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16. Abstract

Adverse weather conditions are responsible for millions of vehicular crashes, thousands of vehicular deaths and billions of dollars in economic and congestion costs. Many transportation agencies utilize a performance or mobility metric to assess how well they are maintaining road access. This research focuses on the development of a winter severity index for the State of Nebraska (NEWINS). NEWINS is an event-driven index that was derived for the Nebraska Department of Transportation (NDOT) and its districts across the state. The NEWINS framework includes a categorical storm classification framework and climatological aspect to capture atmospheric conditions more accurately across the diverse spatial regions of Nebraska.

A ten-year (2006-2016) winter season database of meteorological variables for Nebraska was obtained from the National Centers for Environmental Information. Meteorological parameters were grouped into categories that subsequently provided a storm classification database. The NEWINS is based on a weighted linear combination to the collected database to measure severity statewide and across NDOT individual districts. The NEWINS results were compared to other meteorological variables, many used in other agencies' winter severity indices. This comparison verified the NEWINS robustness for the observed events for the ten-year period. For example, an assessment of the difference between days with observed snowfall versus days with accumulated snowfall revealed a 39% average reduction in days. Furthermore, the NEWINS results highlight the greater number of events during the 2009-2010 winter season, and the lack of events during the 2011-2012 drought year. The NEWINS also shows strong differences monthly and among NDOT districts across the state with a general decrease in events from the western to eastern NDOT districts. In addition, NEWINS storm classifications were compared to NDOT winter maintenance operations performance data for a sample winter season. Last, the 2016-17 winter season was computed to provide a testbed for the NEWINS procedure. It is expected that the NEWINS could help transportation personnel to efficiently allocate resources during adverse weather events, while balancing safety, mobility, and available budget. Further, the theoretical and practical contributions provided by the NEWINS can be used by other agencies to assess their weather sensitivity.

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DEVELOPMENT OF THE NEBRASKA DEPARTMENT OF TRANSPORTATION WINTER SEVERITY INDEX

Nebraska Department of Transportation (NDOT) 2016 Nebraska Transportation Research Council (NTRC) Materials, Pavement, Maintenance, Construction and Geotechnical (MPMC) Grant MPMC-06

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DISCLAIMER

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the writers and do not necessarily reflect the views of the Nebraska Department of Transportation or University of Nebraska.

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1. Introduction

Adverse cold weather conditions**,** most notably snow and ice, threaten surface transportation nationwide and impact roadway safety, mobility and maintenance costs (Pisano et al. 2008; RWMP 2018). During the period from 2005-2014, weather-related vehicular crashes accounted for 22% (1,258,978 crashes) of all reported crashes, resulting in 16% (5,897) of crash fatalities and 19% (445,303) of crash injuries. The United States Department of Transportation (USDOT) National Highway Traffic Safety Administration (NHTSA) estimates the total economic and societal cost of all vehicular crashes in 2010 in the United States was $836 billion (Blincoe et al. 2015; NHTSA 2018). This total includes $242 billion in maintenance and congestion costs and $594 billion from injuries and loss of life. Weather-related vehicular crashes alone may account for approximately $180 billion nationwide, given the relative percentage of such crashes.

Snow and ice reduce pavement friction and vehicle maneuverability, causing slower speeds and reducing roadway capacity. In fact, on snowy or slushy pavement, average arterial speeds decline by 30-40% (RWMP 2018). Highway speeds are reduced by 3-13% in light snow and by 5-40% in heavy snow. In addition to reduction in speed, lanes and roads can be obstructed by snow accumulation, which reduces capacity (i.e., traffic counts; Call 2011) and increases travel time delay. Snow and ice also increase road maintenance costs. Winter road maintenance accounts for roughly 20% of state departments of transportation (DOTs) maintenance budgets. Annually, state and local agencies spend more than two billion dollars on snow and ice control operations and millions of dollars to repair infrastructure damage caused by snow and ice (RWMP 2018). Given the nature of adverse cold weather events (e.g., snowstorms, ice storms), it is prudent to mitigate the impacts of such events on roadways and allocate resources to reduce their severity.

Evaluating the performance of mitigation strategies implemented as part of winter maintenance operations requires consideration of weather conditions, the state of the road network, the maintenance efforts undertaken for a given storm, the resulting road conditions and the interactions among these factors. The main challenge in evaluating this performance is that weather is inherently variable, and its variability complicates assessments of the relative efficiency and effectiveness of different winter maintenance operations (e.g., meeting levels of service standards, salt reduction, budget targets). Therefore, in pursuit of an evaluation metric for winter maintenance operations, a critical need is to assess the severity of individual storms through a winter severity index (WSI).

This analysis allowed development of a WSI for the Nebraska Department of Transportation (NDOT). This Nebraska Winter Severity Index (NEWINS) incorporates various surface and atmospheric data statewide across a ten-year period from July 2006 through June 2016. A literature review and companion survey provided critical background information regarding historic and present WSIs to aid the development of the NEWINS. From these data and subsequent analyses, a single, statewide value for each of the ten winter seasons was computed. A winter season is defined as any snowfall occurring between 1 July of the first year and 30 June of the subsequent year. For example, snowfall occurring between 1 July 2006 through 30 June 2007 would represent the 2006-07 winter season. The NEWINS is unique in that it is a meteorologically-based WSI, rather than related to transportation variables (e.g., accident rate) which may or may not be associated with weather conditions; however, the NEWINS framework is developed with consideration of road impacts and winter maintenance operations. The NEWINS was computed for the entire state of Nebraska and individual transportation maintenance districts within the state.

2. Literature Review

The available literature documenting existing WSIs is described in the following section. First, transportation specific WSIs (Table 2.1) are considered followed by discussion of additional meteorological WSIs. The transportation WSIs are organized based on their developmental similarities. Then, weather classification schemes are considered for the framework of the NEWINS. Last, winter maintenance operations and meteorological data sets used in existing WSIs and their limitations are considered.

a. Existing State Department of Transportation Winter Severity Indices

The literature documenting existing WSIs depicts a highly variable myriad of approaches typically developed for specific state DOTs. Table 2.1 summarizes the documented state DOT WSIs. In total, 19 states have made available documentation regarding their WSI. The remaining 31 state DOTs have either not made available documentation regarding their WSIs or do not have a WSI. Connecticut and Vermont have winter severity indices presently in development (Kipp and Sanborn 2013; Mahoney et al. 2015). Existing WSIs were often developed with relatively small data sets (e.g., less than six locations) and/or limited time frames (e.g., single month and/or winter season) with some noteworthy exceptions (Strong et al. 2005). Few WSIs have considered a winter storm classification framework, though several weather classification schemes exist (e.g., Fujita 1971; Simpson 1974; Kocin and Uccellini 2004; Cerruti and Decker 2011; Edwards et al. 2013). Automated Surface Observing System (ASOS) stations serve as the primary source for many WSIs in addition to Road Weather Information System (RWIS) stations (Strong et al. 2005). As such, air and road temperatures, snowfall, wind and freezing rain data are the most common/important variable inclusions in WSI development. Given the literature, it is important for most of these variables to be included, or at least considered, for the NEWINS.

Table 2.1. Summary of known documented state DOT WSIs.

WSI / States	Air Temp.	Road Temp.	Snowfall	Freezing Rain	Wind	Storm-Based	Sub-Regions	Dependent Variable
Strategic Highway Research Program (SHRP), KS, NH	X		X					None
IN, MN, WI	X		X	X			X	None
IL, MA, ME, PA, WA	X		X	X				None
NY, OK, UT	X	X	X	X	X	X		None
CA, MT, OR	X		X		X		X	Accident Rate
CO, ID		X	X		X	X		Grip
IA		X	X		X	X		None

b. Additional Winter Severity Indices

Many existing WSIs have been developed specifically for transportation-related purposes over relatively short time scales. Non-transportation WSIs have been developed for a wide array of uses such as deer hunting (MNDNR 2018) and are beyond the scope of this work; however, other meteorological WSIs with no specific intended use are mentioned herein. The Accumulated Winter Season Severity Index (AWSSI; Boustead et al. 2015) represents a purely climatology-based meteorological WSI. The AWSSI was developed for over 50 locations in the United States to provide seasonal winter severity values during the period from 1950 through present day (MRCC 2018). Daily points are assigned for specific locations in the AWSSI for predefined thresholds of minimum and maximum air temperatures, snowfall amounts and snow depth. These points are accumulated for an entire winter season to produce a final score that is associated with a given location's winter severity. These final scores are sorted into a categorical range to report final classifications (i.e., mild, moderate, average, severe, extreme). While the AWSSI is a temporally robust WSI, an important limitation is that it is computed on a point-by-point basis. It would be necessary to interpolate winter severity values between points computed by the AWSSI. Another caveat of the AWSSI is that it assesses conditions throughout the entire winter season, not specific to an individual winter storm. This aligns with many of the state DOT WSIs as well; however, winter maintenance operations are more aligned with specific events rather than an entire winter season. A critical discussion during the development of the AWSSI concerned the definition of a winter season. Boustead et al. (2015) note several different definitions for the beginning and end of a winter season. For example, meteorologically / climatologically winter is defined as the months of December, January and February; however, winter events commonly occur outside of this time period. Further, the onset and cessation of winter varies substantially geographically. The AWSSI defined the onset of a winter season once any one of three criteria were met: 1) daily maximum temperature below 32□ (0°C), 2) daily snowfall in excess of 0.1 in. (0.25 cm), or 3) any date after 1 December. Similarly, the AWSSI defines the end of a winter season based on when the last of any four criteria are satisfied: 1) daily maximum temperatures rise above 32□ (0°C), 2) no measurable daily snowfall, 3) snow depth drops below 1.0 in. (2.5 cm), or 4) any date after 1 March. An advantage of this winter season definition is that it provides a concise, strict period for consideration of overall winter severity. A limitation of this definition is that it could omit early/late season snowfalls and/or cold outbreaks. Defining the winter season is crucial for the success of any WSI.

The NWS is experimenting with a prototype Winter Storm Severity Index (WSSI; WPC 2018) to better communicate impacts associated with winter storms as part of its strategic plan calling for an increase in decision support services (Rutz and Gibson 2013). The framework for the WSSI uses a categorical framework to discuss storm severity and impacts (i.e., none, limited, minor, moderate, major and extreme). Unlike the AWSSI and many state DOT WSIs, the WSSI is specific to individual snowstorms. The components of the WSSI include snow amount, blowing snow, ice accumulation, flash freeze and ground blizzard. An event-driven, meteorological index is desirable for the development of the NEWINS and complements the ongoing refinement of the WSSI.

c. Winter Maintenance Operations and Weather Data

Existing WSIs and winter storm classifications rely on transportation and meteorological data. Transportation data from state DOTs includes accident rate, personnel hours, winter maintenance operations costs, traffic speeds and counts, and grip measurements (Strong et al. 2005; Jensen et al. 2013; Blincoe et al. 2015; Walsh 2016). State DOTs use their various data sets to assess the performance of their winter maintenance operations. In many instances, these data are also correlated with the state DOTs' WSI. Such WSIs that are closely related to transportation data (e.g., California, Montana, and Oregon; Strong et al. 2005) are limited in their ability to represent the meteorological conditions present. Meteorological WSIs such as the AWSSI and WSSI that exclusively consider surface and atmospheric weather parameters (Boustead et al. 2015; WPC 2018) are more suited to provide a meteorological diagnosis of severity. Such WSIs, though, rely on accurate meteorological data to be reliable.

For the development of the NEWINS, temperature, snowfall and wind data will be of critical importance. Road temperature and freezing rain data are omitted from the development of the NEWINS despite their desirability, due to their lack of reliability and availability for the entire ten-year study period. To capture the severity influences of individual events, a categorical storm classification framework (e.g., Kocin and Uccellini 2004; Boustead et al. 2015) is desirable over a seasonal/annual averaged approach (e.g., Strong et al. 2005). Despite Iowa's well documented WSI, it lacked consideration of areal coverage, precipitation rate/intensity, event duration and visibility, all of which were identified by NDOT personnel as desirable for inclusion in the NEWINS. Further, given the desire for the NEWINS to serve as an independent, meteorologically driven WSI, it is developed separate from winter maintenance operations data unlike other WSIs (e.g., California, Montana, Oregon; Strong et al. 2005). The strengths of the NEWINS is that it independently and explicitly considers the individual contribution of select meteorological parameters spatiotemporally during events, and the combined influence of these parameters yield a storm classification frequency distribution that is accumulated throughout a winter season. The NEWINS provides a finer resolution than the most existing WSIs by considering storm-level data. Further, the NEWINS focuses on meteorological conditions and can subsequently be compared independently with transportation and winter maintenance data.

3. Methods

The development of the NEWINS first considers the study region and data sets used to define the winter season database. Next, data management and quality control criteria were established to ensure a high-quality data set. Individual events were classified in accordance with the NEWINS categorical framework. Last, the NEWINS was computed and validated against winter maintenance performance data and additional meteorological data.

a. Study Region and Data

The study region for the development of the NEWINS was defined by the state boundaries of Nebraska. and the eight NDOT maintenance districts (Figure 3.1). Atmospheric variables for the NEWINS were obtained from the National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information (NCEI) for all ASOS stations within Nebraska (NCEI 2017a). Hourly data obtained from the ASOS stations included: station name, station elevation, station latitude, station longitude, wind speed, wind gusts, wind direction, cloud cover, visibility, present observed weather, air temperature, dew point temperature, sea-level pressure, station-pressure, and liquid-equivalent precipitation every hour, six hours, and 24 hours (NCEI 2017a; NWS 2018).

Snowfall observations for the NEWINS were obtained from the Global Historical Climatology Network-Daily (GHCN-D) sites within Nebraska (NCEI 2017b). The GHCN-D sites include data from the Community Collaborative Rain, Hail and Snow Network (CoCoRaHS 2018), the Nebraska Rainfall Assessment and Information Network (NeRAIN 2018), and the NWS Cooperative Observer Network (COOP 2018) observations. The majority of the GHCN-D sites record once-daily 24-hour snowfall amounts measured at approximately 0700 local time (LT); however, there can be some temporal variability in the actual measurement time. Given this variability, it is necessary to define a more consistent daily event period. There are approximately 1000 GHCN-D sites statewide.

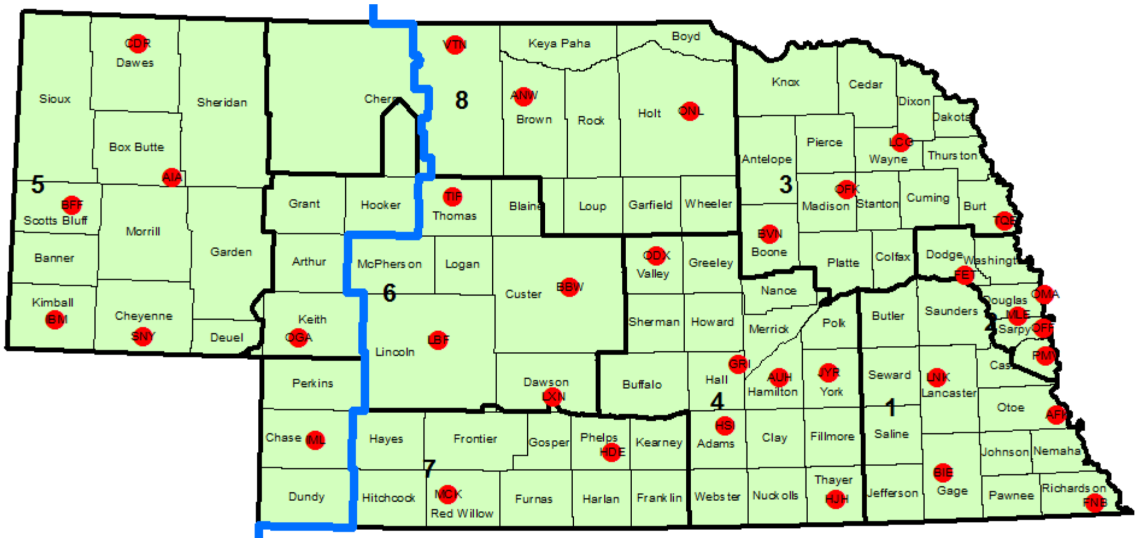

Figure 3.1. State of Nebraska counties with eight Nebraska Department of Transportation (NDOT) maintenance districts outlined in the thick black line. The 35 red dots indicate Automated Surface Observing System (ASOS) stations. The blue line represents the demarcation between Central (east, i.e., to the right) and Mountain (west, i.e., to the left) time zones.

b. Data Management and Quality Control

The abundance of data and having an objective to ensure stringent criteria for the analysis required various quality control procedures prior to the development of the NEWINS. Initially, 39 ASOS stations were included in the analysis; however, the quality control procedures reduced this number to 35 stations. Four ASOS stations were removed from the analysis because either: 1) the station did not have an operational precipitation identification sensor for all or part of the ten-year period or 2) the station had missing data for more than one entire winter season (Table 3.1). The ASOS stations in Columbus (KOLU) and Kearney (KEAR) were removed for failing to have an operational PI. ASOS stations in Blair (KBTA) and Wahoo (KAHQ) were removed since their available data did not extend through the entire ten-year period. Plattsmouth (KPMV) and Wayne (KLCG) each had a single winter season in which no data are available; however, the stations were included in the overall analysis. After quality control, the number of ASOS stations per NDOT district ranged from three stations in Districts 7 and 8 to six stations in District 4 (Figure 3.1). Spatially, the ASOS stations were distributed throughout the NDOT districts to reasonably capture the range of spatial variability in atmospheric conditions.

Hourly ASOS station observations were only incorporated into the analyses if the PI detected frozen precipitation (i.e., snow, ice pellets, mixed precipitation). Freezing rain was not considered in the analyses due to challenges associated with verification of ice accumulation (Changnon and Creech 2003) on spatiotemporal scales necessary for the research objective. For any 24-hour period, it is possible for only a single hour of observations to be included if that was the only instance of frozen precipitation identified. It is also possible for several discontinuous or continuous hours to be included if the precipitation was more intermittent or steady, respectively.

Quality control for these hourly frozen precipitation observations included the computation of dewpoint depression which is the difference between observed air and dewpoint temperatures. Hourly observations were removed from the winter season database if their dewpoint depression exceeded a difference of 30□ (16.7°C). As noted by Jiusto and Wieckmann (1973), extreme dewpoint depressions would not yield tremendous moisture availability for frozen precipitation. It is believed that such extreme dewpoint depressions would either be the result of sensor error or indicative of exceptionally light snowfall.

The GHCN-D sites used in the analysis were only selected if the observation was within an approximate 9 mi. (15-km) spatial threshold of an ASOS station (Figure 3.2). This was intended to ensure spatial consistency between the observed snowfall and the atmospheric conditions present during the snow accumulation period. Further, given the interest in snowfall amounts that would require a winter maintenance operations response (i.e., plowing of measurable snow), GHCN-D sites were removed if the snowfall observations were either missing. To be included in the NEWINS winter season database, GHCN-D sites had to report a measurable snowfall amount.

After quality control, the ASOS station and GHCN-D site data were subsequently merged into a winter season event database. For each date, hourly ASOS station observations in which frozen precipitation was detected were paired with 24-hour snowfall amounts from the GHCN-D sites that adhered to the spatial and temporal criteria. The snowfall observations and number of hours of ASOS station data for each date and location pair were used to derive a snowfall rate variable by dividing snowfall amounts by the number of hours with frozen precipitation observed. Given the derived nature of the snowfall rate variable, rates in excess of 3 in hr^{-1} (7.62

cm hr^{-1}) were removed, given the climatological infrequency of such extreme rates in Nebraska as previously documented by Rasmussen et al. (1999). Another derived variable was “district area” to provide a spatial context for the snowfall. District area was computed by dividing the number of ASOS stations reporting frozen precipitation on a given date in a particular NDOT maintenance district by the total number of ASOS stations possible within that district. Statistical parameters (i.e., minimum, maximum, mean, and median) were computed for all of the available variables from the ASOS stations, GHCN-D sites and derived variables.

Table 3.1. Automated Surface Observing System (ASOS) station information organized by NDOT Maintenance District. Removed column identifies stations omitted from the analysis after quality control.

NDOT District	Station ID	City Name	USAF ID	Lat. (°)	Lon. (°)	Elev. (m)	Time Zone	Removed
1	BIE	Beatrice	725515	40.28	-96.75	403	Central	
1	FNB	Falls City	725533	40.07	-95.58	300	Central	
1	LNK	Lincoln	725510	40.85	-96.77	364	Central	
1	AFK	Nebraska City	725541	40.60	-95.85	354	Central	
1	AHQ	Wahoo	720942	41.23	-96.60	374	Central	X
2	BTA	Blair	720405	41.42	-96.12	396	Central	X
2	FET	Fremont	725564	41.45	-96.52	367	Central	
2	OFF	Bellevue	725540	41.12	-95.92	319	Central	
2	OMA	Omaha	725500	41.32	-95.90	312	Central	
2	MLE	Millard	720308	41.20	-96.12	320	Central	
2	PMV	Plattsmouth	722291	40.95	-95.92	367	Central	
3	BVN	Albion	723441	41.73	-98.05	551	Central	
3	OLU	Columbus	725565	41.45	-97.32	440	Central	X
3	OFK	Norfolk	725560	41.98	-97.43	470	Central	
3	TQE	Tekamah	725527	41.77	-96.18	312	Central	
3	LCG	Wayne	722241	42.25	-96.98	436	Central	
4	AUH	Aurora	725513	40.88	-98.00	550	Central	
4	GRI	Grand Island	725520	40.97	-98.32	561	Central	
4	HSI	Hastings	725525	40.60	-98.43	591	Central	
4	HJH	Hebron	722124	40.15	-97.58	447	Central	
4	EAR	Kearney	725526	40.72	-99.00	649	Central	X
4	ODX	Ord	725524	41.62	-98.95	631	Central	
4	JYR	York	725512	40.90	-97.62	509	Central	
5	AIA	Alliance	725635	42.05	-102.80	1196	Mountain	
5	CDR	Chadron	725636	42.83	-103.10	1010	Mountain	
5	IBM	Kimball	725665	41.18	-103.68	1501	Mountain	
5	BFF	Scottsbluff	725660	41.87	-103.58	1203	Mountain	
5	SNY	Sidney	725610	41.10	-102.98	1307	Mountain	
6	BBW	Broken Bow	725555	41.43	-99.63	776	Central	
6	LXN	Lexington	725624	40.78	-99.77	734	Central	
6	LBF	North Platte	725620	41.12	-100.67	847	Central	
6	OGA	Ogallala	725621	41.12	-101.77	999	Mountain	
6	TIF	Thedford	722211	41.97	-100.57	892	Central	
7	HDE	Holdrege	725628	40.45	-99.32	705	Central	
7	IML	Imperial	725626	40.52	-101.62	998	Mountain	
7	MCK	McCook	725625	40.20	-100.58	782	Central	
8	ANW	Ainsworth	725556	42.57	-100.00	789	Central	
8	ONL	O'Neill	725566	42.47	-98.67	619	Central	
8	VTN	Valentine	725670	42.87	-100.55	788	Central	

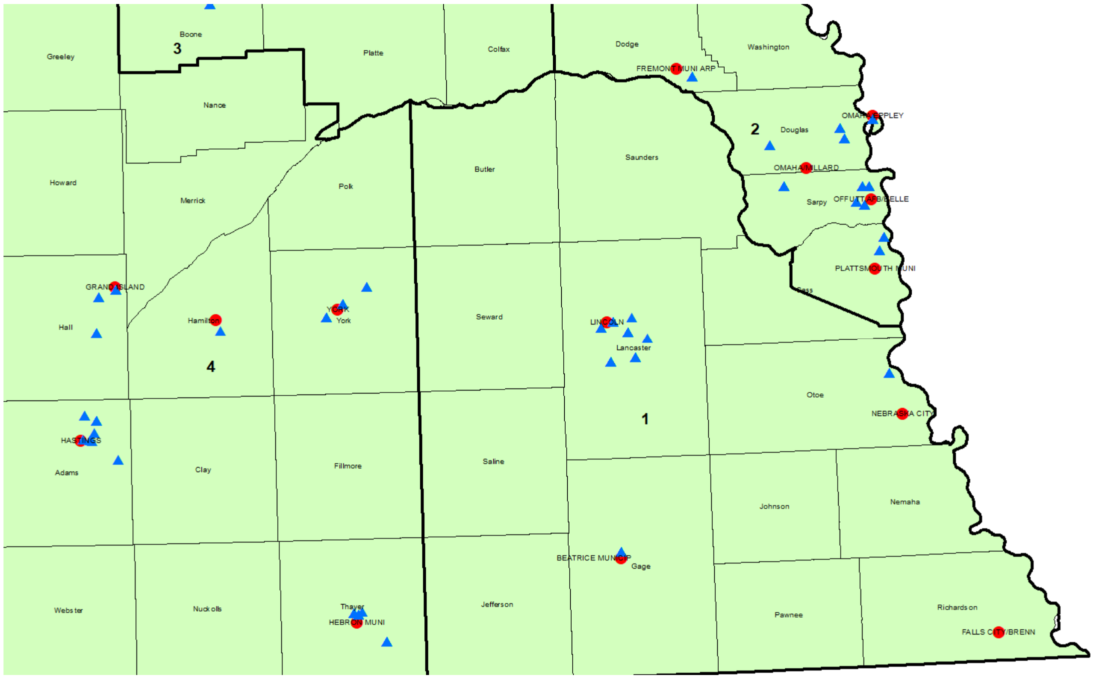

Figure 3.2. Southeast Nebraska counties with four Nebraska Department of Transportation (NDOT) maintenance districts visible outlined in the thick black line. The red dots indicate Automated Surface Observing System (ASOS) stations. The blue triangles show Global Historical Climate Network-Daily (GHCN-D) sites within approximately 9 mi. (15 km) of the ASOS stations that had sufficient data for the analysis.

c. Event Classification

In close consultation with the NDOT, the following variables were selected for the development of the NEWINS: 1) wind speed, 2) visibility, 3) air temperature, 4) duration of snowfall, 5) snowfall, 6) snowfall rate, and 7) district area. These variables were selected on the basis of their reliability from the instrumentation in addition to their importance / impact on NDOT's winter maintenance operations. For inclusion in the winter season database, these weather variables were averaged across each NDOT maintenance district from the available merged ASOS station and GHCN-D site data for each date. Surface (i.e., RWIS) temperature data are not sufficiently quality controlled (Walker and Anderson 2016) and were not available for the entire historical ten-year period and were therefore not included in the development of the NEWINS.

NDOT communicates extensively with its local NWS offices, and it was desirable to create a winter severity index that mirrored existing and possible future NWS products such as the SPC Convective Outlook Severe Thunderstorm Risk Categories (SPC 2016), experimental winter storm threat graphics (NWS 2016), or experimental winter storm severity index (WPC 2018). To this end, in consultation with NDOT, a categorial road weather and winter maintenance operations framework was developed to serve as the foundation for NEWINS (Table 3.2). The objective was to classify individual events within the winter season database into one of six categories from Category 1: trace, low impact storms, no winter maintenance operations activity to Category 6: high, significant impact storms, maximum winter maintenance operations activity with possible suspensions necessary due to safety concerns. This categorical framework was designed with specific consideration given to: 1) road access, 2) road conditions, 3) traffic speeds, 4) treatment operations, and 5) NDOT's winter maintenance performance objective. Road access is defined here as whether the road is open and travel by the public is permitted. Road conditions refers to the amount and type of precipitation accumulation within the driving lanes ranging from wet roads to impassable due to snow and ice coverage. Traffic speeds addresses the likely impact of the weather conditions on free-flow travel speeds. NDOT does not consider specific speed thresholds as a prerequisite to define a meteorological impact as impacts can occur at any speed (NDOT 2016, personal communication). Treatment operations refers to NDOT's winter maintenance operations activities including but not limited to chemical or material applications and mechanical plowing from snow removal. Lastly, NDOT's maintenance performance objective is to return roadway speeds to within 10 mph (16 km hr^{-1}) of the posted speed limit within six hours of precipitation cessation (NDOT 2016, personal communication). The likelihood of attaining that objective is incorporated into the NEWINS categorical framework.

From the road weather/maintenance operations framework, the seven weather variables selected for the NEWINS were placed into the same categorical framework (Table 3.3). Snowfall, air temperature and district area were distributed among the six categories to ensure near-even separation across the range of each variable. For example, each snowfall category range varies between 1-2 in. (2.5-5.1 cm) or each air temperature category contained a 5□ (2.8°C) range, excluding the minimum and maximum categories. Snowfall rate, duration and visibility were distributed among the six categories to ensure near-even frequency of observations within each category. Last, wind speed was distributed among the six categories loosely based on a modified Beaufort wind scale (SPC 2018). Table 3.4 shows the specific distribution of each weather variable and its categorical assignment. Cerruti and Decker (2011) proposed a similar approach in the development of their LWSS.

The NEWINS joins a vast array of WSIs, each with their own respective strengths and caveats. As seen from the SHRP WSI (Boselly et al. 1993), the best approach is for a WSI to be tailored specifically to the needs of the state DOT, since broad, versatile WSIs are often inaccurate due to their simplicity or lack of accounting for localized conditions. Given that the NEWINS was designed with respect to a decadal winter season database, it surpasses the SHRP WSI in terms of considering local and regional weather variability. Further, given the ten-year development period, the NEWINS is surpassed only by the AWSSI (Boustead et al. 2015) in terms of its historical period. Further, with the inclusion of 35 ASOS stations distributed throughout eight transportation districts, the NEWINS provides a greater station density than the AWSSI which considers only approximately 50 locations throughout the United States. Important differences between the NEWINS and AWSSI worth highlighting are that the NEWINS averages conditions across all ASOS stations within each district and throughout the state to derive a categorical frequency distribution and subsequent severity value. The AWSSI only computes a severity value for point locations (Boustead et al. 2015). Another important difference is that the AWSSI considers daily conditions throughout the entire winter season whereas the NEWINS only considers the conditions and impacts associated with specific snowstorms. One final difference is that the AWSSI establishes strict criteria to define the beginning and end of a winter season whereas the NEWINS is more flexible and allows for the precipitation type (i.e., frozen precipitation) to dictate the temporal boundaries of the winter season. Both approaches are relatively transferrable to other applications.

Table 3.2. NEWINS categorical road / maintenance operations impacts.

Variable	Category					
	Trace (1)	**Marginal (2)**	**Slight (3)**	**Enhanced (4)**	**Moderate (5)**	**High (6)**
Road Access	No Road Closures	No Road Closures	Minimal Road Closures	Occasional Road Closures	Numerous Road Closures	Significant Road Closures
Road Conditions	Wet Roads	Wet Roads	Spotty snow and ice-covered roads, otherwise wet	Roads partially covered with snow and ice	Roads completely covered with snow and ice	Impassable roads covered with snow and ice
Traffic Speeds	No speed reduction	No speed reduction	Minimal speed reduction	Considerable speed reduction	Significant speed reduction	Significant speed reduction
Treatment Operations	No Deployment	Minimal Deployment	Partial Deployment	Full Deployment	Full Deployment	Full Deployment with Possible Operation Suspension
Winter Maintenance Performance Objective	Met	Met	Likely Met	Unlikely Met	Not Met	Not Met

Table 3.3. NEWINS categorical weather variable impacts.

Variable	Category					
	Trace (1)	**Marginal (2)**	**Slight (3)**	**Enhanced (4)**	**Moderate (5)**	**High (6)**
Snowfall	Dusting	Light	Light	Considerable	Heavy	Significant
Snowfall Rate	Minor	Minor	Elevated	Elevated	Intense	Extreme
Wind Speed	Light	Light	Moderate	Moderate	Strong	Strong
Air Temperature	Above Freezing	Near / Below Freezing	Below Freezing	Below Freezing	Below Freezing	Well Below Freezing
District Area	Single Location	Partial	Less Than Half	More Than Half	Majority	Complete
Duration	Short	Short	Medium	Medium	Long	Long
Visibility	Good	Good	Fair	Mid-Range	Poor	Poor

Table 3.4. NEWINS categorical weather variables sorted into categorical classifications.

Variable	**Category**					
	Trace (1)	**Marginal (2)**	**Slight (3)**	**Enhanced (4)**	**Moderate (5)**	**High (6)**
Snowfall (in.) ***(cm.)***	< 1.0 *(< 2.4)*	< 2.0 *(< 4.9)*	< 3.0 *(< 7.5)*	< 5.0 *(< 12.6)*	< 7.0 *(< 17.5)*	≥ 7.0 *(≥ 17.5)*
Snowfall Rate (in. hr^{-1}) ***(cm hr^{-1})***	< 0.2 *(< 0.4)*	0.2 *(< 0.6)*	0.3 *(< 0.9)*	0.4 *(< 1.1)*	< 0.6 *(< 1.5)*	≥ 0.6 *(≥ 1.5)*
Wind Speed (mph) ***(ms^{-1})***	≤ 6.0 *(≤ 2.7)*	≤ 11.0 *(≤ 4.9)*	≤ 18.0 *(≤ 8.1)*	≤ 24.0 *(≤ 10.7)*	≤ 31.0 *(≤ 13.9)*	> 31.0 *(> 13.9)*
Air Temperature (°F) ***(°C)***	> 35 *(> 1.7)*	≤ 35 *(≤ 1.7)*	≤ 29 *(≤ -1.7)*	≤ 25 *(≤ -3.9)*	≤ 19 *(≤ -7.2)*	< 15 *(< -9.4)*
District Area (Fraction Area)	≤ 0.2	< 0.4	< 0.5	< 0.75	< 1.0	1.0
Duration (hr.)	≤ 2.0	≤ 3.0	≤ 4.0	≤ 5.0	≤ 8.0	> 8.0
Visibility (mi.) ***(km)***	> 5.0 *(> 8.0)*	≤ 5.0 *(≤ 8.0)*	< 4.0 *(< 6.4)*	< 3.5 *(< 5.6)*	< 3 *(< 4.8)*	< 2.5 *(< 4.0)*

d. Winter Severity Index Computation and Applications

An important challenge to overcome with the categorical framework is that for any given event during a winter season, the magnitude of the weather variables can be quite different for a single maintenance district or across several maintenance districts experiencing the same event. In consultation with NDOT personnel, appropriate weights for the seven weather variables were developed so that a linear combination would yield a single storm categorical classification (Table 3.2) for each event at the district level. Eq. (1) provides the general form of the NEWINS event category. Each weather variable is averaged across the maintenance district and assigned a category based on Table 3.4. Categories for each weather variable are subsequently used in Eq. (1) in lieu of the raw data. This results in the NEWINS event categorical frequency distribution. Table 3.5 provides the final weights assigned to each weather variable category.

$$Category = \beta_1 \times Snowfall\ Cat + \beta_2 \times Snow\ Rate\ Cat + \beta_3 \times Wind\ Speed\ Cat + \beta_4 \times Air\ Temp\ Cat + \beta_5 \times District\ Area\ Cat + \beta_6 \times Duration\ Cat + \beta_7 \times Visibility\ Cat \quad (1)$$

From the categorical frequency distribution, the final NEWINS value is computed according to Eq. (2).

$$NEWINS = \frac{\sum(Category \times Frequency)}{100} \quad (2)$$

This provides the final statewide NEWINS value for a given season. It can also be used to compute an NEWINS value for each individual NDOT maintenance district which can be summed to yield the same final statewide value. The mathematical linear combination / parameter weighting framework of the NEWINS is similar to that used by Wisconsin, Minnesota, Indiana, Illinois, and Pennsylvania for their respective WSIs (Cohen 1981; Strong et al. 2005). An important difference, though, is that the mathematical framework incorporates a categorical framework. Unlike the aforementioned WSIs, though more similar to Iowa (Carmichael et al. 2004; Nixon and Qui 2005; Strong et al. 2005; Qui 2008; Walsh 2016), the NEWINS is an event-based WSI. It considers specific snowstorms in its computation. Limitations of Iowa's WSI, though, are that it does not consider a complete set of relevant variables important to winter maintenance operations (e.g., areal coverage, duration, snowfall rate, visibility) unlike the NEWINS. In terms of a dependent variable, the NEWINS is substantially different from the California, Montana, Oregon, Idaho and Colorado WSIs (Strong et al. 2005; Jensen et al. 2013; Walsh 2016) in that it is a pure meteorological index (like the AWSSI) and not related to accident rate or grip measurements. It is feasible for future correlation of the NEWINS to transportation-related variables; however, no such data are presently available over the entire historical period.

To ensure the reliability of the NEWINS and its components, several different indices were computed and subsequently compared to the NEWINS. An initial snowfall-based index was computed statewide and for each NDOT maintenance district by comparing the number of days with observed frozen precipitation as identified from the ASOS station data (i.e., snow days) to the number of days with observed snow accumulation as identified from the GHCN-D site data (i.e., snowfall days). A second snowfall-based index was computed statewide and for each maintenance district comparing each winter season's total accumulated snowfall to the ten-year average snowfall accumulation. For an independent climate-based index, temperature and precipitation anomalies were obtained from the NOAA NCEI climate division (Figure 3.3) data (ESRL 2017). Nebraska contains eight climate districts which roughly align with NDOT's eight maintenance districts. Additionally, applications of the NEWINS were performed including an example correlation of 2015-16 winter season storm classification to available NDOT traffic speed data, and an analysis of a winter season (i.e., 2016-17) beyond the decadal winter season database used for the development of the NEWINS.

Table 3.5. NEWINS event category linear combination equation weights.

Parameter	NEWINS Parameter Weight
Snowfall Category (β_1)	0.80
Snow Rate Category (β_2)	0.05
Wind Speed Category (β_3)	0.05
Air Temp Category (β_4)	0.05
District Area Category (β_5)	0.02
Duration Category (β_6)	0.02
Visibility Category (β_7)	0.01

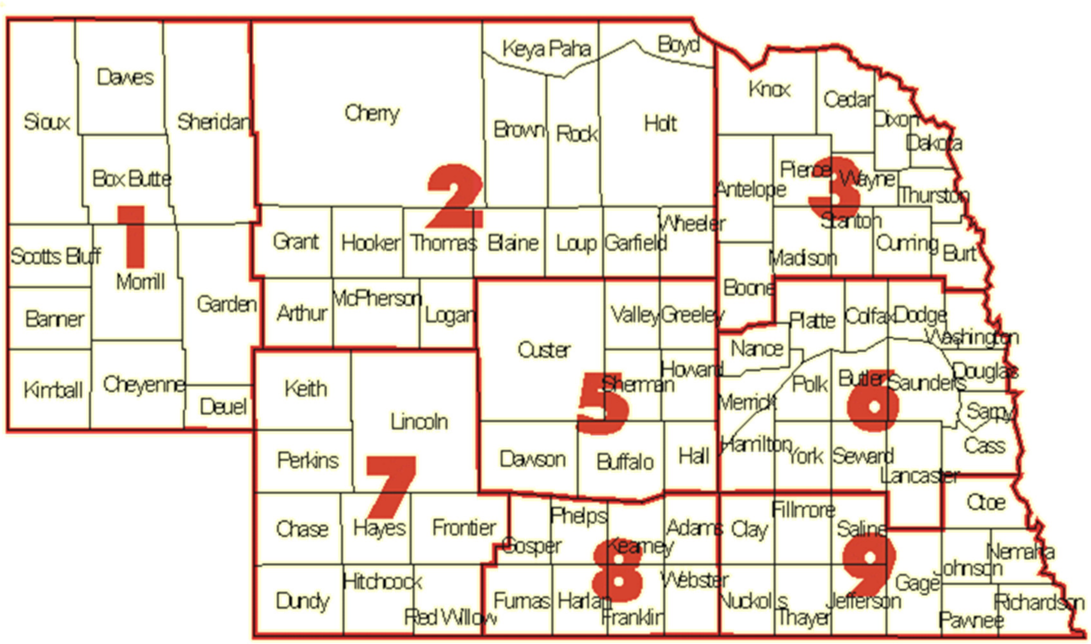

Figure 3.3. NOAA NCEI Nebraska climate districts (CPC 2018).

4. Results and Discussion

Multiple tasks led to the development of the NEWINS and are presented by subsections within this chapter. To provide context and highlight the strengths of the NEWINS, the first task was a comparison analysis of various meteorological indices. The second task was the development and refinement of the NEWINS event classification and mathematical formulas. Furthermore, the third task provides a more in-depth consideration of the NEWINS at the statewide and district levels given the intended use of the NEWINS by NDOT. To apply the NEWINS, the fourth task compared the NEWINS to 2015-16 winter maintenance performance data across NDOT's Interstate 80 test sections. The final task will ensure the reproducibility of the NEWINS methods by computing and comparing the 2016-17 winter season values to the decadal (i.e., 2006-2016) winter seasons.

a. Comparison Indices

Comparison indices were computed to provide additional context for the NEWINS. Some severity indices (e.g., Cohen 1981; Kocin and Uccellini 2004; Strong et al. 2005) consider the spatial distribution of accumulated snowfall throughout an event or entire winter season. Therefore, snowfall-based indices were computed statewide and for each NDOT maintenance district by comparing the annual frequency distribution between the number of days with observed frozen precipitation as identified from the ASOS station data (i.e., snow days) and the number of days with observed snow accumulation (i.e., snowfall days; frozen precipitation accumulation of 0.1 in. [0.25 cm] or greater) as identified from the GHCN-D site data within 15 km of an ASOS station (i.e., snowfall days) for each winter season (Figure 4.1 and Table 4.1). An important caveat to note with this approach is that snow reported at a single ASOS station or GHCN-D site within a NDOT District of any duration would be sufficient to count as a snow or snowfall day, respectively. Statewide, the decade average number of snow days was 116.9 days (Figure 4.1 and Table 4.1). This indicates that for the ten-year period, on average, somewhere within the state receives snowfall nearly one-third of the year. The annual variability in snow day frequency ranged from 76 days during the 2011-12 winter season to 146 days during the 2009-10 winter season. By this measure, it can be stated that 2009-10 was the most severe winter season in the ten-year winter season database and 2011-12 was the least severe if only number of days that snow was observed is taken into consideration. At the NDOT maintenance district level, the decade average snow day frequency ranged from 44.4 days in District 1 (i.e., southeast Nebraska) to 74.1 days in District 5 (i.e., western Nebraska). Inter-annual variability in snow day frequency can be seen among the maintenance districts as well. For example, District 3's highest snow day frequency occurred during the 2012-13 winter season whereas the statewide highest was the 2009-10 winter season (Table 4.1). All districts observed their lowest snow day frequency during the 2011-12 winter season. This consistency among the districts suggests that the 2011-12 winter season was a lower frozen precipitation year relative to the others. Snow day anomalies (Table 4.2) were computed statewide and for each district as well. Statewide, the largest positive snow day anomaly occurred during the 2009-10 winter season and the largest negative snow day anomaly occurred during the 2011-12 winter season. For the maintenance districts, while the largest negative anomalies were consistent with the 2011-12 winter season, the positive anomalies were more variable. For example, District 1's largest positive snow day anomalies occurred in both the 2007-08 and 2009-10 winter seasons (Table 4.2). Similarly, District 8's largest positive anomaly occurred during the 2013-14 winter season (Table 4.2).

Snow days considered only observed frozen precipitation whereas snowfall days considered frozen precipitation accumulation. Snowfall days statewide averaged 71.3 days during the decade (Figure 4.1 and Table 4.3). The statewide range in snowfall day frequency was a minimum of 44 days during the 2011-12 winter season and 87 days during the 2007-08 winter season. By this measure, the 2007-08 winter season was the most severe during the period, while the 2011-12 winter season was the least severe. This difference would suggest that while there was a higher frequency of days with snow during the 2009-10 winter season, that snow tended not to accumulate on all days. Further, this difference in the most severe winter season between the two methodologies highlights the necessity of a more robust winter severity index that assesses details regarding individual storms. Among the districts, decadal average snowfall day frequency ranged from 22.9 days in District 1 to 47.0 days in District 5. This result paired with the snow day frequency demonstrates that the eastern part of the state receives on average approximately half the number of snow/snowfall days as the western part of the state. This quantification could be beneficial to NDOT for the purposes of budgetary planning among the different maintenance districts. Snowfall day anomalies (Table 4.4) further agree with the 2011-12 winter season as the least severe during the period with the largest negative anomaly. The snowfall day anomalies would rank the 2007-08 winter season as the most severe and the 2009-10 winter season, which observed the largest positive anomalies in snow day frequency, would be ranked third behind the 2013-14 winter season.

The percentage reduction between snow and snowfall days is an important statistic for winter maintenance operations (Table 4.5). NDOT personnel state that their operations prepare for a forecast threat of snow and deploy once snow begins (i.e., operations deploy on snow days). The statewide decadal average percentage reduction between snow and snowfall days suggests that 39.0% of the times it snows, the snow does not accumulate. From a winter maintenance operations standpoint, this could equate to a savings in unnecessary deployment expenses. The statewide percentage reduction ranges from 30.4% during the 2015-16 winter season to 45.6% during the 2006-07 winter season. At the district level, decadal percentage reductions range from 36.6% in District 5 to 57.8% in District 8. The high variability in these results further highlights the need for a winter severity index which captures individual events during the winter season rather than a frequency distribution of days with snow falling versus accumulating.

One final snowfall-based index was to observe the winter seasonal accumulated snowfall (Table 4.6). The decadal average statewide snowfall was 42.6 in. (108.2 cm) with a range from 24.1 in. (61.2 cm) during the 2011-12 winter season to 60.2 in. (152.9 cm) during the 2009-10 winter season. This result aligns with the snow day frequency distribution that would suggest the most severe winter season was 2009-10 and the least severe was 2011-12. The average decadal snowfall at the district level ranged from 30.3 in. (76.9 cm) in District 1 to 68.12 in. (173.0 cm) in District 5. This result also aligns with the snow/snowfall day distribution between the eastern and western regions of the state. Snowfall anomalies (Table 4.7) illustrate further spatial variability using snowfall-based winter severity indices. Statewide, the largest positive anomaly occurred during the 2009-10 winter season and the largest negative anomaly occurred during the 2011-12 winter season. However, at the district level, while large negative anomalies were consistent across all eight districts for the 2011-12 winter season, District 8 observed a negative anomaly during the 2009-10 winter season while the remainder of the districts had large positive anomalies. While the spatial variability in snowfall-based indices supports a more robust, event-oriented approach, it also highlights the worthwhile consideration of climate (i.e., temperature and precipitation) anomalies across the state for the ten-year period as well.

In order to consider a longer, climatology-based index, temperature and precipitation anomalies were obtained from the NOAA NCEI climate division data (ESRL 2017). Nebraska contains eight climate districts which roughly align with NDOT's eight maintenance districts. Due to the lack of a perfect alignment; however, the temperature and precipitation anomalies were accumulated across the eight climate districts to provide a statewide value for each winter season. These anomalies would subsequently be compared with the aforementioned snowfall-based winter severity indices and the final NEWINS.

For a climate-based index, precipitation and temperature anomalies were obtained from the eight climate districts within the state of Nebraska (Figure 3.3) from October through April of each winter season and averaged statewide (Table 4.8). For severity purposes, the anomalies are ranked and larger positive precipitation anomalies (i.e., more snowfall possible) while larger negative temperature anomalies (i.e., colder winter) are associated with a higher winter severity. For precipitation anomalies, the 2015-16 winter season observed the largest positive anomaly (4.30 in.; 10.92 cm) while the 2014-15 winter season observed the largest negative anomaly (-2.02 in.; -5.13 cm). From the snowfall data, the most severe 2009-10 winter season ranks third in the precipitation anomalies and the least severe 2011-12 winter season ranks sixth in precipitation anomalies. These results provide stark contrast to the snowfall-based indices. However, while the 2015-16 winter season may have observed an abundance of precipitation, it was not in the form of snow. For temperature anomalies, the 2013-14 winter season observed the largest negative anomaly (-1.46 □; -0.81°C) while the 2011-12 winter season observed the largest positive anomaly (5.18□; 2.88°C). This result agrees with the previous ranking of the 2011-12 winter season as the least severe season from the snowfall data. The 2009-10 winter season ranks second in the temperature anomalies (-1.21□; -0.67°C) which is more in agreement with the snowfall-based index as well. Given the misalignment between climate districts and maintenance districts, it was not feasible to conduct a district level anomaly comparison. The snowfall and climate-based indices support the use of a hybrid approach which considers snowfall and temperature, in addition to other weather variables at the level of individual events.

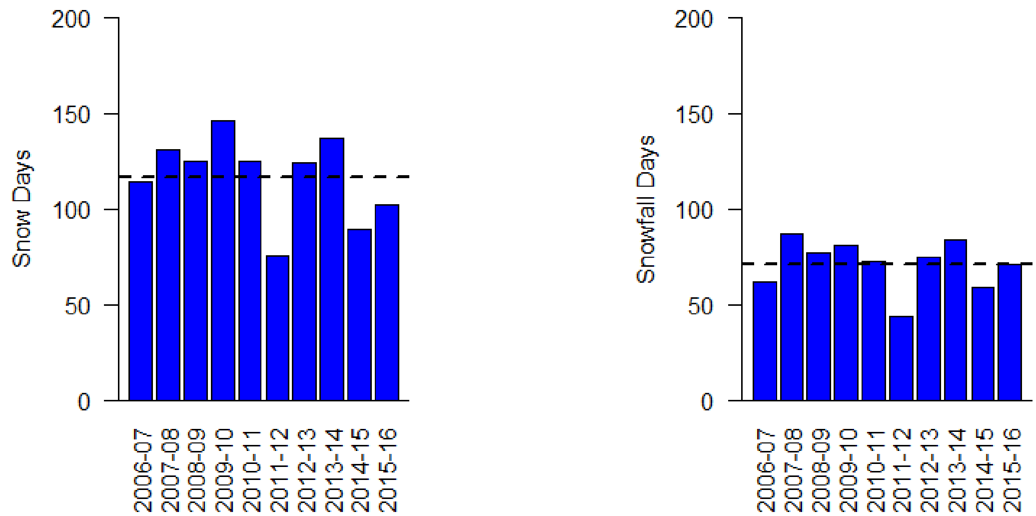

Figure 4.1. Snow (i.e., frozen precipitation identified by ASOS stations) days (left) and snowfall (i.e., accumulation measured by GHCN-D sites) days (right) with respective averages (dashed line).

Table 4.1. District and statewide total snow (i.e., frozen precipitation reported by ASOS) days.

	Snow Days								
Winter Season	**District 1**	**District 2**	**District 3**	**District 4**	**District 5**	**District 6**	**District 7**	**District 8**	**Statewide**
2006-07	36	40	59	53	67	57	42	67	114
2007-08	60	61	68	78	86	77	51	67	131
2008-09	48	55	65	64	71	67	46	75	125
2009-10	60	70	64	81	84	75	61	67	146
2010-11	49	60	63	53	80	61	43	67	125
2011-12	28	22	31	35	50	39	27	34	76
2012-13	51	58	69	63	77	65	44	66	124
2013-14	42	59	62	70	94	75	52	77	137
2014-15	33	39	42	41	61	48	36	45	89
2015-16	37	44	53	44	71	52	43	56	102
Decade Average	44.4	50.8	57.6	58.2	74.1	61.6	44.5	62.1	116.9

Table 4.2. District and statewide snow day anomalies. Blue denotes positive anomalies and gold denotes negative anomalies. The largest positive anomalies are bold, and the largest negative anomalies are italicized.

Snow Days Anomalies									
Winter Season	**District 1**	**District 2**	**District 3**	**District 4**	**District 5**	**District 6**	**District 7**	**District 8**	**Statewide**
2006-07	-8.4	-10.8	1.4	-5.2	-7.1	-4.6	-2.5	4.9	-2.9
2007-08	**15.6**	10.2	10.4	19.8	11.9	**15.4**	6.5	4.9	14.1
2008-09	3.6	4.2	7.4	5.8	-3.1	5.4	1.5	12.9	8.1
2009-10	**15.6**	**19.2**	6.4	**22.8**	9.9	13.4	**16.5**	4.9	**29.1**
2010-11	4.6	9.2	5.4	-5.2	5.9	-0.6	-1.5	4.9	8.1
2011-12	*-16.4*	*-28.8*	*-26.6*	*-23.2*	*-24.1*	*-22.6*	*-17.5*	*-28.1*	*-40.9*
2012-13	6.6	7.2	**11.4**	4.8	2.9	3.4	-0.5	3.9	7.1
2013-14	-2.4	8.2	4.4	11.8	**19.9**	13.4	7.5	**14.9**	20.1
2014-15	-11.4	-11.8	-15.6	-17.2	-13.1	-13.6	-8.5	-17.1	-27.9
2015-16	-7.4	-6.8	-4.6	-14.2	-3.1	-9.6	-1.5	-6.1	-14.9

Table 4.3. District and statewide total snowfall (i.e., accumulation) days.

Snowfall Days									
Winter Season	**District 1**	**District 2**	**District 3**	**District 4**	**District 5**	**District 6**	**District 7**	**District 8**	**Statewide**
2006-07	17	21	21	26	41	26	28	24	62
2007-08	33	36	43	48	57	35	27	30	87
2008-09	24	31	43	34	45	31	28	21	77
2009-10	32	38	43	45	49	39	31	28	81
2010-11	28	37	38	32	51	32	23	38	73
2011-12	9	14	15	16	30	20	16	14	44
2012-13	21	25	28	37	50	38	28	30	75
2013-14	24	35	27	37	61	36	25	23	84
2014-15	18	22	24	24	44	30	24	21	59
2015-16	23	28	31	31	42	35	31	33	71
Decade Average	22.9	28.7	31.3	33.0	47.0	32.2	26.1	26.2	71.3

Table 4.4. District and statewide snowfall day anomalies. Blue denotes positive anomalies and gold denotes negative anomalies. The largest positive anomalies are bold, and the largest negative anomalies are italicized.

Snowfall Days Anomalies									
Winter Season	**District 1**	**District 2**	**District 3**	**District 4**	**District 5**	**District 6**	**District 7**	**District 8**	**Statewide**
2006-07	-5.9	-7.7	-10.3	-7	-6	-6.2	1.9	-2.2	-9.3
2007-08	**10.1**	7.3	**11.7**	**15**	10	2.8	0.9	3.8	**15.7**
2008-09	1.1	2.3	**11.7**	1	-2	-1.2	1.9	-5.2	5.7
2009-10	9.1	**9.3**	**11.7**	12	2	**6.8**	**4.9**	1.8	9.7
2010-11	5.1	8.3	6.7	-1	4	-0.2	-3.1	**11.8**	1.7
2011-12	*-13.9*	*-14.7*	*-16.3*	*-17*	*-17*	*-12.2*	*-10.1*	*-12.2*	*-27.3*
2012-13	-1.9	-3.7	-3.3	4	3	5.8	1.9	3.8	3.7
2013-14	1.1	6.3	-4.3	4	**14**	3.8	-1.1	-3.2	12.7
2014-15	-4.9	-6.7	-7.3	-9	-3	-2.2	-2.1	-5.2	-12.3
2015-16	0.1	-0.7	-0.3	-2	-5	2.8	**4.9**	6.8	-0.3

Table 4.5. District and statewide percent reduction between snow (i.e., precipitation) and snowfall (i.e., accumulation) days.

Snow-Snowfall Days Percentage Reduction									
Winter Season	**District 1**	**District 2**	**District 3**	**District 4**	**District 5**	**District 6**	**District 7**	**District 8**	**Statewide**
2006-07	52.8	47.5	64.4	50.9	38.8	54.4	33.3	64.2	45.6
2007-08	45.0	41.0	36.8	38.5	33.7	54.5	47.1	55.2	33.6
2008-09	50.0	43.6	33.8	46.9	36.6	53.7	39.1	72.0	38.4
2009-10	46.7	45.7	32.8	44.4	41.7	48.0	49.2	58.2	44.5
2010-11	42.9	38.3	39.7	39.6	36.3	47.5	46.5	43.3	41.6
2011-12	67.9	36.4	51.6	54.3	40.0	48.7	40.7	58.8	42.1
2012-13	58.8	56.9	59.4	41.3	35.1	41.5	36.4	54.5	39.5
2013-14	42.9	40.7	56.5	47.1	35.1	52.0	51.9	70.1	38.7
2014-15	45.5	43.6	42.9	41.5	27.9	37.5	33.3	53.3	33.7
2015-16	37.8	36.4	41.5	29.5	40.8	32.7	27.9	41.1	30.4
Decade Average	48.4	43.5	45.7	43.3	36.6	47.7	41.3	57.8	39.0

Table 4.6. District and statewide total seasonal snowfall.

Snowfall Accumulation (in.)									
Winter Season	**District 1**	**District 2**	**District 3**	**District 4**	**District 5**	**District 6**	**District 7**	**District 8**	**State Average**
2006-07	36.6	37.0	32.8	26.0	61.4	46.3	47.7	31.8	40.0
2007-08	36.5	30.6	46.1	43.2	75.0	38.6	42.7	42.1	44.3
2008-09	23.1	32.5	46.6	40.1	57.0	40.9	40.4	41.0	40.2
2009-10	57.7	63.5	63.4	66.7	87.6	60.6	49.9	31.9	60.2
2010-11	38.5	51.4	54.3	53.0	66.5	53.2	41.4	59.6	52.2
2011-12	15.6	28.8	21.1	24.9	31.2	23.0	30.8	17.6	24.1
2012-13	27.2	40.2	37.6	47.9	74.2	51.3	53.6	52.1	48.0
2013-14	21.7	22.6	24.2	33.5	82.7	40.6	36.4	32.9	36.8
2014-15	22.8	22.1	26.6	33.9	69.9	27.6	25.1	30.3	32.3
2015-16	23.0	34.6	59.5	42.6	75.7	47.5	49.4	51.8	48.0
Decade Average	30.3	36.3	41.2	41.2	68.1	43.0	41.7	39.1	42.6

Table 4.7. District and statewide snowfall anomalies. Blue denotes positive anomalies and gold denotes negative anomalies. The largest positive anomalies are bold, and the largest negative anomalies are italicized.

Snowfall Accumulation Anomalies (in.)									
Winter Season	**District 1**	**District 2**	**District 3**	**District 4**	**District 5**	**District 6**	**District 7**	**District 8**	**State Average**
2006-07	6.3	0.7	-8.4	-15.2	-6.7	3.3	5.9	-7.3	-2.6
2007-08	6.2	-5.7	4.9	2.0	6.9	-4.4	0.9	3.0	1.7
2008-09	-7.2	-3.8	5.4	-1.1	-11.1	-2.0	-1.3	1.9	-2.4
2009-10	**27.4**	**27.2**	**22.2**	**25.5**	**19.5**	**17.6**	8.1	-7.2	**17.6**
2010-11	8.2	15.1	13.1	11.8	-1.6	10.2	-0.4	**20.5**	9.6
2011-12	*-14.7*	-7.5	*-20.1*	*-16.3*	*-36.9*	*-20.0*	-10.9	*-21.5*	*-18.5*
2012-13	-3.1	3.9	-3.6	6.7	6.1	8.3	**11.9**	13.0	5.4
2013-14	-8.6	-13.7	-17.0	-7.7	14.6	-2.4	-5.4	-6.2	-5.8
2014-15	-7.5	*-14.2*	-14.6	-7.3	1.8	-15.4	*-16.7*	-8.8	-10.3
2015-16	-7.3	-1.7	18.3	1.4	7.6	4.5	7.7	12.7	5.4

Table 4.8. Average statewide decadal temperature and precipitation anomalies. For precipitation, blue denotes positive anomalies and gold denotes negative anomalies. For temperature, blue denotes negative anomalies (i.e., colder, more severe conditions) and gold denotes positive anomalies (i.e., warmer, less severe conditions). The largest positive anomalies are bold, and the largest negative anomalies are italicized.

Winter Season	Precip. Anomaly (in.)	Precip. Anomaly Rank	Temp. Anomaly (°F)	Temp. Anomaly Rank
2006-2007	2.84	**2**	0.68	**7**
2007-2008	0.74	**5**	-0.58	**3**
2008-2009	1.97	**4**	0.43	**6**
2009-2010	2.71	**3**	-1.21	**2**
2010-2011	-1.57	**9**	-0.23	**4**
2011-2012	-0.10	**6**	**5.18**	**10**
2012-2013	-1.52	**8**	-0.16	**5**
2013-2014	-1.34	**7**	*-1.46*	**1**
2014-2015	*-2.02*	**10**	1.66	**8**
2015-2016	**4.30**	**1**	4.57	**9**

b. Nebraska Winter Severity Index (NEWINS)

The first component of the NEWINS produced a categorical (Table 3.2) frequency distribution of classified events statewide and at the district level (Figure 4.2 and Tables 4.9-4.17) for each of the ten winter seasons within the study period. Statewide, the average number of events was 246.7 (Table 4.9). The 2011-12 winter season had the fewest events with 134, and the 2007-08 and 2009-10 winter seasons were tied for the most events with 305. From the categorical framework, the distribution of events across all winter seasons was right-skewed/tailed (Figure 4.2). Trace (i.e., Category 1) events were the most frequent while high (i.e., Category 6) events were rare with several winter seasons observing none (Table 4.9). Slight (i.e., Category 3) and enhanced (i.e., Category 4) events exhibited higher variability in their frequency distributions. Some winter seasons observed more enhanced events than slight (e.g., 2006-07, 2014-15 winter seasons), where others contained very similar frequencies (e.g., 2008-09, 2011-12, and 2015-16 winter seasons) between the two. Given the categorical assignment (Table 3.2) and Eq. (1), the middle events are likely to overlap with one another as very subtle changes could alter their classification. The extreme events (i.e., trace and high) are more distinct from one another and therefore do not exhibit any degree of overlap. This is an important caveat to note in both the frequency distribution and eventual final NEWINS seasonal values as well. At the district level (Tables 4.10-4.17), District 1 overall had the fewest events with a decadal average of 22.9 while District 5 had the most with a decadal average of 46.6 events. This spatial distribution aligns with the previous snowfall-based data (Tables 4.1-4.7).

The categorical frequency distribution and event classification component of the NEWINS builds on the framework in the development of the NESIS (Kocin and Uccellini 2004) and LWSS (Cerruti and Decker 2011). Cerruti and Decker (2011) observed a similar right-tailed/skewed frequency distribution with higher category (i.e., impact) events exhibiting far lower frequencies relative to lower category events. Also, while the parameter weights differed between the NEWINS and LWSS, both approaches gave the most weight to the snowfall amount parameter. As noted, freezing rain data lacked availability through the ten-year study period and was omitted during the development of the NEWINS, unlike the LWSS which considered freezing rain events. Future refinement of the NEWINS could ensure freezing rain is incorporated into the WSI. These additional improvements could also make the NEWINS framework a candidate for NWS consideration in its WSSI (WPC 2018). The consistency between these results and the literature confirm the NEWINS frequency distribution and its components given the similarities to a manual classification with a more numerous, independent set of researchers.

The final NEWINS was computed via Eq. (2) to provide a single value for each winter season statewide and at the NDOT maintenance district level (Figures 4.3-4.4 and Table 4.18). The statewide decadal average NEWINS value was 4.77. Based on the NEWINS values, the least severe winter season was 2011-12 with a value of 2.49 while the most severe winter season was 2009-10 with a value of 6.33 (Figure 4.3 and Table 4.18). These results generally align with the snowfall-based winter severity indices. At the district level, the NEWINS value summed across all districts would yield the statewide value. District 1 has the smallest contribution on average for the decade (0.44) while District 5 has the largest contribution for the decade (0.90) of any one single district (Table 4.18). This result is to be expected given the relative differences in event frequency and snow/snowfall days between the eastern and western parts of the state. A more detailed consideration of the district level NEWINS values also reveals that while the 2009-10 winter season was the most severe for the entire state, individual districts' most severe winter seasons can be different. For example, District 8's most severe was the 2010-11 winter season with an NEWINS value of 0.83 (Figure 4.4 and Table 4.18). Similar differences between districts were observed in the snowfall-based winter severity indices and it is important that the NEWINS also be able to capture the same level of variability to be reliable. Moreover, this result further highlights the challenge and difficulty of representing an entire state's winter season with a single severity index value.

In addition to seasonal and district values (Table 4.18), the NEWINS was also computed monthly (Table 4.19). Monthly NEWINS values demonstrate the broad variability between winter seasons. For example, the 2014-15 winter season was the only to record events during September. Similarly, the 2011-12 winter season had no events after February while the remaining winter seasons had events at least through April. In general, December, January and February are the months with the largest contribution to the overall winter severity across all ten winter seasons. September and May are the months with the smallest contribution to winter severity during this same period. The most severe month occurred during the 2009-10 winter season in December. This result aligns with the finding of the 2009-10 winter season as being the most severe during the period. The least severe month with any events occurred during the 2008-09 winter season in the month of May. While this was not the least severe winter season overall (i.e., 2011-12), it is expected that severity at the seasonal boundaries (i.e., autumn-winter, winter-spring) would diminish.

The advantages of the NEWINS become more apparent when the NEWINS anomalies (Figure 4.5) are compared with the aforementioned snowfall-based and climate-based index anomalies ranked from most severe to least severe for each respective index (Tables 4.20-4.21). For the snowfall-based anomalies (i.e., snowfall amounts, snow days and snowfall days), there is fair agreement that the 2011-12 winter season was the least severe in the decade and the 2009-10 winter season was the most severe in the decade. The exception is that for the snowfall days anomaly, the 2009-10 winter season is ranked as the third most severe winter season. While there is less consistency on the rank of each winter season's severity, there is fair agreement between the cutoff threshold between positive (i.e., more severe) and negative (i.e., less severe) anomalies for each winter season. The exception to this is with the snowfall anomalies, particularly during the 2015-16 winter season which did have a positive snowfall anomaly (ranked third most severe) but average (i.e., zero anomaly) NEWINS, snow day and snowfall day anomalies (ranked seventh or eighth most severe).

As suggested from the frequency distributions, while there is consistency among the least and most severe winter seasons between the NEWINS and snowfall-based anomalies, the greatest variability is in the middle where subtle differences in the variables of interest can influence the rank of the winter seasons. While the NEWINS and snowfall-based anomalies both exhibit this intermediate variability, one advantage is that the NEWINS considers additional variables (Table 3.4) and not simply event frequency or snowfall amounts exclusively. For the climate-based index anomalies (Table 4.21), temperature anomalies also exhibited a clear cut-off between negative (i.e., more severe in the case of temperature) and positive (i.e., less severe in the case of temperature) anomalies for the corresponding NEWINS anomalies. The precipitation anomalies, though, did not exhibit any clear pattern that was in line with the observed NEWINS or snowfall anomalies. A reason for this is that precipitation anomalies consider both liquid and frozen precipitation; however, the NEWINS and other approaches are only interested in the frozen precipitation. A "wet" or "dry" winter season from the climatological precipitation standpoint can be very different than a "snowy" winter.

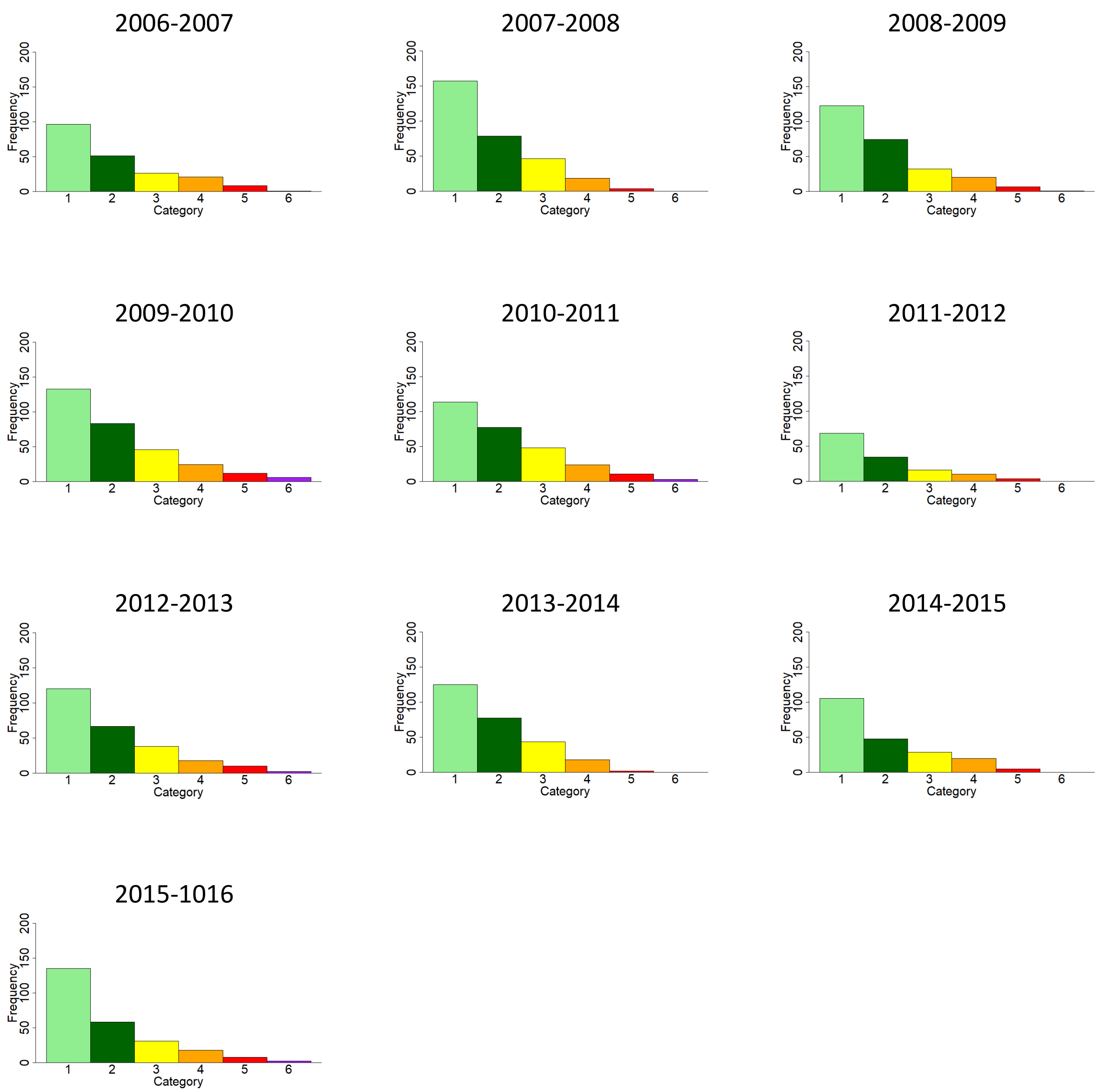

Figure 4.2. NEWINS winter season categorical event distribution.

Table 4.9. Statewide categorical classification frequency distribution.

	Categorical Event Frequency						
Winter Season	**Trace (1)**	**Marginal (2)**	**Slight (3)**	**Enhanced (4)**	**Moderate (5)**	**High (6)**	**Total**
2006-2007	98	51	21	23	10	1	204
2007-2008	155	85	41	22	2	0	305
2008-2009	123	88	22	18	6	0	257
2009-2010	129	96	39	25	13	3	305
2010-2011	114	92	37	23	11	1	278
2011-2012	65	35	15	12	7	0	134
2012-2013	113	74	35	21	13	0	256
2013-2014	136	80	36	13	2	0	267
2014-2015	112	54	19	20	2	0	207
2015-2016	127	67	24	22	12	2	254
Decade Average	117.2	72.2	28.9	19.9	7.8	0.7	246.7

Table 4.10. NDOT District 1 categorical classification frequency distribution.

Categorical Event Frequency District 1							
Winter Season	**Trace (1)**	**Marginal (2)**	**Slight (3)**	**Enhanced (4)**	**Moderate (5)**	**High (6)**	**Total**
2006-2007	6	4	2	4	1	0	17
2007-2008	22	3	3	5	0	0	33
2008-2009	15	6	1	2	0	0	24
2009-2010	13	10	3	3	3	0	32
2010-2011	13	8	2	5	0	0	28
2011-2012	3	2	2	2	0	0	9
2012-2013	12	4	3	1	1	0	21
2013-2014	16	4	2	2	0	0	24
2014-2015	11	3	1	3	0	0	18
2015-2016	12	6	5	0	0	0	23
Decade Average	12.3	5.0	2.4	2.7	0.5	0.0	22.9

Table 4.11. NDOT District 2 categorical classification frequency distribution.

Categorical Event Frequency District 2							
Winter Season	**Trace (1)**	**Marginal (2)**	**Slight (3)**	**Enhanced (4)**	**Moderate (5)**	**High (6)**	**Total**
2006-2007	11	3	1	4	2	0	21
2007-2008	27	4	2	3	0	0	36
2008-2009	19	8	2	1	1	0	31
2009-2010	19	9	3	4	2	1	38
2010-2011	19	7	8	2	0	1	37
2011-2012	6	3	1	1	3	0	14
2012-2013	15	3	2	2	3	0	25
2013-2014	25	9	0	1	0	0	35
2014-2015	16	3	2	0	1	0	22
2015-2016	16	6	1	4	1	0	28
Decade Average	17.3	5.5	2.2	2.2	1.3	0.2	28.7

Table 4.12. NDOT District 3 categorical classification frequency distribution.

Categorical Event Frequency District 3							
Winter Season	**Trace (1)**	**Marginal (2)**	**Slight (3)**	**Enhanced (4)**	**Moderate (5)**	**High (6)**	**Total**
2006-2007	11	3	2	4	1	0	21
2007-2008	18	17	6	2	0	0	43
2008-2009	23	15	1	3	1	0	43
2009-2010	21	14	2	3	2	1	43
2010-2011	14	17	4	2	1	0	38
2011-2012	8	3	2	1	1	0	15
2012-2013	14	6	6	1	1	0	28
2013-2014	15	9	3	0	0	0	27
2014-2015	14	6	1	3	0	0	24
2015-2016	13	7	7	1	2	1	31
Decade Average	15.1	9.7	3.4	2.0	0.9	0.2	31.3

Table 4.13. NDOT District 4 categorical classification frequency distribution.

Categorical Event Frequency District 4							
Winter Season	**Trace (1)**	**Marginal (2)**	**Slight (3)**	**Enhanced (4)**	**Moderate (5)**	**High (6)**	**Total**
2006-2007	16	7	2	0	1	0	26
2007-2008	30	11	5	1	0	0	47
2008-2009	16	12	3	2	1	0	34
2009-2010	22	11	6	4	1	1	45
2010-2011	12	10	5	3	2	0	32
2011-2012	9	2	3	1	1	0	16
2012-2013	19	10	5	2	1	0	37
2013-2014	21	11	4	1	0	0	37
2014-2015	11	8	3	2	0	0	24
2015-2016	15	12	2	0	2	0	31
Decade Average	17.1	9.4	3.8	1.6	0.9	0.1	32.9

Table 4.14. NDOT District 5 categorical classification frequency distribution.

Categorical Event Frequency District 5							
Winter Season	**Trace (1)**	**Marginal (2)**	**Slight (3)**	**Enhanced (4)**	**Moderate (5)**	**High (6)**	**Total**
2006-2007	21	10	5	4	0	1	41
2007-2008	20	18	14	2	0	0	54
2008-2009	18	20	3	4	0	0	45
2009-2010	15	15	11	8	0	0	49
2010-2011	24	15	7	4	1	0	51
2011-2012	16	11	1	2	0	0	30
2012-2013	18	18	10	2	2	0	50
2013-2014	25	20	11	2	2	0	60
2014-2015	17	15	7	4	1	0	44
2015-2016	20	11	2	4	4	1	42
Decade Average	19.4	15.3	7.1	3.6	1.0	0.2	46.6

Table 4.15. NDOT District 6 categorical classification frequency distribution.

Categorical Event Frequency District 6							
Winter Season	**Trace (1)**	**Marginal (2)**	**Slight (3)**	**Enhanced (4)**	**Moderate (5)**	**High (6)**	**Total**
2006-2007	12	5	3	4	2	0	26
2007-2008	18	12	2	2	1	0	35
2008-2009	15	8	5	3	0	0	31
2009-2010	16	15	5	0	3	0	39
2010-2011	11	11	5	1	3	0	31
2011-2012	10	7	2	1	0	0	20
2012-2013	17	13	3	5	0	0	38
2013-2014	19	9	6	2	0	0	36
2014-2015	19	7	1	3	0	0	30
2015-2016	18	11	2	3	1	0	35
Decade Average	15.5	9.8	3.4	2.4	1.0	0.0	32.1

Table 4.16. NDOT District 7 categorical classification frequency distribution.

Categorical Event Frequency District 7							
Winter Season	**Trace (1)**	**Marginal (2)**	**Slight (3)**	**Enhanced (4)**	**Moderate (5)**	**High (6)**	**Total**
2006-2007	10	11	3	1	3	0	28
2007-2008	7	10	6	4	0	0	27
2008-2009	11	12	3	1	1	0	28
2009-2010	10	12	4	3	2	0	31
2010-2011	7	10	2	2	2	0	23
2011-2012	6	3	3	2	2	0	16
2012-2013	9	9	3	5	2	0	28
2013-2014	8	10	5	2	0	0	25
2014-2015	15	5	3	1	0	0	24
2015-2016	19	6	2	2	2	0	31
Decade Average	10.2	8.8	3.4	2.3	1.4	0.0	26.1

Table 4.17. NDOT District 8 categorical classification frequency distribution.

Categorical Event Frequency District 8							
Winter Season	**Trace (1)**	**Marginal (2)**	**Slight (3)**	**Enhanced (4)**	**Moderate (5)**	**High (6)**	**Total**
2006-2007	11	8	3	2	0	0	24
2007-2008	13	10	3	3	1	0	30
2008-2009	6	7	4	2	2	0	21
2009-2010	13	10	5	0	0	0	28
2010-2011	14	14	4	4	2	0	38
2011-2012	7	4	1	2	0	0	14
2012-2013	9	11	3	3	3	0	29
2013-2014	7	8	5	3	0	0	23
2014-2015	9	7	1	4	0	0	21
2015-2016	14	8	3	8	0	0	33
Decade Average	10.3	8.7	3.2	3.1	0.8	0.0	26.1

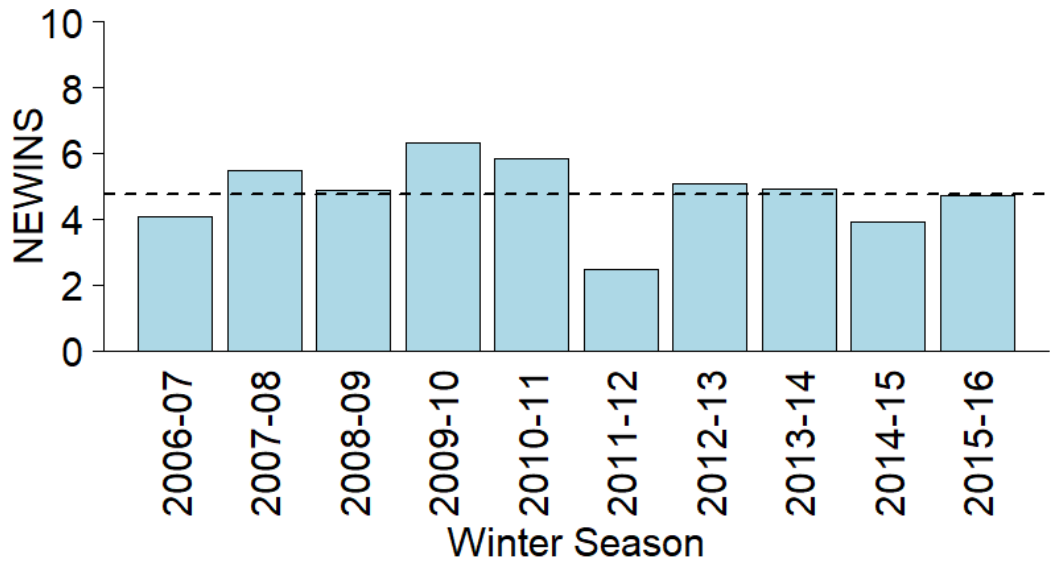

Figure 4.3. NEWINS winter season values with decadal average (black dashed line).

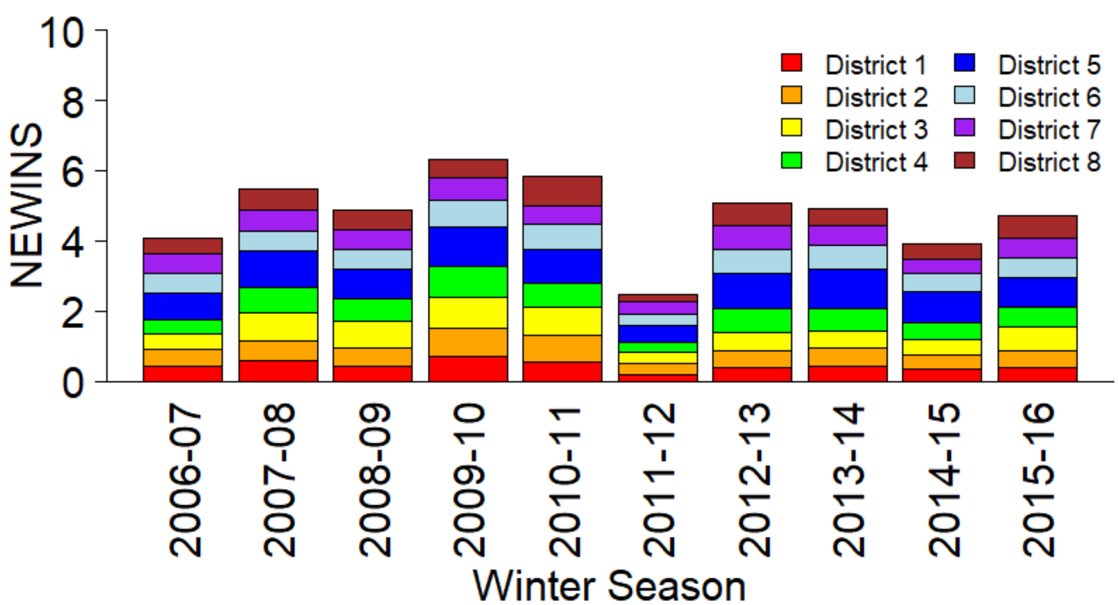

Figure 4.4. NEWINS winter season values with each district's contribution.

Table 4.18. NEWINS district and statewide seasonal values.

NEWINS Values									
Winter Season	**District 1**	**District 2**	**District 3**	**District 4**	**District 5**	**District 6**	**District 7**	**District 8**	**Statewide**
2006-07	0.44	0.46	0.43	0.43	0.74	0.56	0.58	0.43	4.08
2007-08	0.59	0.58	0.79	0.72	1.02	0.58	0.60	0.60	5.47
2008-09	0.41	0.53	0.78	0.63	0.84	0.58	0.56	0.54	4.87
2009-10	0.69	0.81	0.88	0.88	1.11	0.76	0.66	0.53	6.33
2010-11	0.56	0.75	0.79	0.69	0.98	0.70	0.55	0.83	5.84
2011-12	0.19	0.33	0.29	0.30	0.46	0.32	0.35	0.24	2.49
2012-13	0.38	0.48	0.52	0.68	1.00	0.71	0.65	0.65	5.07
2013-14	0.42	0.54	0.46	0.63	1.15	0.66	0.55	0.51	4.93
2014-15	0.36	0.38	0.46	0.49	0.88	0.49	0.42	0.45	3.92
2015-16	0.38	0.51	0.66	0.55	0.84	0.60	0.55	0.66	4.73
Decade Average	0.44	0.54	0.61	0.60	0.90	0.60	0.55	0.54	4.77

Table 4.19. NEWINS monthly values.

NEWINS Monthly Values									
Winter Season	**Sept.**	**Oct.**	**Nov.**	**Dec.**	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**
2006-07	0.00	0.13	0.17	0.68	1.19	1.09	0.40	0.31	0.00
2007-08	0.00	0.00	0.16	1.86	1.05	0.84	0.74	0.54	0.14
2008-09	0.00	0.10	0.36	1.21	1.23	0.85	0.60	0.40	0.01
2009-10	0.00	0.88	0.22	2.05	0.83	1.40	0.57	0.10	0.05
2010-11	0.00	0.00	0.37	0.76	1.81	1.10	1.11	0.43	0.00
2011-12	0.00	0.04	0.28	0.69	0.35	1.11	0.00	0.00	0.00
2012-13	0.00	0.27	0.14	0.79	0.57	0.99	1.04	0.96	0.24
2013-14	0.00	0.10	0.39	0.74	0.59	1.50	0.73	0.44	0.18
2014-15	0.02	0.00	0.57	1.07	0.54	1.19	0.17	0.16	0.11
2015-16	0.00	0.00	0.77	1.31	1.05	0.87	0.50	0.13	0.05
Decade Average	0.002	0.152	0.343	1.116	0.921	1.094	0.586	0.347	0.078

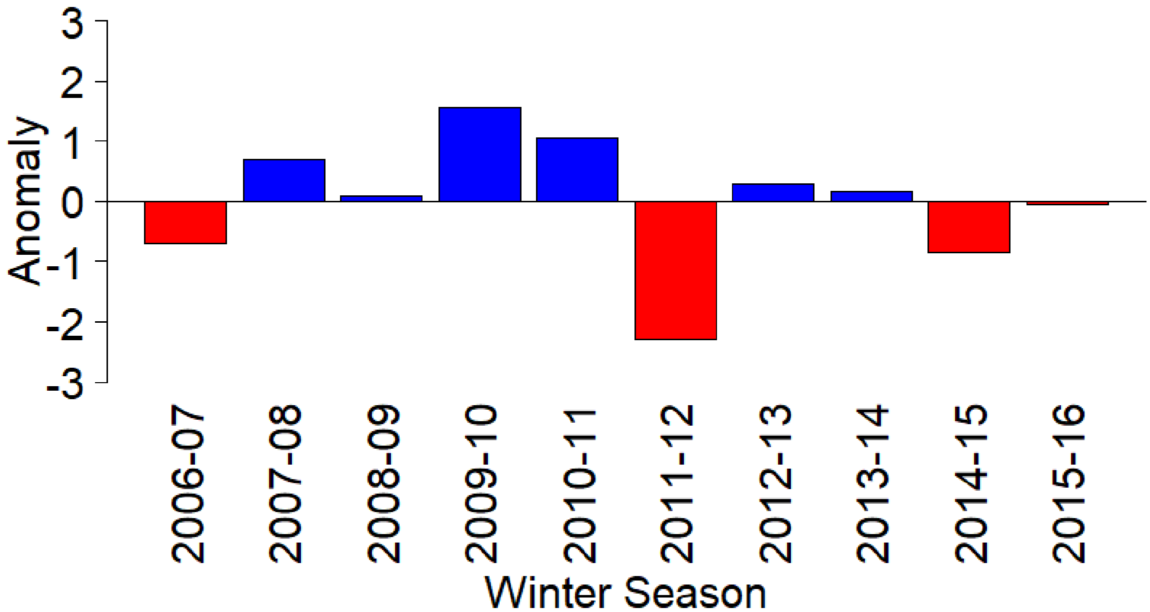

Figure 4.5. NEWINS winter season anomalies with positive (blue) and negative (red).

Table 4.20. NEWINS statewide seasonal anomalies ranked from lowest (i.e., most severe) to highest (i.e., least severe) versus snowfall, snow day, and snowfall day anomalies. Blue denotes positive anomalies and gold denotes negative anomalies

Statewide NEWINS, Snowfall, Snow Days and Snowfall Days												
Winter Season	NEWINS	NEWINS Anomaly	NEWINS Anomaly Rank	Average Snowfall (in.)	Snowfall Anomaly (in.)	Snowfall Anomaly Rank	Snow Days	Snow Days Anomaly	Snow Days Anomaly Rank	Snowfall Days	Snowfall Days Anomaly	Snowfall Days Anomaly Rank
2009-10	6.3	1.6	**1**	60.2	17.6	**1**	146	29.1	**1**	81	9.7	**3**
2010-11	5.8	1.1	**2**	52.2	9.6	**2**	125	8.1	**4**	73	1.7	**6**
2007-08	5.5	0.7	**3**	44.3	1.7	**5**	131	14.1	**3**	87	15.7	**1**
2012-13	5.1	0.3	**4**	48.0	5.4	**3**	124	7.1	**6**	75	3.7	**5**
2013-14	4.9	0.2	**5**	36.8	-5.8	**8**	137	20.1	**2**	84	12.7	**2**
2008-09	4.9	0.1	**6**	40.2	-2.4	**6**	125	8.1	**4**	77	5.7	**4**
2015-16	4.7	0.0	**7**	48.0	5.4	**3**	102	-14.9	**8**	71	-0.3	**7**
2006-07	4.1	-0.7	**8**	40.0	-2.6	**7**	114	-2.9	**7**	62	-9.3	**8**
2014-15	3.9	-0.9	**9**	32.3	-10.3	**9**	89	-27.9	**9**	59	-12.3	**9**
2011-12	2.5	-2.3	**10**	24.1	-18.5	**10**	76	-40.9	**10**	44	-27.3	**10**

Table 4.21. NEWINS statewide seasonal values, snowfall, temperature and precipitation anomalies. For NEWINS, snowfall and precipitation anomalies, blue denotes positive anomalies and gold denotes negative anomalies. For temperature, blue denotes negative anomalies (i.e., colder, more severe conditions) and gold denotes positive anomalies (i.e., warmer, less severe conditions).

Statewide NEWINS, Snowfall, Temperature and Precipitation										
Winter Season	**NEWINS**	**NEWINS Anomaly**	**NEWINS Anomaly Rank**	**Average Snowfall (in.)**	**Snowfall Anomaly (in.)**	**Snowfall Anomaly Rank**	**Precip. Anomaly (in.)**	**Precip. Anomaly Rank**	**Temp. Anomaly (°F)**	**Temp. Anomaly Rank**
2009-10	6.3	1.6	**1**	60.2	17.6	**1**	2.7	**3**	-1.3	**2**
2010-11	5.8	1.1	**2**	52.2	9.6	**2**	-1.6	**9**	-0.2	**4**
2007-08	5.5	0.7	**3**	44.3	1.7	**5**	0.7	**5**	-0.5	**3**
2012-13	5.1	0.3	**4**	48.0	5.4	**3**	-1.5	**8**	-0.2	**5**
2013-14	4.9	0.2	**5**	36.8	-5.8	**8**	-1.3	**7**	-1.4	**1**
2008-09	4.9	0.1	**6**	40.2	-2.4	**6**	2.0	**4**	0.4	**6**
2015-16	4.7	0.0	**7**	48.0	5.4	**3**	4.3	**1**	4.5	**9**
2006-07	4.1	-0.7	**8**	40.0	-2.6	**7**	2.8	**2**	0.7	**7**
2014-15	3.9	-0.9	**9**	32.3	-10.3	**9**	-2.0	**10**	1.6	**8**
2011-12	2.5	-2.3	**10**	24.1	-18.5	**10**	-0.1	**6**	5.2	**10**

c. *NEWINS 2015-16 Winter Season Maintenance Performance Comparison*

NDOT's performance objective for its winter maintenance operations is to maintain traffic speeds along the Interstate 80 corridor at or above 65 mph (29.1 m s^{-1}) for both directions (i.e., eastbound and westbound) within six hours of the precipitation ending (NDOT 2016, personal communication). The 2015-16 winter season NDOT performance data were available for 15 events throughout the state (Table 4.22). Of these 15 events, seven resulted in the performance objective not being met. Reasons for the performance objective not being met range from truly severe weather conditions to vehicular crashes and necessary road closures. The performance data for the 2015-16 winter season was related to the individual NEWINS storm classifications for each of the Interstate 80 districts (Table 4.22). The results show that, in general, the performance objective was met for lower impact Category 1-3 events (e.g., 16 November 2015, 16 January 2016), but not for higher impact Category 4-6 events (e.g., 15 December 2015, 1 February 2016). Some important caveats were identified in this comparison analysis. First, NDOT's event definition is based on precipitation that causes a maintenance response (e.g., wet snow, freezing rain, potential for icy roads) regardless of the final snowfall accumulation (NDOT 2016, personal communication). Given that the NEWINS only considers events with accumulated snowfall, this results in events included in NDOT's maintenance database that are missing from the NEWINS database (e.g., "NA" on 16 November 2015; Table 4.22). Future alignment of event definitions is necessary to improve the usefulness of the NEWINS. An additional caveat is that some low events result in performance objectives not being met (e.g., 26 November 2015, District 5). Upon discussion with NDOT, it was revealed that this was due to the Wyoming DOT closing its roads due to significantly worse weather conditions creating a backup of traffic into Nebraska (NDOT 2016, personal communication). This is an important consideration as the NEWINS is a pure meteorological index and does not consider transportation-related incidents (e.g., road closures, highway crashes). NEWINS did exhibit skill in identifying higher impact/severity storms associated with more numerous road instances of road closures.

Table 4.22. Interstate 80 corridor district-level 2015-16 winter maintenance performance evaluation. NDOT's event criteria (i.e., green and red boxes) was precipitation that resulted in maintenance activity (NDOT 2016, personal communication). Green boxes indicate where the performance objective was met. Red boxes indicate where the performance objective was not met. The numbers within the boxes represent the 2015-16 winter season NEWINS storm classification and "NA" denotes the storm failed NEWINS criteria. This could be due to several reasons; for example, lack of accumulation (i.e., snow days versus snowfall days), snow melted before observation time, or freezing rain events which were omitted from the NEWINS.

Storm Date	District 5	District 6	District 4	District 1	District 2
11/10/2015	*2*	-	-	-	-
11/16/2015	*1*	*1*	*NA*	*NA*	*NA*
11/17/2015	-	-	-	*NA*	-
11/26/2015	*1*	*NA*	*2*	*NA*	*1*
11/29/2015	-	*2*	-	-	*3*
12/1/2015	-	-	*1*	-	-
12/12/2015	*2*	*1*	*1*	*1*	*2*
12/15/2015	*6*	*4*	*2*	-	-
12/22/2015	*NA*	*1*	-	*2*	*1*
12/25/2015	*5*	*2*	*1*	*3*	*4*
12/29/2015	-	-	*1*	*1*	*1*
1/7/2015	-	-	*2*	*1*	*2*
1/16/2016	*1*	-	*1*	-	-
1/18/2016	-	-	-	*1*	*2*
2/1/2016	*4*	*5*	*5*	*3*	*4*

d. NEWINS 2016-17 Winter Season Application

The 2016-17 winter season NEWINS was computed to provide further validation and verification of the methods. From a categorical frequency distribution perspective (Figure 4.6), the 2016-17 winter season was very similar to the 2011-12 winter season (Figure 4.2). Both winter seasons had a relatively low number of events. Consideration of the statewide and district NEWINS values (Figures 4.7 and 4.8) shows that 2016-17 was well below average and rivaled the 2011-12 winter season for the lowest severity. Last, consideration of the NEWINS anomalies (Figure 4.9) provides further confirmation of the 2016-17 winter season's place as the second least severe winter after the 2011-12 winter season. An important consideration regarding the addition of a new winter season is whether or not the average NEWINS value should be fixed based on the decadal period or adjusted to accommodate additional winter seasons. In the decadal anomalies (Figure 4.5), the 2015-16 winter season is slightly below average; however, when considering the 11-year anomalies with an adjusted average, the 2015-16 winter season is slightly above average (Figure 4.9). This discrepancy is also apparent when considering a snowfall accumulation-based index and comparing decadal versus 11-year averages (Table 4.23). To prevent such variation as more winter seasons are incorporated into the NEWINS, it is recommended that the decadal average be fixed, and subsequent winter seasons compared to it. Only after an additional decade has passed should the average be considered based upon either the new decade or the entire two-decade period.

The snowfall accumulation-based index also yields an interesting result when comparing the least and greatest amounts at the district level. For the 2016-17 winter season, Districts 1, 2, 4 and 7 observed their least snowfall amounts in the 11-year period. Districts 3, 5, 6, 8 and the entire state, though, observed the least snowfall amounts during the 2011-12 winter season which has previously been identified as the least severe. District 8, however, had its highest seasonal snowfall amount during the 2016-17 winter season while all other districts observed markedly lower amounts (Table 4.23). This is also apparent in the district NEWINS values where District 8 has a larger contribution to the overall severity during the 2016-17 winter season (Figure 4.8). This finding further supports the use of the NEWINS in lieu of snowfall-based indices given such high variability in seasonal meteorological conditions that must be captured.

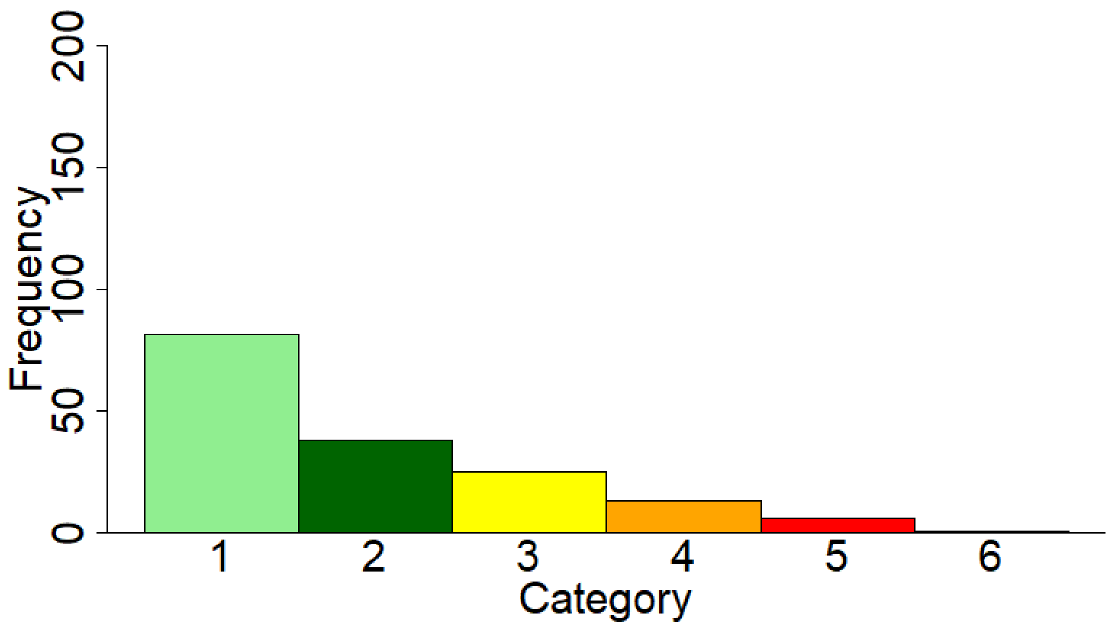

Figure 4.6. NEWINS 2016-2017 winter season categorical event distribution.

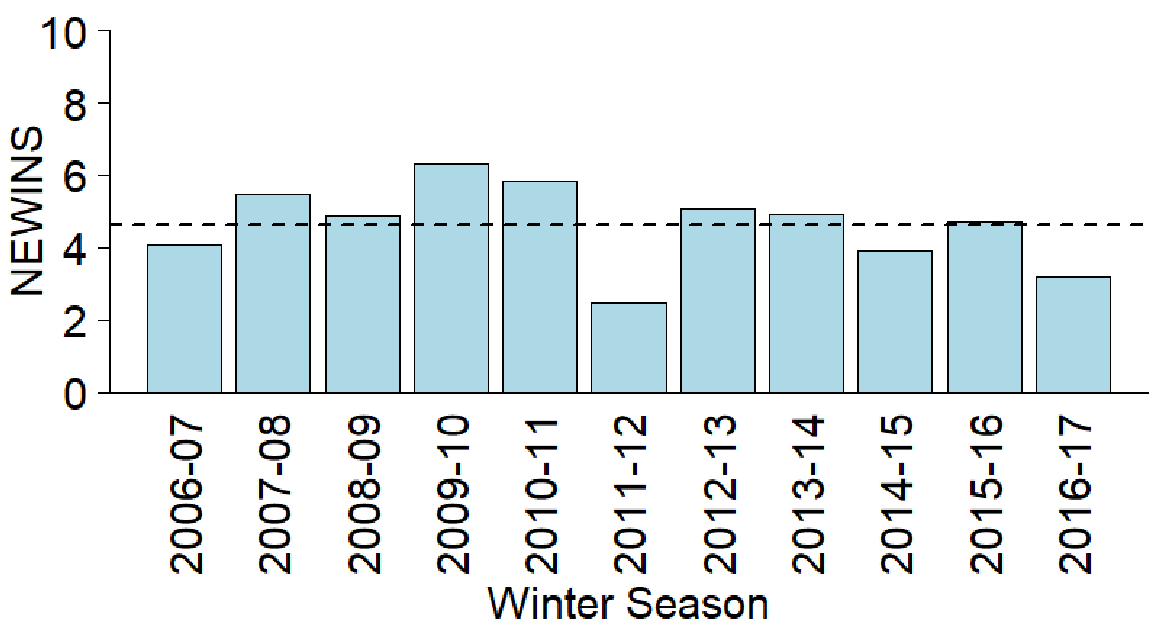

Figure 4.7. NEWINS winter season values with decadal (i.e., 2006-2016) average (black dashed line).

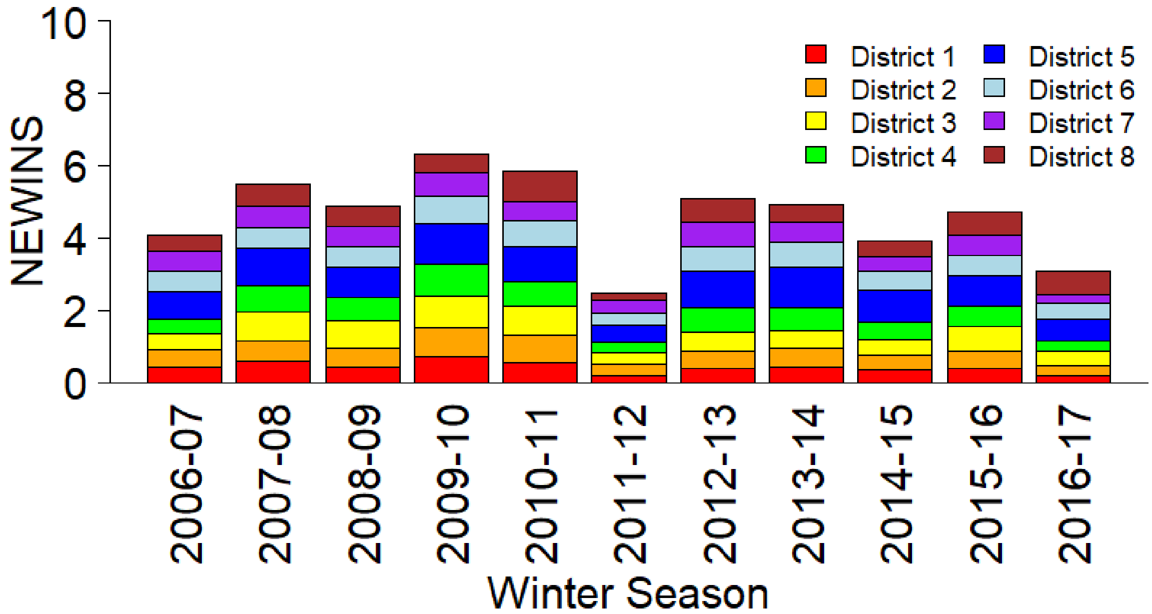

Figure 4.8. NEWINS winter season values with each district's contribution.

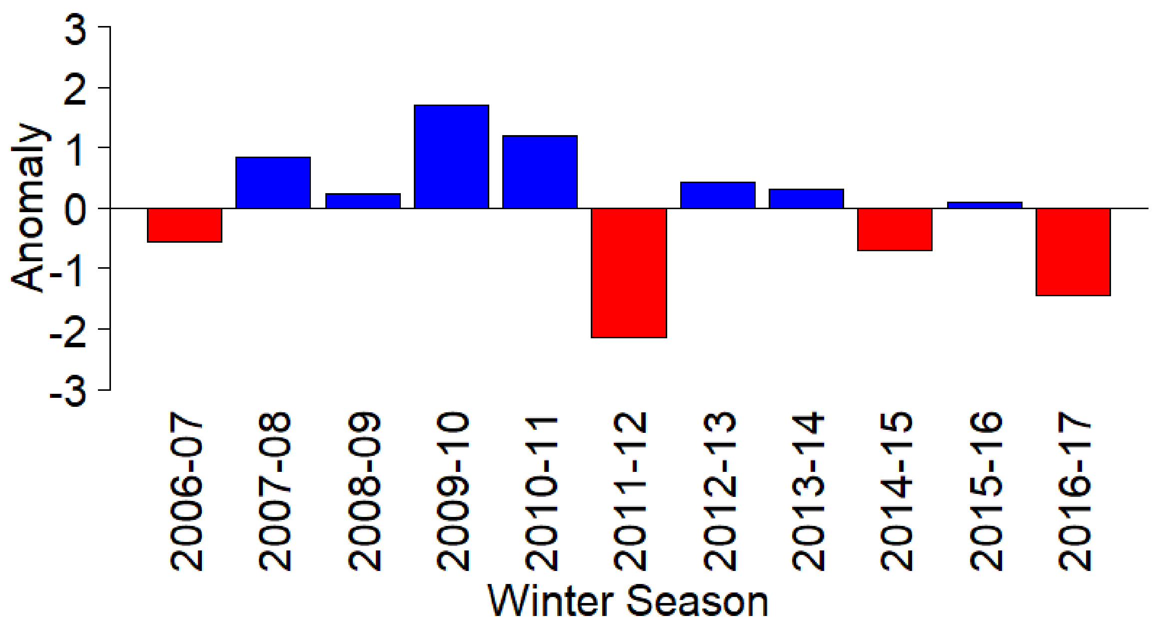

Figure 4.9. NEWINS winter season anomalies based on 11-year average with positive (blue) and negative (red).

Table 4.23. Decadal and 11-year district and statewide total snowfall.

	Snowfall Accumulation (in.)								
Winter Season	**District 1**	**District 2**	**District 3**	**District 4**	**District 5**	**District 6**	**District 7**	**District 8**	**State Average**
2006-07	36.6	37.0	32.8	26.0	61.4	46.3	47.7	31.8	40.0
2007-08	36.5	30.6	46.1	43.2	75.0	38.6	42.7	42.1	44.3
2008-09	23.1	32.5	46.6	40.1	57.0	40.9	40.4	41.0	40.2
2009-10	57.7	63.5	63.4	66.7	87.6	60.6	49.9	31.9	60.2
2010-11	38.5	51.4	54.3	53.0	66.5	53.2	41.4	59.6	52.2
2011-12	15.6	28.8	21.1	24.9	31.2	23.0	30.8	17.6	24.1
2012-13	27.2	40.2	37.6	47.9	74.2	51.3	53.6	52.1	48.0
2013-14	21.7	22.6	24.2	33.5	82.7	40.6	36.4	32.9	36.8
2014-15	22.8	22.1	26.6	33.9	69.9	27.6	25.1	30.3	32.3
2015-16	23.0	34.6	59.5	42.6	75.7	47.5	49.4	51.8	48.0
2016-17	8.5	15.0	34.6	12.7	54.1	29.4	18.4	61.6	29.3
Decade Average	30.3	36.3	41.2	41.2	68.1	43.0	41.7	39.1	42.6
11-Year Average	28.3	34.4	40.6	38.6	66.8	41.7	39.6	41.2	41.4

5. Summary and Conclusion

The winter severity index developed specifically for NDOT is known as the NEWINS. The NEWINS serves an integral role in providing an independent, meteorological baseline for ten winter seasons beginning in July 2006 through June 2016 for the state of Nebraska. Further, through the development of the NEWINS, a winter event categorical classification framework was developed. This classification framework allowed for a weighted linear combination of seven key weather variables to create a frequency distribution of events for each winter season. This frequency distribution ultimately resulted in the final seasonal NEWINS value. The NEWINS values were also compared alongside snowfall-based and climate-based index approaches.

A literature review highlights best practices for state DOTs regarding their needs, sources, perceptions, and use of weather information in addition to the existence and application of WSIs. The literature review highlights the need for a continuous close partnership between the transportation community and the weather enterprise to ensure forecast accuracy and WSIs are always refined, tailored to the needs of the end-user and caveats communicated. State DOTs rely on weather information typically in advance of a storm for preparation purposes, while tactical weather information during/after a storm is generally of lesser importance. These findings advocate for future research to focus on the forecasting aspect and allow WSIs to have predictive capabilities.

Consideration of the annual distribution of days with observed snowfall (i.e., snow days) versus days with observed snowfall accumulation (i.e., snowfall days) revealed an average 39% reduction between the two for the ten-year period. These results also revealed that the western part of Nebraska receives twice as many days with snowfall compared to the eastern part of the state. From a snowfall accumulation perspective, the western part of Nebraska receives more than twice the amount of snowfall as the eastern part. A consideration of snow day, snowfall day and snowfall amount anomalies underscore the spatial and temporal variability that the NEWINS must consider. The snow data (i.e., days and amount) suggest the 2011-12 winter season was the least severe compared to the 2009-10 winter season which was the most severe.

Climatological liquid precipitation and temperature anomalies provided an additional context for the NEWINS results. Liquid precipitation anomalies were not well aligned with the snow anomalies and NEWINS results, likely due to the combination of both rain and snow events in precipitation data. The temperature anomalies showed better alignment with the snow data and NEWINS results, including a clear separation between positive and negative anomalies when compared to different winter season severities.

The NEWINS results highlight the 2011-12 winter season as the least severe and the 2009-10 winter season as the most severe during the study period. These two winter seasons were also identified similarly by the other index measures. The NEWINS also highlights the spatial differences in winter severity, especially between eastern and western regions of Nebraska. More substantial differences and inconsistency arose between the NEWINS and other (i.e., snowfall-based and climate-based) index approaches during the intermediate winter seasons where subtle differences could alter a particular season's ranking. Inclusion of the 2016-17 winter season identified important considerations for an overall average, or baseline, NEWINS value. A fixed average NEWINS ensures that the inclusion of future winter seasons (e.g., 2016-

17) does not influence the anomalies of existing winter seasons (e.g., 2015-16). The average should only be adjusted upon the addition of several (e.g., five to ten) new winter seasons.

The overall strengths of the NEWINS are that it 1) considers a wide range of surface, ASOS-based meteorological variables, 2) incorporates a categorical frequency distribution framework related to weather impacts on road conditions and winter maintenance operations, 3) is robust and flexible enough to be computed easily at the statewide and district levels, 4) can be continuously and easily modified to include additional parameters such as freezing rain and road temperature, and 5) can be easily correlated to available transportation data (e.g., traffic speeds, winter maintenance operations costs) once available.

The benefits of the NEWINS are that it allows NDOT to assess the performance of its winter maintenance operations activities, resource allocations and other expenses with respect to the severity, or magnitude, of each winter season. NDOT's goal is to efficiently maintain safety and mobility for the public and commercial transportation interests. This information can be used to increase efficiency in resource allocation and maintenance operations, in addition to the identification of conditions which would prompt the need for increases or reductions in assets. Further, the NEWINS considers multiple weather variables across spatiotemporal scales to provide the best resolution of true winter severity in a framework that can be tailored to the end-user needs. Moreover, it is flexible and robust enough to be transferred to other regions and applications (e.g., modification of variables and weight sensitivity for different industries).

Future avenues for research include adding a predictive, forecasting value to the NEWINS so that it can be used as a planning tool in addition to a post-winter season assessment. To this end, machine and deep learning algorithms can take advantage of the categorical frequency distribution framework component of the NEWINS for future studies. Additional prospects for the NEWINS include correlation to more robust winter maintenance operations data such as salt usage, personnel hours, lane miles plowed, crash data or costs. To accomplish this, the NEWINS could be tailored to specific locations and/or road segments for more meaningful correlation with maintenance data. Given the present lack of freezing rain data in the NEWINS framework, further work could include incorporation of these data to allow for consideration of all winter weather precipitation types. Last, the NEWINS framework can be adaptive to provide meteorological guidance for diverse sectors (e.g., renewable energy, agriculture) and end-users (e.g., insurance adjusters, weather derivative traders) to quantify their exposure and sensitivity to atmospheric conditions.

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APPENDIX A: NEWINS Data Instructions and Procedure

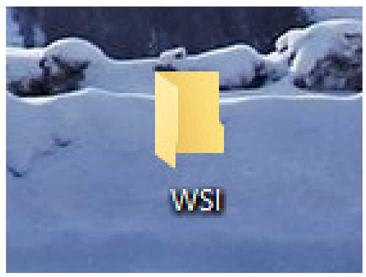
In order to run the WSI program, R and Rstudio must be downloaded to the computer.

The following are the links to download these free programs. These programs download in a similar fashion to any other program. Select your operating system and following the prompts.

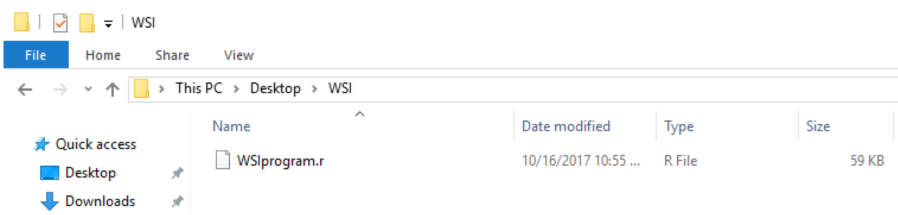
Download for R(Must be downloaded first):
https://cran.rstudio.com/

Download for Rstudio:
https://www.rstudio.com/products/rstudio/download/#download

1. Create a folder to store the R file and the data. In this case, I've created the file on my desktop.

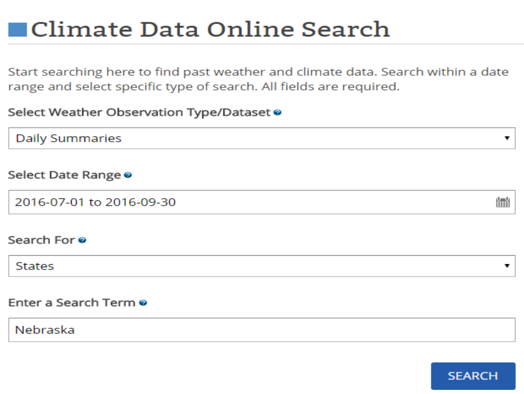


2. In this folder, place the provided R script.

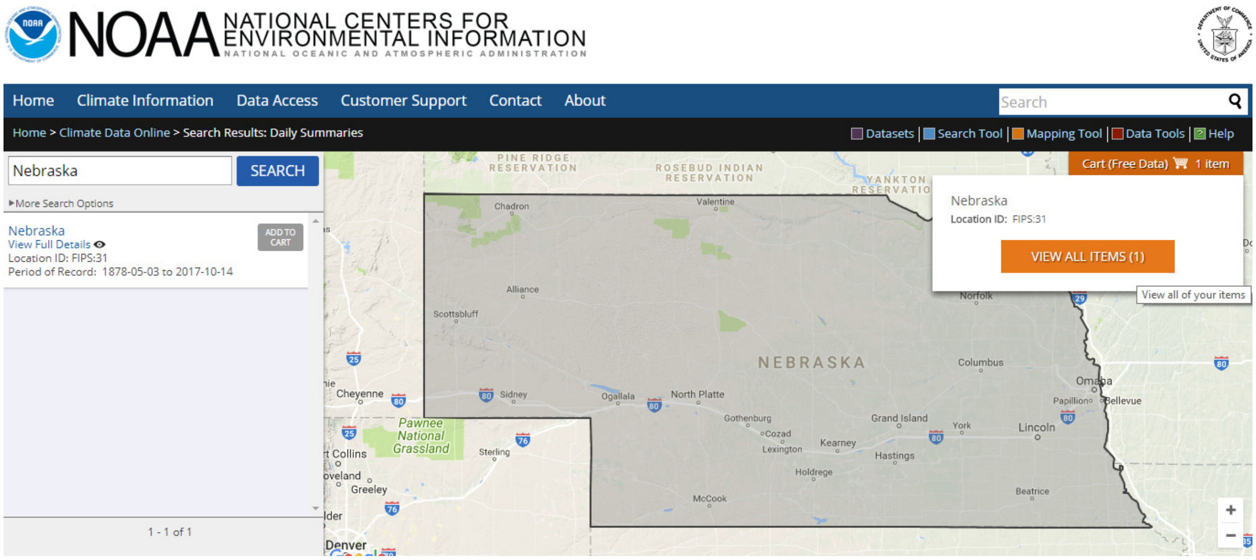


3. Next, we will download the GHCN data. Go to the following link.
https://www.ncdc.noaa.gov/cdo-web/search

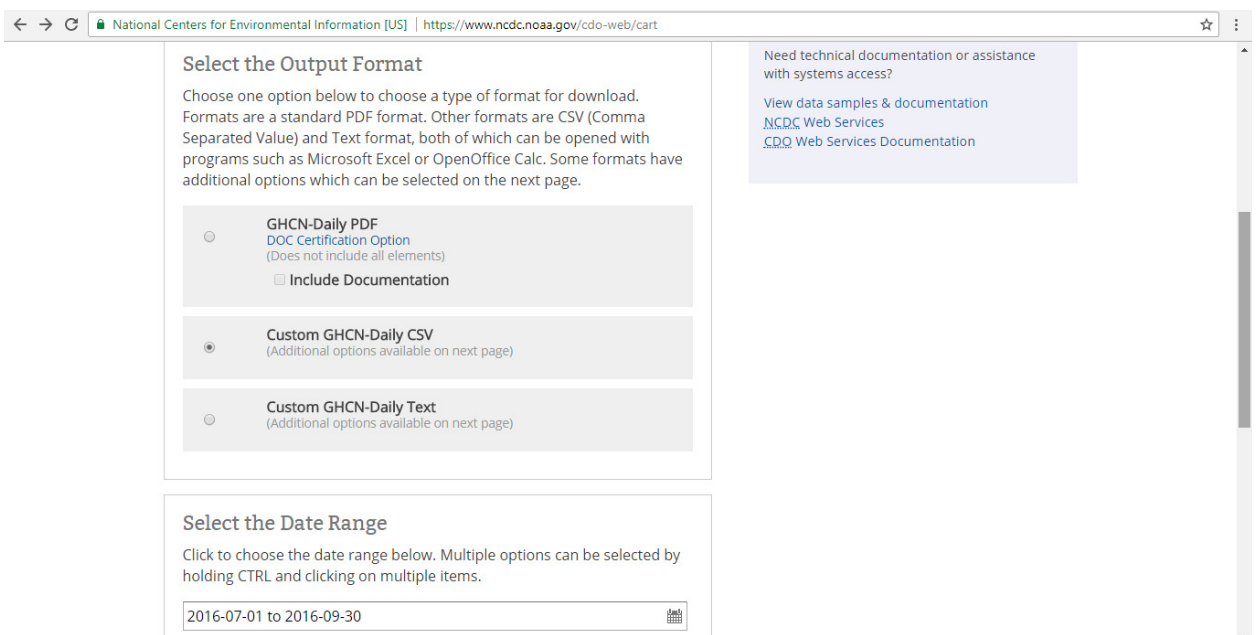
4. Enter the data in the following format. Note: Due to restrictions on the amount of data you can download. You will have to select data in 4 sets. July-September, October-December, January-March, and April-July.



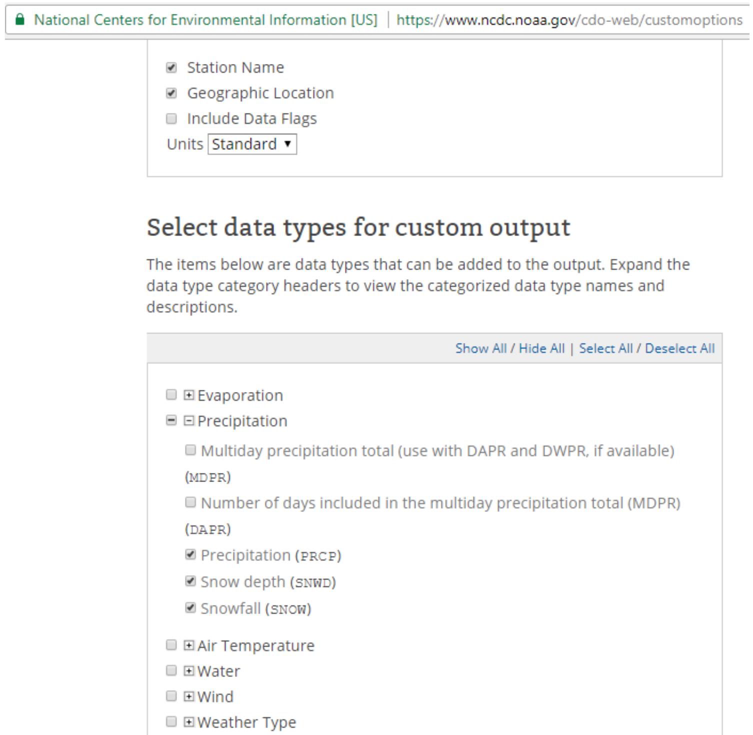
5. On the next screen, Click "Add to Cart" on the left side, and then view all items on the right side.



6. Select the output type as CSV. Then click "Continue" at the bottom of the page.



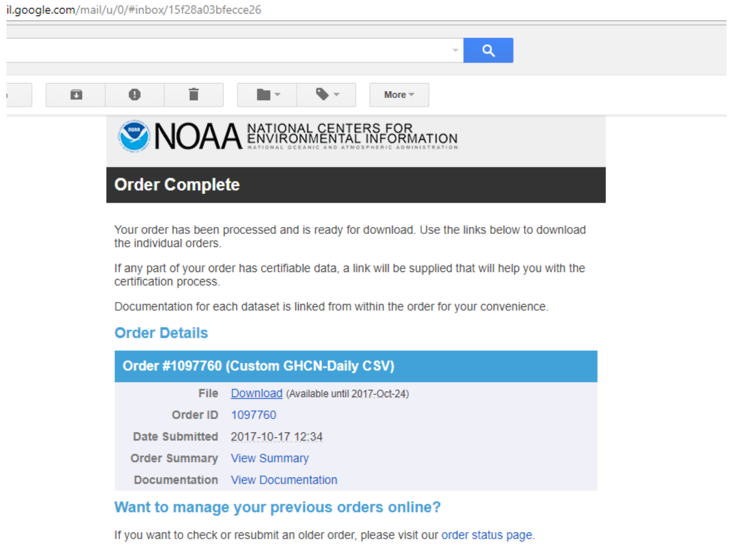
7. On the next page, select the following boxes: “Station Name”, “Geographic Location”, then under the precipitation tab “Precipitation (PRCP)”, “Snow Depth(SNWD)”, “Snow Fall(SNOW)”



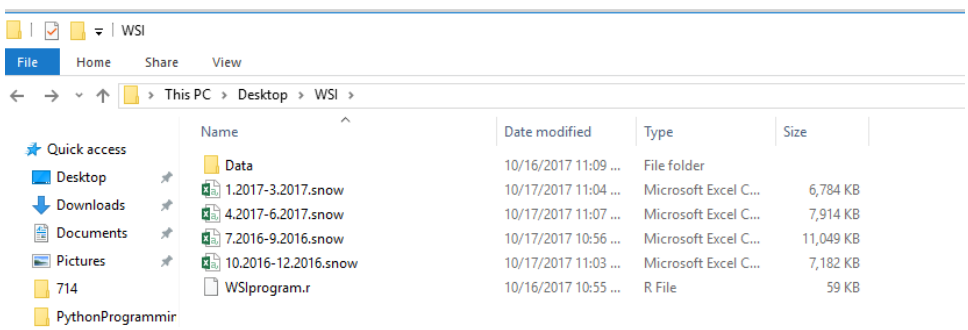
8. Finally, the last page will ask for an e-mail address. Enter the e-mail that you would like the data to send to and click “Submit Order”. Note: Depending on the day data is requested, data could arrive in e-mail between 1 minute and 2-3 days.

9. Repeat this process to download the entire data set for the desired winter season. Next requesting data for October 1 – December 31 then January 1 – March 31 and finally April 1 – June 30.

10. Once you receive an e-mail with your data. Click download within the e-mail.



11. Place the downloaded files into the WSI folder you previously created. Rename the files in the format indicated in the picture below.



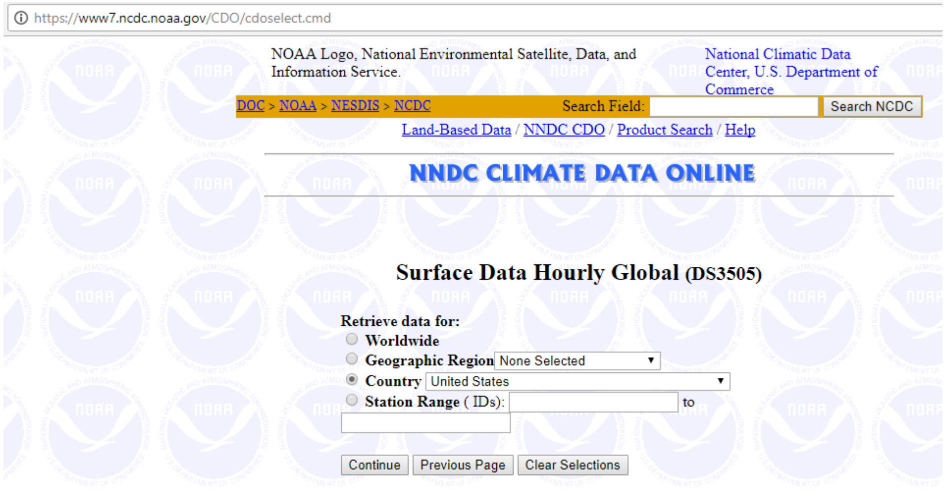
12. Next you will need to download the ASOS data. Go to the following link.

https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/automated-surface-observing-system-asos

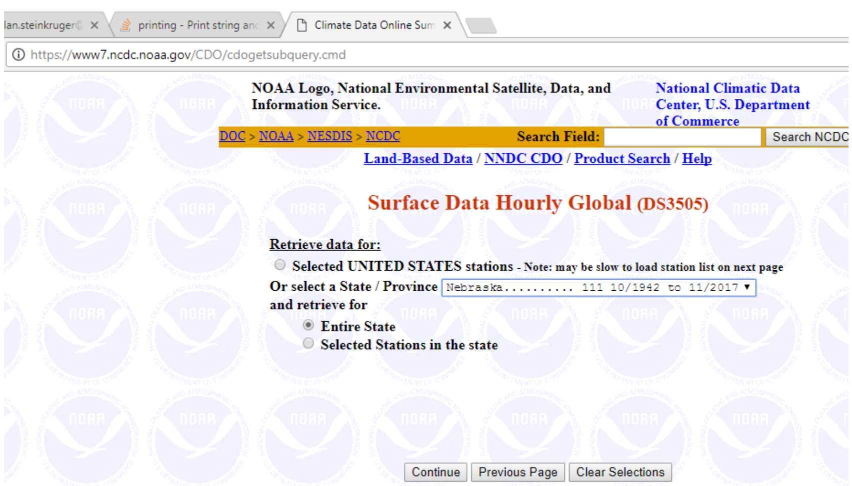
13. Select the "User Interface Page" Option

14. Select "Continue with SIMPLIFIED options"

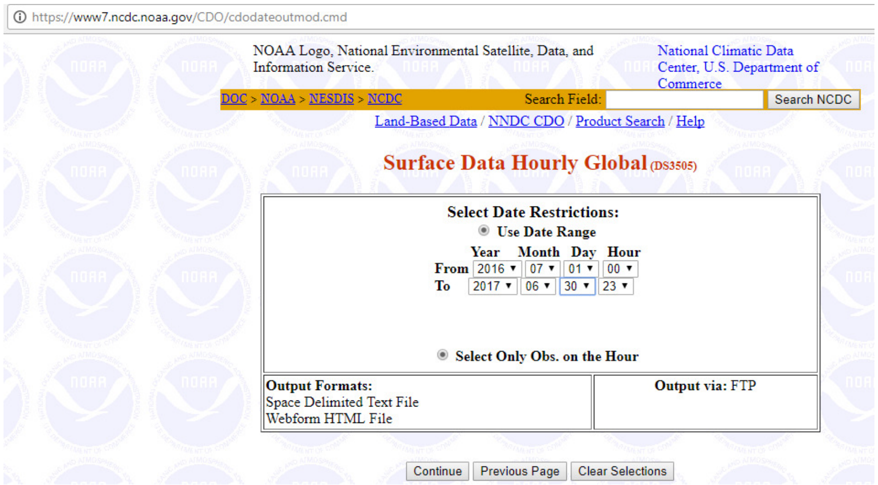
15. Select the Country option and “United States” and hit Continue.



16. Next, choose the Entire State option and then select “Nebraska” and hit continue

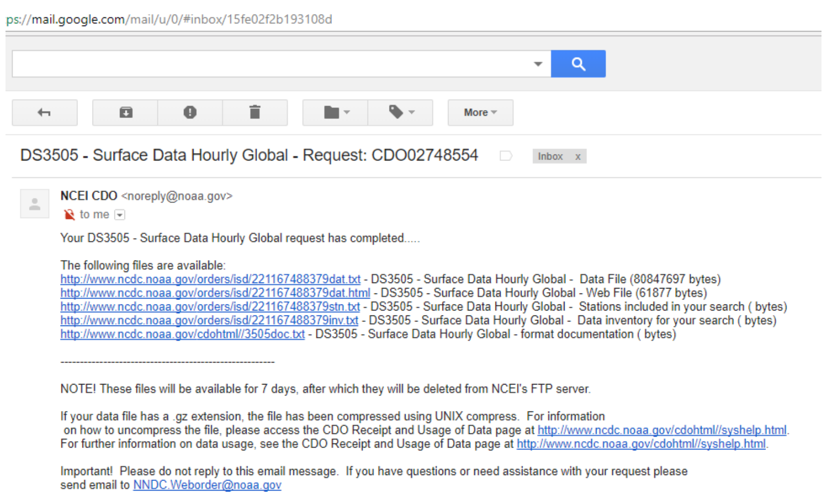


17. Input your desired date range. The range should be between 07/01 of some year to 06/30 of the next year. The image below provides an example. Additionally, check "Select only obs. on the hour"

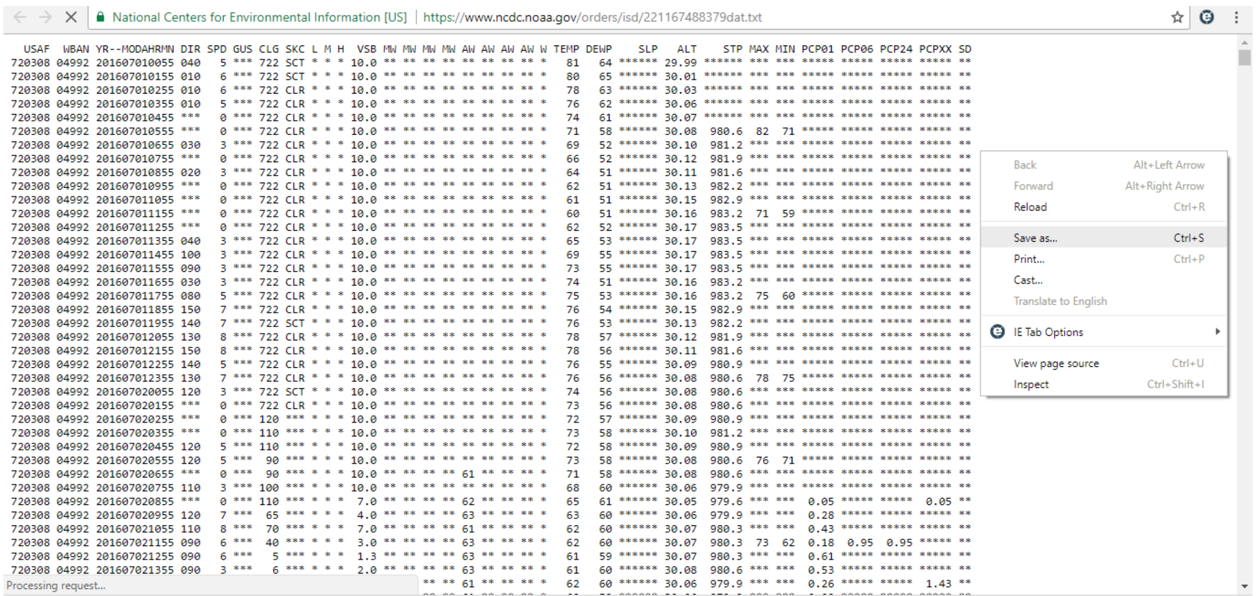


18. On the next page, enter your e-mail address and confirm your data selection.

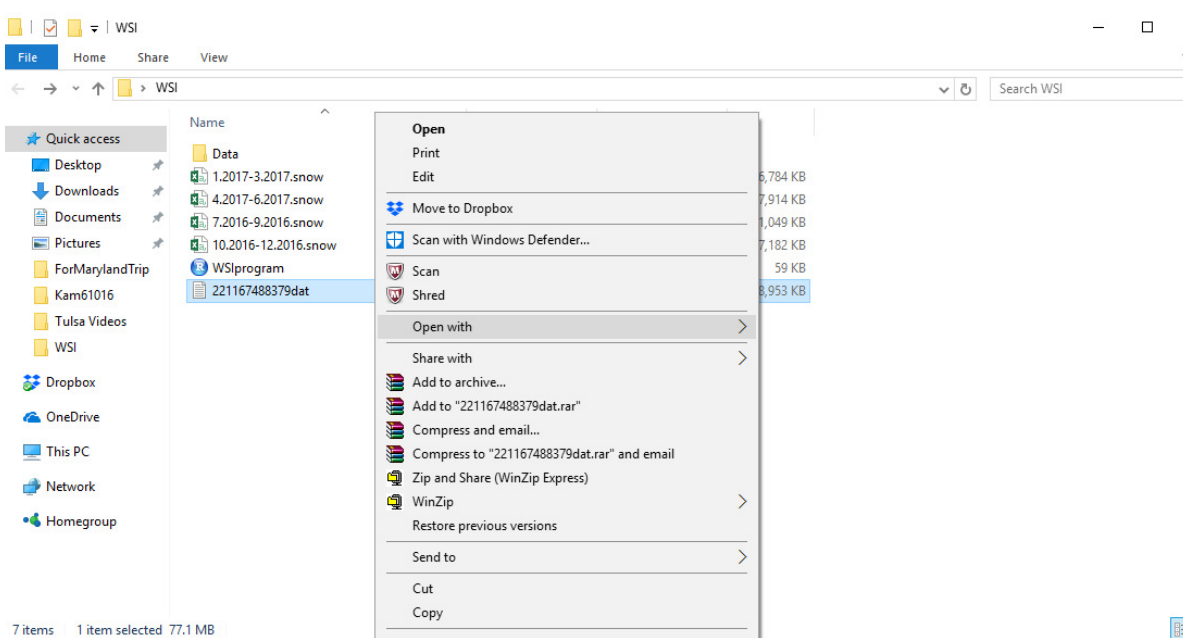
19. Again, the data may take a while to arrive at your email. When the e-mail arrives, select the top .txt link provided by NCEI. A webpage should open with a long list of data.



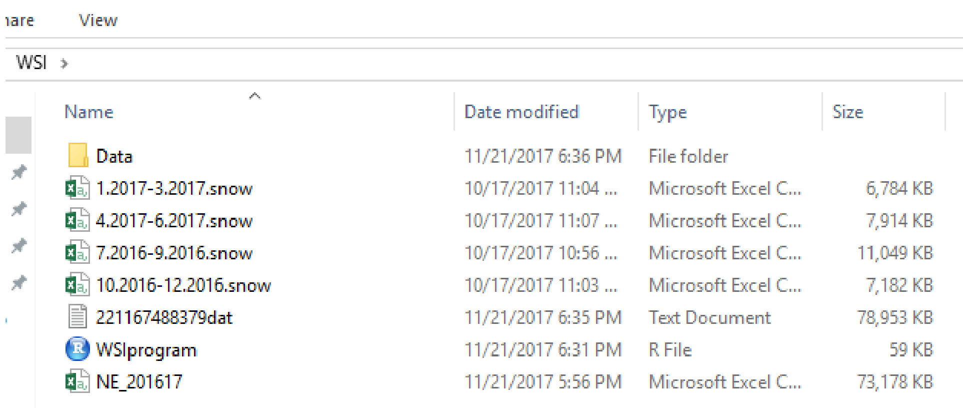
20. Once your web browser opens the .txt file, right click within the browser and select "Save As.." Save the file to the folder you previously created.



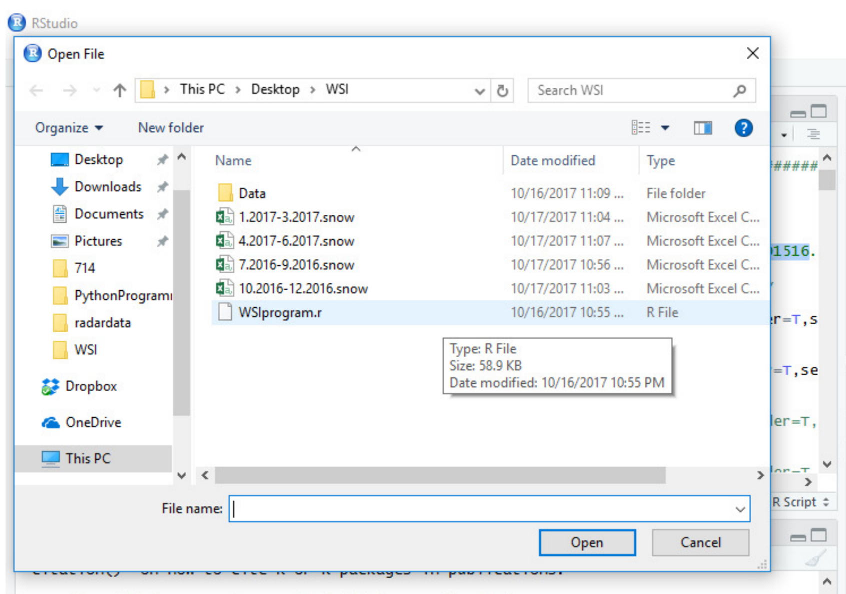
21. Next, you need to convert the .txt file into a .csv to do this right click on the file and select "Open with" and choose Microsoft Excel(If Microsoft excel is not available it is necessary to find another way to convert the .txt file into a .csv. In some cases, this process may be possible through an online website.)



22. Once in Microsoft Excel, choose "Save As" and under file format select ".csv" Save the file to the WSI folder you previously created. Rename the file in the following format: NE_201617 Change the year as necessary. The directory should now look like the following.



23. Next we need to modify the r file and run the program. First, open up Rstudio. Go to File > Open File… > Find the folder you have stored the .r file in and select the file ending in .r

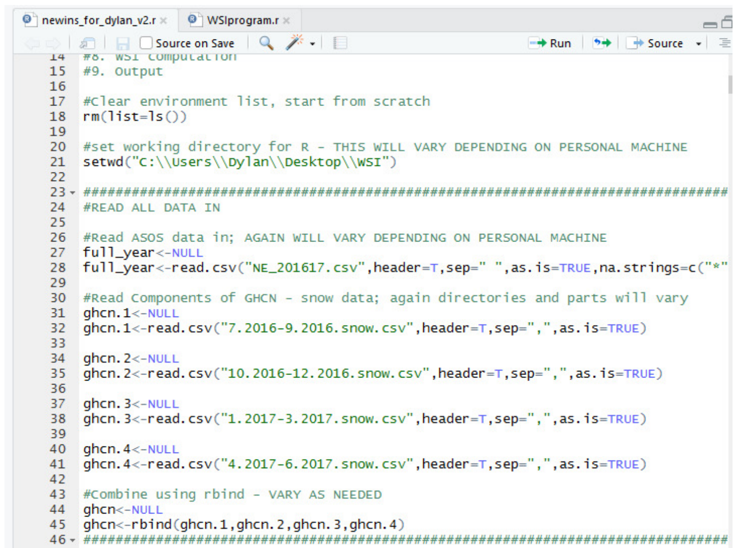


24. The r code should now appear in the top left corner.

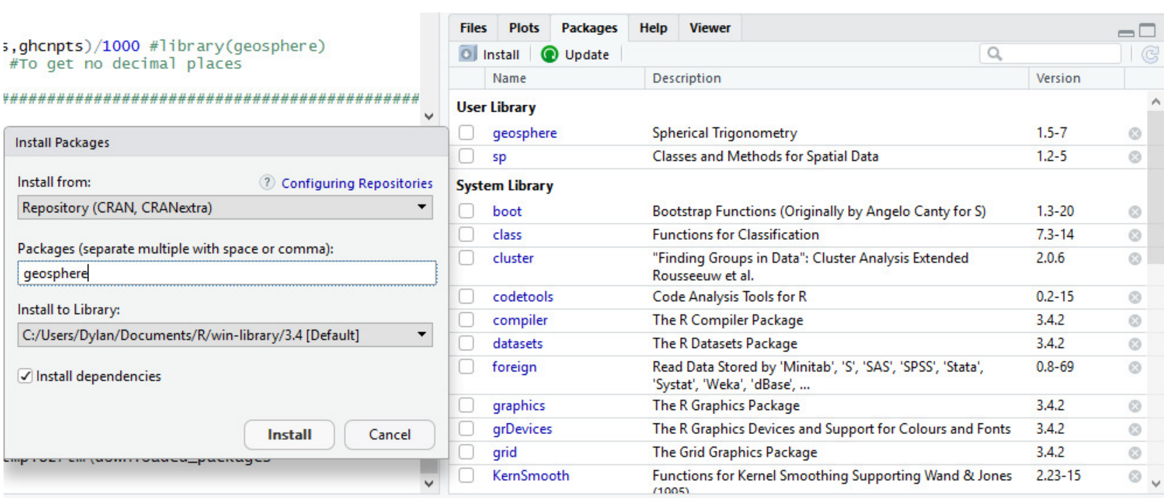
25. Next, we will input the file names into the r code.

Use the following format to input file names within quotes ("") at the specified lines. NOTE: These are the files you previously saved in the WSI folder. Change names as necessary to ensure the program can find the correct files.

Line 21: The directory of the folder you are housing all the files in. See picture example below.
Line 28: NE_201617.csv
Line 32: 7.2016-9.2016.snow.csv
Line 35: 10.2016-12.2016.snow.csv
Line 38: 1.2017-3.2017.snow.csv
Line 41: 4.2017-6.2017.snow.csv



26. One package is required to run the R script. In the bottom right hand window select the "Packages" tab. Underneath the tab, select "Install". In the next window, type in "geosphere" and click "Install" within the window.



27. Finally, press ctrl + alt + r and the program will output the desired file to your original WSI folder.