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The influence of temperature on #ClimateChange and #GlobalWarming discourses on Twitter

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Abstract
Research suggests non-experts associate different content with the terms "global warming" and "climate change." We test this claim with Twitter content using supervised learning software to categorize tweets by topic and explore differences between content using "global warming" and "climate change" between 1 January 2012 and 31 March 2014. Twitter data were combined with temperature records to observe the extent to which temperature was associated with Twitter discussions. We then used two case studies to examine the relationship between extreme temperature events and Twitter content. Our findings underscore the importance of considering climate change communication on social media.

Introduction

Global concerns about climate change vary. Generally, citizens of European nations are more worried about its immediacy compared to Americans and countries that are high emitters of carbon dioxide tend to exhibit less concern about its impacts [Wike, 2016]. Climate change refers to statistical changes in the Earth's climatic system and associated events over long timescales [American Meteorological Society, 2012]. Global warming, a byproduct of climate change, refers to the increase in average global temperature due to anthropogenic emissions, primarily carbon dioxide. While the terms "global warming" and "climate change", are often used interchangeably by media to refer to the same phenomenon [IPCC, 2013], they evoke different associations among lay audiences [Leiserowitz et al., 2014; Schuldt, Konrath and Schwarz, 2011; Schuldt and Roh, 2014; Whitmarsh, 2009]. For example, quantitative and qualitative surveys show that the term "global warming", relative to "climate change", evokes more concern among residents in the south of England [Whitmarsh, 2009]. Further, the former elicits more associations with temperature and human causality. In the present study, we further scholarship on people's associations with these terms in the context of social media.

Online media are becoming one of the prime means through which people encounter scientific information. Although Americans, relative to British adults,

tend to look to the Internet more for scientific information, the use of social media has increased worldwide. The abundance of interactive, Web-2.0 media have expanded our ability to engage in discussions with each other about a variety of scientific issues [Brossard, 2013; Scheufele, 2013]. These technologies also offer rapid and widespread information sharing. Twitter, a social microblogging platform, has become a significant environment for real-time opinion sharing, interaction with experts and non-experts alike, and information dissemination related to diverse issues ranging from politics [Papacharissi and Fatima Oliveira, 2012] to nanotechnology [Runge et al., 2013]. Understanding and mapping discourses surrounding scientific issues on social media are valuable to the scholarship and practice of science communication. While online opinions are not always representative of public opinion, the sentiments and discussions expressed online represent untapped sources of data that can be leveraged to inform science communication scholars and practitioners [Yeo and Brossard, 2017].

While scholars have linked Twitter discourse to temperature changes and climate change [Kirilenko, Molodtsova and Stepchenkova, 2015], there has been no investigation of the topics of discussion associated with the terms "global warming" and "climate change." This motivates us to explore the discursive contexts in which audiences use these. Further, while studies have examined the relationship between Twitter activity, local changes in temperature, and mass media, in the present work we explore how regional temperature changes and topics discussed on Twitter using the two terms are related. In doing so, we obtain insight into people's perceptions and associations with these terms through spontaneous expressions of opinion.

Thus, the goals of this study are two-fold: (i) to determine whether differences exist in topics of Twitter conversation using the terms "climate change" and "global warming" within the context of six topics of discussion in which these terms are often used (energy, weather, policy, environment, political theater, and factual statements; see Methods for further explanation); and (ii) to explore whether temperature variations across geographic regions in the United States and in response to extreme temperature events are related to Twitter reactions using the terms "climate change" or "global warming." Given the context of our study, we focus our review of the literature on scholarship primarily conducted in the United States.

Literature review   *Differences in public opinion regarding global warming and climate change*

Among Americans, a stark political partisan divide in climate change opinions persists. This divide began to widen in the early 1990s when discussions among non-experts became more politicized [Boykoff and Boykoff, 2004; Boykoff and Boykoff, 2007; Dunlap and McCright, 2008; Leggett, 2001; Trumbo, 1996] and is apparent in how people associate weather events with the two terms. While there is no difference among Democrats, many Republicans and Independents believe global warming, compared to climate change, is more likely to impact weather in the United States "a lot" [Leiserowitz et al., 2014]. Further, Republicans are more likely to suggest a large-scale effort to reduce climate change than to reduce global warming [Leiserowitz et al., 2014]. Other research has shown that the terms have different implications of seriousness across party lines; Republicans rate "climate

change" as more serious while Democrats rank "global warming" as more serious [Villar and Krosnick, 2011].

Predilections for climate change-related terms exist across different segments of the public, despite a large portion of people having no preference [Akerlof and Maibach, 2011]. "Global warming" was found to be more polarizing and preferred by those who believe climate change is occurring, while those who believe it was not occurring opted for "climate change." Similarly, polarization has been observed on coverage of the issue in mass and social media such as Twitter, with differences in the frames and partisanship associated with the two terms [O'Neill et al., 2015; Pearce et al., 2014; Williams et al., 2015]. "Global warming" was more commonly associated with tweets using a hoax frame ("global warming is a hoax/fraud") and more often used in Republican than Democratic states [Jang and Hart, 2015].

Opinions about global warming and climate change on Twitter

Until recently, most studies of non-expert discourses surrounding global warming and climate change did not focus specifically on social media communications [Nielsen and Kjærgaard, 2011]. Yet, Twitter has risen in popularity over the last several years. In 2014, 23 percent of online American adults used Twitter [Duggan et al., 2015]. Among Twitter users, 59 percent use the platform to attend to news [Gottfried and Shearer, 2016]. Importantly, Twitter is used worldwide and has four times as many international users compared to in the United States [DeSilver, 2016].

While the opinions on Twitter do not necessarily reflect public opinion [Mitchell and Hitlin, 2013], it remains valuable to examine discourses on this platform. Twitter content is posted in real-time, and represents unsolicited, instantaneous responses to current issues in broader society. Studies employing such reactive opinions are not well represented in the literature on lay discourse about global warming and climate change, as earlier studies primarily employ survey methodologies that allow participants to reflect more deeply on the issue.

Recent studies have begun to analyze the nature of a broad range of scientific discourses on Twitter, including the Higgs-Boson particle [Boyle, 2012], nuclear energy [Kim et al., 2016], nanotechnology [Runge et al., 2013; Yeo et al., 2014a], and the arsenic bacteria controversy [Yeo et al., 2016]. Researchers have even used Twitter content to analyze political discourse [Beauchamp, 2016; Small, 2011], as well as in concert with users' geographic locations to map real-time earthquake events in Japan [Sakaki, Okazaki and Matsuo, 2013]. Many of these scientific issues have been addressed in detail in online news media. Given that scientific issues covered by mainstream media have previously trended on Twitter, that the issue of climate change receives extensive media coverage, and that climate adaptation and mitigation are significant societal issues that have ethical and legal implications, examining opinions expressed on Twitter will improve our understanding of how people spontaneously react to global warming and inform communication efforts around this issue.

Recent studies have begun to use Twitter data to study specific conversations related to climate change [Su, Akin and Brossard, 2017]. For example, Pearce et al. [2014] investigated conversations surrounding the release of the International Panel

on Climate Change (IPCC) Working Group I report to examine how Twitter users formed communities around this issue. Using network analysis, they showed that content focused on both the science and politics surrounding climate change and users were more likely to share information with like-minded others, further underscoring the polarized nature of discourse on this issue. Another study tracked changes in climate change sentiment on Twitter using happiness scores to determine how sentiment varied in response to news and events about climate change [Cody et al., 2015]. On average, "global warming" tweets were more negative and profane, contained more climate denier information, and had fewer mentions of science. Over the study period, decreases in happiness were observed to coincide with the occurrence of several natural disasters (e.g., Hurricane Sandy in 2012).

Another recent study investigated changes in the volume of global warming and climate change online searches in concert with emotional response to these topics using Google and Twitter, respectively [Lineman et al., 2015]. They showed that Twitter posts between 12 October and 12 December 2013 were more negative about global warming. While this study provides a foundation for understanding temporal changes in search interest and related emotional response to these two terms, the specific contexts and topics in which these terms have been considered has not been investigated. Therefore, one goal of our study is to investigate differences in global warming and climate change tweets in the context of topics in which these two terms are commonly used. By categorizing daily Twitter discourse into various topics of discussion, we can improve our understanding of how often these terms are used, including whether one term is "preferred" over the other within various topics of discussion.

Given the evident differences in social media conversations about climate change using these terms, we set out to determine whether differences exist in the average daily number of Twitter posts using the terms "climate change" and "global warming" within the context of six topics of discussion. For each topic, we test the following hypothesis:

> *H1:* The average daily number of Twitter posts about "global warming" will differ significantly from that of "climate change" over the period studied (1 January 2012 and 31 March 2014).

Global warming, climate change, and extreme weather

People tend to rely on cognitive shortcuts when forming attitudes toward scientific issues [Brossard and Nisbet, 2007; Brossard et al., 2009; Finucane et al., 2000; Su et al., 2016; Yeo et al., 2014b], including climate change. For example, the likability of weather forecasters has been linked to greater perceptions of harm caused by the phenomenon [Anderson et al., 2013]. Climate change opinions can also be predicted by geographic variability; patterns of climate opinion among Americans vary with expected political patterns as more politically liberal states exhibit greater levels of concern relative to conservative ones [Howe et al., 2015]. Other scholarship has also shown that global warming opinions are tied to outdoor temperature [Joireman, Truelove and Duell, 2010] as well as *perceptions* of temperature [Li, Johnson and Zaval, 2011]. Higher actual and perceived

temperatures are associated with greater belief in the occurrence of global warming. Moreover, abnormal temperature events have greater influence on people's belief in, and concern about, climate change [Zaval et al., 2014]. Such examples underscore a demonstrated link between macro-level phenomena and individual behaviors [Schwarz and Clore, 1983]. Thus, occurrences such as weather events can influence people's perceptions of, and sentiment toward, global warming.

Few studies have examined Twitter discourse related specifically to weather. One study found tweet volume to be highly correlated with the number of people affected by tornado watches and warnings, suggesting that Twitter may be a useful platform for disseminating information and understanding audience reactions to severe weather [Ripberger et al., 2014]. Kirilenko, Molodtsova and Stepchenkova [2015] found that during extreme weather events (quantified using anomalous temperature data), there was an increase in the number of tweets about climate change, especially for colder and wetter regions of the United States and during the months of December to February and June to August.

While these recent studies consider the volume of tweets, these studies do not specifically categorize their content. Understanding differences in content would further develop our understanding of the emotional response Twitter users have when discussing these terms. Furthermore, while Kirilenko, Molodtsova and Stepchenkova [2015] provide a foundation for understanding the relationship between extreme weather and global warming/climate change tweet volume, a more in-depth investigation of this relationship in the context of notable events would shed light on *why* we observe changes in opinions during such extreme events.

This motivates us to explore the relationship between global warming and climate change tweets and temperature across regions in the United States in addition to during extreme temperature events. We explore these relationships in the context of the research questions below:

> *RQ1*: Is regional temperature in the United States associated with Twitter posts using the term global warming and/or climate change?
>
> *RQ2*: Are tweets about climate change or global warming related to temperature during the month of an extreme temperature event?

We investigate RQ1 by examining correlations between regional temperature in the United States over the study period and tweets about global warming and climate change. To address RQ2, we use case studies focusing on two events, a heat wave (March 2012) and a cold surge (January 2014). Case studies have been used by atmospheric scientists who aim to investigate relationships between a weather event and its associated atmospheric and/or societal response [e.g., Mohri, 1953; Hakim, Keyser and Bosart, 1996; Winters and Martin, 2016; Bosart et al., 1996]. While the results of case studies are not generalizable, such analyses allow us to observe interesting trends in tweets and extreme temperatures, which can be combined with statistical analyses to further our understanding of relationships of interest.

We build on previous work in the following ways: (i) we investigate how these terms are used in different topics of conversation on social media with a multi-year census of tweets; and (ii) we examine the influence of regional temperature on unsolicited expressions and in reaction to a significant heat wave and cold surge event.

Methods

Twitter data

We used the software, ForSight, from the social media monitoring company, Crimson Hexagon, to classify tweets into topic categories. ForSight is a supervised learning software that detects and tracks underlying linguistic patterns, based on concepts identified by human coders using an initial training set, and applies the learned algorithm to analyze the remaining, typically large, amounts of social media texts [Hopkins and King, 2010]. Scholars have argued for applying this hybrid content analysis method to social media discourses as it possesses the reliability and efficiency of computer-based coding while preserving the latent validity of human coding [Su et al., 2017; Su, Akin and Brossard, 2017]. Others have examined and verified such supervised learning programs [Collingwood and Wilkerson, 2012]. Specifically, ForSight has been verified through comparison with surveys data and election results [Ceron et al., 2014; Hitlin, 2015]. These scholars, among others, have also verified the resilience of supervised learning programs based on the training set used for the program [Collingwood and Wilkerson, 2012; Hopkins and King, 2010]. Using a large and randomly distributed subset of the sample posts improves the accuracy of the program, in addition to extensive human coding [Collingwood and Wilkerson, 2012; Neuendorf, 2017].

We collected and analyzed a census of publicly-available tweets posted between 1 January 2012 and 31 March 2014 using ForSight. A total of 3,732,058 English-language tweets from the United States were collected and analyzed.[1] ForSight uses monitors with intelligent algorithms and a Boolean logic-based keyword search to track linguistic patterns based on training by human coders. To train the algorithm, the program randomly samples from the census of publicly available tweets based on the given keywords. To ensure a representative and high-quality subset of tweets is used to train the algorithm, the posts are categorized by human coders according to a codebook. During the process of manually coding the random sample, only mutually exclusive and unambiguous examples were used to train the monitors. Non-exclusive tweets (i.e., those that could fit into multiple categories) were not included in the training subset. Human-coders thus analyzed more posts that were subsequently included in the training subset. Once consensus between coders is reached, the trained categories are used by the software to analyze the remaining posts. Training the algorithm with human coding requires a minimum of 20 posts, as recommended by Crimson Hexagon, in each defined category. Additional research by Hopkins and King [2010] suggests a total of 100 hand-coded items is sufficient for reliable results (in their analysis, 100 congressional documents were distributed into seven categories).

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[1]We distinguished retweets from original posts in our analysis; approximately equivalent proportions were retweets in both monitors (climate change: 41 percent, global warming: 37 percent). Since we quantified Twitter discourses to which users are exposed in aggregate, the question of whether posts are original or retweets, while interesting, is not the focus of the current work.

We used two separate monitors for this study, each with individual keywords.[2] Tweets were coded into one of the six categories based on the topic: (i) energy; (ii) weather; (iii) policy implications; (iv) environment; (v) political theater; and (vi) statements about climate change or global warming. Categories were chosen based on an initial inductive examination of a randomly selected sample of tweets as they reflect common themes associated with discussions of the issue. Other categories, such as human health, were not commonly included in Twitter discourse relative to the categories selected. This is relatively unsurprising as climate change is not widely recognized as a health issue among American publics [Akerlof et al., 2010]. This is similarly the case in Canada [Cardwell and Elliott, 2013]. We combined this inductive process with our collective experience with climate science education and research. Examples of each category are shown in Table 1. Tweets that expressed opinions about fracking, fossil fuels, and nuclear or renewable energy were coded in the energy category. Those related to temperature, precipitation, seasons, or extreme weather events were classified as weather. Policy implications included mentions of cap and trade, carbon limits or tax, and public projects. Tweets in the environment category included mentions of agriculture, habitat loss, and extinction. Political theater tweets had to be actor-focused, containing specific mentions of public figures. Lastly, tweets that were declarations such as "Climate change is a fact" were categorized as statements about "climate change" or "global warming."

Temperature data and calculations

To identify events of interest, we used surface temperature data from the Climate Forecast System Reanalysis (CFSR) dataset [Saha et al., 2010], which has a horizontal resolution of 0.5°and a temporal resolution of 6 hours. Temperature anomalies were computed by subtracting daily average temperature from climatological temperature for a given day; positive (negative) temperature anomalies indicate the observed temperature was warmer (colder) than average. For each spatial point, the climatological mean temperature was determined by first applying a 21-day running mean centered over the day of interest. Then, the 30-year temperature average at the point of interest over the years 1980–2009 was calculated. Finally, we computed the square of each daily temperature anomaly, which represents a first-order measure of the variability of temperature at each spatial point:

$$T_{\text{sq. anom.}} = (T - T_{\text{climo}})^2$$

where T is the daily average surface temperature and T_{climo} is the climatological mean at that point.

Data analysis

To address H1, we used independent samples t-tests to assess whether average daily posts in each topic of conversation on Twitter containing the keywords "global warming" differed significantly from those containing the keywords "climate change" over the study period (Table 2). To account for multiple

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[2]Keywords for the climate change and global warming monitors are ("climate change" OR "#climatechange" OR "#climate #change") and ("global warming" OR "#globalwarming" OR "#global #warming"), respectively.

Table 1. Examples of categorized tweets containing the keywords climate change and global warming.

	Climate change ($N = 2,235,046$)	Global warming ($N = 1,497,012$)
Energy ($N = 363,561$)	Keystone XL would have little impact on climate change, State Dept. says http://t.co/lFoxELKXfF	Danish company to supply 60MW of wind turbines to US. http://t.co/hzIMTQzu6X #energy #renewables #windfarms #globalwarming
Environment ($N = 1,006,988$)	Study: Ocean wildlife already altering behavior due to #climate change. http://t.co/t0oOtTLZ2j #wildlife #fishing #oceans	RT @UncleRUSH: 40 billion animals killed per yr greatest cause of global warming, waste of water & resources cause of sickness... diary ai...
Policy implications ($N = 349,615$)	State Dept. Budget Includes Nearly Half a Billion for Climate Change: The State Department's $51.6 billion bud... http://bit.ly/Yg7Jsm	Obama Blew $120 Billion on Global Warming Projects – 80% Went to Top Donors http://shar.es/R4lmt via @gatewaypundit
Political theater ($N = 691,535$)	John Kerry: Climate change as big a threat as terrorism, poverty, WMDs – CNN: Secretary of... http://goo.gl/fb/uhirh	Al Gore sued by over 30.000 Scientists for Global Warming fraud / John C...: http://youtu.be/FfHW7KR33IQ
Statements ($N = 525,738$)	The changed the name from "global warming" to "climate change", but we're still supposed to be worried about the warming, right?	How's that global warming working out for you?
Weather ($N = 794,621$)	#GlobalWarming #ClimateChange comes to DC/MD/VA with another foot of snow. Screw the #fundraisers who blame this on CO2 from Humans. #tcot	I love my state. Only in California is it 80 degrees in winter. Unfortunately global warming is has everything to do with it.

comparisons and reduce the risk of Type I error, we adjusted our level of significance (α) based on the Bonferroni procedure [Rosenthal and Rubin, 1983; Wright, 1992]; we set $\alpha = \frac{0.05}{6} = 0.008$.

To answer RQ1, we examined correlations between monthly average anomalous temperature and $T_{\mathrm{sq.\,anom.}}$, and that of number of tweets per capita about global warming and climate change. In the analysis that addressed RQ1, we did not differentiate between topics of conversation. Instead, we compared the monthly average of climate change and global warming tweets with temperature data from six regions in the United States over the study period (Supplemental Table 4 and Supplemental Figure 4). Regions were modified using tagged geographic location in Twitter data. ForSight uses two different methods to assign location data to tweets; approximately 1 percent of the tweets are geo-tagged by the user. The locations of the remaining tweets are estimated based on contextual clues, including users profile information, time zones, and language. The location estimation methodology is similar to that described by Beauchamp [2016]. Of the

Table 2. Descriptive statistics and results of independent samples *t*-tests comparing means of daily global warming and climate change tweets in topic categories over the study period (1 January 2012 – 31 March 2014). Positive values of Cohen's *d* indicate that discussions using global warming have higher average daily posts.

Topic category	Climate change M (SD)	Global warming M (SD)	t (df)	p	Effect size (Cohen's d)
Energy	137.67 (183.37)	305.16 (281.51)	-14.28 (1409.7)	$\leq .001$	0.705
Environment	992.31 (632.78)	234.23 (315.97)	30.71 (1204.9)	$\leq .001$	-1.516
Policy implications	325.88 (331.86)	99.96 (149.32)	17.79 (1138.9)	$\leq .001$	-0.878
Political theater	578.67 (1099.46)	263.64 (339.19)	7.85 (974.7)	$\leq .001$	-0.387
Statements	367.21 (1181.14)	271.15 (273.72)	2.22 (907.8)	0.026	-0.110
Weather	320.61 (469.37)	647.26 (821.86)	-9.89 (1303.5)	$\leq .001$	0.488

3,732,058 total tweets, approximately 15 percent were excluded from analysis as they were not geo-tagged and could not be estimated, resulting in 3,181,229 posts.

The presence of seasonality within our temperature data has the potential to confound our analysis. For example, if number of tweets per capita is significantly correlated with temperature, then peak temperatures due to seasonality may lead to misleading conclusions. To alleviate this, we examined correlations between Twitter posts per capita and anomalous temperature, and between posts per capita and $T_{\text{sq. anom.}}$.

To address RQ2, we conducted case studies focused on two separate extreme temperature events occurring in March 2012 and January 2014. As weather events are not consistent across the United States, not all delineated regions were affected by these extreme weather events. We identified the specific regions affected and used these as case studies. We did not differentiate between discursive topics in this analysis. During the March 2012 "heat wave", temperatures were warmer than normal, particularly in the Northeast, Southeast, and Midwest, with average monthly anomalies of +5.7°C, +5.0°C, and +8.0°C, respectively. During the January 2014 "cold surge", all except for the Western and High Plains regions experienced below average temperatures. Temperature anomalies ranged from -0.05°C in the Southeast to -3.1°C in the Midwest. This "cold surge" event coincided with President Obama's 2014 State of the Union address in which he stated "Climate change is a fact" [Obama, 2014]. In both case studies, daily anomalous temperature was compared with daily number of global warming and climate change messages per capita on Twitter. We then determined whether anomalous temperature was significantly correlated with posts for each term.

Results and discussion	A total of 3,732,058 posts were collected over the study period (Figures 1 and 2). To address our hypothesis, we compared average daily tweets of climate change and global warming in each of the six topics of discourse. We find partial support for H1. Mean differences were significant for five of the six topics with medium to large effect sizes (Table 2); only statements made using the terms "global warming" and "climate change" did not differ significantly. A possible explanation for this finding is that it may indicate Twitter audiences do not hold different associations with these terms when using them in posts unrelated to the other five categories. This emphasizes that the context of discussion matters. When the discursive context was not clearly defined, Twitter users did not appear to hold different associations with these terms.

In discussions of energy and weather, the daily average tweets about global warming were significantly greater than those about climate change. In discussions of the environment and those related to policy or politics, daily mean posts about climate change were significantly greater. The differences were smallest for the weather (Cohen's $d = .488$) and political theater (Cohen's $d = -.387$) categories, and highest in the environment category (Cohen's $d = -1.516$). The significant differences in mean daily posts are consistent with previous studies that suggest these terms are not synonymous for online audiences. In addition to attaching different attitudes to these terms [Cody et al., 2015; Jang and Hart, 2015; Leiserowitz et al., 2014], our results show that Twitter audiences use global warming and climate change in different contexts.

Climate change was used more frequently when discussions were related to political issues. This may reflect the evolution in climate rhetoric [for details, see Besel, 2007] during the Bush administration. Frank Luntz, a Republican strategist, recommended that conservative-leaning politicians use "climate change" instead of "global warming", as the former was found to induce less dread and fear among public audiences [Luntz, 2005]. With respect to the phrase global warming, our results suggest users associate temperature with this phenomenon. While this finding supports prior work linking climate perceptions and beliefs to temperature [Joireman, Truelove and Duell, 2010; Li, Johnson and Zaval, 2011], future research is required to confirm this hypothesis.

To address RQ1, we set our significance level at 0.05 and used bivariate analysis to examine the relationships between the average monthly geo-tagged tweets per capita using both terms with anomalous temperature and $T_{\text{sq. anom.}}$ over the six regions of the continental United States (Table 3). Climate change posts were not significantly correlated with either anomalous temperature or $T_{\text{sq. anom.}}$ in any geographic region. However, we found a significant positive correlation between global warming posts per capita and anomalous temperature in the Midwest where warmer temperatures were associated with more tweets about global warming ($r = .417$, $p = .030$). With regards to $T_{\text{sq. anom.}}$, global warming tweets were correlated with this measure in the High Plains ($r = .522$, $p = .005$), Midwest ($r = .475$, $p = .012$), Southern ($r = .405$, $p = .036$), Southeast ($r = .467$, $p = .014$), and Northeast ($r = .549$, $p = .003$) regions. In all cases, greater deviations of temperature from the mean were associated with more Twitter messages per capita about global warming.
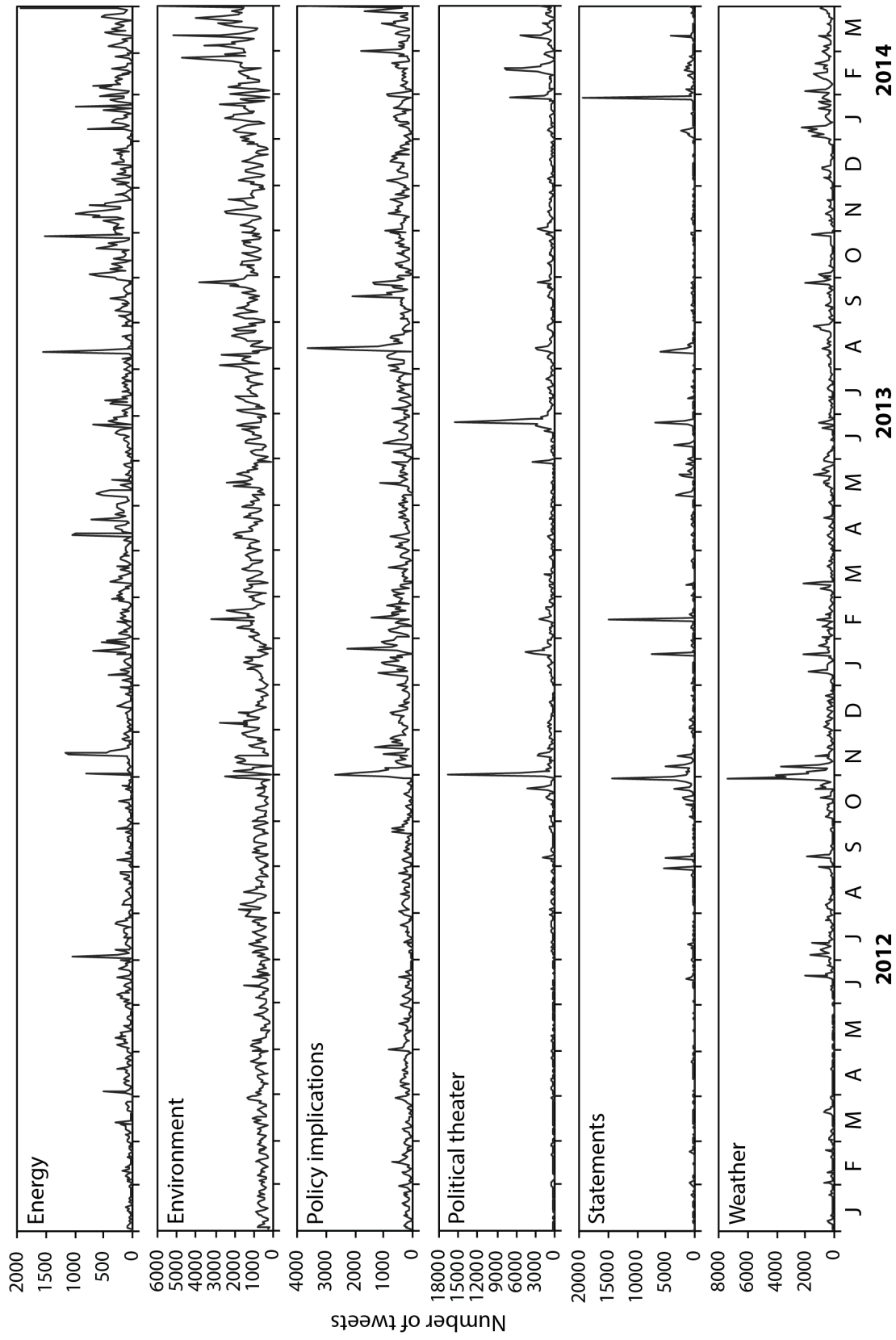
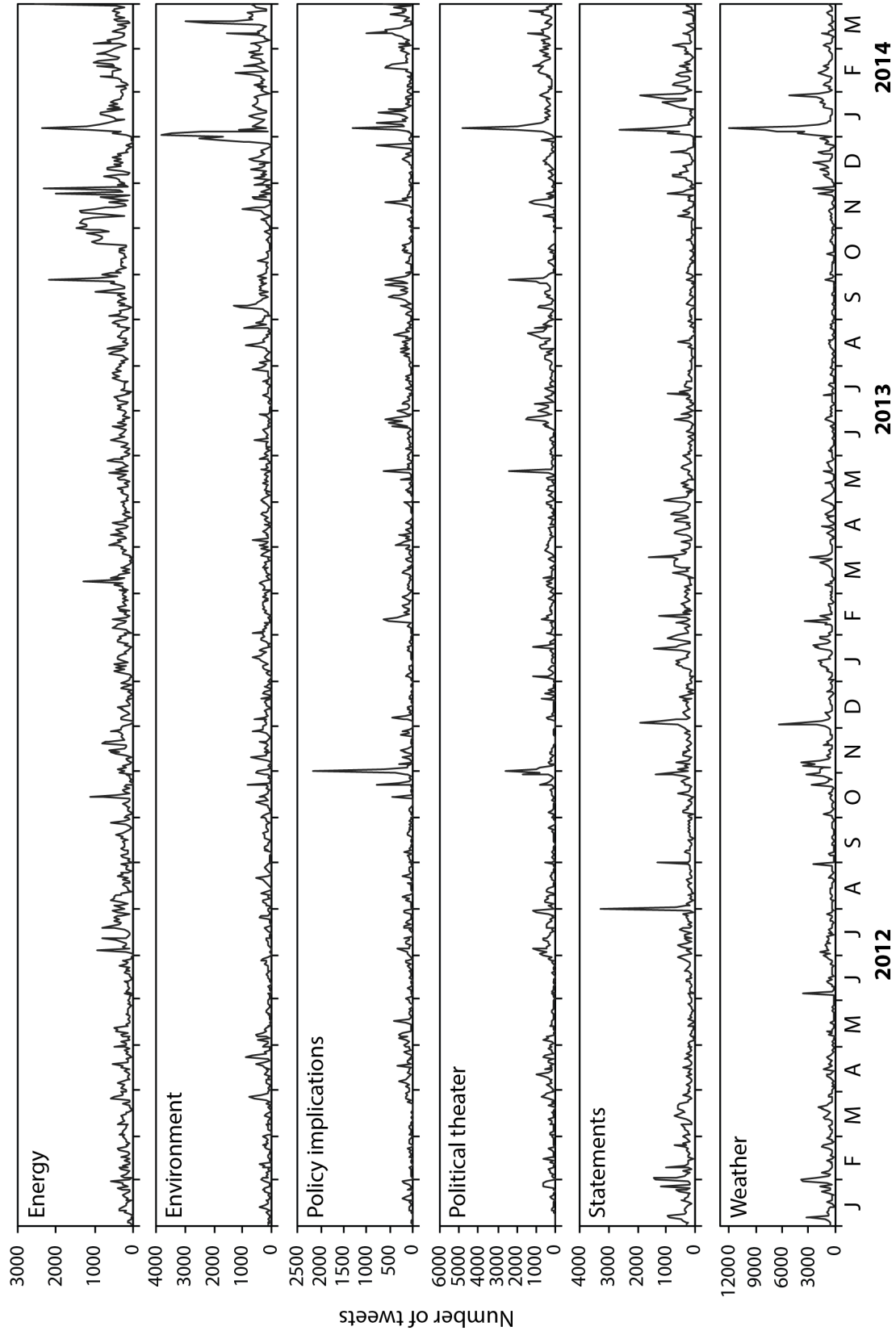**Figure 1.** Time series of daily Twitter posts about climate change.

Figure 2. Time series of daily Twitter posts about global warming.

Table 3. Pearson's correlations and p-values (in parentheses) between monthly average $T_{\text{sq. anom.}}$, temperature anomaly, and total daily Twitter posts per capita between January 2012 and March 2014 in the US.

		Western	High Plains	Midwest	Southern	Southeast	Northeast
Temp. anom. (°C)	Global warming	.152 (.450)	.222 (.265)	.417 (.030)	.042 (.834)	.048 (.813)	.256 (.198)
	Climate change	.288 (.145)	−.165 (.411)	−.050 (.806)	−.273 (.168)	−.288 (.145)	−.340 (.082)
$T_{\text{sq. anom.}}$ (°C²)	Global warming	.134 (.506)	.522 (.005)	.475 (.012)	.405 (.036)	.467 (.014)	.549 (.003)
	Climate change	.042 (.836)	.199 (.321)	.184 (.358)	.232 (.244)	.074 (.713)	.135 (.501)

In the Western United States, neither climate change or global warming tweets were correlated with anomalous temperature or $T_{\text{sq. anom.}}$. The Western region includes the largest latitude range, as well as significant topographic differences relative to the other regions. Thus, the lack of correlation between temperature and posts about either climate change or global warming may be a product of combining states with highly variable temperatures. Taken together with our finding that global warming relative to climate change is used more frequently when the topic of conversation is weather, these results may be indicative of Twitter users commenting on the juxtaposition of the phrase global warming and low temperatures. For example, anomalously warm (cool) days in regions aside from the West may be perceived as events that support (refute) the phenomenon, thus leading users to turn to Twitter to express their views. These results could imply a deeper issue of climate literacy — global warming and climate change are used by experts to describe the same phenomenon, but Twitter audiences understand and use the terms differently. Moreover, it underscores how concern and belief in global climate change are, to some extent, driven by physical experiences with temperature [Zaval et al., 2014].

Thus far, we have referred to audiences on Twitter generally as non-experts. It is worth noting that numerous sources have tracked the demographics of users across the years. In surveys conducted by the Pew Research Center [Greenwood, Perrin and Duggan, 2016], at the beginning of this data collection period in 2012, 16 percent of online adults used Twitter. By the end in 2014, this number had increased to 23 percent. Compared to other social media, Twitter performs well with younger and more educated users, and has seen increases in users across a diversity of demographic groupings [Duggan et al., 2015; Greenwood, Perrin and Duggan, 2016]. Few studies have actively examined the breakdown of Twitter users across the roles they may play for specific issues (e.g., stakeholders, journalists, and politicians). While studies in political communication have found that elite actors, such as political leaders and traditional journalists, are prevalent on Twitter and can dominate online discussions [e.g. Conway, Kenski and Wang, 2015; Wells et al., 2016], there is evidence that "ordinary" users can disrupt traditional power systems via social media [Meraz, 2009].

Analyses specific to those tweeting about climate change are even more limited. Newman [2016] tracked those who tweeted about climate change or the fifth IPCC report a few days before and after the release date. Using a sample of "high attention" tweets, Newman examined these users to determine who had a large impact on the conversation, separating them into six categories. He found that non-elite (i.e., lay audience) accounts were the largest group with 35 percent of the 100 top retweeted posts. The remaining five groupings were more evenly split: media organizations (17 percent), political/advocacy organizations (16 percent), governmental/NGO (12 percent), journalists (9 percent), and finally, scientists (7 percent). While there is a diversity of actors represented within the Twitter conversation, it is important to note that not only do non-elite users contribute to the climate change conversation on Twitter, they are able to attract high levels of attention. While Newman [2016] focused only on the top-100 most attention-garnering accounts, the proportion of non-elite users will likely increase when all tweets are considered.

Case studies

In March 2012, the continental United States experienced temperatures significantly above normal, especially in the Northeast, Southeast, and Midwest regions [Borth, Castro and Birk, 2012]. We used this month as a case study to explore whether anomalous temperatures in these regions were related to the volume of tweets. Temperatures were slightly above average during the first week of March 2012 (Figure 3a). During this week, the volume of posts about climate change and global warming were relatively constant. However, after 11 March, temperatures were consistently about 8°C warmer than average until 24 March. With the onset of higher temperatures, trends in global warming tweets increased relative to those of climate change. The greatest daily volume of global warming posts (~570) coincided with the greatest temperature anomaly (21 March). The highest daily posts about climate change on Twitter (~432) occurred on 29 March after the warmest period of the month.

Anomalous temperatures were significantly correlated with daily average volume of global warming messages ($r = 0.466$, $p = .008$) but not with those of climate change ($r = 0.191$, $p = .304$). Regional differences in the United States are highlighted when we examine the relationships between temperature deviations and Twitter posts (Table 3). In particular, the Midwest region was most drastically affected by the "heat wave" [Borth, Castro and Birk, 2012]; this is reflected in Twitter discourse on global warming. In March 2012, users in the Midwest tweeted more about global warming when temperatures were above average. Although it would be challenging to argue that tweets about global warming are driving temperature deviations in the United States, these results do not demonstrate causation. It is worth noting the potential for regional politics to affect the volume of Twitter posts in the regions examined. While this is beyond the scope of this study, we remain confident in our results as the rural-urban divide in the United States, compared to regional politics, is more likely to influence the political choices and related opinions of American voters [McKee, 2008; Scala and Johnson, 2017].

The second case study evaluated relationships between temperature and Twitter messages in January 2014. During this period, the continental United States
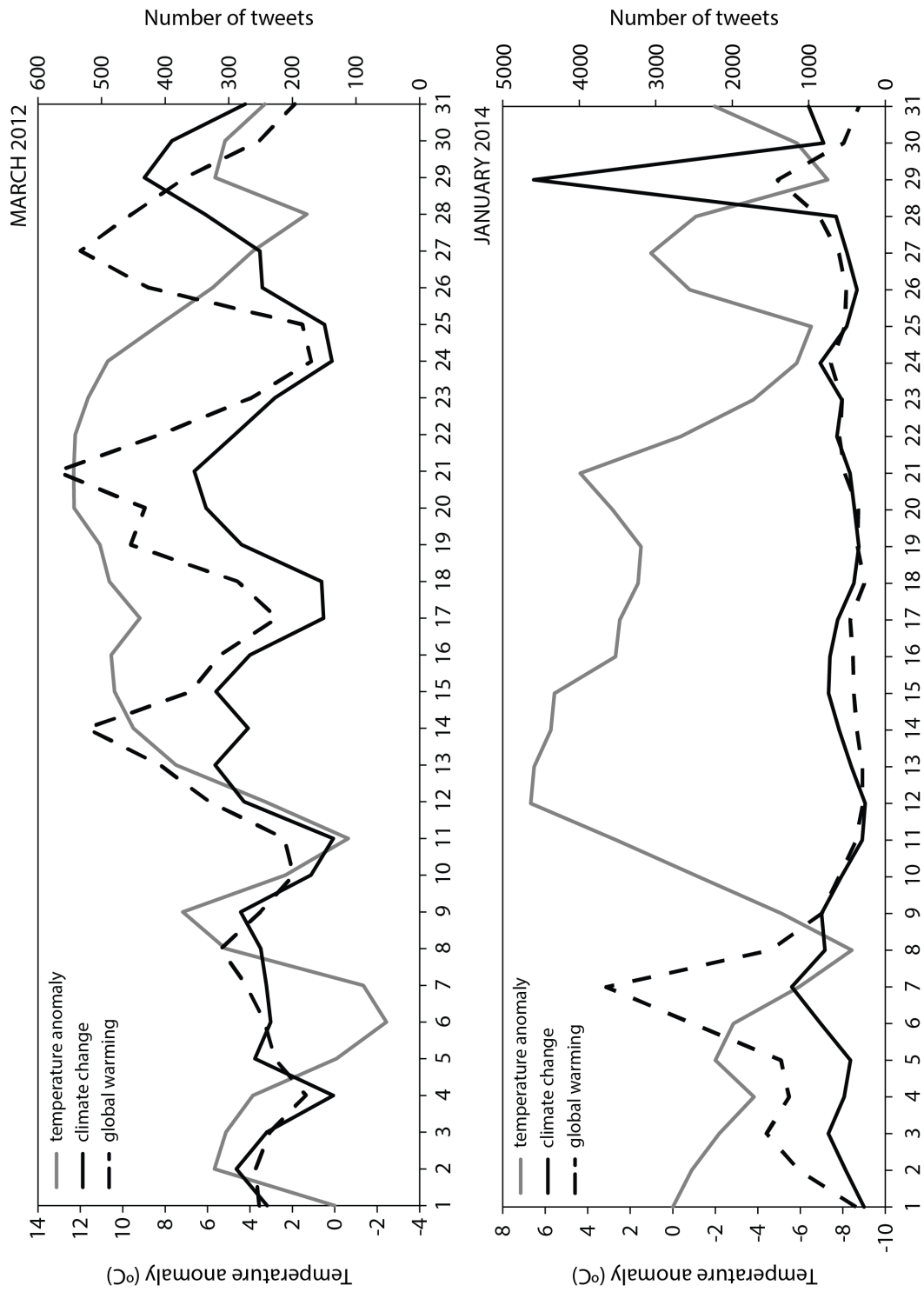
Figure 3. Trends in temperature and tweets per capita about climate change and global warming with respect to the March 2012 "heat wave" in the Midwest, Northeast, and Southeast regions, and January 2014 "cold surge" across all geographic regions.

experienced an abnormally cold month [Lindsey, 2014] with three dramatic decreases: January 6–8, 21–25, and 27–29. All three periods were associated with significant cold air outbreaks over the eastern part of the country. Moreover, on 28 January, President Obama overtly mentioned climate change in the State of the Union address [Obama, 2014].

Peaks in tweets occurred within one day of the temperature deviation minima associated with the dates listed (Figure 3b). This may be a result of users commenting on forecasts of the events as well as the events themselves. These results suggest forecasted cold surge events may be tied to significant increases in tweets. The volume of global warming tweets between 6–8 January and 21–25 January were higher than that of climate change. The converse was observed during and immediately following the State of the Union address (January 27–29). In this case, Twitter messages about climate change outnumbered those related to global warming. The greatest number of global warming posts occurred on 7 January (~3,650), while the maximum volume for climate change occurred on 29 January (~4,600). We found significant negative correlations between anomalous temperature and both global warming ($r = -.666$, $p \leq .001$) and climate change tweets ($r = -.385$, $p = .032$) for the entire month of January. The correlation between anomalous temperature and global warming reactions supports our finding that the volume of global warming messages on Twitter is associated with changes in temperature. This also supports our finding that the volume of climate change reactions on this social platform is strongly associated with political commentary.

Limitations

While this study is one of the few to investigate Twitter discourses surrounding global warming and climate change topics, some limitations exist. First, we underscore that opinions expressed on Twitter do not necessarily reflect those of publics [Mitchell and Hitlin, 2013]. However, it remains valuable to examine these discourses as they are real-time sharing of opinions. Such reactive and unsolicited expressions provide insight into how global warming and climate change are associated with temperature and extreme events when these issues arise in conversation.

A second limitation is that not all users report the location from which they are tweeting. Since our sample of geo-tagged Twitter posts is a subset (85 percent) of that used to analyze the topics of conversation, it is only able to provide a proxy for climate change and global warming discourses, and their relationships with temperature. Despite this limitation, our findings support previous research on the relationship between Twitter discourses and variability in temperature [Joireman, Truelove and Duell, 2010; Li, Johnson and Zaval, 2011], which gives us confidence that our results provide valid insight.

Lastly, the geographic regions defined are large enough in some cases that we may be averaging out some important temperature information. For example, the Western region includes a large area that spans various climates that can differ in temperature significantly during each season. Therefore, while no significant correlations arise in our study in the Western United States, the inclusion of so

many climates within a region may play a role in this. Future studies might find it fruitful to consider correlations between temperature and tweets within smaller geographic regions.

Conclusions

Our goal was to investigate differences in topics of Twitter discourses using the terms global warming and climate change. Using automated content analysis with a supervised learning technique, we categorized discursive topics over a period of 27 months. Additionally, we examined the link between temperature and those discourses. The present work builds on scholarship examining perceptions [Joireman, Truelove and Duell, 2010; Li, Johnson and Zaval, 2011] and tweets about global warming and climate change [Kirilenko, Molodtsova and Stepchenkova, 2015; Lineman et al., 2015] by considering the topics of Twitter discourse related to each term and investigates of the role of extreme temperature events on such discussions. We first addressed whether significant differences in global warming and climate change posts on Twitter about various topics of discussion existed. Then, we examined whether daily average temperatures and extreme temperature events were correlated with global warming and climate change tweets.

We found the topic of discussion was an important factor in whether messages about global warming or climate change were more prevalent. While more reactions to global warming were observed for topics related to weather and energy, more climate change tweets were about environmental and political content. Consistent with previous research [Kirilenko, Molodtsova and Stepchenkova, 2015], our findings also showed that posts about global warming (but not climate change) were significantly correlated with anomalous temperature and impacted by seasonality. This result was further supported in our case study of the "heat wave", where a statistically significant correlation between anomalous temperature and global warming reactions was observed. The January 2014 "cold surge" case study supported our finding that political statements appear to be associated with more climate change tweets relative to global warming.

These results have implications for climate change communication. Our findings underscore the importance of considering how communication may translate into concerns among lay audiences. Here, we demonstrate that Twitter audiences associate different dimensions of the phenomenon with the terms "climate change" and "global warming." This highlights a need for strategic use of these terms as they may influence public discourses of climate change. However, the nature of the influence is likely to vary across different segments of the publics [Villar and Krosnick, 2011]. Depending on the policy issue at hand, it may be important to use the appropriate term to describe the phenomenon that resonates with people's internal schema when developing messages about various aspects of the issue, such as using global warming to communicate energy issues and climate change for environment-related issues. It may also be more effective to discuss the issue using global warming during periods of temperature extremes, as we found evidence of a strong link between the term and anomalous temperature and $T_{\text{sq. anom.}}$. Alternatively, "climate change" appears to be more linked with the political aspects of the issue; this term may be more appropriate for use in general discourses related to policies or the phenomenon itself.

As previous research conducted in the UK suggests that the term "global warming" is associated with higher concerns for the issue [Whitmarsh, 2009], our demonstration of linkages with temperature becomes more pertinent as it may indicate periods of high attention and concern. "Heat waves" and "cold surges" may be ideal times to discuss policies or communicate about climate change, as both interest and attention increase.

Lastly, despite the large number of people who recognize the need for significant lifestyles changes due to climate change, attitudes toward climate change are also tied to extreme temperature. This suggests there may be a disconnect between public opinion and behavior change, as attitudes and attention levels fluctuate with changes in temperature [Bamberg and Möser, 2007; Kollmuss and Agyeman, 2002]. Since our results are based on correlations, future work should probe causal relationships underpinning these findings and should consider how discourses on other Web-2.0 media are affected by physical factors.

Appendix A. Supplemental table and figure

Table 4. List of geographic regions in the United States modified from those delineated by the National Weather Service's Regional Climate Centers.

Region	States
High plains	Colorado, Kansas, Montana, Nebraska, North Dakota, South Dakota, Wyoming
Midwest	Illinois, Indiana, Iowa, Kentucky, Michigan, Minnesota, Missouri, Ohio, Wisconsin
Northeast	Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, West Virginia
Southeast	Alabama, Florida, Georgia, North Carolina, South Carolina, Virginia
Southern	Arkansas, Louisiana, Mississippi, New Mexico, Oklahoma, Tennessee, Texas
Western	Arizona, California, Idaho, Nevada, Oregon, Utah, Washington
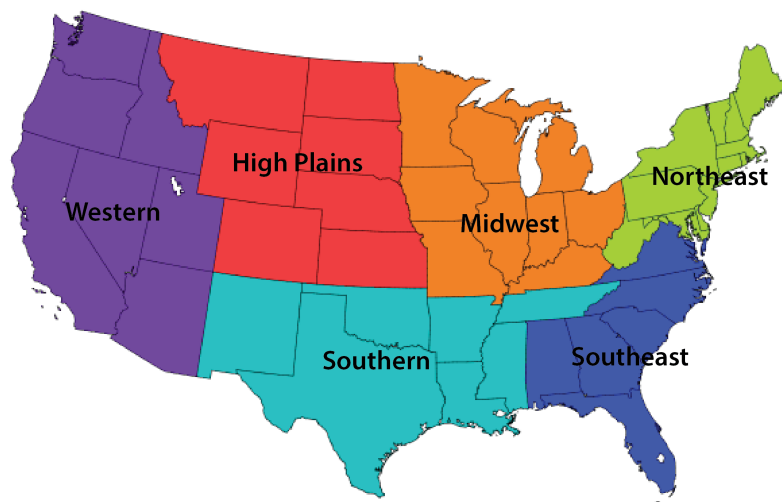
Figure 4. Map of United States regions modified from those delineated by the National Weather Service's Regional Climate Centers.

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