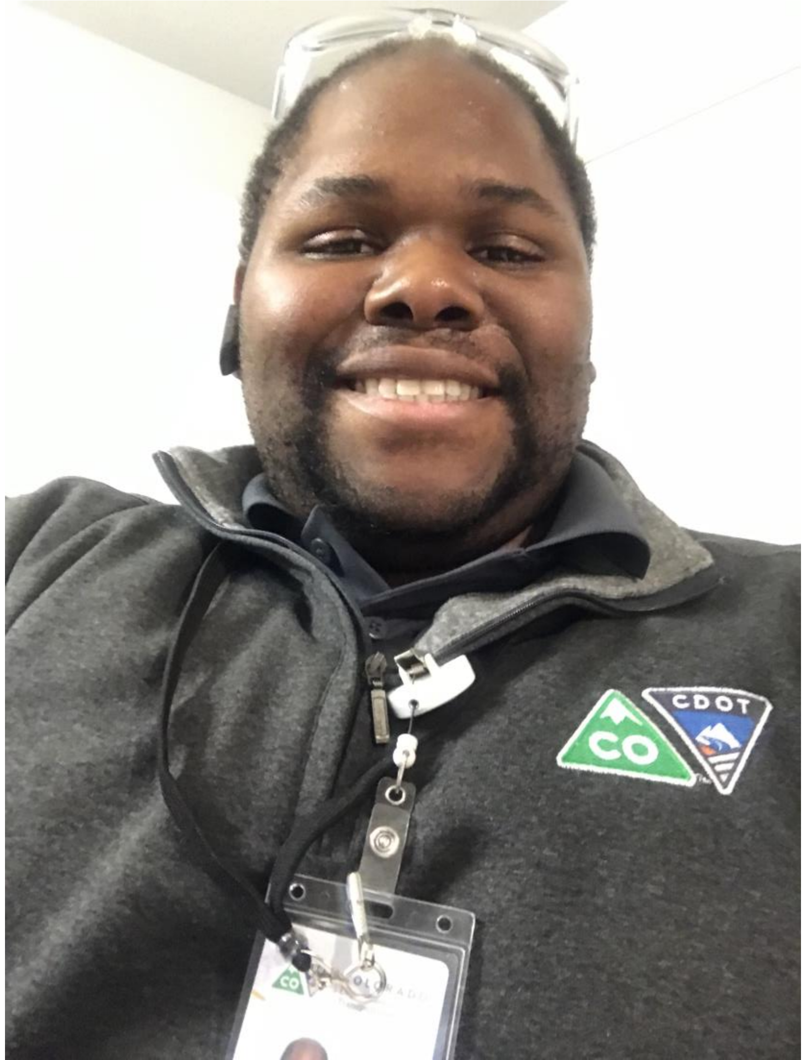
Transportation-Centric Winter Severity Index and Connections to Synoptic Environments

Curtis L. Walker, Ph.D., A.M.ASCE

13 December 2022

NSF

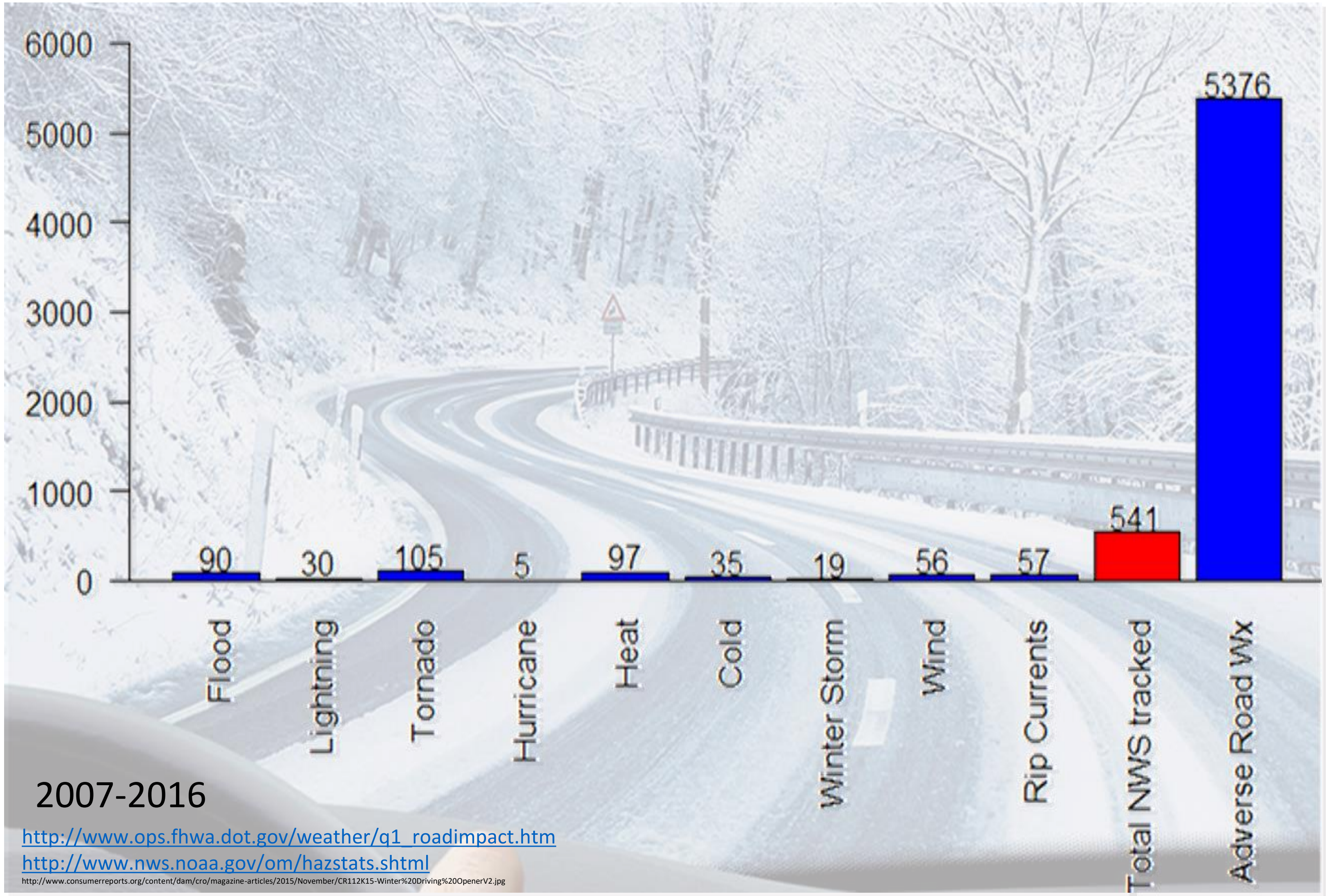
NCAR
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH



Surface Transportation Meteorology Expertise

- Currently a Project Scientist at NCAR (RAL, WSAP)
- Previously an NCAR Advanced Study Program (ASP) Postdoctoral Fellow
- Colorado Department of Transportation, Division of Maintenance and Operations, Meteorology/Weather Operations
- Associate Member (A.M.), American Society of Civil Engineers (ASCE)
- University of Nebraska-Lincoln
  - ➢ M.S., Ph.D., Atmospheric Science
- State University of New York (SUNY), College at Oneonta
  - ➢ B.S., Meteorology

Impacts of Adverse Weather on Roads



2007-2016

http://www.ops.fhwa.dot.gov/weather/q1_roadimpact.htm
http://www.nws.noaa.gov/om/hazstats.shtml
http://www.consumerreports.org/content/dam/cro/magazine-articles/2015/November/CR112K15-Winter%20Driving%20OpenerV2.jpg

- **Safety** – 21% of U.S. Highway crashes (1.2 million); ~418,000 injuries
- **Economic** – Cost per crash ~$15,000; congestion costs ~$9.5 billion
- **Environmental** – Air quality and local watershed pollution
- **Social** – Inconvenience of traffic delays

NHTSA 2016, NWS 2018, USDOT 2018

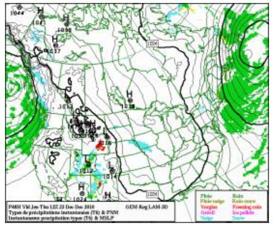
Department of Transportation Winter Severity Index

http://www.robsonforensic.com/upload/articles/RWIS_Header.jpg

Cold Winter
Average Winter
Warm Winter

Nebraska Winter Severity Index (NEWINS)

Storm-Level Data



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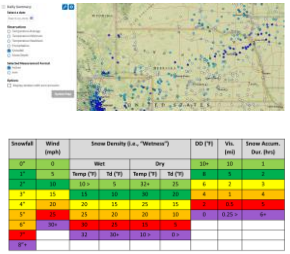
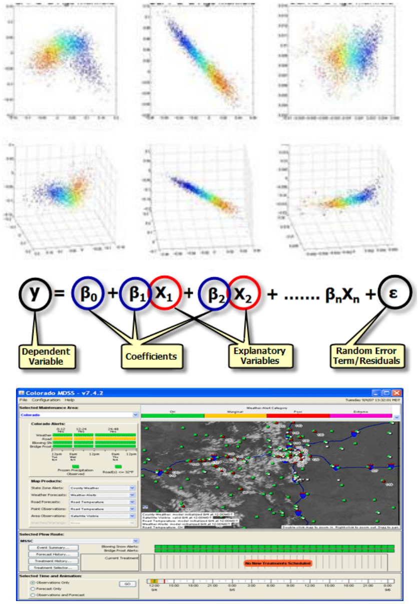


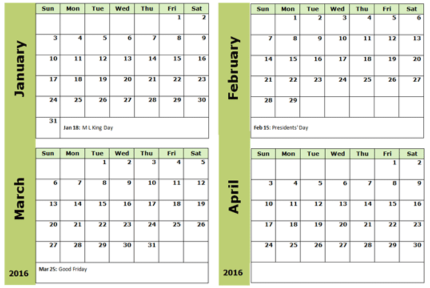
Classify Storms

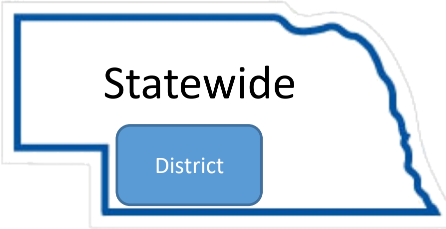


Statistical Analyses and Physical Meteorological Processes

Develop Nebraska Winter Severity Index

Monthly and Seasonal

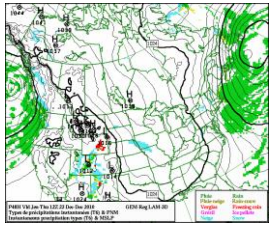




Nebraska Winter Severity Index (NEWINS)

Identification of events (i.e., snowstorms) from 10-year period October 2006-April 2016

Storm-Level Data



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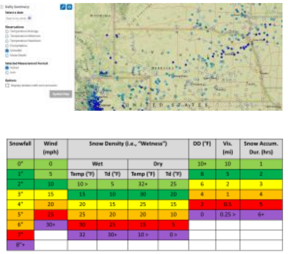

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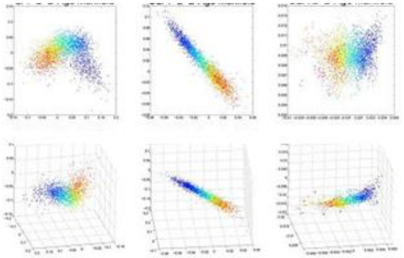

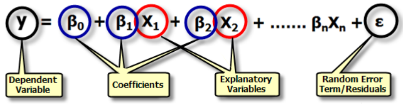

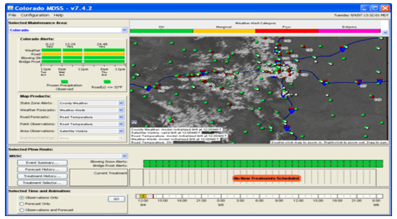

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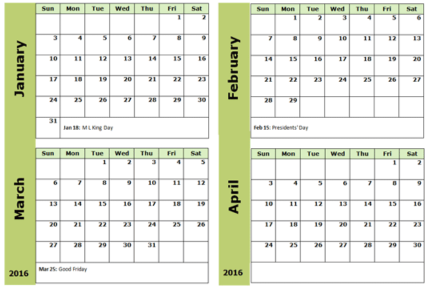
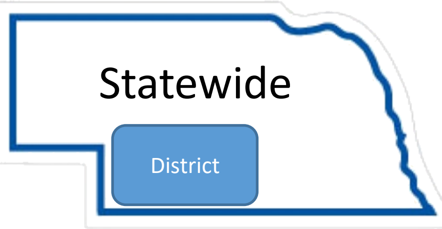
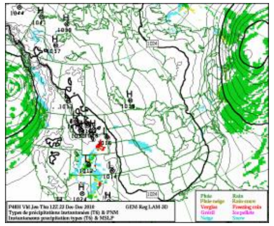
Monthly and Seasonal





Nebraska Winter Severity Index (NEWINS)

Storm-Level Data



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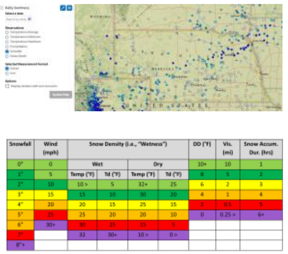
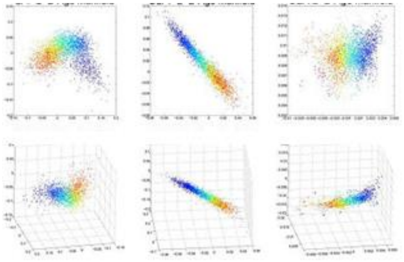
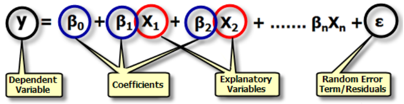
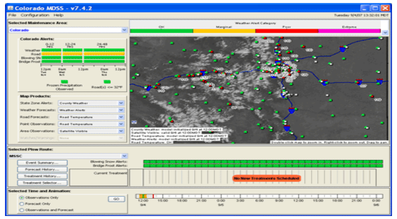


Classify Storms

Determine important meteorological variables and storm classification for winter severity index







Statistical Analyses and Physical Meteorological Processes

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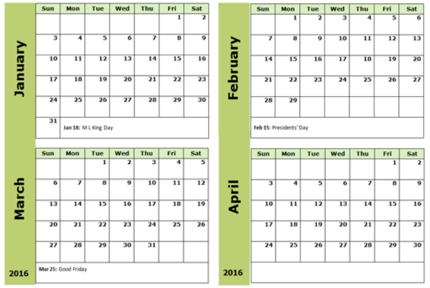
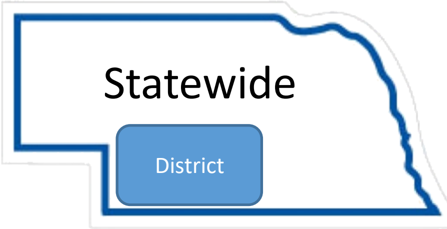
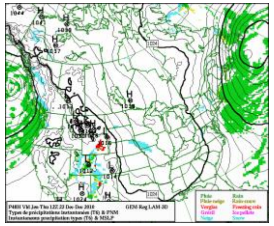


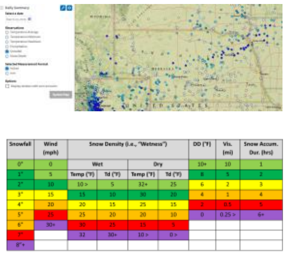


Nebraska Winter Severity Index (NEWINS)

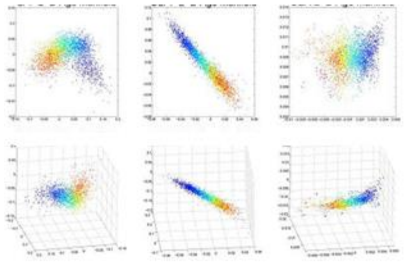
Storm-Level Data

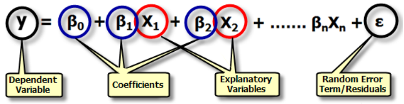


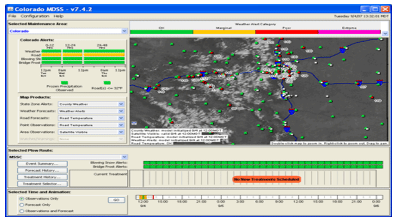
Select Variables



Classify Storms







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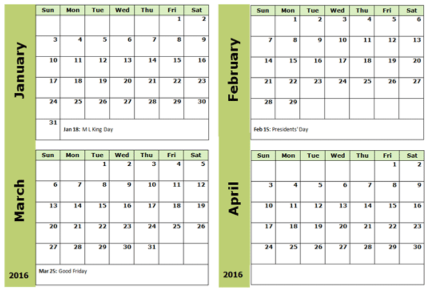
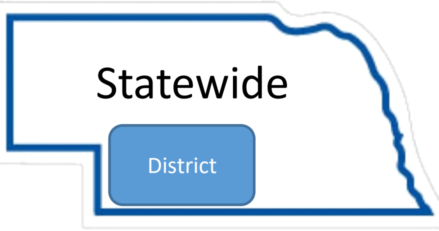
Monthly and Seasonal



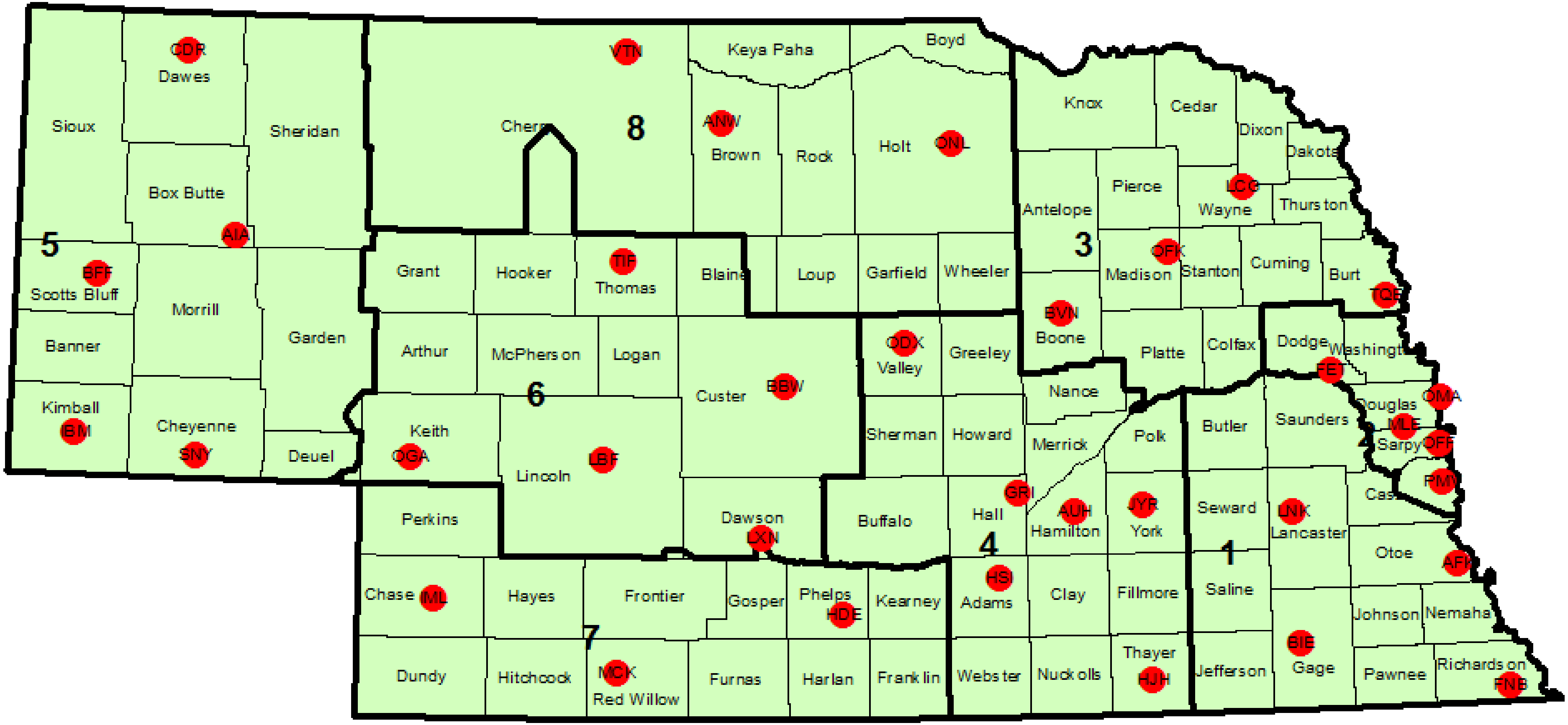


Compare winter weather severity index with winter maintenance operations

Data Sources

1. National Centers for Environmental Information (National Oceanic and Atmospheric Administration)

   - Automated Surface Observing System



Sioux
Dawes
CDR
Sheridan
Box Butte
AIA
5
Scotts Bluff
BFF
Morrill
Garden
Banner
Kimball
Cheyenne
SNY
Deuel
VTN
8
Keya Paha
Boyd
ANW
Brown
Rock
Holt
ONL
Grant
Hooker
Thomas
TIF
Loup
Garfield
Wheeler
Arthur
McPherson
Logan
6
Custer
BBW
ODX
Valley
Greeley
Keith
OGA
Lincoln
LBF
Perkins
Dawson
LXN
Sherman
Howard
Buffalo
Hall
GRI
4
Chase
IML
Hayes
Frontier
7
Gosper
Phelps
HDE
Kearney
Adams
HSI
Dundy
Hitchcock
MCK
Red Willow
Furnas
Harlan
Franklin
Webster
Nuckolls
Knox
Cedar
Dixon
Antelope
3
Pierce
Wayne
LCG
Thurston
Madison
OFK
Stanton
Cuming
Burt
TQE
BVN
Boone
Platte
Colfax
Dodge
FET
Nance
Merrick
Polk
Butler
Saunders
OMA
MLE
Sarpy
OFF
PMV
2
AUH
Hamilton
JYR
York
Seward
LNK
Lancaster
1
Clay
Fillmore
Saline
Otoe
AFK
Johnson
Nemaha
Thayer
HJH
Jefferson
BIE
Gage
Pawnee
Richardson
FNB

Data Sources

1. National Centers for Environmental Information (National Oceanic and Atmospheric Administration)

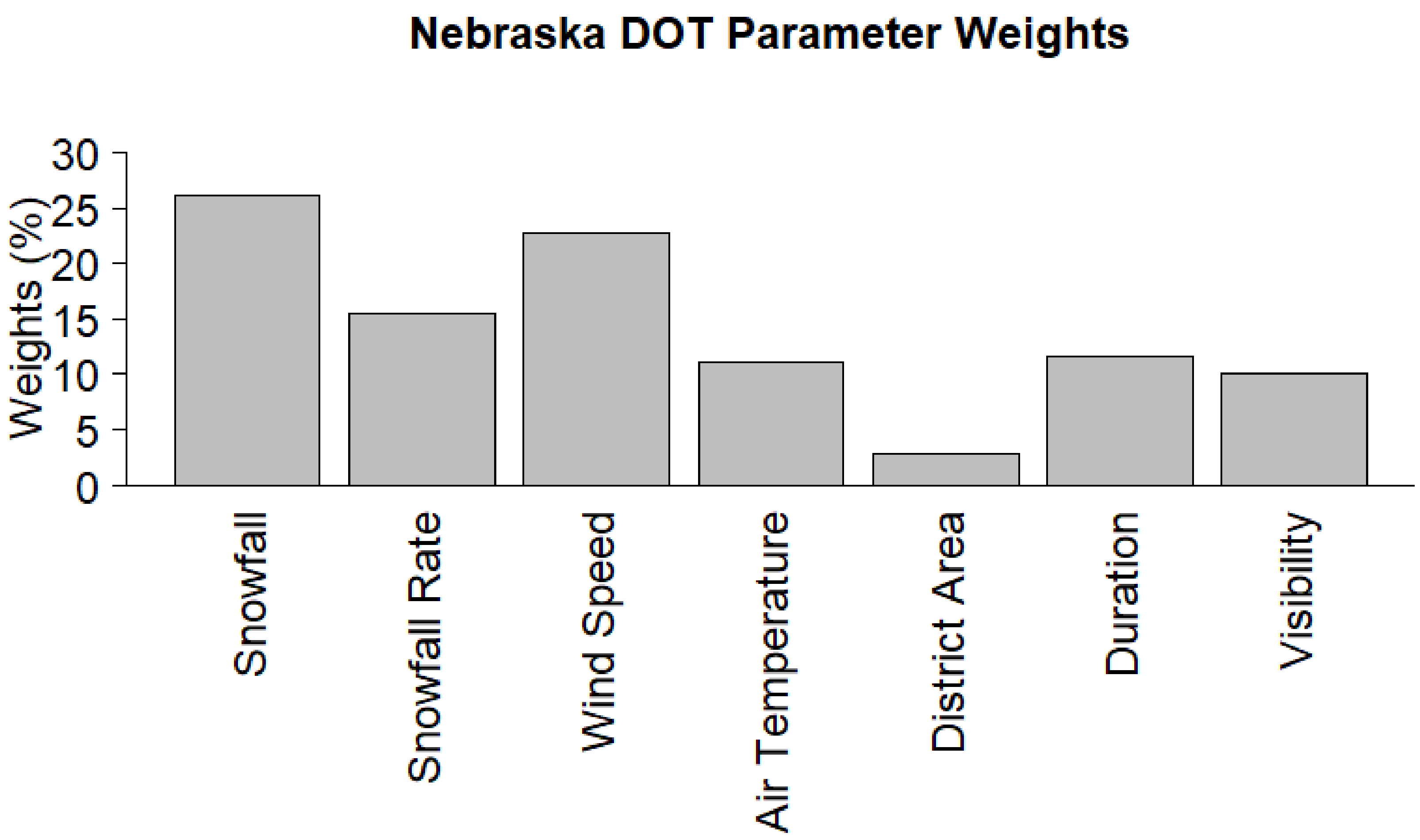
- Automated Surface Observing System

- Global Historical Climatology Network – Daily
  - Community Collaborative Rail, Hail and Snow Network (CoCoRaHS)
  - Cooperative Observer Network (COOP)
  - Nebraska Rainfall and Assessment Network (NeRain)

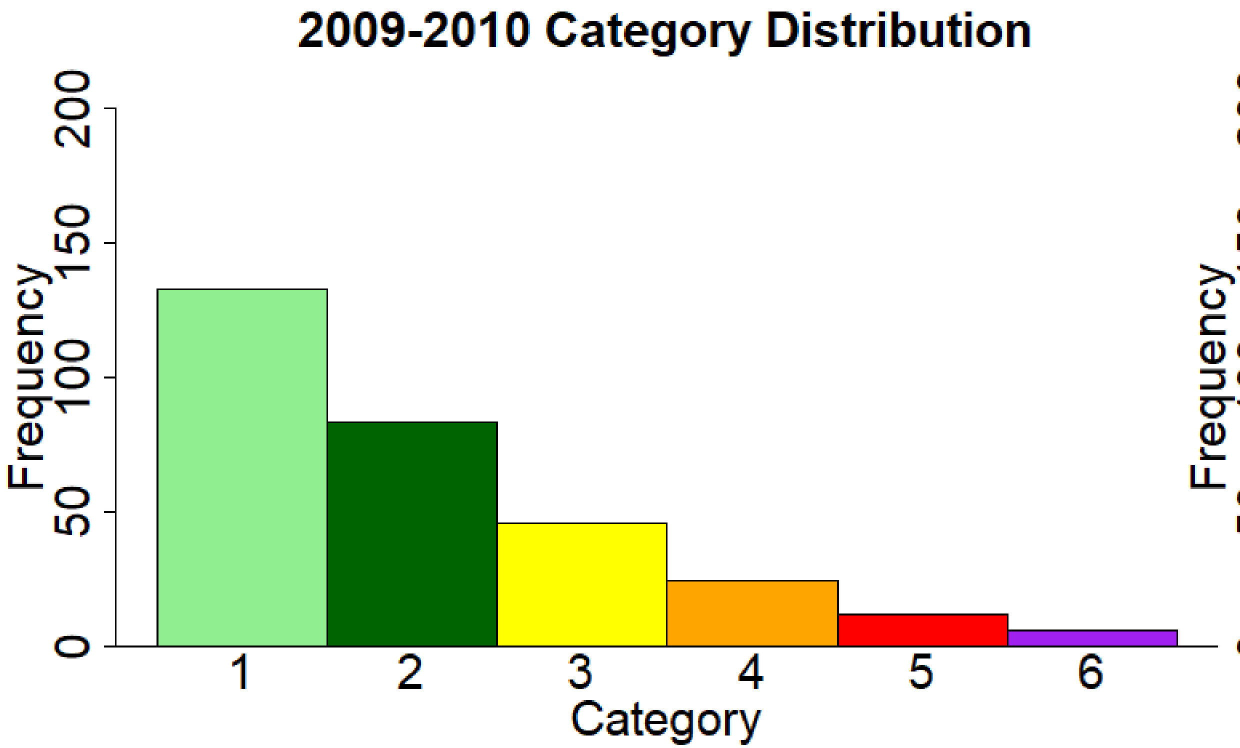
Parameter	Category					
	Trace (1)	Marginal (2)	Slight (3)	Enhanced (4)	Moderate (5)	High (6)
Road Access	No Impact	No Impact	Minimal road closures	Occasional road closures	Numerous Road Closures	Significant Road Closures
Road Conditions	Wet Roads	Wet Roads	Spotty snow and ice covered roads, otherwise 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 Impact	No Impact	Minimal speed reductions	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
Storm Classification Road Impacts						

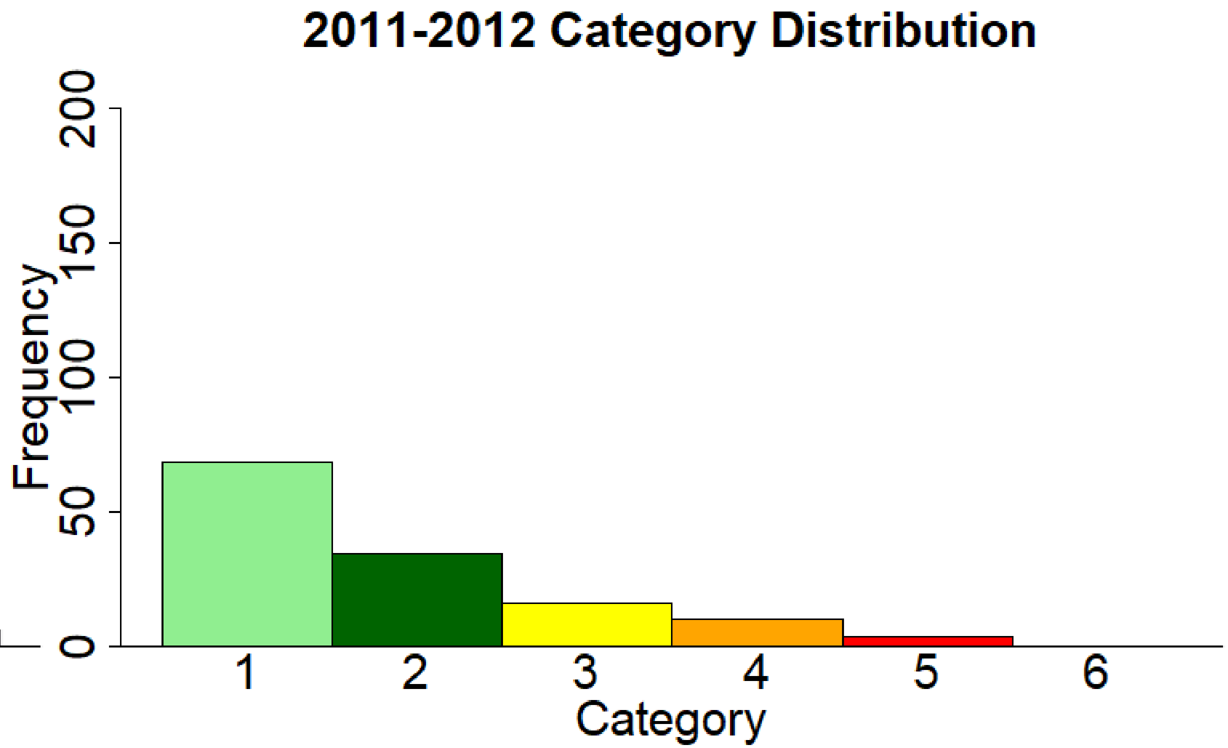
Storm Classification Weather Parameters

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



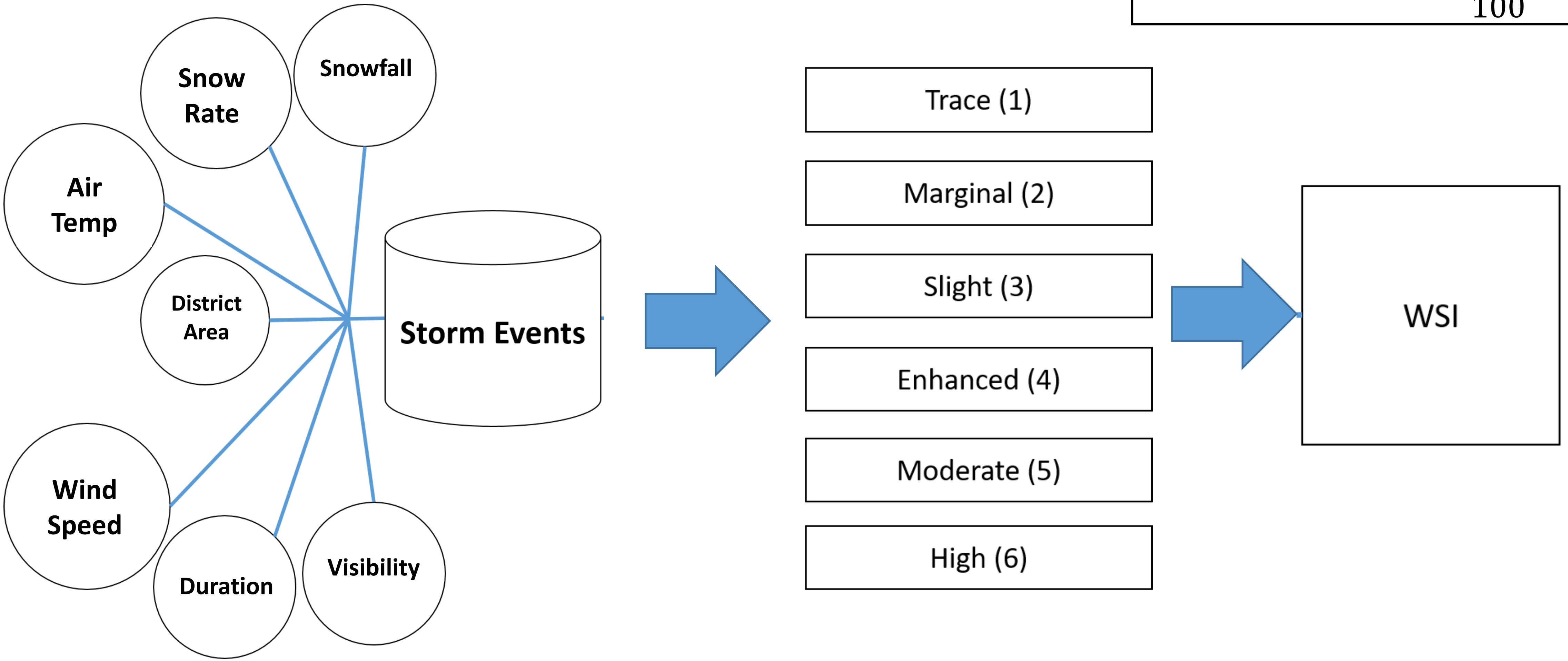
Nebraska DOT Weather Parameter Importance


2009-2010 Category Distribution
Frequency
0
50
100
150
200
1
2
3
4
5
6
Category

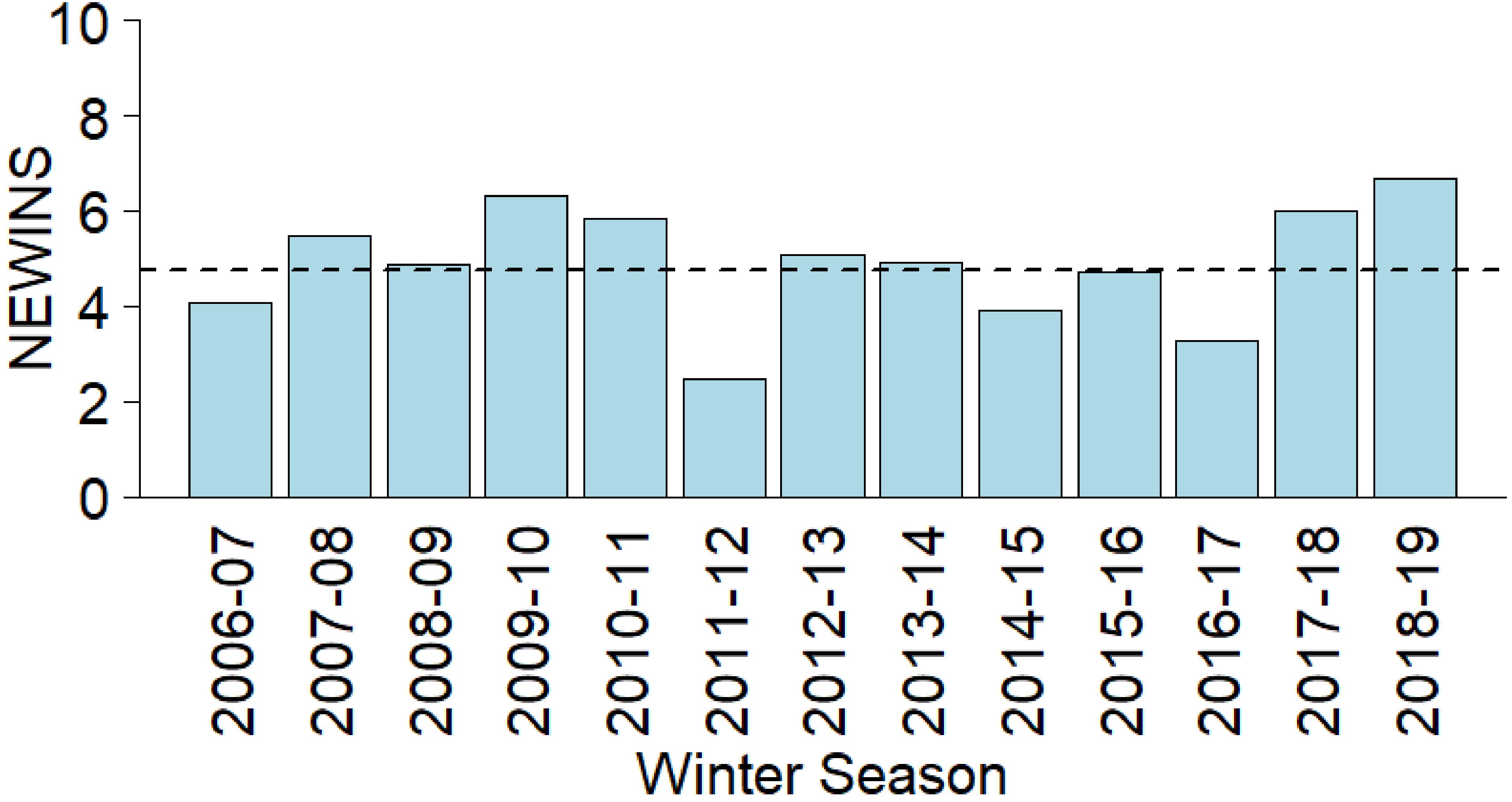

2011-2012 Category Distribution
Frequency
0
50
100
150
200
1
2
3
4
5
6
Category

NEWINS Computation

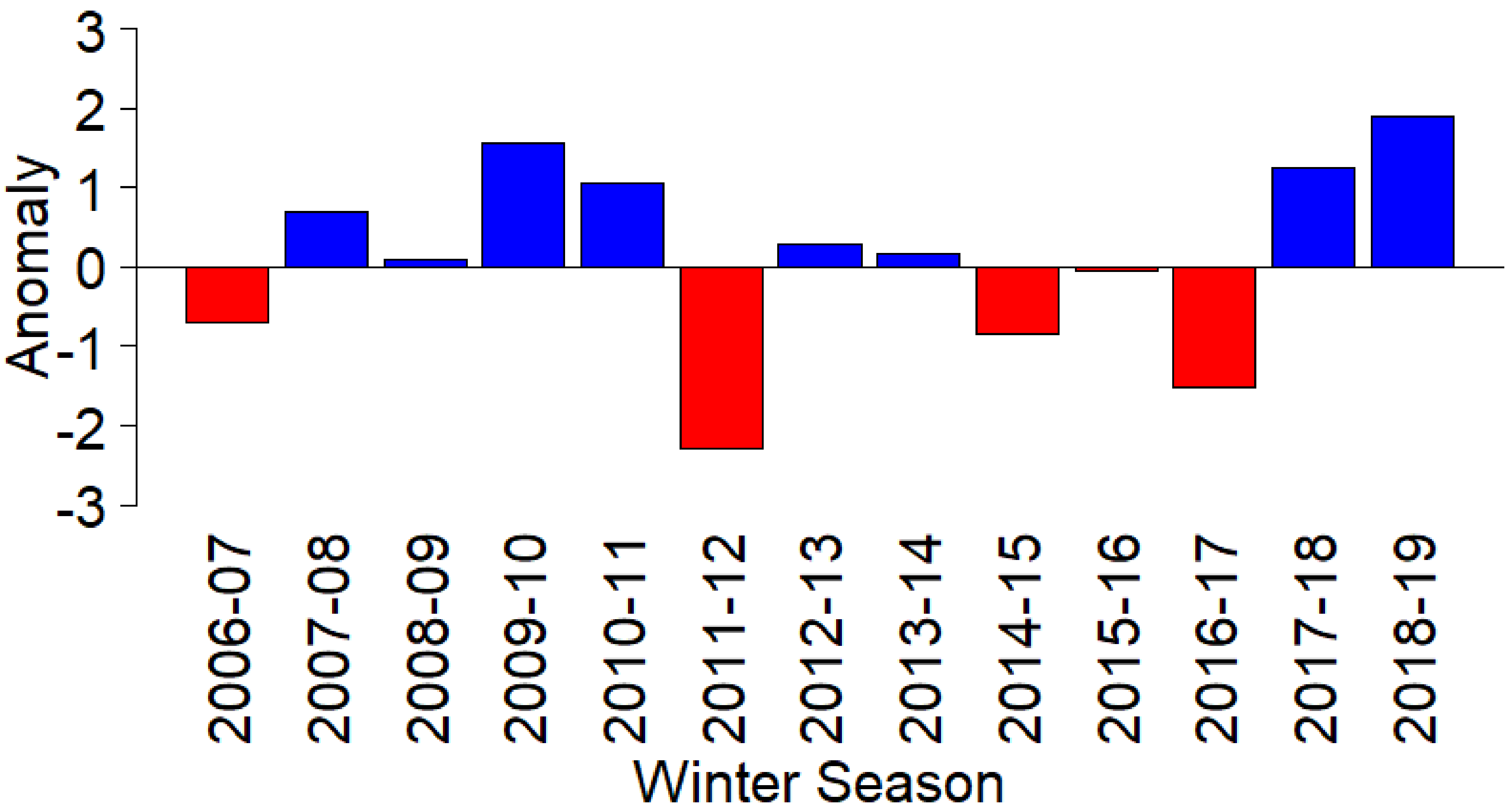
$$\text{NEWINS} = \frac{\sum(Category \times Frequency)}{100}$$



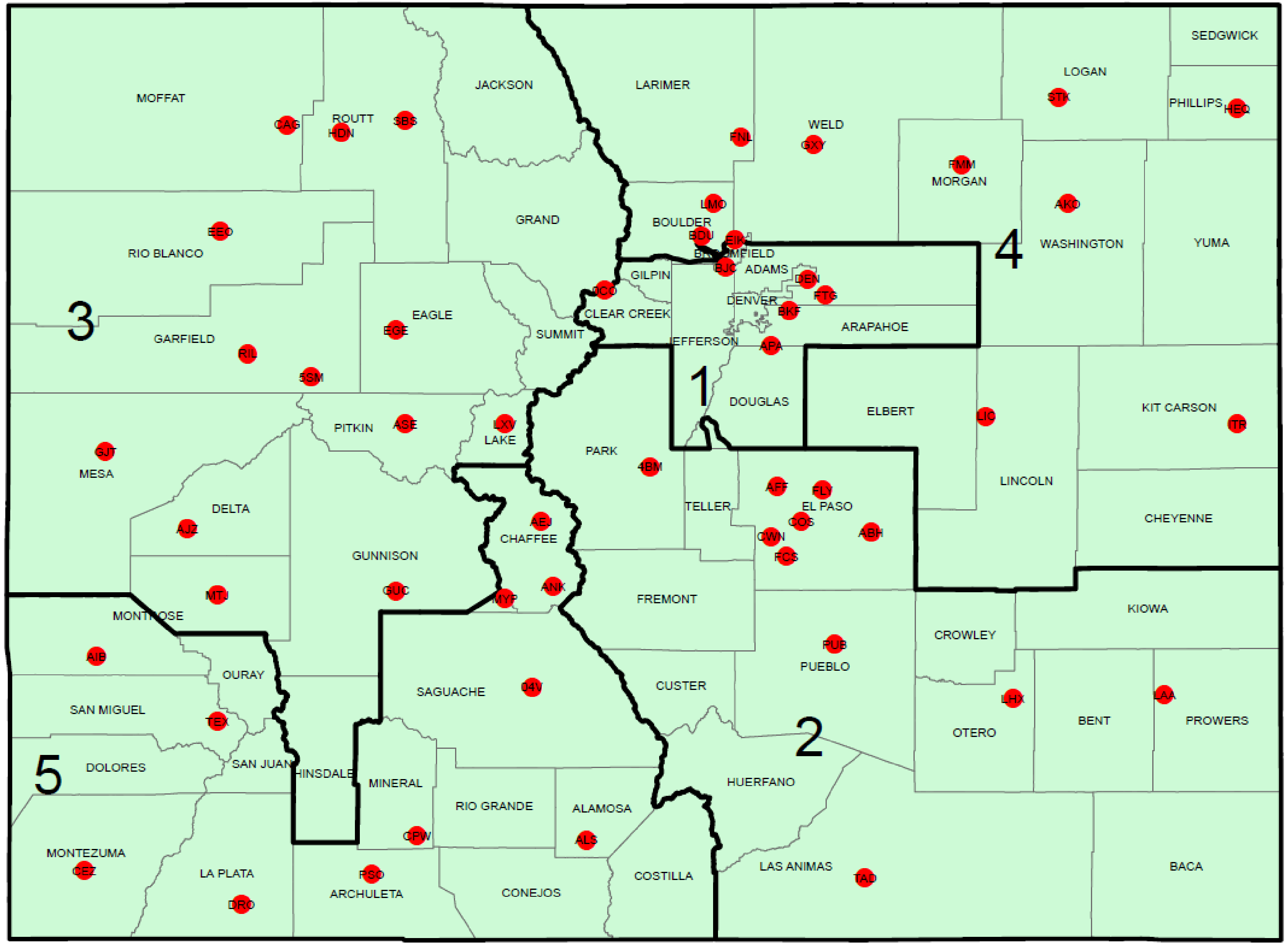
Nebraska Winter Severity Index for 2006-2019



Nebraska Winter Severity Index Anomalies for 2006-2019

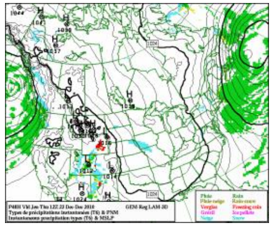


Expansion to Other States: Colorado Example

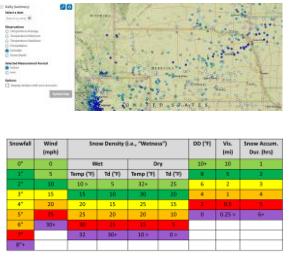


Colorado Winter Severity Index (COWINS)

Storm-Level Data



Select Variables



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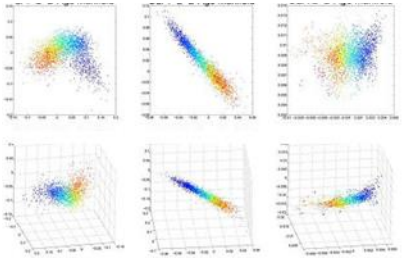
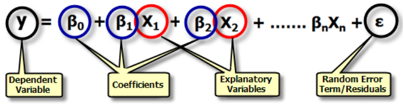
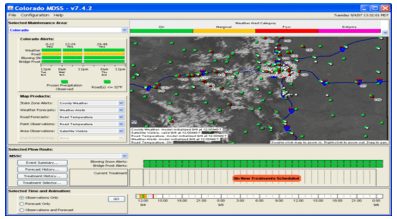


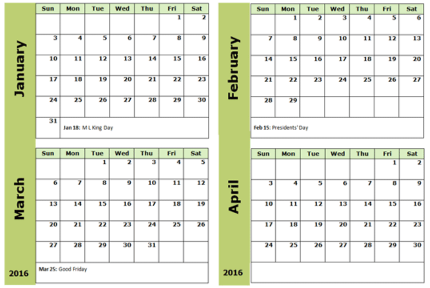


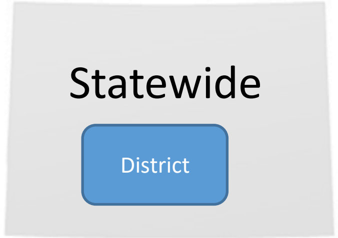


Statistical Analyses and Physical Meteorological Processes

Develop Colorado Winter Severity Index

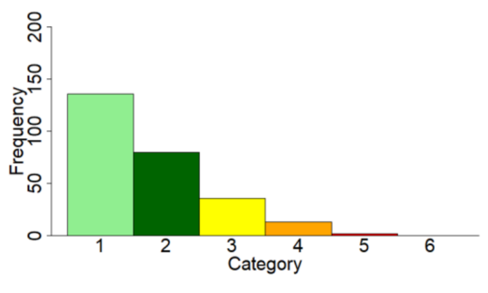
Monthly and Seasonal

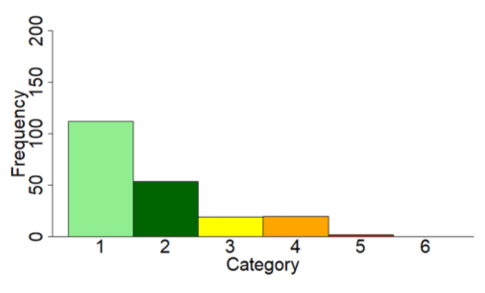


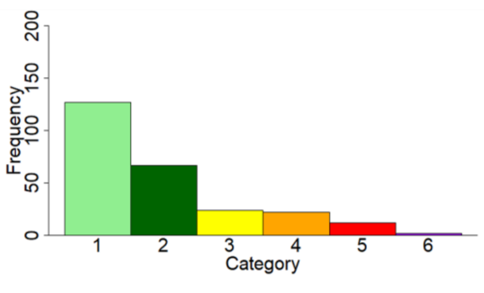


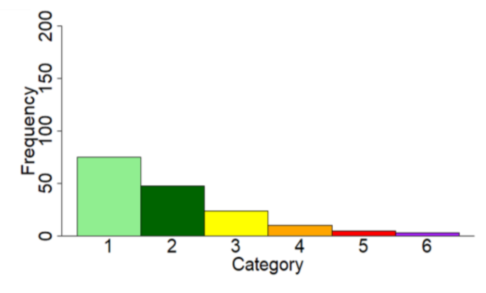
NE-CO Frequency Classification Comparison

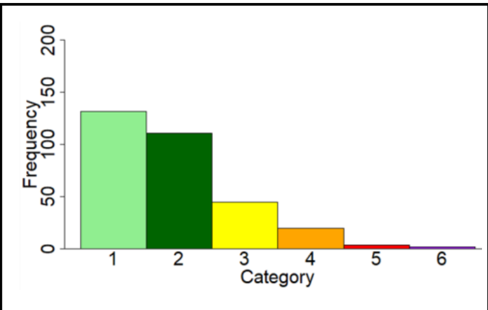
NE





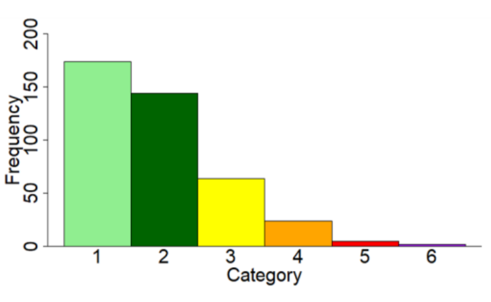


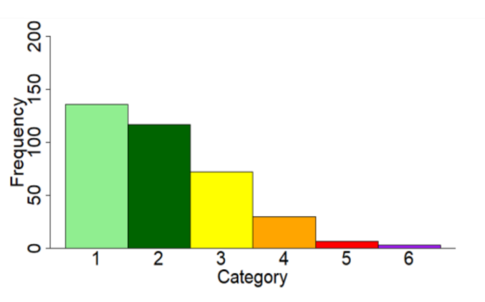


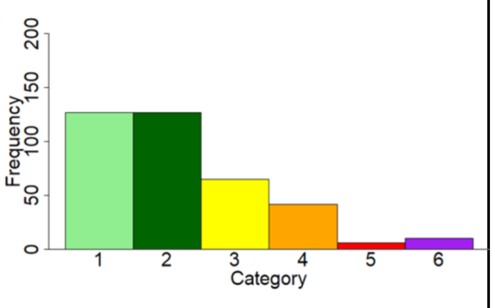


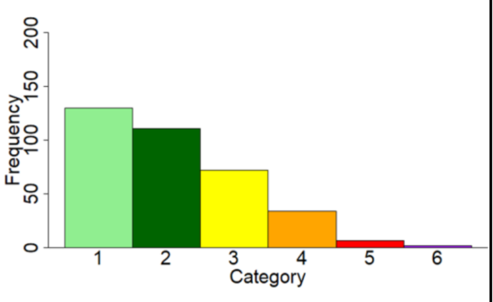
	2013-2014	2014-2015	2015-2016	2016-2017	2017-2018

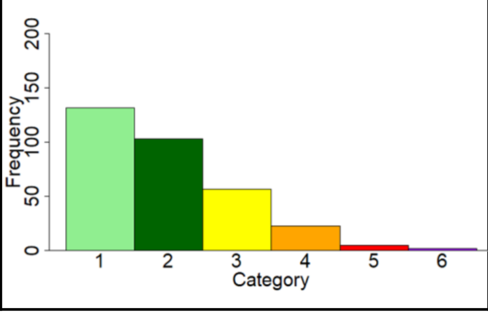
CO

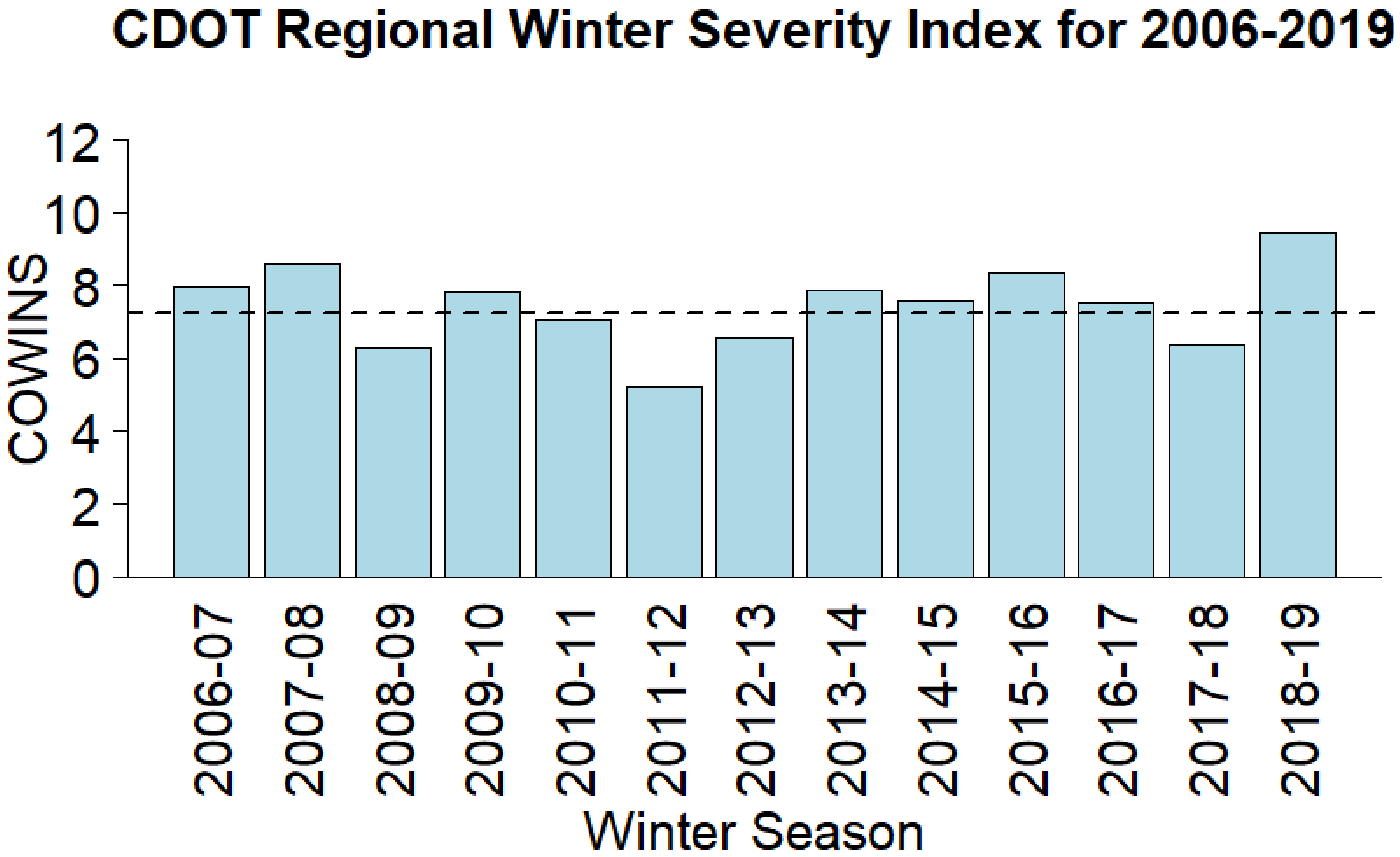




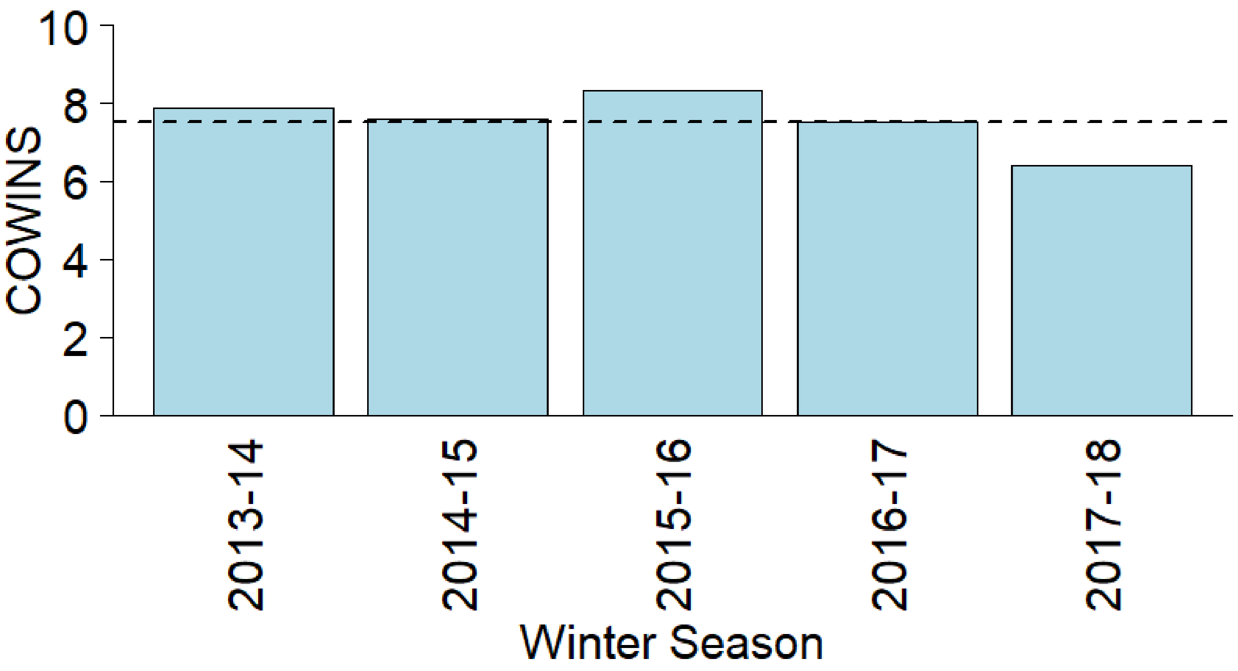




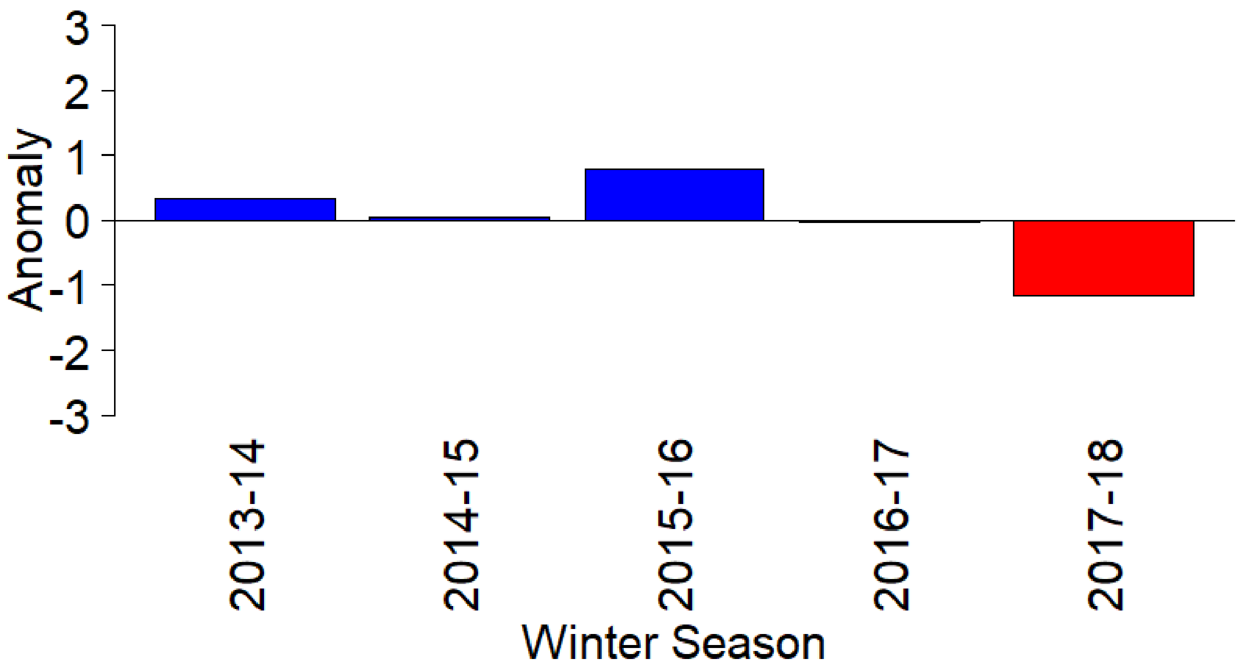



CDOT Regional Winter Severity Index for 2006-2019
COWINS
12
10
8
6
4
2
0
2006-07
2007-08
2008-09
2009-10
2010-11
2011-12
2012-13
2013-14
2014-15
2015-16
2016-17
2017-18
2018-19
Winter Season

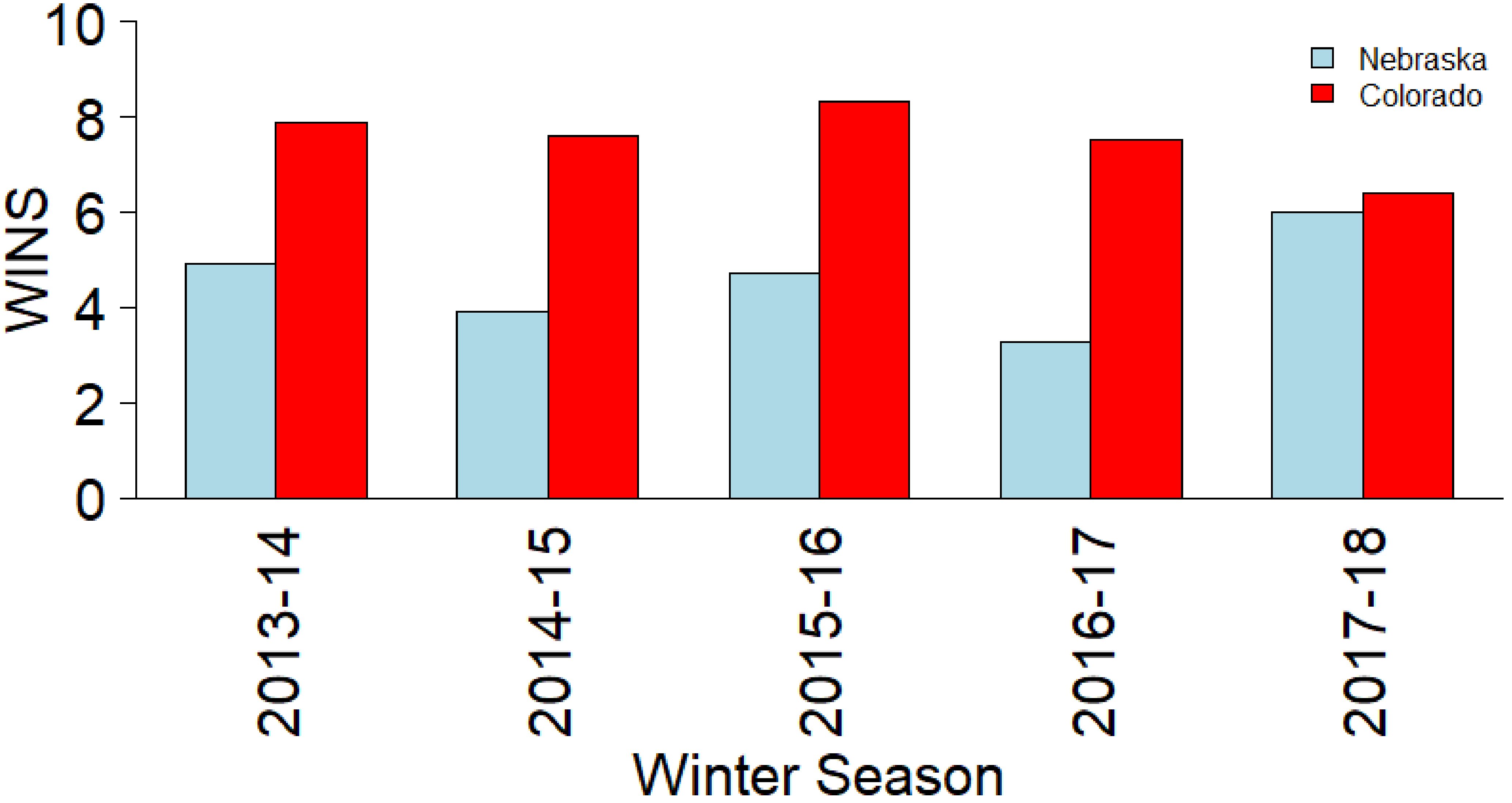
Colorado Winter Severity Index for 2013-2018



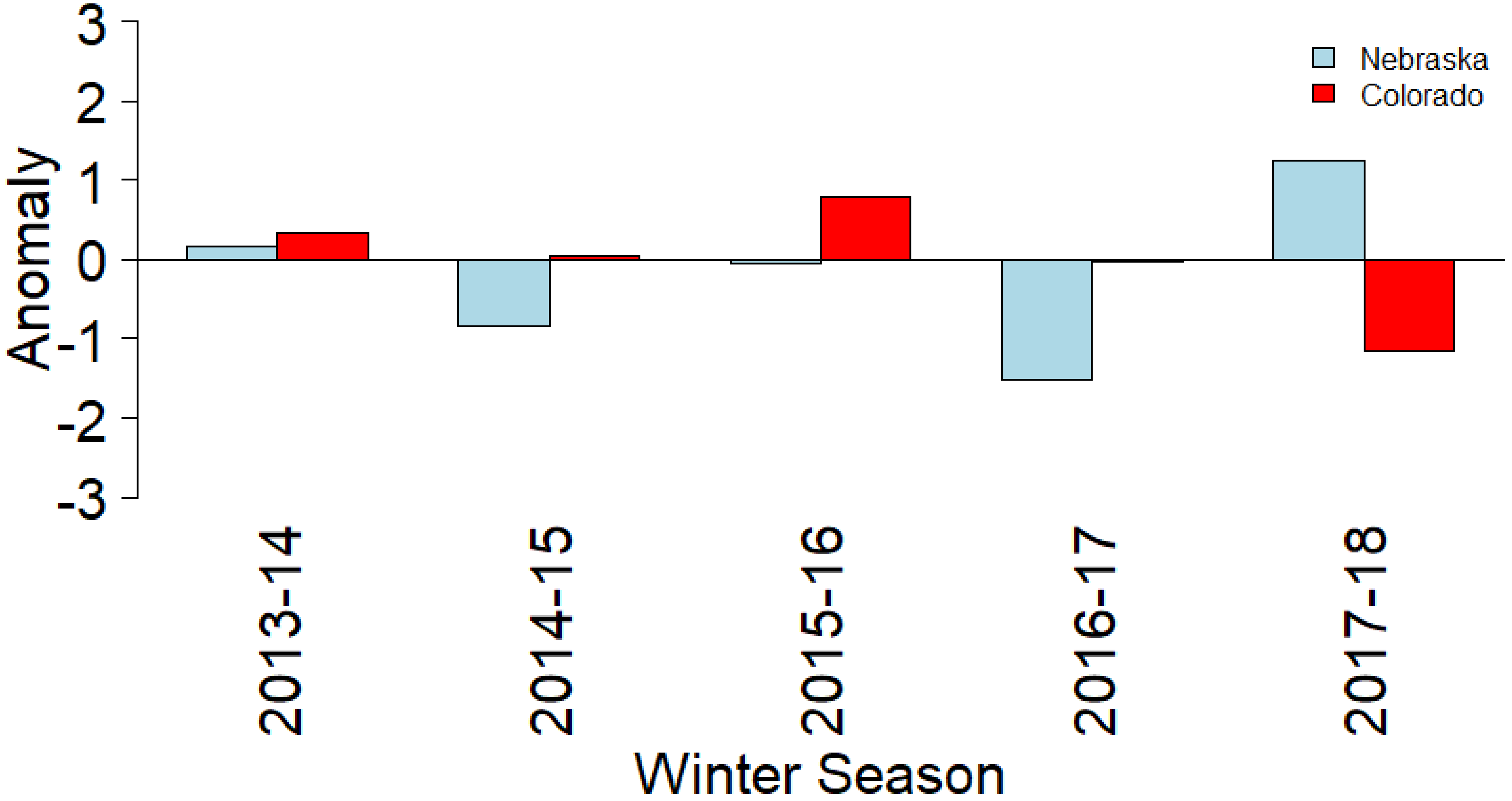
Colorado Winter Severity Index Anomalies for 2013-2018



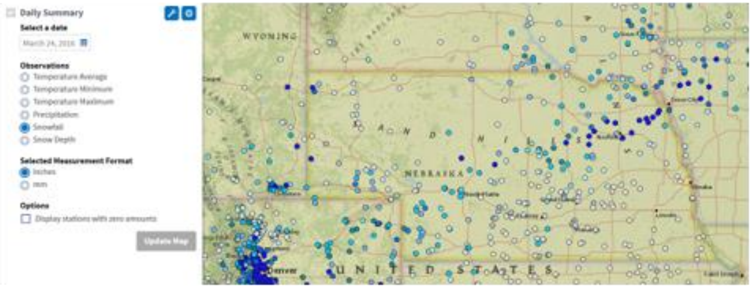
NE versus CO Winter Severity Index (WINS) for 2013-2018

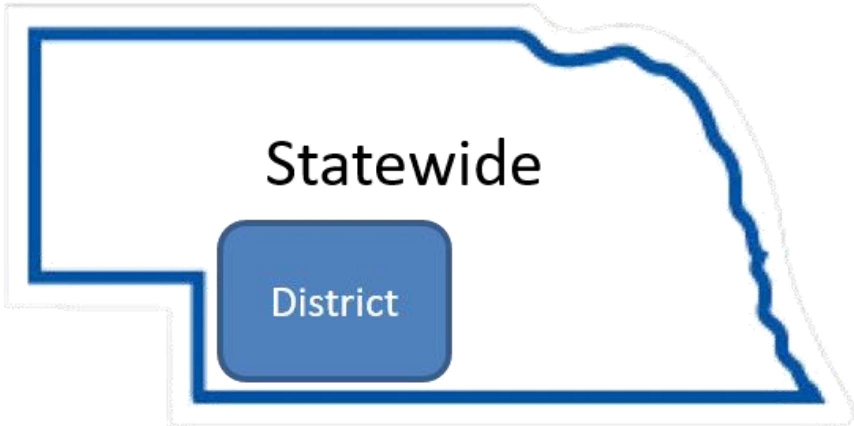


NEWINS versus COWINS Anomalies



Nebraska Winter Severity Index Framework





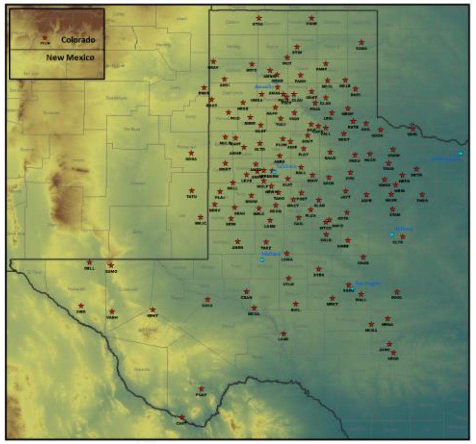
Weather Decision Support & Maintenance Operations + Storm-Level Data & Classification = **Winter Severity Index**

Snowfall	Wind (mph)	Snow Density (i.e., "Wetness")				DD (°F)	Vis. (mi)	Snow Accum. Dur. (hrs)
0"	0	Wet		Dry		10+	10	1
1"	5	Temp (°F)	Td (°F)	Temp (°F)	Td (°F)	8	5	2
2"	10	10 >	5	32+	25	6	2	3
3"	15	15	10	30	20	4	1	4
4"	20	20	15	25	15	2	0.5	5
5"	25	25	20	20	10	0	0.25 >	6+
6"	30+	30	25	15	5			
7"		32	30+	10 >	0 >			
8"+								

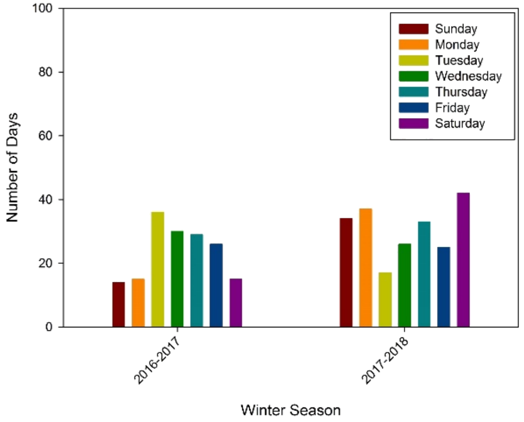
Monthly and Seasonal

Future Severity Index Possibilities

1) Higher Resolution



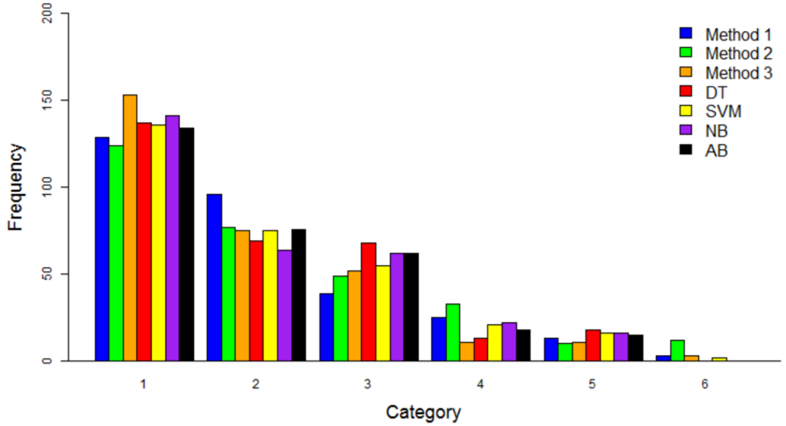
2) Day of the Week



3) Teleconnections

Year	WSI Anomaly Rank	ENSO Phase
2009-10	1	El-Nino
2010-11	2	La-Nina
2007-08	3	La-Nina
2012-13	4	Neutral
2013-14	5	Neutral
2008-09	6	La-Nina
2015-16	7	El-Nino
2006-07	8	El-Nino
2017-18	9	La-Nina
2014-15	10	El-Nino
2016-17	11	La-Nina
2011-12	12	La-Nina

4) Sensitivity Analyses



NEWINS El-Nino/La-Nina Comparisons

Year	WSI Anomaly Rank	ENSO Phase
2018-19	1	El-Nino
2009-10	2	El-Nino
2010-11	3	La-Nina
2007-08	4	La-Nina
2020-21	5	La-Nina
2017-18	6	La-Nina
2019-20	7	Neutral
2012-13	8	Neutral
2008-09	9	La-Nina
2015-16	10	El-Nino
2013-14	11	Neutral
2006-07	12	El-Nino
2014-15	12	El-Nino
2016-17	14	La-Nina
2021-22	15	La-Nina
2011-12	16	La-Nina

ENSO adapted from: http://ggweather.com/enso/oni.htm

A Jet-Centered Framework for Examining Synoptic Environments Conducive to High Plains Winter Weather Events

Andrew C. Winters

Department of Atmospheric and Oceanic Sciences (ATOC)

University of Colorado Boulder

Curtis L. Walker

Research Applications Laboratory (RAL)

National Center for Atmospheric Research

Boulder

NCAR

NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

NSF

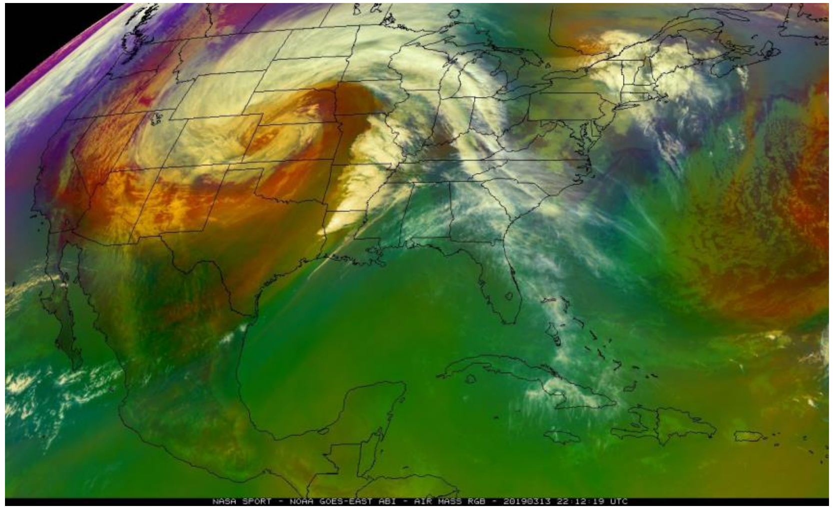
Background image: Aaron Ontiveroz, The Denver Post

Motivation

- Adverse winter weather conditions result in billions of dollars in economic costs and thousands of attributable fatalities each year (**Steiner et al. 2015; Lazo et al. 2020**).

- **High Plains winter storms** feature unique synoptic evolutions, which involve mesoscale and microscale terrain influences.

Jerilee Bennett, The Gazette



NOAA; NASA SPoRT

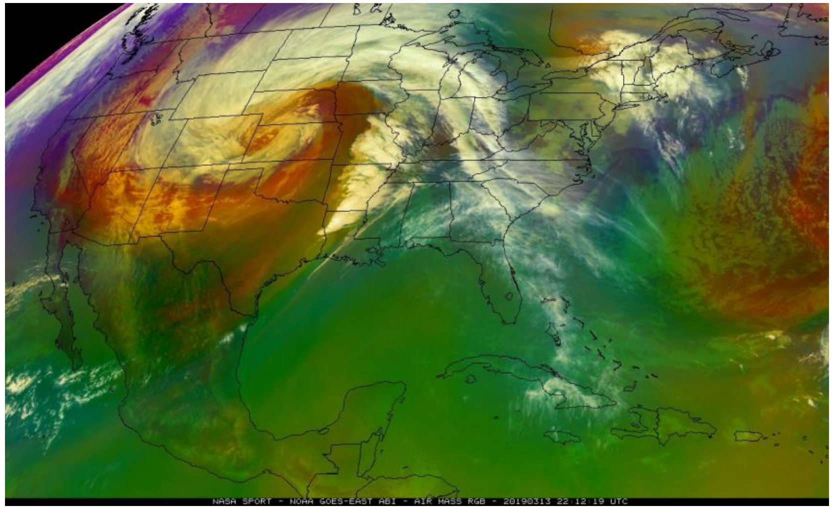
Motivation

- Numerous studies have developed **winter severity indices (WSIs)** to quantify winter storm impacts.

- **WSIs** provide a mechanism to translate hydrometeorological impacts into a rating of winter storm severity.

- On the synoptic scale, winter storms are closely tied to the positions of surface cyclones and anticyclones.

Jerilee Bennett, The Gazette



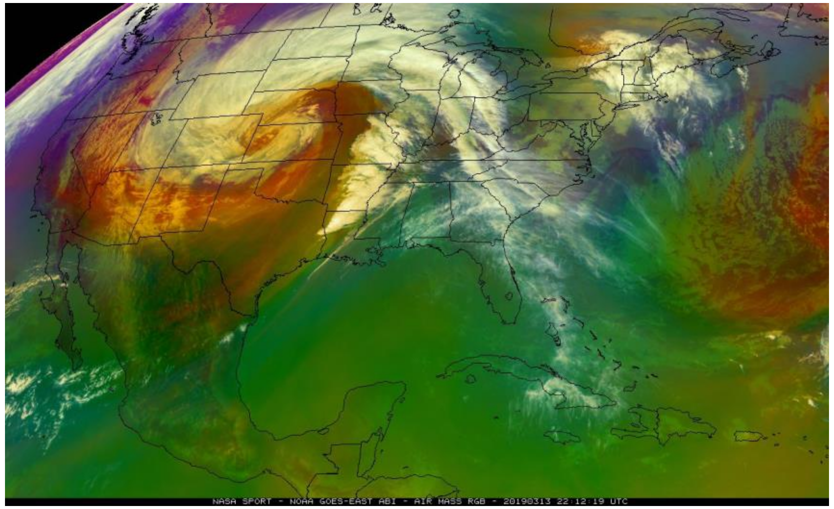
NOAA; NASA SPoRT

Motivation

- The positions of surface cyclones and anticyclones are strongly modulated by the state and evolution of the upper-tropospheric jet stream.

- This study uses a jet-centered approach based on the state and evolution of the **North Pacific Jet (NPJ)** and **North Atlantic Jet (NAJ)** to investigate synoptic-scale environments conducive to High Plains winter storms.

Jerilee Bennett, The Gazette

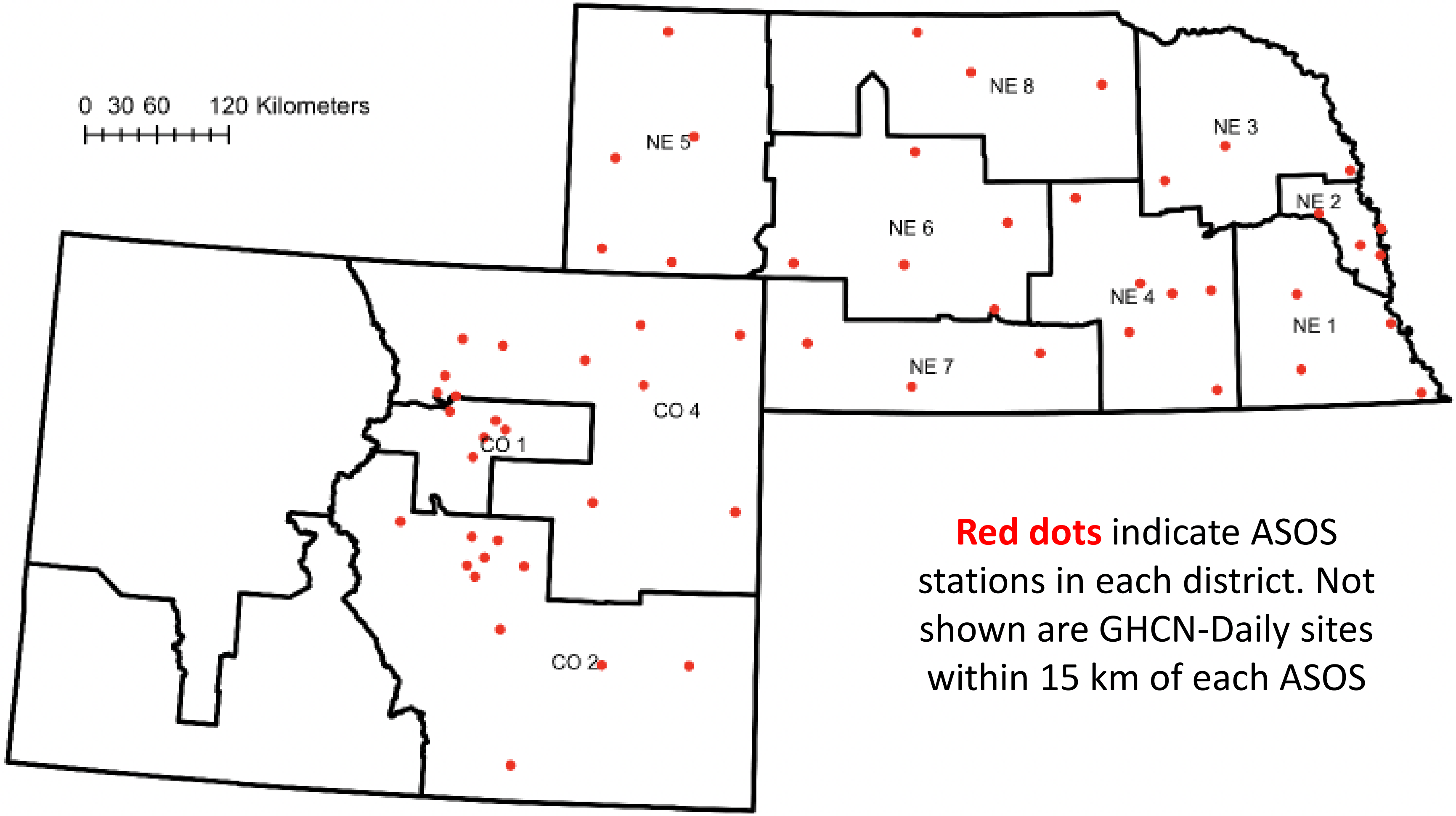


NOAA; NASA SPoRT

Methodology

Identification of High Plains Winter Storms

Winter storms during 2006–2019 are identified across a study domain divided into Department of Transportation districts in Colorado and Nebraska **(Walker et al. 2019)**



Red dots indicate ASOS stations in each district. Not shown are GHCN-Daily sites within 15 km of each ASOS

Identification of High Plains Winter Storms

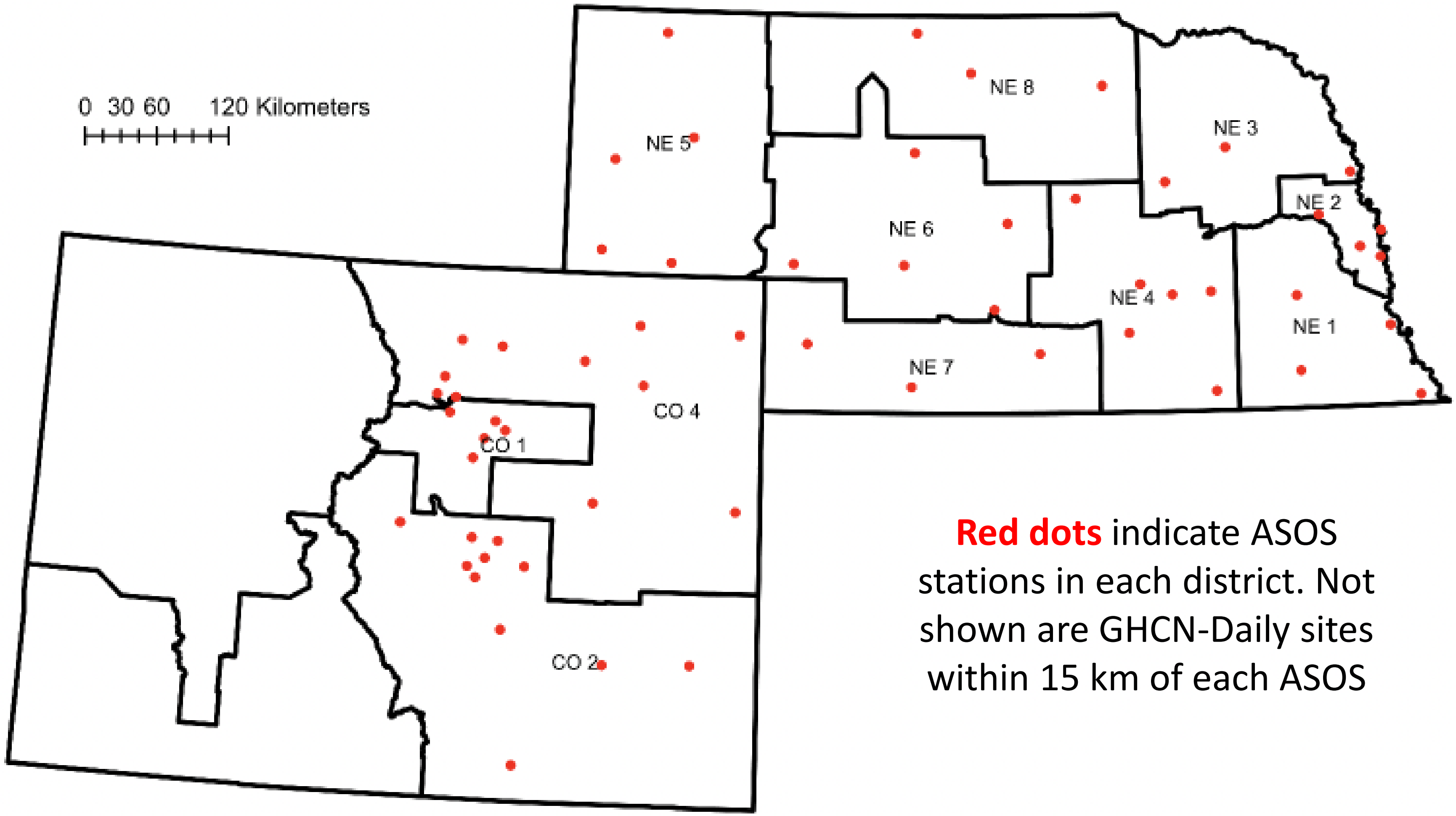
Observations from each district are used to assign a WSI value that characterizes a winter storm's impacts in that district.

Variable	Category					
	Trace (1)	**Marginal (2)**	**Slight (3)**	**Enhanced (4)**	**Moderate (5)**	**High (6)**
Snowfall (in) *(cm)*	Dusting < 1.0 *(< 2.4)*	Light < 2.0 *(< 4.9)*	Light < 3.0 *(< 7.5)*	Considerable < 5.0 *(< 12.6)*	Heavy < 7.0 *(< 17.5)*	Significant ≥ 7.0 *(≥ 17.5)*
Snowfall Rate (in hr^{-1}) *(cm hr^{-1})*	Minor < 0.2 *(< 0.4)*	Minor 0.2 *(< 0.6)*	Elevated 0.3 *(< 0.9)*	Elevated 0.4 *(< 1.1)*	Intense < 0.6 *(< 1.5)*	Extreme ≥ 0.6 *(≥ 1.5)*
Wind Speed (mph) *(ms^{-1})*	Light ≤ 6.0 *(≤ 2.7)*	Light ≤ 11.0 *(≤ 4.9)*	Moderate ≤ 18.0 *(≤ 8.1)*	Moderate ≤ 24.0 *(≤ 10.7)*	Strong ≤ 31.0 *(≤ 13.9)*	Strong > 31.0 *(> 13.9)*
Air Temperature (°F) *(°C)*	Above Freezing > 35 *(> 1.7)*	Near / Below Freezing ≤ 35 *(≤ 1.7)*	Below Freezing ≤ 29 *(≤ -1.7)*	Below Freezing ≤ 25 *(≤ -3.9)*	Below Freezing ≤ 19 *(≤ -7.2)*	Well Below Freezing < 15 *(< -9.4)*
District Area (Fraction Area)	Single Location ≤ 0.2	Partial < 0.4	Less Than Half < 0.5	More Than Half < 0.75	Majority < 1.0	Complete 1.0
Duration (hr)	Short ≤ 2.0	Short ≤ 3.0	Medium ≤ 4.0	Medium ≤ 5.0	Long ≤ 8.0	Long > 8.0
Visibility (mi) *(km)*	Good > 5.0 *(> 8.0)*	Good ≤ 5.0 *(≤ 8.0)*	Fair < 4.0 *(< 6.4)*	Mid-Range < 3.5 *(< 5.6)*	Poor < 3 *(< 4.8)*	Poor < 2.5 *(< 4.0)*

A district's WSI is determined based on a weighted average of the categories for each of the 7 variables in the table

Identification of High Plains Winter Storms

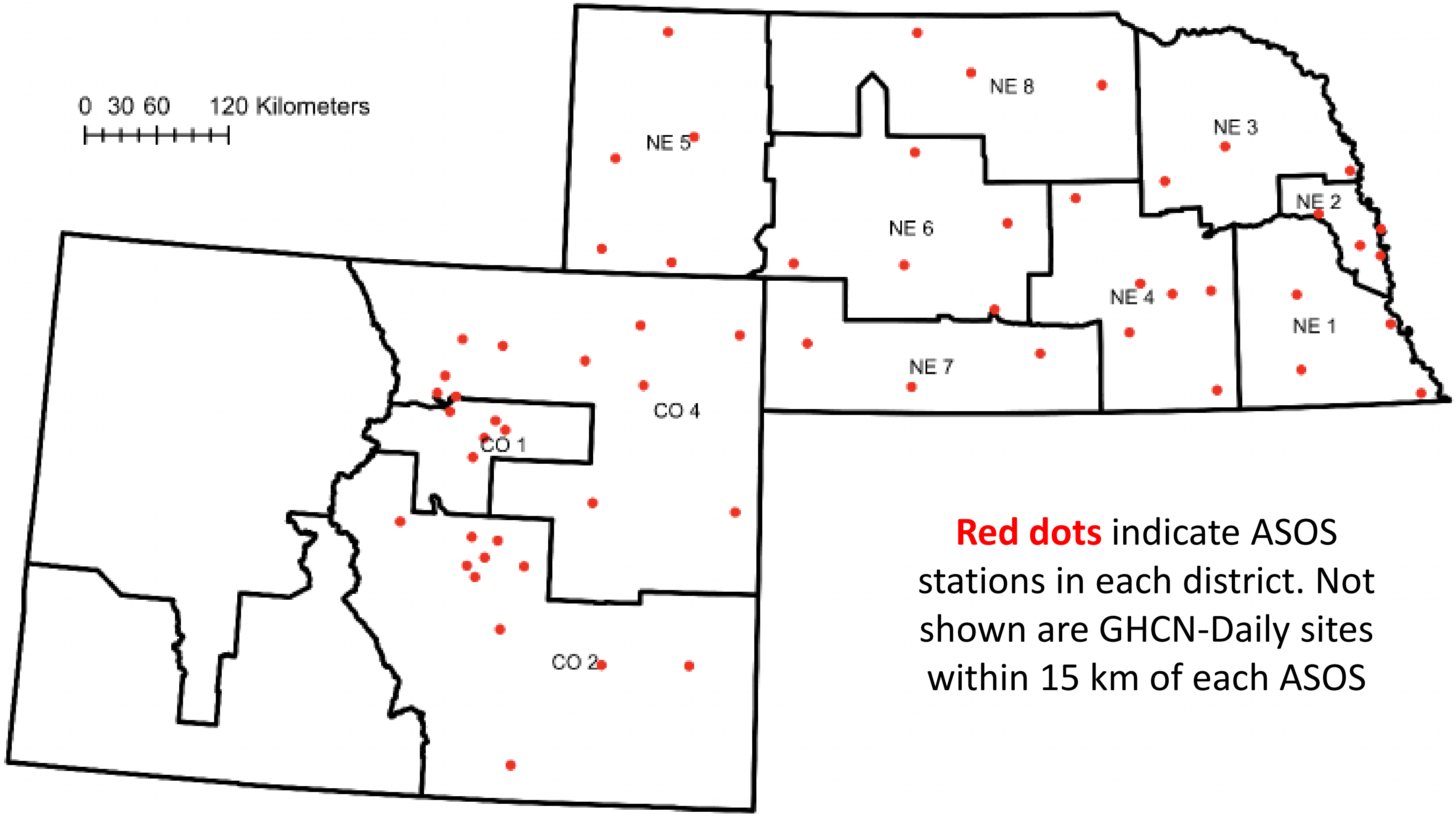
For this study, a winter storm is required **to impact more than half of the districts** in each state (WSI ≥ 1).



Red dots indicate ASOS stations in each district. Not shown are GHCN-Daily sites within 15 km of each ASOS

Identification of High Plains Winter Storms

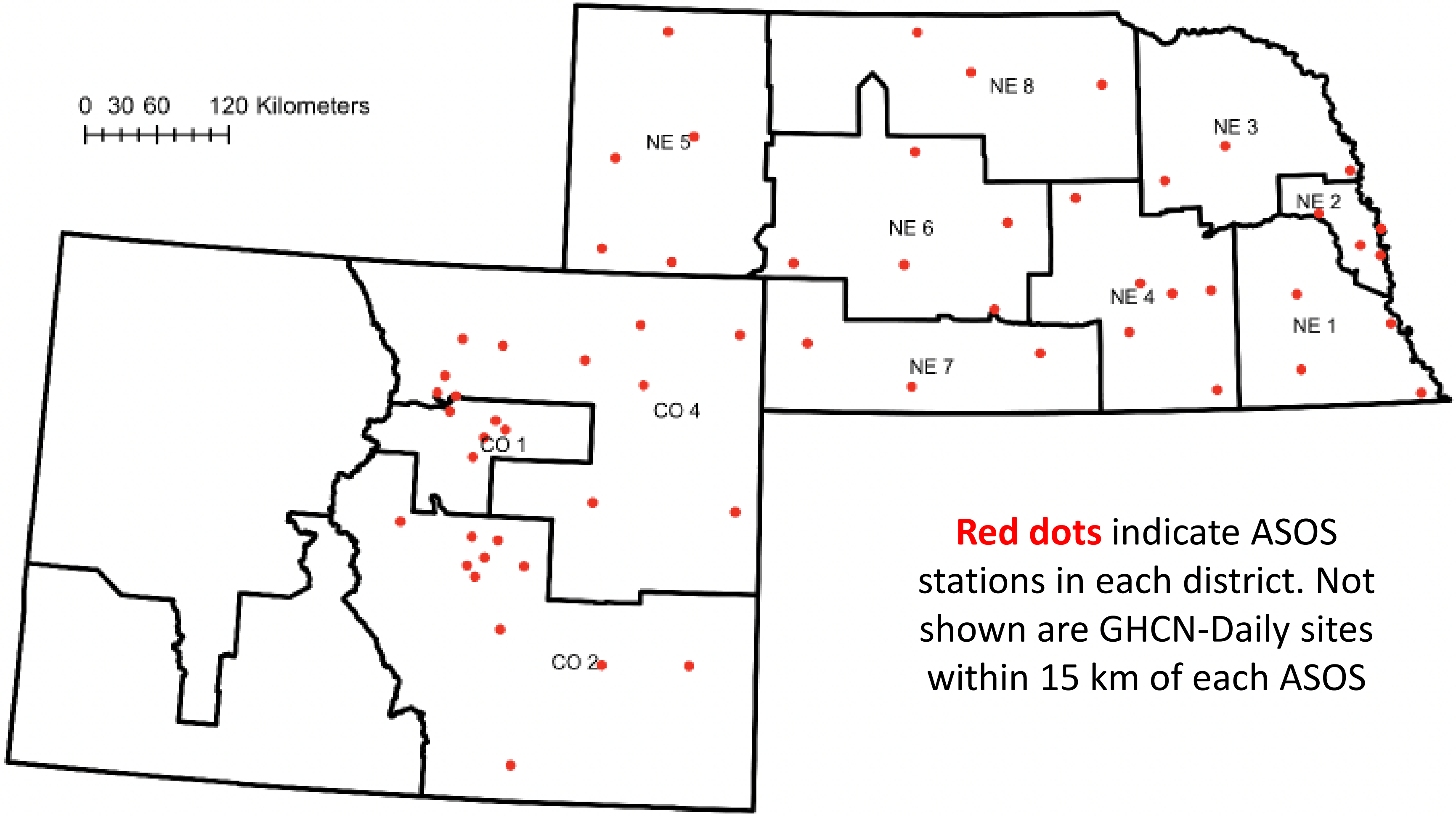
The WSIs for all qualifying districts during a winter storm are averaged to produce **an aggregate WSI rating** for that storm (N=220)



Red dots indicate ASOS stations in each district. Not shown are GHCN-Daily sites within 15 km of each ASOS

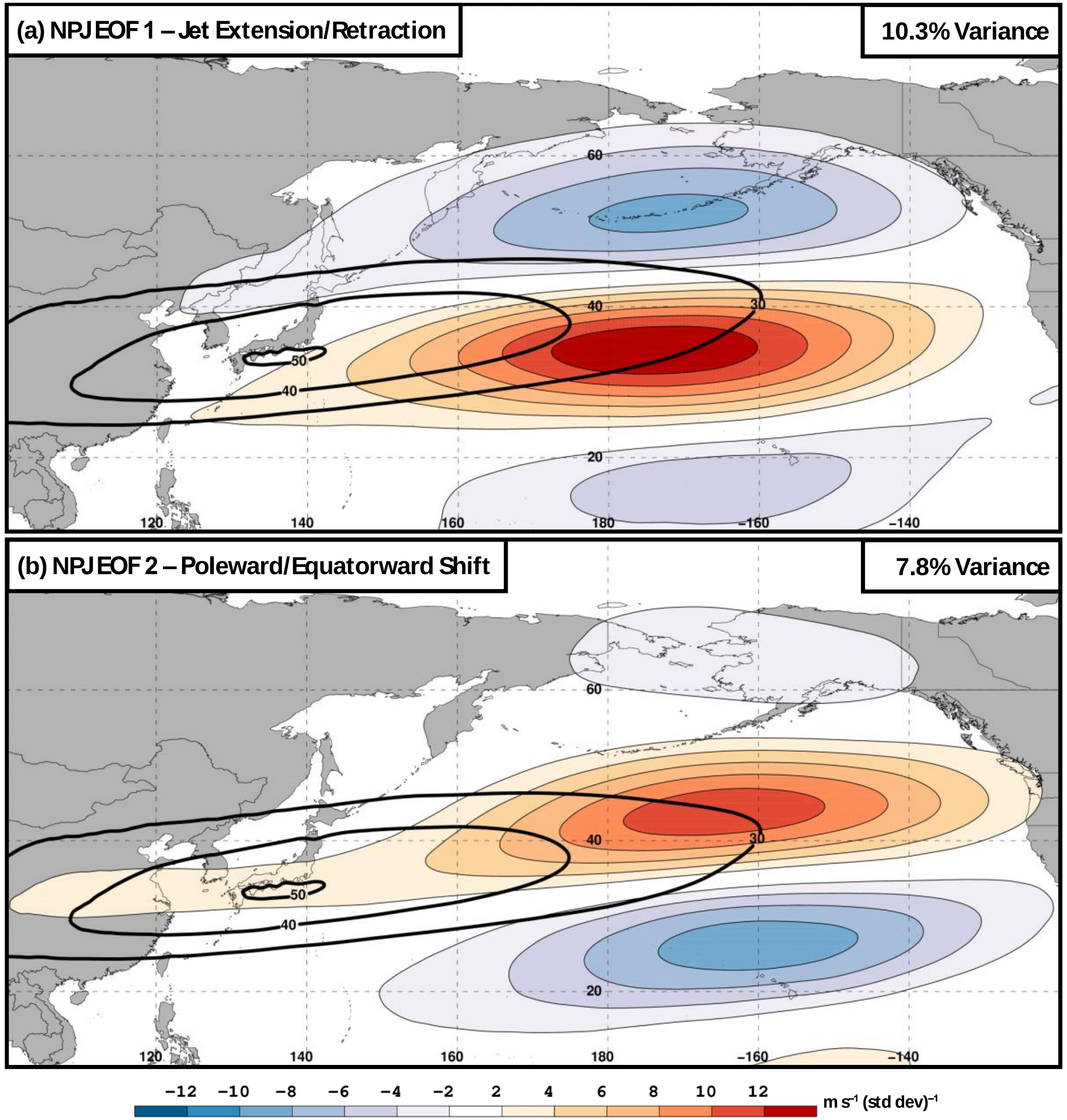
Identification of High Plains Winter Storms

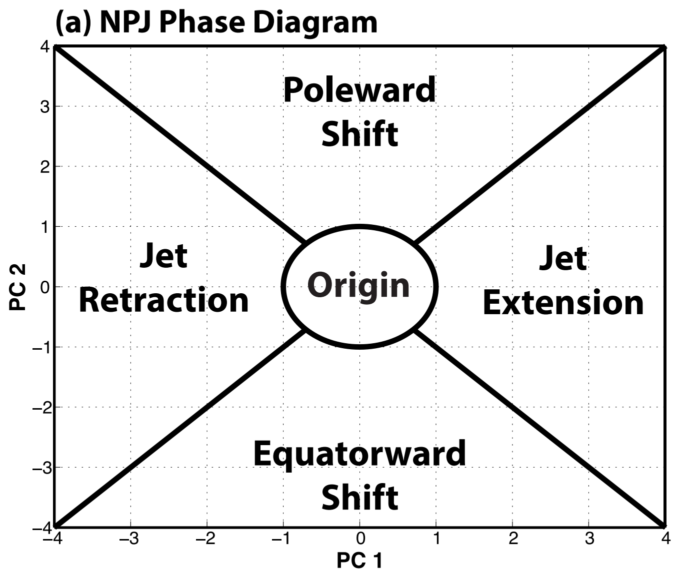
Winter storms are divided into **High Impact** and **Low Impact Events** based on whether their aggregate WSI ranks in the top/bottom 25% of all events.



Red dots indicate ASOS stations in each district. Not shown are GHCN-Daily sites within 15 km of each ASOS

The NPJ Phase Diagram





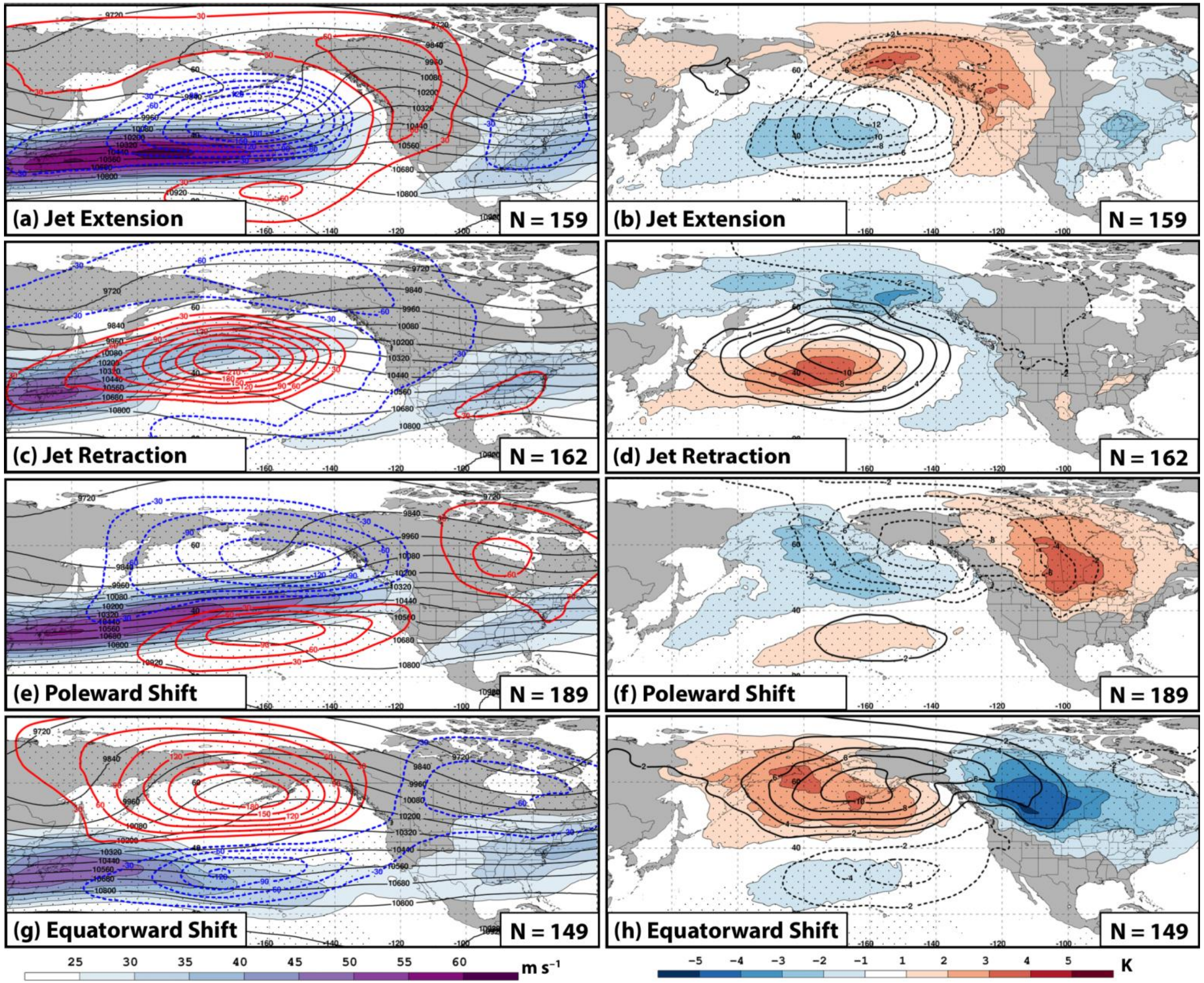
Sept.–May mean 250-hPa zonal wind: black contours

Sept.–May 250-hPa zonal wind EOF patterns: shading

Winters et al. 2019

The NPJ Phase Diagram

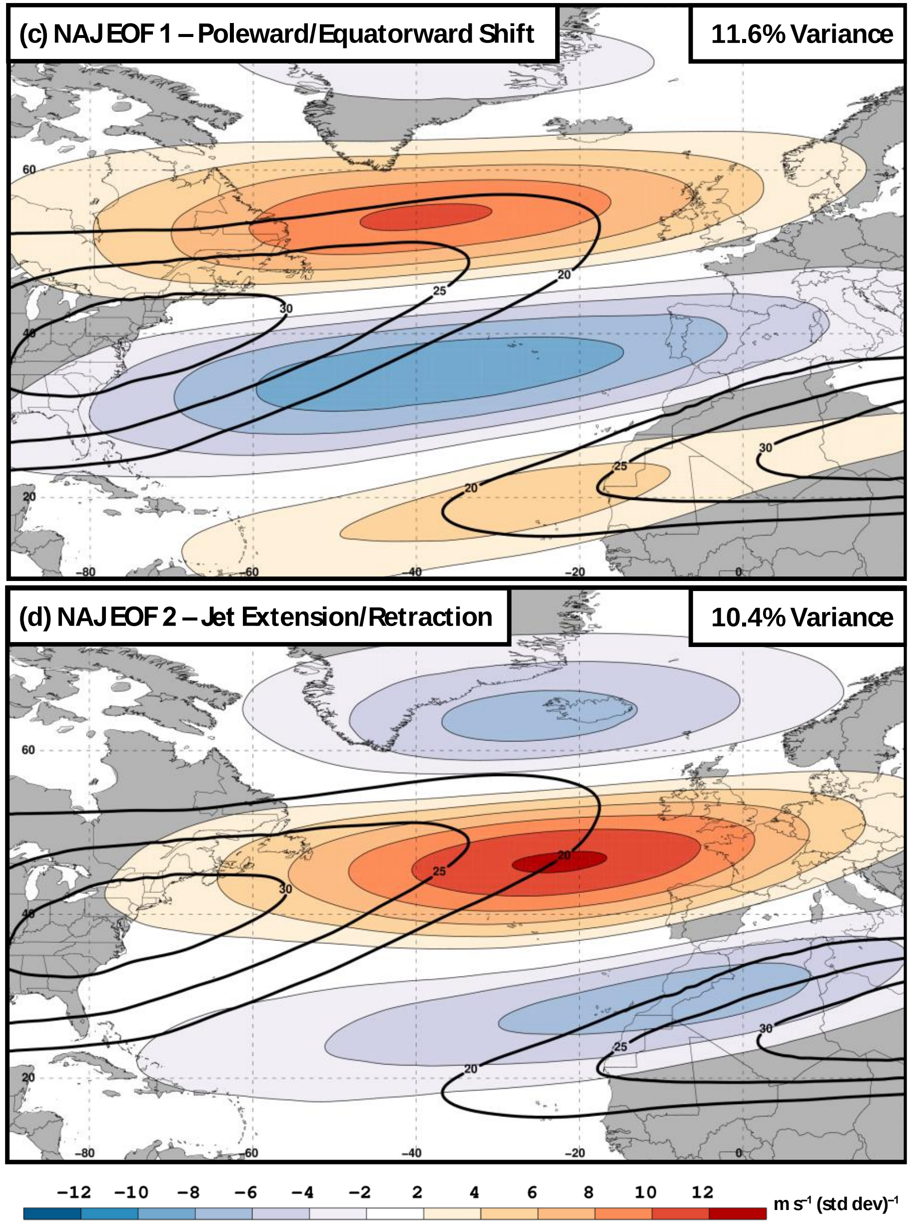
Each NPJ regime is associated with distinct sensible weather impacts over North America

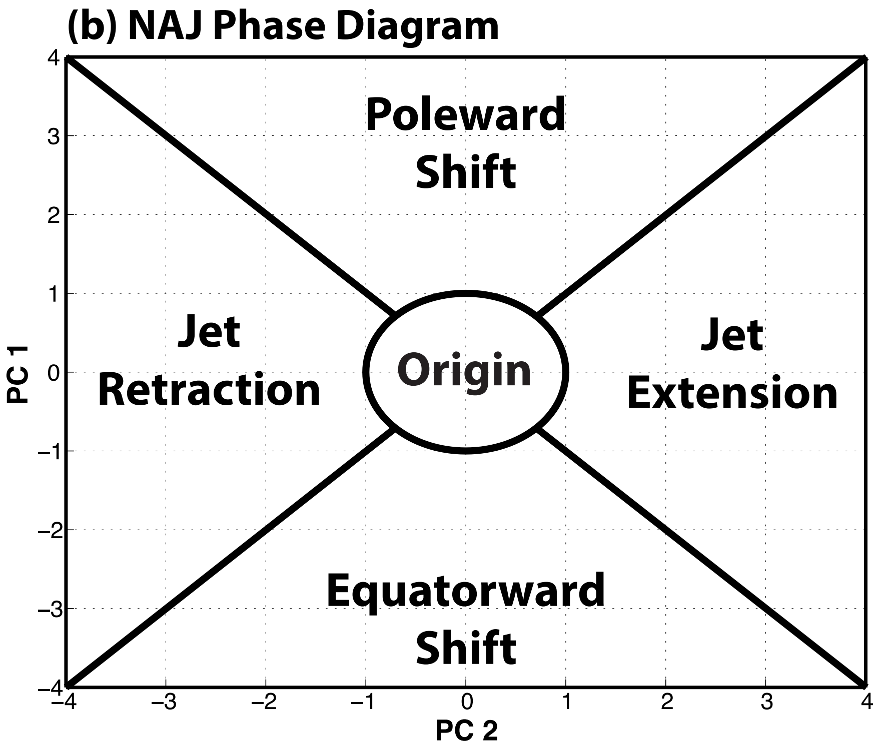


Left: 250-hPa heights, wind speed, and height anomalies

Right: 850-hPa temperature anomalies and MSLP anomalies

The NAJ Phase Diagram



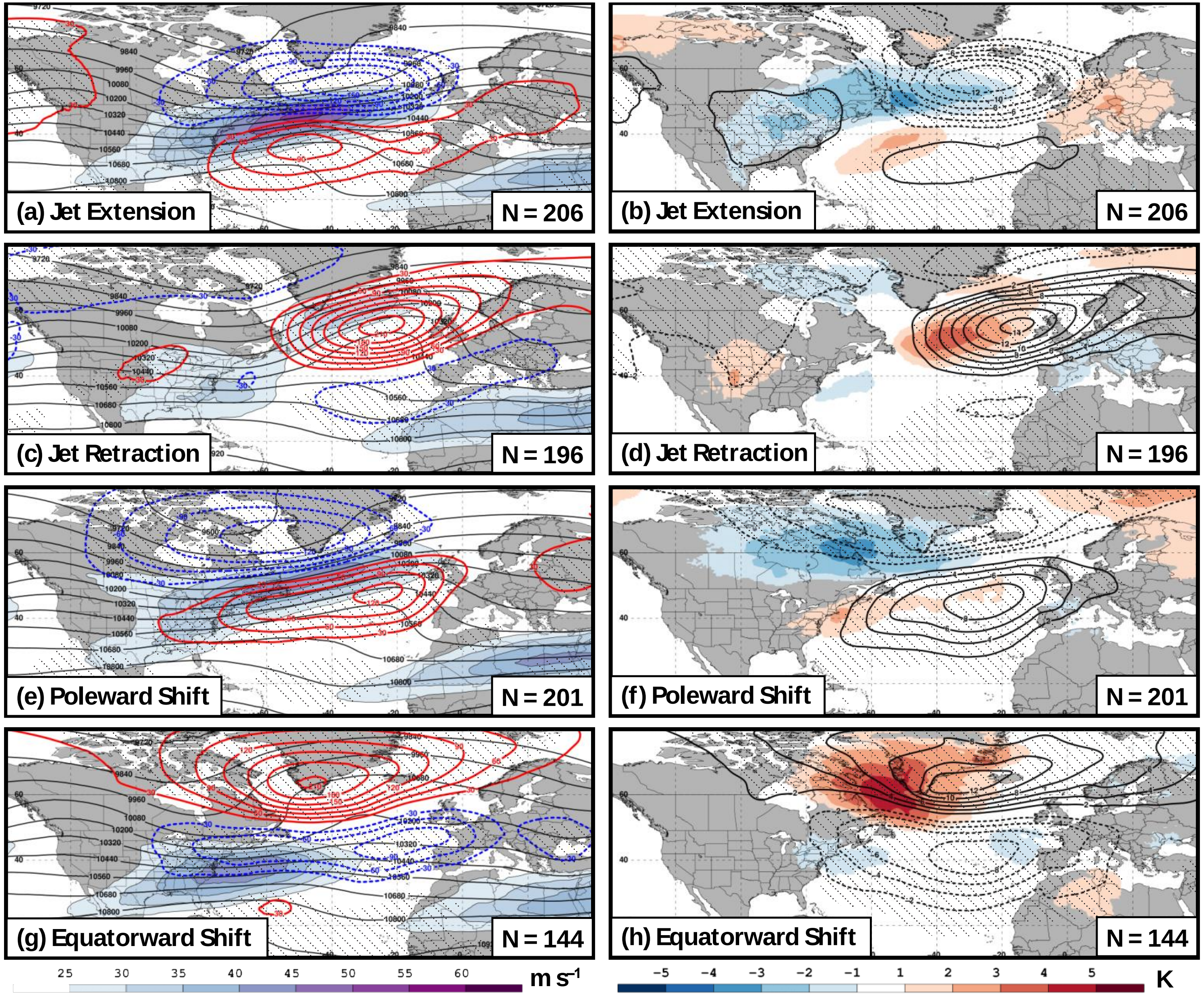


Sept.–May mean 250-hPa zonal wind: black contours

Sept.–May 250-hPa zonal wind EOF patterns: shading

The NAJ Phase Diagram

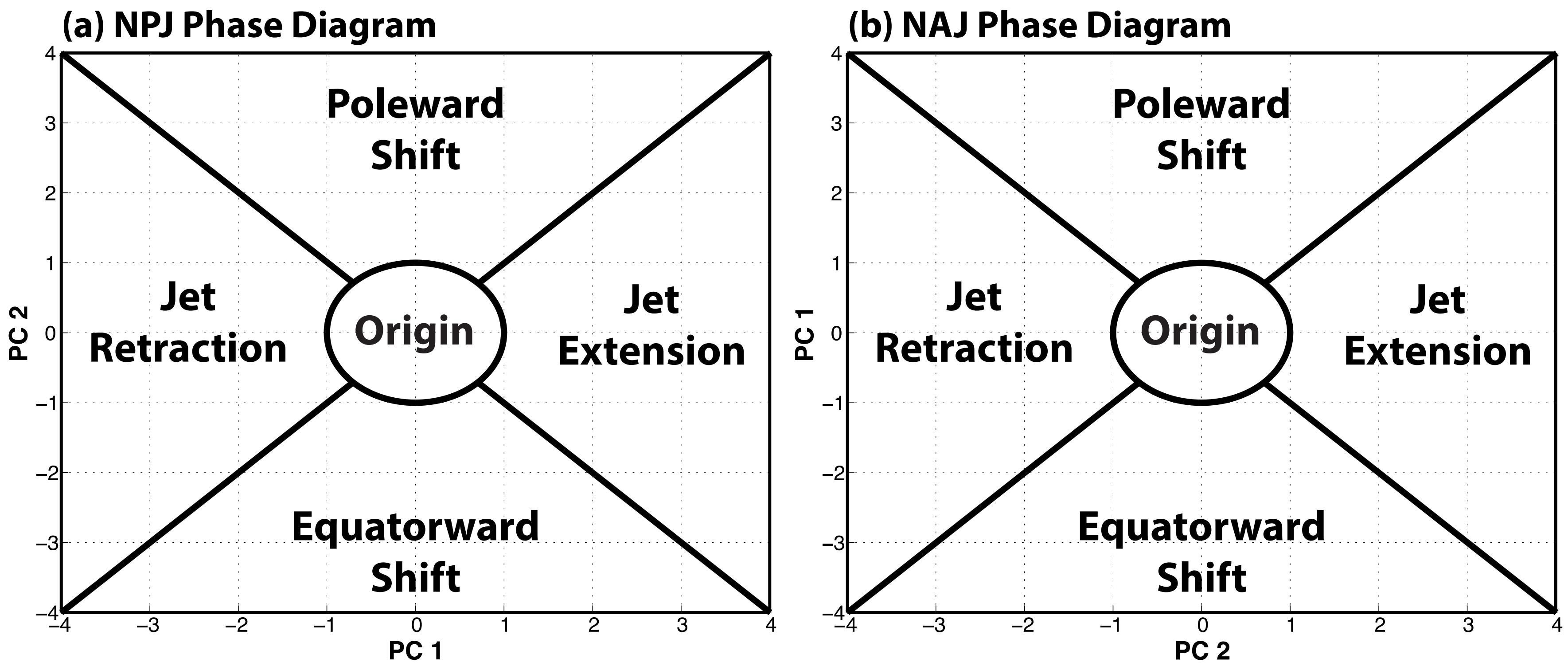
Each NAJ regime is associated with distinct sensible weather impacts over North America



<u>**Left:**</u> 250-hPa heights, wind speed, and height anomalies

<u>**Right:**</u> 850-hPa temperature anomalies and MSLP anomalies

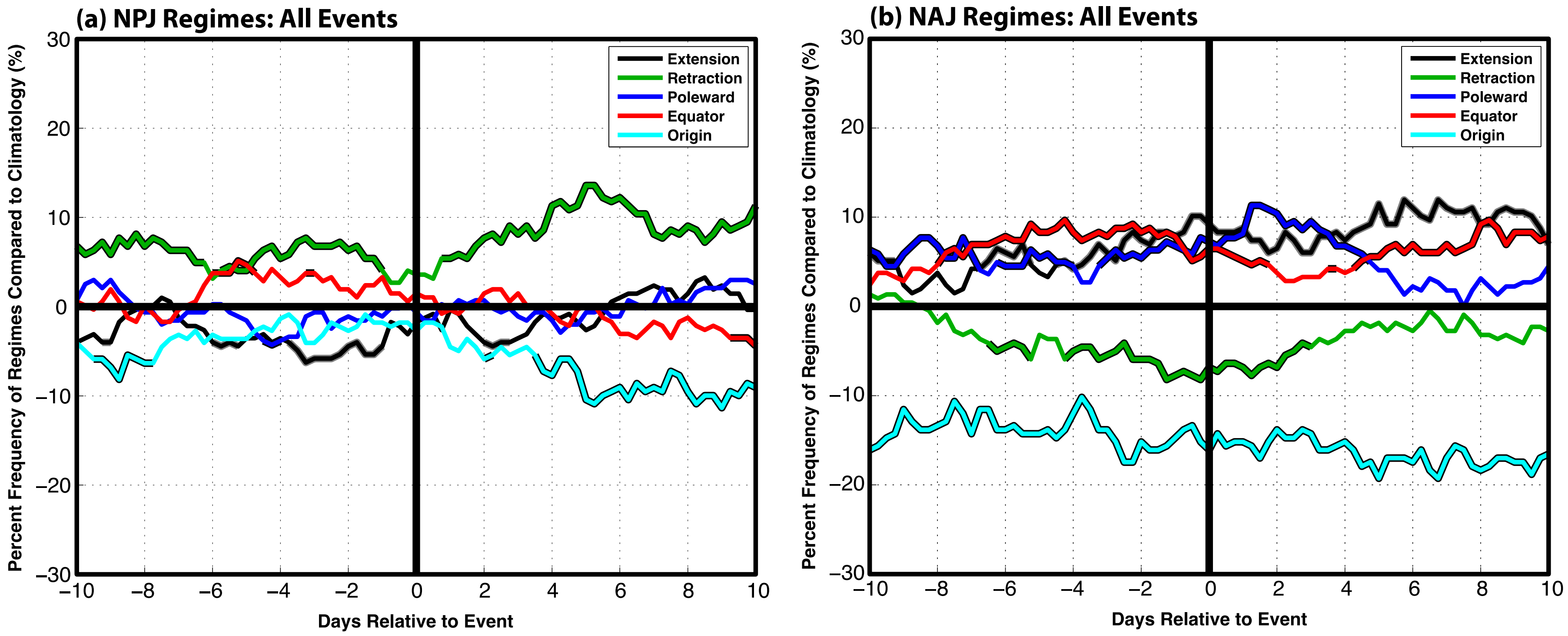
Classification of Winter Storms



All 220 winter storms are classified into **NPJ and NAJ regimes** based on the projection of the NPJ and NAJ within the NCEP Climate Forecast System Reanalysis **(Saha et al. 2010, 2014)** onto their respective phase diagrams during the 20-day period centered on each event.

Characteristics of High Plains Winter Storms

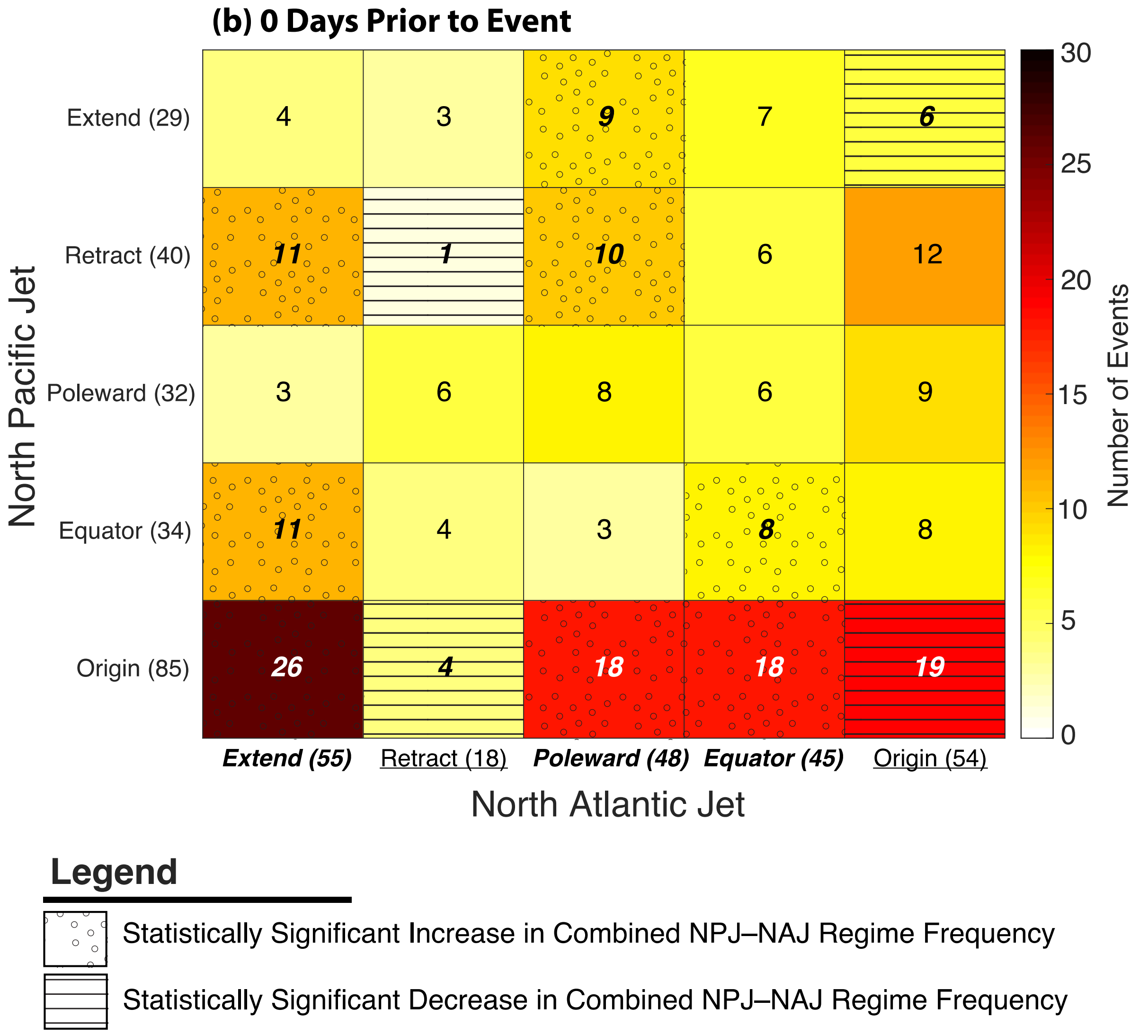
Characteristics of High Plains Winter Storms



NPJ retractions are favored prior to a winter storm and increase markedly in frequency after the start of each event.

NAJ retractions are not preferred prior to High Plains winter storms.

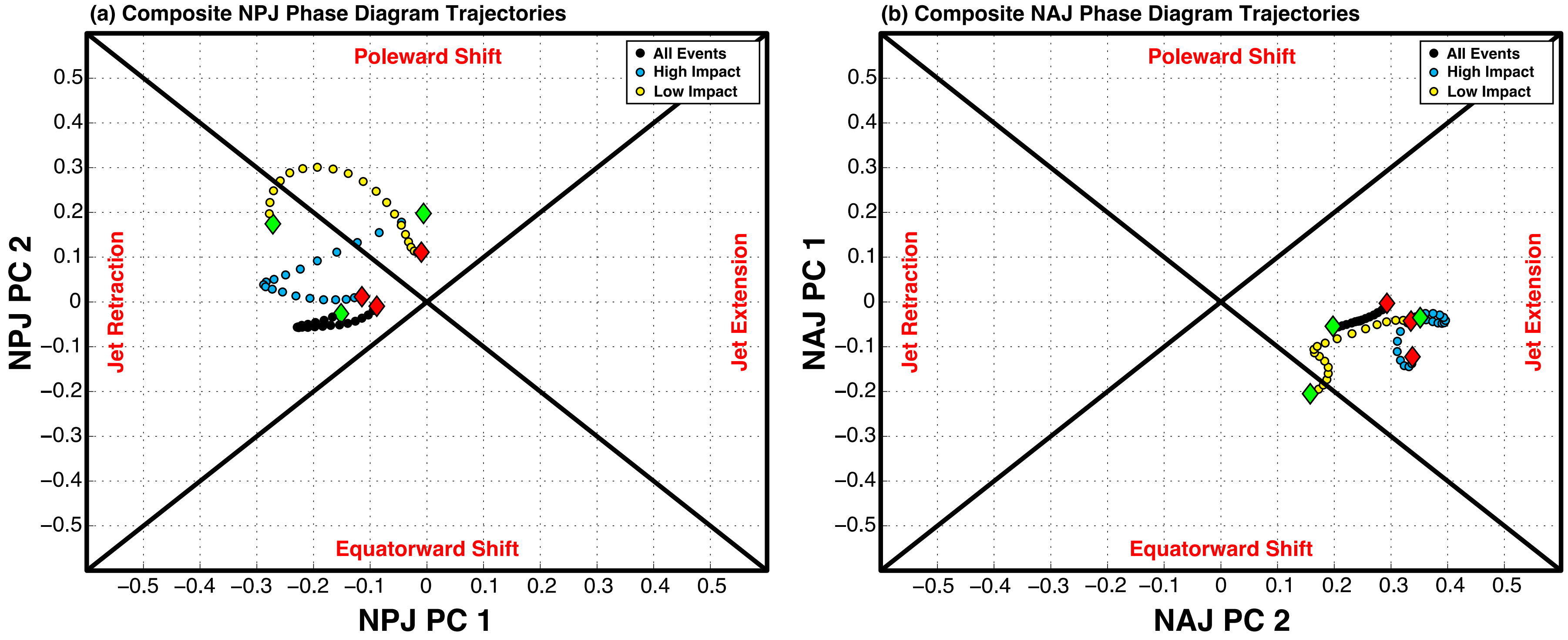
Characteristics of High Plains Winter Storms



Select combinations of **NPJ–NAJ regimes** are significantly more frequent at the start of a winter storm.

Highlights the value of considering the characteristics of both the NPJ and NAJ in tandem.

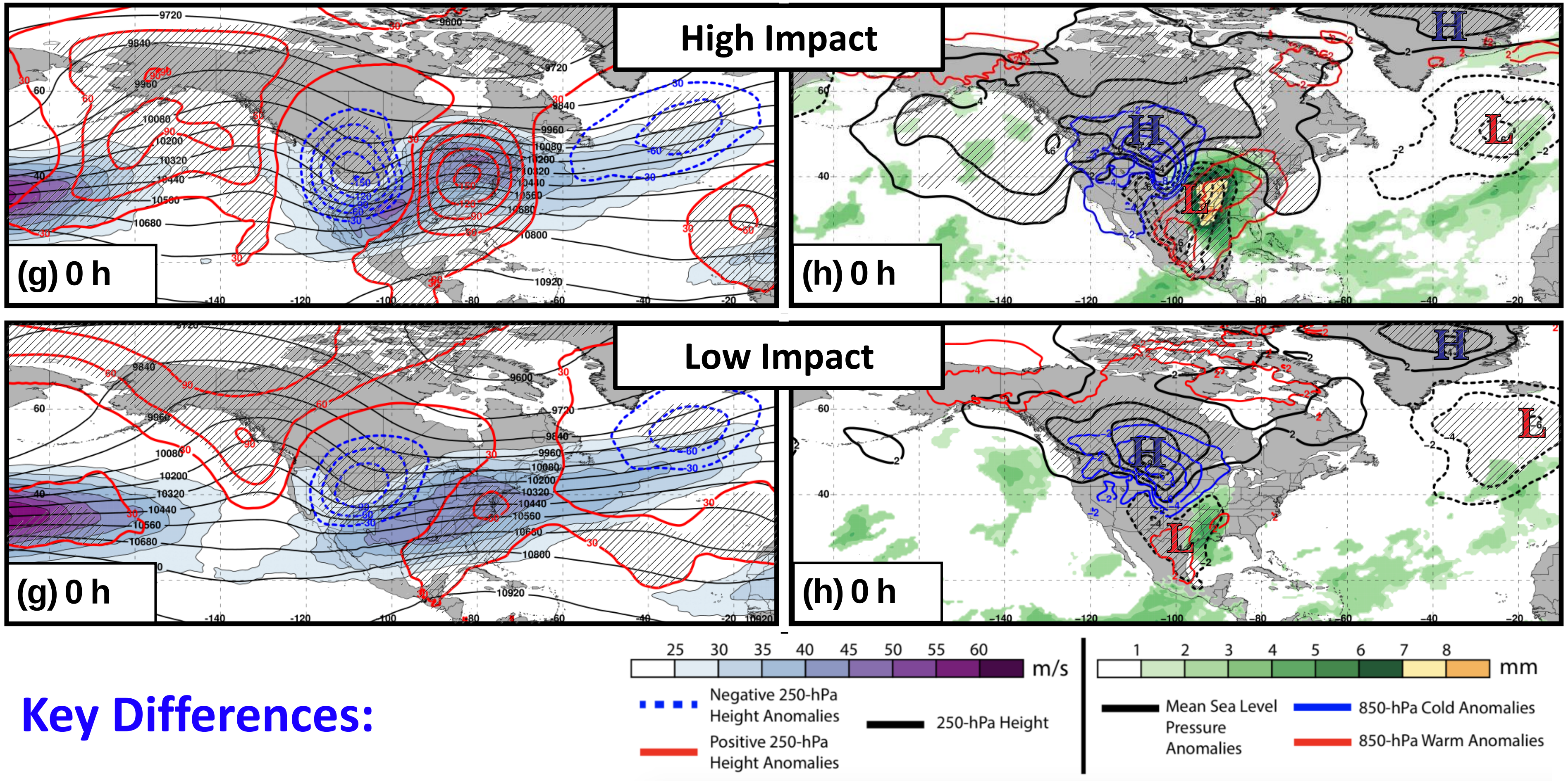
Characteristics of High Plains Winter Storms



Evolutions toward an **NPJ retraction** are preferred prior to a winter storm, while the NAJ evolves slightly towards an **NAJ extension**.

Evolutions for **High Impact** and **Low Impact Events** feature noticeable differences.

High Impact vs. Low Impact Events

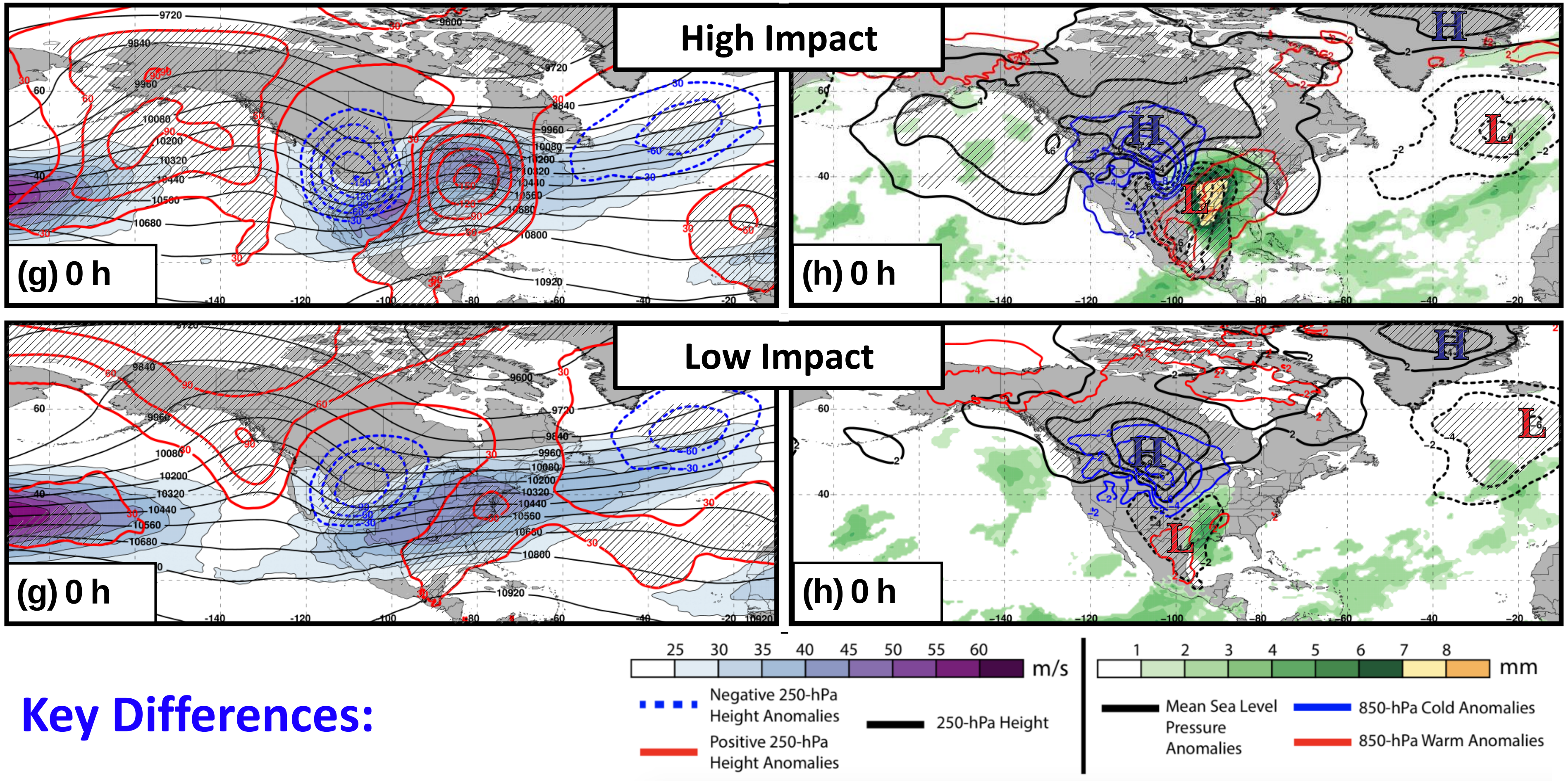


Key Differences:

(1) NPJ is more extended with a higher-latitude ridge during Low-Impact Events.

(2) Positively-tilted and weaker trough during Low-Impact Events.

High Impact vs. Low Impact Events



Key Differences:

(3) Surface cyclone is weaker during Low-Impact Events.

(4) Baroclinicity and low-level moisture weaker during Low-Impact Events.

Summary

- High Plains winter storms can have considerable economic and societal impacts.

- This study uses a jet-centered approach to examine synoptic environments conducive to High Plains winter storms.

- NPJ retractions are generally preferred prior to High Plains winter storms, while NAJ retractions are not.

- High-Impact events are characterized by:
  (1) A more amplified flow pattern / negatively-tilted trough
  (2) Stronger surface baroclinicity
  (3) Stronger surface cyclones
  (4) Increased poleward moisture transport

Future of this Work?

- Effectively communicate the overlap and distinctions of DOT WSIs with NWS WSSI (minimize conflict, confusion, and redundancy)

- DOTs are exploring predictive WSIs for their resource planning and personnel scheduling

- Understand motorist behavior with respect to products such as WSSI

- Explore how jet-centered WSI framework may inform snowpack formation and water resource implications; S2S forecasts

Sample NEWINS Forecast Graphic

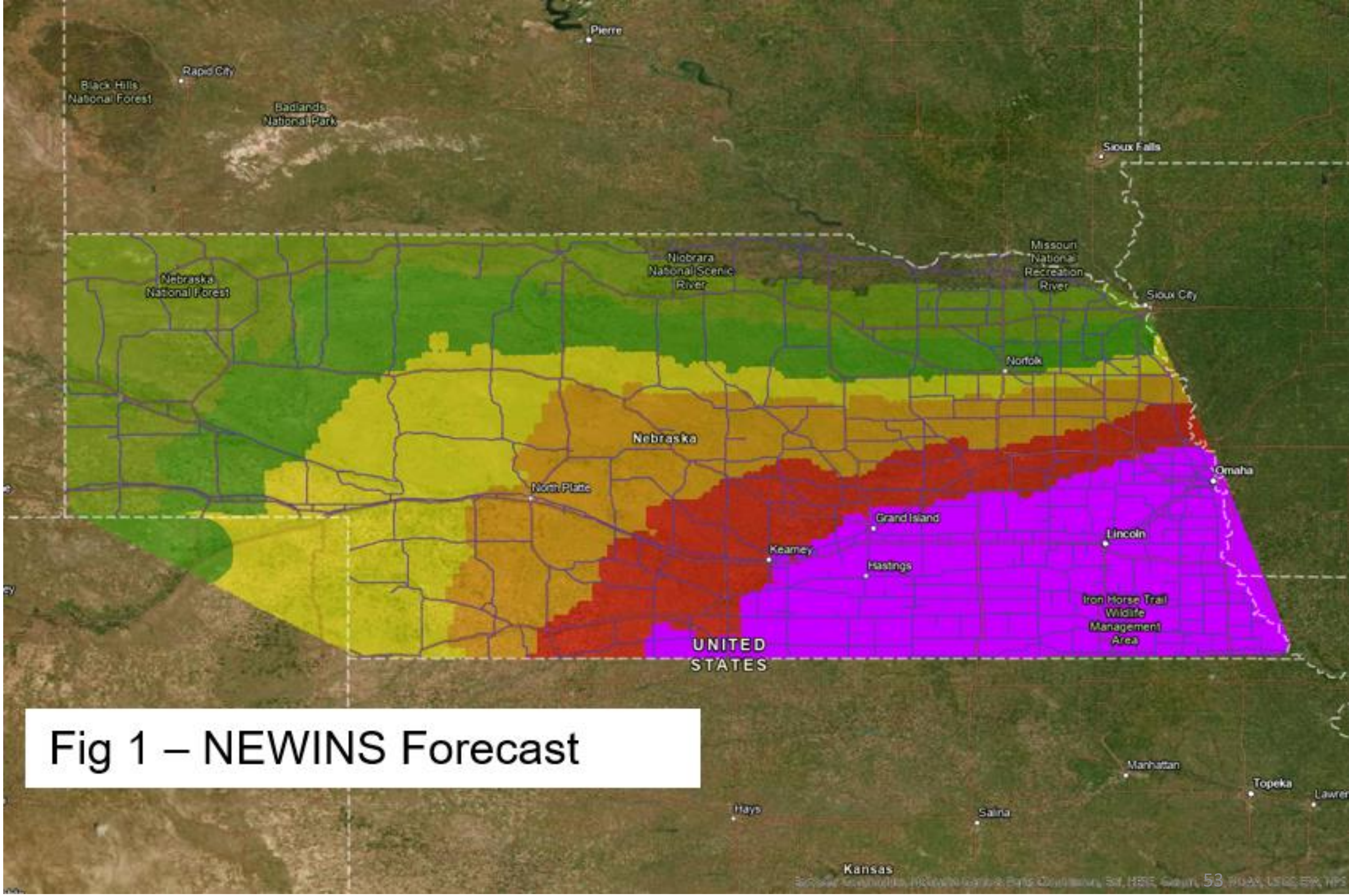


Fig 1 – NEWINS Forecast

NEWINS Forecast Compared to WSSI

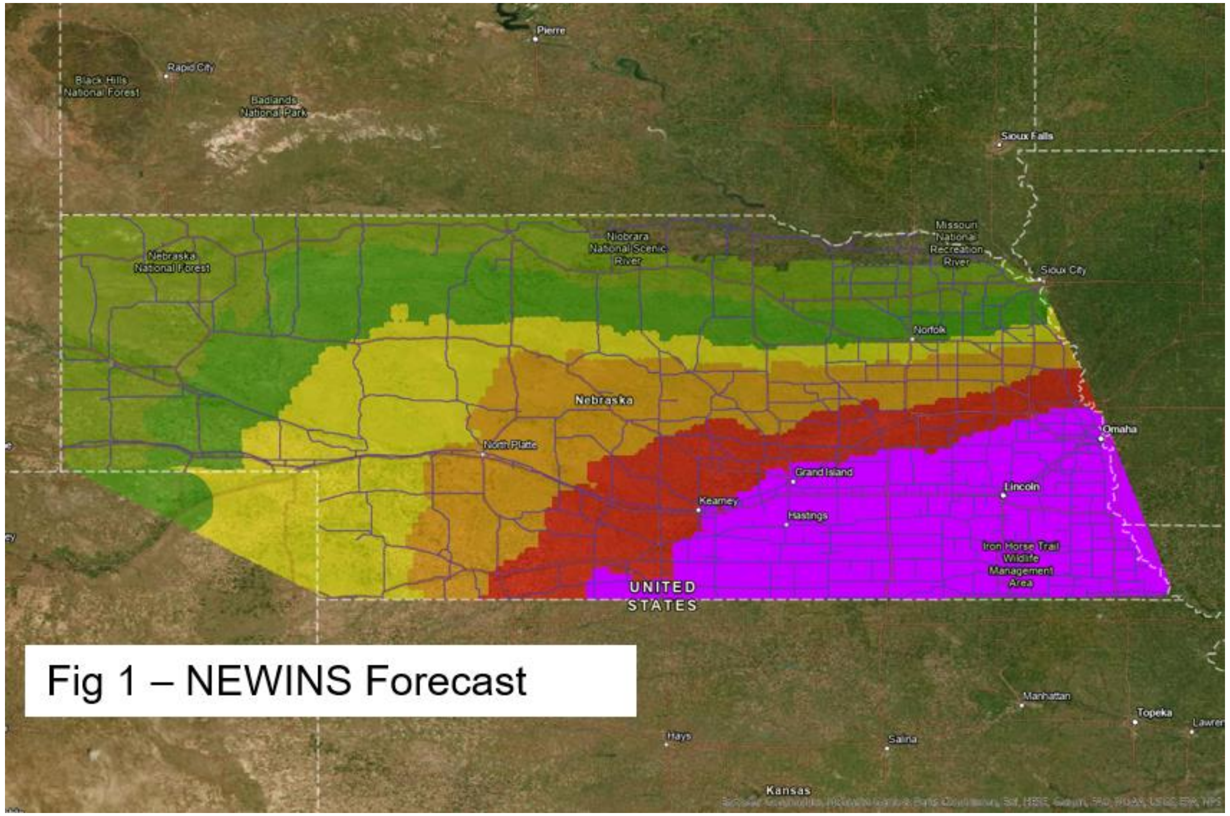


Fig 1 – NEWINS Forecast

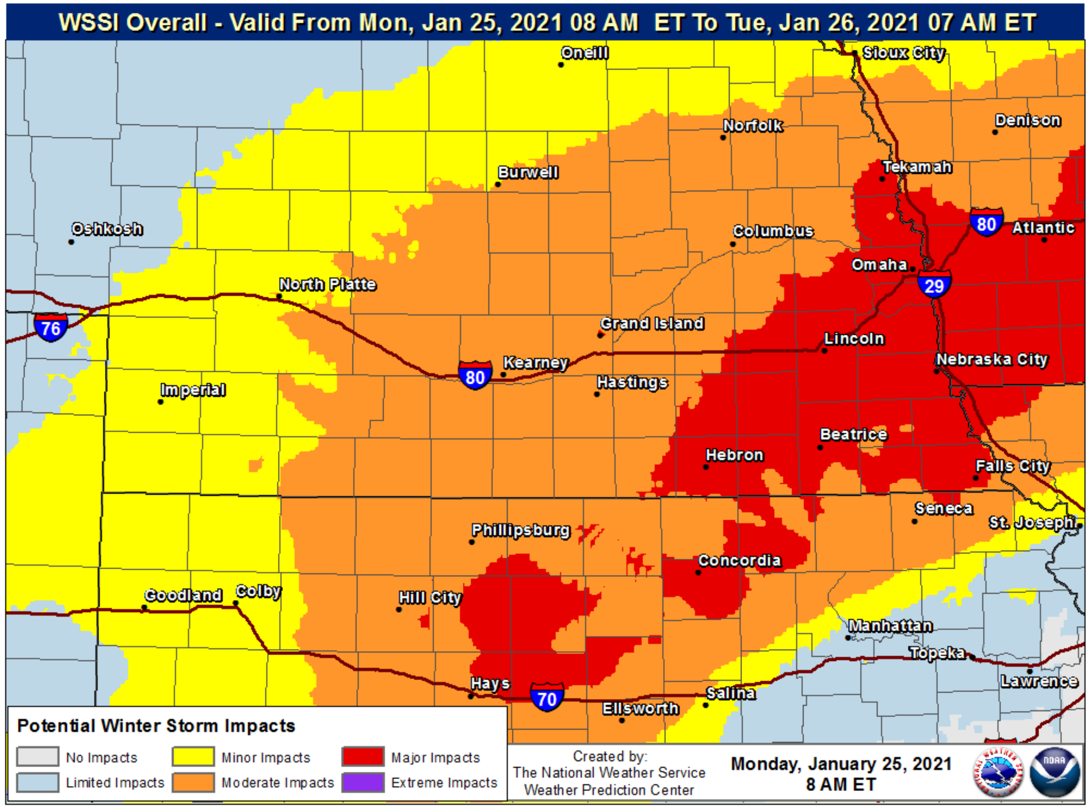
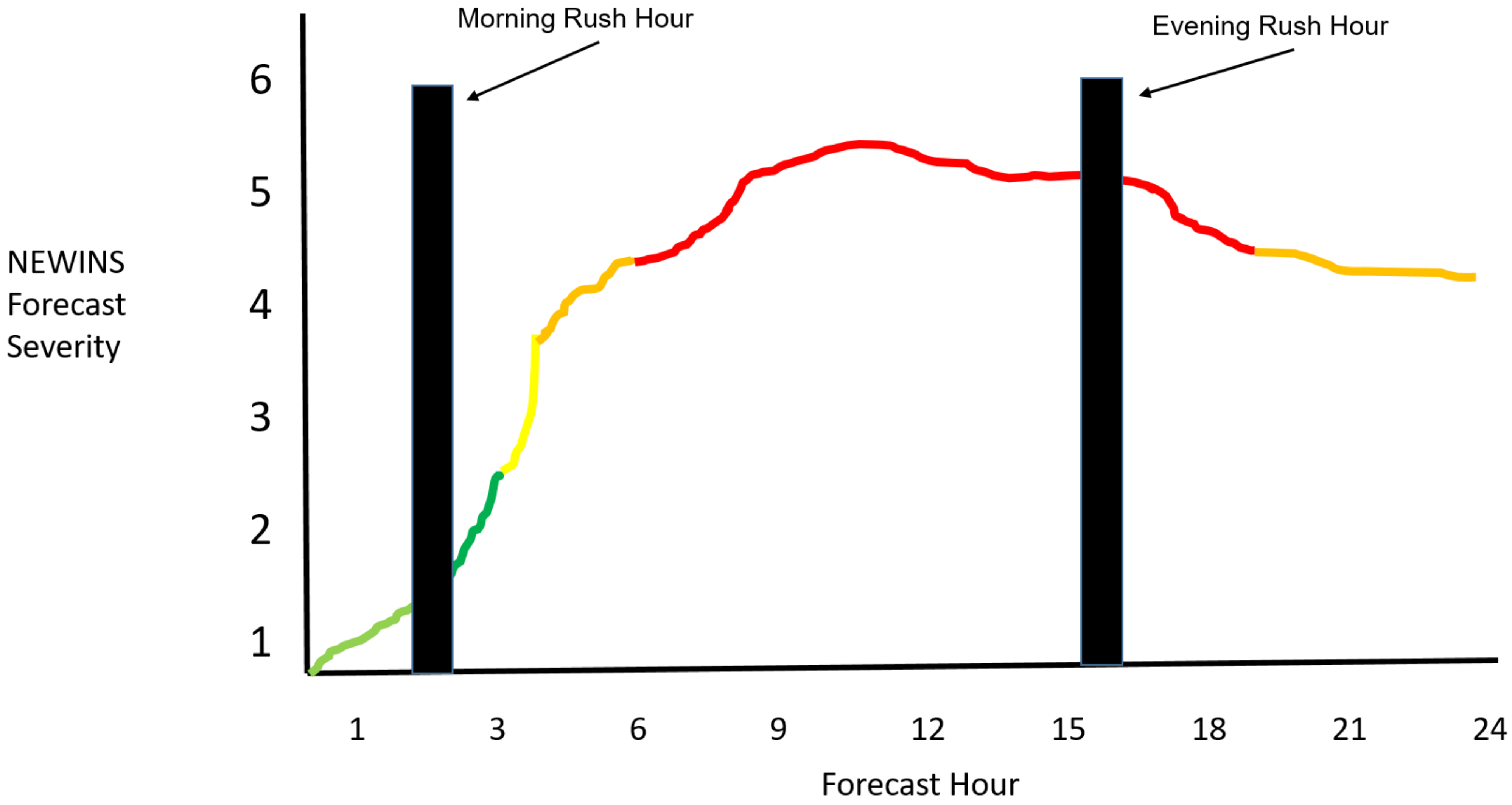


Fig 2 - Superintendent Area 24 Hour NEWINS Forecast



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Dr. Curtis L. Walker

walker@ucar.edu

(303) 497-1448

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