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Spatial Accuracy of Climate Networks in Nebraska

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SPATIAL ACCURACY OF CLIMATE NETWORKS IN NEBRASKA

by

Andrea June Coop

A Thesis

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Master of Science

Major: Natural Resource Sciences

Under the Supervision of Professors Kenneth G. Hubbard and David B. Marx

Lincoln, Nebraska

July, 2011
Climate data has become increasingly scrutinized for its accuracy because of the need for reliable predictions about climate change. The U.S. has taken great strides to keep up with the demand for accurate climate data. Over the last thirty years, vast improvements to instrumentation, data collection, and station siting have created more accurate data records. This study is to explore the accuracy of existing networks. This study analyzes three climate networks used in Nebraska: the U.S. Historical Climatology Network (HCN), the Automated Weather Data Network (AWDN), and the newest network, the U.S. Climate Reference Network (CRN). Each of these networks has its own instrumentation, collection methods and station sites. Maximum and minimum surface temperature from the three networks and the spatial structure of temperature variations at the surface are compared. Two different timeframes, 2005-2009 and 1985-2005, were used to include the newest network, CRN, in the analysis. Daily data were collected from each of these networks within the specified timeframe. Root mean square error (RMSE) between each candidate station and the surrounding stations within 500 kilometers were calculated and evaluated to determine spatial accuracy of the network. This study found that in the 5 year analysis, CRN versus AWDN, the two networks were not significantly different enough to denote the network with high spatial accuracy. For
the 21 year analysis, HCN versus AWDN, AWDN stations showed higher spatial accuracy (smaller error) than HCN stations for the variable of maximum temperature. The error for the two networks were not significantly different enough to decipher the network with the higher spatial accuracy.
ACKNOWLEDGEMENTS

I would like to thank the University of Nebraska-Lincoln, the High Plains Regional Climate Center and the National Climatic Data Center. I would like to thank Dr. Kenneth Hubbard for his extensive help and guidance throughout the research and writing of this thesis. I would like to thank Dr. David Marx for co-advising and keeping this project on track using his extensive knowledge of statistics. I would also like to thank Dr. Martha Shulski for serving on my thesis committee. I would also like to thank all of the authors of the work that is referenced in this paper.
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<td>AWDN</td>
<td>Automated Weather Data Network</td>
</tr>
<tr>
<td>CDIAC</td>
<td>Carbon Dioxide Information Analysis Center</td>
</tr>
<tr>
<td>CRN</td>
<td>Climate Reference Network</td>
</tr>
<tr>
<td>HCN</td>
<td>Historical Climatology Network</td>
</tr>
<tr>
<td>HPRCC</td>
<td>High Plains Regional Climate Center</td>
</tr>
<tr>
<td>NCDC</td>
<td>National Climatic Data Center</td>
</tr>
<tr>
<td>NOAA</td>
<td>National Oceanic and Atmospheric Administration</td>
</tr>
<tr>
<td>NWS</td>
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CHAPTER 1- INTRODUCTION

Documentation of the present climate is a necessity for business activities, protection of life and property, projections of future climates and agriculture to name a few (Goody et al. 2002). Depending on the type of research or activity that a person is utilizing the climate data for, determines that type of climate data that needs to be collected. In recent years, the need for high quality climate data which is regionally, nationally and globally representative has increased substantially due to the spotlight on climate change. The U.S. has made substantial strides in successfully answering that call for high quality representative data by creating, updating, and deploying climate networks throughout the country. The longest running observation network, Cooperative Observer Program (COOP), established in 1890, relied on thousands of volunteers to record data from each of the weather stations around the U.S. According to Fiebrich (2009), author of “History of Surface Weather Observations in the United States,” “During the early 1900s, numerous observer stations moved from farms to residential districts of towns, where service was available to mail the observation forms. By 1926, more than 5,000 observing locations were located throughout the U.S., West Indies, and the Caribbean. By 1958, the COOP program had grown to nearly 14,000 observers” (82). As technology improved, the bias created by different observation times, dissimilar instrumentation and multiple station relocations became more evident (Wendland & Armstrong 1993; Wu et al. 2005). After realizing the bias from the COOP stations, a new network, the Historical Climatology Network (HCN) was developed in the mid-
1980s (CDIAC, http://cdiac.ornl.gov/epubs/ndp/ushcn/daily_doc.html). This network still used the COOP stations but only a small subset that were considered to be “the best.” These included stations with the longest record and least amount of station moves. Inconsistencies within the HCN dataset from time of observation differences, instrumentation changes, station relocations, and observer bias have also been scrutinized over the past twenty years (Hubbard et al. 2004, Vose & Menne 2004, Davey & Pielke 2005, Pielke et al. 2007). Fiebrich (2009) goes on to describe the development of automated weather stations in the U.S. “In 1939, the Bureau of Aeronautics in the U.S. Navy began to actively develop automated weather stations. The first station became operational in 1941. The station, which weighed one ton, transmitted data via radio and was powered by a gasoline electric plant. An IBM weight-driven clock turned the station on and off according to the preferred observation interval. The station’s 80-gallon fuel tank held enough gasoline for two to four months of operation. The human receiver interpreted the transmission by timing the signals and comparing them to a set of calibration curves” (82). The National Center for Atmospheric Research developed a portable automated weather station beginning in 1973 (Fiebrich 2009). The station was capable of running on battery power and transmitting data from a network of stations in real time (Fiebrich 2009). With automation, the biases created by volunteers dropped significantly. Automation allows for hourly data to be collected along with daily measurements collected at the same time every day. The networks following the development of HCN were developed and deployed on a state and regional basis (Meyer & Hubbard 1992; Hoogenboom 1997). Organizations like the High Plains Regional
Climate Center (HPRCC) in Lincoln, Nebraska felt a need for an unbiased, spatially dense, variable diversified (e.g. solar radiation, wind speed, and humidity observations) climate record for their research and agriculture industries in real-time or near real-time. As a result the HPRCC developed the Automated Weather Data Network (AWDN) in the early 1980s (Hubbard et al. 1982, Meyer & Hubbard 1992, Fiebrich 2009). The U.S. deployed their newest network in 2004, the Climate Reference Network (CRN), as an answer for the need for a high quality representative look at national climate change over the next 50 to 100 years (Hubbard et al. 2005). Learning from the inconsistencies in the COOP and HCN datasets, CRN stations are installed in areas where construction, urbanization or any other microclimate bias will not affect the measurements; three redundant measurements of temperature and two individual measurements of precipitation are collected to recognize any sensor problems and ensure the accuracy of the measurement; calibration and maintenance are top priority for each weather station to also ensure the accuracy of each measurement taken (Gallo 2004, Hubbard et al. 2005, Fiebrich 2009).

The difference between accuracy and precision can be described in many ways. In the study by Melvin et al. (2008) a hypothetical climate network is developed to, “examine the influence of sensor precision and accuracy on the ability to discover unambiguously the atmospheric spatial variability over a local, simple terrain” (265). Melvin et al. describe the difference between accuracy and precision for the purposes of their study; Accuracy is defined as the “systematic error or bias of the sensor measurements” while precision is defined as the “random errors associated with sensor
measurements” (265). The authors state that the results from their study are specific to the purpose of the study but the methods used can be used to determine error in other aspects of climate networks (Melvin et al. 2008). The methods for our study are very similar to the methods used in Melvin et al. (2008) which are described later in this paper.

Past literature shows that the accuracy of instrumentation for each network has been heavily researched and published but research on the spatial accuracy of each network has been much more limited (Hubbard 1993, Wendland & Armstrong 1993, Hubbard et al. 2004, Lin & Hubbard 2004, Gallo 2004, Vose & Menne 2004, Wu et al. 2005, Melvin et al. 2008). Accuracy of instrumentation is an extremely important aspect to each network and to the quality of data that is collected from that network which is why so much research has focused on the topic. Routine calibration, maintenance and replacement of old instruments are the key to maintain the integrity of a network. This notion has had a large impact on the implementation of the CRN stations which follow strict guidelines for instrumentation to ensure no bias related to instrumentation (National Climatic Data Center (NCDC), http://www.ncdc.noaa.gov/crn/).

Weather patterns are constantly changing. As these patterns sweep across the network, various sites will be exposed to different parts of the pattern and the observation from two sites at the same time may differ accordingly. Additionally, inversions and lapse temperature can be introduced by topographic and atmospheric conditions. Generally, two sites in close proximity will be highly correlated while the correlation will decrease as the distance between sites increases. When these statistical measurements are plotted according to the separation of distance, the resulting graph or map can be used to
answer questions like “how close do the stations need to be to achieve a certain network goal?” The goal could be to represent all points in the area of the network to 1 degree Celsius. The map would also be useful in determining where any new stations should be located in the existing network. Spatial accuracy studies, in the past, focused on the desirable spatial density of networks to provide an accurate portrayal of climate variability (Vose & Menne 2004). Vose & Menne (2004) describe the preferred spatial density for the CRN in the contiguous U.S. as variable depending on the intention of the data being collected. “For example, if minimizing the number of stations is a high priority in a real-world application, then a network as small as about 25 stations may be a viable option because the largest gains in performance occur up to that point. If trend detection is a high priority, then a network of 135 stations is a better alternative because discernable improvement continues until the network reaches that size and because sampling variability becomes minor for higher densities” (2970).

The purpose of this study is to determine how accurate the networks are in representing points that do not have a station located there; How well does the network estimate every point within the network focus area? The ability to accurately estimate weather variables in every location covered by a climate network is such an important asset. Networks such as CRN have a very low spatial density. In Nebraska alone, only four stations are available; two of which are paired together in Lincoln, NE. This is not a shortcoming for its stated purpose, however it may not provide enough observations for accurately mapping temperature and following smaller scale temperature patterns because a substantial amount of land area is left unmonitored and unrepresented in the
interpolation of weather variables in that area. To examine patterns in unmonitored areas, estimations from nearby stations are calculated. The study described in this paper determines if those estimations are truthful to the actual observations. The focus of this study is the spatial accuracy of HCN, AWDN and CRN stations in the state of Nebraska. In other words, how well do the statistical measures vary with distance of separation for these networks? We were limited to a short time period for the comparison of CRN and AWDN due to the recent implementation of CRN. Our hypothesis is that CRN stations provide the most spatially accurate (smallest error) climate data compared to AWDN and HCN stations because of the state-of-the-art instrumentation and multiple temperature and precipitation sensors on site.

The objective of this study is to increase knowledge about spatial accuracy of existing networks and to increase understanding of the importance of knowing how spatially accurate a climate network is. As knowledge about climate networks increase, more reliable climate networks are deployed which increases that amount of reliable climate data available.
CHAPTER 2- BACKGROUND OF CLIMATE NETWORKS

Automated Weather Data Network

The Automated Weather Data Network (AWDN) is installed and maintained by the High Plains Regional Climate Center (HPRCC). This automated weather network was developed in support of agriculture in the state of Nebraska (Hubbard, 1982). According to the HPRCC website, AWDN sites “record hourly data for air temperature and humidity, soil temperature, wind speed and direction, solar radiation, and precipitation.” This network is the only of the three networks analyzed in the paper that is not a national climate network. AWDN weather stations are located in the states of Colorado, Iowa, Kansas, Minnesota, Missouri, Montana, North Dakota, Nebraska, South Dakota and Wyoming. Table 2.1 describes the instrumentation of each AWDN site. The table includes the sensor name, the variable that is being measured, the installation height of that sensor, and the accuracy of the sensor. Photo 2.1 is an actual visual representation of the AWDN site in Merna, Nebraska.

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Variable</th>
<th>Installation Height</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermistor</td>
<td>Air Temperature</td>
<td>1.5 m</td>
<td>0.25°C</td>
</tr>
<tr>
<td>Thermistor</td>
<td>Soil Temperature</td>
<td>-10 cm</td>
<td>0.25°C</td>
</tr>
<tr>
<td>Si Cell Pyranometer</td>
<td>Radiation-Global</td>
<td>2 m</td>
<td>2%</td>
</tr>
<tr>
<td>Cup Anemometer</td>
<td>Wind Speed</td>
<td>3 m</td>
<td>5%</td>
</tr>
<tr>
<td>Wind Vane</td>
<td>Wind Direction</td>
<td>3 m</td>
<td>2 degrees</td>
</tr>
<tr>
<td>Coated Circuit</td>
<td>Relative Humidity</td>
<td>1.5 m</td>
<td>5%</td>
</tr>
<tr>
<td>Tipping Bucket</td>
<td>Precipitation</td>
<td>0.5 to 1 m</td>
<td>5%</td>
</tr>
</tbody>
</table>

Table 2.1 Instrumentation description of AWDN site
Source: HPRCC website (http://www.hprcc.unl.edu/awdn/)
United States Climate Reference Network

The United States Climate Reference Network (CRN) is a network of 114 weather stations in the contiguous U.S.; the stations are installed and maintained by the National Oceanic and Atmospheric Administration (NOAA). CRN stations were developed and deployed to create a network that would confidently identify climate change throughout the nation (http://www.ncdc.noaa.gov/crn/). The NCDC website describes the vision of the CRN program, “is to maintain a sustainable high-quality climate observation network that 50 years from now can with the highest degree of confidence answer the question:

Photo 2.1   AWDN weather station; Merna, NE; Photograph courtesy of the HPRCC website (http://www.hprcc.unl.edu/awdn/).
How has the climate of the nation changed over the past 50 years?” Substantial research was conducted to determine site locations that would display regional and national representation, sensitivity to the measurement of climate variability, long term site stability, proximity to other observation sites, access throughout the year and a true picture of natural risk and vulnerability (http://www.ncdc.noaa.gov/crn).

Each CRN weather station takes three redundant measurements of temperature and two measurements of precipitation. Solar radiation, surface radiative temperature, surface winds and relative humidity are also measured at each CRN site. Table 2.2 describes the sensors at each site, what variable is being measured and the height of each sensor. According to NCDC, each site is equipped with “a standard set of sensors, a data logger and a satellite communications transmitter, and at least one weighing rain gauge encircled by a wind shield. The hourly observations and the fifteen minute precipitation data are stored in a data logger attached to the tower. A GOES satellite transmitter sends the data to the National Climatic Data Center where the data undergo a quality control check and are placed on the Web several times a day” (http://www.ncdc.noaa.gov/crn).

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Variable</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Temperature Sensors enclosed in Aspirated Solar Radiation Shields</td>
<td>Placed on a 3m tower at a height typically 1.5 meters above the surface of the ground. Some sites where large snowfall and snow depths occur, the height may be adjusted.</td>
</tr>
<tr>
<td>Cup Anemometer</td>
<td>Wind Speed</td>
<td></td>
</tr>
<tr>
<td>Pyranometer</td>
<td>Solar Energy</td>
<td></td>
</tr>
<tr>
<td>Infrared Thermometer</td>
<td>Surface Temperature</td>
<td></td>
</tr>
<tr>
<td>Relative Humidity Sensor</td>
<td>Relative Humidity</td>
<td></td>
</tr>
</tbody>
</table>

Table 2.2 Instrumentation description for CRN sites.
Source: NCDC website (http://www.ncdc.noaa.gov/crn)
To ensure that this network creates an unbiased confident vision of the national climate, routine calibration and maintenance are critical.

**United States Historical Climatology Network**

The United States Historical Climatology Network (HCN) is a network developed in the mid-1980s by NOAA’s National Climatic Data Center (NCDC) and the Department of Energy’s Carbon Dioxide Information Analysis Center in response to the need for “an accurate, unbiased, modern historical climate record for the United States” (CDIAC, http://cdiac.ornl.gov/epubs/ndp/ushcn/daily_doc.html). HCN is a subset consisting of over 1200 weather stations that have been selected from NOAA’s National Weather Service networks; U.S. Cooperative Observer Network (mostly rural areas) and synoptic network (airports or urban areas). This network collects maximum and minimum temperature, precipitation, snow fall amount and snow depth (CDIAC, http://cdiac.ornl.gov/epubs/ndp/ushcn/daily_doc.html). According to the CDIAC website, this subset of stations “were originally selected according to factors such as record longevity, percentage of missing values, spatial coverage as well as the number of station moves and/or other station changes that may affect data homogeneity” (CDIAC, http://cdiac.ornl.gov/epubs/ndp/ushcn/daily_doc.html). The HCN data have been through several quality control revisions throughout its history due to changes in station relocation, instrumentation, and observing practices (Menne et al., 2009). The bias that affects the largest number of COOP/HCN stations is the switch from liquid –in-glass (LIG) thermometers to maximum-minimum temperature sensors (MMTS) “In 1983, the
NWS (National Weather Service) began to replace LIG maximum-minimum thermometers with electronic sensors at the approximately 5300 NWS cooperative stations in the United States” (Wendland & Armstrong 1993). Wendland & Armstrong (1993) continue to describe the difference between the LIG thermometers and the MMTS that replaced them.

The MMTS senses maximum and minimum temperatures by means of a single thermistor that continually senses the current temperature and preserves the highest and lowest values since the instrument was last reset. The MMTS sensor is shielded from sunlight by a white plastic louvered “beehive” about 25 cm high and about 20 cm in diameter. Traditionally, LIG thermometers have been installed within a white, wooden cotton-region shelter (CRS), with double roof and louvered sides, about 50 cm x 90 cm horizontally, and 80 cm high. The instruments are about 1.7 m above the ground. (233)

According to Menne et al. (2009), revisions, such as the ones needed because of the replacement of thermometers, have reduced the uncertainty of the monthly HCN dataset. More research should be done to find nonclimatic shifts in the data to create a homogeneous monthly dataset.

NCDC has since released a daily dataset from the HCN stations. This dataset contains maximum and minimum temperatures along with precipitation totals from 138 of the “most reliable, consistent and unbiased” stations (CDIAC,
According to the CDIAC website, records were evaluated for quality assurance. The website goes on to list the quality issues that were evaluated:

- The degree to which each station maintained a constant observation time for maximum and minimum temperatures, excursions from a station’s predominant observing time of no more than four years being desired;
- At least 95% of a station’s pre-1951 data should be contained in NCDC digital daily archives;
- A station’s potential for heat island bias over time should be low;
- Quality assessments based upon the decile ranking assigned by Karl et al. (1990) to the stations’ monthly maximum/minimum temperature data for certain quality characteristics.

To provide better spatial coverage of the HCN daily data, some of these restrictions were relaxed in a limited number of cases. The HCN daily dataset differs from the HCN monthly dataset because no bias adjustments have been attempted to account for instrumentation changes, observation changes, or station relocations.
Maximum and minimum daily surface temperature data for three climate networks in Nebraska were analyzed for this study. The data were acquired from their respective website databases; National Climatic Data Center (CRN and HCN) and High Plains Regional Climate Center (AWDN). Data were analyzed in system international units. To statistically compare between networks, samples from the same time period must be used. Otherwise, any differences between networks could be due to the difference in time period. To accommodate more recent networks, two separate time periods were used for comparison; CRN and AWDN data were analyzed using the 5-year period of 2005-2009; AWDN data were also analyzed using a 21-year period of 1985-2005 along with data for the same time period from HCN. The second time period, 1985-2005, was the longest period of comparison that still included a large number of AWDN stations. The climate in Nebraska varies from semi-arid in the west to sub-humid in the east. The candidate stations from each network were selected with this in mind (see Fig 3.1). In addition, these candidate stations corresponded with the locations of the Nebraska CRN weather stations due to their low density; only four CRN weather stations are within the state of Nebraska. Candidate stations from HCN were chosen based on completeness of record also. Stations with more than 5 percent missing data for the selected period were excluded from this study. All candidate stations are located in northwest, northwest central and southeast Nebraska.
Data from weather stations within a radius of 500 kilometers from each of the candidate stations for all three climate networks were also obtained. Because of the large distances between the CRN stations, 500 kilometers was chosen to ensure that the analysis for the CRN stations had a sufficient number of surrounding stations to be compared with. (To see a full list of stations used in this analysis including neighboring stations, refer to Appendix A.) These neighboring stations were used to calculate the spatial accuracy of the network near the specified candidate site. Neighboring stations with more than 5 percent missing data for the necessary period of record were excluded.
from the analysis due to bias that might occur from estimating large amounts of missing
data.

Missing values for HCN and CRN were estimated using a technique called
inverse distance weighting. Estimations for missing data for AWDN is calculated using
spatial regression test (Hubbard and You 2005, You et al. 2007). Both inverse distance
weighting (IDW) and spatial regression test (SRT) were calculated for the HCN and CRN
stations that were used. These methods of estimating missing values in weather data are
described in an article by You el al. (2007). The authors describe the difference between
IDW and SRT methods.

The SRT is a quality control approach that checks whether the variable
falls within the confidence interval formed from surrounding station data
during a time period of length n….Unlike distance weighting techniques,
this approach selects those stations that compare most favorably to the
station of interest, and these may or may not be the closest stations…. The
IDW method is a simple distance weighted estimate of the value at the
target station. The assumption here is that surrounding stations should
receive more weight if they lie in closer proximity to the target station
than other neighbours. (778)

Although You et al. (2007) concluded that SRT calculates better estimates
than IDW in most areas; the improvement of SRT within the Great Plains
compared to IDW is much smaller than areas with more topographic relief (787).
To quantify the reliability of the estimations in this study, various actual values from the record of a station were set-aside and marked as missing values. That station was then ran through the program and the resulting estimated values were then compared to the actual values.

Figure 3.2  Regression of RMSE (°C) versus distance from candidate station (km).

To find the spatial accuracy for each candidate station, all surrounding stations within 500 kilometers and with a specified period of record with less than 5% missing data were used to define the relevant statistics. First, each surrounding station was paired with the candidate station to determine the variance ($r^2$) and the root-mean-square-error (RMSE) from daily data on a per month basis between the candidate station and the surrounding stations (Linacre, 1991). The resulting values were then stored together with the distance of separation from the candidate station. These values were then plotted on a monthly basis as shown in Figure 3.2. The regression line shown in Figure 3.2...
represents the best fit to the data where the intercept is forced through zero. This is consistent with a zero RMSE between collocated weather stations.

The second-order polynomial equation extracted from the regression line is a direct estimate of how error increases with distance of separation. This process was repeated for each candidate station and for both maximum and minimum temperature. The resulting values were illustrated creating a table to estimate error as distance increases and season’s change (Table 3.1, Figure 3.3). The distances for these estimates were determined by the spatial distribution of the two networks being compared. The

<table>
<thead>
<tr>
<th>Candidate Station</th>
<th>Maximum Temperature</th>
<th>Minimum Temperature</th>
</tr>
</thead>
<tbody>
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<td>150 km</td>
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<tr>
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<tr>
<td>May</td>
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<td>1.83</td>
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<td>June</td>
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<td>1.72</td>
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<td>July</td>
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<td>August</td>
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<td>September</td>
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<td>2.11</td>
</tr>
<tr>
<td>December</td>
<td>1.71</td>
<td>2.46</td>
</tr>
</tbody>
</table>

Table 3.1  Estimated RMSE (°C) vs. distance from candidate station (km) based on second-order polynomial equations from monthly regressions for Harrison (CRN); maximum and minimum temperature; 2005-2009
to the closer proximity of the HCN and AWDN stations. The resulting information is summarized in Table 3.1 and Figure 3.3.

![Mitchell Farms (AWDN)-Tmax (2005-2009)](image)

Figure 3.3 Estimated RMSE with varying distances (km) from the candidate station throughout the year.

Based on the spatial accuracy (RMSE) illustrated in Figure 3.3, we assume the smaller the RMSE the more accurate the network. As shown in Figure 3.3, smaller distances of separation from the candidate station will increase the spatial accuracy. As stations are farther from the candidate station, error increases (e.g. a station at 100 km would be expected to have a RMSE of 2° C while at 300 km the RMSE would climb to approximately 4.5° C). This occurs because both stations do not sample the same air at the same time. The same meteorological events such as cold and warm fronts are experienced within a reasonable time of each other. This idea does not hold true for all locations. In some mountainous regions, moving a station only a couple of meters can
completely change the climatic features around that station. In the case of this study, moving a station only a couple of meters will not drastically change its climatic characteristics.
CHAPTER 4- RESULTS

Quality Control of Estimated Values

To determine the quality of the estimations of the missing values that were described in the methodology section, Harrison (HCN) and Lincoln 11 (CRN) were evaluated. Actual values from one of the surrounding stations of each of these candidate stations were chosen to replace actual observations with missing values. For Harrison (HCN), the station in Holdrege, Nebraska for the entire year of 1992 was evaluated (Figs. 4.1 & 4.2). Holdrege, NE is 451 kilometers from the candidate station, Harrison. For Lincoln 11 (CRN), the station in Des Moines, Iowa for the entire year of 2007 was evaluated (Figs. 4.3 & 4.4). The station in Des Moines, IA is 313 kilometers from the candidate station, Lincoln 11. The graphs (Figures 4.1 -4.4) that compare the actual observations versus the estimated values from the program are below.

![Graph showing the comparison of actual observations vs. estimated values for Harrison (HCN) and Holdrege, NE for 1992. The equation of the regression line is y = 0.9192x + 1.9518 with R² = 0.9358.](image-url)

Figure 4.1 Actual observations (°C) vs. estimated values (inverse distance weighting) (°C) for Holdrege, NE; 1992; Maximum temperature; Harrison (HCN); 21 year analysis
Figure 4.2  Actual observations (°C) vs. estimated values (inverse distance weighting) (°C) for Holdrege, NE; 1992; Minimum temperature; Harrison (HCN); 21 year analysis

Figure 4.3  Actual observations (°C) vs. estimated values (inverse distance weighting) (°C) for Des Moines, IA; 2007; Maximum temperature; Lincoln 11 (CRN); 5 year analysis
For both stations evaluated, the actual observations versus the estimated values calculated using the inverse distance weighting always correlated above 93 percent. For the purposes of this study, the level of correlation was high enough to proceed with the estimated values.

**5 year analysis (2005-2009)**

The first analysis was a comparison of maximum and minimum temperature from January 2005 to December 2009 of four candidate stations from both CRN and AWDN climate networks. The direct comparisons between climate networks (based on location and completeness of climate record) are as follows: Harrison (CRN) and Mitchell Farms (AWDN); Lincoln8 (CRN) and Havelock (AWDN); Lincoln 11 (CRN) and Lincoln 27E
56S (AWDN); Whitman (CRN) and Gudmundsen Research (AWDN). Each comparison was based on the estimated root mean square error that was explained above. Maximum temperature graphs are pictured below (Figs 4.5-4.12). All other data results will be presented in tables (Tables 4.1 -4.4). Graphs for all data results can be found in Appendix C at the end of this paper. The first thing to notice when comparing Harrison (CRN) and Mitchell Farms (AWDN) is how the spatial accuracy changes drastically throughout the year. During the summer season, June through August, spatial accuracy displays an increase. While in the winter, error increases. This is the case for all of the stations analyzed in this paper for both maximum and minimum temperature. According to Hubbard (1994), “part of this variability is associated with the seasonal warming and cooling trends while the remainder result from a number of other factors including the number of air masses and the speed of passage through the area of interest, the amount and type of cloud cover, the amount and location of snow cover” (39). Not only does error increase in the winter months but the spread of error between the 100 km surrounding station and 300 km surrounding station also increases in the winter. For Harrison and Mitchell Farms for maximum temperature (Figs 4.5, 4.6), the spread between 100 and 300 km is over 2.5 degrees Celsius. While in July, the spread is less than 2 degrees Celsius. The spread again reaches over 2 degrees in December. According to the comparison between these two candidate stations to create a network with spatial accuracy of less than 2 degrees Celsius, weather stations would have to be sited within 100 km of each other during the year. During the summer months, stations
could be as much as 150 km apart and still meet the criteria of less than 2 degrees Celsius of error.

The graphs below have outlined the results for the maximum temperature variable for this study. Table 4.1 highlights the maximum and minimum temperature for the five year analysis between CRN and AWDN along with showing the difference between comparison of CRN and AWDN candidate stations. A positive result in the “difference” column shows error is higher for the CRN than the AWDN candidate station. A negative result demonstrates greater spatial accuracy for the CRN candidate station rather than the AWDN candidate station. The table features three months (January, June and December) for each station to show the variability of error throughout the year. A table of differences for each month is also included (Table 4.2).

Figure 4.5
Figure 4.6

**Mitchell Farms (AWDN)-Tmax (2005-2009)**

Figure 4.7

**Lincoln8 (CRN)-Tmax (2005-2009)**
Figure 4.8

Havelock (AWDN)-Tmax (2005-2009)

Root Mean Square Error (°C)

Month

Figure 4.9

Lincoln11 (CRN)-Tmax (2005-2009)

Root Mean Square Error (°C)

Month
Figure 4.10

Lincoln (27E 56S) (AWDN)-Tmax (2005-2009)

Figure 4.11

Whitman (CRN)-Tmax (2005-2009)
Figures 4.5-4.12 Estimated RMSE (°C) for varying distances (km) from candidate station evaluated throughout the year; Maximum Temperature; 2005-2009; 4.5) Harrison (CRN), 4.6) Mitchell Farms (AWDN), 4.7) Lincoln 8 (CRN), 4.8) Havelock (AWDN), 4.9) Lincoln 11 (CRN), 4.10) Lincoln (27E 56S) (AWDN), 4.11) Whitman (CRN), 4.12) Gudmundsen Research (AWDN)

21 year analysis
Table 4.3 keeps the same format as Table 4.1 illustrating maximum temperature and minimum temperature for HCN and AWDN candidate stations for the 21 year analysis (1985-2005). January, June and December are again displayed to show variability throughout the year. The difference between the paired candidate stations used for comparison is also featured and follows the same rules as the above table; a positive result shows larger error for the HCN candidate station than the AWDN and a negative result larger error for the AWDN candidate compared with the HCN candidate station. Table 4.4 also follows the same format as Table 4.2 which includes the difference between each set of paired stations for every month throughout the year. As described in
length in the methodology, the 21 year analysis uses a smaller spatial distribution (25, 50, 75, 100, and 125 km) to estimate spatial accuracy. To continue with the threshold of 2 degrees of error that was used in the results for the 5 year analysis, AWDN stations must be within 75 km of each other. Some cases showed that stations could reach a distance of 100 km and still maintain the threshold of 2 degrees error. HCN on the other hand has to sustain a distance within 50 km to uphold the 2 degrees error. In very few cases, a distance of 75 km still preserved the threshold.
<table>
<thead>
<tr>
<th>Candidate Station</th>
<th>Time of Year</th>
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<th>Minimum Temperature</th>
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<td></td>
<td>100 km</td>
<td>150 km</td>
<td>200 km</td>
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<tr>
<td>CRN-Harrison</td>
<td>January</td>
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<td></td>
<td>June</td>
<td>1.19</td>
<td>1.72</td>
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<td></td>
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<td>1.71</td>
<td>2.46</td>
</tr>
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<td>1.91</td>
<td>2.69</td>
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<td></td>
<td>June</td>
<td>1.46</td>
<td>2.07</td>
</tr>
<tr>
<td></td>
<td>December</td>
<td>1.75</td>
<td>2.49</td>
</tr>
<tr>
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<td>January</td>
<td>-0.02</td>
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<tr>
<td></td>
<td>June</td>
<td>-0.26</td>
<td>-0.35</td>
</tr>
<tr>
<td></td>
<td>December</td>
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<td>-0.03</td>
</tr>
<tr>
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<td></td>
<td>June</td>
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<td></td>
<td>December</td>
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</tr>
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<td>1.26</td>
<td>1.76</td>
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<tr>
<td></td>
<td>December</td>
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<td>June</td>
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<td>-0.36</td>
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</table>

Table 4.1 Estimated RMSE (°C) vs. distance from candidate station (km) for January, June and December; CRN vs. AWDN; 2005-2009; Harrison (CRN) vs. Mitchell Farms (AWDN), Lincoln8 (CRN) vs. Havelock (AWDN), Lincoln11 (CRN) vs. Lincoln (27E 56S) (AWDN), Whitman (CRN) vs. Gudmundsen Research (AWDN).
<table>
<thead>
<tr>
<th>Candidate Station</th>
<th>Time of Year</th>
<th>Maximum Temperature</th>
<th>Minimum Temperature</th>
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<td></td>
<td>December</td>
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<tr>
<td>Difference between Lincoln 11 (CRN) &amp; Lincoln (27E 56S) (AWDN)</td>
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<td></td>
<td>February</td>
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<td>0.04</td>
</tr>
<tr>
<td></td>
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<td>-0.09</td>
</tr>
<tr>
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<td>0.08</td>
</tr>
<tr>
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Table 4.2 Difference between CRN & AWDN based on estimated RMSE (°C) vs. distance from candidate station (km) for each month throughout the year; CRN vs. AWDN; 2005-2009; Harrison (CRN) vs. Mitchell Farms (AWDN), Lincoln8 (CRN) vs. Havelock (AWDN), Lincoln11 (CRN) vs. Lincoln (27E 56S) (AWDN), Whitman (CRN) vs. Gudmundsen Research (AWDN).
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<td>0.93</td>
</tr>
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<td>December</td>
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<td>1.20</td>
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<td>0.86</td>
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<td></td>
<td>December</td>
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<td>0.81</td>
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<td>0.52</td>
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<td>December</td>
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<td>1.36</td>
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<td>0.81</td>
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<td>December</td>
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<td>1.43</td>
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<td>1.15</td>
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<td>December</td>
<td>0.71</td>
<td>1.37</td>
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<td>AWDN-Arthur</td>
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<td>0.54</td>
<td>1.06</td>
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<td>June</td>
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</tr>
<tr>
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<td>0.20</td>
<td>0.37</td>
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<tr>
<td></td>
<td>June</td>
<td>0.19</td>
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<tr>
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<td>December</td>
<td>0.20</td>
<td>0.37</td>
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</table>

Table 4.3  Estimated RMSE (°C) vs. distance from candidate station (km) for January, June and December; HCN vs. AWDN; 1985-2005; Harrison (HCN) vs. Gordon (AWDN), Ashland (HCN) vs. Mead (AWDN), David City (HCN) vs. Mead (AWDN), Gothenburg (HCN) vs. Arthur (AWDN).
## Difference Between HCN and AWDN (1985-2005)

<p>| Candidate Station | Time of Year | Maximum Temperature | | Minimum Temperature | |
|-------------------|--------------|----------------------|-----------------------------|-----------------------------|
|                   |              | 25 km | 50 km | 75 km | 100 km | 125 km | 25 km | 50 km | 75 km | 100 km | 125 km |
| <strong>Difference between Harrison (HCN) &amp; Gordon (AWDN)</strong> | January      | 0.27   | 0.52   | 0.72   | 0.90   | 1.04   | 0.23   | 0.43   | 0.60   | 0.75   | 0.87   |
|                   | February     | 0.26   | 0.49   | 0.68   | 0.85   | 0.98   | 0.21   | 0.39   | 0.55   | 0.68   | 0.80   |
|                   | March        | 0.29   | 0.54   | 0.75   | 0.93   | 1.08   | 0.18   | 0.35   | 0.49   | 0.61   | 0.71   |
|                   | April        | 0.27   | 0.51   | 0.71   | 0.88   | 1.02   | 0.14   | 0.27   | 0.38   | 0.48   | 0.56   |
|                   | May          | 0.24   | 0.45   | 0.63   | 0.79   | 0.91   | 0.10   | 0.19   | 0.27   | 0.33   | 0.38   |
|                   | June         | 0.19   | 0.35   | 0.49   | 0.61   | 0.71   | 0.09   | 0.17   | 0.24   | 0.30   | 0.35   |
|                   | July         | 0.11   | 0.20   | 0.28   | 0.34   | 0.39   | 0.04   | 0.07   | 0.09   | 0.11   | 0.13   |
|                   | August       | 0.15   | 0.28   | 0.40   | 0.49   | 0.56   | 0.07   | 0.14   | 0.19   | 0.23   | 0.27   |
|                   | September    | 0.24   | 0.45   | 0.64   | 0.79   | 0.92   | 0.09   | 0.17   | 0.24   | 0.29   | 0.34   |
|                   | October      | 0.41   | 0.78   | 1.09   | 1.36   | 1.59   | 0.19   | 0.36   | 0.50   | 0.63   | 0.73   |
|                   | November     | 0.30   | 0.57   | 0.80   | 1.00   | 1.16   | 0.20   | 0.37   | 0.52   | 0.65   | 0.75   |
|                   | December     | 0.26   | 0.50   | 0.70   | 0.87   | 1.01   | 0.21   | 0.41   | 0.57   | 0.72   | 0.84   |
| <strong>Difference between Ashland (HCN) &amp; Mead (AWDN)</strong> | January      | 0.27   | 0.52   | 0.73   | 0.91   | 1.06   | 0.09   | 0.17   | 0.24   | 0.29   | 0.33   |
|                   | February     | 0.25   | 0.46   | 0.66   | 0.82   | 0.96   | 0.07   | 0.13   | 0.18   | 0.21   | 0.24   |
|                   | March        | 0.28   | 0.53   | 0.75   | 0.94   | 1.10   | 0.13   | 0.24   | 0.34   | 0.42   | 0.48   |
|                   | April        | 0.25   | 0.47   | 0.67   | 0.84   | 0.99   | 0.11   | 0.20   | 0.29   | 0.35   | 0.40   |
|                   | May          | 0.14   | 0.27   | 0.39   | 0.48   | 0.56   | 0.07   | 0.14   | 0.19   | 0.23   | 0.27   |
|                   | June         | 0.12   | 0.23   | 0.32   | 0.41   | 0.47   | 0.05   | 0.10   | 0.13   | 0.16   | 0.19   |
|                   | July         | 0.09   | 0.18   | 0.25   | 0.32   | 0.38   | 0.04   | 0.07   | 0.10   | 0.13   | 0.15   |
|                   | August       | 0.12   | 0.22   | 0.32   | 0.40   | 0.47   | 0.02   | 0.03   | 0.04   | 0.04   | 0.05   |
|                   | September    | 0.22   | 0.43   | 0.61   | 0.77   | 0.91   | 0.06   | 0.11   | 0.15   | 0.18   | 0.20   |
|                   | October      | 0.25   | 0.47   | 0.67   | 0.85   | 0.99   | 0.08   | 0.16   | 0.21   | 0.26   | 0.30   |
|                   | November     | 0.21   | 0.38   | 0.51   | 0.59   | 0.63   | 0.07   | 0.14   | 0.19   | 0.23   | 0.26   |
|                   | December     | 0.21   | 0.39   | 0.55   | 0.68   | 0.80   | 0.07   | 0.14   | 0.19   | 0.23   | 0.26   |
| <strong>Difference between David City (HCN) &amp; Mead (AWDN)</strong> | January      | 0.35   | 0.67   | 0.94   | 1.17   | 1.37   | 0.14   | 0.26   | 0.36   | 0.45   | 0.51   |
|                   | February     | 0.29   | 0.55   | 0.79   | 0.99   | 1.15   | 0.11   | 0.20   | 0.28   | 0.34   | 0.40   |
|                   | March        | 0.37   | 0.69   | 0.98   | 1.23   | 1.44   | 0.15   | 0.28   | 0.39   | 0.48   | 0.56   |
|                   | April        | 0.32   | 0.61   | 0.86   | 1.08   | 1.26   | 0.14   | 0.26   | 0.36   | 0.44   | 0.51   |
|                   | May          | 0.21   | 0.39   | 0.56   | 0.70   | 0.81   | 0.19   | 0.35   | 0.50   | 0.62   | 0.72   |
|                   | June         | 0.19   | 0.35   | 0.49   | 0.62   | 0.72   | 0.15   | 0.28   | 0.39   | 0.49   | 0.57   |
|                   | July         | 0.13   | 0.24   | 0.34   | 0.43   | 0.50   | 0.07   | 0.14   | 0.19   | 0.23   | 0.27   |
|                   | August       | 0.10   | 0.20   | 0.28   | 0.35   | 0.40   | 0.06   | 0.10   | 0.14   | 0.17   | 0.20   |
|                   | September    | 0.20   | 0.38   | 0.54   | 0.68   | 0.79   | 0.11   | 0.21   | 0.30   | 0.37   | 0.42   |
|                   | October      | 0.28   | 0.53   | 0.75   | 0.95   | 1.11   | 0.12   | 0.22   | 0.30   | 0.37   | 0.42   |
|                   | November     | 0.27   | 0.48   | 0.65   | 0.77   | 0.85   | 0.16   | 0.30   | 0.41   | 0.51   | 0.59   |
|                   | December     | 0.29   | 0.55   | 0.77   | 0.97   | 1.13   | 0.13   | 0.24   | 0.34   | 0.42   | 0.48   |</p>
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<th>Maximum Temperature</th>
<th>Minimum Temperature</th>
</tr>
</thead>
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<td>50 km</td>
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</tr>
<tr>
<td>December</td>
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<td>0.20</td>
<td>0.37</td>
</tr>
</tbody>
</table>

Table 4.4 Difference between HCN and AWDN based on estimated RMSE (°C) vs. distance from candidate station (km) for each month throughout the year; HCN vs. AWDN; 1985-2005; Harrison (HCN) vs. Gordon (AWDN), Ashland (HCN) vs. Mead (AWDN), David City (HCN) vs. Mead (AWDN), Gothenburg (HCN) vs. Arthur (AWDN).
CHAPTER 5- DISCUSSION

For this study when considering the difference between RMSE of one network versus another, a difference of +/- 0.5 degrees Celsius or greater will be considered significant because anything in the range +/- 0.5 degrees would be indistinguishable from differences expected due to the precision of the instruments used. The values in Tables 4.1, 4.2, 4.3 and 4.4 that are highlighted were above that threshold. Melvin et al. (2008) describe their findings on instrument precision; “For Tmax (Tmin), an instrument precision of 0.6°C (0.7°C) was determined to be adequate to distinguish atmospheric variability in the presence of instrument precision. Several manufacturers currently design temperature sensors with precisions between 0.2 and 0.7°C, which meet the determined criteria” (269).

5 year analysis

For the comparison of CRN and AWDN for the time period of 2005-2009, there were no values that were significantly different for any distance for maximum temperature. In other words, the difference between CRN and AWDN stations for maximum temperature is not enough to be considered significant. For the analysis of minimum temperature, the comparison between Harrison (CRN) and Mitchell Farms (AWDN) had the most values that were considered significantly different. These values included the entire months of February, July, August and October for all distances. The months of January, April, June and September showed significance beginning at the distance of 150 kilometers from the candidate station. May, November and December only showed significance when the distance of separation was at least 200 km. March
was the only month that did not show any significantly different values. All of the values that showed significance between Harrison and Mitchell Farms illustrated that Mitchell Farms was the more accurate of the two.

The other values within the 5 year analysis that are significantly different (Lincoln 8 (CRN) vs. Havelock (AWDN), 150 and 200 km, January; Lincoln 11 (CRN) vs. Lincoln (27E 56S) (AWDN), 150 and 200 km, January) are all exactly -0.5˚C. For the comparison of Whitman (CRN) vs. Gudmundsen Research (AWDN), July and August show values that are significantly different. All seven of these values are negative. This denotes that for all eleven values the CRN station (Lincoln 8, Lincoln 11 and Whitman) has higher spatial accuracy than the AWDN station (Havelock, Lincoln (27E 56S) and Gudmundsen Research).

For the purpose of this study, the comparison between CRN and AWDN do not show enough significant difference for maximum or minimum temperature to decipher which network has better spatial accuracy than the other.

21 year analysis

The comparison between HCN and AWDN for the time period of 1985-2005 indicated that maximum temperature is more likely to be significantly different than minimum temperature. Every station comparison for maximum temperature shows at least a few values that are significant (especially January, February, March, April, October, November and December values for distances 50 through 125 km). Summer months show less significantly different values than spring and winter. In the case of
Ashland (HCN) vs. Mead (AWDN), June, July and August do not show any values that are significantly different. For all of the values that are significantly different, the AWDN station has a lower error (higher spatial accuracy) than the HCN.

The only comparisons for minimum temperature that exceeded the thresholds are Harrison (HCN) and Gordon (AWDN) (January, February, October, November and December for 75, 100 and 125 km; March for 100 and 125 km; April for 125 km) and David City (HCN) and Mead (AWDN) (January, March, April and June for 125 km; May for 75, 100 and 125 km; November for 100 and 125 km).

This study shows, for the comparison between HCN and AWDN, AWDN has higher spatial accuracy than HCN for the variable of maximum temperature. More than 50% of the values evaluated for maximum temperature were significantly different and showed that AWDN has lower error (higher spatial accuracy) than HCN. The results for minimum temperature did not show enough values that are significantly different to determine if one network was more spatially accurate than the other.
CHAPTER 6-CONCLUSION

The purpose of this study was to determine the spatial accuracy of three climate networks in Nebraska (AWDN, CRN and HCN). The spatial accuracy as defined in this study was a representation of how well networks could estimate areas in which weather stations were not present. The comparison between CRN and AWDN evaluated distances of 100, 150, 200, 250 and 300 km. The comparison between HCN and AWDN was able to analyze closer distances due to the higher spatial density of the two networks (25, 50, 75, 100 and 125 km). This study found that for the comparison of CRN and AWDN the error from each network was not significantly different enough to decipher the network with the higher spatial accuracy. The comparison between HCN and AWDN showed that for maximum temperature only AWDN had higher spatial accuracy while minimum temperature was not significant enough to make a decision about higher spatial accuracy.

This study presents a baseline of how accurate estimates made within these networks are when calculated. The need for continued research to ensure that climate networks are collecting reliable data is still present. As research improves, so does our knowledge about calibration of instruments, consistency in observation time and consistency in location which helps to create, develop and deploy even better networks than before.
REFERENCES

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"U.S. Surface Climate Observing Reference Networks." *National Climatic Data Center (NCDC)*. NOAA Satellite and Information Service. 

<http://www.ncdc.noaa.gov/crn/>


<http://ftp.ncdc.noaa.gov/pub/data/ushcn/products/daily01/>


Wu, Hong, Kenneth G. Hubbard, and Jinsheng You. "Some Concerns When Using Data from the Cooperative Weather Station Networks: A Nebraska Case Study."


### Appendix A - List of Stations used in Analysis

#### Table A.1

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<td>Des Moines IA</td>
<td>Lander WY</td>
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<td>Lincoln 11 NE</td>
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<th>AWDN 5 Years</th>
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</thead>
<tbody>
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<td>Dell Rapids SD</td>
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Table A.4

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Appendix B

C*********************************************************************
C
C    THIS IS THE PROGRAM FOR COMPUTING SPATIAL STATISTICS FOR A
C    GROUP
C    TEST VERSION BEGUN JULY 18, 1989
C    LATEST UPDATES MARCH 29, 2011
C*********************************************************************

DIMENSION Z(200,12,8000),S(12,200),S2(12,200),SXY(12,200,200),
X V(12,200,200),fcnt(12,200),jcnt(12,200)
Dimension x(200,12,8000)
DIMENSION SP(12,200,200),AI(12,200,200),DIS(200,200)
DIMENSION ANG(200,200),SLAT(200),SLON(200)

C*********************************************************************
C****NOTE, THE DIMENSIONS ABOVE ARE A FUNCTION OF MAINLY THE
C    NUMBER I
C    OF STATIONS THAT ARE GOING TO BE RUN (I.E. 200), 8,000 IS THE # I
C    OF POSSIBLE DAYS IN period , UP TO 12 VARIABLES CAN BE STUDIEDI
C    AT ONE TIME
C*********************************************************************

DIMENSION NV(12)
REAL LAT,LONG

integer*4 today(3), now(3)
C Keep track of the month day and year for each data value
integer*4 MoP(200,12,8000),DaP(200,12,8000),YrP(200,12,8000)
C---Dimensions MoP(K,IV,#pts)
C    K is the station number
C    IV is the variable number
C    # pts is how many points are available for each variable during the time
C    period specified
C    MoP = Month for a given point
C    DaP = Day for a given point
C    YrP = Year for a given point

C Fort.17 a list of station: name,long, lat, dis STE of y on x for max&min
C Fort.91 stations in row 1, day c1,mon,day, &Yr for a given pt, followed by
C    Tx&Tn for each station
C Fort.92 a listing for all years to follow the if test on which data to include
C Fort.98 KK,IV,ID,Zold,Z(KK,IV,ID)
C    The columns are station, variable,day, old, & new value
C Fort.99 STname, STid, LAT, LONG for row 1, then index ptr, YR, mon, day, VAL(1), VAL(2)
C all stations and all days are listed in fort.99
C Fort.101 The Calendar day, Mon & day, and year from subroutine Cald
C Fort.105 IV, (fcnt(1,k), k=1, ISS), variable name, then % missing for each station

INTEGER STid

INTEGER NPARM, PC(50)

INTEGER HR, MIN, DAY, MON, YR, YRC, CALDC
INTEGER CALDB, CALDE, YRB, YRE

REAL*4 VAL(50)
REAL*4 SLAT, SLON
CHARACTER*1 ANS

CHARACTER*15 STname
Character*15 ST(200), TOB
Character*80 FILEname, junk

C----- Open the Output Files
OPEN(10, FILE='R2.DAT')
OPEN(11, FILE='SEE.DAT')
OPEN(12, FILE='STATS.DAT')
WRITE(*,*) ' OPENED R2 ETC'

50 FORMAT(A20)
51 FORMAT(1X, A20)

C***** CURRENT TIME
call idate(today) ! today(1) = day, (2) = month, (3) = year
call itime(now) ! now(1) = hour, (2) = minute, (3) = second
write ( *, 1000 ) today(2), today(1), today(3), now
1000 format ( 'Date ', i2, '/', i2, '/', i4, '; time ', & i2, ':', i2, ':', i2 )
MON=today(2)
DAY=today(1)
YR=today(3)
WRITE(*,*) ' time section'
WRITE(*,5) MON, DAY, YR, HR, MIN
5 FORMAT(I2, '/', I2, '/', i4, ',3I4)

C----- SET UP THE DATE
CALL CALDAYS(CALDC, MON, DAY, YR)
YRC=YR

C DEFINE OR READ IN THE DESIRED DATE
WRITE(*,135)
FORMAT(' DO YOU WANT YESTERDAYS DATA (Y/N) ? ')
READ(*,109,ERR=119)ANS
write(*,*) ANS
109 FORMAT(A1)
IF(ANS .EQ. 'N' .OR. ANS .EQ. 'n')THEN
WRITE(*,112)
FORMAT(' PLEASE ENTER YEAR, Beg CALENDAR DAY, # DAYS & END
YEAR')
READ(*,*,ERR=113) YRC,CALDC,NDAY,YRE
WRITE(12,*) YRC,CALDC,NDAY,YRE
WRITE(*,*) YRC,CALDC,NDAY,YRE
ENDIF
C----CALDB = the beginning Calendar day for each year included
C____CALDE = the ending Calendar day for each year included
YRB=YRC
CALDB=CALDC
CALDE=CALDC+NDAY-1
ENDF
WRITE(*,*) 'WORK WITH ALL PAIRS (Y) OR PAIR ONLY 1ST STN(N)'
READ(*,109,ERR=129)ANS
write(*,*) ANS
KPAIR=1
IF(ANS .EQ. 'N' .OR. ANS .EQ. 'n')THEN
KPAIR=0
ENDIF
WRITE(*,*) YRC,CALDC,HRC,MINC,BMIN
C****************************************************************
C    THE FOLLOWING VARIABLE NUMBERS ARE FOR THE IN
DICATED
PARAMETERS
C
C 11-- MAXIMUM DAILY TEMPERATURE
C 12-- MINIMUM DAILY TEMPERATURE
C 20-- AVERAGE DAILY HUMIDITY
C 30-- SOIL TEMPERATURE
C 40-- WIND SPEED
C 80-- SOLAR RADIATION
C 90-- PRECIPITATION
C 64-- ACCUM GDD 40 FROM JAN 1
C 65-- ACCUM GDD 50 FROM JAN 1
C 70-- EVAPOTRANSPIRATION (ET)
C 71-- ACCUM ET
C 91-- ACCUM PRECIP FROM JAN 1
C
C****************************************************************

NPARM=2
KS=0

C----Initialize the arrays to 0.0
DO 200 L=1,200
DO 200 IV=1,12
S(IV,L)=0.
S2(IV,L)=0.
DO 200 K=1,200
SXY(IV,K,L)=0.
V(IV,K,L)=0.
AI(IV,K,L)=0.
SP(IV,K,L)=0.
fcnt(IV,L)=0
jcnt(IV,L)=0
200  CONTINUE

C----Initialize the data arrays to -9999
DO 210 K=1,200
DO 210 I=1,12
DO 210 J=1,8000
Z(K,I,J)=-9999
210  Continue

NP=(YRE-YRB+1)*NDAY
Z(1,1,1),Z(200,1,8000)

C****************************
C********** LOOP TO READ IN Station file names **********
C********** And other information **********

10  Write(*,*) 'Enter Stations file name'
   read(*,*,END=9000,ERR=10) FILEname
   write(*,*) FILEname
   OPEN(15,FILE=FILEname)
   Read(15,*) STname, STid, LAT, LONG
15  Format(A10,1x,a6,2f8.2)
   write(99,*) STname, STid, LAT, LONG
C____READ in the line of variable headings

Read(15,1019) junk
1019 format(a80)
Write(*,1019) junk
C____Increment the counter for this station and put its name into the array along with
C____the latitude and longitude
    KS=KS+1
    ST(KS)=STname
    IDAY=0

C******************************************************************************

    WRITE(12,*) KS,FILENAME,STname,STid
    WRITE(*,*) KS,FILENAME,ST(KS)

C____Here are the Latitude and Longitude
    SLAT(KS)= LAT
C_____IF you were going to plot the data, then scale the Latitude by 1.32
C     SLAT=1.32 * LAT
    SLON(KS)= LONG
C*********** FIND THE VARIABLES THAT DEFINE THE SAMPLING PERIOD****

C******************************************************************************

C***** READ IN THE DATA FOR Each Station (KS)
900   Read(15,*,END=10,err=900) MON,DAY,YR,TOB,Val(1),Val(2)
    Write(92,*) YR,YRB,YRE
    IF(YR.LT.YRB) go to 900
    WRITE(92,*) YR,’>’,YRB
    IF(YR.gt.YRE) GO TO 900
    WRITE(92,*) YR,’<’,YRE
    CALL CALDAYS(CALDC,MON,DAY,YR)
C------Does this day lie within the the period of interest
    IF(CALDC.LT. CALDB .OR. CALDC .GT. CALDE) Go To 900

    IDAY=IDAY+1
    index=(YR-YRB)*NDAY+CALDC-CALDb+1
    write(99,*) index,YR,mon,day,VAL(1),VAL(2)
CxxxxxxSAVE the Date for each point
    MoP(KS,1,Index)= mon
    DaP(KS,1,Index)= day
    YrP(KS,1,Index) =YR

C******************************************************************************
C     SORT THE DATA FOR THE KV'TH VARIABLE BY STATION KS, VARIABLE
C     AND DAY (IDAY) and CONVERT TO SI UNITS AT THE SAME TIME
C*********************************************************************
 c     Z(KS,1,IDAY)= (VAL(1)-32.)*5./9.
 c     Z(KS,2,IDAY)= (VAL(2)-32.)*5./9.
 c     Z(KS,1,Index)= VAL(1)
 c     Z(KS,2,Index)= VAL(2)

 c___Identify the variable codes
     PC(1)= 11
     PC(2)= 12
 c     Z(KS,3,IDAY)= VAL(3)
 c     Z(KS,4,IDAY)= (VAL(4)-32.)*5./9.
 c     Z(KS,5,IDAY)= VAL(5)*0.447
 c     Z(KS,6,IDAY)= VAL(6)*(4.186E-02)
 c     Z(KS,7,IDAY)= VAL(7)*25.4
 c     Z(KS,8,IDAY)= VAL(8)*5./9.
 c     Z(KS,9,IDAY)= VAL(9)*5./9.
 c     Z(KS,10,IDAY)= VAL(10)*25.4
 c     Z(KS,11,IDAY)= VAL(11)*25.4
 c     Z(KS,12,IDAY)= VAL(12)*25.4
 c     write(12,19) ks,iday,(z(ks,kv,iday),kv=1,4)
 19    format(2i4,4f8.3)
     DO 1420 KV=1,2
 c     Z(KS,KV,IDAY)=VAL(KV)
C IF THE NUMERICAL VALUES ARE LARGE DECREASE BY 3 ORDERS OF
MAGNITUDE
     IF(PC(KV).EQ.64) Z(KS,KV,IDAY)=Z(KS,KV,IDAY)/100.
     IF(PC(KV).EQ.65) Z(KS,KV,IDAY)=Z(KS,KV,IDAY)/100.
1420   CONTINUE

GO TO 900
9000   ISS=KS
       NVV=NPARM
       Iday=NP

       write(*,*) 'After the 9000 loop'
C*** NO STATUS PROBLEMS IF WE MADE IT TO THIS POINT
C*** CALCULATE THE DISTANCE BETWEEN STATIONS (KM)
*******************
DO 250 K=1,ISS
DO 250 L=1,ISS
ALT1=SLAT(K)
ALT2=SLAT(L)
ALN1=-SLON(K)
ALN2=-SLON(L)
call distance(ALT1,ALN1,ALT2,ALN2,DIST)
call angles(ALT1,ALT2,ALN1,ALN2,AA)
ANG(K,L)=AA
DIS(K,L)=DIST
250 continue
write(12,*)'DISTANCE (km) BETWEEN STATIONS'
write(12,393) (K,K=1,ISS)
do 260 K=1,ISS
write(12,633) K,(DIS(K,L),L=1,ISS)
633 format(i4,200f6.0)
260 continue
write(12,*)'ORIENTATION BETWEEN STATIONS'
write(12,393) (K,K=1,ISS)
do 270 K=1,ISS
write(12,634) K,(ANG(K,L),L=1,ISS)
634 format(i4,200f6.1)
270 continue
Cc23456
C____ QC Check for -9999. and estimate from surrounding stations
C____ Use Inverse Distance Weighting
c_____ Begin QC QC QC QC QC QC QC QC
C  Check for the Max .lt. Min) and save original data in the X array
DO 870 KK=1,ISS
DO 860 ID=1,IDAY
X(KK,1,ID)=Z(KK,1,ID)
X(KK,2,ID)=Z(KK,2,ID)
Tx=Z(KK,1,ID)
Tn=Z(KK,2,ID)
if(TX.LE.TN) then
  z(kk,2,ID)=-9999
  z(kk,1,ID)=-9999
endif
write(90,*) st(kk), kk, ID, Tx, Tn
860 continue
870  Continue
C----We will go through this code twice, 1st time the distance weighting
C----2nd time use the a and b coefficients from the best fit line, this removes
C----systematic bias,  KF=1 the first time through
    KF=0
880  KF=KF+1

C.......IF KF=2 then reset Z and the sums
    IF(KF.EQ.2) then
        DO 855 KK=1,ISS
        DO 855 iv=1,NVV
            fcnt(iv,kk)=0
        DO 855 IDA=1,iday
            z(kk,iv,ida)=x(kk,iv,ida)
        ENDIF
855  Continue
    DO 209 L=1,200
    DO 209 IV=1,12
        S(IV,L)=0.
        S2(IV,L)=0.
        DO 209 K=1,200
            SXY(IV,K,L)=0.
            fcnt(IV,L)=0
            jcnt(IV,L)=0
        209  CONTINUE
    ENDIF
    DO 820 KK=1,ISS
    DO 820 IV=1,NVV
        DO 820 ID=1,IDAY
            C....Here IDAY is the total # of days e.g. 10years of julys makes IDAY=310
            C.....Check for missing (-9999. or +9999) at the stations
            IF(Z(kk,IV,ID).lt.-50. .OR.Z(kk,IV,ID).gt.135.)then
                fcnt(IV,kk)=fcnt(IV,kk)+1.0
            SN=0
            SD=0
            MM=0
            Zold=Z(kk,IV,ID)
C.....Do this inverse distance weighting the first time through
   IF(KF.eq. 1) then

   Do 800 K=1,ISS

   IF(k.NE.kk) then
   c-----K is the index pointing to the neighboring stations
   IF(Z(k,IV,ID).gt.-50. .AND.Z(k,IV,ID).lt.55.)then
      SN=SN+Z(K,IV,ID)/DIS(KK,K)
      SD=SD+1.0/DIS(KK,K)
      MM=MM+1
   ENDIF
   ENDIF

  800   CONTINUE

   IF(MM.GT.0) Then
      Z(KK,IV,ID)=SN/SD
   ELSE
      jcnt(IV,KK)=jcnt(IV,KK)+1
      Z(KK,IV,ID)=Z(KK,IV,ID-1)
   ENDIF
   Write (97,*) KK,IV,ID,x(KK,IV,ID),Z(KK,IV,ID),KF

   ELSE

C-----2nd time arround (KF=2)we do the spatial regression weighting......

C....You get here on the second time through the data....... 
   Do 865 K=1,ISS
   IF(k.NE.kk) then
   c-----KK is the station to be estimated and k represents the surrounding stations
   IF(Z(k,IV,ID).gt.-50. .AND.Z(k,IV,ID).lt.55.)then
      SN=SN+ (SP(IV,KK,K)*Z(K,IV,ID)+AI(IV,KK,K))/V(IV,KK,K)
      SD=SD+1.0/V(IV,KK,K)
      MM=MM+1
   ENDIF

  865   CONTINUE

   IF(MM.GT.0) Then
      Z(KK,IV,ID)=SN/SD
   ELSE
ELSE
   jcnt(IV,KK)=jcnt(IV,KK)+1
   Z(KK,IV,ID)=Z(KK,IV,ID-1)
ENDIF

   Write (98,*) KK,IV,ID,x(KK,IV,ID),Z(KK,IV,ID),KF
ENDIF
C23456

ENDIF
820   CONTINUE

C____ END of QC QC QC QC QC QC QC

c234567
   write(91,910) (ST(k),K=1,KS)
910   format(20x,200(2x,A8,2x))

   DO 850 IDA=1,IDAY
      Write(91,911) IDA,Mop(1,1,ID),DaP(1,1,ID),YrP(1,1,ID),
      1 (Z(K,1,IDA),Z(K,2,IDA),K=1,KS)
911   format(4i5,200(2f6.1))
850  CONTINUE

C*** BEGIN TO FORM THE SUMS
*************************************************
C*** S IS THE SUM OF Z
C*** S2 IS THE SUM OF SQUARED VALUES OF Z
C*** SXY IS THE SUM OF PRODUCTS OF Z AT LOCATION X AND Y
C*************************************************

DO 2030 IVa=1,NVV
   DO 2030 K=1,KK
      fcnt(IVA,K)=100.0*fcnt(IVA,K)/float(IDAY)
   2030    Continue

   DO 370 IVA=1,NVV
      NV(IVA)=PC(IVA)
      DO 366 IH=1,IDAY
         364   NDP=NDP+1
         DO 368 K=1,ISS
            C   WRITE(*,600) IH,NS(K),NV(IVA),Z(K,IVA,IH)
         600      FORMAT(1X,3I5,F12.3)
         S(IVA,K)=S(IVA,K)+Z(K,IVA,IH)
         S2(IVA,K)=S2(IVA,K)+Z(K,IVA,IH)**2
         DO 368 L=1,ISS
      END
      S2(IVA,K)=S2(IVA,K)+Z(K,IVA,IH)**2
SXY(IV,K,L) = SXY(IV,K,L) + Z(K,IV,IH)*Z(L,IV,IH)
SXY(IVA,K,L) = SXY(IVA,K,L) + Z(K,IVA,IH)*Z(L,IVA,IH)

368 CONTINUE
366 CONTINUE
370 CONTINUE

C*** CALCULATE THE STATISTICAL PROPERTIES
**********************************************************************
C*** V IS THE VARIANCE       *****
C*** AI IS THE INTERCEPT     *****
C*** SP IS THE SLOPE         *****
C*** V IS USED AGAIN FOR s.e.e. *****
C**********************************************************************

360 CONTINUE
   DO 610 IV=1,NVV
   DO 610 K=1,ISS
   C      WRITE(*,601) NS(K),NV(IV),S(IV,K),S2(IV,K)
   DO 610 L=1,ISS
   C      WRITE(*,602) NS(K),NS(L),NV(IV),SXY(IV,K,L)
610   CONTINUE
   601   FORMAT(1X,2I5,2E15.3)
   602   FORMAT(1X,3I5,E15.3)
   C      WRITE(*,601) NDP
   C       NDP=NDP/NVV
   NDP=IDAY
   ADAY=IDAY
   WRITE(*,371) NDP
371   FORMAT(' # DATA PTS.=',I6)
C---Variance calculation
   DO 380 IV=1,NVV
   DO 380 K=1,ISS
   DO 380 L=1,ISS
   V(IV,K,L)=ADAY*SXY(IV,K,L)-S(IV,K)**2/(ADAY*S2(IV,K)-S(IV,L)**2)
   V(IV,K,L)=V(IV,K,L)**2/(ADAY*S2(IV,K)-S(IV,L)**2)
380      CONTINUE
   C      WRITE(10,512) (NV(IV),IV=1,NVV)
   512   FORMAT(13X,20I5)
   DO 500 K=1,ISS
   IF(KPAIR.EQ.0 .AND.K.GT.1) GO TO 500
   write(*,*) iday,kpair,k
   DO 510 L=K,ISS
   ALT1=1.32*SLAT(L)
   ALN1=SLON(L)
   WRITE(10,511) K,L,ALT1,ALN1,DIS(K,L),ANG(K,L),
X (V(IV,K,L), IV=1,NVV)
511 FORMAT(2I4,F5.1,F7.1,F5.0,F5.2,12F5.2)
510 CONTINUE
500 CONTINUE
   DO 390 IV=1,NVV
      WRITE(12,392) NV(IV)
392 FORMAT(' VARIANCE FOR VARIABLE',I3)
   WRITE(12,393) (K,K=1,ISS)
393 FORMAT(3X,200I6)
C------VARIANCE written out
   DO 390 K=1,ISS
      WRITE(12,391) K,(V(IV,K,L),L=1,ISS)
391 FORMAT(1X,I2,200F6.2)
390 CONTINUE
C---Offset calculation
   DO 400 IV=1,NVV
   DO 400 K=1,ISS
   DO 400 L=1,ISS
      c AI(IV,K,L)=S(IV,L)*S2(IV,K)-S(IV,K)*SXY(IV,K,L)
      c DEN=ADAY*S2(IV,K)-S(IV,K)**2
      c AI(IV,K,L)=AI(IV,K,L)/DEN
AI(IV,K,L)=S(IV,K)*S2(IV,L)-S(IV,L)*SXY(IV,K,L)
DEN=ADAY*S2(IV,L)-S(IV,L)**2
AI(IV,K,L)=AI(IV,K,L)/DEN
400 CONTINUE
   DO 410 IV=1,NVV
      WRITE(12,402) NV(IV)
402 FORMAT(' OFFSET FOR VARIABLE',I4)
   WRITE(12,393) (K,K=1,ISS)
C---Offset print out
   DO 410 K=1,ISS
      WRITE(12,397) K,(AI(IV,K,L),L=1,ISS)
410 CONTINUE
C---Slope Calculation
   DO 420 IV=1,NVV
   DO 420 K=1,ISS
   DO 420 L=1,ISS
      SP(IV,K,L)=ADAY*SXY(IV,K,L)-S(IV,K)*S(IV,L)
      DEN=ADAY*S2(IV,L)-S(IV,L)**2
      SP(IV,K,L)=SP(IV,K,L)/DEN
420 CONTINUE
   WRITE(12,393) (K,K=1,ISS)
   DO 430 IV=1,NVV
WRITE(12,431) NV(IV)
431   FORMAT(' SLOPES FOR VARIABLE',I4)
WRITE(12,393) (K,K=1,ISS)
   C--Slope Print out
   DO 430 K=1,ISS
   WRITE(12,397) K,(SP(IV,K,L),L=1,ISS)
397      FORMAT(1X,I2,200F6.2)
430      CONTINUE
   C---Standard Error of Estimate CALCULATION
   DO 720 IV=1,NVV
   DO 720 K=1,ISS
   DO 720 L=1,ISS
      V(IV,K,L)=S2(IV,k)-AI(IV,K,L)*S(IV,k)-SP(IV,K,L)*SXY(IV,K,L)
   IF(V(IV,K,L).LT.0.0) THEN
      V(IV,K,L)=0.0
      ENDIF
      V(IV,K,L)=SQRT(V(IV,K,L)/(IDAY-2))
720    CONTINUE
   DO 700 K=1,ISS
   IF(KPAIR.EQ.0 .AND.K.GT.1) GO TO 700
   DO 710 L=K,ISS
      ALT1=1.32*SLAT(L)
      ALN1=SLON(L)
   C---Standard Error of Estimate Print out to 17
   WRITE(17,171) ST(L),slon(l),slat(L),DIS(K,L),(v(iv,k,l),iv=1,nvv)
171   format(a7,20f8.2)
   WRITE(11,711) K,L,ALT1,ALN1,DIS(K,L),ANG(K,L),
   X  (V(IV,K,L),IV=1,NVV)
711   FORMAT(2I4,F5.1,F7.1,F5.0,F5.2,12F7.2)
710    CONTINUE
700    CONTINUE
   513   FORMAT(3X,20I7)
   C---SEE Print out
   DO 730 IV=1,NVV
   WRITE(12,731) NV(IV)
731      FORMAT(' S.E.E. FOR VARIABLE',I4)
   WRITE(12,513) (K,K=1,ISS)
   DO 730 K=1,ISS
   WRITE(12,797) K,(V(IV,K,L),L=1,ISS)
797      FORMAT(1X,I2,200F7.2)
730 CONTINUE
   write(105,1021) (K,K=1,ISS)
1021 format(200(5x,i3))
   do 2020 IV=1,2
       write(105,1020) IV,(fcnt(1,k),k=1,ISS)
1020 format(i3,200(f5.1,4x))
2020 CONTINUE

IF(KF.eq.1) Then
   GOTO 880
Endif
STOP 'Normal Stop'

9191 Backspace (15)
   READ(15,*) JUNK
   WRITE(*,*) JUNK
   IF(KF.eq.1) Then
      GOTO 880
   Endif
   STOP
END

C**********************************************************
SUBROUTINE DISTANCE(ALT1,ALN1,ALT2,ALN2,DIST)
C**** R=EARTH RADIUS (KM)
C**** X,Y,Z ARE CALCULATED FROM SPHERICAL COORDINATES
DEFINITIONS
C**** Leaving DIST with unis of KM
R=6368.
   API=3.1415927
   CON=2*API/360.
   X1=R*SIN(CON*(90.-ALT1))*COS(CON*ALN1)
   Y1=R*SIN(CON*(90.-ALT1))*SIN(CON*ALN1)
   Z1=R*COS(CON*(90.-ALT1))
   X2=R*SIN(CON*(90.-ALT2))*COS(CON*ALN2)
   Y2=R*SIN(CON*(90.-ALT2))*SIN(CON*ALN2)
   Z2=R*COS(CON*(90.-ALT2))
C**** DISTANCE BETWEEN POINT 1 AND POINT 2 IS CALCULATED FROM
SPACE
C**** COORDINATES (NOT ALLOWING FOR CURVATURE OF EARTH
DIST=(X2-X1)**2+(Y2-Y1)**2+(Z2-Z1)**2
DIST=SQRT(DIST)
RETURN
END
SUBROUTINE ANGLES(ALT1,ALT2,ALN1,ALN2,AA)
API=3.1415
API2=2.*API
CC=API/2
A=ALN1-ALN2
B=ALT2-ALT1
IF(B.EQ.0) THEN
  AA=CC
ELSE
  AA=ATAN(A/B)
ENDIF
IF(ALT2.LT.ALT1.AND.ALN1.GT.ALN2) AA=API+AA
IF(ALT2.LT.ALT1.AND.ALN2.GE.ALN1) AA=API+AA
IF(ALT2.GE.ALT1.AND.ALN2.GT.ALN1) AA=API2+AA
RETURN
END

SUBROUTINE CALDAYS(CALD,MON,DAY,YR)
   C******   CALCULATES THE CORRESPONDING CALENDAR DAY
   INTEGER CALD,MON,DAY,YR
   INTEGER LEAP
   INTEGER NDAY(12)
   DATA NDAY/31,28,31,30,31,30,31,31,30,31,30,31/
   DATA NDAY/1,32,60,91,121,152,182,213,244,274,305,335/
   LEAP=0
   X=YR
   X=X/4.
   K=X
   K=K*4
   IF(K.EQ.YR) LEAP=1
   CALD=NDAY(MON)+DAY-1
   IF(LEAP.GT.0.AND.MON.GT.2) CALD=CALD+LEAP
   WRITE(101,*) CALD,MON,DAY,YR
RETURN
END
Appendix C

5 year analysis (2005-2009) CRN vs. AWDN; Estimated RMSE (°C) for varying distances (km) from candidate station evaluated throughout the year; Maximum & Minimum Temperature

Figure C.1

![Graph of Harrison (CRN)-Tmax (2005-2009)](image)

Figure C.2

![Graph of Harrison (CRN)-Tmin (2005-2009)](image)
Figure C.3

![Mitchell Farms (AWDN)-Tmax (2005-2009)](chart1)

Figure C.4

![Mitchell Farms (AWDN)-Tmin (2005-2009)](chart2)
Figure C.5

Lincoln 8 (CRN)-Tmax (2005-2009)

Figure C.6

Lincoln 8 (CRN)-Tmin (2005-2009)
Figure C.7

![Graph showing Root Mean Square Error (°C) for Havelock (AWDN)-Tmax (2005-2009)]

Figure C.8

![Graph showing Root Mean Square Error (°C) for Havelock (AWDN)-Tmin (2005-2009)]
Figure C.9

![Lincoln 11 (CRN)-Tmax (2005-2009)](image)

Root Mean Square Error (°C) vs. Month

Figure C.10

![Lincoln 11 (CRN)-Tmin (2005-2009)](image)

Root Mean Square Error (°C) vs. Month
Figure C.11

Lincoln (27E 56S) (AWDN)-Tmax (2005-2009)

Figure C.12

Lincoln (27E 56S) (AWDN)-Tmin (2005-2009)
Figure C.13

Whitman (CRN)-Tmax (2005-2009)

Figure C.14

Whitman (CRN)-Tmin (2005-2009)
Figure C.15

Gudmundsen Research (AWDN)-Tmax
(2005-2009)

Root Mean Square Error (°C)

Month

Figure C.16

Gudmundsen Research (AWDN)-Tmin
(2005-2009)

Root Mean Square Error (°C)

Month
21 year analysis (1985-2005) HCN vs. AWDN; Estimated RMSE (°C) for varying distances (km) from candidate station evaluated throughout the year; Maximum & Minimum Temperature

Figure C.17

Harrison (HCN)-Tmax (1985-2005)

Figure C.18

Harrison (HCN)- Tmin (1985-2005)
Figure C.19

Gordon (AWDN)-Tmax (1985-2005)

Figure C.20

Gordon (AWDN)-Tmin (1985-2005)
Figure C.21

Ashland (HCN)-Tmax (1985-2005)

Figure C.22

Ashland (HCN)- Tmin (1985-2005)
Figure C.23

![Graph: Root Mean Square Error (°C) vs Month for Mead (AWDN)-Tmax (1985-2005)]

Figure C.24

![Graph: Root Mean Square Error (°C) vs Month for Mead (AWDN)-Tmin (1985-2005)]
Figure C.25

David City (HCN)-Tmax (1985-2005)

Figure C.26

David City (HCN)- Tmin (1985-2005)
Figure C.27

Mead (AWDN)-Tmax (1985-2005)

Figure C.28

Mead (AWDN)-Tmin (1985-2005)
Figure C.29

Gothenburg (HCN)-Tmax (1985-2005)

Root Mean Square Error (°C)

Month

Gothenburg (HCN)- Tmin (1985-2005)

Root Mean Square Error (°C)

Month
Figure C.31

Arthur (AWDN)-Tmax
(1985-2005)

Root Mean Square Error (°C)

Month

0.0 1.0 2.0 3.0 4.0 5.0 6.0
1 2 3 4 5 6 7 8 9 10 11 12

Root Mean Square Error (°C)

Month

25
50
75
100
125

Figure C.32

Arthur (AWDN)-Tmin
(1985-2005)

Root Mean Square Error (°C)

Month

0.0 1.0 2.0 3.0 4.0 5.0 6.0
1 2 3 4 5 6 7 8 9 10 11 12

Root Mean Square Error (°C)

Month

25
50
75
100
125