BAMS Article

The Long Winter of 1880/81

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ABSTRACT: The story of the winter of 1880/81 in the central United States has been retold in historical fiction, including Laura Ingalls Wilder's *The Long Winter*, as well as in local histories and folklore. What story does the meteorological data tell, and how does it measure up when compared to the fiction and folklore? What were the contributing factors to the severity of the Long Winter, and has it been or could it be repeated? Examining historical and meteorological data, reconstructions, and reanalysis, including the Accumulated Winter Season Severity Index, the Long Winter emerges as one of the most severe since European-descended settlers arrived to the central United States and began documenting weather. Contributing factors to its severity include an extremely negative North Atlantic Oscillation pattern, a mild to moderate El Niño, and a background climate state that was much colder than the twentieth-century average. The winter began early and was particularly cold and snowy throughout its duration, with a sudden spring melt that caused subsequent record-setting flooding. Historical accounts of the winter, including *The Long Winter*, prove to be largely accurate in describing its severity, as well as its impacts on transportation, fuel availability, food supplies, and human and livestock health. Being just one of the most severe winters on record, there are others in the modern historical record that do compare in severity, providing opportunity for comparing and contrasting the impacts of similarly severe winters.

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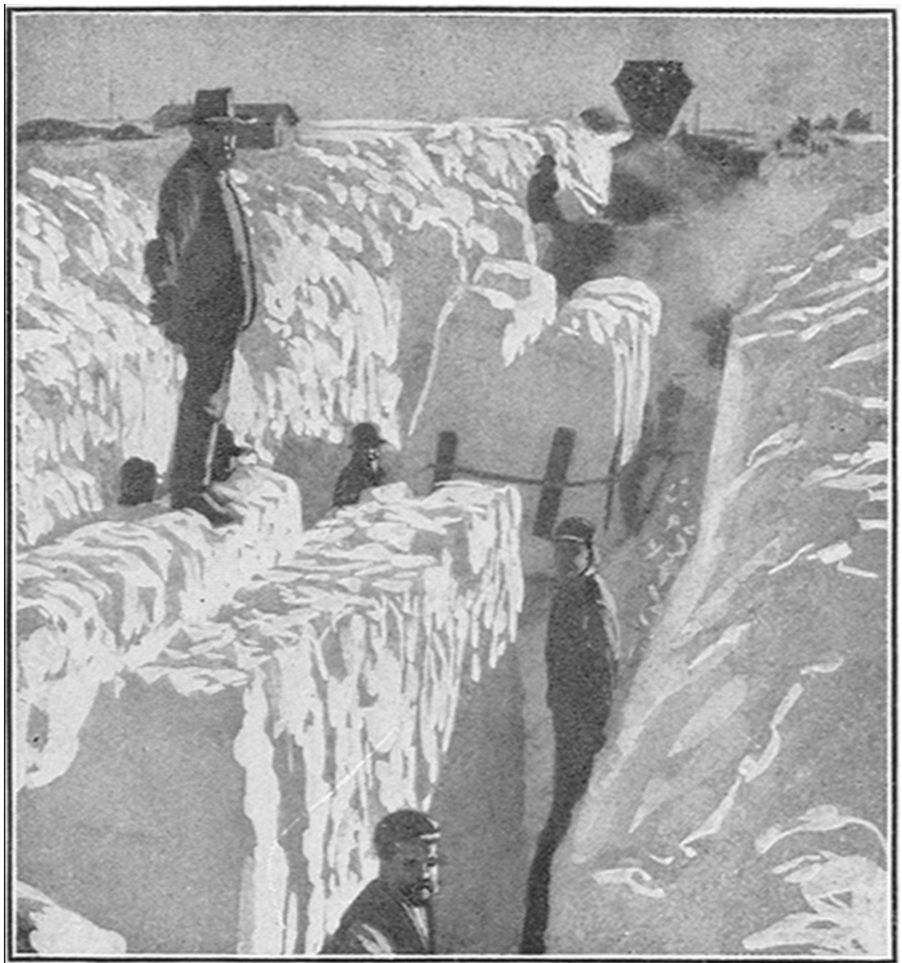

OPENING THE ROAD IN 1881.

*B*ut even after Laura was warm she lay awake listening to the wind's wild tune and thinking of each little house, in town, alone in the whirling snow with not even a light from the next house shining through. And the little town was alone on the wide prairie. Town and prairie were lost in the wild storm which was neither earth nor sky, nothing but fierce winds and a blank whiteness.

—Laura Ingalls Wilder, *The Long Winter*

The winter of 1880/81, featured in the Laura Ingalls Wilder historical fiction account, *The Long Winter* (Wilder 1940), was strikingly difficult across much of the plains and Midwest. The book, set in De Smet, Dakota Territory (present-day South Dakota; 60 km west of Brookings and 53 km east of Huron), was a fictionalized account of Wilder's childhood experiences. For six months, the Ingalls family endured persistent blizzards, bitter cold, and near starvation. The winter was featured in other historical fiction accounts (i.e., Rolvaag 1927), in the history of the Chicago and North Western Railroad (Stennett 1905), and in several town histories across the region (i.e., Clark 1893; Robinson 1904; Jones 1937). In documentation, the winter is often referenced as the "Hard Winter" (Robinson 1904) or the "Starvation Winter" (Clark 1893). In fact, Wilder initially titled her book *The Hard Winter* on the first draft of the manuscript submitted to Harper and Collins Publishers; the publisher urged Wilder to change the title to be less frightening to her child readers (Hill 2007). While Wilder's account of the winter was a work of historical fiction, the book contained many verifiable facts, including those regarding the meteorological events of the Hard Winter. Both meteorological records and nonmeteorological accounts indicate that the winter was particularly long, snowy, and cold.

Laura Ingalls Wilder (1867–1957) was an American author, writing the *Little House* book series between 1932 and 1943. Born in Pepin, Wisconsin, to Charles and Caroline (Quiner) Ingalls, she was the second of four daughters in the family; a son, born between the third and fourth daughters, died in infancy. Throughout her childhood, following promises of the Homestead Act of 1863, the Ingalls family migrated among Wisconsin, Kansas, Minnesota, Iowa, and eventually Dakota Territory (South Dakota). At age 18, Laura married Almanzo Wilder; their daughter, Rose, was born a year later. The Ingalls family's experiences during Laura's childhood are chronicled in the *Little House* book series, a set of historical fiction books for children and young adults based on events in her childhood. Some aspects of the books are more fictionalized than others, and the books are laced with detailed accounts of specific weather and climate events. In adulthood, Rose, herself an author and writer, would become an editor and advisor to Laura's works, often shaping the narrative and structure of the stories produced by Laura. Thus, while it is feasible to look at the *Little House* books as a starting point for past events, the events and their details must be corroborated with evidence to determine their veracity. In other words, we must do some work to determine which parts of Laura's stories were fact-based and which parts may have been fiction or exaggeration.

Though well documented in historical accounts, the Hard Winter of 1880/81 is absent from analysis or documentation in scientific literature, a gap we will fill here. In addition to a case study of the winter of 1880/81, including documenting available data and investigating contributing large-scale teleconnection patterns, this study returns to the literary and historical documentation to connect the event to its impacts. As recently as 2013/14, an anomalously severe winter blanketed much of the United States east of the Rocky Mountains, with impacts ranging from a high number of school "snow day" closures to impeded transportation and commerce and increased energy costs. Understanding the impacts of recent severe winters relative to historical extremes allows us to place these events in context, anticipating both their meteorological extremity and their potential for impacts that can be anticipated during future events.

Meteorological data

Meteorological data in the central Great Plains region in the early 1880s were sparse in coverage, especially when seeking stations with long-term records that pre-date the Hard Winter and continue through the present. As with many investigations of historical weather events, the few official and routine observations must be supplemented with historical and anecdotal information to create a description of the winter of 1880/81. The disparate datasets and qualitative information must be combined in a meaningful way to create an accurate description of the weather and climate events while also retaining their unique historical perspectives.

Station-based temperature and precipitation data were collected through the Applied Climate Information System (ACIS; Hubbard et al. 2004) for stations listed in Table 1. The sites used in this study that are continuous from 1880 to the present are among those considered to be "threaded" records, with station moves across metropolitan areas collected into one continuous data record (DeGaetano et al. 2015). Thus, an important caveat with the data are that each station may include multiple, though related, sites, with variations in site location and instrumentation through the period of record. For example, at Minneapolis–St. Paul, Minnesota, the threaded site includes the St. Paul Signal Service from 1871 to 1891, the Minneapolis Weather Bureau Downtown from 1891 to 1930, and Minneapolis–St. Paul International Airport from 1938 to present, with the National Weather Service (NWS) supplying supplemental observations from 2000 to 2004. While some conclusions may be drawn about the long-term record at these stations, including records and extremes, they should be made with caution and supported by analysis of homogenized station data.

Digitization of historical weather observations provided by the Climate Database Modernization Project (CDMP; Dupigny-Giroux et al. 2007) yielded data previously unavailable for computer analyses and in closer proximity to De Smet. Observations were taken at three military forts in the eastern half of South Dakota during the winter of 1880/81: Fort Bennett (now under present-day Lake Oahe in central South Dakota), Fort Randall (near Pickstown in southeast South Dakota), and Fort Sisseton (between Sisseton and Britton in northeast South Dakota; February 1881 data are missing). In addition, historical observations were available for Yankton, South Dakota, a site that later established a long-term climate record. The historical data often included not only temperature and precipitation information, but also often included observations of precipitation type, wind description, and other meteorological and astronomical phenomena. Locations of both long-term and historical weather observing sites are in Fig. 1.

Table 1. List of continuous-record stations used to analyze the Hard Winter of 1880/81, including station period of record. Stations with "thr" in the abbreviation are threaded sites. POR indicates the period of record for the station/thread.

City, State	Abbr.	POR
Aberdeen, South Dakota	ABR	Jan 1893–present
Des Moines, Iowa	DSMthr	Jan 1878–present
Detroit, Michigan	DTWthr	Jan 1874–present
Fargo, North Dakota	FAR	May 1891–present
Huron, South Dakota	HONthr	Jul 1881–present
Lansing, Michigan	LANthr	Jan 1863–present
Minneapolis–St. Paul, Minnesota	MSPthr	Jan 1872–present
Omaha, Nebraska	OMAthr	Jan 1871–present
Pierre, South Dakota	PIR	Jul 1933–present

Neither the long-term climate records nor the historical data included direct measurements of snowfall or snow depth during the winter of 1880/81, which is typical of the period. Occurrences of snow were derived from a combined interpretation of temperature and precipitation data, as well as precipitation type descriptions from the historical records, when available. The Accumulated Winter Season Severity Index (AWSSI; Mayes Boustead et al. 2015) assigns point values to each day of a winter season based on thresholds of maximum and minimum temperatures, as well as snowfall and snow depth; the sum of daily points through a winter season characterizes the severity of that season, as well as a time series of AWSSI for all winters on record at a station. In addition to assessing the total AWSSI accumulation, we can assess the temperature and snow contributing components separately to contextualize their relative contributions to the winter severity. The precipitation-based calculation of AWSSI (pAWSSI; Mayes Boustead et al. 2015) estimates daily snowfall and snow depth based on temperature and precipitation observations, using empirical analysis. The pAWSSI provides a longer period of record for locations that do

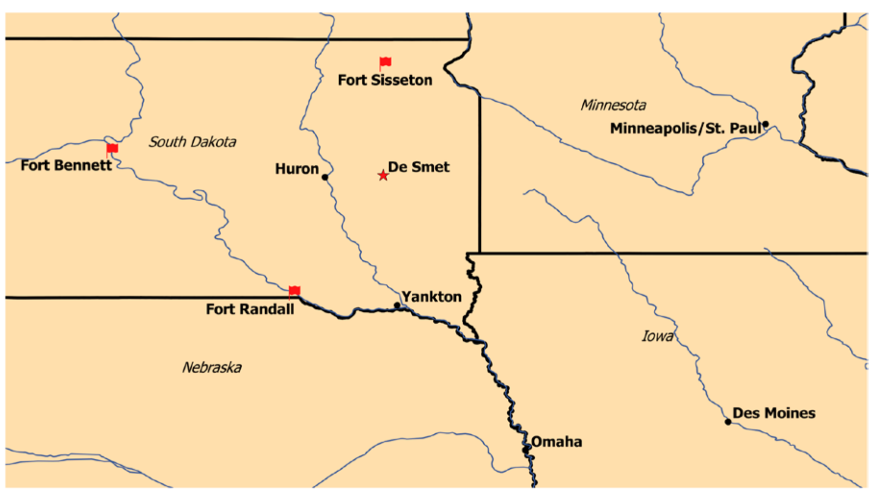

Fig. 1. Locations with data available for the winter of 1880/81. Sites marked with a flag are CDMP sites; others are sites with continuous records. De Smet, South Dakota—the setting of Laura Ingalls Wilder's *The Long Winter*—also is noted for reference. Huron, South Dakota, was not available until April 1881 and also is included for reference.

not have direct snowfall and snow depth measurements, allowing time series analyses of the severity of the winter season by approximating snowfall based on observed daily temperatures and precipitation. In this case, using pAWSSI allows analysis of the winter of 1880/81 based on existing records, even without direct snowfall and snow depth observations. Some sites do have a period of record that predates the winter of 1880/81 and allows for direct comparison between that winter and more recent ones; other sites only are available for one or a few winters and will be compared to the longer records of nearby stations to be placed into context.

Historical reconstructions of the Hard Winter were used to investigate the average synoptic-scale weather patterns. Gridded reanalysis data available through NOAA Earth Systems Research Laboratory (ESRL) were used to create composite synoptic plots (available online at www.esrl.noaa.gov/psd/data/20thC_Rean/). The data are from the Twentieth Century Reanalysis Project version 3 (Slivinski et al. 2019; Compo et al. 2011), which utilized synoptic pressure, sea surface temperature, and sea ice distribution to create a reanalysis that spans the period 1836–2015. Using the database, we constructed composites of synoptic fields relative to both a modern base period (1981–2010) and a late-1800s base period (1871–1900), depending on the application and field being investigated.

Overview of the winter of 1880/81

"A b-b-b-b-blizzard!" Ma chattered. "In Oc-October! I n-n-never heard of..."

—Laura Ingalls Wilder, *The Long Winter*

A number of specific events marked the winter of 1880/81 and appeared in documentation among the many sources of data. The winter began early, with a blizzard in eastern South Dakota and surrounding areas on 15–18 October 1880. While October blizzards are fairly rare (Edwards et al. 2014), they are even rarer in the eastern half of the state (Coleman and Schwartz 2017; Schwartz and Schmidlin 2002). In the October Blizzard of 1880, a surface low pressure system stalled in northwest Iowa and northeast Nebraska (Fig. 2); to its northwest,

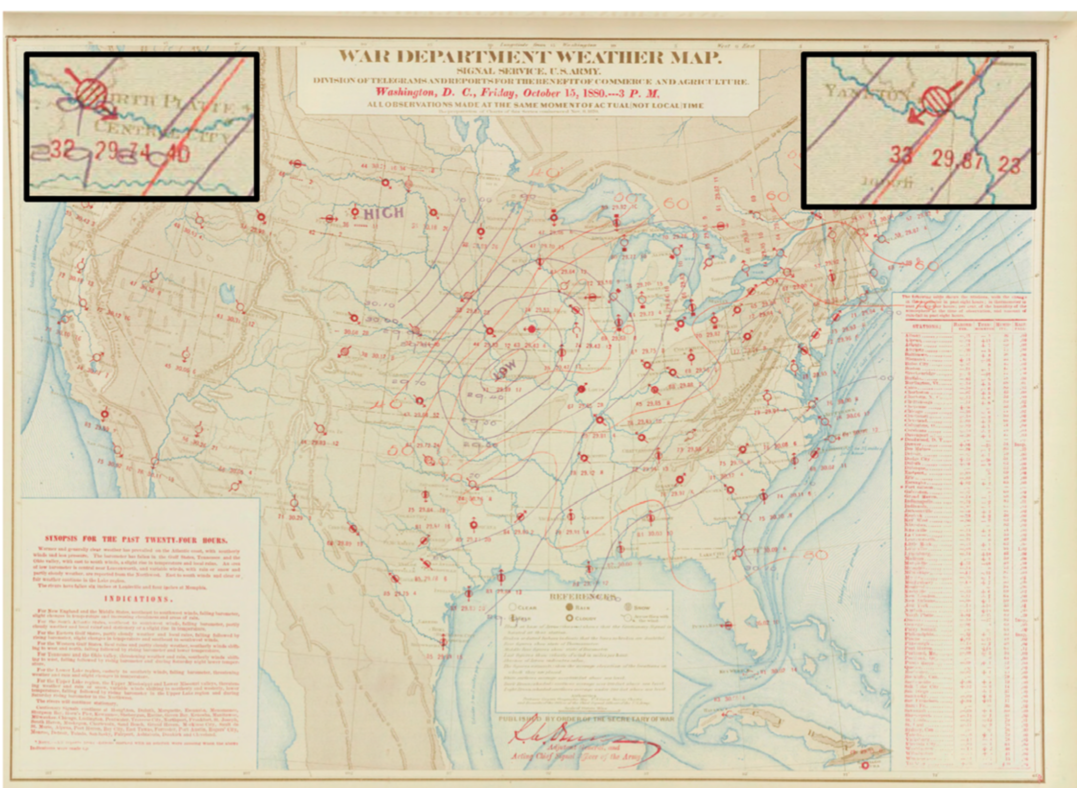

Fig. 2. Surface analysis at 2000 UTC (1500 eastern standard time) 15 Oct 1880. (top right) Yankton, South Dakota, and (top left) North Platte, Nebraska, stations are in insets.

a prolonged period of precipitation combined with a cold air pocket that brought subfreezing temperatures and gusty winds as a tight pressure gradient persisted. The combination of precipitation at subfreezing temperatures—snowfall—and strong winds due to a tight pressure gradient likely produced the blizzard conditions noted by Wilder. The stalled system allowed snowfall and blowing snow to last for two to three days in the region, with anecdotal reports such as Wilder's account supported by observational data from both continuous and CDMP station records.

Following the October blizzard, milder weather did provide a brief respite, but wintry weather returned by mid-November. Station observations indicate a number of snow and potential blizzard events in December, including Wilder's own "schoolhouse blizzard"—a blizzard that struck while she and her sister, Carrie, were at school and in which she found herself struggling to get home. Another blizzard that began on Christmas Day in eastern South Dakota also was documented accurately by Wilder (1940) as beginning late on Christmas Day. After a cold but relatively snow-free period in late December to early January, storm frequency increased from early January through the month of February. For the 59 days of January and February, among all CDMP sites in eastern South Dakota as well as nearby Des Moines, Iowa (DSM); Minneapolis–St. Paul, Minnesota (MSP); and Omaha, Nebraska (OMA), there were just 12 days with no probable snow reported at any sites in the region. Otherwise, snow fell in at least one observing location on all the other days.

Milder days began to mix into the observations beginning in March, but most days remained below freezing at all sites in the region. Snowfall frequency decreased, but we did infer a number of potential snow days across the region throughout the month. Cold conditions continued into the first half of April. The last suspected snow day occurred across the region on 10–12 April 1881. From 14 April onward, maximum temperatures rose above freezing each day and remained there throughout the spring, and even minimum temperatures only fell to near or below freezing readings at Fort Randall and Fort Sisseton, while no other suspected snow days occurred.

But was it the "hardest" winter ever in the area around De Smet—or, more specifically, was it the most severe, according to the AWSSI? Using the pAWSSI formulation of AWSSI, we reconstructed the winter of 1880/81 for a number of sites across the United States (Fig. 3), including both long-term sites and historical (CDMP) sites. The upward leaps in the pAWSSI for MSP and DSM (Figs. 4a and 4b, respectively) parallel the rapid increase in winter conditions. The October blizzards initiated pAWSSI accumulation at both sites, with small bumps away from the zero line; more aggressive accumulation began around 10–15 November.

Via the pAWSSI (Fig. 3), the Hard Winter ranked as the most extreme (highest point total) in the period of record at OMA; DSM; Dodge City,

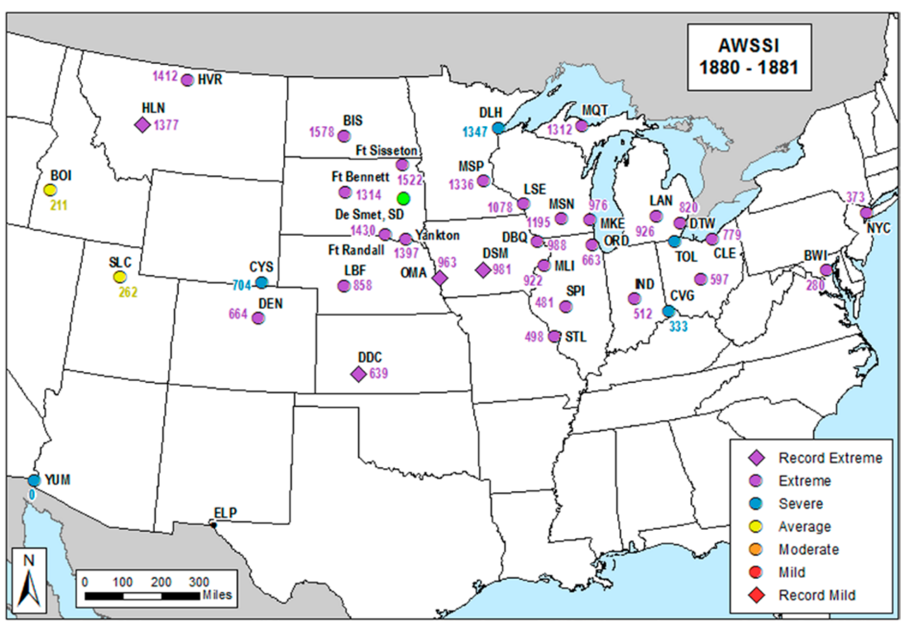

Fig. 3. pAWSSI calculated value at observing sites, with category color-coded based on the period of record for each site. Record extreme sites are denoted with a purple diamond marker. De Smet, South Dakota, is included on the map (green dot) for reference.

Kansas (DDC); and Helena, Montana (HLN), as well as the second most extreme of all winters in the period of record at MSP. Even as far east as Detroit, Michigan (DTW), and Lansing, Michigan (LAN), the winter ranked among the top five. While long-term station records are not available for the CDMP sites, their values can be compared to nearby records at Aberdeen, South Dakota (ABR); Fargo, North Dakota (FAR); Huron, South Dakota (HON); and Pierre, South Dakota (PIR), as well as cooperative observing stations near the CDMP sites (Boustead 2014), though it is worth noting that the periods of record for those sites did not include the colder decades from the late 1800s to early 1900s. In all cases, the CDMP sites are near the record values in those nearby locations. The accumulation at Fort Sisseton was remarkable considering data for the entire month of February were missing. The temperature component of pAWSSI at continuous sites (Boustead 2014) was the highest on record at both DSM and OMA, but fell all the way to ranking nineteenth at MSP; both DTW and LAN ranked as fourth highest. For the snow component of pAWSSI (Boustead 2014), MSP endured its highest snow ranking on record and DSM ranked as second highest, while OMA fell down to twelfth highest; DTW and LAN were in the top three and six, respectively. Among the CDMP sites, most of the accumulations for the snow component were well above normal but not near records; the exception is at Yankton, where the reading was closer to those record values.

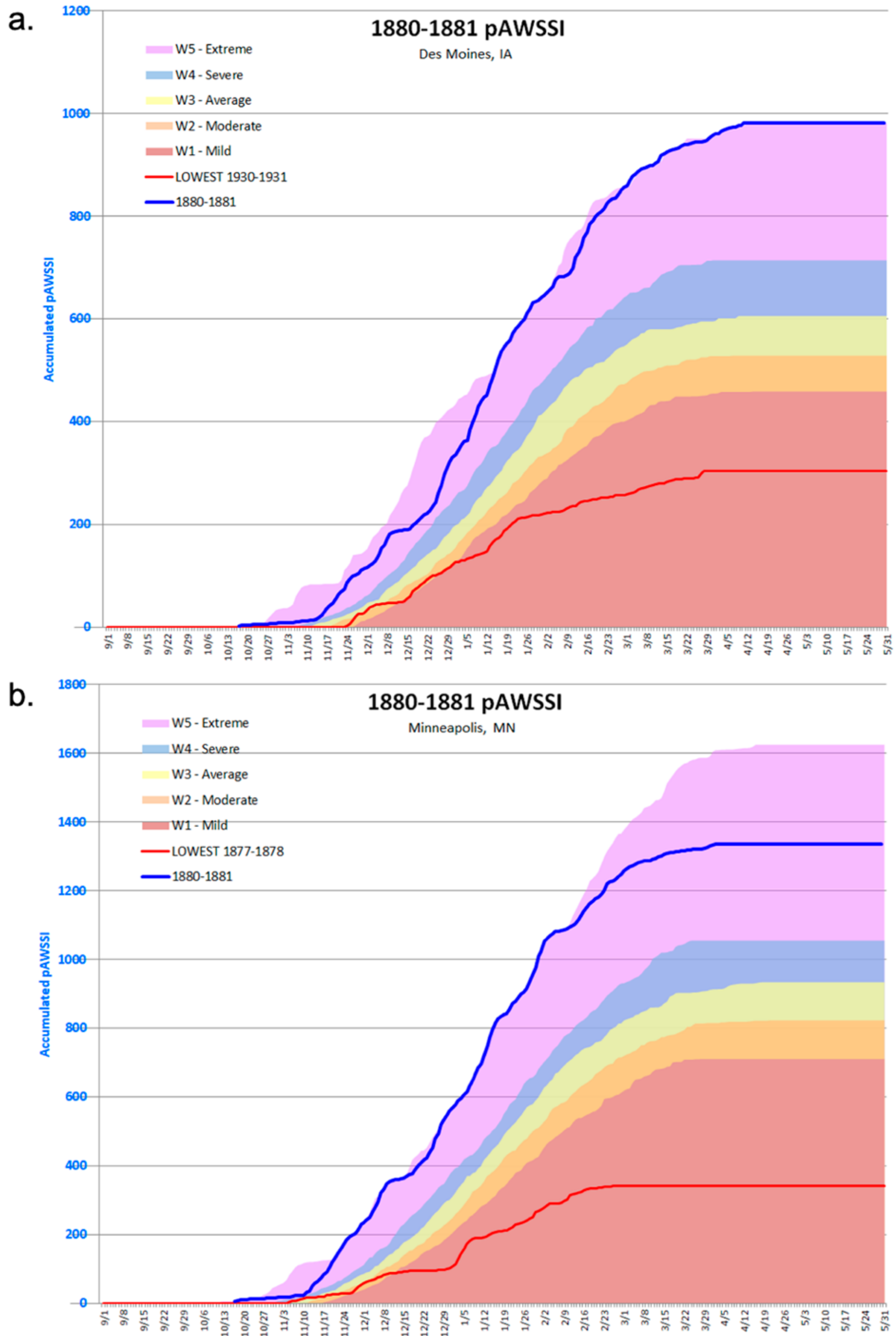

Fig. 4. pAWSSI accumulation through the winter of 1880/81 at (a) Des Moines, Iowa (DSM), and (b) Minneapolis–St. Paul, Minnesota (MSP). The total accumulation for 1880/81, along with the distribution of all five categories of AWSSI for the period of record, are included, as well as the record lowest year for reference.

In many locations, the more devastating impact of the Hard Winter arrived not just with the winter itself but with the spring that followed it, as rapid snowmelt contributed to both ice jam and snowmelt flooding across much of the north-central United States (Hoover et al. 1988). Ice jam flooding arrived first, in early to mid-April, as rain fell on top of snow and ran off, swelling rivers and breaking up thick ice covering them. Later, from April through May, rivers swelled again with copious amounts of runoff as the deep and extensive snowpack melted. The Missouri and Mississippi Rivers, as well as most of their tributaries upstream of their confluence, were swelled to record levels that stood for decades and, in a few locations, still stand as the flood of record or were broken only within the last decade. In the northern plains, the Red River and its tributaries also reached record to near-record readings. Towns such as Vermillion, South Dakota, and Green River, Nebraska, suffered severe damage due to floods (Hoover et al. 1988), prompting the movement of these settlements to higher ground or even spelling the end of some settlements.

Why so cold and snowy?

> The Indian meant that every seventh winter was a hard winter and that at the end of three times seven years came the hardest winter of all. He had come to tell the white men that this coming winter was a twenty-first winter, that there would be seven months of blizzards.
>
> —Laura Ingalls Wilder, *The Long Winter*

Analysis of the global teleconnection patterns during the winter of 1880/81 provides context for the synoptic-scale patterns and resulting temperature and precipitation patterns experienced in the central United States. While no teleconnection pattern ensures an outcome for a given winter (e.g., Deser et al. 2017, 2018), the global influences can increase or decrease the likelihood of some outcomes. Such is the case for the winter of 1880/81, with canonical patterns in association with some teleconnections but conditions outside the favored outcomes of others. Among the teleconnection patterns we can examine, either directly or by inference using composite patterns, are El Niño–Southern Oscillation (ENSO), the North Atlantic Oscillation (NAO), the Pacific decadal oscillation (PDO), the Tropical–Northern Hemisphere (TNH) pattern, and the Pacific–North American (PNA) pattern.

While it maybe be described as a weather reflection of other atmospheric and oceanic driving factors, the relationships between the NAO and North American weather patterns are strong and warrant examining here. NAO is strongly associated with temperature in the central Great Plains and also precipitation to some extent (Boustead 2014; Higgins et al. 2002). As with many teleconnection patterns, there is no single dataset that defines NAO, and many analyses exist (Hurrell and Deser 2009). This study utilized data from the Climate Analysis Section of the National Center for Atmospheric Research (Hurrell 2018), spanning 1864–2018. In this dataset, the NAO index is based on the difference in normalized sea level pressure (SLP) between Lisbon, Portugal, and Stykkisholmur/Reykjavik, Iceland. Hurrell normalized the sea level pressure anomalies at each station by dividing the seasonal mean pressure by the standard deviation of the long-term mean (1864–1983), using normalization to avoid the series being dominated by the greater variability of the northern station.

Temperatures tilt strongly toward the coldest third of climatology in the central United States in association with negative NAO. During the winter of 1880/81, one of the strongest negative NAO episodes since 1871 was in place, an analysis that was corroborated by Marsh (2000). Based on the Hurrell (2018) database of NAO index, the December–March (DJFM) average NAO index was −3.80, which was tied for the fifth-lowest DFJM NAO index from 1864–2018 (Table 2). The peak monthly station-based NAO index of −5.9 occurred in January 1881, which as of publication remains the lowest monthly index on record in any month, and the NAO index of −4.7 in October 1880 is the lowest for any October on record to date. The reflection of abnormally cold temperatures across the central and eastern United States during the winter of 1880/81, even relative to a colder base climate state of 1871–1900 (Fig. 5), is a reflection of the canonical negative-NAO pattern.

To investigate ENSO, the oceanic Niño index (ONI) dataset available from NOAA Climate

Prediction Center (CPC) spans the period from 1950 to present. ONI is widely used in NOAA applications of ENSO studies, as well as in the operational definition of El Niño and La Niña utilized by CPC, which defines an El Niño (La Niña) episode by the presence of a sea surface temperature (SST) anomaly greater (less) than 0.5°C (–0.5°C) in the Niño-3.4 region for five consecutive 3-month-average periods (Kousky and Higgins 2007). To examine conditions in 1880/81, however, we obtained reconstructed monthly SST anomaly data for the Niño-3.4 region based on Extended Reconstruction SST version 5 (ERSSTv5) data (Huang et al. 2017) for January 1871 through May 2019, which were then combined to produce ONI calculations to designate ENSO phases (McNoldy 2019).

Table 2. Lowest 10 monthly NAO index values and lowest 10 DJFM NAO values, from Hurrell (2018) data. The year in the DJFM rankings represents the last year of the winter, such that 1881 represents Dec 1880 through Mar 1881.

Month	NAO Index	Year	NAO DJFM
Jan 1881	**–5.9**	1969	–4.89
Dec 2010	–5.6	2010	–4.64
Aug 1877	–5.5	1895	–3.97
Dec 1878	–5.5	1936	–3.89
Jan 1963	–5.1	**1881**	**–3.80**
Feb 1895	–4.9	1917	–3.80
Aug 1885	–4.9	1996	–3.78
Oct 1880	**–4.7**	1963	–3.60
Sep 1976	–4.6	1870	–3.01
Dec 2009	–4.6	1965	–2.88

While not as pronounced as the negative NAO, the ENSO phase was weakly El Niño during the winter of 1880/81. ERSSTv5 data (McNoldy 2019) indicate a weak El Niño during the winter months, with 3-month average SST anomaly in the Niño-3.4 region at or above 0.5 from September–November 1880 through June–August 1881. The highest 3-month average SST anomaly of 0.8 occurred in March–May. Allan et al. (1991) corroborates the conclusion that a weak to moderate El Niño was in place during the winter of 1880/81. The winter of 1880/81 lacked canonical El Niño features like an unusually strong subtropical jet across the southern United States or Gulf of Mexico (Fig. 6).

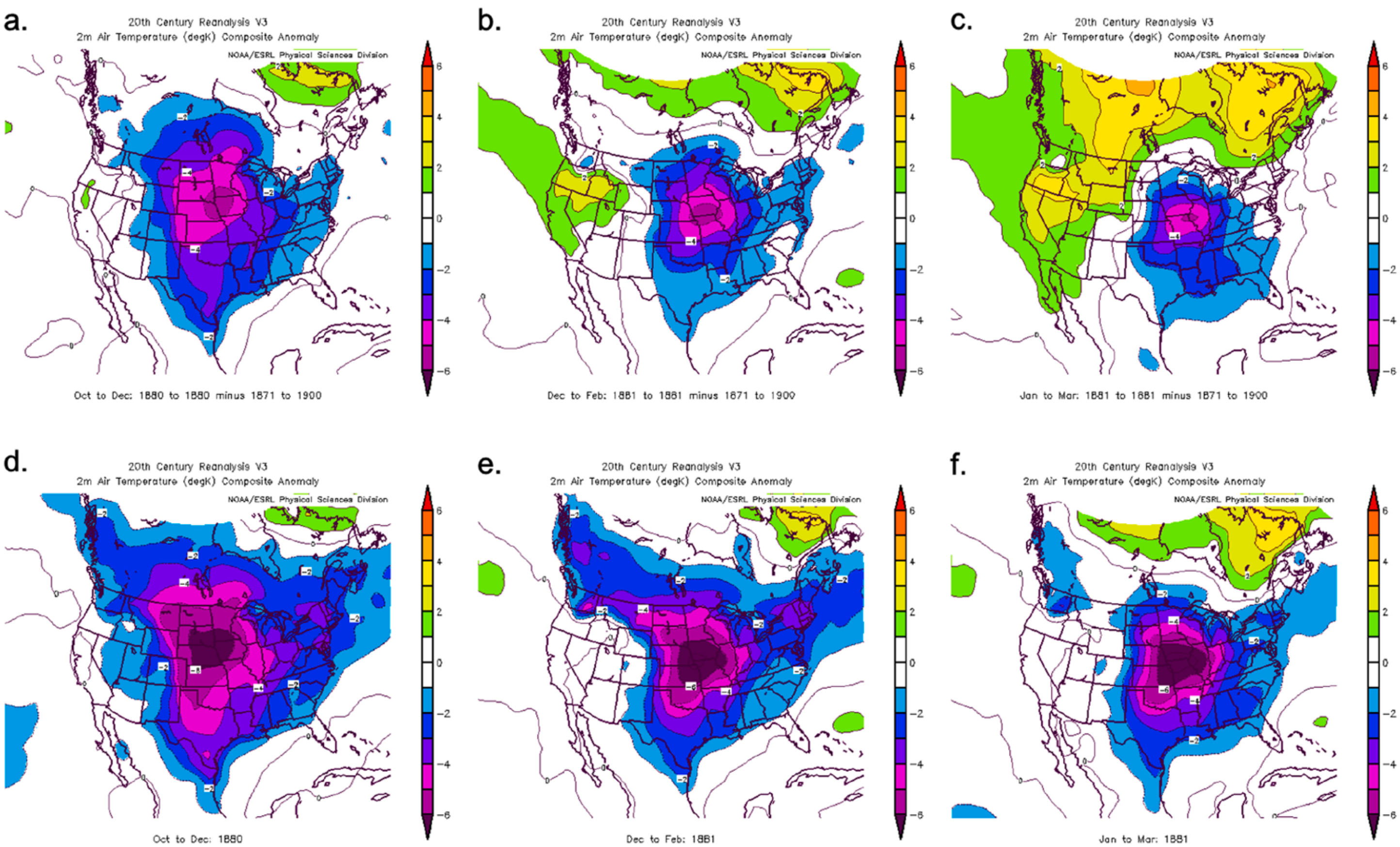

Fig. 5. Temperature anomalies (K) compared to an 1871–1900 base period for (a) October–December (OND) 1880, (b) December–February (DJF) 1880/81, and (c) January–March (JFM) 1881, as well as compared to a 1981–2010 base period for (d) OND 1880, (e) DJF 1880/81, and (f) JFM 1881.

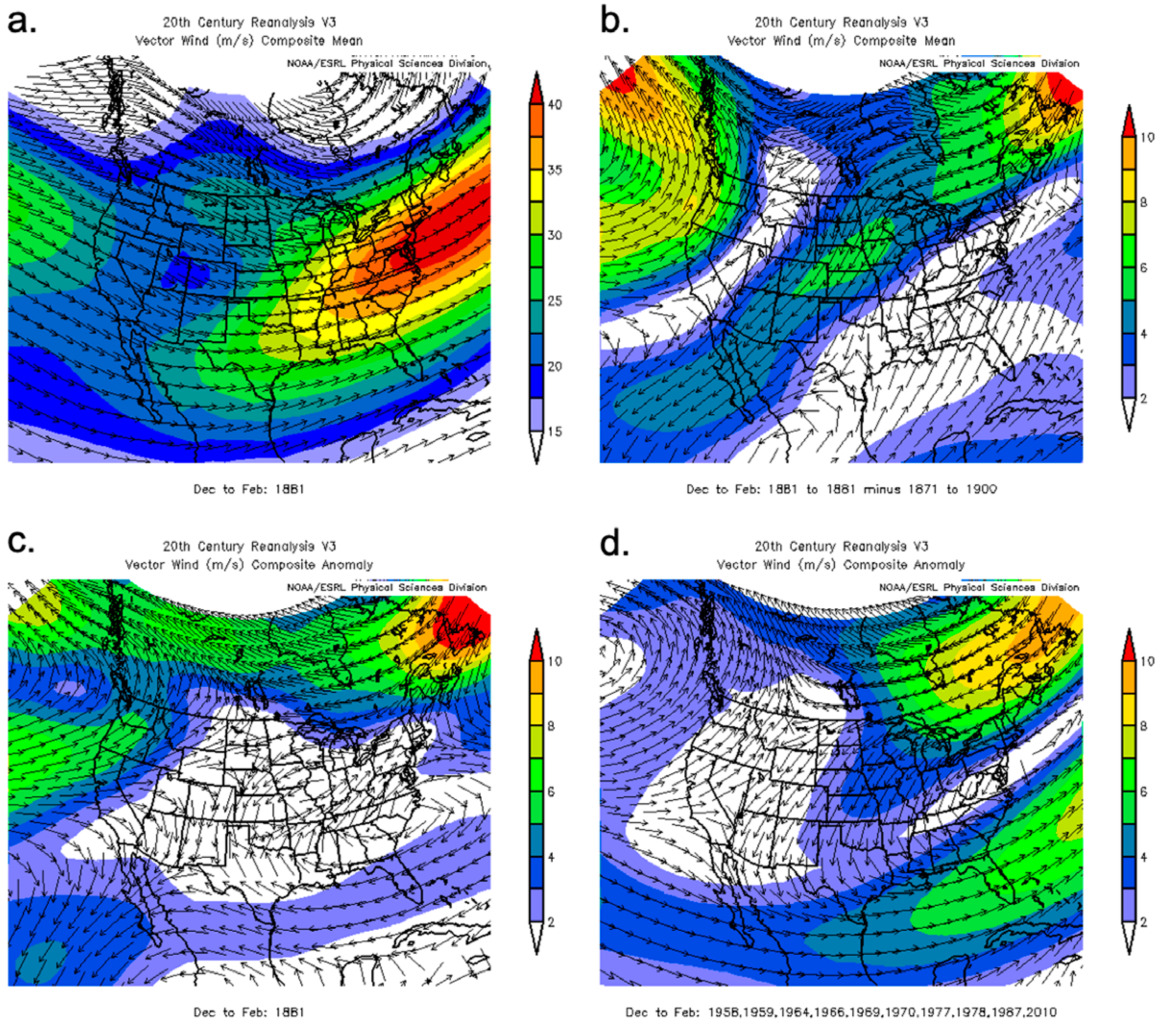

Fig. 6. For DJF 1880/81, 300-hPa wind (m s^{-1}) as (a) mean, (b) anomaly relative to 1871–1900 base period, (c) anomaly relative to 1981–2010 base period, and (d) averaged anomaly for all 10 years from 1950 to 2019 with both El Niño and negative NAO, relative to 1981–2010 base period.

While possibly less influential, other teleconnection patterns, as well as internal atmospheric variability, also influence the pattern for a given winter, including the winter of 1880/81. Some of those are related to ENSO enough that one phase is commonly associated with either El Niño or La Niña. The PDO, which is itself a combination of physical processes and not one singular entity (Newman et al. 2016), is often associated with El Niño when in a negative phase. PDO index data retrieved from NCEI (www.ncdc.noaa.gov/teleconnections/pdo/) support that the PDO was mostly negative to slightly positive from September 1880 through April 1881. The negative phase of PDO can be accompanied by negative temperature anomalies in the western Great Lakes to northern and central Great Plains and much of the Rockies. Again, the winter of 1880/81 lacked the classic features of PDO, such as an anomalous southerly component of the upper-level jet along the Pacific coast of North America (Fig. 6).

The TNH has increased its profile as another marker of ENSO-like patterns. In its negative phase, which is associated with El Niño, it also can be associated with negative temperature anomalies from the Great Lakes through the central Great Plains and toward the Rockies, along with unusually wet conditions from Minnesota across the Dakotas and toward the central and northern Rockies. While the TNH index is not available prior to 1950, analysis of the canonical negative TNH pattern indicates a reasonable match with the pattern in December–February 1880/81. In its negative phase, the TNH features anomalously low geopotential heights over the Gulf of Alaska and above-average heights in eastern Canada (Barnston and Livezey 1987; Barnston et al. 1991), a pattern loosely replicated in 1880/81 (Fig. 7). The upper-level jet corresponds to this pattern, with an anomalous northerly component along the Pacific coast of North America and an anomalous northeasterly component (suppressed jet) in eastern North America (Fig. 6).

Another pattern associated with wintertime impacts in interior North America, the PNA pattern, again tends to follow ENSO. Positive PNA tends to accompany El Niño and is more typically associated with above-normal temperatures in the northwestern half of the continental United States, including the central and northern plains to the Midwest and Great Lakes. The canonical 500-hPa geopotential height pattern for positive PNA includes anomalously low heights in the eastern Pacific Ocean and eastern United States, with anomalously high heights centered over western North America. As with TNH, a record is not available prior to 1950, but the 500-hPa geopotential height and 300-hPa wind patterns of December through February 1880/81 loosely and weakly reflect positive PNA (Figs. 6 and 7).

The combination of the discernible teleconnection patterns analyzed here add weight to the conclusion that this was a deeply anomalous pattern. The observed weather patterns were outside of canonical impacts associated with El Niño and negative PDO, though very much aligned with anticipated impacts associated with negative NAO and consistent to some degree with negative TNH and positive PNA patterns. That the winter conditions could become so cold and snowy for such a prolonged period of time across such a wide swath of central North America indicates that its driving forces were able to overcome the other teleconnections that could oppose such conditions.

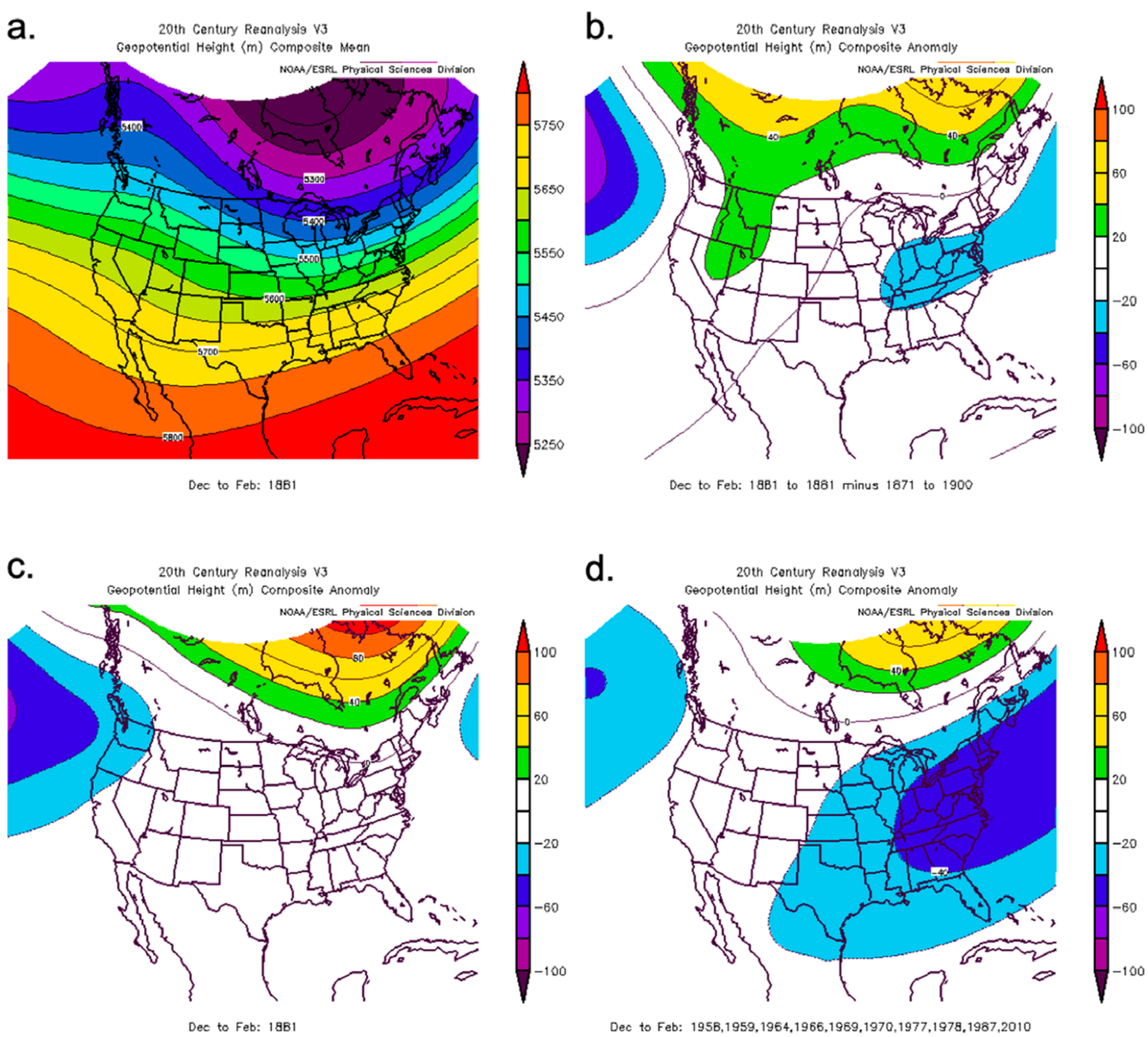

Fig. 7. As in Fig. 6, but for 500-hPa geopotential height (m).

Composite images of several common synoptic environmental parameters support the starkly negative temperature anomalies centered over the central United States during December through February 1880/81, relative to both an 1871–1900 base period (Figs. 5a–c) and 1981–2010 (Figs. 5d–f). We will focus on December through February as the center of the winter season, while acknowledging the even stronger anomalies in October through December and that cold anomalies continued into March. Off the coast of the Pacific Northwest, southerly 300-hPa wind anomalies indicate that the 300-hPa jet (Fig. 6) was rounding the base of an anomalous Gulf of Alaska 500-hPa low (Fig. 7). A downstream upper-level ridge was centered over the western United States and western Canada, with northwesterly flow in the central United States and central Canada and an upper-level trough over the Great Lakes to eastern Canada. While 500-hPa geopotential height anomalies were not strong when compared to either a modern (1981–2010) or historical (1871–1900) base period, the 300-hPa wind anomalies indicate a northeasterly anomalous component from eastern Canada through the Great Lakes and central Great Plains, corresponding to a weaker polar jet at that latitude. The pattern in the midlatitudes corresponds to the composite for all years since 1950 with a combined El Niño and negative NAO, despite differences with the subtropical jet stream.

Mean sea level pressure (MSLP) anomalies (Fig. 8) indicate a low-pressure anomaly off the coast of the Pacific Northwest, corresponding to the anomalously low 500-hPa geopotential heights in the Gulf of Alaska, as well as off the coast of the northeastern United States and eastern Canada. Anomalous high pressure extends from central Canada into the central United States, particularly along the central Great Plains to western Great Lakes. The ridging may

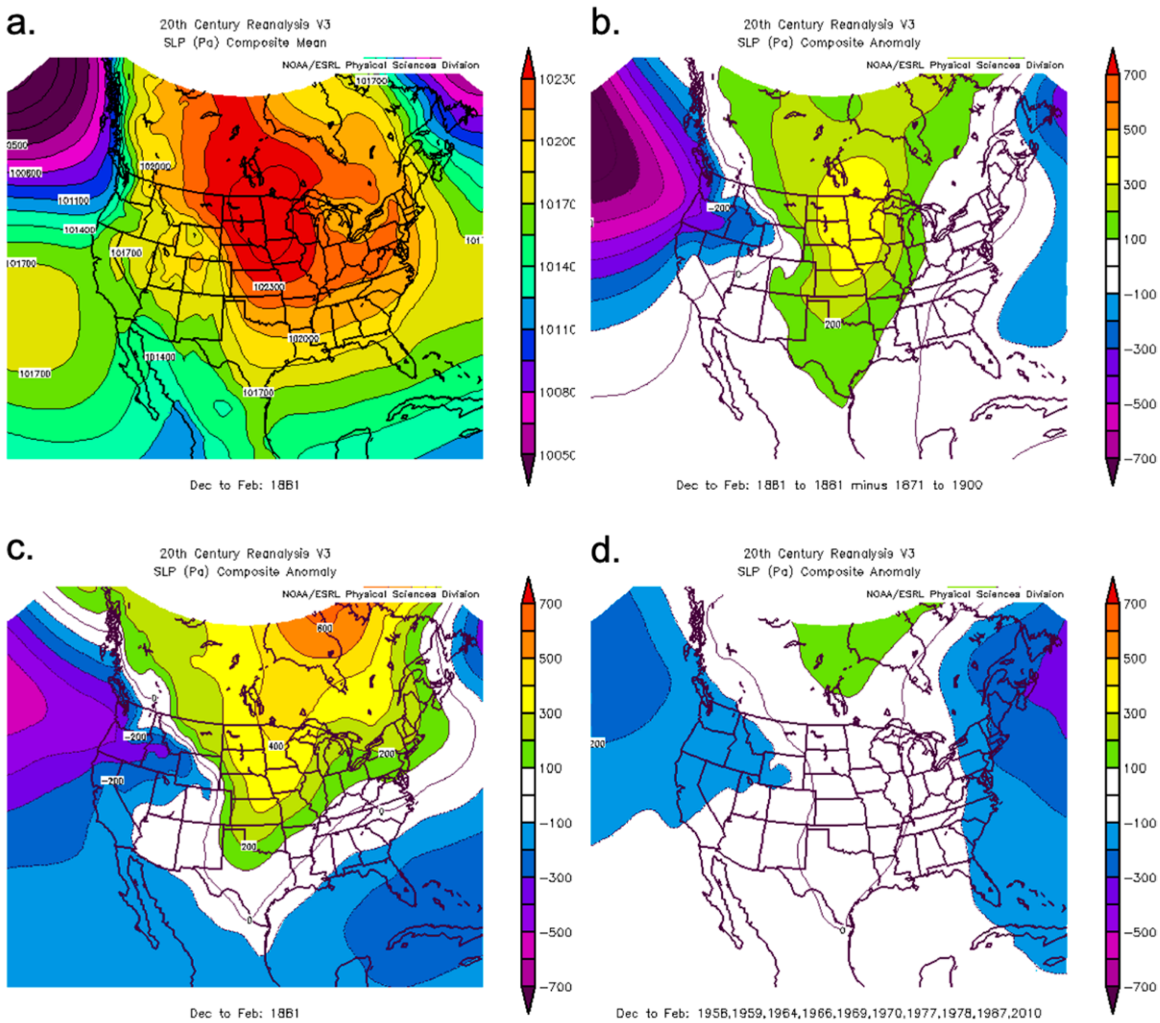

Fig. 8. As in Fig. 6, but sea level pressure (Pa).

correspond to the cold-air outbreaks pervasive through the Long Winter. The mean MSLP field indicates a pressure gradient dominant from central Nebraska and central South Dakota through western South Dakota, corresponding to increased surface wind speeds. Overall, compared to the composite of El Niño–negative NAO, the MSLP pattern is a more amplified version of the pattern.

Given the strongly anomalous cold temperatures marking December 1880 through February 1881, it is no surprise that many moisture fields also indicate reduced moisture capacity. That said, anomalously high 2-m relative humidity extended across much of the central United States, including into southeast South Dakota and southern Minnesota (Fig. 9). The increased relative humidity is influenced by both the lower temperatures and the presence of moisture near the surface, including potentially from precipitation as well as ambient water vapor. Relative humidity was anomalously high across much of the central to western United States relative to both base periods, with a core of most anomalous relative humidity centered in the High Plains and extending across Nebraska and Iowa, with South Dakota and southern Minnesota on the northern fringe of positive anomalies.

The combination of strongly negative NAO and varying strength of El Niño has occurred two other times since 1950, when modern ENSO data are available: 1968–69 and 2009–10. According to AWSSI analysis (Fig. 4 in Mayes Boustead et al. 2015), the winter of 2009–10 was in the extreme category (81st percentile and higher) from the northern Rockies through the central Great Plains, as well as in the mid-Atlantic, though the Great Lakes ranged from mild

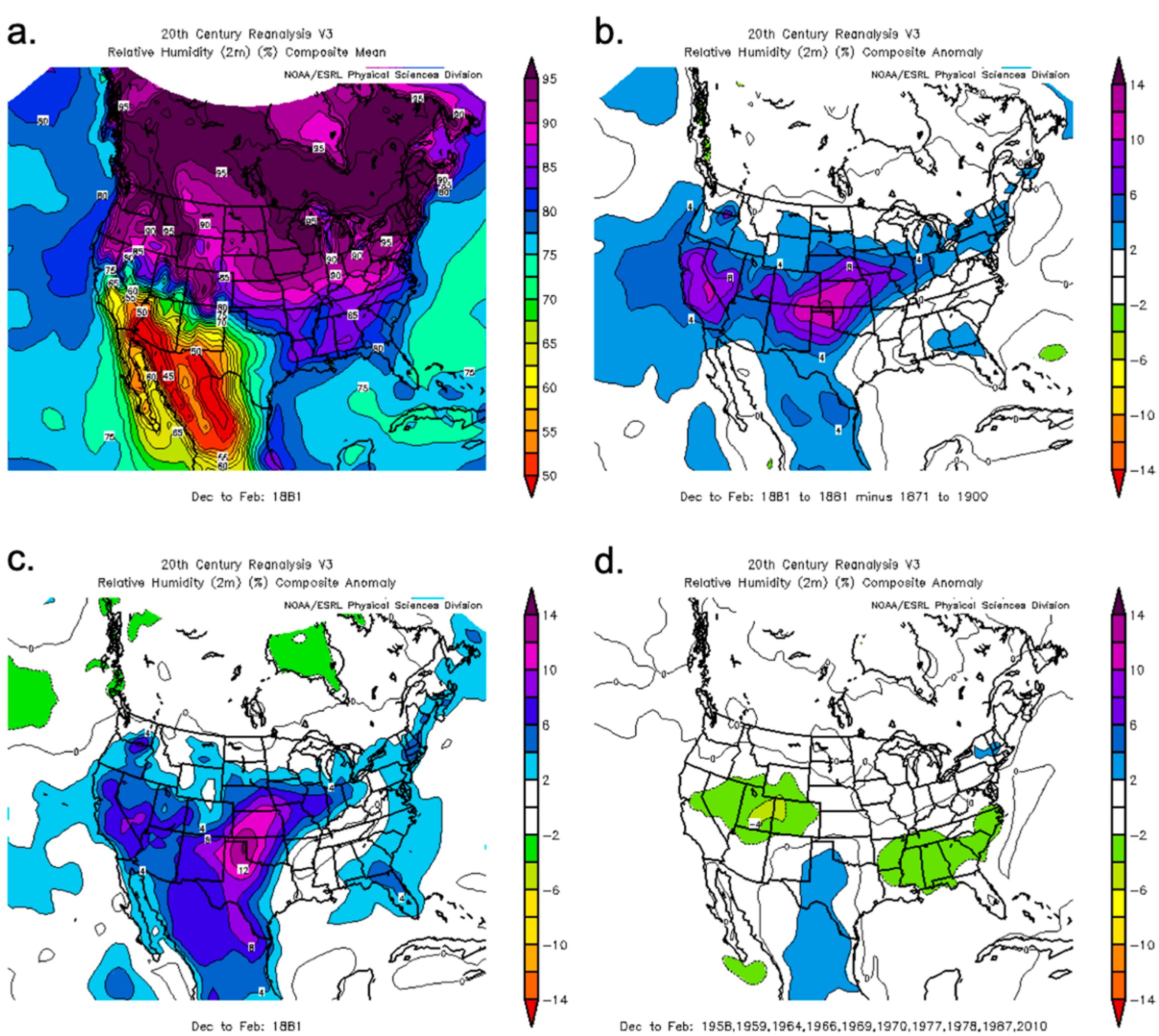

Fig. 9. As in Fig. 6, but 2-m relative humidity (%).

(20th percentile and lower) to severe (61st–80th percentiles) categories. Thus, while several stations were near record severity, the impact was more regional than in 1880/81. Similarly, the winter of 1968/69 (not shown) was in the extreme category from the northern Rockies to the northern and central Great Plains, with more variability in intensity across the Great Lakes to eastern United States. Additionally, the winters of 1976/77 and 1977/78 both were characterized by a weaker but still negative NAO and an El Niño; those two winters, especially 1977/78, rank among the most severe at nearly every station in the AWSSI analysis for the period 1951–2013. Among the 10 winters since 1951 with both negative NAO and El Niño, just two (1957/58 and 1986/87) had above-average total AWSSI at more sites than below average. Overall, the characterization of El Niño–negative NAO winters as more likely to be severe to extreme than average to mild in the central United States applies in most cases, particularly with a strongly negative NAO. Thus, the winter of 1880/81 fits observed patterns given the ENSO and NAO combination in place during the winter months.

Impacts and historical significance

> Laura tried to think of the good brown smell and taste of the beef for dinner tomorrow, but she could not forget that now the houses and the town would be all alone until spring. There was half a bushel of wheat that they could grind to make flour, and there were the few potatoes, but nothing more to eat until the train came. The wheat and the potatoes were not enough.
>
> —Laura Ingalls Wilder, *The Long Winter*

Though meteorological data were scarce for the Hard Winter, evidence of its severity exists in documents including historical archives, journals, town histories, and newspapers. Such anecdotal data are subjective and could be prone to exaggeration, as well as a lack of historical context or comparative value. That said, consensus of multiple voices from multiple sources about the nature of the winter provide confidence in conclusions about it. *The Long Winter* itself was a form of nonmeteorological documentation of the winter; confidence increases in its description of the winter of 1880/81 when matched to other documentary data, but it especially increases when matched to meteorological data. Wilder catalogued a series of events, from the October blizzard through the abrupt April thaw, that were supported by available meteorological observational data. Winter weather became not just a background, but rather an antagonist, threatening the survival of the Ingalls family.

Fig. 10. Cleaning snow away from the railroad tracks at Kelly's Cut, 0.8 km (0.5 mi) west of Sleepy Eye, Minnesota, in March 1881. Image courtesy of Chicago and North Western Archives.

Railroad impacts during the Hard Winter were documented in a number of sources, most notably Stennett (1905) and a reprint of Stennett (2007; Fig. 10). Wilder (1940) documents cessation of railroad activity in late December, with trains not returning to De Smet, South Dakota, until early May; the timeline corroborates with Stennett (1905) and other sources. During that gap, food and fuel could not be transported to settlers in the region via rail. Because of the abundant snowfall, overland transport also was hampered, though some travel via horse and horse-drawn sleigh was possible. In the spring, roads and rails remained impassable for weeks due to flooding.

Without an influx of food and fuel, settlers turned to their local communities to compile and share resources. Wilder (1940) describes her community doling out food supplies based on needs of the families, though fuel was sold in a more opportunistic fashion to the highest bidder. The Ingalls family, like many in the plains during that winter and others, twisted prairie hay into sticks to burn as fuel after coal supplies were exhausted; hay sticks burn rapidly and thus are not favorable as a sustained heat source. While some communities did send their seed wheat to a flour mill to grind, the Ingalls family and many others (Stennett 1905) were forced to grind their wheat in home coffee mills to make a wheat mush that could be baked into bread or cooked into a gruel (Hill 2014).

Casualty records for the Hard Winter are scarce, but no single event within the winter has been documented to have the casualty rate of the single blizzard in January 1888, often dubbed the "Children's Blizzard" and documented in Laskin (2004) and Kocin (1983). One can speculate that with harsh winter conditions beginning early and continuing through several months, those who lived in affected regions were not taken by surprise by individual blizzard events as they were in January 1888. Laura herself generalized to Rose in letters (Wilder 1937; Wilder 1938) that most townspeople stayed home and hunkered down for much of the winter. The impact of the near-starvation of many area settlers on their future health remains unquantified.

Native American pictoral calendars (such as winter counts) provide context to the Hard Winter, as well. Counting calendars typically pick the most prominent feature of interest as a label for the winter season. Not every winter with abundant snow or extensive cold may be labeled with such descriptors, but the presence of the descriptors does indicate that the features were notable or predominant in the location of the count keepers. The winter of 1880/81 was labeled "Hard winter deep snow" by the John K. Bear and Big Missouri calendars (Therrell and Trotter 2011; Howard 1976; Cohen 1939). Other winters with similar descriptors, according to Therrell and Trotter (2011), include "Deep snow" (1703, 1722–23), "Hard winter, deep snow" (1811–12), "The snow was very deep" (1827–28), "There was a great deal of snow on the ground" (1830–31), "Deep snow winter" (1841–42), and "Deep snow winter" (1877).

Meteorological records support the conclusion that the Hard Winter of 1880/81 was among the most severe since settlers of European descent arrived in the Great Plains region and began keeping records. In most instances, it was not the most severe winter on record at any one location, though it remains the coldest winter on record in a couple of locations and likely the snowiest winter among a subset of locations, when examining the rankings among temperature records, precipitation records, and AWSSI and pAWSSI totals. It was and remains, however, among the top five in severity—by one or more measures—in a wide swath from the central Great Plains and northern plains to the Great Lakes. The winter struck early in the settlement of Dakota Territory and surrounding locations, and many settlers were not prepared with enough food and fuel resources to endure a winter with no or limited transportation by road or rail. Contributing factors to the cold and snowy winter include the colder background climate in the 1880s, combined with one of the strongest negative NAO episodes on record and a weak to moderate El Niño. Other contributing factors not assessed in this study may exist, warranting continued studies of extreme winters such as the Hard Winter to help anticipate conditions that favor extreme winter severity. The Hard Winter found its way into historical memory via town histories, weather and flooding records, and one woman's fictionalized stories of her youth.

> There were houses in town, but not even a light from one of them could reach another. And the town was all alone on the frozen, endless prairie, where snow drifted and winds howled and the whirling blizzard put out the stars and the sun.
>
> —Laura Ingalls Wilder, *The Long Winter*

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