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RESEARCH ARTICLE

The Occurrence of Extreme Monthly Temperatures and Precipitation in Two Global Regions

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ABSTRACT

Recently, there has been focus on extreme weather events and the connection to climate change and weather variability. Most work is related to individual events rather than mean monthly conditions. This study examines the occurrence of extreme monthly temperature and precipitation events in the central United States (cUSA) and southwest Russia (swRUS). The surface data were provided by the Missouri Climate Center and the Russian Hydrometeorological Center for an extended period (126 years for cUSA and 71 years for swRUS). An extreme event is defined such that a large enough sample is gathered without losing the meaning of extreme. The results demonstrate that in cUSA, there was no preference for warm or cold anomalies. For swRUS, there was a preference for cold (warm) anomalies early (late) in the period, which was characterized by steadily increasing temperatures. There was a tendency in both locations for extreme months during a preferred phase of the El Niño Southern Oscillation. In both regions, there was no significant signal in extreme temperature related to longer term climatic cycles, whereas for precipitation there was a relationship to the Pacific Decadal Oscillation for cUSA. Additionally, cold monthly anomalies were associated with persistent and strong upstream blocking events. Finally, two case studies are examined for the cUSA.

KEYWORDS

Blocking; climate change; extremes; interannual variability; interdecadal variability

In recent years, there has been increased attention paid to the recurrence of extreme weather in research and by the general community, especially within the context of climate and climate change (e.g., Intergovernmental Panel on Climate Change [IPCC] 2013, 2014). Recent research, however, has demonstrated that even with an increase in temperature globally, important interannual and interdecadal weather and climate variability can still impart a strong signal on local or regional climate (*e.g.*, Klyashtorin and Lyubushin 2007; Tsonis, Swanson, and Kravtsov 2007; Swanson and Tsonis 2009; Johnstone and Mantua 2014). Johnstone and Mantua (2014) showed that interdecadal variability related to the Pacific Decadal Oscillation (PDO) contributed strongly to the climate record of the northwest United States since 1900. Also, many researchers have examined the interannual and interdecadal variability of temperature and other variables regionally (e.g., Gershanov and Barnett 1998; Birk *et al.* 2010; Lupo, Smith, *et al.* 2012).

Studies of the interannual or interdecadal variability of the occurrence of extreme weather or climate events is not new and has typically been accomplished using phenomenological events such as hurricanes (*e.g.*, Zuki and Lupo 2008; Lupo 2011; Lupo, Latham, et al. 2008), tornadoes (*e.g.*, Marzban and Schaefer 2001; Akyuz, Chambers, and Lupo 2004), or atmospheric blocking events (*e.g.*, Hakkinen, Rhines, and Worthen 2011; Lupo, Mokhov, *et al.* 2012; Mokhov *et al.* 2012). Many have examined the

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occurrence of extreme temperatures and how their incidence might change in the twenty-first century (e.g., Birk *et al.* 2010; IPCC 2013). Other studies have attributed the recent occurrence of extreme events to climate change (e.g., IPCC 2013; National Academy of Sciences 2016). Very few have examined the frequency of months that are associated with extreme temperatures and precipitation, however.

The goal of this research is to examine the incidence of extremely warm and cold (wet and dry) months occurring in two regions of the globe, the central United States (cUSA) and southwest Russia (swRUS). A case study of two anomalously warm months in the cUSA region (December 1889 and March 2012) was conducted to further garner an understanding of how atmospheric behavior associated with the extreme month compared to that of a historically "normal" month or season. This study is also unique because many papers have demonstrated the occurrence of extremely cold months over North America that have been related to Pacific Region ridging or atmospheric blocking (*e.g.*, Quiroz 1984; Jensen 2015). To our knowledge, there is no comparable study for either region of interest (cUSA or swRUS) for extremely warm months. The results of this study would have implications for long-range weather forecasting.

Data and analysis

Data

The data used in this study are described here. For the cUSA, surface temperature and precipitation records from the Columbia, Missouri, station were obtained from the Missouri Climate Center (MCC) at the University of Missouri in Columbia. These records go back to 1889, providing for a 126-year data set through 2014, and were provided in degrees Fahrenheit and inches. The data for swRUS were surface temperature and precipitation data for the Belgorod Oblast (Belgorod-Fenino station) obtained from the All Russia Research Institute of Hydrometeorological Information-World Data Centre (RIHMI-WDC; see http://meteo.ru/) for 1944 to 2014, or seventy-one years. These data were provided in degrees Celsius and millimeters. Ratley, Lupo, and Baxter (2002), Birk *et al.* (2010), Newberry *et al.* (2016), and Lebedeva et al. (2016) demonstrate that these data will generally be representative of their regions as a whole.

The cUSA region is delineated as the eastern two thirds of Missouri and western Ilinois, and the swRUS region is the Belgorod Oblast (Figure 1). The cUSA is part of the Midwest region of the United States, which is defined as Missouri and surrounding states. Additionally, the cUSA and swRUS study regions are chosen such that each region can be considered to have the same interannual variability throughout in the temperature and precipitation records in general (see Ratley, Lupo, and Baxter 2002; Birk *et al.* 2010; Lebedeva *et al.* 2016). In this study, the actual units for surface temperature are not germane to the analysis because here the departures from the means are examined (*e.g.*, Lupo *et al.* 2003). Additionally, the National Centers for Environmental Prediction and National Center for Atmospheric Research (NCEP/NCAR) reanalyses and the NCEP twentieth-century reanalyses were plotted on a 2.5° × 2.5° latitude and longitude grid. The 500 hPa geopotential height fields (m) were used primarily.

Finally, the blocking archive at the University of Missouri (http://weather.missouri.edu/gcc) was used to compile the character of atmospheric blocking events associated with extreme months, particularly occurrence dates, duration (days), intensity (unitless), and location (longitude). Atmospheric blocking is persistent, closed ridging in the jet stream that can occur episodically and dominate the weather and climate of an entire season in the regions under which they occur and including the upstream and downstream locations. For example, persistent blocking was responsible for the 2010 heat wave that affected Eastern Europe and western Russia (*e.g.*, Lupo, Mokhov, *et al.* 2012), or the cold winter of 2013–2014 over the eastern two thirds of the United States (*e.g.*, Jensen 2015).

Analysis

To be considered an extreme event in the cUSA, this study specified that the monthly mean temperature for the region of study had to be at least three standard deviations above or below the seasonal mean derived from the entire data set. The three standard deviation value was based on the seasonal mean so

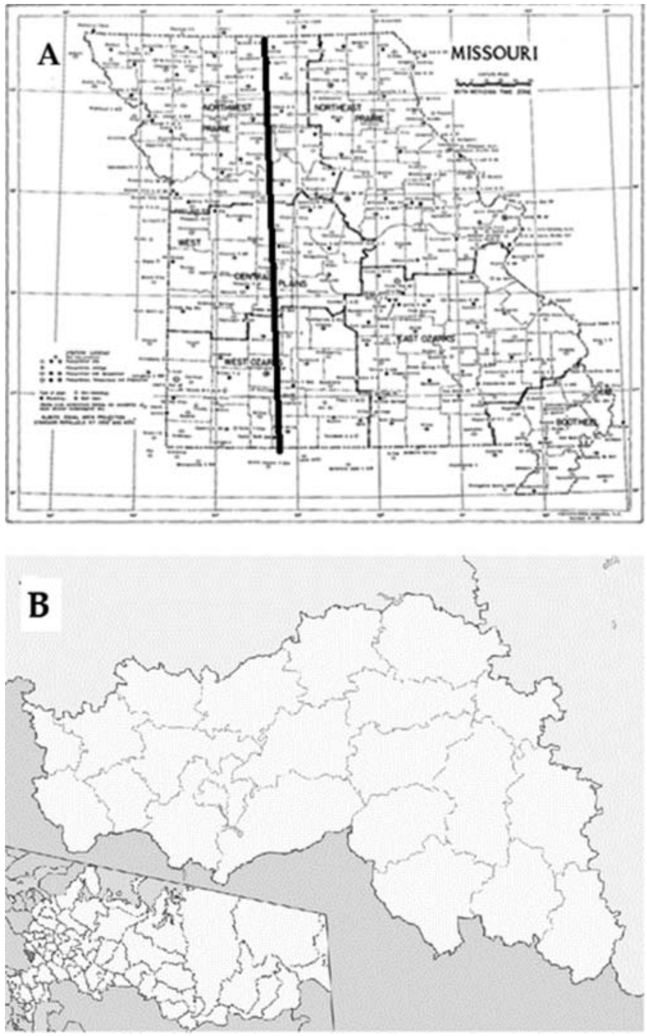

Figure 1. Maps of the study region showing the (a) cUSA (east of the black line), and (b) swRUS. The map for Missouri was provided from the United States Department of Commerce Weather Bureau and shows the Climatological Divisions from 1957 to present. The map for the Belgorod Oblast shows the relative location (Inset) within Russia.

that the sample size produced was large enough for statistical analysis. Also, in a normally distributed data set such as temperature (*e.g.*, Lupo *et al.* 2003), three standard deviations represent approximately 1 percent of the distribution. Additionally, the monthly standard deviations for each season are similar (*e.g.*, Lupo *et al.* 2003), thus it is considered here that an anomalously warm or cool month could occur in any of the three months for that season. The values used in this study are presented in Table 1. Because there were 1,512 events in the cUSA and 852 in swRUS, our sample size based on three standard deviations from the monthly mean should represent only fifteen and nine events, respectively. Applying the seasonal standard deviation criterion (three σ; see Table 1) used yielded a sample size of ninety-three and forty-five months, respectively in the cUSA and swRUS (about 6 percent of all months for each region). This is greater than the number predicted by using a standard normal monthly distribution, but not so many months that the meaning of an extreme event would be lost. Because precipitation is not normally distributed (Hagen *et al.* 2010), only the three wettest and driest months for the cUSA and the two wettest and driest months for swRUS were chosen from the data set. This provides us with approximately as many months (seventy-two for the cUSA and forty-eight for swRUS, respectively) for the precipitation analysis in each region as there were for the temperature data for consistency.

Table 1. The criterion used for each season in the central United States (cUSA) and southwest Russia (swRUS) to determine an extremely warm or cold month.

Season	Three seasonal σ (cUSA °F/sw RUS °C)
Winter (December–February)	10.2 / 7.8
Spring (March–May)	6.6 / 5.6
Summer (June–August)	6.5 / 4.4
Fall (September–November)	6.3 / 4.4

Note: See Lupo et al. (2003) for the monthly mean and standard deviations for cUSA.

The definition for El Niño Southern Oscillation (ENSO) used was the Japanese Meteorological Association (JMA) definition. The list of years and their associated ENSO phase can be found in Table 2. This definition has been used in many published studies (*e.g.*, Birk *et al.* 2010 and references therein). The PDO is defined as a warm or cool phase based on the relative comparison of the predominant sea surface temperature (SST) pattern in the Western versus Eastern Pacific region and as defined in Birk *et al.* (2010). The eras are shown in Table 3. In swRUS, we examined eras in association with the North Atlantic Oscillation (NAO) as well (Table 3).

Climatological study

The climatological analysis found ninety-three and forty-five months for cUSA and swRUS, respectively, which met the three seasonal standard deviation criteria shown in Table 1. Tables 4 and 5 show

Table 2. Center for Ocean-Atmospheric Prediction Studies Japan Meteorological Agency El Niño Southern Oscillation Index, 1889 to present.

El Niño	Neutral	La Niña
1888	1890–1891	1889
1896	1894–1895	1892–1893
1899	1897–1898	1903
1902	1900–1901	1906
1904–1905	1907	1908–1910
1911	1912	1916
1913	1914–1915	1922
1918	1917	1924
1925	1919–1921	1938
1929–1930	1923	1942
1940	1926–1928	1944
1951	1931–1937	1949
1957	1939	1954–1956
1963	1941	1964
1965	1943	1967
1969	1945–1948	1970–1971
1972	1950	1973–1975
1976	1952	1988
1982	1953	1998–1999
1986–1987	1958–1962	2007
1991	1966	2010
1997	1968	
2002	1977–1981	
2006	1983–1985	
2009	1989–1990	
2014–2015	1992–1996	
	2000–2001	
	2003–2005	
	2008	
	2011–2013	

Note: See also Birk et al. (2010).

Table 3. Center for Ocean-Atmospheric Prediction Studies Pacific Decadal Oscillation (PDO) Index, 1900 to present and the North Atlantic Oscillation (NAO).

Year range	Mode
1900–1924	–PDO
1925–1946	+PDO
1947–1976	–PDO
1977–1998	+PDO
1999–2014	–PDO
1944–1950	+NAO
1951–1973	–NAO
1974–2008	+ NAO
2009–2014	–NAO

Note: For the PDO, modes are high (positive) and low (negative). For the NAO, a positive (negative) value represents a more meridional (zonal) flow over that region, See https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-station-based; Birk et al. (2010).

the seasonal breakdown of the normalized extreme monthly temperature anomalies for cUSA and swRUS using the values in Table 1. Overall, there were slightly more warm anomalies for the cUSA and cold anomalies for swRUS, but the distribution of warm and cold anomalies represented close to 50 percent of the total occurrences of extreme months for the entire 126-year (or 71-year) period. Comparing both regions demonstrates that in the cUSA an extremely warm or cold month occurred in three of every four years (ninety-three events in 126 years), but approximately two times in three years (forty-five events in 71 years) in the swRUS region, if it is assumed these events occur at regular intervals. The more frequent occurrence of extremes in the cUSA is to be expected because it is a more continental region using the Zenker Continentality Index (*e.g.*, Matveev 2003; Matveev *et al.* 2017; cUSA = 62.8 *vs.* swRUS = 45.6). This index is proportional to the amplitude of the annual cycle and the latitude of the location.

Appendix A, however, shows the occurrences of extreme monthly temperature events for the cUSA was more frequent from 1900 to 1939, but relatively constant during other periods. In swRUS, the decade of the 1950s showed the most occurrences of extreme monthly temperatures, and the decade of the 1960s showed the fewest. For precipitation (Appendix B), the decadal variability was less pronounced in both regions. Interdecadal variability is discussed later.

Examining individual seasons for both regions demonstrates that whereas the raw values for extreme monthly departures were largest in the winter months (not shown), the normalized values were largest and these occurred more frequently during the transition seasons of spring and fall (Tables 4 and 5). In the winter season for the cUSA, cold extremes occurred three times as often as warm anomalies; however, during the summer season, warm extreme months occurred about twice as often. This dominance of cold (warm) anomalies in the cold (warm) season is particularly true for swRUS as well (Table 5).

There was little overall temperature trend during the 126-year period (slightly positive, not statistically significant) in the cUSA region using running thirty-year means, which are typically used to define climatology. The winter season temperatures showed the largest increase (about 1°F) and the spring showed only a slight increase in temperature. Summer showed no change in temperature, and the fall season temperatures decreased about 0.7°F over the period of record. Within the swRUS region, temperature increased 1.53°C for the annual value over the seventy-

Table 4. Statistics for the central United States: Raw counts of warm and cold anomalies by season, percentage (count / total years), and the most extreme value (and year) normalized using Table 1.

Category	Winter	Spring	Summer	Fall	Total
Warm	5 / 4% / 1.6–12/1889	15 / 12% / 2.5–3/2012	13 / 10% / 1.4–7/1980	14 / 11% / 1.8–10/1963	47 / 37% / 2.5–3/2012
Cold	15 / 11% 1.6–1/1977	13 / 10% / 1.8–3/1906	7 / 5% / 1.3–8/1915	11 / 9% / 1.6–10/1925	46 / 37% /1.8–3/1906

Table 5. Statistics for southwest Russia: Raw counts of warm and cold anomalies by season, percentage (count / total years), and the most extreme value (and year) normalized using Table 1.

Category	Winter	Spring	Summer	Fall	Total
Warm	1 / 1% / 1.0–2/2002	9 / 12% / 1.1–3/2007	7 / 10% / 1.5–8/2010	14 / 11% / 1.810/1963	47 / 37% / 2.5–3/2012
Cold	8 / 11% 1.4–1/1950	4 / 6% / 1.4–3/1952	N/A	11 / 9% / 1.6–10/1925	46 / 37% / 1.8–3/1906

year period, a result statistically significant at 95 percent using an F test, $F(70) = 2.99$. During the winter and spring seasons, the increase was more than 2°C, whereas during the summer and fall seasons, the increase was smaller, around 0.7°C and 1°C, respectively. Only the spring and summer increases were significant at the 95 percent confidence level, however, $F = 2.87$ and $F = 3.85$, respectively. Because the swRUS region showed constant increases in temperature overall, it is no surprise that seventeen of twenty-one (four of twenty-one) warm (cold) anomalies occurred after 1990. The cUSA temperatures have varied over the 126-year period (Appendix A). Thus, it might be instructive to examine the occurrence of these anomalies with respect to interannual and interdecadal variations.

Interannual and interdecadal variability

In this section, occurrences stratified by ENSO phase are normalized and represented as a mean annual occurrence because ENSO neutral years account for a majority of the periods of study for both regions. In the cUSA, there were sixty-eight neutral years, thirty La Niña events, and twenty-eight El Niño events, whereas in swRUS, these counts were thirty-nine, seventeen, and fifteen years, respectively. Tables 6 and 7 show the ENSO variability of extremes for both temperature and precipitation in both regions.

An examination of Table 6 shows that extremely warm or cold monthly temperatures in cUSA are most likely during the neutral and El Niño phase. During La Niña months (thirty years), extremely warm or cold months were likely to occur during one month in every two La Niña years, translating to a 4 percent probability of any given La Niña month being extreme. Here, 4 percent was calculated by dividing sixteen events by (30 years $\times$ 12 months/year^{-1}), and all the calculations in this discussion were performed identically. The likelihood becomes 7 percent for extreme months occurring during El Niño (twenty-eight years) or neutral years (sixty-eight years). In swRUS, the occurrence of extreme monthly temperatures was more likely in both La Niña (seventeen years) and El Niño (fifteen years) phases (about 6 percent probability) as opposed to the neutral (thirty-nine years; about 4 percent). There was some variability by season in swRUS in that during the fall season, La Niña was more likely to have an extreme temperature occurrence. The other seasons, however, were similar to the overall occurrence across each phase. In swRUS, the probability of extreme warm or cold months was similar to that of cUSA overall. For neutral years in the cUSA, there were more warm extreme months, but there were more cold anomalies in El Niño years. In the cUSA summer, neutral months accounted for 70 percent of all summer extreme months, and this was the highest percentage among any of the seasons for that region.

Table 6. The occurrence of extreme temperature/precipitation months stratified by El Niño Southern Oscillation (ENSO) phase and season expressed as occurrence per year (count/number of ENSO years) for each phase in the central United States.

Phase	Winter	Spring	Summer	Fall	Total
El Niño (28)	0.19/0.19	0.27/0.07	0.17/0.07	0.30/0.07	0.82/0.41
Neutral (68)	0.19/0.19	0.24/0.16	0.21/0.19	0.16/0.18	0.79/0.65
La Niña (30)	0.07/0.03	0.13/0.20	0.03/0.10	0.17/0.13	0.53/0.47

Table 7. The occurrence of extreme temperature/precipitation months stratified by El Niño Southern Oscillation (ENSO) phase and season expressed as occurrence per year (count/number of ENSO years) for each phase in southwest Russia.

Phase	Winter	Spring	Summer	Fall	Total
El Niño (15)	0.13/0.20	0.27/0.13	0.13/0.20	0.20/0.27	0.73/0.80
Neutral (39)	0.10/0.15	0.15/0.22	0.07/0.20	0.20/0.20	0.51/0.78
La Niña (17)	0.19/0.19	0.19/0.06	0.13/0.06	0.31/0.00	0.81/0.31

For precipitation in both regions, the distributions were different from the temperature (Tables 6 and 7). In the cUSA, neutral years produced extreme wet or dry months most frequently, whereas in swRUS it was El Niño and neutral years producing the most extremes (Table 7). In the cUSA the neutral years dominated the summer season, but during the other seasons shared predominance with either El Niño (winter) or La Niña (spring, fall; Table 6). For swRUS, La Niña years were as common as the other phases during the winter season only (Table 7).

An examination of the occurrence of extreme months in association with the positive and the negative PDO eras in the cUSA showed only a weak tendency toward the occurrence of extreme warm months with the warm phase of the PDO and cold months in the cold PDO phase (Table 8). In swRUS, there was a greater tendency toward extreme warm months during the positive NAO (Table 8), due to more meridional flow for the region as opposed to the negative phase, which is more zonal. This might be due to the variations in the occurrence of blocking, which is discussed in the next section. There was a strong association for the occurrence of wet extremes during the positive phase of the PDO and dry extreme during the negative PDO phase in the cUSA (Table 8). According to Birk *et al.* (2010) and many others, the positive phase of the PDO is also known as the warm phase and vice versa. In the swRUs region, there was only weak variability in wet versus dry months during phases of the NAO.

December 1889 and March 2012 case studies

Conditions over North America

Here two case studies of extremely warm events are examined as researchers have long associated ridging and blocking with cold winters in the cUSA (*e.g.*, Quiroz 1984; Jensen 2015). Also, Lupo, Mokhov, *et al.* (2012) studied the summer of 2010 drought that affected western Russia, including the Belgorod region, which was due to strong and persistent blocking. Studying warm extremes in the cUSA has not been performed recently, although examining the anatomy of anomalous summer season warm temperatures was done previously (Namias 1982, 1983; Lupo and Bosart 1999). Namias (1982 1983) attributed anomalous summer season warm temperatures to enhanced ridging over the cUSA, and Lupo and Bosart (1999) examined precursors to the 1980 drought. None of these studies, however, looked into the Pacific region flow regimes.

During December 1889, the mean temperature was 49.3°F (9.6°C) in the cUSA, and was 16.1°F (9.0°C) above the December mean, which was the second largest monthly anomaly overall

Table 8. The ratio of extreme warm to cold (wet or dry) months with respect to the Pacific Decadal Oscillation (PDO) phase for the central United States and the North Atlantic Oscillation (NAO) phase for southwest Russia.

	Temperature	Precipitation
PDO+	1.13	1.58
PDO–	0.89	0.63
NAO+	1.40	0.80
NAO–	0.62	1.33

Note: A value greater than one indicates more warm or wet months, and vice versa.

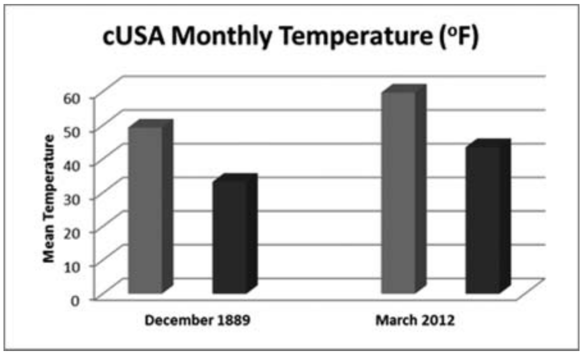

Figure 2. The observed temperature for December 1889 and March 2012 (Grey) in the cUSA (°F) compared to the mean (black) (source: Missouri Climate Center).

for the entire period of record (Figure 2) For the month of March 2012, the comparative numbers were 59.7°F (15.4°C) and 16.2°F (9.0°C) above the March averages. This represents the largest monthly anomaly of the cUSA. Table 4 demonstrates that these two months were 1.6 and 2.5 standard deviations above their respective seasonal averages. A surface map (Figure 3). would demonstrate that the anomalous warm temperatures of both months dominated most of the United States east of the Rocky Mountains, and in the case of 2012 temperature anomalies of 5 to 10°F (3.0–5.6°C) or greater were even observed in upstate New York and New England (see Figure 3B and National Climatic Data Center).

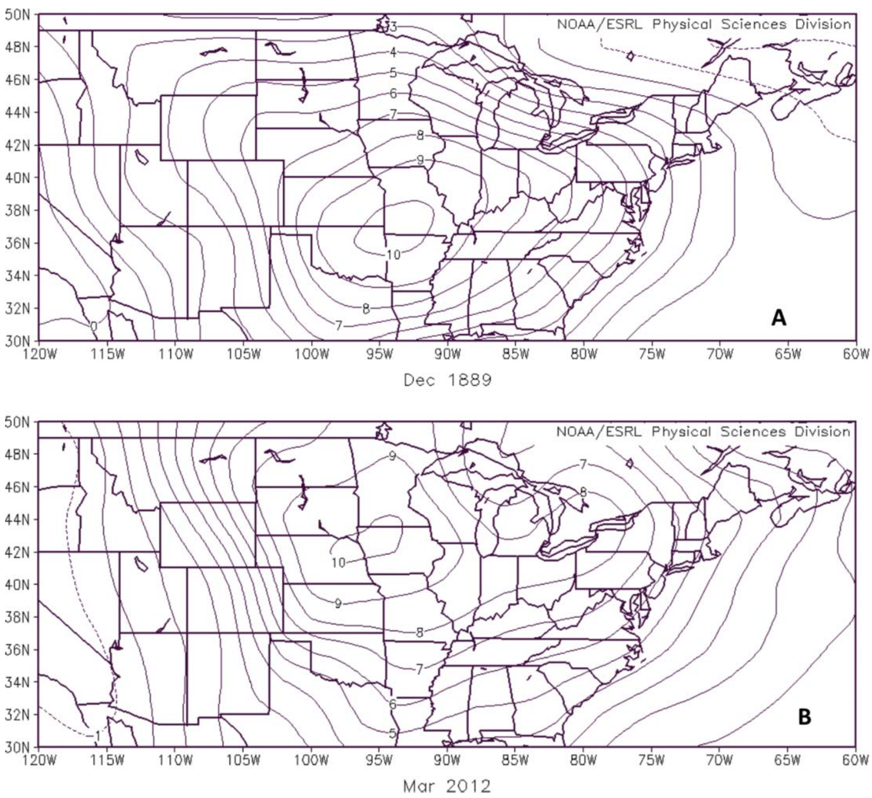

Figure 3. The surface temperature anomaly maps for (a) December 1889, and (b) March 2012. The units are (°C) and the source is the NCEP 20th Century re-analyses.

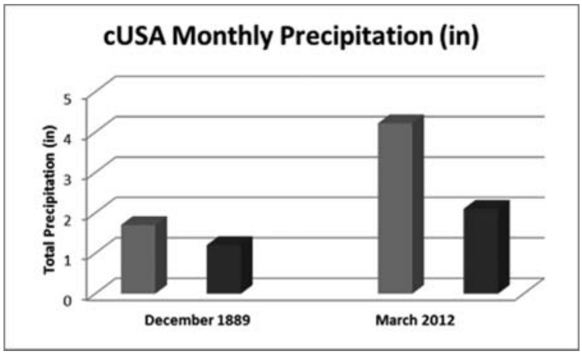

Figure 4. Same as Fig. 2, except for precipitation (in).

Examining the monthly precipitation from both months demonstrates that both months were wetter than normal (Figure 4), which is at least partially a function of the anomalous warm temperatures. In spite of the atypical warmth, however, neither of these months was among the wettest on record. Although it would be difficult to calculate the evaporation potential for each month, especially for December 1889, comparing each month to a month in the year with a mean temperature similar to that observed for both cases would demonstrate that the precipitation would be near normal for March 2012 (comparing to April, 55°F; and May, 64.3°F), and drier than normal for December 1889 (comparing to October, 57.4°F; and November, 44.0°F).

Additionally, precursor conditions (previous three months) did not provide a strong indication that these extreme warm months would occur following them. The temperature data for the three preceding months would indicate that although it was warmer than normal before March 2012, it was cooler than normal before December 1889 (Table 9). Also, the three prior months generally featured above normal precipitation (Table 9).

Figure 5 illustrates the mean geopotential 500 hPa heights for the North American region during the months for the two case studies. The two patterns are quite similar, showing ridging over the east central United States, but weak troughing along the southern part of the West Coast. The 500 hPa ridging is just a little farther east in the March 2012 case as shown in Figure 6 when comparing the location of each anomaly. The anomalies in Figures 3 and 6 are remarkably similar in magnitude and coverage as well. The two maps demonstrated a flow regime similar across the Midwest United States, suggesting persistent warm air advection from the southwest might have contributed to the higher than average temperatures seen throughout the months.

Atmospheric blocking

During the extreme warm months, there was anomalous ridging over North America. A;though it is well known that anomalously cold months are associated with atmospheric blocking over the

Table 9. The observed and mean temperature (°F) and precipitation (in.) for the three months prior to December 1889 and March 2012 for the central United States.

Month	Observed temperature (°F)	Mean temperature (°F)	Observed precipitation (in.)	Mean precipitation (in.)
September 1889	64.8	68.7	1.39	4.17
October 1889	53.4	57.4	3.62	3.06
November 1889	41.3	44.0	2.72	2.44
December 2011	37.7	33.2	3.51	2.02
January 2012	35.4	29.5	0.74	1.82
February 2012	39.9	33.1	2.67	1.90

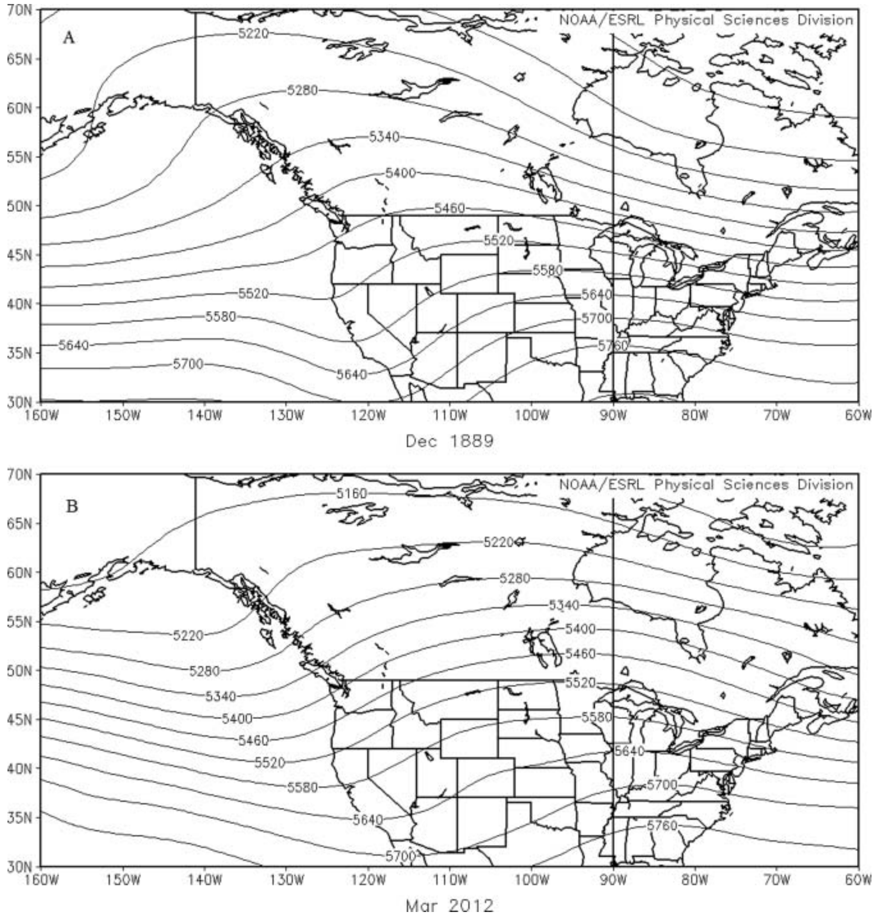

Figure 5. The mean 500 hPa geopotential height maps (m) for (A) December 1889, and (B) March 2012. The contour interval is 60 m., and the source is the NCEP 20th Century re-analyses.

Pacific Ocean basin (*e.g.*, Quiroz 1984; Lupo, Kelsey, *et al.* 2008b), the occurrence of blocking for December 1889 and March 2012 demonstrated there were no blocking events in the Pacific Region basin. Fall 1889 had to be analyzed separately using the Wiedenmann *et al.* (2002) methodology and 500 hPa height fields available from the twentieth-century reanalyses (see earlier). In March 2012, a very strong zonal pattern dominated the Northern Hemisphere (positive Arctic Oscillation [AO]; see http://www.cpc.ncep.noaa.gov/products/precip/CWlink/daily_ao_index/ao.shtml). Just as found for the precursor surface records, however, there was no indication that there was more or less Pacific Region blocking than usual in the three months prior over the Pacific Region. Typically, in the fall (September–November) there are one to two blocking events per year, and two were observed in 1889 over the Pacific, whereas for winter 2011–2012 (December–February), three events are typical and three were observed. The only similarity in the precursor conditions was that both years were characterized as La Niña (December 1889) or cold neutral Pacific Region SST anomalies (March 2012; see http://coaps.fsu.edu).

Additionally, there have been eight warm extremes in the cUSA since July 1968 and during only one of these months did blocking occur over the Pacific Ocean basin (one event; see the MU blocking archive). In contrast, during the sixteen extreme cold months, blocking occurred during ten months for a total of fourteen atmospheric blocking events (some months were associated with two events). These blocking events persisted for an average of 7.6 days, and their intensity was classified as typical for the winter season (3.50) using the Block Intensity (BI) Index

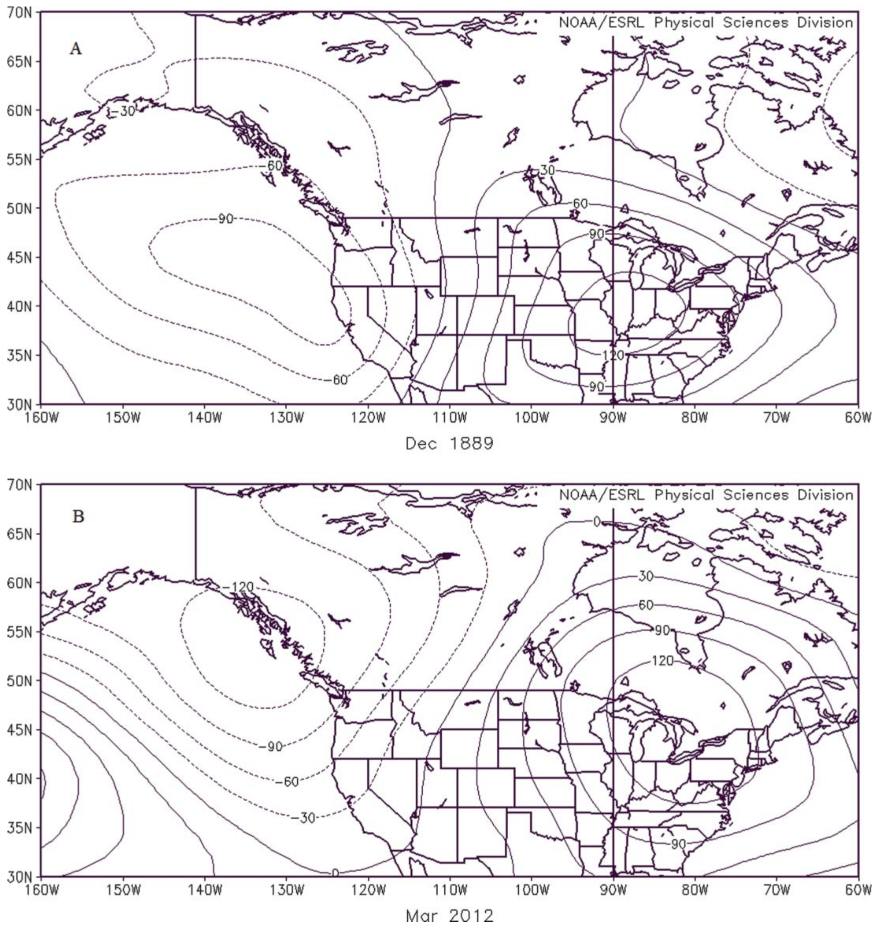

Figure 6. As in Fig. 5, except for the 500 hPa height anomalies (m), and a contour interval of 30 m.

of Wiedenmann *et al.* (2002). In swRUS, during the same time period there were ten extremely cold months and all ten were associated with atmospheric blocking in the Atlantic sector upstream. There were a total of fifteen blocking events associated with the cold months. The blocking events persisted for 11.2 days and were associated with a mean BI of 3.78. There were nineteen extreme warm months in the swRUS region, and eighteen of these warm months were associated with blocking either over the swRUS region or downstream. During these eighteen months, there were thirty-two blocking events. These events persisted for 9.2 days with a BI of 2.76. Although the values are typical for the primary season in which blocking occurred, the cold extremes were associated with longer lasting and stronger blocking events.

Summary and conclusions

A study of the occurrence of extremely warm, cold, wet, and dry months for extended time series of temperature and precipitation data for the cUSA and swRUS regions showed that in both regions there was no general tendency toward the occurrence of warm versus cold anomalies, beyond what would be expected randomly. Whereas the strongest raw temperature anomalies occurred during the winter months, the strongest normalized anomalies occurred during the transition seasons in both regions. Additionally, there were no long-term trends in the preference of warm or cold anomalies with time in the cUSA, but for swRUS cold anomalies occurred preferentially before 1990 and warm anomalies preferentially after this year. Both results are consistent with the strength of long-term temperature trends.

The long-term variability showed no statistically significant interdecadal variability in temperature or precipitation, but there was strong variability associated with precipitation and the PDO in the cUSA. With respect to ENSO, there was a tendency toward the more frequent occurrence of extreme temperature anomalies was during El Niño and neutral years in the cUSA, but during El Niño and La Niña in swRUS. For precipitation, neutral years (neutral and El Niño) were far more likely to feature precipitation extremes.

The case studies demonstrated anomalous ridging over much of the eastern United States, while there was no Pacific Region blocking during either month. Both anomalies were of similar magnitude and extent. Neither warm anomaly was accompanied by a consistent precursor signal three months in advance. In examining the association of extremes with upstream blocking, during extremely warm (cold) months, the occurrence of blocking is suppressed (enhanced) in the cUSA. These blocking events were typical of the region in terms of persistence and intensity. In swRUS, there were twenty-nine extremely warm or cold months since 1968, and nearly every one of these was associated with blocking. In the case of cold (warm) months, blocking occurred upstream (over or downstream) of the region.

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Appendix A

The decadal count of extreme warm and cold anomalies for the cUSA and swRUS. Note that for the cUSA the 1890s included the one extreme warm month from 1889 and the 2010s only contains information up to 2014. For swRUS the 1940s began with 1944.

	cUSA			swRUS		
Decade	Cold	Warm	Total	Cold	Warm	Total
1890	2	5	7			
1900	7	4	11			
1910	8	5	13			
1920	5	1	6			
1930	1	13	14			
1940	2	4	6	1	1	2
1950	3	5	8	10	0	10
1960	3	2	5	2	0	2
1970	6	0	6	3	3	6
1980	5	1	6	3	1	4
1990	1	1	2	3	4	7
2000	3	4	7	1	6	7
2010	0	2	2	0	7	7
Total	46	47	93	23	22	45

Appendix B

As in Appendix A. There were no wet or dry anomalies in 1889 for the cUSA.

	cUSA			swRUS		
Decade	Wet	Dry	Total	Wet	Dry	Total
1890	4	1	5			
1900	1	5	6			
1910	1	4	5			
1920	5	0	5			
1930	1	3	4			
1940	4	3	7	2	5	7
1950	1	7	8	2	4	6
1960	1	3	4	5	2	7
1970	1	3	4	4	3	7
1980	7	2	9	7	2	9
1990	5	2	7	2	3	5
2000	4	2	6	1	2	3
2010	1	1	2	1	3	4
Total	36	36	72	24	24	48