TEMPERATURE BEHAVIOR DIFFERENCES BETWEEN THE VALLEY AND RIDGE TOP IN THE LA CROSSE, WISCONSIN AREA

Jeffrey S. Boyne
National Weather Service
La Crosse, Wisconsin

1. Introduction

During the last Great Ice Age, glaciers surrounded the Driftless Area of southwest and west-central Wisconsin, southeast Minnesota, northeast Iowa and northwest Illinois. As these glaciers retreated, the water that was released from the glacial lakes and rivers carved out the bluffs, coulees, and river valleys in the region. Many of the towns and cities that were settled in the region were located in these coulees and river valleys; and the weather observation sites are located in these same locales. As a result, the temperature behavior and climatology in the valleys is fairly well understood, but less is known about the behavior on top of the surrounding bluffs. In January 1997, the La Crosse National Weather Service Office (ARX) began to take daily weather observations on top of La Crosse Ridge (approximately 650 feet

Fig. 1. The relief map above shows the locations and elevations of the two observation points used in this study. ARX is located on a ridge top overlooking the city of La Crosse, Wisconsin. The La Crosse Automated Surface Observation System (ASOS) is located at the La Crosse Municipal Airport (LSE) on French Island near the center of the Mississippi River Valley. These two sites are 4.9 miles apart and there is an elevation difference of 655 feet. The black numbers represent the elevation in feet above sea level.

above the valley floor). This site is located approximately five miles southeast of the Automated Surface Observation System (ASOS) at the La Crosse Municipal Airport (LSE) on French Island (Fig. 1). As a result, the behavior of the valley and ridge temperatures, comparatively, can be investigated.

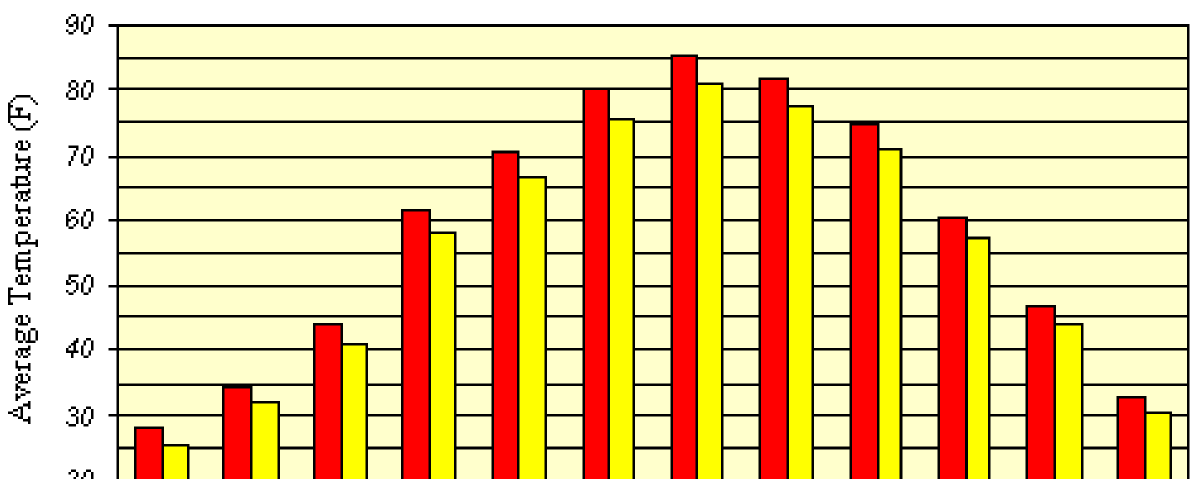
2. Data and methodology

This study assesses the monthly and daily maximum and minimum temperatures for both sites (LSE and ARX) during the ten-year period from January 1, 1997 (the first day that temperature observations were taken at ARX) through December 31, 2006 (a total of 3,652 days). The monthly temperatures were obtained from the daily temperature data.

3. Results

a. Maximum temperature behavior at ARX and LSE

Throughout the year, the average monthly maximum temperatures were warmer at LSE than ARX (Fig. 2). These differences ranged from 2.6°F to 4.7°F (Fig. 3). The largest departures occur from May to September (between 3.9°F and 4.7°F). July had the largest difference (4.7°F) closely followed by June (4.5°F). The smallest departures occurred from November through February (between 2.6°F and 2.8°F) with February having the smallest difference (2.6°F). The maximum temperatures were correlated extremely well between the two sites throughout the year (Fig. 4). With the exception of July (0.973), the correlation between the two sites was 0.980 or greater. The slightly weaker correlation in July may be related to the weaker synoptic forcing that typically occurs during mid summer allowing microclimates to have a stronger influence on temperature. Like the monthly data, the daily



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
LSE Max	28.0	34.6	44.1	61.4	70.6	80.2	85.4	81.6	74.9	60.4	46.6	32.9
ARX Max	25.3	32.0	40.9	58.0	66.7	75.7	80.7	77.4	70.9	57.3	43.8	30.1

Fig. 2. Average monthly maximum temperatures for LSE and ARX. The red boxes indicate which site averaged warmer temperatures for that particular month.

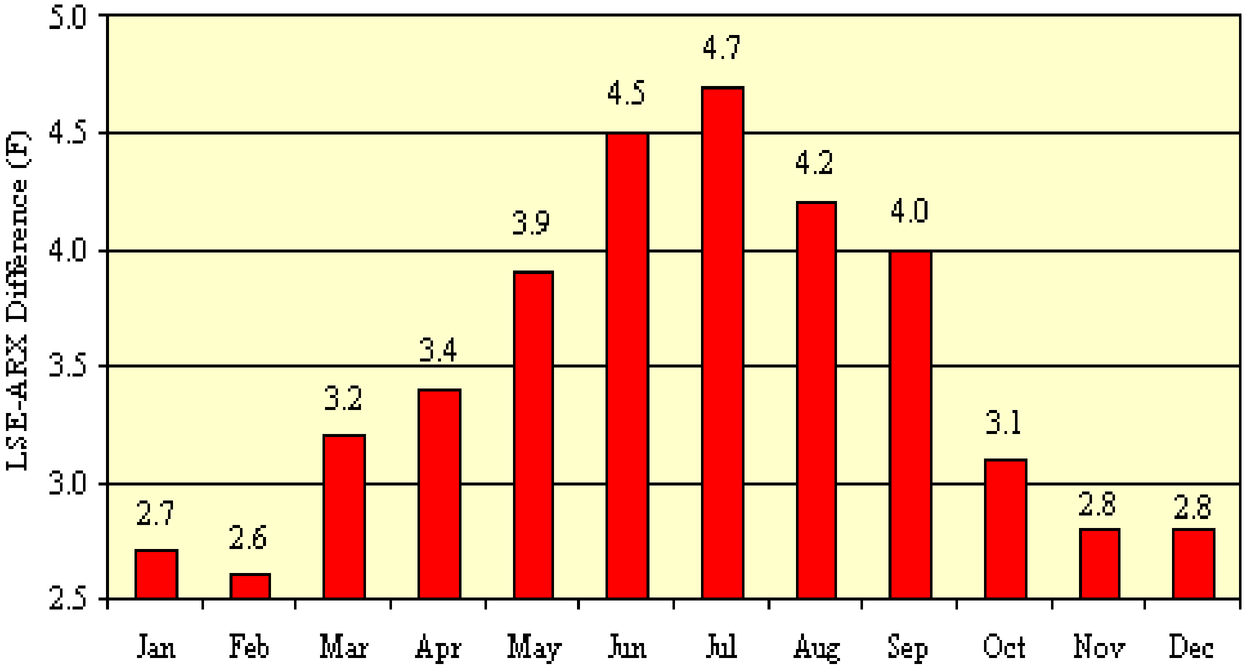


Fig. 3. Average monthly maximum temperature differences (LSE-ARX) between the two sites.

maximum temperature at LSE tended to be warmer than ARX on a high percentage of days (96.3%). There were only 53 days (1.5%) when LSE was colder than ARX and 82 days (2.2%) they had the same temperature. This resulted in a Pearson correlation coefficient of 0.998 which is better than any individual month (Fig. 4). This higher daily versus monthly correlation is a result of more days being better correlated during the decade than any individual month. A linear regression on this daily maximum temperature data set provided a covariance of 0.995

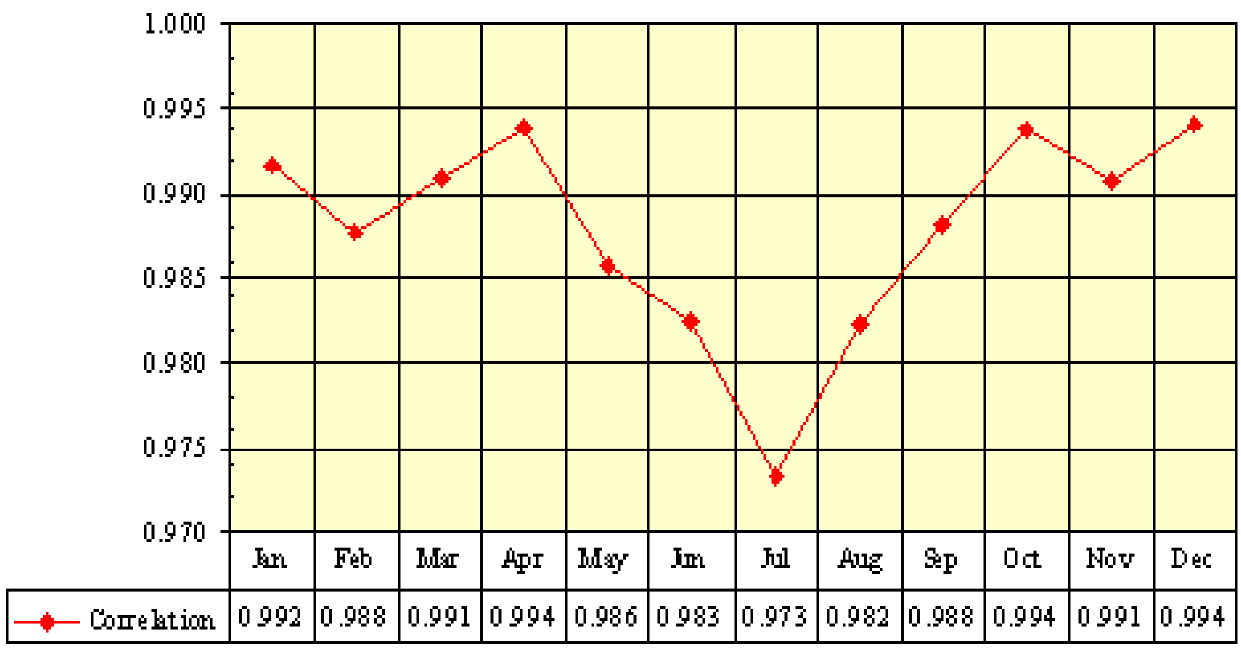


Fig. 4. The Pearson correlation coefficient for the daily maximum temperature data, by month, from LSE and ARX.

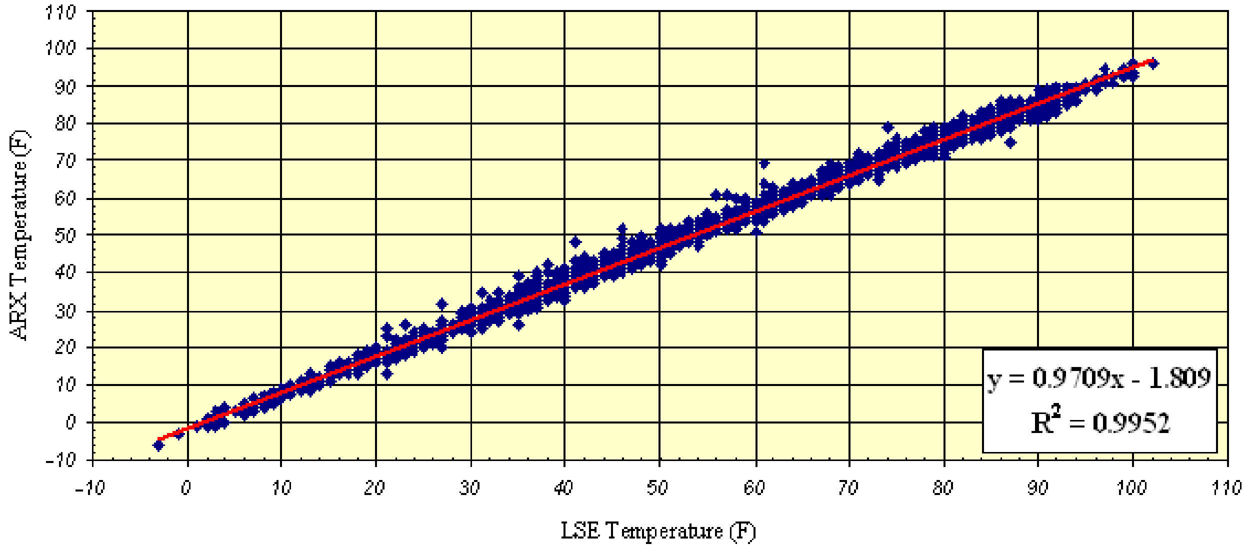
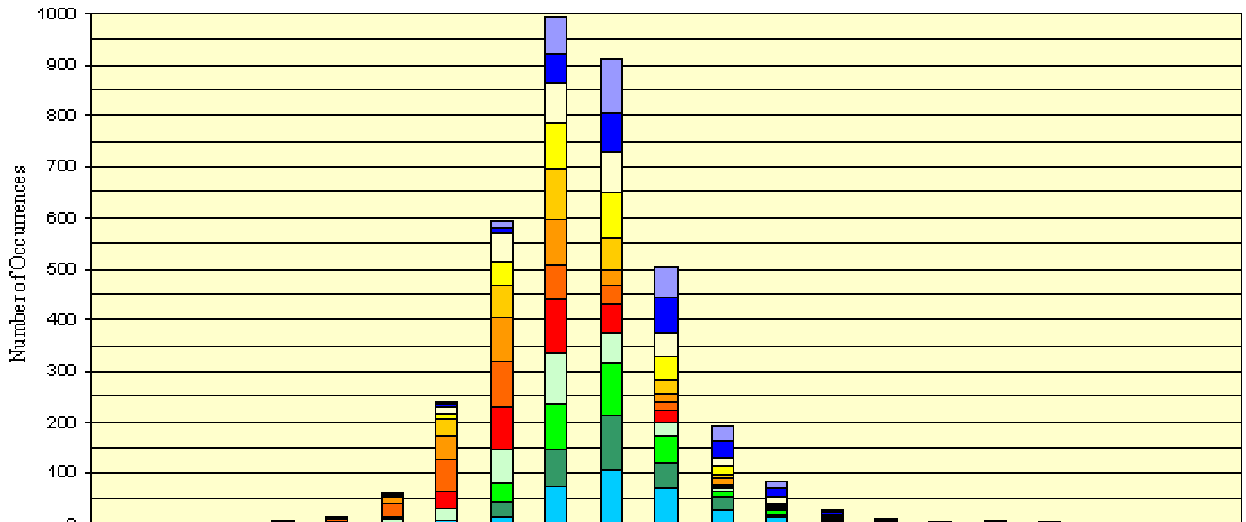


Fig. 5. Scatter plot of the LSE and ARX daily maximum temperature data with linear regression line (red). R^2 is the covariance value.



	12	11	10	9	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8
Jan	0	0	0	0	2	0	4	11	72	107	61	31	13	4	2	1	2	0	0	0	0
Feb	0	0	0	1	0	1	7	13	55	76	69	34	16	6	3	0	1	0	0	0	0
Mar	0	0	0	0	0	2	10	54	81	79	46	16	14	4	1	2	0	0	0	1	0
Apr	0	0	0	0	0	1	12	45	87	88	48	14	3	1	0	1	0	0	0	0	0
May	0	0	0	1	2	5	35	64	101	62	23	10	3	2	0	0	0	1	0	0	1
Jun	1	0	0	1	4	13	45	86	88	32	18	12	0	0	0	0	0	0	0	0	0
Jul	0	0	0	1	6	24	61	89	70	36	17	4	1	1	0	0	0	0	0	0	0
Aug	0	0	0	1	1	8	33	84	102	55	24	1	1	0	0	0	0	0	0	0	0
Sep	0	0	0	1	1	7	25	65	101	62	28	6	3	0	0	0	0	1	0	0	0
Oct	0	0	0	0	0	0	2	39	89	103	50	13	10	3	1	0	0	0	0	0	0
Nov	0	0	0	0	0	1	0	26	75	105	51	25	7	5	2	0	1	1	1	0	0
Dec	0	0	0	0	0	0	5	16	72	106	69	27	11	2	1	0	1	0	0	0	0

Fig. 6. The variability of daily maximum temperature differences between LSE and ARX by month with the mode (red highlighted values) of the differences for each month. Differences by month are summed in the bar graph. Positive (negative) differences (top row of data) indicate LSE's maximum temperature was warmer (colder) than ARX.

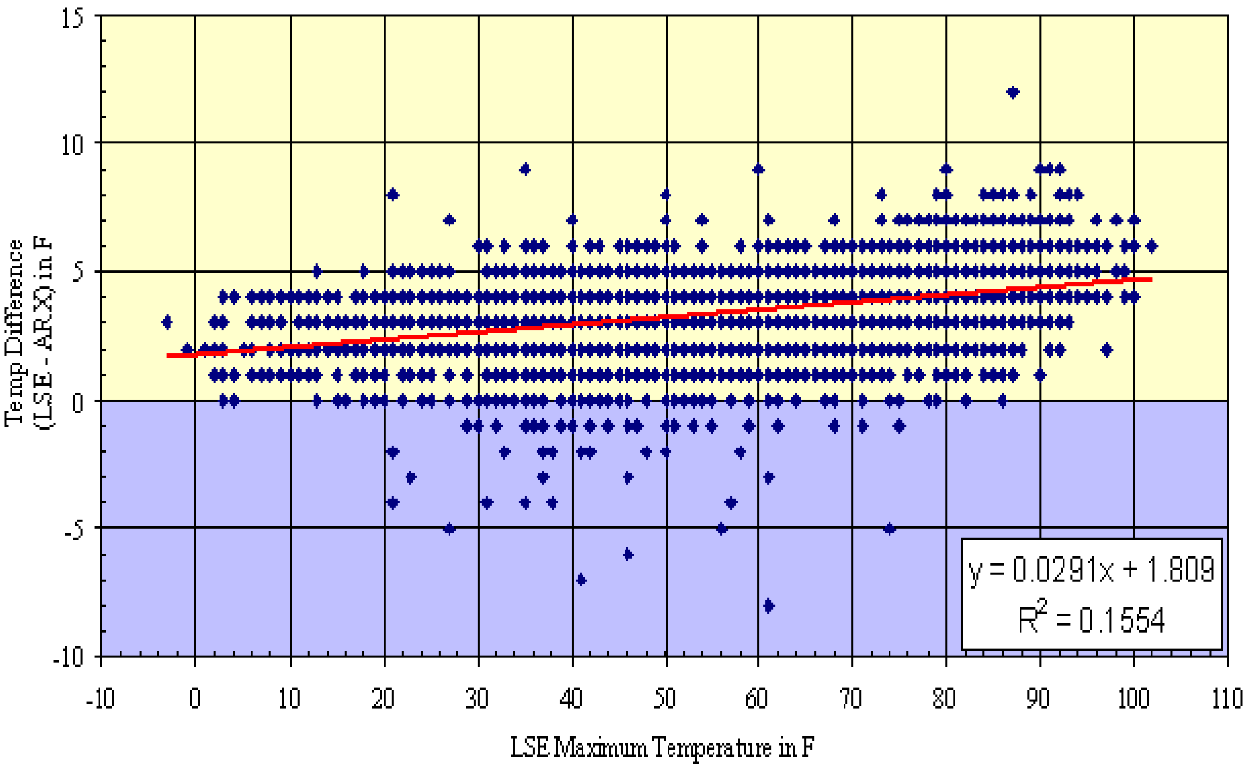


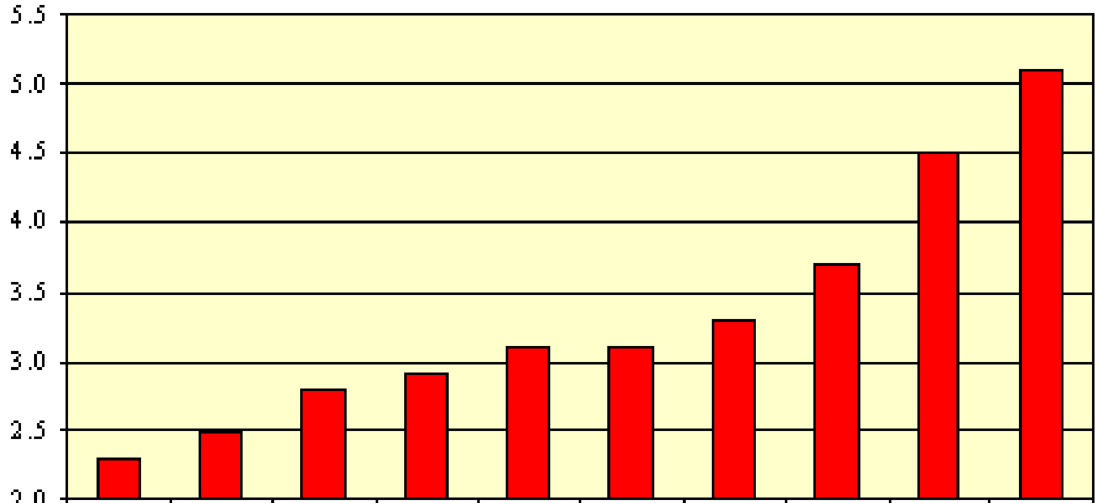
Fig. 7. A linear regression (indicated by the red line) of LSE maximum temperature compared to the temperature difference (LSE-ARX) between the two sites. R^2 is the covariance value.

(Fig. 5). This suggests that the two sites tend to differ strongly in the same direction (e.g., as LSE gets warmer, so does ARX and vice versa).

Looking at the magnitude of the maximum temperature difference between LSE and ARX, the data show a relatively uniform bell curve (Fig. 6). The curve was centered on LSE being 3.51°F (mean) warmer than ARX with the centered 50% of the population between 3.0°F and 5.0°F. Even though a direct comparison of the maximum temperatures at the two sites yielded a strong covariance (0.995), a much different result occurred when the LSE maximum temperature was compared with the temperature difference between the two sites. A linear regression of this data set only yielded a covariance of 0.1554 (Fig. 7). This suggests statistically that just over 15% of the difference between the two sites (LSE-ARX) can be predicted when LSE's maximum temperature is known. When the daily maximum temperatures are compared to specific temperature ranges, the average temperature differences (LSE-ARX) between the two sites increase as LSE maximum temperature increases (Fig. 8, a parallel trend to the slope seen in Fig. 7). In addition, it is not too surprising to see that the best Pearson correlation coefficients occur when LSE's temperature is below 20°F (Fig. 9), because the spread is 5°F or less (Fig. 7).

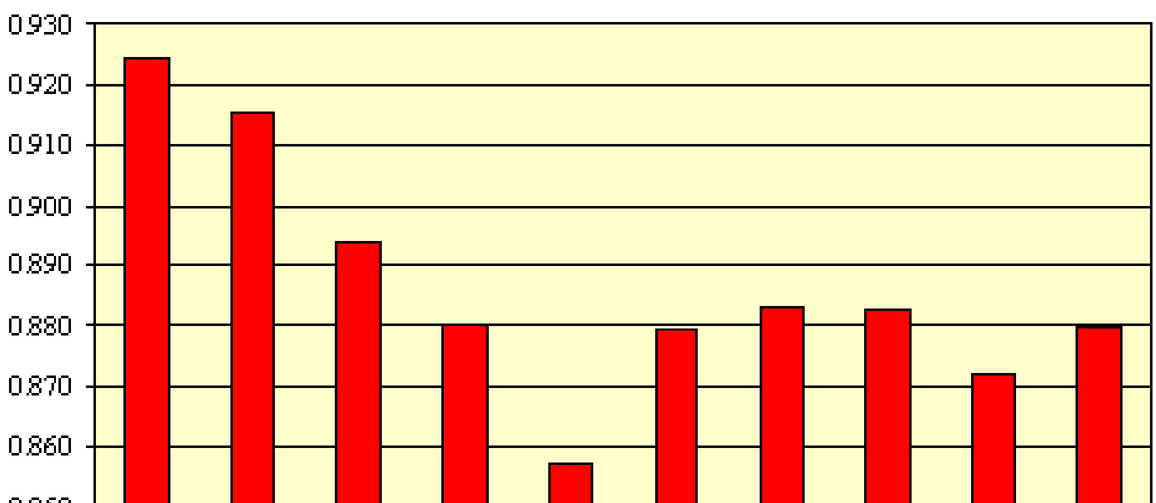
b. Minimum temperature behavior at ARX and LSE

Unlike the average maximum monthly temperatures, the average monthly minimum temperature at LSE was not always warmer than ARX. The only time of the year in which LSE had an average temperature warmer than ARX was from May through August (Fig. 10). During the remainder of the year, ARX had a warmer or identical temperature to LSE. Even



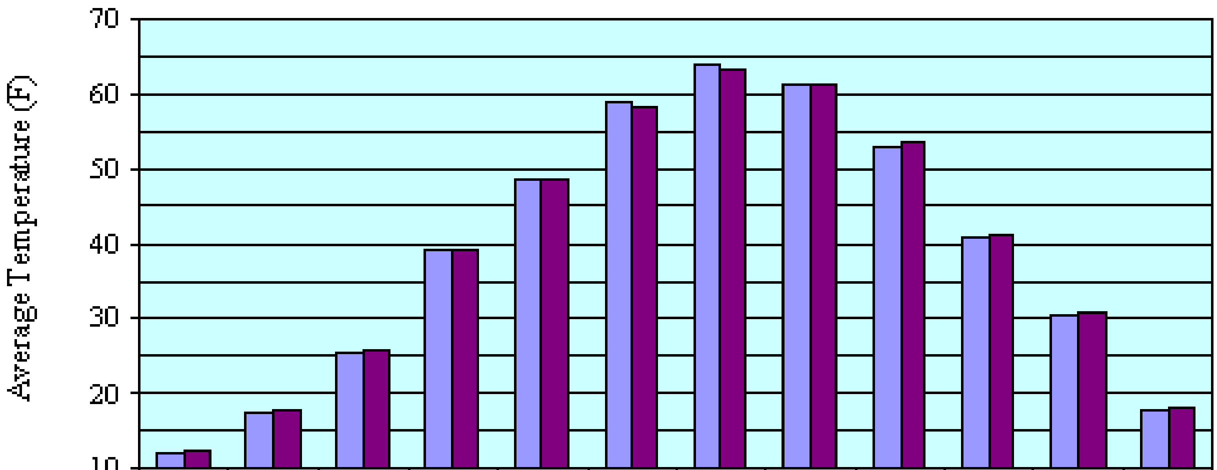
LSE Max Temp	< 10 F	10F to 19F	20F to 29F	30F to 39F	40F to 49F	50F to 59F	60F to 69F	70F to 79F	80F to 89F	90F +
Avg Max Diff	2.3	2.5	2.8	2.9	3.1	3.1	3.3	3.7	4.5	5.1

Fig. 8. Average temperature difference (LSE-ARX) of maximum temperatures compared to specific LSE maximum temperatures ranges.



LSE Max Temp	< 10 F	10F to 19F	20F to 29F	30F to 39F	40F to 49F	50F to 59F	60F to 69F	70F to 79F	80F to 89F	90F +
Correlation	0.924	0.916	0.894	0.881	0.857	0.879	0.883	0.883	0.872	0.880

Fig. 9. The Pearson correlation coefficients for LSE and ARX for various LSE maximum temperature ranges.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
LSE Min	12.0	17.2	25.5	39.2	48.7	58.9	64.2	61.2	53.1	40.8	30.4	17.7
ARX Min	12.3	17.6	25.6	39.2	48.5	58.3	63.6	61.0	53.5	41.3	30.5	17.8

Fig. 10. Average monthly minimum temperatures for LSE and ARX. The purple boxes indicate which site averaged colder temperatures for that particular month.

though these differences exist between the two sites, they were less than six-tenths of a degree throughout the year (Fig.11). LSE was six-tenths of a degree warmer than ARX in both June and July. Meanwhile in October, ARX was five-tenths of a degree warmer than LSE.

Correlation analysis on the minimum temperature data reveals a weaker relationship than maximum temperatures. This was especially true from April through August (Fig. 12) when the synoptic forcing is typically weaker allowing microclimates to have a stronger influence on temperatures. For the daily minimum temperatures throughout the ten-year period, LSE was warmer than ARX on 1,885 days (51.6%), LSE was colder than ARX on 1,400 days (38.4%),

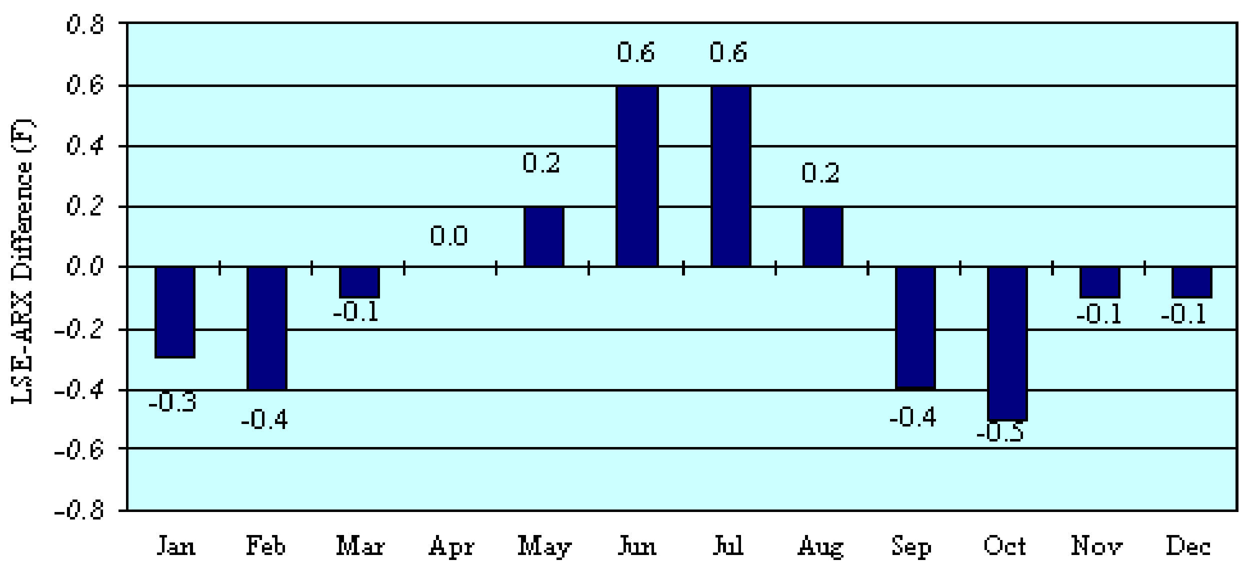


Fig. 11. Average monthly minimum temperature differences between the two sites (LSE-ARX) .

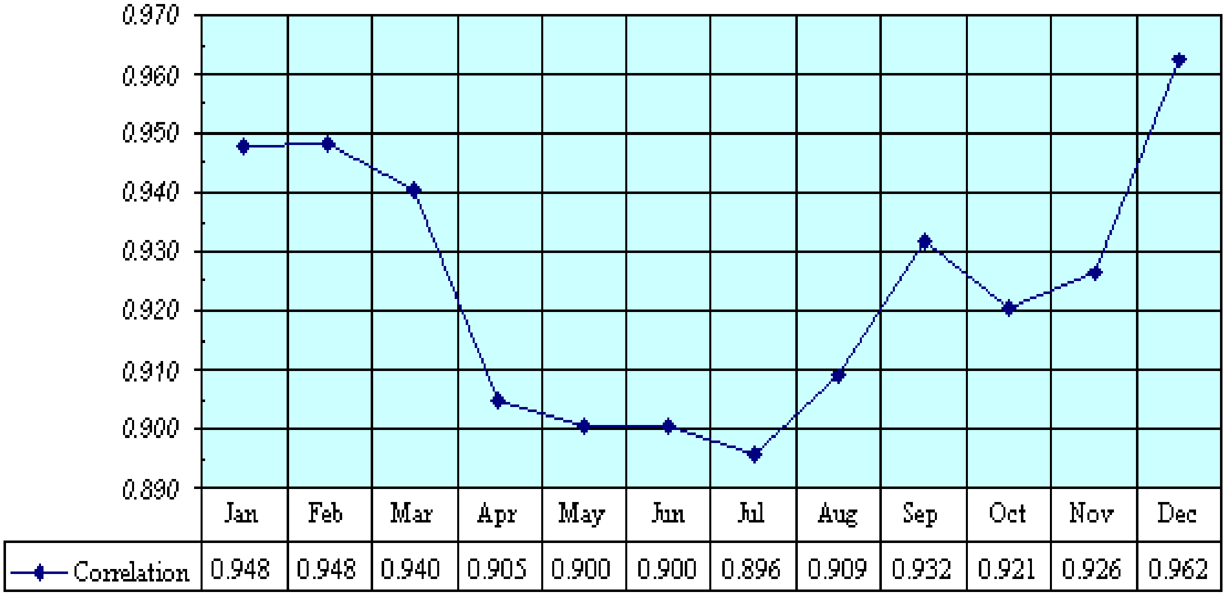


Fig. 12. The Pearson correlation coefficient for the daily minimum temperature data, by month, from LSE and ARX.

and the two sites had the same temperature on 367 days (10%). Even with the spread indicated in the data, the daily minimum temperature still had a high Pearson correlation coefficient of 0.984 and a covariance of 0.995 (Fig. 13). Like the maximum temperatures, this is simply a result of more days being better correlated during the decade than any individual month.

Unlike the symmetric bell curve that appeared in the maximum temperature data (recall Fig. 6), an asymmetric distribution was observed in the minimum temperature data. The most

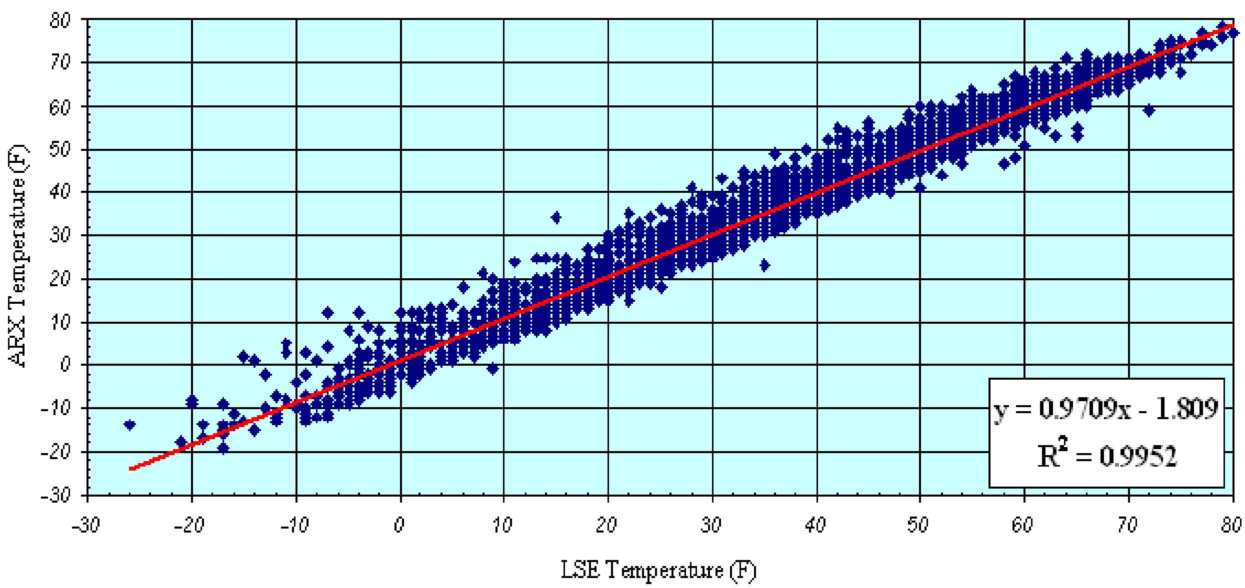
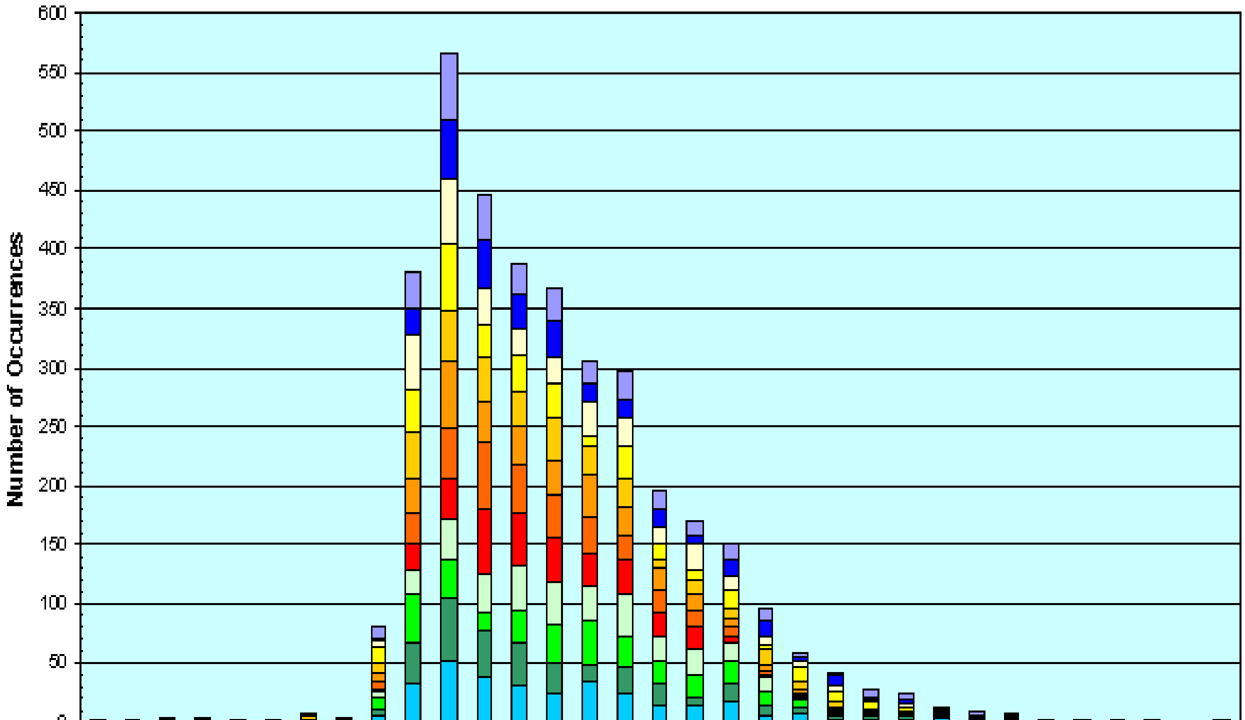


Fig. 13. Scatter plot of the LSE and ARX daily minimum temperature data with linear regression line (red). R^2 is the covariance value.

common minimum temperature difference (mode) between the two sites was 3 °F (LSE warmer than ARX, Fig. 14).

To further investigate the variability in daily minimum temperatures between the two sites, a comparison between the minimum temperature difference and the LSE minimum temperature was completed (Fig. 15). The scatter plot showed a wide spread in the relationship. As a result, it is not too surprising that the covariance on these data was a very poor 0.0287, suggesting statistically that the temperature difference between the two sites cannot be predicted when LSE's minimum temperature is known. When the difference between the two



	13	12	11	10	9	8	7	6	5	4	3	2	1	0	-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12	-13	-14	-15	-16	-17	-18	-19
Jan	0	0	0	0	0	0	0	0	12	32	55	38	26	28	20	23	16	10	14	11	2	1	7	5	1	4	2	1	0	1	0	0	1
Feb	0	0	0	1	0	0	2	0	1	23	51	41	29	30	15	17	15	9	14	12	3	9	1	3	2	2	1	0	0	1	0	0	0
Mar	0	0	0	0	0	0	0	0	5	45	53	33	23	23	28	23	15	21	11	8	7	6	2	3	1	0	2	0	0	0	0	0	1
Apr	0	0	0	0	0	0	0	0	13	37	57	26	30	30	10	27	12	9	15	4	11	7	6	4	2	0	0	0	0	0	0	0	0
May	0	0	1	0	0	1	3	1	9	39	44	38	30	34	24	24	8	12	10	13	8	6	2	2	1	0	0	0	0	0	0	0	0
Jun	0	1	1	2	1	0	1	0	6	28	57	34	31	30	35	24	18	13	7	5	3	0	2	0	0	0	1	0	0	0	0	0	0
Jul	1	0	0	0	0	0	1	1	8	27	42	56	41	35	31	20	19	15	7	3	2	1	0	0	0	0	0	0	0	0	0	0	0
Aug	0	0	0	0	0	0	0	0	2	23	35	56	47	39	28	30	20	19	7	2	1	1	0	0	0	0	0	0	0	0	0	0	0
Sep	0	0	1	0	1	0	0	0	4	20	34	31	36	36	30	35	21	21	14	12	2	2	0	0	0	0	0	0	0	0	0	0	0
Oct	0	0	0	0	0	0	0	0	10	42	33	17	28	32	36	27	18	19	19	11	6	4	3	2	2	0	1	0	0	0	0	0	0
Nov	0	0	0	0	0	0	0	0	7	32	52	39	35	27	14	23	19	7	16	11	6	3	3	3	0	2	1	0	0	0	0	0	0
Dec	0	1	0	0	0	0	0	1	4	34	52	38	32	23	35	23	15	14	17	4	7	1	1	2	3	1	0	0	1	0	1	0	0

Fig. 14. The variability of daily minimum temperature differences between LSE and ARX by month with the mode (purple highlighted values) of the differences for each month. Differences by month are summed in the bar graph. Positive (negative) differences (top row of data) indicate LSE's minimum temperature was warmer (colder) than ARX.

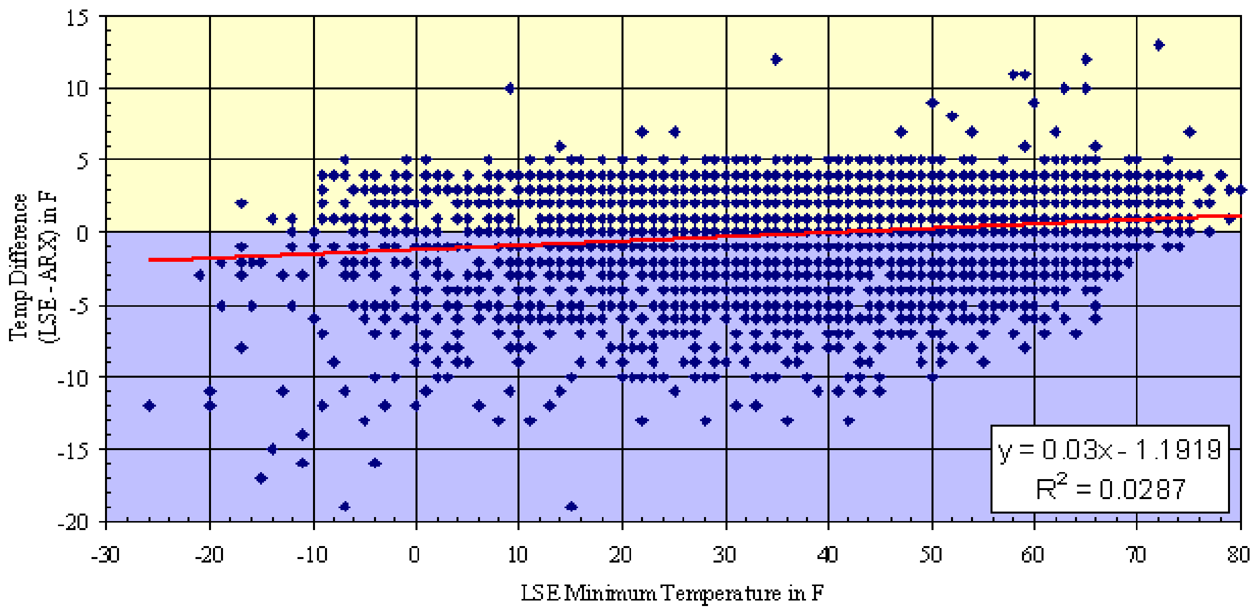
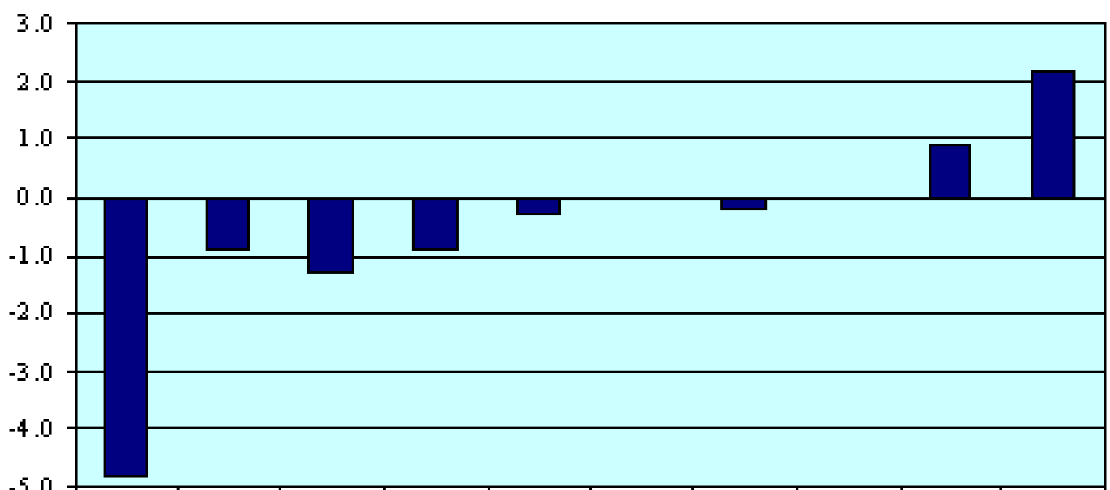


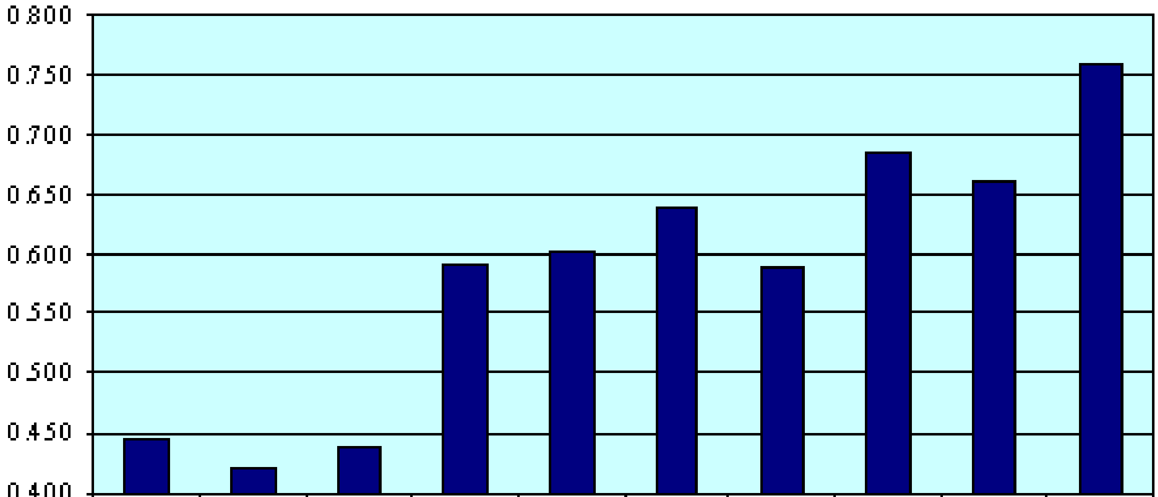
Fig. 15. A linear regression (indicated by the red line) of LSE minimum temperature compared to the temperature difference between the two sites (LSE-ARX). R^2 is the covariance value.

sites (LSE-ARX) is compared to specific temperature ranges at LSE, the average temperature differences (LSE-ARX) were generally less than a degree (Fig. 16). The two exceptions occurred at the opposite ends of the spectrum. When LSE was -10°F or colder, LSE averaged 4.8°F colder than ARX. This occurred on only 33 days and the spread ranged from -16°F to 1°F. On 26 of these 33 days, LSE was colder than ARX (78.8%), on 4 days (12.1%) LSE was warmer than ARX, and on 3 days (9.1%) they shared the same minimum temperature.



LSE Min Temp	-10F or less	-1F to -9F	0F to 9F	10F to 19F	20F to 29F	30F to 39F	40F to 49F	50F to 59F	60F to 69F	70F to 80F
■ Avg Min Diff	-4.8	-0.9	-1.3	-0.9	-0.3	0.0	-0.2	0.0	0.9	2.2

Fig. 16. Average temperature difference (LSE-ARX) of minimum temperatures compared to specific LSE minimum temperatures ranges.



LSE Min Temp	-10F or less	-1F to -9F	0F to 9F	10F to 19F	20F to 29F	30F to 39F	40F to 49F	50F to 59F	60F to 69F	70F to 80F
■ Correlation	0.444	0.421	0.437	0.590	0.601	0.639	0.590	0.686	0.661	0.758

Fig. 17. The Pearson correlation coefficients for LSE and ARX for various LSE minimum temperature ranges.

When LSE was 70°F or warmer, LSE averaged 2.2°F warmer than ARX and the spread ranged from 0°F to 9°F. This occurred on 113 days and with the exception of July 21, 2005, LSE was warmer than ARX. As a result, it is not too surprising that the best correlation (0.758, Fig. 17) occurred when LSE had a minimum temperature between 70°F and 80°F.

4. Conclusions

Even with the addition of temperature data on the ridge tops, understanding intricacies of the temperatures in the Coulee Region still shows some significant challenges. The results of the maximum temperatures show some small promise for adding detail to the graphical forecasts, but the minimum temperature results suggest no help in improving forecasts. Future studies may want to investigate the effect of the Mississippi River water temperature, dew point, and even cloud cover on the terrain induced temperature variation in the Coulee Region.

5. Acknowledgments

A special thanks to Glenn Lussky (MIC - NWS La Crosse) and Dan Baumgardt (SOO - NWS La Crosse) for their guidance in this project, and Randy Breeser (DAPM - NWS La Crosse) for his aid in designing the relief map (Fig. 1) in this paper. Finally, Robert E. Livezey (Chief of Climate Services Division at the Office of Climate, Water, and Weather Services/ NWS) for his aid in interpreting some of the statistical results.

6. References

Martin, L., 1965: *The Physical Geography of Wisconsin*. University of Wisconsin Press, 636 pp.