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The Effect Of ENSO On Nebraska Winter Snowfall

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THE EFFECT OF ENSO ON NEBRASKA WINTER SNOWFALL

By

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Introduction

For quite some time, research has been on going to describe how Earth is impacted by the El Niño-Southern Oscillation (ENSO) (Walker, 1924). ENSO refers to two separate phenomena that are correlated with each other. The first half of the term, El Niño, was originally described as a weak annual warming of ocean water along the coast of Peru and Ecuador (Trenberth, 1997). Since its discovery, the definition of this anomaly has expanded to include an abnormal warming of ocean water along the equator across the entire Pacific basin (Glantz, 1996). The latter half of the ENSO term, Southern Oscillation, refers to the shift of high and low pressure across the basin between the eastern and western hemisphere (Stenseth et al., (2003). The term ENSO also includes an anomalous decrease in sea surface temperatures (SST) in the same region, which is called La Niña. Quantitatively, one way which El Niño (La Niña) can be defined is as SST greater than or equal to 0.5°C above normal (less than or equal to 0.5°C below normal) for the tropical Pacific 4°S-4°N and 150°W-90°W (Japan Meteorological Agency, 1991).

It has been well documented that ENSO has an impact on many parts of the globe in terms of anomalous temperature and precipitation patterns (Ropelewski and Halpert, 1986; Kurtzman and Scanlon, 2007; Schubert et al., 2007). In the United States, the Gulf States receive above normal precipitation from October through March during an El Niño event. The Great Basin in the Southwest region of the US experiences higher than normal precipitation from the month of April through October (Ropelewski and Halpert, 1986). In the same study, Ropelewski and Halpert (1986) also found that there was some ENSO-related response in the High Plains region, but the response was not consistent. A more recent study by Kurtzman and Scanlon (2007) shows that a region stretching from the Carolinas across the southern US to Southern California receives statistically significant above normal precipitation during El Niño from October to March and below normal precipitation during La Niña for those same months. The Midwest region from Texas to South Dakota also showed statistically significant precipitation above normal during El Niño and below normal precipitation during La Niña, especially in southwest Nebraska. This study used the season of October to March for analysis because of its highest correlation between ENSO and precipitation for some areas of the US based on studies done by Ropelewski and Halpers (1986) and Redmond and Koch (1991).

The analysis in the studies by Ropelewski and Halpert (1986) and Kurtzman and Scanlon (2007) used precipitation data based on climate divisions in the US. This works well when analyzing effects on precipitation and temperature due to ENSO on a national scale, but loses resolution when focusing on a specific state or region. A study by the Climate Prediction Center (CPC) (2003) suggests that Nebraska is influenced by ENSO, affecting precipitation during the time period from December to March (Figure1). This map shows that of the eight climate divisions in Nebraska, the four divisions with highest percent of normal precipitation are South Central, Central, East Central and Northeast. While this has more focus on the state of Nebraska compared to Kurtzman and Scanlon (2007), it's still a very low resolution compared to an analysis of individual station data.

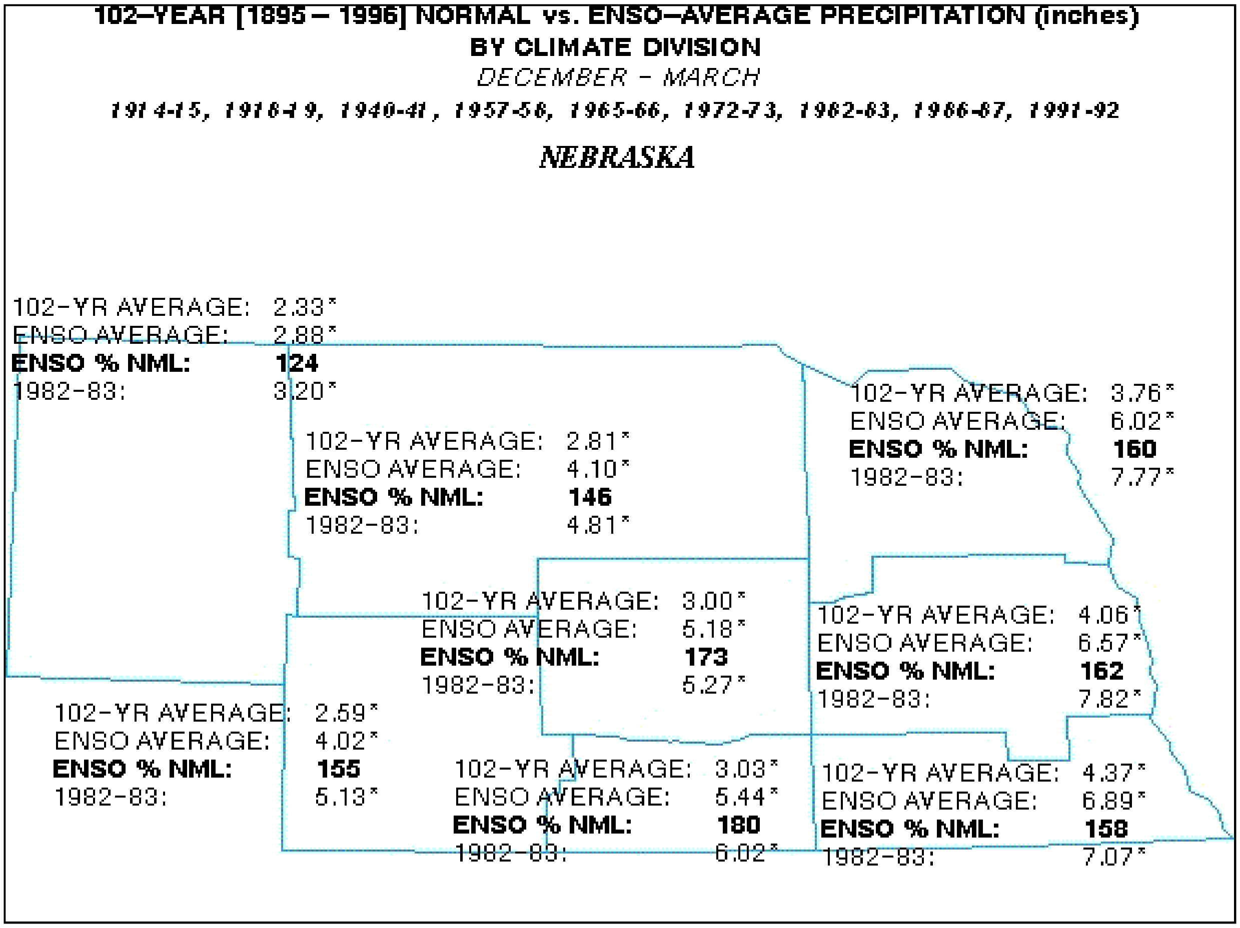

Figure 1 Normal versus ENSO average precipitation for Nebraska. From (reference).

The objective for this thesis is to conduct an analysis of the precipitation anomalies in the state of Nebraska during El Niño and La Niña to determine using individual climate station data higher resolution anomaly patterns.

Data and Methods

Data for this research was obtained from the United States Historical Climatology Network (USHCN) available at http://cdiac.ornl.gov/epubs/ndp/ushcn/ushcn.html. The USHCN is a network of 1218 meteorological data collection stations that gather daily and monthly data records in the continental US. Daily data include observations of maximum and minimum temperature, precipitation amount, snowfall amount, and snow depth; monthly data consist of monthly-averaged maximum, minimum, and mean temperature and total monthly precipitation. Most recording stations belong to the U.S. Cooperative Observing Network, a network in which volunteer citizens are trained by the National Weather Service (NWS) to take temperature and precipitation observations. The remaining stations consist of first order recording sites which are maintained by the NWS or the Federal Aviation Administration. The period of record varies for each station. Stations included in the USHCN data set were chosen using a number of criteria including length of record, percent of missing data, number of station moves and other station changes that may affect data homogeneity, and resulting network spatial coverage (Karl et al., 1990;Menne et al., 2009).

For this project, monthly precipitation totals were downloaded from USHCN for the 45 data sites located across Nebraska (Figure 2) for the time period 1895 to 2007. For the purposes of this study, the winter season was defined by the months of December, January and February (DJF). While previous studies focused on the October to March time period (Ropelewski and Halpert , 1986; Kurtzman and Scanlon, 2007), DJF was selected for this study because Nebraska typically receives much less precipitation in the winter compared to the fall in terms of liquid volume. This will show how much influence ENSO has on winter precipitation compared to precipitation over a six month period. For the purposes of this analysis, the winter of 1895 is designated by the December of 1895 followed by January and February of 1896. Monthly data were sorted and summed to yield the winter seasonal totals for each site from which long term means (LTMs) were calculated. Data from each year were then sorted into ENSO respective phases using the index developed by the Japan Meteorological Agency (JMA) (Japan Meteorological Agency (1991). The JMA-index is based on observed SSTs from 1949 to the present (Japan Meteorological Agency (1991). For the years 1868 to 1948, SST were reconstructed using an orthogonal projection technique. The index was then applied to all years with the reconstructed and observed SST. The index is a 5-month running mean of spatially averaged SST anomalies over the tropical Pacific: 4°S-4°N, 150°W-90°W. If index values are 0.5°C or greater for 6 consecutive months (including October through December), the ENSO year of October through the following September is categorized as El Niño, La Niña (index values equal or exceed -0.5°C), or neutral (all other values). This index was used in this study due to its long record of ENSO phases back to the year 1868 in order to match USHCN data from 1895 to 2007.

Finally, with each year designated as warm phase (El Niño), cool phase (La Niña) or neutral, a mean precipitation value for each phase for each site was calculated. A percent of normal was then calculated for all locations for each phase as:

$$\frac{\text{ENSO Phase DJF Mean Precipitation}}{\text{DJF LTM Precipitation}} \times 100\%$$

ArcMap 9.3.1 developed by ESRI was used to visually display the information. Nebraska county boundaries and city locations (City Points TIGER 2007, Nebraska Spatial GIS Database, http://www.dnr.state.ne.us/databank/spat.html) for the 45 data sites were used to build the base for maps to display the LTM and percent of normal for each phase. Note: The Purdum data site was not included in the City Points data file and was added by importing the latitude and longitude of the site and adding it as an X-Y coordinate into ArcMap). The LTM, ENSO phase mean and percent of normal were imported into the attributes for their respective map shapefiles. Data were tested for statistical significance using the Student T Test to compare the LTM with the phase mean for each site (Table 1).

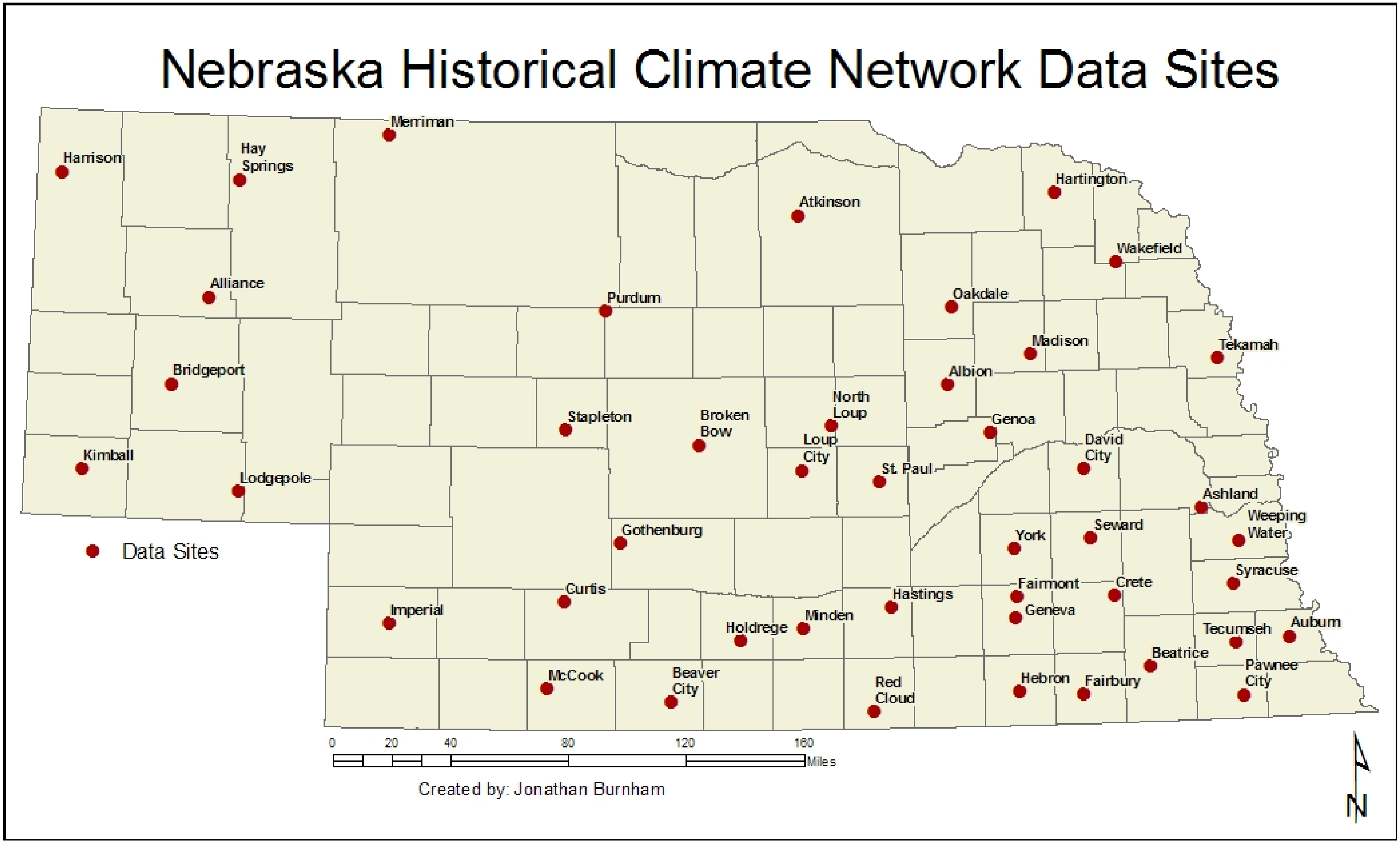

Figure 2: Locations of the Historic Climate Network data sites used in this study.

Results

During El Niño, winter precipitation was above normal for a majority of the sites in Nebraska for the 112 year study period. (Figure 3) Curtis, Gothenburg and Minden were all over 130% of normal and Imperial, McCook, Beaver City, Holdrege, Stapleton, Broken Bow, and St. Paul were all over 120% of normal. Of these, Curtis and Gothenburg were statistically significant at the 95% level. Imperial, McCook, Beaver City, Holdrege, Minden and Broken Bow were statistically significant at the 90% level (Appendix A). The epicenter of 95% significance is around Curtis and Gothenburg, with surrounding sites above 90% significance. Albion, Genoa, Fairmont and Crete are also above 90% significance, showing a southwest to northeast trend or swath across the state of sites that have significant precipitation above normal due to the effects of El Niño. Conversely, winter precipitation at four sites in the western panhandle was below normal as was one site in the southeast corner of the state. At most the departure from normal is only 5%. None of the five sites were statistically significant.

In general, La Niña has an opposite effect on winter precipitation in Nebraska than El Niño does. These results show that a majority of the state had below normal precipitation(Figure 3). Four sites in the panhandle had above normal precipitation, but only by a slight amount. McCook, Gothenburg, Stapleton, North Loup, Atkinson and Hartington are statistically significant at the 95% level. Imperial, Loup City, Beatrice, Madison and Wakefield are statistically significant at the 90% level. A southwest to northeast trend also exists, but the epicenter is no longer in the southwestern part of the state. Furthermore, sites that have statistically significant values (above 90% and 95%) significance are more dispersed than they were during the El Niño phase. Compared to the El Niño results shown in Figure 2, La Niña still shows a southwest to northeast trend (Figure 3). However, this trend is shifted northward compared to the El Niño trend.

During the Neutral phase Atkinson was 108% of normal, which was the largest departure from 100% (Figure 4). All other sites were close to the LTM which would be expected during the neutral phase.

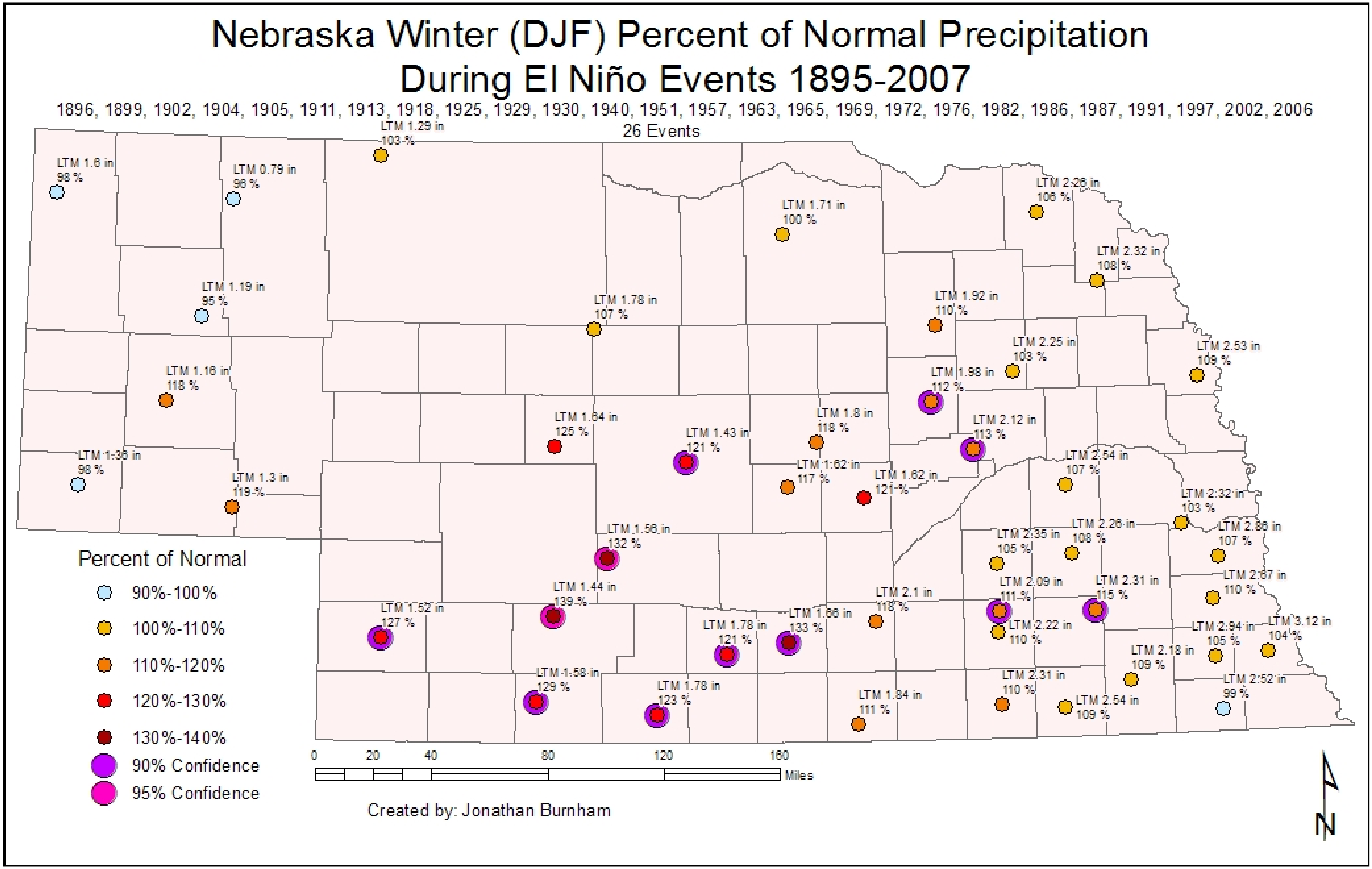

Figure 3: Percent of normal precipitation for each data site during El Niño

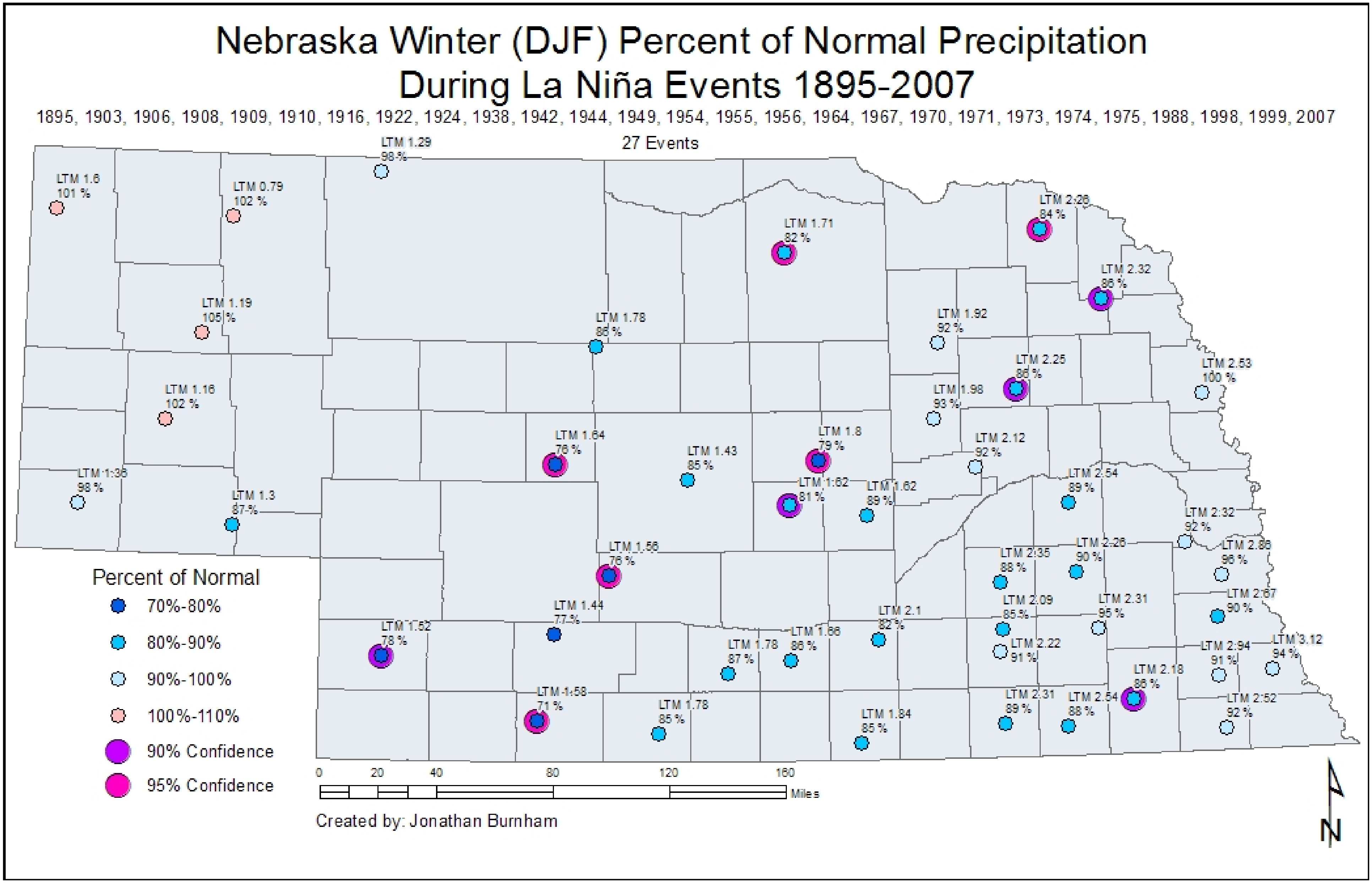

Figure 4: Percent of normal precipitation for each data site during La Niña.

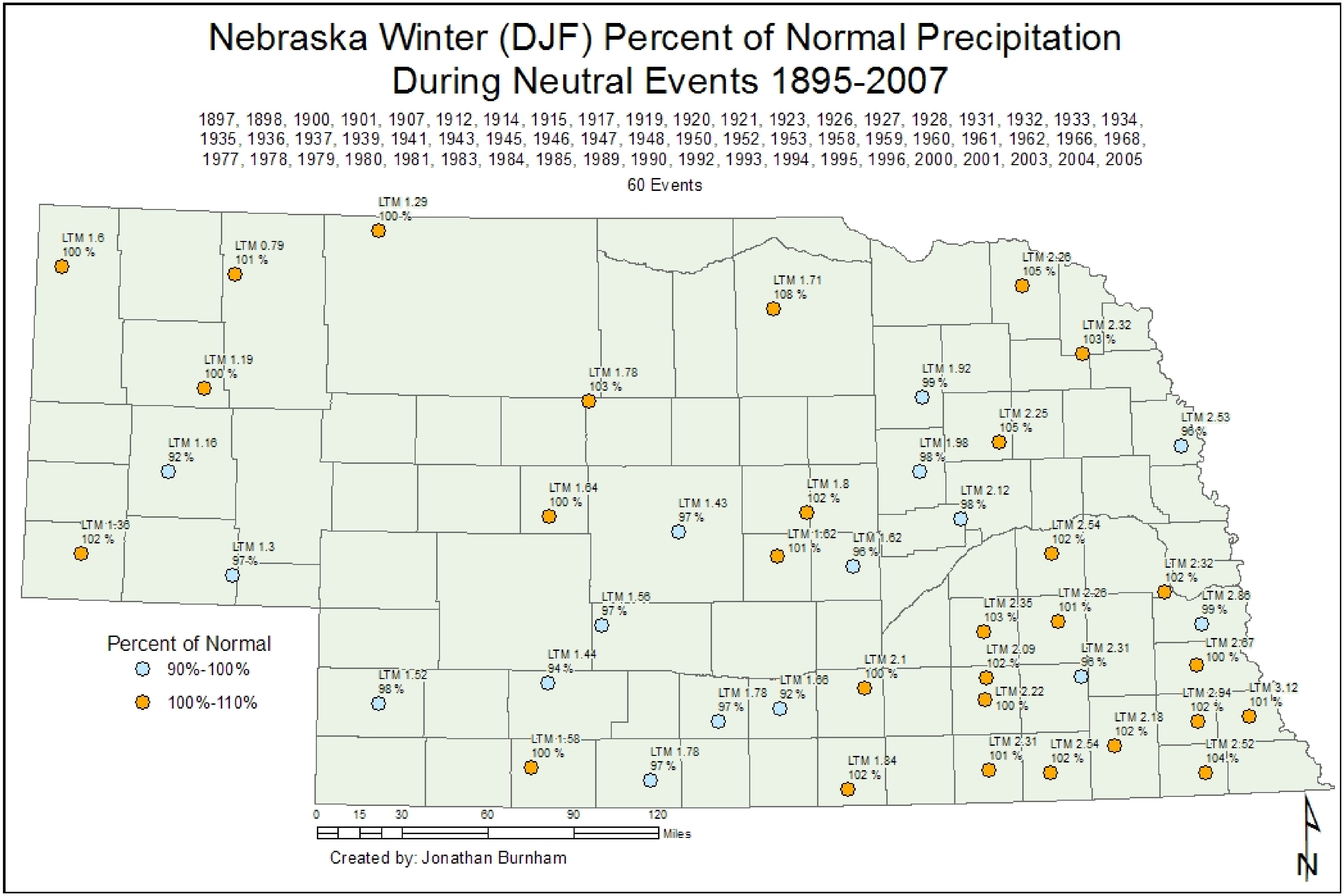

Figure 5: Percent of normal precipitation for each data site during Neutral phases.

Discussion

At least for the El Niño, the results of this study are generally consistent with those from the Climate Prediction Center and Kurtzman and Scanlon (2007). This study found that the lowest percent of normal precipitation (95%) occurred at Alliance during El Niño compared to the lowest value of 124% of normal in the panhandle climate division of the CPC study. The highest value in this study is 139% of normal at Curtis while the CPC study has a maximum value of 180% of normal in the south-central climate division of Nebraska. The CPC study used 102 years of data from 1895 to 1996, but only used nine El Niño events from 1914-15, 1918-19, 1940-41, 1957-58, 1965-66, 1972-73, 1982-83, 1986-87 and 1991-92. It is possible that the differences between this study and the CPC study is that analysis was done using specific sites, instead of climate divisions, as well as the time period and number of El Niño events that occurred.

When precipitation is analyzed based on absolute differences in normal precipitation compared to precipitation during El Niño, the southern US overwhelms the rest of the country in terms of precipitation anomalies *Kurtzman and Scanlon* [2007]. However Kurtzman and Scanlon (2007) did find a high relative anomaly in Nebraska. This study confirms the relative anomaly in the southwest part of the state as well as a slightly weaker anomaly in the northeastern part of Nebraska. While the southern US experiences increased precipitation due to increased storm tracks from the shift of the Sub Tropical Jet [Trenberth et al., 1998; Eichler and Higgins, 2006] the mechanism that causes increased winter precipitation in Nebraska is less certain. A study done by Noel and Changnon (1998) analyzed cyclone frequency during El Niño and found that when the 28°C SST isotherm is west of 150°W, cyclone frequency increased 15%-30% through the Midwest and northern plains. This may be attributed to the northern jet stream and Alberta Clipper track being displaced further south *Noel and Changnon* [1998]. However, this does not explain the lower than normal precipitation during La Niña that is seen in the same region as the above normal precipitation during El Niño.

Summary and Conclusion

The phenomenon known as ENSO is an anomaly of above normal (below normal) SST during El Niño (La Niña) and a shift of atmospheric pressure in the Pacific basin. Despite its location in the Pacific, ENSO has teleconnections to weather patterns in other parts of the globe, changing circulation, temperature and precipitation. While this is clearly seen on a national scale in the US, it is less obvious in the state of Nebraska. Using historical precipitation data from the USHCN, this study confirms the findings of other studies (Kurtzman and Scanlon, 2007; Ropelewski and Halpert, 1986) that a precipitation anomaly occurs during El Niño and La Niña in the southeast and northwest parts of Nebraska. What is less clear is the mechanism involved in producing higher than normal precipitation during El Niño and less than normal precipitation during La Niña besides an obvious lack of winter storm systems moving through the area.

Site	WARM PHASE			COOL PHASE			NEUTRAL PHASE		
	t-value	degrees of freedom	p-value	t-value	degrees of freedom	p-value	t-value	degrees of freedom	p-value
Albion	-1.7435	28.297	0.0921	0.3735	46.459	0.7105	0	118	1
Alliance	-1.3009	27.605	0.204	-0.3724	51.046	0.7111	0	118	1
Ashland	-1.4244	29.012	0.165	0.9452	60.826	0.3483	0	118	1
Atkinson	-0.0335	37.064	0.9735	2.3986	68.746	0.01917	0	118	1
Auburn	-1.4034	29.826	0.1708	0.752	51.968	0.4554	0	118	1
Beatrice	-1.6587	28.673	0.1081	1.6915	63.344	0.09566	0	118	1
Beaver Cit	-1.9917	28.538	0.05605	0.9707	48.495	0.3365	0	118	1
Bridgeport	-1.684	27.555	0.1035	-0.72	39.413	0.4758	0	118	1
Broken Bo	-1.7969	28.111	0.0831	0.9091	47.927	0.3679	0	118	1
Crete	-1.8109	29.418	0.08038	0.1109	50.256	0.9121	0	118	1
Curtis	-2.0899	28.293	0.04574	1.4336	57.381	0.1571	0	118	1
David City	-1.6192	29.14	0.1162	1.2643	58.242	0.2112	0	118	1
Fairbury	-1.6275	29.38	0.1143	1.3076	53.867	0.1965	0	118	1
Fairmont	-1.7387	28.684	0.09282	1.4142	49.766	0.1635	0	118	1
Geneva	-1.6404	28.919	0.1117	0.7906	58.338	0.4324	0	118	1
Genoa	-1.7866	28.692	0.08457	0.4941	50.931	0.6234	0	118	1
Gothenbur	-2.0733	32.083	0.04626	2.0142	52.052	0.04917	0	118	1
Harrison	0.2335	40.812	0.8165	-0.0791	54.906	0.9373	0	118	1
Hartington	-0.5081	34.997	0.6146	2.0048	65.332	0.04914	0	118	1
Hastings	-1.3517	35.63	0.185	1.6149	65.475	0.1112	0	118	1
Hay Spring	0.3573	40.831	0.7227	-0.0876	54.585	0.9305	0	118	1
Hebron	-0.8573	34.193	0.3972	1.1521	58.895	0.2539	0	118	1
Holdrege	-1.6986	34.074	0.09851	0.9215	50.329	0.3612	0	118	1
Imperial	-1.8224	33.547	0.07732	1.7562	65.314	0.08375	0	118	1
Kimball	0.1756	35.784	0.8616	0.3012	61.508	0.7643	0	118	1
Lodgepole	-1.2978	32.292	0.2036	0.9552	57.289	0.3435	0	118	1
Loup City	-1.0613	31.877	0.2965	1.863	68.549	0.06674	0	118	1
Madison	-0.2605	37.027	0.7959	1.6688	63.703	0.1001	0	118	1
McCook	-1.9863	35.749	0.0547	2.4613	74.515	0.01616	0	118	1
Merriman	-0.2385	37.054	0.8128	0.1198	67.977	0.905	0	118	1
Minden	-1.9148	31.181	0.06474	0.5789	49.815	0.5653	0	118	1
North Loup	-1.3184	32.931	0.1965	2.0571	48.414	0.04508	0	118	1
Oakdale	-0.8402	34.936	0.4065	0.623	50.442	0.5361	0	118	1
Pawnee C	0.0593	34.334	9533	1.0402	65.585	0.3021	0	118	1
Purdum	-0.6372	39.365	0.5277	1.5487	56.682	0.127	0	118	1
Red Cloud	-0.7501	32.783	0.4586	1.5168	56.211	0.1349	0	118	1
Saint Paul	-1.5884	35.137	0.1212	0.5488	55.314	0.5853	0	118	1
Seward	-0.6027	34.467	0.5506	0.976	49.612	0.3338	0	118	1
Stapleton	-1.4336	30.283	0.1619	2.6857	57.623	0.00944	0	118	1
Syracuse	-0.7903	33.544	0.4349	1.1269	62.441	0.2641	0	118	1
Tecumseh	-0.4487	33.949	0.6565	1.1092	51.169	0.2725	0	118	1
Tekamah	-0.8725	35.28	0.3888	-0.3887	50.505	0.6991	0	118	1
Wakefield	-0.638	33.542	0.5278	1.7553	55.054	0.08478	0	118	1
Weeping W	-0.5763	34.944	0.5699	0.2767	53.003	0.7831	0	118	1
York	-0.3843	34.727	0.7031	1.4235	56.713	0.1601	0	118	1

Table 1: Results from the Student's T-Test.

References

Brown, D. P., and A. C. Comrie (2004), A winter precipitation "dipole" in the western United States associated with multidecadal ENSO variability, *Geophys. Res. Lett.,* 31, L09203, doi:10.1029/2003GL018726.

ENSO Impacts on the U. S. (2003, January 14) National Weather Service-Climate Prediction Center. Retrieved February, 2010, from http://www.cpc.noaa.gov/products/predictions/threats2/enso/elnino/ne_bar.html

Dracup, J. A., and E. Kahya (1994), The relationships between United States streamflow and La Niña events, *Water Resour. Res.,*30, 2133-2141.

Eichler, E., and W. Higgins (2006), Climatology and ENSO-related variability North American extratropical cyclone activity, *J. Clim., 19*, 2076-2093.

"ENSO Index According to JMA SSTA." FSU Center for Ocean-Atmospheric Prediction Studies COAPS. Retrieved February, 2010, From <http://www.coaps.fsu.edu/jma.shtml>.

Glantz, M. H., 1996: Currents of Change: El Niño's Impact on Climate and Society. Cambridge University Press, 194 pp.

Gutzler, D. S., D. M. Kann, and C. Thornbrugh (2002), Modulation of ENSO-based long-lead outlooks of southwestern US winter precipitation by the Pacific decadal oscillation, *Weather Forecasting, 17*, 1163-1172.

Japan Meteorological Agency Marine Department, 1991: Climate charts of sea surface temperatures of the western North Pacific and the global ocean. 51 pp. Karl, T. R., C. N. Williams, Jr., and F. T. Quinlan. 1990. United States Historical Climatology Network (HCN) Serial Temperature and Precipitation Data. ORNL/CDIAC-30, NDP-019/R1. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tennessee.

Kahya, E., and J. A. Dracup (1993), United States streamflow patterns in relation to the El Niño-Southern Oscillation, *Water Resour. Res., 29*, 2491-2503.

Kurtzman, D., and B. R. Scanlon (2007), El Niño-Southern Oscillation and Pacific Decadal Oscillation impacts on precipitation in the southern and central United States: Evaluation of spatial distribution and predictions, *Water Resour. Res.,* 43, W10427, doi:1029/2007WR005863.

Menne, M. J., C. N. Williams, Jr., and R. s. Vose, 2009. United States Historical Climatology Network (USHCN) Version 2 Serial Monthly Dataset. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Nebraska City Points-2007 TIGER (2007), U.S. Department of Commerce, U.S. Census Bureau, Geography Division, Obtained from "Nebraska Spatial GIS Databases." Nebraska Department of Natural Resources. Retrieved February, 2010, From <http://www.dnr.state.ne.us/databank/spat.html>.

Nebraska County Boundaries-2007 TIGER (2007), U.S. Department of Commerce, U.S. Census Bureau, Geography Division, Obtained from "Nebraska Spatial GIS Databases." Nebraska Department of Natural Resources. Retrieved February, 2010, From <http://www.dnr.state.ne.us/databank/spat.html>.

Noel, J., and D. Changnon (1998), A pilot study examining US winter cyclone frequency patterns associated with three ENSO parameters, *J. Clim., 11,* 2152-2159.

Redmond, K. T., and R. W. Koch (1991), Surface climate and streamflow variability in the western United States and their relationship to large-scale circulation indexes, *Water Resour. Res., 27*, 2381-2399.

Ropelewski, C. F., and M. S. Halpert (1986), North American precipitation and temperature patterns associated with the El Niño-Southern Oscillation (ENSO), *Mon. Weather Rev.,* 114, 2352-2362.

Stenseth, Nils Chr., Geir Ottersen, James W. Hurrell, Atle Mysterud, Mauricio Lima, Kung-Sik Chan, Nigel G. Yoccoz, and Bjørn Ådlandsvik. "Review Article. Studying Climate Effects on Ecology through the Use of Climate Indices: the North Atlantic Oscillation, El Niño Southern Oscillation and beyond." *Proceedings of the Royal Society B: Biological Sciences* 270.1529 (2003): 2087-096. Print.

Trenberth, K. E. (1997), The definition of El Niño, *bull. Am. Meteorol. Soc.*, 78, 2771-2777.

Trenberth, K. E., G. W. Branstator, D. Karoly, A. Kumar, N. C. Lau, and C. Ropelewski (1998), Progress during TOGA in understanding and modeling global teleconnections associated with tropical sea surface temperatures, *J. Geophys. Res., 103*, 14,291-14,324.

Walker, G. T., (1924): Correlation in seasonal variation of weather, IX: A further study of world weather. *Mem. Indian Meteor. Dept., 24, 275-332*