to them, including weather forecasts and predictions of their opponents' potential moves. For instance, an employer might take a hard-line approach toward a union if he/she anticipates severe weather conditions will weaken a forthcoming strike. Therefore, the findings of this analysis should not be interpreted as ''weather to movement'' causality. Rather, the paper proposes a mechanism combining the weather to movement effect and people's reactions to it.

When we acknowledge the duality of weather's effects, some interesting research questions emerge. For example, are employers more likely to take a tough stance toward a recalcitrant union in the late fall than in the early spring? By the same token, we might analyze government documents on movement repression to see if meteorological factors affect decisions in policing events.

6. Limitations and future agenda

This paper, of course, has some limitations, which could be informative and suggest some promising directions for future research. First, scholars could expand the research scope. This research only involves two major cities in the northeastern United States and has limited generalizability: the perceived weather condition and subjective comfort levels are bounded by the specific urban microsetting and might differ in other contexts. For example, the dynamics of social movements in rural areas, suburbs, or small towns might differ from those in a metropolis. Also, the political processes in a democratic society like the United States differ from those in nondemocratic societies, where there are higher risks and more fundamental grievances, and this may well affect mobilization. In the future, we can make across-culture and/or across-climate comparisons to further our understanding of how social movements are embedded in natural and societal contexts. For instance, as hypothesis 1.2 on political opportunity context is supported, social movement events in nondemocratic societies may be less weather-sensitive than movements in democratic societies. In nondemocracies, there may be a scarcity of political opportunities, and people may not be able to afford to wait for better weather. Of course, this will remain guesswork until further study. Finally, people from different cultures could have different perceptions of weather desirability, different ways of calculating cost and profit in decision making, different network structures, and various mobilizing processes, which could potentially change the story.

Second, the data and methods of this research are still coarse. As data availability limits it, this research only studies the weather on the starting day of movements. As explained before, most events (91% of all events; see footnote 4) in the DoCA dataset last for a single day, and there is no detailed record of the daily (or even better, hourly) changes in the number of participants for those lasting longer. Also, the weather records are retrieved from the nearest station instead of specific microsettings. This method is not ideal since the weather could vary greatly in different locations in a city (especially a metropolis) and at different times of day. These inaccuracies in temporal and spatial aspects might prevent us from discovering a more detailed weather–movement dynamic. Future research could try to find dynamic patterns in how weather affects the rise and fall of social movements. It would be interesting if researchers could collect information on long-duration protests to see whether and how movement dynamics (start/end, rise/fall) correlate with weather changes. Qualitative research and analysis of interviews, diaries and memoirs, media, and video materials may enrich our knowledge.

Third, we need more discussion of how to better measure weather desirability. The use of raw temperature and precipitation, instead of an overall subjective comfort measure, as the independent variable is preliminary. This method ignores many other factors contributing to weather desirability, such as wind, humidity, snow, sunshine, lightning, and so on. This issue will become more important when the research scope expands to a larger region or across countries. There will be more heterogeneity in climates and weather, and people's subjective perceptions of comfort will vary greatly. If future scholars could suggest a more authoritative and operationalizable measure of weather desirability, that would be beneficial for researchers on relevant subjects.

Finally, the present research calls attention to the seasonal patterns and temporal aspects of social movements. As the NBR models show, the weather predictors and seasonal variables are both significant in a single model. That reminds us not to confuse weather effects with seasonal patterns. It also triggers an interesting question: if the seasonal effects are not completely explained by weather cycles, what other factors could be behind them? Figure 1 and Table 2 find winter months and summer months are less active, which could be explained as a consequence of weather. However, why are the spring months, March–May, still more active than the autumn months? Why do seasonal patterns remain salient when the weather is controlled? The answers to the questions will reveal much about the mechanisms of movement mobilization.

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