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The winter of 1827–1828 over eastern North America: a season of extraordinary climatic anomalies, societal impacts, and false spring

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Abstract This study reconstructed the weather and its impacts on society for the winter of 1827–1828, focusing on the eastern United States. Data comprise of daily and monthly instrumental records, diaries with both daily and seasonal resolution, newspapers, fur trapper accounts, and tree-rings. Temperature anomalies were calculated and mapped based on the means during the 1820–1840 period to account for different fixed observation times. Precipitation frequencies provided direct comparisons of the 1827–1828 weather with modern climatic normals. Daily plots of temperature also reveal weather variations at daily time-frames. Results indicate that the eastern United States experienced strong positive temperature anomalies that are among the most extreme known in the historical record, particularly its large spatial extent. In contrast, historical evidence reveals strong negative temperature anomalies over northwestern North America, and positive temperature anomalies are evident for coastal Alaska. These temperature anomaly patterns sharply contrast to what is normally experienced during a warm El Niño event. Furthermore, results clearly describe remarkable climatic impacts in the Southeast U.S., including widespread blossoming of fruit trees in mid-winter (false spring) that led to a widespread severe killing frost in early April of 1828. Widespread positive precipitation frequency anomalies are also evident for much of the Southeast U.S., which also played a prominent role on winter vegetation growth. Other weather events and impacts include unusual opening of river traffic in winter in New England, severe flooding in the Mississippi River Valley, and heavy snowfall in northwestern North America.

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1 Introduction

Climatic extremes of particular years at seasonal and intra-annual resolution are responsible for significant economic losses in modern and historical civilizations. Such extremes include individual years of extreme drought and heat waves (e.g., Kalkstein 1998), extremes of El Niño or La Niña (Changnon et al. 2000), extreme fire years (Kitzberger et al. 2001), cold air outbreaks and killing frosts (Attaway 1997; Kunkel et al. 2004), and flooding events at shorter timescales (Hirschboeck 1991). Society may not properly prepare for extreme climatic events if planning schemes are based on the past 100 years, as the modern climate record is too short to encompass the full range of climatic extremes that may occur (Stockton 1990). Harmful climatic impacts in the future may also be significantly enhanced if such climatic extremes become more frequent (Karl et al. 1996).

Furthermore, little attention has been focused on climatic extremes of the past. During the colonial and antebellum periods of eastern North America from approximately 1700–1860, societies undoubtedly were quite sensitive to climatic extremes. Widespread belief of the constant latitude climate myth and ideas of climate determinism during much of this period illustrates that societies in the pre-modern era knew little on the range of climatic extremes that could occur, which include more frequent colder winters on the North American continent as compared to Europe (Kupperman 1982, 1984; Koeniger 1988; Stewart 1997). Abnormally warmer winters also occurred in the past, though these events have received less attention (Ludlum 1968).

Documentary and early instrumental data can be used to accurately reconstruct climatic extremes and hazards at daily to decadal timescales when properly screened for data reliability and carefully analyzed in terms of the climate signal (e.g., Mock 1991; Chenoweth 1996). The winter of 1827–1828 is a classic example of a climatic extreme that is considered ‘unprecedented’ when considering only the modern twentieth century climate record alone. David Ludlum summarizes the meteorological aspects of this winter as follows (Ludlum 1968, p. 97):

> The winter season of 1827–1828, or more truly the lack of it, constituted an outstanding event in the meteorological history of the eastern half of the United States. No other winter in our period was so warm. The wide geographical extent and the unbroken duration of the warmth appeared to be unique in the American experience.

We expand much further here on reconstructing the weather during the winter of 1827–1828 for North America, with an emphasis on the Southeast United States (U.S.) We focused on these aspects because (1) much of the eastern United States, particularly the Southeast U.S., experienced a widespread warm winter subsequently followed by a widespread killing frost (“false spring”) with such an impact that has never been experienced in the twentieth century (Ludlum 1968; Ehrhardt 1990); (2) the Southeast U.S. may have experienced widespread wetness that contributed to “false spring” conditions; (3) the meteorological impacts on society were clearly quite diverse, prominent, and not considered much in the American historical climate impacts literature (e.g., Baron 1989); (4) 1827–1828 has been categorized as a “very strong” El Niño event (Quinn 1992), comparable with the very strong events of 1877–1878, 1982–1983, and 1997–1998; and (5) a unique network of ample tree-ring, documentary, and early instrumental data are available to reconstruct the meteorology of the Southeast U.S. in detail to supplement previous studies for the Northeast U.S. (Ludlum 1968).

2 Data and study area

2.1 The study area

The primary focus of the study is on the region bounded by the 98th meridian to the west, the U.S./Canadian border to the north, the Atlantic coast to the east, and the U.S. Gulf coast to the south (Fig. 1; Table 1). The 98th meridian was chosen in order to include several instrumental weather stations and some documentary records that existed west of the Missouri River during the winter of 1827–1828. Mapping of spatial weather anomalies is possible for this bounded region; however, our study also examined some available early instrumental and documentary weather data for parts of western North American to assess potential continental-scale weather patterns and controls.

Fig. 1 Map of station locations and selected diarists for the study. Please refer to Table 1 for abbreviations

Table 1 Locations of meteorological stations and selected diarists that provided detailed daily weather information for the winter of 1827–1828

Location identification	Station or diarist
1	Alexandria, VA
2	Augusta, GA
3	Boston, MA
4	Charleston, SC
5	Cincinnati, OH
6	Concord, NH
7	Cumberland House, Manitoba, Canada
8	Fort Armstrong, IL
9	Fort Brady, MI
10	Fort Brooke FL
11	Fort Chipewyan, Alberta, Canada
12	Fort Clinch, FL
13	Fort Constitution, CT
14	Fort Crawford, WI
15	Fort Gibson, OKL
16	Fort Howard, WI
17	Fort Independence, MA
18	Fort Jesup, LA
19	Fort Johnston, NC
20	Fort Mackinac, MI
21	Fort Marion, FL
22	Fort McHenry, MD
23	Fort Monroe, VA
24	Fort Moultrie, SC
25	Fort Pike, LA
26	Fort Preble, ME
27	Fort Severn, MD
28	Fort Snelling, MN
29	Fort Sullivan, ME
30	Fort Towson, OKL
31	Fort Washington, MD
32	Fort Wolcott, RI
33	Halifax, Nova Scotia, Canada
34	Huntsville, AL
35	Illoolook, AK (7 years)
36	Jefferson Barracks, MO
37	Montreal, Quebec, Canada
38	Nashville, TN
39	Nassau, Bahamas
40	Natchez, MS
41	New Bedford, MA
42	New Orleans, LA
43	Newport, RI
44	Newport Barracks, KY
45	Philadelphia, PA
46	Pittsfield, MA
47	Savannah, GA
48	Sitka, AK

(*Continued on next page*)

Table 1 (*Continued*)

Location identification	Station or diarist
49	Washington, DC
50	Wilmington, DE
51	York Factory, Manitoba
a	Albany, NY
b	Auburn, NY
c	Cambridge Washington, NY
d	Canandaigua, NY
e	Cherry Valley, NY
f	Clinton, NY
g	Dutchess, NY
h	Erasmus Hall, NY
i	Fort Columbus, NY
j	Lasinburgh, NY
k	Middlebury, NY
l	Montgomery, NY
m	Newburgh, NY
n	Onandaga, NY
o	Pompey, NY
p	St Lawrence, NY
q	Union Hall, NY
r	Utica, NY
s	Watervliet, NY
t	West Point, NY
B	William Bartell, northeast SC (Bartell 1978)
H	Hughes Diary, Richmond VA (Hughes Family 1819–1837)
JW	Joshua Whitman, North Turner ME (*Maine Farmer* 1840)
LH	Leonard Hill, Bridgewater MA (Hill 1969)
M	D.T. Merritt, Halifax County VA (Merritt 1820–1866)
RM	Robert McGuire, Monroe LA (McGuire 1818–1852)
S	Shirley Plantation, VA (Shirley Plantation Collection 1993)
T	John Peyre Thomas, Santee River, SC (Thomas 1827–1857)
TH	Thomas Hazard, Kingston RI (Hazard 1930)
WC	William Clark, St. Louis MO (Clark 1940)
WN	William Nevitt, Natchez MS (Nevitt 1827–1832)

Diarists are represented in capital letters. Please refer to Fig. 1 for specific location

2.2 Instrumental data

The U.S. Army Surgeon General recorded daily instrumental meteorological data beginning around 1819, continuing to the late nineteenth century (Lawson 1855; Darter 1942; Fleming 1990). Seventy-two stations were in operation during 1828, mostly encompassing the region east of the Mississippi River (Fig. 1, Table 1). The weather variables reported include temperature, prevalent wind direction, and descriptive weather conditions. The U.S. Army Surgeon General data also included wind speed on a numerical scale from 0–10, with 0 indicating calm conditions and 10 indicating a violent hurricane. Cloudiness also followed a numerical scale from 0–10, with 10 indicating overcast conditions (Lawson 1855). Additional daily instrumental weather data were recorded in New York by the NY Academy Network (Hough 1855, 1872), as well as by some medical organizations such as the Charleston Board of

Health (Aldredge 1940), and by some private weather enthusiasts (Fleming 1990). Precipitation records were rare prior to 1836, with less than ten stations outside of New York state operating in 1828.

These early instrumental data were carefully screened for data quality (Baron 1989; Chenoweth 1993). Temperature data problems include different routine fixed observation times that affected the compatibility with modern data (Mitchell 1958), and by different thermometer exposure situations involving azimuth, shelters, and building material (Chenoweth 1992, 1993). Precipitation data problems include the conversion of snowfall to liquid, some high placements of rainfall gauges (e.g., eight feet high and rooftop) that caused lower liquid accumulation due to increasing wind speeds (Sevruk 1987), and gaps in time (sometimes several days or more) when precipitation gauges were actually measured that may result in evaporative loss of water. This underestimation of precipitation generally is more apparent in cold-season precipitation (Mock 2000). Other problems concerning the accuracy of nineteenth century precipitation records include changes in the environment surrounding precipitation gauges and in instrumentation (Peterson et al. 1998).

2.3 Documentary records

Instrumental weather records during 1827–1828 can be supplemented temporally and spatially with exactly-dated documentary records such as diaries, ship logbooks, annals, and newspapers (Ludlum 1968; Baron 1989). Daily documentary records provide the highest resolution of all the paleoclimatic proxy data types, enabling the construction of daily weather maps in some cases (Kington 1988; Wilson 1992). The richest daily records of documentary data enabled the expression of precipitation into frequencies instead of magnitudes. The precipitation frequency reconstructions can often be directly compared with modern climatic data (Mock 1991). Precipitation frequencies may also more accurately reflect homogeneous responses to synoptic-scale atmospheric circulation (Woodhouse and Meko 1997).

The bulk of the daily manuscripts analyzed in this study are plantation diaries and journals of the American South, since the farmers' lifestyle was very much related to time and space of weather events. Because plantations were a commercial enterprise, careful daily record-keeping was essential, providing detailed direct daily weather information for some geographic areas devoid of instrumental records (Stewart 1997). Original sources were consulted as much as possible because typescripts can provide erroneous edited information. Southern archives visited by the authors include the Library of Congress, the University of Virginia Library, College of William and Mary, Virginia Historical Society, Colonial Williamsburg Foundation, South Caroliniana Library, South Carolina Historical Society, the Waring Historical Library in Charleston SC, the Hill Memorial Library at Louisiana State University, the University of Arkansas Mullins Library, the Georgia Historical Society, the University of Georgia Hargrett and Manuscript Rare Book Library, the Howard-Tilton Library at Tulane University, the P.K. Yonge Library at the University of Florida, the Tennessee State Library, the Southern Historical Collection at the University of North Carolina, and Duke University. The authors also retrieved some daily documentary weather information from twenty-one diaries (excluding verbal weather information in instrumental records), though just twelve of them are regarded as providing constantly detailed information on a daily basis (Table 1).

Newspapers provided very detailed verbal weather descriptions, but most information was generally related to extreme daily weather events and generalized weather over the course of the last week or month. Newspapers also provided useful information on the rising and falling levels of rivers, phenological descriptions, and weather impacts on society.

Sometimes, sufficient time elapsed from the weather event to the time that it was published in the newspapers, particularly as related to letters and news contributed by citizens living in rural areas. Most newspapers had a section on the "agricultural news" that sometimes dedicated weather information from states throughout the eastern United States. This study utilized information from forty-one different newspapers that covered the eastern United States. Typically, each newspaper provided from three to about a dozen different descriptions of weather during the winter.

2.4 Tree-ring data

A widespread network of tree-ring chronologies is now available for most of North America, including data from over 850 locations all of which date earlier than 1828 (Cook et al. 2004). This ring-width chronology network is based on exactly-dated core samples and cross sections from several species (Stahle et al. 2004), most of which are sensitive in part to precipitation. Severe subfreezing temperatures during the period of active cambial division are also recorded as frost damaged rings, including the bristlecone pine record of early-season frosts (fall) in the Great Basin and Rocky Mountains which has been linked to the worldwide chronology of explosive volcanic eruptions (LaMarche and Hirschboeck 1984) and to nineteenth century environmental extremes in the western U.S. by Brunstein (1996). Frost rings can be recognized by unique anatomical features, which have been shown empirically and experimentally to arise from subfreezing temperatures during the growing season (i.e., generally $\leq$–5.0 °C; Stahle 1990). Deciduous white oak (*Quercus alba* and *Q. stellata*) chronologies in the south-central and southeast U.S. record late season (spring) freeze events, which have been particularly prevalent over the southern Great Plains region (Stahle 1990). These springtime freeze events are often referred to as "false spring," and are often preceded by abnormally warm conditions during the late winter and early spring (e.g., Ludlum 1968). These mild conditions are then abruptly terminated by the late outbreak of a cold air mass with severe subfreezing temperatures. The anatomical features of frost rings in deciduous white oaks include, lunate vessels (collapsed by freezing of extra-cellular water), disrupted rays, abnormal parenchyma, all set in a discolored zone or lesion, typically during the onset of growth in the earlywood component of the annual ring (Stahle 1990).

A chronology of 70 frost ring/false spring event episodes has been compiled for the south-central United States (Stahle 1990; Stahle and Cleaveland 1995), and has recently been supplemented with frost ring data from red oak (*Q. rubra*) trees in the southern Appalachians and chinkapin oak (*Q. muhlenbergii*) from the Guadalupe Mountains of west Texas and southern New Mexico. Together these various oak records indicate 85 separate false spring events over the past 400 years extending from the southern Rockies to the southern Appalachians, including widespread tree-ring evidence for the intense false spring episode of 1827–1828.

3 Methodology

3.1 Temperature

Almost all instrumental meteorological observations of temperature were based on fixed observation times during 1827–1828. This differs from routine practices conducted since the late nineteenth century that record maximum and minimum daily temperatures (Darter 1942). Furthermore, fixed observation times differed between stations and different networks. For example, the U.S. Army Surgeon General network's monthly temperatures often based their

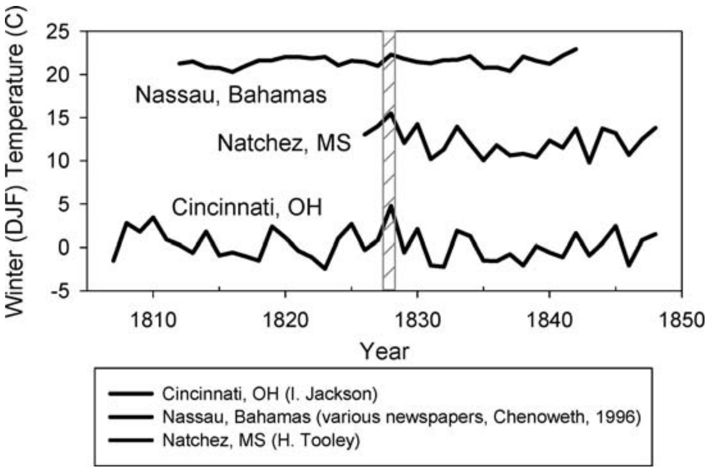


Fig. 2 Winter (December–February) temperature trends for Natchez MS, Nassau Bahamas, and Cincinnati OH covering the timeframe from 1807–1849

observations at 7 am, 2 pm, and 9 pm (Lawson 1855); This differs from those by the New York Academies Network's temperature observations based at before sunrise, 3 pm, and an hour after sunset (Hough 1855). Additional records differed as well, such as those at Huntsville, Alabama (based on generally early morning, 2 pm, and evening), Nassau, Bahamas (8 am, noon, and 3 pm), and the Charleston Board of Health, South Carolina (9 am, noon, and 3 pm). Only a very small number of stations during 1828 operated near the locations of modern-day stations, thus adding the uncertainty of mesoscale geographic variations in the assessment of historical temperature anomalies.

Therefore, the most accurate method readily available was to compute monthly temperature anomalies as deviations from temperature averages of each station within the period from 1820–1840. This period was chosen because it encompasses the timeframe of common overlap for the bulk of the instrumental records used in the study. This method preserves the aspects of fixed temperature observations as well as the routines of data observations at each station, enabling the assessment of reliable spatial and temporal patterns (Chenoweth 2001). This aspect is illustrated graphically from Cincinnati, Ohio; Nassau, Bahamas; and Natchez, Mississippi (Fig. 2). All three stations reveal the extraordinary high temperatures for the winter of 1827–1828 relative to other years in the early nineteenth century. Temperature anomalies for each month from December 1827–April 1828, as well as seasonal (winter) December–March anomalies, were computed for stations with at least 15 years of data within 1820–1840 with the same fixed observation times. These anomalies were mapped to assess geographical temperature variations across eastern North America.

Some detailed documentary data such as plantation diaries and newspapers cover timeframes typically ranging from about 5 years up to 40 years. These materials offer a qualitative assessment of temperature anomalies. A content analysis was done on monthly and seasonal aspects of these long-term documentary records. This method has been used to reconstruct past climate (Baron 1982; Kastellet et al. 1998). Content analysis critically examines the vocabulary of the historical records and categorizes these records. Data incorporated in the content analysis also includes temperature-related natural phenomena, such as phenology and other impacts. Although individual biases from personal experience affected opinions and perceptions of weather among different diarists, this content analysis procedure still identified the prominent anomalies for 1827–1828 as compared to other years since the warmth was so pronounced. A content analysis was only done on historical phrases specific to monthly and seasonal aspects. It is important not to confuse these historical phrases with daily data, which may represent different meteorological phenomena that occurred on short timeframes. The content analysis categorized qualitative temperature observations into three categories: above normal, normal, and below normal. These results were incorporated on the temperature anomaly maps.

The assessment of daily to weekly weather variations within the winter of 1827–1828 is also vital to assess the persistence of temperature anomalies, as well as determine how these weather variations impacted society. Daily morning and afternoon temperatures were plotted seasonally for each station, with corresponding fixed hourly modern daily averages were incorporated when possible. Documentary data were also closely examined in conjunction with the daily instrumental data, as they provided clues on how the environment and society responded to weather (e.g., frosts, rising river from melting snowpack).

3.2 Precipitation

Precipitation frequencies from both early instrumental and documentary evidence are among the most reliable and plentiful climatic indicators for the historical climatologist, as these reconstructions can often be directly compared with modern climatic data and reflect synoptic-scale features. This aspect is particularly important for the winter of 1827–1828, as few stations recorded instrumental precipitation amounts. However, the reconstruction of precipitation frequency is not straightforward, as often observers under-recorded the number of rain days in a given month and season. Observers may not have noted nighttime precipitation, or they may have been insensitive to light precipitation events. Thus, a reliable precipitation frequency reconstruction must rely heavily on diarists who were sensitive to weather (including rainfall) on an everyday basis, and recorded precipitation and cloudiness conditions at least several times each day.

In this method of precipitation frequency reconstruction, modern analog stations were sought close to the historical stations that most likely had reliable rain day counts during 1827–1828 in the eastern United States (Fig. 1). The modern data were taken from two networks covering the period 1948–1999: the U.S. Hourly Precipitation Network and the National Weather Service's Cooperative (COOP) network. The latter consists of stations that have only one observation time per day and may have some underestimation of rain days due to aspects such as the evaporation of liquid. Thus, the U.S. Hourly Data were preferred if available. The definition of a rain day was defined as any day with precipitation amount equal or greater than 0.01 inches (0.0252 cm). Reconstructed precipitation frequencies for 1827–1828 were compared to the modern climatic normals. We also conducted a similar analysis but for snow days on the diary of Peter Skene Ogden (1971), who was based in southeastern Idaho near present-day Pocatello. Ogden and his party of fur trappers were encamped within a very small area during virtually the entire winter of 1827–1828, and this situation offered a unique opportunity in snow frequency reconstruction (Mock 1989).

3.3 The April 1828 killing frost event

Instrumental and documentary data were also used to reconstruct the spatial extent of the great killing freeze of April 1828 over the Southeast U.S. These impacts of the killing frost are not as clearly apparent for the Northeast U.S., thus we focused exclusively on the Southeast

U.S. given the available data and because widespread April killing freezes in the Deep South are very unusual (Parnell 2005). The particularly warm winter made this abnormal freeze event extremely detrimental by enabling the "false spring" conditions to occur in the winter season. As instrumental records were based on fixed observation times (e.g., 7 am), any report of subfreezing temperatures would be very high conservative estimates of daily minimum temperature. Careful attention was given to the documentary data to assure that such descriptions of frosts were very likely reflective of air temperatures at or below 0 °C (32 °F). Plantation diaries and newspapers provided the bulk of the frost descriptions. However, some descriptions at times may refer to frost conditions when crops may appear in the form of "frost-type damage", but may not actually always respond to frosts directly. Thus, we discriminated verbal descriptions of 'killing frosts and 'white frosts'. The "killing frost aspect", dealt with the widespread killing of several types of crops. Most likely, a widespread killing frost of corn, for example, reflects minimum air temperatures that are likely well below freezing temperature (Baron and Smith 1996). The following description at Huntsville, Alabama, describes a typical example of a killing frost that occurred in early April 1828 (American Farmer 1828):

> On the nights of the 5th and 6th instant we had a freeze and frost here that has destroyed our gardens; and what is uncommon, the peas in the gardens are entirely killed. Our corn that has been planted the 1st of March, and of some growing size, was killed into the ground; the wheat was in a common way, about eighteen inches high, it is killed to the root; I had one hundred and sixty acres sowed. All the fruit entirely killed that had bloomed. I discover a part of my apples not bloomed, and some few of the plum kind, such as the damson and other late plums and cherries. The ground was frozen three or four inches deep, and we had ice an inch thick. Such cold weather was never felt in Alabama in April.

All of the evidence indicating a frost from both the tree-ring, instrumental, and documentary data were combined together, with presence of subfreezing temperatures from instrumental data, and frosts from documentary evidence plotted at the regional scale for the American Southeast. Tree-ring results were also plotted on the map, using a presence/absence criteria of frost ring damage.

4 Results

4.1 Temperature and moisture conditions over northeastern North America

Temperature anomaly maps indicate widespread and persistent positive anomalies for most of the winter of 1827–1828, particularly during January to March (Fig. 3, April map is not shown, as it does not exhibit the positive anomalies as clearly as the winter months). Magnitudes of the positive anomalies during January and February of 1828 mostly exceed 4 °C, which is comparable with magnitudes of extreme winter events such as the cold winter months of 1976–1977 (Wagner 1977). Ludlum (1968) also described that no other period in the nineteenth century appeared to be this warm. Watson (1857) summarized the conditions of this abnormally warm winter for Pennsylvania.

> This winter of 1827–1828 is remarkable for its mildness – no snow, or frost, and the plough enabled to cut the furrows! mild rains every where instead of snows. The gazettes every where teem with notices of the unusual mild weather. Even boats, in January, are

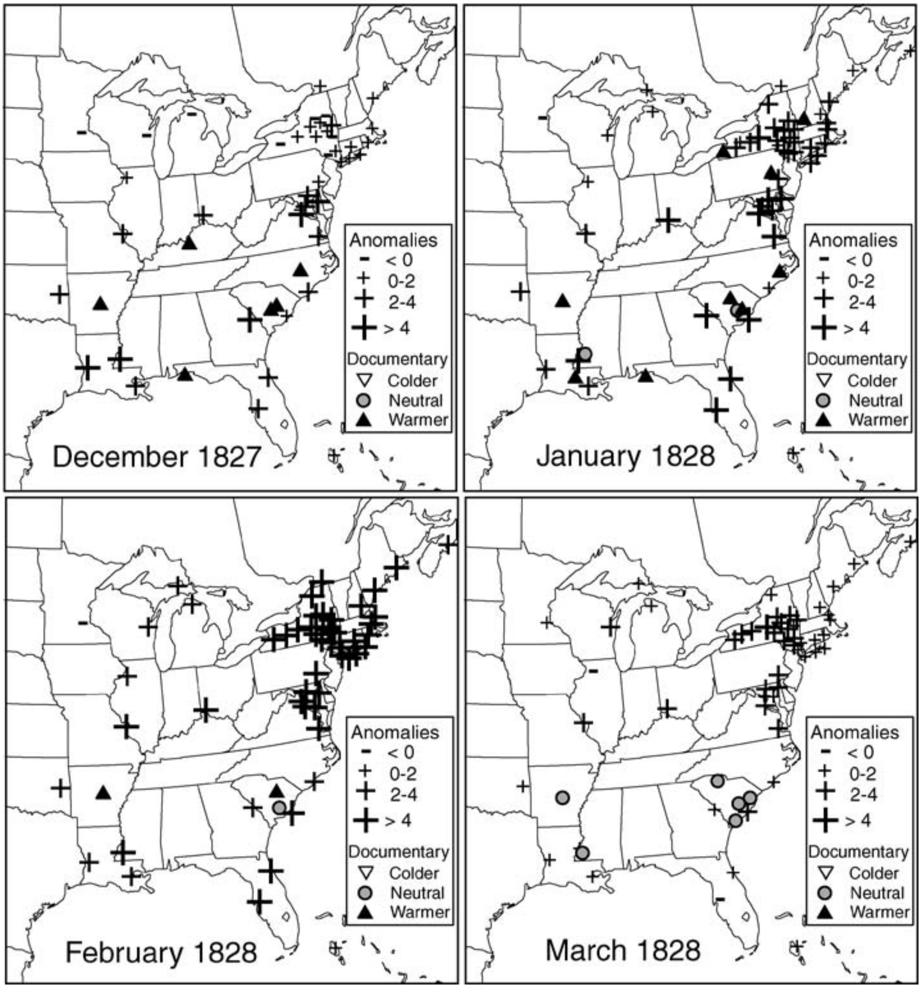


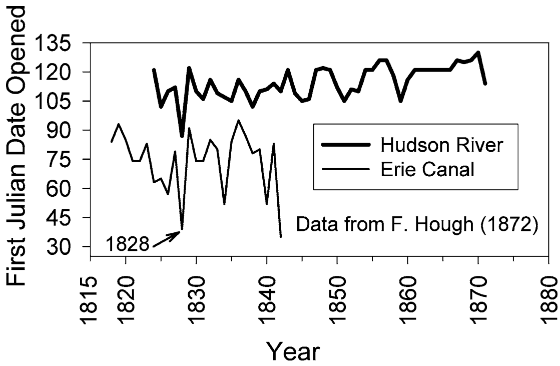
Fig. 3 Temperature anomalies for the winter of 1827–1828 for eastern North America for each winter month, based on the means of the 1820–1840 reference period. Anomalies are in degrees Celsius, and the documentary data are in relative terms

> descending the Susquehanna from as far as the Bald Eagle! Even as late as the 7th of February, it is stated from the Juniata that arks were still passing down that river, and that this is the first winter ever known that the river has continued clear of ice! On the 9th of February a shad, caught near Bombay hook, was bought in the Philadelphia market for the Mansion-house hotel. This, so far, has been the rainy winter. The mildness of the winter prevented the usual storing of ice for the fish markets, &c. – a thing unprecedented.

The warm winter's impact was also felt outside the Northeast U.S., as recorded in the *Daily National Intelligencer* (1828) on March 20.

> *Ice.* – The remarkable winter which we have had, has produced a curious state of things. We are told, says the Boston Palladium, that the supplies of ice for Martinique, St.

Fig. 4 Time series plot of first dates annually when the Erie Canal and Hudson River opened due it being free of ice, covering the period from 1818–1871. Data are from Hough (1872)



> Thomas, and Havana, have been shipped; and also for all the Southern part of the United States, New Orleans, Charleston, Savannah, and as far North as North Carolina. But North of Wilmington, including all the towns and cities as far as Providence, the supplies have almost totally failed.

Time series of the first Julian date of the opening of the Erie Canal, New York, are available from 1871 back to around 1818, with similar data for the nearby Hudson River back to 1824 (Hough 1872). The opening dates are indicative of winter ice severity in the rivers. The dates on these New York rivers reveal the extraordinarily unusual early opening of the canals in the winter and spring of 1828 (Fig. 4). However, some ships even defied these early Julian dates for the region, as indicated in the following descriptions from the *Albany Argus* (1828) on January 8 and 19 respectively:

> We learn that the steam-boat Olive Branen came up on Saturday as far as Athens. Should the weather continue as mild as it is present, the river will be in a day or two as clear of ice every where as it is now here. A vessel will leave our wharves this morning for New York.

> *The Navigation.* – The steam-boat Saratoga, Capt. Pierce, arrived yesterday from New York, and returns this morning. The river is now free from ice, and the weather favorable to a continuance of the navigation.

Plots of daily temperature data reveal that although a few cold air outbreaks occurred in the winter of 1827–1828, such as toward the end of January at Auburn, New York and Washington, D.C. (Figs. 5 and 6), no sustained period of subfreezing conditions is clearly evident. This is in contrast with the Midwest U.S., particularly from Fort Snelling, Minnesota, where temperatures in early winter indicate more influence from colder air masses (Fig. 5). Diarists and meteorological observers in the Northeast U.S. generally did not write of severe winter storms, but it appears that snowfall and snow depth was likely somewhat below average as compared to early nineteenth century standards. A thirty-year weather record kept by Joshua Whitman, of North Turner in Maine (Maine Farmer 1840), reveals that the number of snow days in 1827–1828 was about average, but winter snow depth was somewhat below the lower 25th percentile with respect to his entire record due to the widespread and persistent warmth of that winter (Table 2). Precipitation frequency counts from diarists in Kingston, Rhode Island and Bridgewater, Massachusetts also reveal similar aspects of a somewhat dry but generally normal winter (Table 2). The meager snow amounts seem to have been more severe towards the mid-Atlantic states. A weather observer at Washington, D.C. recorded

Table 2 Selected descriptive statistics for North Turner ME (Maine Farmer 1840), Kingston RI (Hazard 1930), and Bridgewater MA (Hill 1869) for winter (December–March of 1827–1828)

Location and variable	Period and sample size	Q1/Median/Q3	Winter 1827–1828
North Turner ME, snow days	1811–1840, 30 years	42.75/47.50/50.25	48
North Turner ME, Average winter snow depth (cm)	1813–1840, 28 years	38.90/46.43/53/50	36.51
Kingston, RI precip. days	1779–1840, 55 years	31/37/41	38
Bridgewater, MA precip. days	1807–1869, 63 years	31/36/41	31

Q1 and Q3 represent the 25th and 75th percentile thresholds

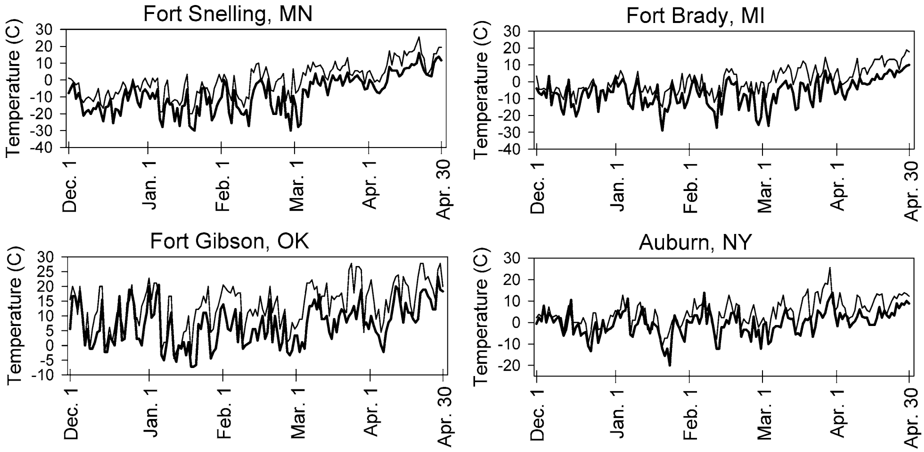


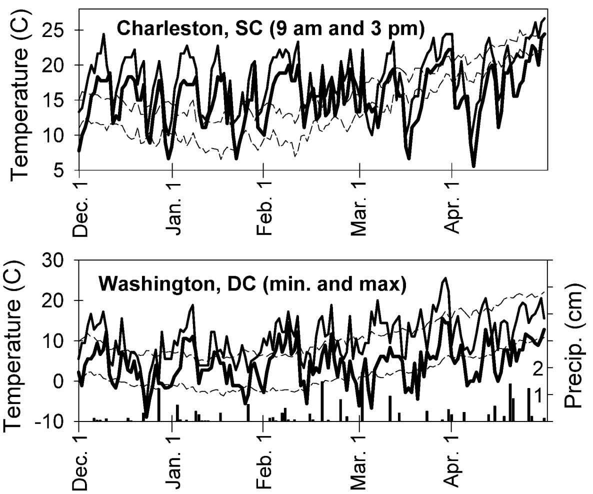
Fig. 5 Daily temperature graphs (morning and afternoon) for selected stations in the Central and Northeast U.S. for the winter of 1827–1828. The bolder line represents early morning temperatures

only one noticeable snow day (December 22, 0.25 inches of water) in mid-winter. When this low number is combined with a small sleet that occurred in early April, its snowfall total for the season of 1827–1828 likely ranks among the lowest ever recorded for the area.

4.2 Temperatures over the American Southeast

Early instrumental data, supplemented by documentary data, illustrate that positive temperature anomalies were prevalent throughout the Southeast U.S. from December 1827 to February 1828 (Fig. 3). No such warm winter of this magnitude spatially has occurred since that time (Stahle 1990; Parnell 2005). December anomalies are generally quite strong over 4 °C, and this is not evident in the Northeast U.S. Analyses of daily temperature trends from Charleston, South Carolina indicate temperatures continuously above the ranges of modern daily normals, stronger than those as illustrated by the record from Washington, D.C. (Fig. 6). Some days from selected locations (e.g., Charleston, Nashville, Fort Jessup) are characterized with afternoon temperatures of around 25 °C (mid 70 s °F), which is very unusual in mid-winter (Fig. 7). Numerous plantation diaries comment on the extreme warmth. John Peyre Thomas (1827–1857) of eastern South Carolina, for example, felt it was quite unusual on January 4, 1828 that it was "Clear & quite warm, we sit the whole morning without a fire. . . Thermometer was 79° at 4 oclock P.M."

Fig. 6 Daily temperature graphs for Charleston, SC and Washington, D.C. The thin lines represent the daily normal ranges of diurnal temperature variability from daily and hourly modern data (1961–1995). The darkest black line represents early morning temperatures, and the top dark line represents early-mid afternoon temperatures



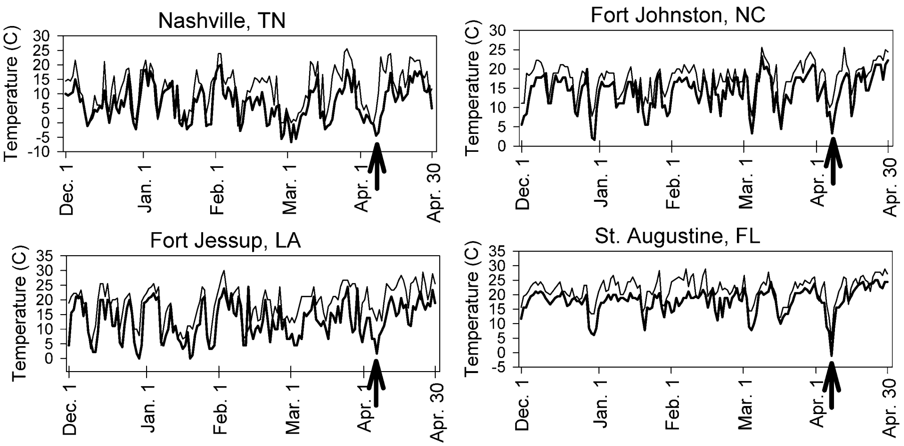


Fig. 7 Daily temperature graphs (morning and afternoon) for selected stations in the Southeast U.S. for the winter of 1827–1828. The bolder line represents early morning temperatures. The thick arrows depict the early April killing frost event

Although the instrumental data network for the Southeast U.S. emphasizes the Gulf and Atlantic coasts, more descriptions from documentary evidence in the interior clearly indicate the presence of abnormal warm winter temperatures and associated impacts. Undoubtedly, the warm weather was very conducive to the growth of luxuriant vegetation and agricultural crops that normally would not thrive long or blossom in the winter season. The following is a summary from the *Pensacola Gazette and West Florida Advertiser* (1828), dated January 11, 1828.

> *The Weather.* – If we may judge from the weather and the appearances of vegetation this is not Winter. Roses have been in full bloom here during the whole month of December-the trees are all budding and the weather is uncomfortably warm for winter clothing. Within the last ten days the thermometer has been as high as 75. We had no severe frost until the night of the 28th ult., and since the 1st inst. there has been no appearance

> of cold. On the 1st of January, a large watermelon which had grown in an open field without any protection from the weather was eaten in this City!

The *Village Messenger* (1828) from Fayetteville, Tennessee, provided a summary of this abnormal warm winter on March 14, 1828, though a bit affected as well from the wet conditions.

> The winter is more than half gone, and there has not been a winter's day since the 1st of Dec. The oldest do not remember a winter so mild an[d] the superstitious, (among whom we beg to be registered, being satisfied to keep company with the Johnson and Littletons), are looking out for convulsions in the natural and moral world, as the proper succession to so unprecedented in state of weather. The hyacinth which never blooms before the middle of February, blossomed in this place, before the middle of January-the peach is slightly in bloom, which seldom blooms before the 1st March. Roses have bloomed in Wheeling, and green peas reared in open air, have been gathered in Charleston, South Carolina, in January. Nature seems to have determined to supply the usual quantum of cold, by an extra supply of moisture. It has been raining, with but few days intermission since the 1st Dec.-at least it has not been shining. Mr. Jefferson estimated in a series of experiments, the average quantity of rain, one year with another in Virginia, at 47 inches-The Wheeling Gazette conjectures that five feet of rain have fallen at that place within 3 months, & we believe the quantity has been quite as excessive over the general average, here. All have made up their minds not to expect fruit this year.

The *Georgia Messenger* (1828, Macon, Georgia) described that "fresh shad were a rich commodity in markets by Christmas", thriving from the warm conditions. A report from the *Arkansas Gazette* (1828), dated March 12, 1828, provides an additional perspective of evidence of abnormally warm temperatures and impacts.

> The usual harbingers of that delightful season, the *Martins*, made their appearance about a week since; and its influence is seen on every side, in the putting forth of the buds and blossoms of every description of early vegetation. Peach and plumb trees are now in full blossom, and there has not been a day since the first week in January that we have not seen their blossoms. It is quite likely that they have been affected by the frosts, but from present appearances, the crop of fruit will be abundant.

Some of the press from the Northeastern U.S., such as the *Farmers Cabinet* from Amherst, New Hampshire, also reported unusual blossoming of plants, but widespread occurrence of such events was not likely, given the occasional subfreezing conditions that occurred.

Temperature anomalies over the Southeast U.S. are only slightly positive for March 1828, due to several cold waves that came through the region (Figs. 3, 6 and 7). These cold waves include some weak frost events and ice. Illustrating a few examples, William John Connors and Daniel Cannon Webb from northeast South Carolina and Charleston respectively reported four days in March with frost. Webb (1817–1850) described the frost on March 5 in the most detail, writing that the "Thermometer said to be 2 degrees below freezing-Ice said to be in the City, and was in fact at my house... But the Garden does not show effects of frost." Thus, the idea of a continuously warm Southeast U.S. in the winter of 1827–1828 without frost for the coastal states is not true, though the March frosts are not severe at a large regional scale. Interestingly, the relatively cold excursions in March may have been conducive to some fruit trees for enhancing their chilling requirement in winter that enhanced subsequent blossoming and growth later in the spring.

Table 3 Precipitation frequencies, ranks, and 75th percentile thresholds from modern analogs for selected stations covering January–February 1828, otherwise noted[a]

Diarist/location	Precipitation days	Rank/years	Modern 75th precipitation
R.F. McGuire/Monroe, LA	29	1 out of 7	23
Fort Jessup, LA	33	1 out of 23	21
J. Nevitt, near Natchez, MS	26	1 out of 5	24
H. Tooley, Natchez, MS	33	4 out of 25	24
Augusta Arsenal, GA	21	3 out of 17	23
Northeast SC (Bartell diaries)	18	5 out of 42	19
J.P. Thomas/Santee R. region, SC	20	2 out of 8	26
D.T. Merritt, Halifax Co., VA	20	1 out of 12	24
Shirley, near Hopewell, VA	28	1 out of 15	24
Hughes diary, Richmond, VA	27	1 out of 17	24
I. Jackson record, Cincinnati, OH	29	2 out of 35	26
Washington DC (Nat. Intelligencer)	23	1 out of 19	24
Nashville, TN	29	N.A.	25
St. Louis, MO (W. Clark)	21	N.A.	21

N.A.: not available. Charleston, SC January/February rainfall = 16.07 in. (40.82 cm). Nashville, TN December–February rainfall = 31.16 in. (79.15 cm). Ogden diary, SE Idaho. DJF snow days = 43. Modern normal = 24

4.3 Moisture conditions over the American Southeast

Reconstructions of the precipitation frequencies, with an emphasis on January and February of 1828, clearly indicate that much of the Southeast U.S. from the Gulf Coast to Virginia was abnormally wet-this aspect has not been previously described by Ludlum (1968) (Table 3). Diarists, scattered at various locations over the Southeast U.S., clearly experienced many more precipitation days than other years that they recorded in their records, despite varying record lengths. Most of the reconstructed precipitation frequencies also generally exceeded the 75th percentile of precipitation frequency thresholds based on their nearby modern climate analog stations. Limited precipitation gauge data for the American Southeast reveal that the winter of 1827–1828 may have been one of the wettest in the last few hundred years. The Charleston, South Carolina total of 16.07 inches (40.82 cm) for January/February of 1828 is the fifth wettest out of the entire record of 234 years. The Nashville, Tennessee total of 31.16 (79.15 cm) inches for December–February by far exceeds the modern record of 24.77 inches that started in 1871. Numerous verbal accounts confirm these extraordinary wet conditions. For example, The *Village Messenger* (Fayetteville, Tennessee) on February 22, 1828 that "For the last two months it has rained almost every day (*Village Messenger* 1828). The water courses in this part of the country have been swollen, and the bottom lands inundated to an extent, and for a longer time, than we ever before witnessed." The abnormal wetness also seems to have spread over geographical areas not represented by the reconstructions in Table 3, according to broad verbal accounts from North Carolina, Arkansas, and into Kentucky. The *Raleigh Register and North Carolina Gazette* (1828) provided such an example of a freshet, dated February 12, 1828.

> *Freshet.* –The North-West branch of Cape Fear River, began to swell on Saturday last, 2d inst. and continuing to swell till the following Tuesday morning, rose to the height of 45 feet at Fayetteville. – All the low grounds were covered, by the expanse of waters.

> It is reported that much rain has fallen in the upper country since the swell; and if so, we may expect the flood to continue for some days. – *Cape Fear Rec*.

An article appeared later in the same paper on February 29, providing some advice on how to adapt to the wet conditions.

> *Damp Destroyer.* – During the present extremely damp season, it may increase the comfort of such of our readers as wish to try the experiment-that by placing an unstopped bottle, or more open vessel, if convenient, containing strong sulphuric acid, in any part of a room, the moisture of the air becomes rapidly absorbed, and the salubrity of the apartment consequently improved. The great capacity of sulphuric acid for vapor, and the cheapness of the acid, renders this mode of absorbing humidity very economical.

Flooding became a problem for some river basins in the Southeast U.S., including the Mississippi. The river rose among the highest in recorded history for the City of New Orleans (Monette 1903; Saikku 2005). The *New Orleans Argus* (1828) provided a general account on February 28, 1828.

> HIGH WATER. – The oldest inhabitants do not recollect ever to have seen the Mississippi river so high in the month of February, as it is at this time. The water does not lack thirteen inches of being at its highest point, and if credit is to be given to reports brought by steam boats, another heavy freshet from the Ohio, is pouring upon us. If the upper Mississippi and Missouri are not blocked with ice, the consequences will be most disastrous to Louisiana. Already, we understood, the fertile parish of Concordia is inundated, and we much fear that many plantations in Racourci, and the whole settlement of Gross Tete will share a similar fate.

Similarly, but farther up the Mississippi, flooding was a problem as recorded by the *Illinois Intelligencer* (1828) at Vandalia, Illinois on February 9, 1828.

> *The late rise of the Ohio*, as we learn from the Shawneetown paper, was unprecedented, having driven the inhabitants of that place from the lower to upper apartments of their dwellings. The editor of the Gazette, seems by his own account, to have suffered in a especial manner. With six feet of water upon his lower floor, he was compelled to retreat to his office garret, and so violent was the storm, that he remained for some time uncertain, whether he was to be a victim to the winds or waves. A corn dumpling, instead of an olive branch, brought him in a canoe, was a token that the waters were subsiding, and that he was to be spared to write an account of his "moving accidents." The inhabitants of Shawneetown, it appears, have not been materially injured by the freshet. There appears to be some difficulty among them about the day of the week: some contending that the dry land appeared on Friday, and others on Monday. In this "chronological dilemma," the editors of the Gazette justly fears some may have broken the Sabbath.

Although moisture conditions generally were quite high throughout the Southeast, spatial and temporal variability of conditions was evident, and the Ohio River with its tributaries did not appear to experience continuously wet conditions. *The Focus* (1828), a newspaper based out of Louisville, Kentucky, described "high waters and deep roads" on January 8, but it reported that "The river is now so low that the steamboats seldom pass the Falls" by March 25.

Tree-ring data from 835 sites over North America provide a unique perspective to assess detailed patterns of drought for a particular year within the last few thousand years, with

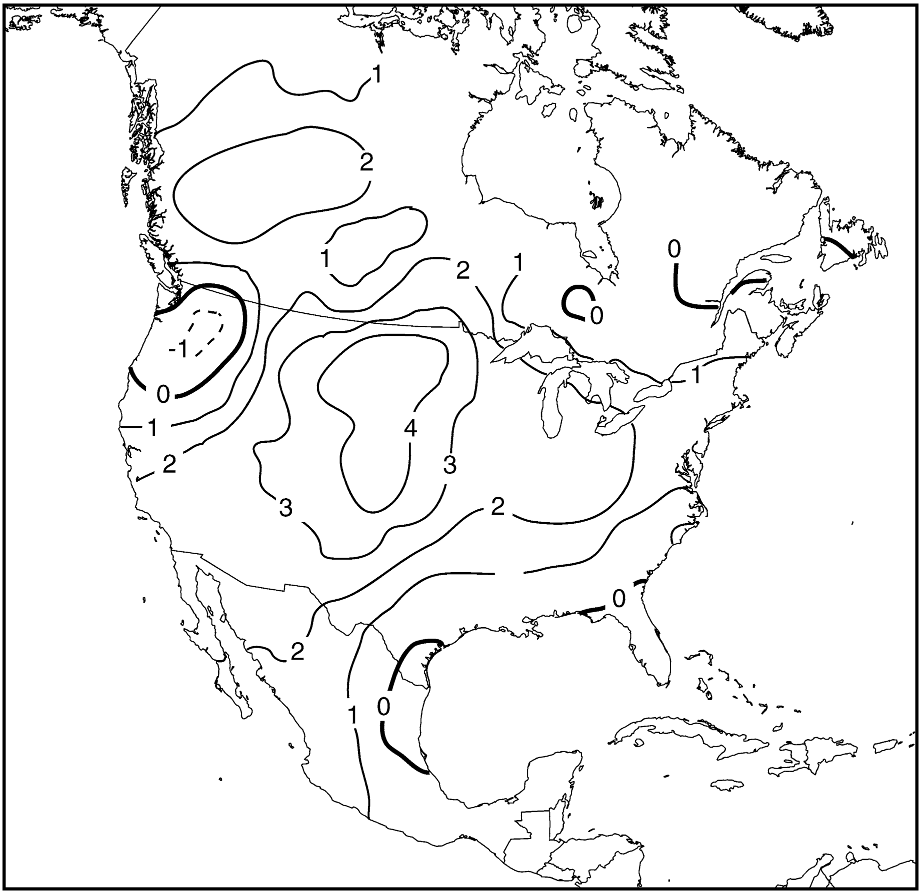


Fig. 8 Distribution of Palmer Drought Severity Indices (PDSI) for 1828 as reconstructed by 835 tree-ring chronologies (Cook and Krusic 2004)

detailed spatial resolution for all of North America generally available for the last thousand years (Cook and Krusic 2004). Drought is represented as values of the summer Palmer Drought Severity Index (PDSI). The map for 1828 reveals large-scale patterns of positive indices centered over the North American continent and extending virtually over the entire United States (Fig. 8). Such a widespread pattern of positive PDSI values for a particular year is quite uncommon, and the lack of drought in 1828 clearly reflects the importance of previous high winter soil moisture recharge, which is evident from the copious documentary and instrumental data.

4.4 The killing frost of early April

Plots of daily morning temperatures for weather stations over the Southeast U.S. clearly indicate the presence of the killing frost event of April 5–7 (Fig. 6). The morning temperatures were either the coldest, or comparable with any morning temperatures, within the entire winter of 1827–1828 (Figs. 6 and 7). The Charleston, South Carolina and St. Augustine,

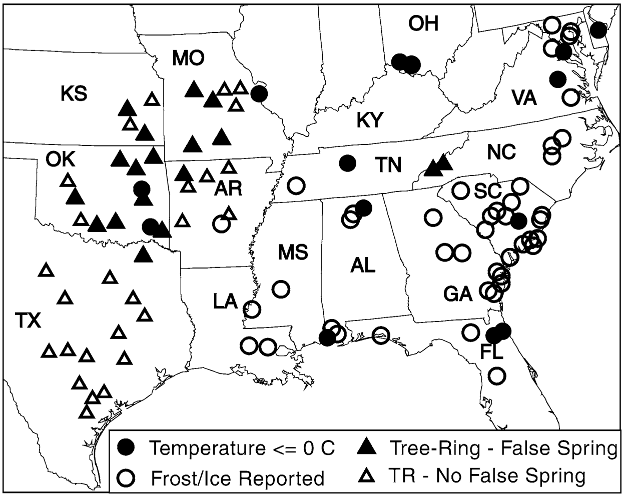


Fig. 9 Map illustrating the killing frost event of early April 1828, as recorded by tree-ring, documentary, and instrumental data. Tree-ring data were taken from Stahle (1990)

Florida plots suggest that the coldest temperatures for the entire winter and spring were likely concentrated in the southeast Atlantic coastal area during the April frost event. Given the overall abnormally warm winter temperatures and high precipitation throughout the Southeast U.S., the vegetation was no doubt much more susceptible for damage by early April than any time earlier that year.

Both documentary, instrumental, and tree-ring data illustrate the spatial extent of the April killing frost event extending from northeast Texas to Missouri, and spreading eastward to Ohio and Maryland (Fig. 9). Of importance, since the tree-ring frost data rely on a lower temperature criteria for defining a frost event than the documentary data, with temperatures generally $\leq$–5.0 °C, the indications of "No False Spring" from oak trees in areas such as Texas do not necessarily imply that conditions near freezing did not occur. The lack of documentary data in Texas, Kansas, and most of Missouri and Arkansas prevented the detection of sub-freezing conditions in these "No False Spring" locations. Documentary data from Florida carefully illustrate that the extent of the frost was confined to an area north of Fort Brooke (Tampa), Florida, but killing frost conditions covered most of the Gulf States except perhaps specifically along the coast in isolated areas. Killing frost events tend to mostly be sub-regional in spatial scale, and the areal extent of the 1828 extreme frost event has not been equaled since up to today, except perhaps only for a similar event in April 1849 (Ludlum 1968), and for a very prominent severe frost event centered further westward over the South-Central U.S. in 1826 (Stahle 1990). However, the instrumental data and the tree-ring data suggest that the April 1828 event was generally characterized with colder temperatures than the April 1849 event.

Diaries and press accounts reveal the impacts and characteristics of the April killing frost event. For example, John Nevitt (1827–1832), of Natchez, Mississippi, described on April 5, 1828, that the "Weather cold at night light Black frost wind strong from North & West." Agricultural damage was unquestionably extensive, but since the agricultural frontier of the South was not in full bloom as it was in the later antebellum years leading up to the Civil

War, farmers generally did not despair. Alexander Robert Lawton (1828) summarized his thoughts near Beaufort, South Carolina on April 6, 1828.

> On sunday night 6th April, we had a very large frost and thick ice, such as ever occur'd at this season since I was born; as I am informed. It totally destroyed all my wheat & my neighbors [wheat], and the rye that had shot out heads; killed whole beds of garden peas that were full of grown peas; destroyed almost everything in our gardens; killed my watermelons & pumpkins which were both up, & has cut down all my corn & destroyed a good deal of it so that I shall have to plant it over smartly

The *Pensacola Gazette and West Florida Advertiser* (1828) described the following on April 18, 1828.

> *The Weather.* – The night of Sunday the 6th inst. and the following morning were colder than any we had during the past winter. Ice was formed thicker than a dollar, and the Gardens of the city and its vicinity, together with most of the fruit (which was very forward on account of the total absence of winter) were entirely destroyed. The crops will probably be more backward than usual this season.

The *Frederick-Town Herald* (1828), based at Frederick, Maryland, described a different type of agricultural impact, related to apples and also described a snowstorm.

> After an unusually mild winter and early spring, we have, within the last week, been visited with some severe weather. Monday [April 7] last was quite a winter day; more snow fell than in any one day during the season, and had it not melted as it fell must have been several inches deep. In the course of the night it cleared off, and was followed by a severe frost, which, we understand, has destroyed the peaches and done considerable damage to the apples and most other fruit. Indeed, several persons of whom we have enquired, suppose the apples are also destroyed. That may be the case in some orchards, but we are induced to believe the apples have escaped in most instances with but partial injury.

The snowstorm associated with the killing frost event apparently took some Southeast residents by surprise after the warm winter, as summarized by an account from the *City Gazette and Commercial Daily Advertiser* (1828) at Charleston, SC on April 11, 1828.

> The Weather – "Accounts from various quarters represent in as lugubrious terms as the papers of this city used, the uncomfortable feelings experienced, from the late sudden and severe chances of the weather. To commence at Washington, the *Intelligencer* of the 5th observes, "*After a winter with no winter, we were yesterday morning visited by a considerable fall of snow, and last evening, for a short time, with a violent snow storm.*" In Raleigh (N.C.) the most frequent and disagreeable vacillations between cold and temperate, were experienced during the week commencing Sunday the 30th March, until the Friday following, when the hopes of the gardens were destroyed by frost which was succeeded on the next night by snow. And in the Georgetown, in this state, the Editor of the *Intelligencer* remarks, that the cold weather has at length arrived, exhibiting ice on Monday last of the thickness of the quarter of an inch, cutting down the Corn and injuring the Rice so much, as to render it necessary in some cases to plant over. A singular coincidence (if such it may be called) is noticed in the same quarter, of ripe blackberries having been gathered on the same day, in the vicinity of the town."

5 Meteorological conditions over western North America

Although instrumental and documentary weather evidence for the winter of 1827–1828 is relatively scarce over western North America as compared to the eastern counterpart (Fig. 10), data and analyses clearly illustrate abnormally colder winter conditions. Peter Skene Ogden (1971), whose diary near present-day Pocatello, Idaho is by far the most detailed account for the western region, saw early signs of a severe cold winter on November 23, 1827 when the "River was covered with Ice." On November 28, Ogden wrote that "we were in motion and descended the stream one mile, and crossed over with I may say the greatest difficulty [Snake River], from the quantity of floating ice, which was the cause of many of our weak horses falling and had nearly been drowned." The Snake River today rarely freezes over in a given winter, much less this early in the winter.

Ogden reported 17 snow days in December, 12 snow days in January, and 14 snow days in February at his winter camp by the Snake River. These numbers clearly exceed the median modern normals (1939–2003) of 8.9, 9.0, and 7.0 snow days respectively for the three winter months. The 43 snow days for December-February is the second highest during the 1939–2004 period (Fig. 11). A statistically significant relationship exists between winter

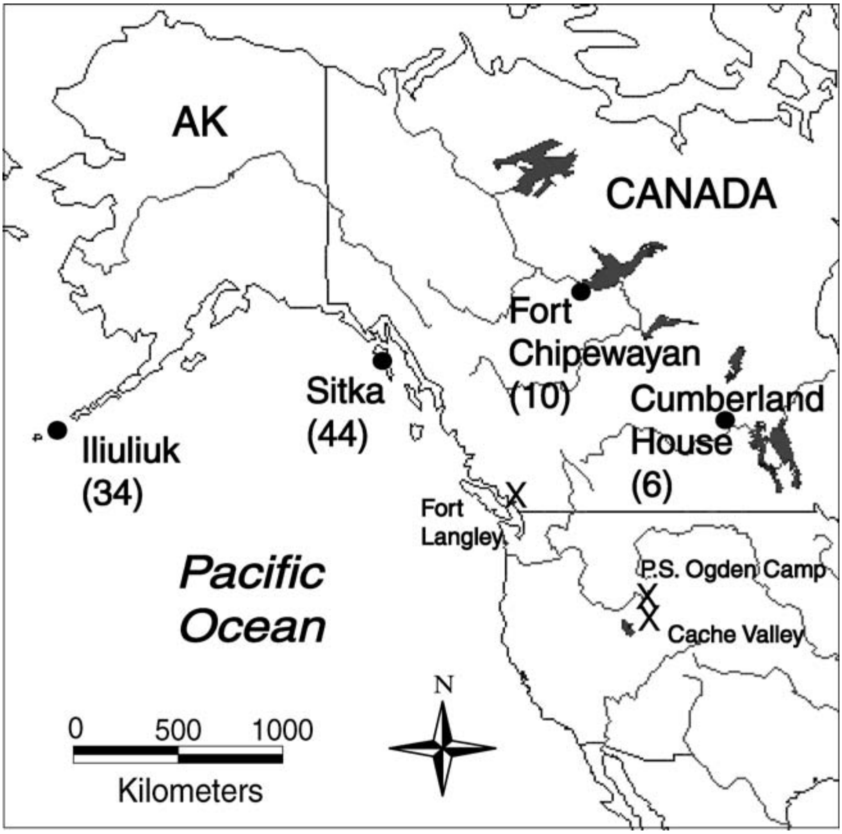


Fig. 10 Map of locations where weather observations were taken during the winter of 1827–1828 in western North America

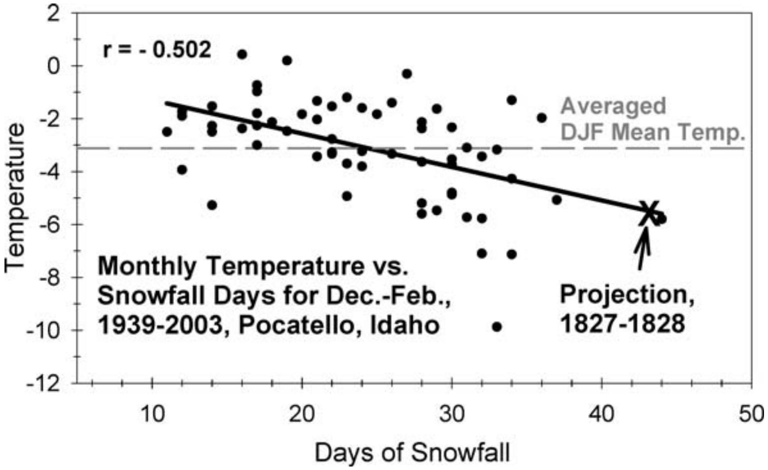


Fig. 11 A scatterplot illustrating the relationship of winter snow days versus winter temperature (C) from Pocatello, Idaho and comparisons with the winter snow frequency reconstruction for 1827–1828

temperature and snowfall frequency ($r = -0.502$, $p < 0.01$). Therefore, abnormally cold temperatures are expected to mostly correspond with abnormally high snowfall frequencies, with relatively milder temperatures occurring within southerly flow ahead of cold fronts during some days. The following verbal accounts from Ogden's diary describe some of these meteorological conditions.

> Again another snow storm. This is certainly an uncommon severe winter, for the last month we have not had two days following of fair weather. It is hoped we shall have an early spring. We have however from the great quantity of snow to apprehend an overflowing of the small streams, which will prove most injurious to our trapping (December 30, 1827).

> Again another snow storm which has far surpassed any other we have had this season. What will become of us I cannot say; two thirds of our horses will certainly die, nor can I afford them any relief. All over the country it is the same, such a severe winter was never experienced before. The climate of this quarter is certainly experience a change, and for trappers and horses not a very desirable one, as the hunters can no longer employ horses or hunt on foot from the depth of snow, they are now making snow shoes and the remainder pass their time in gambling. (January 3, 1828).

> We experienced another severe snow storm during the night and during the day a gale of wind from the southward and weather mild, but the snow is not melting. (February 7, 1828).

Similar abnormally cold and stormy conditions also occurred at Fort Langley, British Columbia, as well as by recollections from other Hudson's Bay Company fur trappers in the Cache Valley of northern Utah. The Fort Langley journals (MacLachlan 1998), though not as detailed with weather information as the Ogden diary, describe abnormal conditions of ice in the nearby Fraser River not far from the Pacific coast, as well as frequent cold and snowy conditions, particularly for December 1827 and January 1828. Daniel T. Potts, who was based in Cache Valley, Utah, recollected in October 1828 of the previous winter's weather (Ashley 1964).

> The first snow fell on the third of September when it snowed for three days without intermission the snow remained on the ground upwards of knee deep and I think must have felt [fell] fully waist deep this had not the least effect on any kind of vegetation as it appears addapted to the climate the winter remained gentle untill the first of December when the power vengence was poured out on us the N.E. winds and more particularly South accompanied with A continued snow untill the first of march when it somewhat abated the snow remained upwards of four feet deep on the level for twenty days in succession the great spirrit the sun refused to visit us the like has [not] been know[n] by the oldest livers which I suppose is not less than one hundred [years] or upwards.

Potts' weather account is quite similar to that of other Hudson's Bay Company fur trappers, indicating that the winter storm track likely also affected the area south of the Snake River Plain.

Several instrumental records in Alaska and western Canada also provide some information on the weather in western North America during the winter of 1827–1828. Much of the data in Canada were recorded by the Hudson's Bay Company. Monthly temperatures from Fort Chipewayan (based on sunrise, noon, and sunset observations) for December 1827 and January 1828 are −17.6 and −8.7 °C respectively. These values are at least several degrees colder than corresponding modern climate normals, but further information on thermometer exposures are needed for rigorous temperature corrections. Similar meteorological conditions are evident from Cumberland House, suggesting that a broad area of abnormally cold conditions extended from northwestern North America to the American Midwest. A seven-year record from Illuliuk, Alaska, based on morning, noon, and night fixed observation times (Dall and Baker 1879; Veniaminov 1984), lists monthly temperatures for December 1827 and January 1828 of 1.9 and 4.6 °C respectively (February 1828 values appear about normal). Although this record is short, it suggests that southwestern Alaska was characterized with abnormally warm winter conditions within a seven-year period and with corresponding modern climate normals. An instrumental record from Sitka Alaska reveals monthly winter temperatures about normal, suggesting that the location is generally in a transition from positive to negative temperature anomalies, but little is known on the specifics of this instrumental record (Dall and Baker 1879).

6 Inferences on synoptic patterns and teleconnections

The reconstruction of large-scale weather patterns for the winter of 1827–1828 reveals prominent positive temperature anomalies over much of the eastern U.S. generally east of the Mississippi River. Prominent negative winter temperature anomalies are evident from Fort Snelling, Minnesota spreading to the Northwest U.S. coast. Positive winter temperature anomalies likely encompassed an area centered over the southern Alaskan coast. This positive-negative-positive anomaly pattern from west to east likely relates to a ridge centered in southern Alaska, a strong trough centered over the interior Northwest U.S., and a strong ridge over much of the eastern U.S. The temperature anomaly patterns for the winter of 1827–1828 are clearly opposite of those anomalies normally experienced during an El Niño winter. They also clearly differ from anomaly patterns that occurred in other very strong El Niño events such as in 1877–1878, 1982–1983, and 1997–1998. Normally in such warm events, positive temperature anomalies are prevalent over much of western Canada and the Pacific Northwest due to the establishment of the positive mode of the Pacific North American (PNA) teleconnection pattern (Leathers et al. 1991; Zhang et al. 1997). The ridge over the western U.S. is associated with a strong trough east of the Rocky Mountains, which is associated with negative winter temperatures over much of the Gulf States (Ropelewski and Halpert 1986; Diaz and Kiladis 1992). A stronger Aleutian low in the North Pacific Ocean is also normally experienced in winters following El Niño events (Cayan 1996), but the limited Alaskan data for early 1828 suggest that such a feature is not clearly evident. The increased winter wetness over the Southeast U.S. may be consistent with El Niño conditions, but the snowy and cold conditions over the Far West U.S. are normally not so. In summary, the winter conditions in 1827–1828 resemble a strong reverse PNA pattern (RPNA).

Perhaps the unusual reconstructed temperature and synoptic patterns for the winter of 1827–1828 over North America indicate that such a strong El Niño event did not take place that year. Tree-ring reconstructions of the Niño 3 Index by Cook (2000) and a multiproxy Niño 3 reconstruction by Mann et al. (2000) reveal no El Niño event for that year. The examination of rainfall data from Madras and Nagpur in India indicates no clear signs of a weakened summer monsoon in 1828 (Clayton 1927), which is also inconsistent with what is normally experienced in El Niño conditions (Diaz and Kiladis 1992). In a reassessment of Quinn's (1992) ENSO historical reconstructions for 1828 off the west coast of South America, Ortlieb (2000) classified it as a "Very Strong" Event but described the timing of the event later than Quinn, with some documentary evidence indicating heavy rainfall occurring around March of 1828, too late to impact North America weather in the winter of 1827–1828. Reconstructions of monthly North Atlantic Oscillation (NAO) indices by Jones et al. (2001) reveal high NAO indices in December and January, and reconstructions by Luterbacher et al. (2002) indicate a high NAO index for mostly just December. Although the NAO may be responsible for creating positive temperature anomalies along the east coast of North America (Hurrell and Van Loon 1997), a persistent NAO is not evident for all of the winter and the NAO also cannot adequately explain the strong positive temperature anomalies along the Gulf Coast and the strong temperature anomalies further to the west. Reconstructions of the Pacific Decadal Oscillation indicate that 1827 and 1828 do not fall in any unique extremes of positive or negative modes (e.g., Biondi et al. 2001; MacDonald and Case 2005). The unique winter conditions of false spring over the eastern states, in strike contrast to the extreme cold and snow of northwestern North America, appear to not be clearly associated with any large-scale teleconnection forcing, and no particular large volcanic eruption is known to exist around 1827 or 1828. However, further data at the hemispheric and global scales would be needed to closely assess any teleconnection patterns and the exact state of ENSO (e.g., Chenoweth 1996), and perhaps influences on the PNA pattern from the Asian continent (Leathers and Palecki 1992).

The major false spring event of the winter of 1827–1828 was largely distinguished by a late and very prominent killing frost over the Southeast U.S. in early April 1828, likely one of the most severe in the last several hundred years with no event approaching its magnitude since that time. The synoptic-scale circulation patterns likely reversed sharply to a strong trough east of the Rocky Mountains and spilling cold air over eastern North America southward to northern Florida. Reports of clear skies and cold, light northerly winds immediately after the killing frost are indicative of a strong cold-core high pressure center traversing the American South (e.g., Marengo and Rogers 2000).

7 Conclusions

This paper provides a detailed reconstruction of the unusual warm weather and meteorological impacts that prevailed during the winter of 1827–1828 over North America, with a focus on the American Southeast, but adding much additional information on temperature patterns and anomalies, as well as on moisture characteristics than by the study by Ludlum (1968). Several important implications result from the findings of this paper.

(i) The warmth of the winter of 1827–1828 over eastern North America is comparable with the magnitudes of other widespread warm winters of the last 300 years, but it is unprecedented in its combined spatial extent and persistence, as well as its relationship to the anomalously cold winter farther westward. Precipitation conditions over the Southeast were clearly much above modern climatic normals, consistent with nationwide patterns of the lack of drought during summer 1828 as reconstructed from a large network of tree-rings.

(ii) The anomalies and inferences on synoptic-scale atmospheric circulation for 1827–1828 are completely opposite of what is normally expected during El Niño events, representing a strong reverse PNA pattern. This winter may in part be related to a strong positive mode of the North Atlantic Oscillation, but it cannot be explained by it alone. The unusual and anomalous winter of 1827–1828 over North America raises some questions on the specific nature of the very strong El Niño event for this year.

(iii) This study stresses the important role of climate variability in historical extreme events and how it is associated with specific societal impacts. Meteorological extremes and variability create the important and diverse meteorological impacts on river traffic, agriculture, climatic perceptions, and on the natural landscape. Scholars interested in the interrelationships between history, environment, and climate cannot simply regard climate as constant-nor can they simply assume past climate as generally colder or more extreme during the Little Ice Age (e.g., Mock and Lawson 2001).

(iv) The killing frost of early April 1828 is among the strongest and most widespread killing frost event for the American Southeast within the last several hundred years. No doubt, catastrophic agricultural damage well beyond dollars losses typical for the catastrophic freezes that resulted from citrus frost events in Florida would result if they occur in the near future, as such events are quite rare at the regional scale. Some scholars have implied that the early nineteenth century was abnormally warm in the early nineteenth century, enabling orange growing well northward of its present-day range into South Carolina (Attaway 1997). Questions on the specific nature and societal impacts of nineteenth century killing frosts, as well as other weather hazards at daily resolution, remains to be closely assessed with agricultural activities during the colonial period.

Reconstructions of climatic extremes from early instrumental and documentary data are plentiful for much of the late eighteenth and early nineteenth centuries for eastern North America. Other interesting frost extremes, such as the Great Freeze of 1835 over the Southeast U.S. the big False Spring event of 1826 centered over the South-Central U.S. (Stahle 1990), and other big killing frost events in the western United States (Brunstein 1996) can be reconstructed in a similar methodology conducted in this paper. Historical applications to other types of weather hazards, such as ice storms, specific hurricanes, and specific snowstorms, is also highly feasible. Regardless, rigorous historical weather and climate reconstructions require careful analyses of data quality and some numerical comparisons as they relate with the variability in the modern climate record. The NOAA Climate Data Modernization Project (CDMP) has made a lot of early instrumental data and some documentary data for North

America easily accessible electronically, which when combined with newly acquired data from historical archives, will enable scholars to more easily conduct such detailed case studies of weather extremes at the synoptic scale.

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