Climate Data Continuity with ASOS

Report for Period April 1996 through June 2000

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Climatology Report No. 00-3

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1. Introduction

The Automated Surface Observing System (ASOS) was introduced into the field by the National Weather Service (NWS) in the fall of 1992. The current study of Data Continuity began soon thereafter to evaluate temperature, humidity, precipitation and wind observations as instruments and the location of instruments were changed. All three instruments (hygrothermometer, heated-tipping bucket precipitation gage and anemometer) required modification to become acceptable for NWS field use. Temperature was improved quickly and became a stable and accurate instrument. Humidity has been continued but the NWS has plans to shift from the chilled mirror to a capacitance type observing system. The anemometer hardware was improved and discussions continue related to software. The precipitation gage was found unsuitable for frozen precipitation but was improved as a rain gage. Evaluations were made in Data Continuity studies for rain. Work is progressing in the NWS to develop an all season precipitation gage.

Results of temperature comparisons of ASOS and the predecessor HO-83 prior to the present report were made by McKee et al (1996), Schrump and McKee (1996) and McKee et al (1997a). A summary of the results included the following:

- ASOS is accurate to ± 0.3°F relative to a calibrated field standard instrument.
- The HO-83 (predecessor to ASOS) had a warm bias with respect to a calibrated field standard averaging +0.57°F and a range from near zero to more than 1.0°F.

- Local effects at night due to site relocation are quite variable, usually negative, with a few having ASOS minimum temperatures more than 1°F cooler than the previous location even though the location change was less than one mile horizontally and 100 feet vertically.
- Local effects in the daytime and solar heating in the maximum temperatures show that the HO-83 has another bias which is quite variable and is at least 1°F warm at some locations.

Results of the rain comparisons prior to the present report were given by McKee et al (1997b), Butler and McKee (1998), McKee et al (1998) and McKee et al (1999). Most of the comparisons involved observations between July 1996 and a variable end date of May to November 1997. Two types of comparisons were made. The first was a comparison of rain with ASOS and a co-located gage at four sites. The second was a comparison of ASOS with the Universal Rain Gage which were less than one mile apart at 13 sites. The ratio (ASOS/Co-located Gage) of accumulated precipitation at the four co-located sites was 0.93, 0.97, 1.02 and 1.02 for one minute ASOS observations. These results are encouraging. The ASOS gage is designed to be accurate to ± 4%. The ratio of accumulated rain at the 13 sites of ASOS to the Universal gage had an average of 0.97 with a range of 0.77 to 1.06. The gage with the 0.77 was deduced to be a faulty gage and the next smallest value was 0.87. This comparison with gages up to one mile apart seems quite reasonable.

The wind comparisons showed speed and direction to be quite similar. A comparison of gusts has been an issue. ASOS reports 5 sec gusts and a recommendation has been made for ASOS to change to 3 sec which is more in line with users interest and the predecessor F-420C peak gust records.

The goal of the present report is to summarize recent CDCP activities. We examine the possibility of forming climatological averages and estimating equivalent 30-year "normals" for ASOS sites for temperature. We assess the change in temperature with the introduction of ASOS. We compare precipitation for operational summary of the day observations. Wind comparisons are summarized. Finally, we describe some issues concerning snow data that have resulted from the introduction of ASOS.

Seven preprints to AMS Conferences for the period February 1997 to May 2000 and one publication from the Western Snow Conference 2000 proceedings are included as Appendix A as the major presentation of the results of these studies to the scientific community.

2. Temperature

Two questions were raised when ASOS was introduced, 1) What change occurred in the maximum and minimum, and 2) can a climatological average (or 30-year normal) be estimated for the ASOS observations? The questions are related since weather forecasts and verifications, climate monitoring, and applications all need to know how current observations relate to the past and how they deviate from an average state of climate.

The model we start with is to assume that we can use a reference site (usually a NWS coop site) with a longer and stable record to assist in answering the two questions.

The critical assumption is that the temperatures at the ASOS site and a given reference site differ by an additive bias. In particular, this model has the form

$$(T_a - b_a) - (T_c - b_c) = B \qquad \text{Eq. (1)}$$

where b_a and b_c are the instrument biases of the ASOS and reference site, respectively, and B is a measure of the climate difference between the two sites. The magnitude of B will usually vary with weather conditions (due to the ASOS-reference temperature difference $T_a - T_c$) and will be different for each reference station considered.

Initial work has focused on the ASOS site at Lambert Field in St. Louis, MO. The Lambert Field ASOS was commissioned in May of 1996. Reference sites were selected from the network of NWS Cooperative stations in the St. Louis area. To provide an initial confirmation/rejection of our model assumptions, the frequency distributions of the temperature difference between the ASOS and Coop stations during the ASOS era (1996-present) were analyzed. The method used to calculate temperature differences for daily maximum (T_{mx}) temperatures depended on whether or not the Coop site observations were made in the morning or evening. For AM reading Coop stations, the current day's maximum temperatures were differenced with the previous day's temperatures at Lambert Field. For PM sites, the current day's temperatures were differenced with the same day's temperatures at Lambert Field. Seasonal frequency distributions were generated for both T_{mx} and T_{mn}.

For a given ASOS/Coop site pair, the frequency distributions for the temperatures of the two sites in question are assumed to be normal with different means and standard deviations. We expect the distribution curve of the temperature ***difference*** between two sites to be centered at the bias (difference in the means), with little spread around this value. Figure 1 shows the frequency distribution for the ASOS at Lambert Field, St. Louis, a nearby Coop at St. Charles and the difference between them. The frequency distribution for the ASOS-Coop temperature difference should have a smaller standard deviation and fewer outliers than the individual temperature frequency distributions. The smallest variances were generally found for the summer and fall seasons, while the largest variances were found during the winter and spring seasons (Table 1). This indicates that the large air mass changes dominate seasons in which weather is more variable (e.g., winter, spring).

Figure 1 shows the winter maximum temperature difference with a mean of 0.9°F and standard deviation of 2.7°F. The distributions also indicates a tail to the distributions with occasional difference larger than 5°F. In the summer (Table 1) the standard deviation is 1.7°F. These indicate that the two locations are a different climate and the comparisons are different under different weather conditions – cloud, wind, precipitation. Larger differences appear in winter with cold air masses.

Table 1. Averages and standard deviations for the COOP – ASOS temperature difference frequency distributions of Jerseyville and St. Charles.

		T_{max}		T_{min}	
Station	**Season**	**Mean (°F)**	**St. Dev. (°F)**	**Mean (°F)**	**St. Dev (°F)**
Jerseyville	DJF	2.9	2.8	3.7	4.2
	MAM	2.1	3.0	3.1	4.2
	JJA	1.5	1.9	4.3	3.7
	SON	1.5	2.4	4.9	3.8
St. Charles	DJF	0.9	2.7	2.4	3.9
	MAM	0.8	2.6	2.5	3.7
	JJA	0.9	1.7	3.3	2.9
	SON	0.4	2.2	3.5	3.6

Coop sites from the St. Louis area were considered for further analysis only if there had been no significant instrument and/or location changes indicated at the site during the period (1996-1999). Cumulative sum plots of temperature differences over the 1990-1999 period (Figures 2, 3) were used to help identify any possible instrument and/or location changes. Such changes are often indicated by marked changes in slopes of the cumulative sum plots. Also, the site's data record should be relatively complete and stable (noise-free). From this procedure, the sites of Jerseyville 2SW, IL, and St. Charles, MO, were selected.

A trip to St. Louis, MO, was made on the week of April 10-14, 2000 in order to accomplish two main goals. The first goal was to visit Coop sites and note location characteristics (surrounding topography, proximity to buildings, etc.) to finalize selection. The second objective was to determine the instrument biases of both the Lambert ASOS site and selected Coop sites. Side-by-side measurements were taken at the ASOS and St. Charles Coop sites, using the RM Young temperature sensor (RMY) (Table 2). Time limitations precluded observations at Jerseyville. The Weldon Spring site was included since it will likely be used in future comparisons. For Coop sites, RMY measurements were compared with the on-site MMTS temperature sensor. The Coop measurements each consisted of approximately 20-minute blocks of observations. Readings were taken at the St. Charles site on the evening of April 11, while readings were taken at Weldon Spring on the morning and evening of April 12 and the morning of April 13.

Table 2. Results of temperature reading comparisons of RMY with ASOS and the St. Charles and Weldon Spring Coop sites, April 11-13, 2000. All times are Central Standard Time.

Location	Observation Date (Time)	Ref. Sensor	Sampling Interval	Reference – RMY (°F)
Lambert Field	4/11/00(1130) – 4/13/00(1250)	ASOS	5 min.	+0.04
St. Charles	4/11/00(1605-1625)	MMTS	60 sec.	-0.55
Weldon Spring	4/12/00(0737-0757)	MMTS	60 sec.	+0.33
Weldon Spring	4/13/00(1650-1710)	MMTS	60 sec.	-0.62
Weldon Spring	4/14/00(0812-0826)	MMTS	60 sec.	+0.20

The Lambert Field data indicated in Table 2 was actually a mix of 5 minute and hourly data. The average difference between the ASOS and RMY instruments was 0.04°F. The measurements were also broken down into daytime and nighttime readings. For the daytime readings, the calculated ASOS-RMY difference was –0.07°F, while the nighttime difference was + 0.13°F. These are within the ± 0.3°F reported by McKee et al (1996). Measurements at the St. Charles and Weldon Spring Coop sites indicated that the MMTS readings were generally within 0.6°F of the RM Young readings. These and the ASOS results both appear to be within the range of expectation for the observing systems.

The question of what was the effect of introducing ASOS has been addressed using the accumulated sums of Eq. 1 with b_a - b_c = 0 which is given by

$$\sum_{i=1}^{n}(T_a - T_b) = nB \qquad \text{Eq. (2)}$$

The graph of this relationship is shown in Fig. 2 and Fig. 3 for Lambert and St. Charles and Lambert and Jerseyville. When B is stable the graph shows a rather straight line and B is the slope of the line. Gaps in observational data appear as horizontal straight line segments as in Figure 2c in 1991. Such gaps were not included in the regression fits. Regression lines were fit to the pre-1996 and post-1996 portions of the curve. The pre-

1996 portion of the curve defines the bias between the coop site and the HO-83 which was the predecessor to ASOS. The post-1996 portion defines the relationship between the coop site and the ASOS. This analysis was also done for the average temperature given by

$$T_{avg} = \frac{T_{mx} + T_{mn}}{2} \qquad \text{Eq. (3)}$$

The estimate of climate average temperatures for some time period for ASOS is done using Eq. (1) to define B and then to apply the B to a longer period using the Eq. (1) in another form of

$$\overline{T}_a = \overline{T}_c + B \qquad \text{Eq. (3)}$$

where $\overline{T}_a$ and $\overline{T}_c$ are climate average temperatures for some specified period. In this case of a demonstration we used a three-year period in which the ASOS was present and a 10-year period of 1990-1999. This approach essentially assumes that the value of B does not change over the period of the climate average.

3. Temperature discussion

The results of the calculated biases for pre and post-ASOS periods at St. Charles and Jerseyville are given in Tables 3, 4 and 5. Values in these tables are the result of a least squares fit to the accumulated sums. Consequently, they are not identical to values in Table 1. Columns with 1990-1996 and 1996-1999 are the pre and post-ASOS biases and the column with ASOS at the top is the difference post-pre ASOS. For example, from Table 3 the change at Jerseyville in the winter season (DJF) from pre-ASOS to post-ASOS was –0.9°F showing that the ASOS temperatures were cooler than the HO-83 temperatures. In fact all of the values on Tables 3, 4 and 5 are negative showing ASOS is cooler. The magnitude of the change with ASOS differs for T_{mx}, T_{mn} and T_{avg} and for seasons. The largest are in winter and spring in the T_{mn} values.

Table 3. Temperature difference from Lambert Field (HO-83 and ASOS) to nearby Coop sites for T_{MX} for Pre-ASOS (1990-1996; HO-83 - Coop), ASOS change (1996), and ASOS-era (1996-1999; ASOS – Coop).

Station	Season	1990-1996 (°F)	1996-1999 (°F)	ASOS Change (°F)
Jerseyville	DJF	3.5	2.6	-0.9
	MAM	3.2	1.9	-1.3
	JJA	2.3	1.2	-1.1
	SON	2.2	1.6	-0.6
St. Charles	DJF	1.8	1.0	-0.8
	MAM	1.5	0.7	-0.8
	JJA	2.4	1.0	-1.4
	SON	1.5	0.5	-1.0

Table 4. Same as Table 3, except for T_{mn}.

Station	Season	1990-1996 (°F)	1996-1999 (°F)	ASOS change (°F)
Jerseyville	DJF	6.6	3.4	-3.2
	MAM	5.7	3.1	-2.6
	JJA	5.6	4.3	-1.3
	SON	6.7	5.1	-1.6
St. Charles	DJF	4.5	2.4	-2.1
	MAM	4.7	2.5	-2.2
	JJA	4.9	3.3	-1.6
	SON	5.5	3.6	-1.9

Table 5. Same as Table 3, except for T_{avg}.

Station	Season	1990-1996 (°F)	1996-1999 (°F)	ASOS change (°F)
Jerseyville	DJF	5.1	3.1	-1.9
	MAM	4.4	2.5	-1.9
	JJA	3.9	2.9	-1.0
	SON	4.5	3.4	-1.1
St. Charles	DJF	2.8	1.7	-1.1
	MAM	3.1	1.6	-1.5
	JJA	3.6	2.1	-1.5
	SON	3.5	2.0	-1.4

Table 6. Seasonal T_{mx} (°F) ASOS derived (1990-1999) and actual (1996-1999) averages. Official 1961-1990 climate normals are also included.

Season	DJF	MAM	JJA	SON
Derived ASOS (1990-1999)				
Jerseyville	43.2	64.9	86.3	67.8
St. Charles	43.3	65.0	86.4	67.8
Actual ASOS (1996-1999)	43.7	64.9	86.1	68.5
Climate normal (1961-1990)	40.7	65.9	87.3	67.7

Table 7. Same as Table 6, except for T_{mn} (°F).

Season	DJF	MAM	JJA	SON
Derived ASOS (1990-1999)				
Jerseyville	26.7	45.3	68.2	48.8
St. Charles	26.8	45.2	67.9	48.3
Actual ASOS (1996-1999)	28.3	45.7	68.2	49.4
Climate normal (1961-1990)	23.4	46.0	68.0	48.8

Table 8. Same as Table 6, except for T_{avg} (°F)

Season	DJF	MAM	JJA	SON
Derived ASOS (1990-1999)				
Jerseyville	35.0	55.1	77.4	58.3
St. Charles	35.1	55.1	77.1	58.1
Actual ASOS (1996-1999)	36.0	55.0	77.1	59.2
Climate normal (1961-1990)	32.3	55.9	77.6	58.3

The differences in B that are of special interest are the difference in Jerseyville and St. Charles in the same season. For example in DJF in 1990-1996 in T_{MN} Jerseyville is 6.6°F cooler than the HO-83 at Lambert Field while St. Charles is 4.5°F cooler than the HO-83. In 1996-1999 the respective values compared to ASOS are 3.4°F and 2.4°F. The fact that the difference between the HO-83 and two Coop sites was 6.6°F and 4.5°F is a reflection that the two Coop sites do not have the same climate. This is to be expected. When ASOS is used as the common reference the values changed to 3.4°F and 2.4°F.

The first conclusion is that the change from the HO-83 to the ASOS has lead to cooler temperatures for ASOS. This change could be due to a change in the instrument and a change in the location of the instrument. The question of what was the effect of the introduction of ASOS does not appear to have a simple answer. The observations using Jerseyville would indicate a change pre and post ASOS to be 6.6°F to 3.4°F or a cooling of 3.2°F. For St. Charles the observations show a change of 4.5°F to 2.4°F or a cooling of 2.1°F. Two scenarios would account for the difference of 3.2°F and 2.1°F. The first is that a different set of weather conditions occurred in the 1990-1996 period compared to the 1996-1999 period. The second is that the move of the ASOS to a new location resulted in a different climate location and the differences should not be expected to be the same. This second scenario, which is quite likely, would mean that it is not possible to determine a single number as a bias to adjust the historic climate record at Lambert Field to be in agreement with the ASOS climate record after June 1996. Two details of the impact of ASOS at Lambert Field are shown in Tables 3 and 4. The change in temperature from pre-ASOS to post-ASOS installation shows larger cooling relative to Jerseyville in winter and spring but larger cooling relative to St. Charles in summer and fall. Also, the cooling is larger in minimum than in maximum temperatures. This means the impact could be different in energy applications for winter nights than for summer days.

The estimate of climate values of temperature over 3 and 10-year periods of time for ASOS using Eq. 3 are presented in Tables 6, 7 and 8. The climate normals for 1961-1990 are also given as reference values. Notice that the climate estimates are much more similar to each other than the values of the *B*'s given in Table 3, 4 and 5. This implies that the biases, which are different for each site, may change in time and they may change in a similar way. If this is true, then it is more feasible to estimate the climate average for ASOS over some time period then to actually make an accurate time series from the Lambert Field site combing historical data with the ASOS data. The key is whether or not the B's remain similar over time.

The temperature difference of Lambert Field minus St. Charles is given in Figure 4 for winter and Figure 5 for summer. The one-year average is simply the 90 or so data points for the season for the year. Longer averages are plotted at the ending year of the average. In winter the temperature differences for the maximum and minimum temperatures have varied 4 to 5°F during the period 1950 to 1999. This means the B's of Eq. 1 do not remain the same for long periods of time. Variations in the B's could be due to changes in weather conditions, instruments, observation times, location of sensor, or the local environment. For this example the changes are significant and they are reflected through all averaging times for 1 to 30 years. The result is that the estimate of ASOS temperatures for the past 10 years seems reasonable but little confidence would be placed on estimates of 20 to 30 years. The climate normals given in Tables 6, 7 and 8 are quite different from ASOS in winter because of larger variation in the relationships shown in Figure 4. The lack of stability in the differences in Fig. 4 and 5 really limits the accuracy of any attempt to make a simple estimate of the impact of ASOS on climate records and to estimate normals for the ASOS site at Lambert Field. It is certainly possible that much of the differences could be explained with appropriate information from station metadata. The primary concern would be with observation times.

4. Precipitation

A comparison of the ASOS operational daily rain amounts has been made with the Universal Gage at 38 locations during 1996, 1997 and 1998. Results were reported by McKee et al. (2000a and b) which are attached in Appendix A. These results show that the ASOS rain observations are quite reasonable. The one concern is that some fraction of the gages may not perform well. A total of 10 sites include some data where the ASOS observations are edited to be the Universal values. Some of these sites could have an ASOS that performs poorly. A recommendation is for all NWS offices to have a Standard Rain Gage (SRG) that can be used to verify ASOS reports on occasion to be certain the ASOS is performing well. The SRG could be placed at an office if the distance is a mile or less or at the ASOS location if the distance from the office is much more than one mile. There are occasions in which good gages have problems due to insects or objects in the gage. If an ASOS gage is found to be out of specification, it could be replaced.

Four of the locations with three years of comparative observations are in warm climates with small chance of frozen precipitation. These four locations (GSP, ILM, JAX, LCH) were used to analyze daily observations throughout each of the three years 1996, 1997 and 1998. A scatter diagram for each year and the accumulated ratio of ASOS to Universal precipitation is shown in Fig. 6 for each location. GSP observations are very stable and well behaved. The annual ASOS to Universal ratios are 0.95, 0.95 and 0.94 with about 110 inches of accumulated rainfall. In contrast the ILM observations are more variable and the three-year ratios of ASOS to Universal are 0.95, 0.91, and 0.87. This decrease does raise a concern about the continuing quality of the observations. This is an example of a location in which a SRG could be used to confirm the ASOS observations.

5. Wind

A summary of the work on the wind observations is included in Appendix B. Five papers were presented at scientific meetings during the period January 1998 through December 1999.

An analysis of 12 stations with one year of hourly observations reported by Lockhart (2000) showed an average different (ASOS – CONV) of –0.4 kts with a range from –1.3 kts to 0.3 kts. A regression analysis showed at all 12 sites that ASOS reported lower speeds at low speed, and reported higher speeds than the CONV at higher speeds. An analysis of calms reported for 18 sites showed that ASOS reported nearly twice the number of calms at most sites. For wind direction the analysis of 18 sites showed a mean difference of 2 degrees with a standard deviation of 22 degrees.

6. Continuity of Snowfall Measurements

The deployment of ASOS in the 1990s had a direct and immediate effect on the collection of snow data in the U.S. ASOS was developed to meet requirements for aviation weather observations specified by the Federal Aviation Administration. The measurement of snowfall was not a requirement. The new system did not measure snowfall or total depth on the ground without human augmentation. Since the ASOS tipping bucket precipitation gage tended to seriously under measure the water content, this meant that winter precipitation measurements were seriously compromised at hundreds of ASOS sites across the country.

Snowfall may not have been an FAA requirement, but it was a public expectation. Many cities in the U.S. had snowfall records dating back to the late 1800s that were no longer being maintained. The winter of 1995-96 brought this situation to the attention of the public as record snows fell across much of the Mid Atlantic and New England region.

During 1996, the National Weather Service Office of Meteorology took action to alleviate some of the developing problems. A plan was formulated to make use of the NWS Cooperative Program (primarily volunteer weather observers from practically every county in the country) and special snow spotters to supplement ASOS and attempt to offset some of the snow measurement deficiencies associated with the system. Near real-time communication of daily observations was increased so that the reports from many of the nation's cooperative stations reached NWS offices quickly. Webpages were created displaying daily snowfall and snowdepth data all over the country. Procedures were tested whereby snowfall observations from locations near airport weather stations could be incorporated into the archived climatological records (Local Climatological Data, LCD, summaries) for these stations. Many of the larger airports ended up requiring contract observers to be in place "on site" to provide backup and augmentation to ASOS to assure continuous and complete data collection. This provided the opportunity for maintaining some of the original snow and water content measurements.

A special workshop of snow measurement experts was held in Boulder, Colorado in September 1996. The outcome of this meeting was a new set of snow measurement guidelines (NWS, 1996) that were very promptly accepted and distributed to weather observers nationwide. For the first time since procedures for aviation weather observations were developed years before, a concerted effort was made to bring consistency to snowfall observation and reporting procedures for all NWS weather stations including both cooperative and airways stations.

For the most part, this move toward consistency was enthusiastically embraced. However, it raised an important question regarding the measurement of snow. The guidelines stated "This measurement should be taken minimally once-a-day (but can be taken up to four times a day) . . . . Never sum more than four 6-hourly observations to determine your 24-hour total." Since snow melts, settles and is redistributed by wind, is their any single measurement frequency (hourly, four times per day, once daily, etc.) that is better than others, and do all stations need to employ the same frequency of measurement (or time interval between measurements) in order to document snowfall accumulation consistently? The new guidelines took a practical approach allowing cooperative stations, airport weather stations, and special snow spotter networks to all come under the same measurement guidelines. But in function what it means is that some stations may measure snowfall once daily at a particular time of day. Others could be measuring daily at four times per day at six-hour intervals. Any combination of up to four measurements per day at intervals no closer together then six hours would also be acceptable under the new measurement guidelines.

Inconsistent measurement frequencies are not new (Doesken and Judson, 1996). For many years, some airport weather stations have been measuring snowfall, along with the defined airways measurement of increases in snowdepth (traditionally the "SNOINCR" remark found in aviation weather observations), ***at hourly intervals*** during periods of falling snow. Other airport weather stations were only measuring actual snowfall at ***six-hour increments***. Most cooperative observers have been measuring just ***once daily***, although some could very well have been measuring more often. Some observers only measure at a scheduled observation time each day while others measure as soon as snowfall has diminished.

Is there a difference? Does it matter? Common sense tells us that, unlike rain, the more often we measure snow the more snowfall we measure. However, no research could be found that quantified this relationship. This issue was faced head on in January 1997 when a remarkably heavy snow in the Great Lakes snowbelt appeared to set a new national 24-hour snowfall record in upstate New York. The reported daily snowfall total of 77 inches, measured by a careful and skillful volunteer, was the sum of six separate measurements during the day, some of which were taken at short intervals less than six hours apart. Based on the new measurement guidelines, this observation was not accepted as a new national snowfall record (NOAA 1997).

This experience pointed out the need to better understand the question of how much effect measurement frequency and time interval between snowfall measurements actually has. Volunteer weather observers cannot be required to take observations exactly every six hours. Likewise, those remaining weather stations that are still fully staffed would seem ill advised to only go out and measure snow once per day. Is there a solution to this dilemma, or must data users simple come to understand that the measurement of snowfall is only an approximation that may not be comparable from one station to the next?

6.1 Data Collection. Beginning in the fall of 1997, weather observers from several parts of the country were identified to help with the study. The goal was to collect coincident data on accumulated snowfall using measurement intervals of one hour, three hours, six hours, twelve hours and once-daily and compare the results. Steve McLaughlin of the Buffalo, NY NWS Forecast Office and John Quinlan from the National Weather Service Albany, NY WFO each had strong interests in this project and already had there own volunteer networks in place. In addition, individual volunteers were identified in Colorado, Ohio, North Carolina, Maryland and New Jersey. A total of nearly 30 volunteers were identified to help with this study.

Based on the availability of volunteer observers, storms from December 1997 through March 1998 were targeted. Unfortunately, there were hardly any snowstorms that winter in the Northeastern U.S. where most volunteers were located. Therefore, the project was extended for a second season for the 1998-1999 winter. Additional volunteers were recruited in the Virginia- Maryland area with the help of the Sterling, VA WFO. Snowfall was again light, but a number of small and large events were sampled. A few more storms were sampled during the winter of 1999-2000.

Most volunteers provided their own equipment (precipitation gage and snow boards). Equipment was not fully standardized. The size and appearance of snowboards used in this study were not confirmed. However, observers all shared a passion for snow and a desire to be of service. Observers set up several snowboards (interval boards). During snow events, snow was measured and then cleared from each respective snowboard at each respective interval.

Despite the large number of enthusiastic volunteers, only 64 independent sets of comparative data were collected. There were reasons for this small sample size. First, there just weren't that many storms during this period of study, as the U.S. experienced some very mild winter weather following the 1997 El Nino. Second, many potential storm events included periods of rain, ice pellets or freezing rain which interfered with comparisons. Finally, it is very difficult for individual volunteers working alone to take measurements every hour or even every six hours for a sustained period of time. Work schedules, family and the need to sleep simply did not allow them to take measurements from beginning to end in most storms.

Of the 64 interval comparisons that were gathered over the two winters of the study, only a handful included complete beginning to end comparisons for each of the five measurement intervals (hourly, three-hour, six-hour, twelve hour and once daily). Figures 7a-c show examples of snowfall accumulations from selected storms where most intervals were measured. In each case, snowfall accumulations increased as the inteval between measuring and clearing the snowboards decreased.

6.2 Analysis and Results. Individual cases were compiled into composite statistics. Snowfall for each measurement interval was summed to produce storm totals and compared. Many reports were incomplete so that not all potential observation intervals could be compared during every snow event. For example, an observer may have taken hourly readings for six hours and measured snow accumulation for the six-hour period on a separate snowboard. However, that observer may have omitted the 3-hour interval reading and may not have been available for the 12 or 24-hour readings.

All complete samples were summed and compared. Table 9 summarizes the results. Based on 28 independent samples of snowfall measurements taken every six hours and a matched set taken at the end of 24 hours, 6-hour samples summed to 164.4 inches as compared to 24-hour measurements which summed to 138.4 inches. For this data set, which included measurements from several parts of the country, the sum of measurements taken at six-hour intervals exceeded the total from once-daily measurements by 19%. The six-hourly measurements typify traditional airways observations, while once-daily readings are typical for NWS cooperative stations. This suggests that airport weather stations, which have employed 6-hour observations of snowfall, may have a historic bias toward higher observed snowfall totals compared to nearby cooperative stations.

Table 9. Comparison of accumulated snowfall totals for specified measurement intervals for 64 snow events. This is a composite of all observations for all participating stations. Only periods with matching coincident measurements are included. The number of events in each comparison category is less than 64 since not all intervals were compared for each storm.

Snow Measurement Intervals Compared	Number of Snow Events	Accumulated Snowfall (Inches)	
6 Hours to 1 Hour	45	6: 284.6	1: 327.9
6 Hours to 3 Hours	9	6: 42.2	3: 49.5
6 Hours to 12 Hours	16	6: 118.5	12: 108.6
6 Hours to 24 Hours	28	6: 164.4	24: 138.4
1 Hour to 12 Hours	15	1: 131.2	12: 106.3
1 Hour to 24 Hours	17	1: 118.6	24: 91.2
12 Hours to 24 Hours	7	12: 42.2	24: 37.6

There were 45 sets of hourly data summed to six-hour totals compared to independent measurements of snow accumulation cleared from the snowboard every six hours. Total snowfall from hourly increments summed to 327.9" compared to 284.6 inches for the measurements at the end of each 6-hour period. This difference of 43.3 inches (15%) showed that frequent measurement again increased apparent observed snowfall totals.

There were only 17 complete samples where snowfall totals measured every hour were summed and compared to once-daily readings. For these storms, the sum of hourly measurements exceeded the values from once-daily snowboard measurements by 30%. Hourly measurement intervals for snowfall accumulation have never been encouraged, but some NWS stations have taken that approach to measurement for many years.

6.3 Discussion and Conclusion. The observation frequency does make a difference. As common sense tells us, the more often we measure snowfall and clear it from our measurement surface, the more snowfall we measure. Based on a relatively small set of data, 19% more snowfall was reported with a six-hour measurement interval than if the measurements were only taken once every 24 hours. When observations were taken at hourly intervals, 15% more snow was reported than when measurements were taken every six hours. Comparing hourly to once-daily measurements (for a different set of days), hourly observations yielded 30% more reported snowfall than once-daily readings.

The results showed general consistency from storm to storm and from one region of the country to another. However, considerable variations were noted. Many factors contribute to variations such as temperature, time of day, age of snow, wind conditions, snow density and crystal type. This study did not address these factors. It is possible that with more data we will be able to refine the relationships between measurement interval and snow accumulation. With continued interest from several WFO's we hope to continue this study informally to address this issue.

The results suggest that because of the dynamic nature of snow, it would be best if all snow measurement stations used the same frequency for observations. Realizing that with a network composed of both volunteers and professional, it may not be practical or even possible for all snow observations to be taken at the same time and with the same frequency, is there any way to reduce the observed differences? Differences between 6-hourly and once daily observations could be minimized if cooperative observers measured snowfall as soon as snow diminished instead of waiting until the scheduled time of observation.

Some would argue that the measurement of snowfall will always be imprecise and that differences of 15-30% are tolerable provided that the measurement of water content (a problem in its own right) is taken more accurately. Automated measurements of total depth of snow on the ground may be practical in the near future at ASOS sites. Should we even bother to measure snowfall? It is a fair question. However, with more than 100 years of snowfall records for hundreds of locations across the country, with a population fascinated by snow and crippled by its impacts, and with the National Weather Service forecasting and verifying snowfall amounts, snow measurements will remain useful and important.

7. Conclusions

The analysis of ASOS temperature observations compared with NWS coop site leads to two preliminary conclusions. One conclusion is that the determination of a single bias adjustment value for each season cannot be done with great accuracy. If the need is for an estimate within 0.5 – 1.0°F, then it probably can be met. A second preliminary conclusion is that estimates of ASOS climatic averages for periods on the order of 10 years appear quite good but are dependent on the identified biases remaining rather stable over time.

For rainfall the ASOS rain gage appears to work quite well for daily precipitation. The concern is that some fraction of the gage may not perform well and they should be checked.

Evaluations of snow observations indicate that the frequency of observations impact observed snowfall totals significantly.

ASOS observed wind speed and direction are acceptable with mean speeds differently less than 1 kt and direction by 2 degrees. ASOS does report more calms than the predecessor F420C.

References

Butler, R.D., and T.B. McKee, 1998: ASOS heated tipping bucket performance assessment and impact on precipitation climate continuity. Climatology Report 98-2, Atmospheric Science Paper No. 655, Department of Atmospheric Science, Colorado State University, Fort Collins, CO, June, 83 pp.

Doesken, N.J., and A. Judson, 1996: The Snow Booklet. *A Guide to the Science, Climatology and Measurement of Snow in the United States*. Atmospheric Science Department, Colorado State University, Fort Collins, CO, June, 84 pp.

Doesken, N.J., and T.B. McKee, 2000: Life after ASOS (Automated Surface Observing System) – progress in National Weather Service snow measurement. Proceedings, 68th Annual Western Snow Conference, April 18-20, Port Angeles, Washington.

Lockhart, T.J., 2000: A summary of wind climate continuity with ASOS. 12th AMS Conference on Applied Climatology. 8-11 May, Asheville, NC, 131-133.

McKee, T.B., N.J. Doesken, and J. Kleist, 1996: Climate data continuity with ASOS (Report for the period September 1994 – March 1996). Climatology Report No. 96-1, Colorado Climate Center, Atmospheric Science Department, Colorado State University, Fort Collins, CO, March, 117 pp.

McKee, T.B, N.J. Doesken, J. Kleist, and N.L. Canfield, 1997a: Climate data continuity with ASOS – Temperature. 13th AMS International Conference on IIPS for Meteorology, Oceanography and Hydrology, 2-7 February, Long Beach, CA, pp. 70-73.

McKee, T.B., N.J. Doesken, J. Kleist, R. Butler, and N.L. Canfield, 1997b: A comparison of precipitation measurements with the ASOS heated tipping bucket rain gage and the universal rain gage. 10th AMS Conference on Applied Climatology, 20-24 October, Reno, NV, pp. 161-162.

McKee, T.B., N.J. Doesken, J. Kleist, R. Butler, and N.L. Canfield, 1998: Climate data continuity of rain observations with ASOS. 14th AMS International Conference on IIPS for Meteorology, Oceanography and Hydrology, 11-16 January, Phoenix, AZ, pp. 517-520.

McKee, T.B., Capt. R. Butler, N.J. Doesken, J. Kleist, and N.L. Canfield, 1999: Climate data continuity with ASOS rain observations. 11th AMS Conference on Applied Climatology, 10-15 January, Dallas, TX, pp. 47-49.

McKee, T.B., N.J. Doesken, J. Kleist, and N.L. Canfield, 2000a: Climate data continuity with ASOS rain observations. 16th AMS International Conference on IIPS for Meteorology, Oceanography and Hydrology, 9-14 January, Long Beach, CA, pp. 318-319.

McKee, T.B., N.J. Doesken, J. Kleist, C.A. Davey, and N.L. Canfield, 2000b: Climate data continuity with ASOS in precipitation and temperature. 12th AMS Conference on Applied Climatology, 8-11 May, Asheville, NC, pp. 134-135.

National Weather Service (NWS), 1996: Snow Measurement Guidelines (revised 10/28/96). U.S. Department of Commerce, NOAA, NWS, Silver Spring, MD, October.

NOAA, 1997: Evaluation of the Reported January 11-12, 1997, Montague, New York, 77-Inch, 24-Hour Lake-Effect Snowfall. Special Report. National Weather Service, Office of Meteorology, Silver Spring, MD, U.S. Government Printing Office, March, 41 pp.

Schrump, A.D., and T.B. McKee, 1996: Temperature data continuity with the Automated Surface Observing System (ASOS). Climatology Report 96-2, Atmospheric Science Paper #616, Department of Atmospheric Science, Colorado State University, Fort Collins, CO, June, 242 pp.

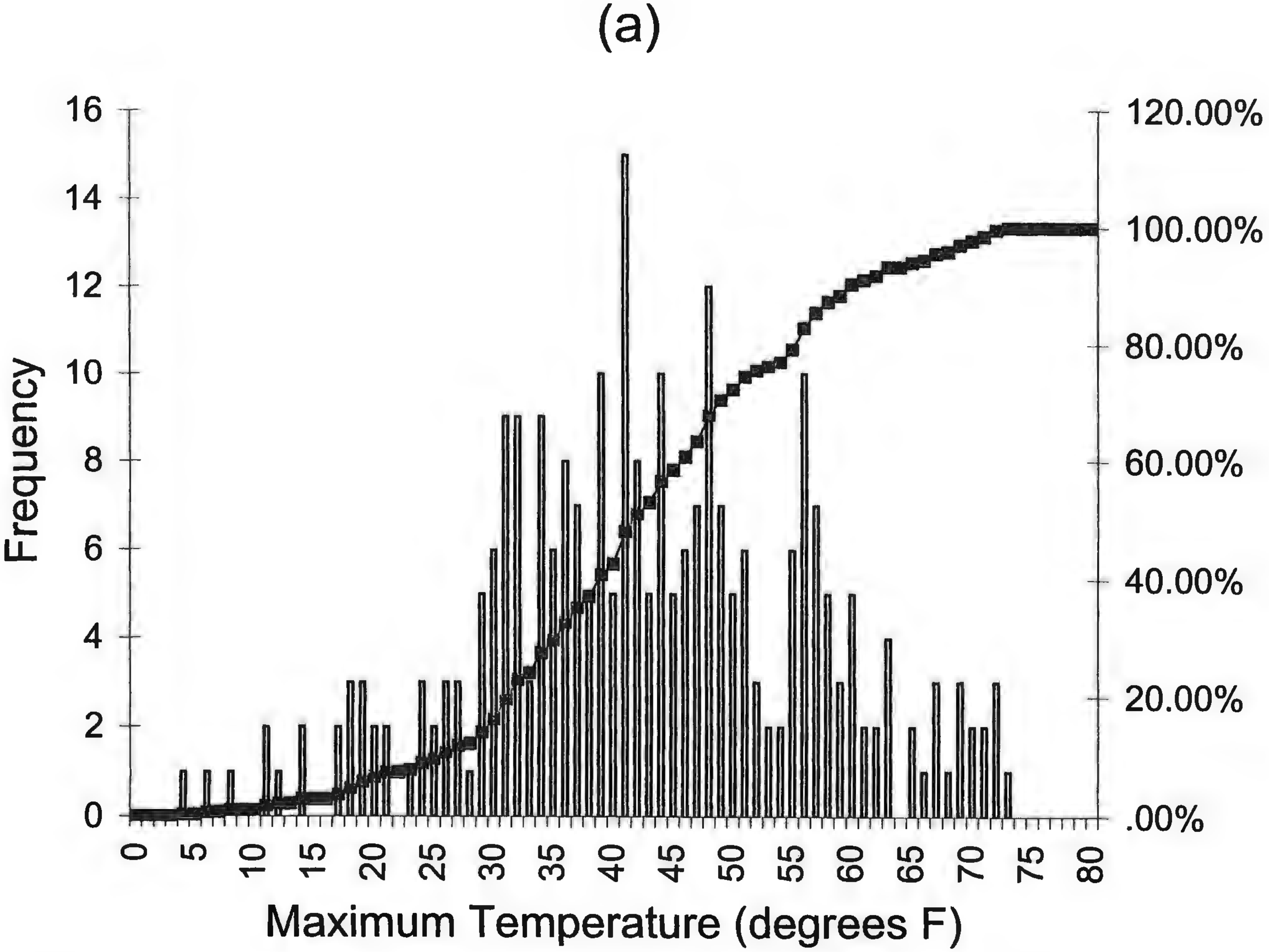

Figure 1a. Frequency distribution of winter (DJF) maximum temperature for St. Louis Lambert Field

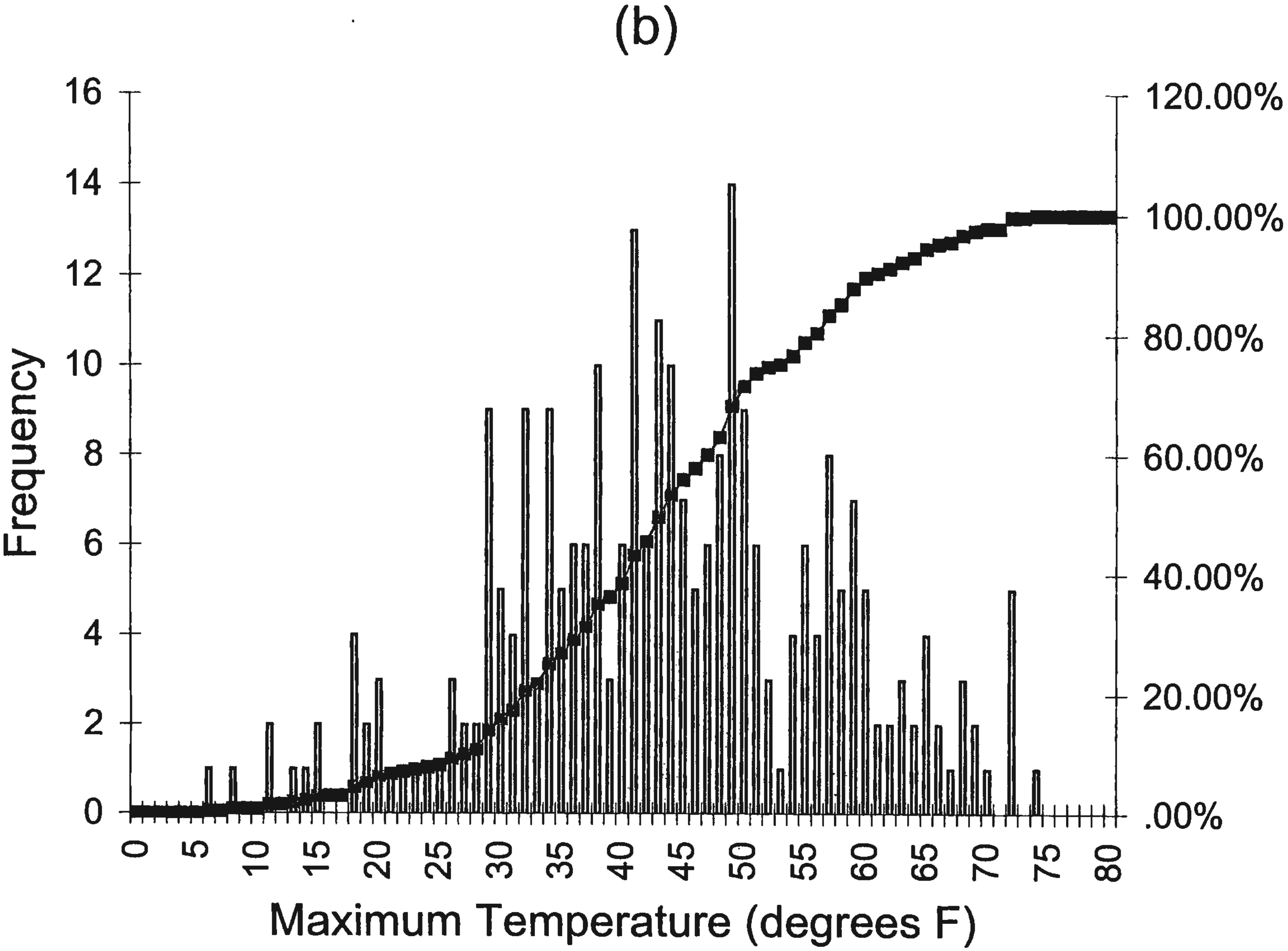

Figure 1b. Frequency distribution of winter (DJF) maximum temperature for St. Charles.

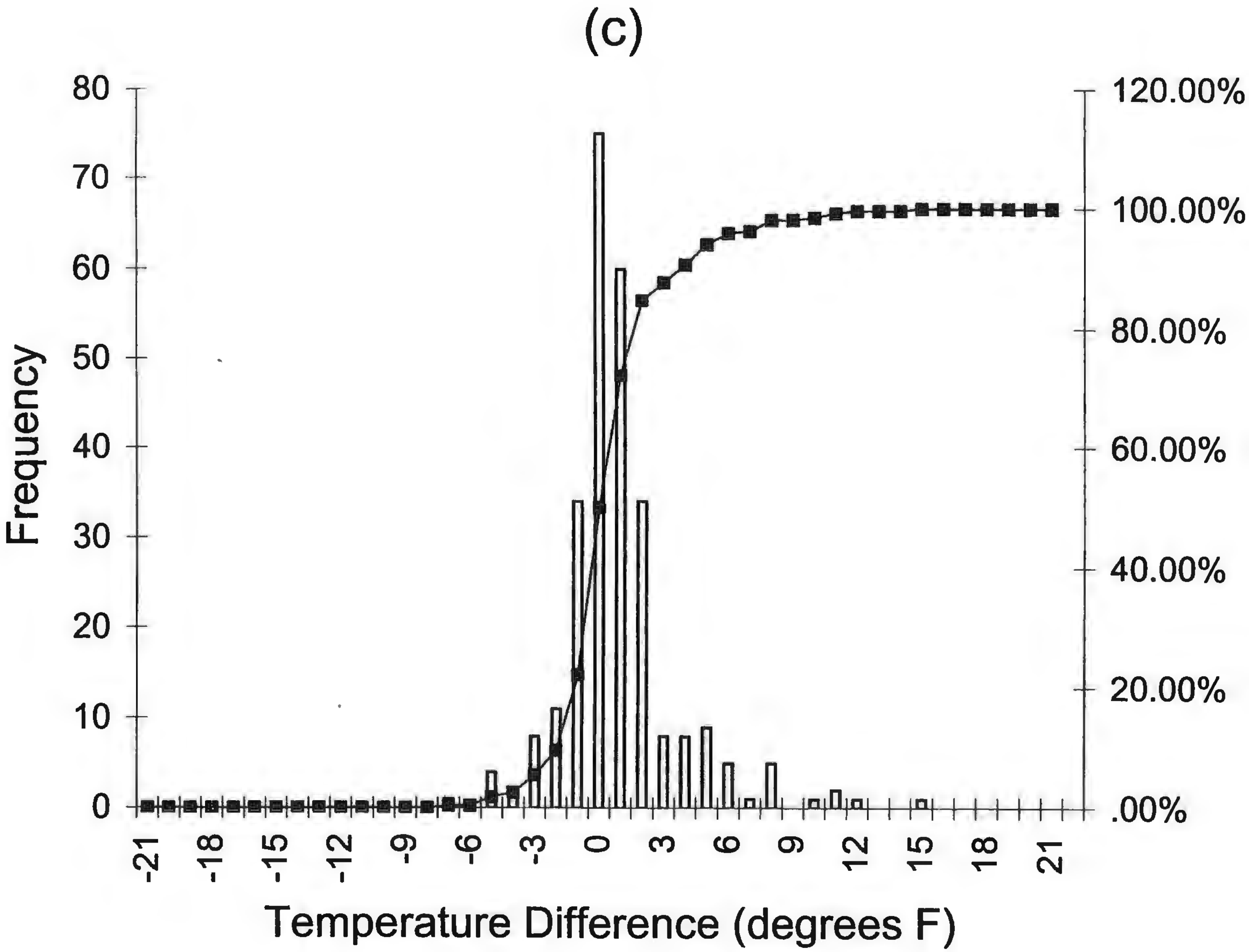

Figure 1c. Frequency distribution of winter (DJF) maximum temperature for Lambert Field – St. Charles.

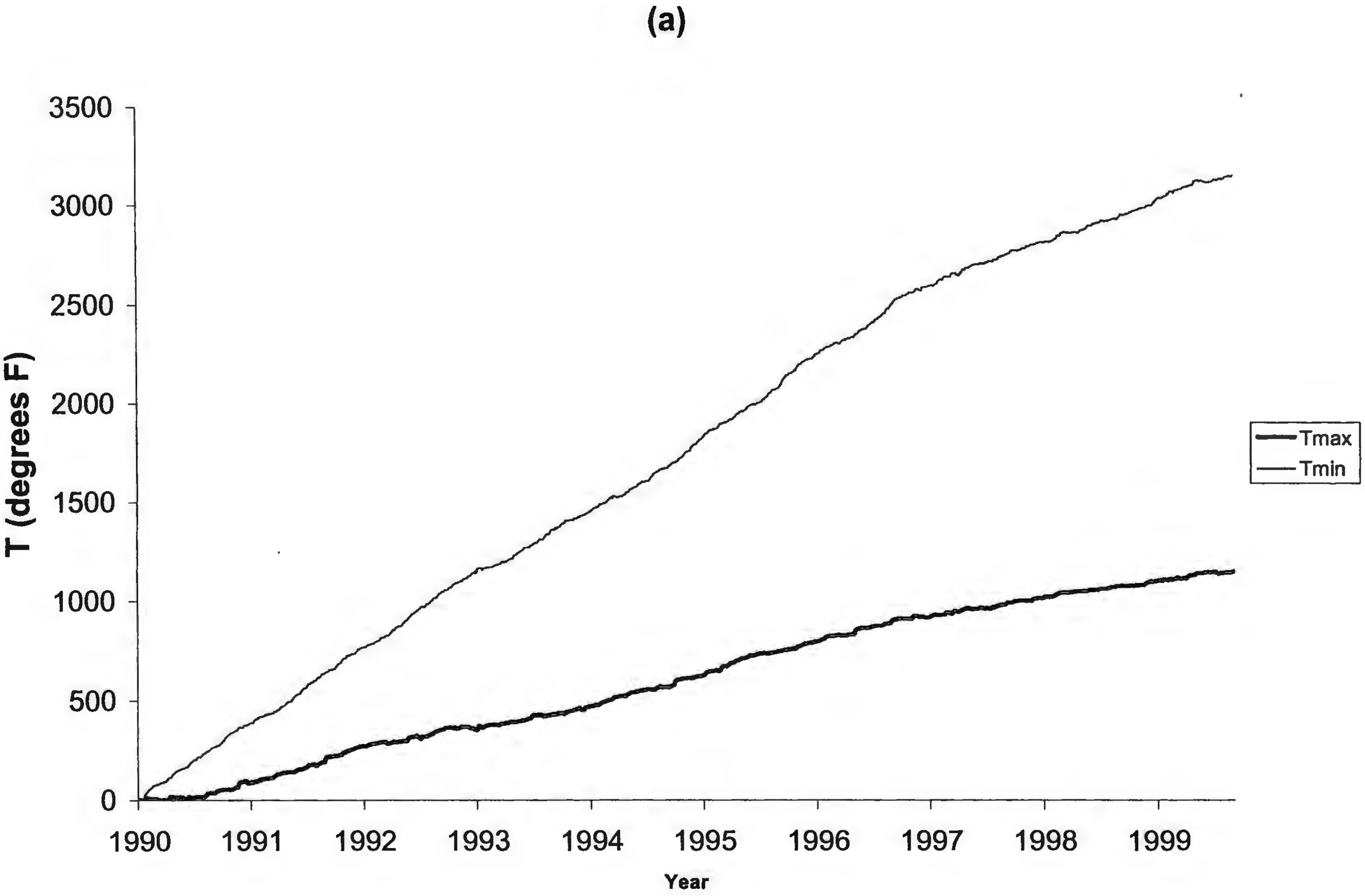

Figure 2a. Lambert Field – St. Charles maximum and minimum temperature difference cumulative sums for 1990-1999 for winter (DJF).

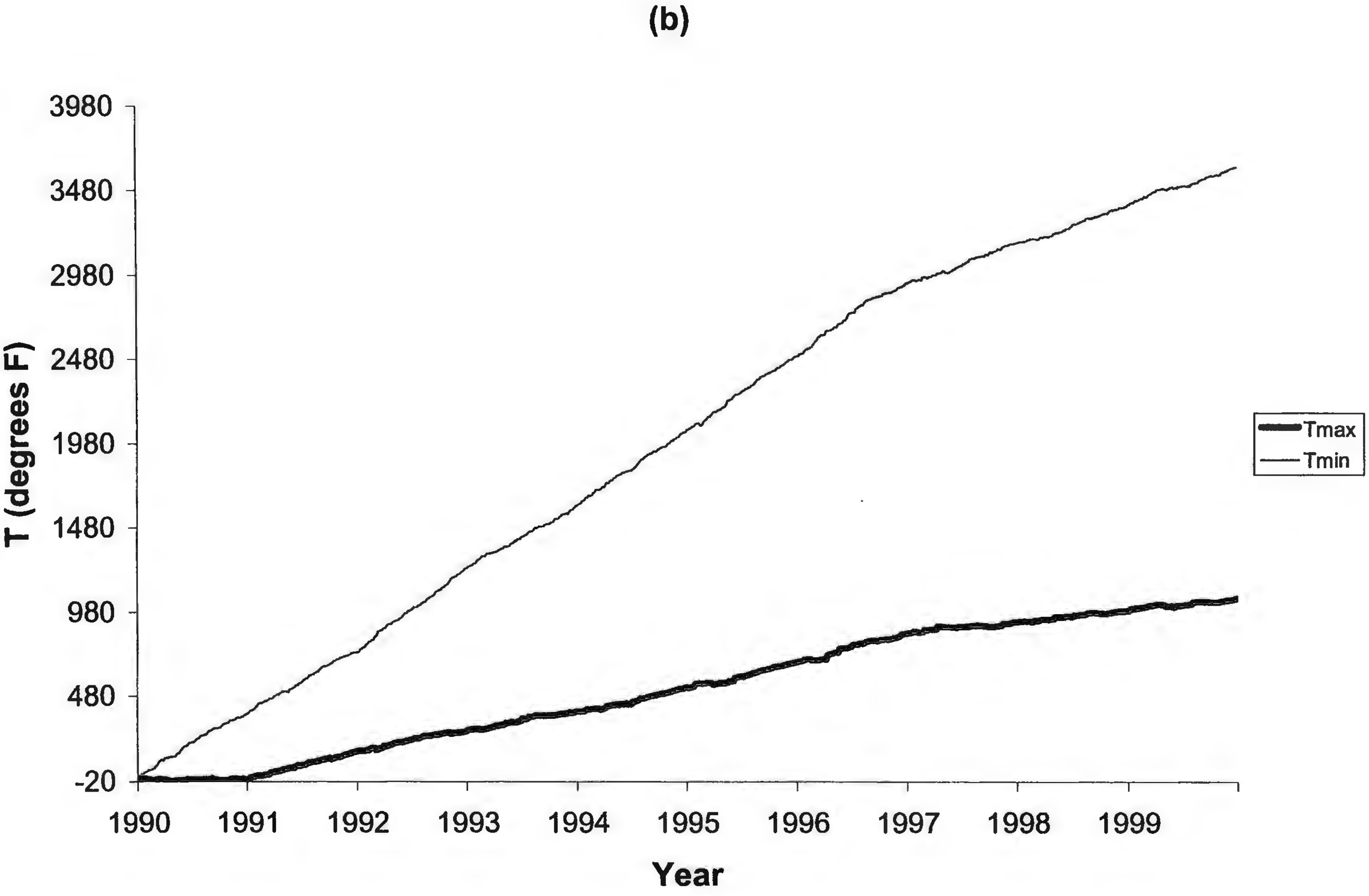

Figure 2b. Lambert Field – St. Charles maximum and minimum temperature difference cumulative sums for 1990-1999 for spring (MAM).

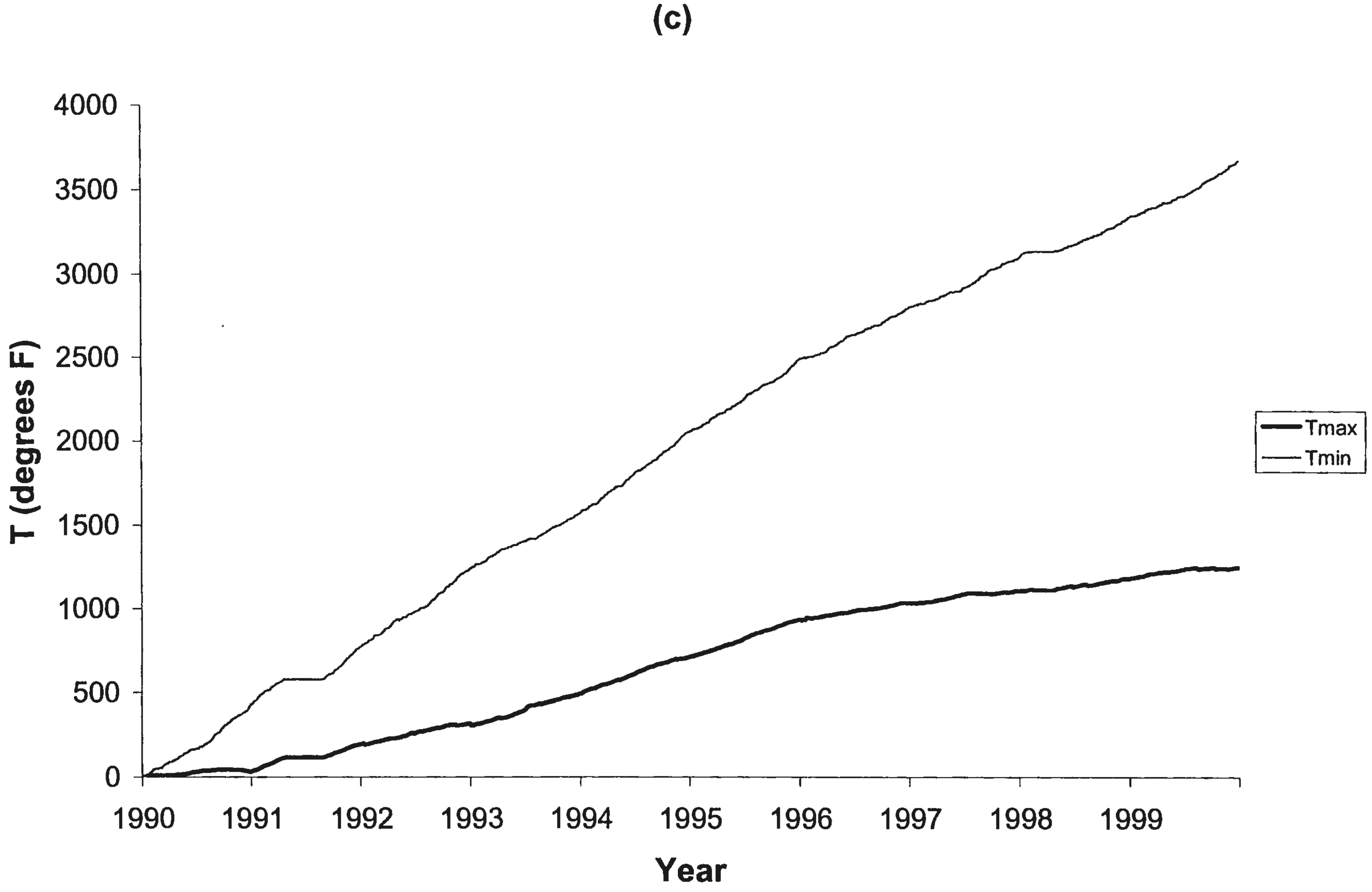

Figure 2c. Lambert Field – St. Charles maximum and minimum temperature difference cumulative sums for 1990-1999 for summer (JJA).

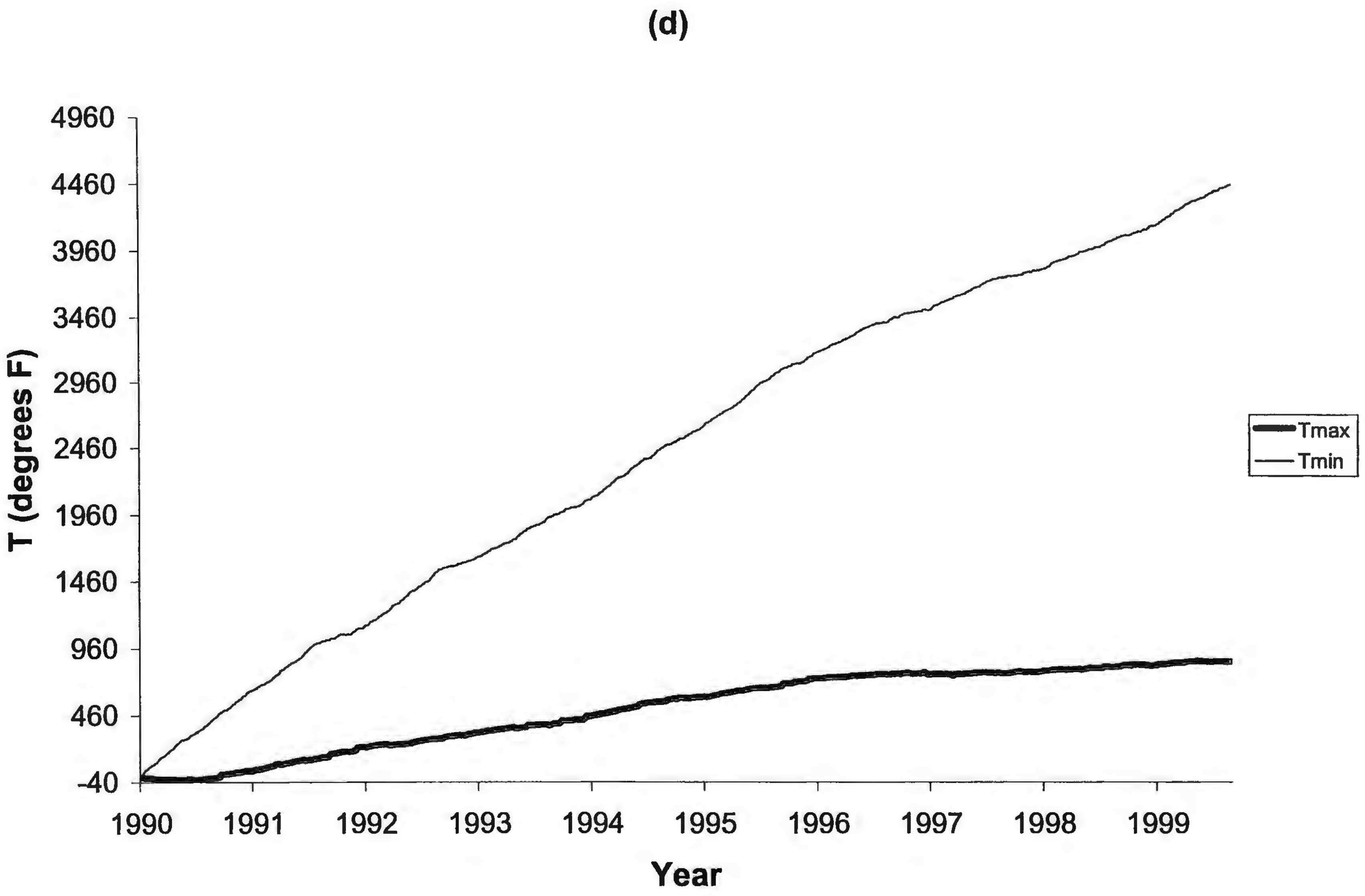

Figure 2d. Lambert Field – St. Charles maximum and minimum temperature difference cumulative sums for 1990-1999 for fall (SON).

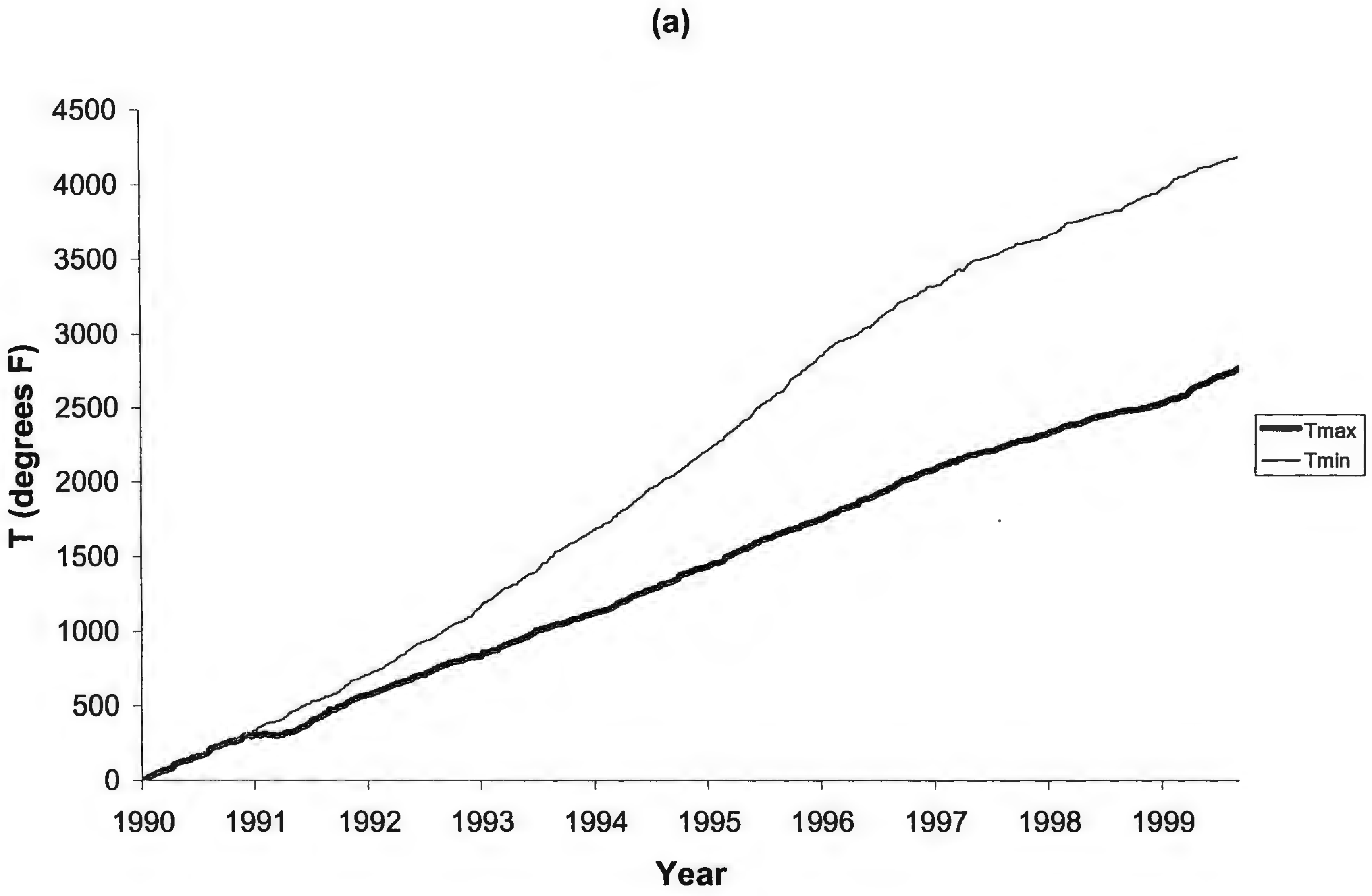

Figure 3a. Lambert Field – Jerseyville maximum and minimum temperature difference cumulative sums for 1990-1999 for winter (DJF).

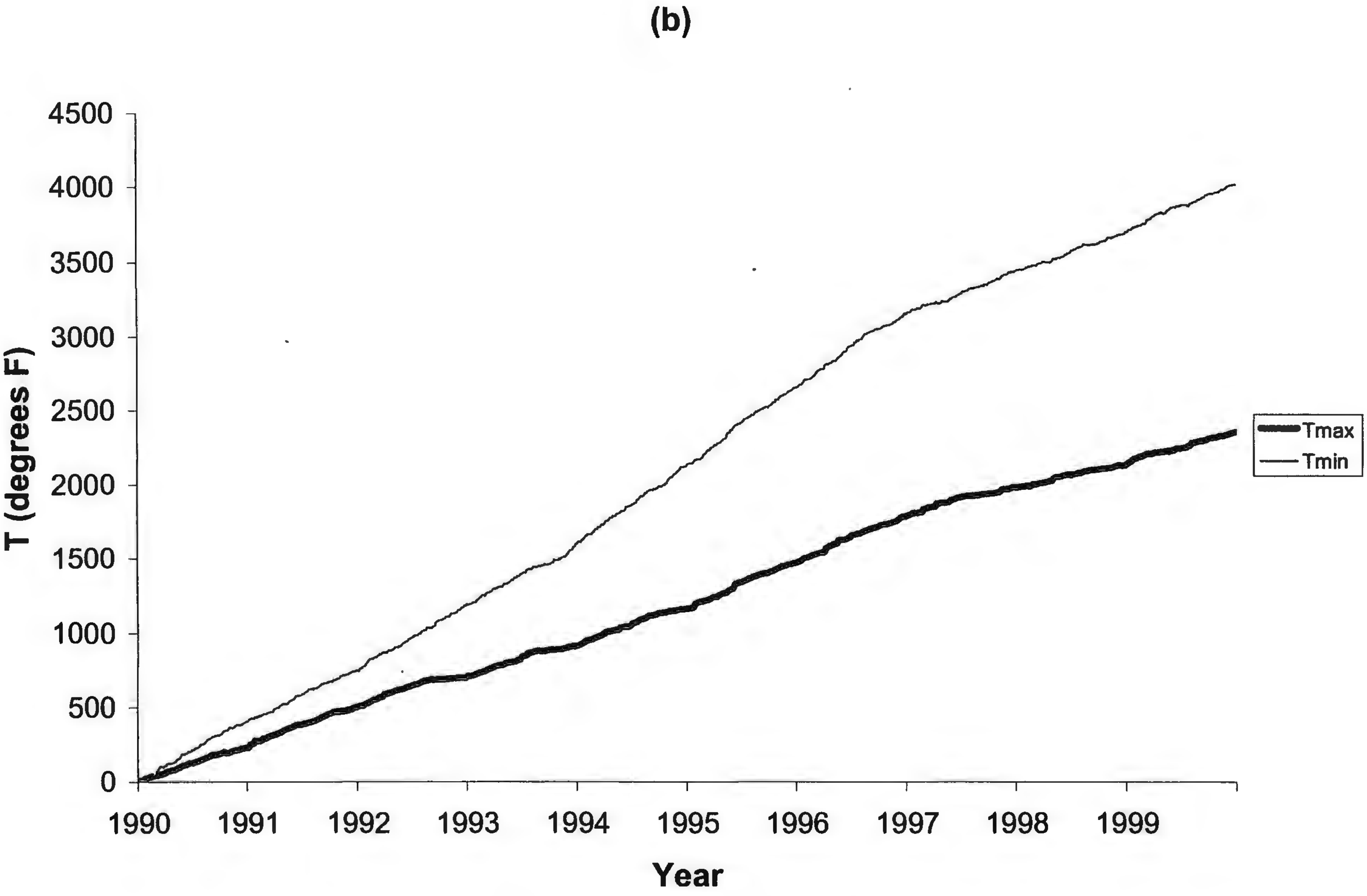

Figure 3b. Lambert Field – Jerseyville maximum and minimum temperature difference cumulative sums for 1990-1999 for spring (MAM).

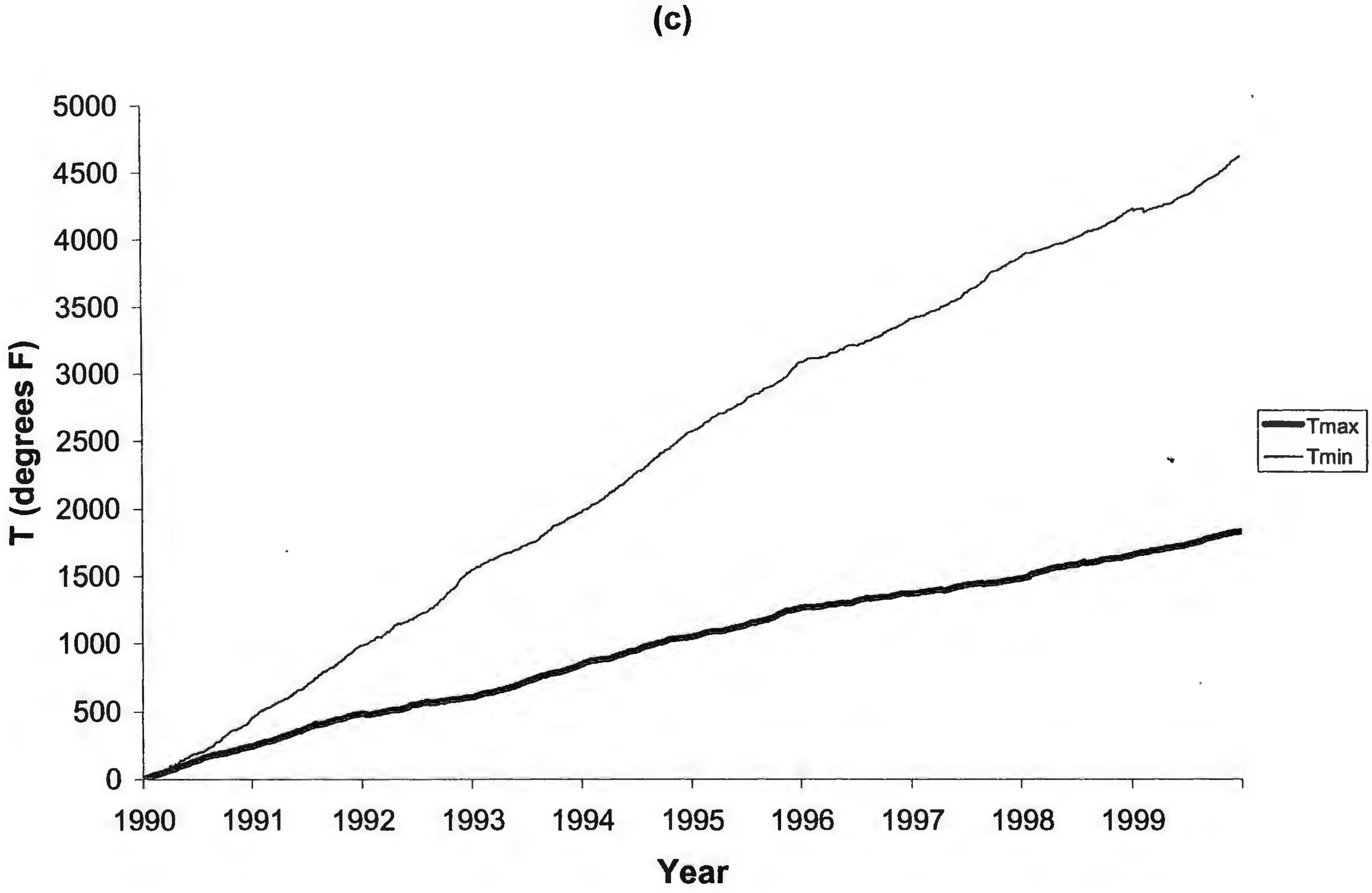

Figure 3c. Lambert Field – Jerseyville maximum and minimum temperature difference cumulative sums for 1990-1999 for summer (JJA).

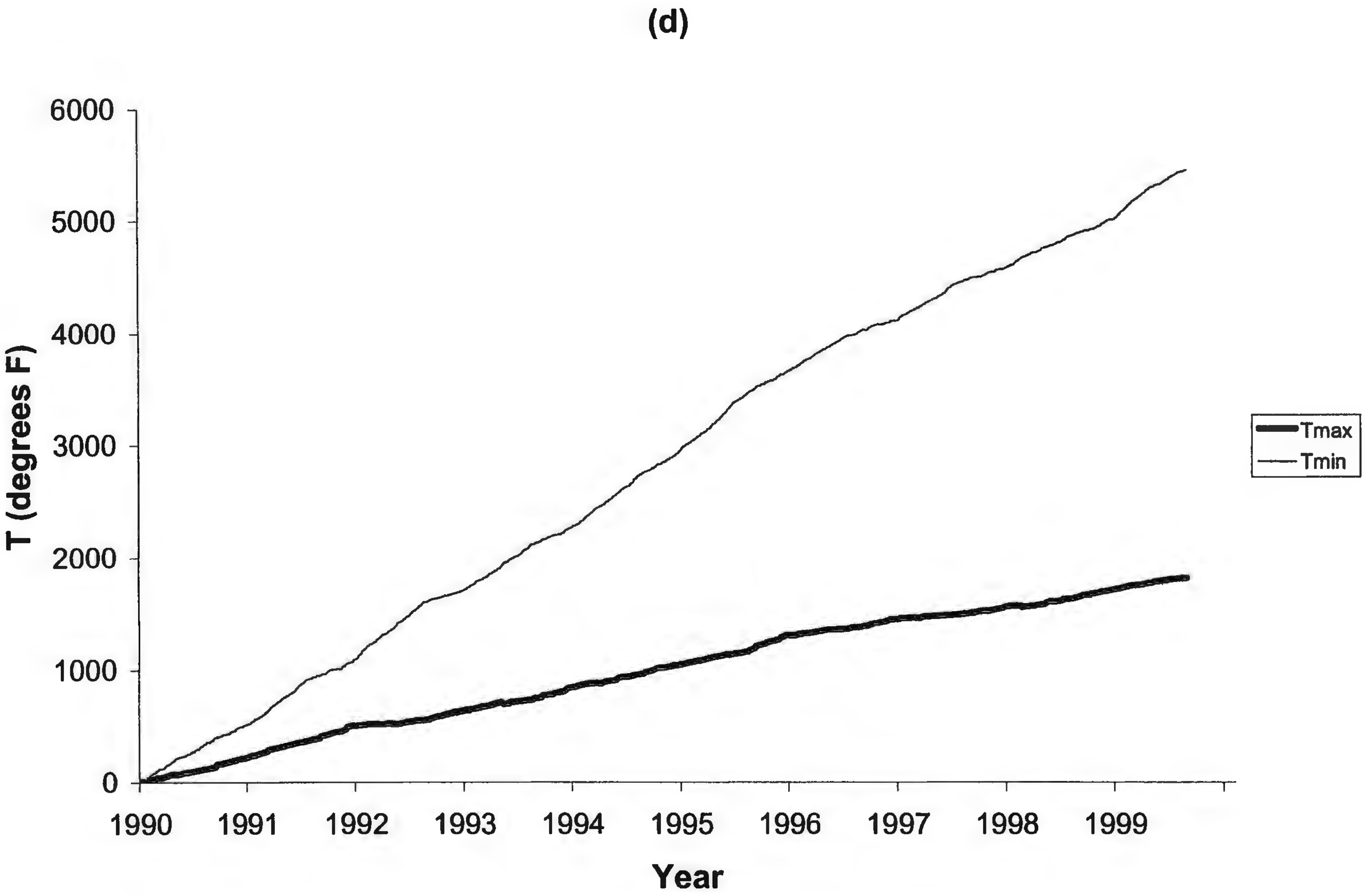

Figure 3d. Lambert Field – Jerseyville maximum and minimum temperature difference cumulative sums for 1990-1999 for fall (SON).

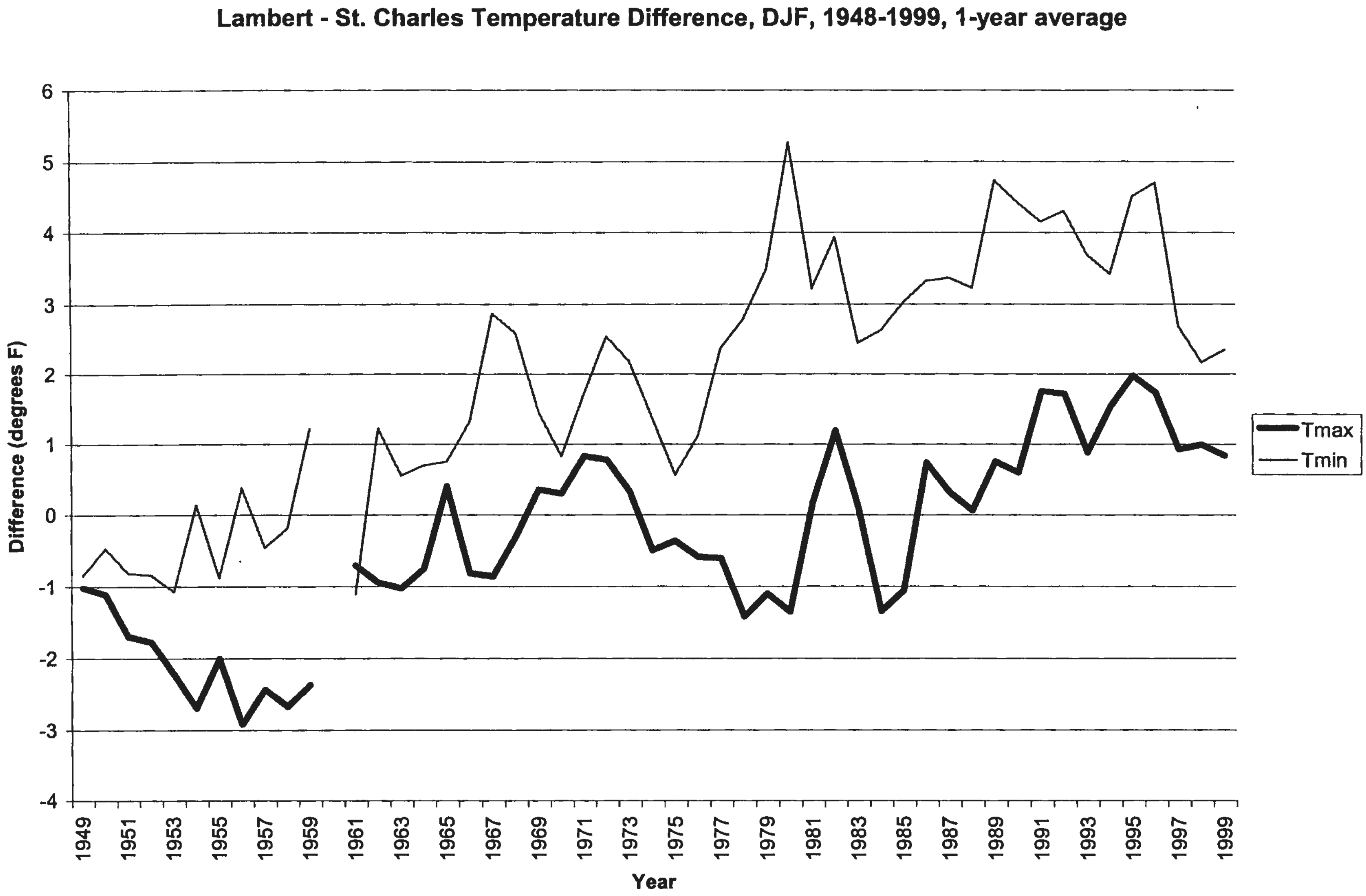

Figure 4a. Lambert Field – St. Charles temperature difference for winter (DJF) for 1948-1999 for 1 year. Data points are midway between ticks.

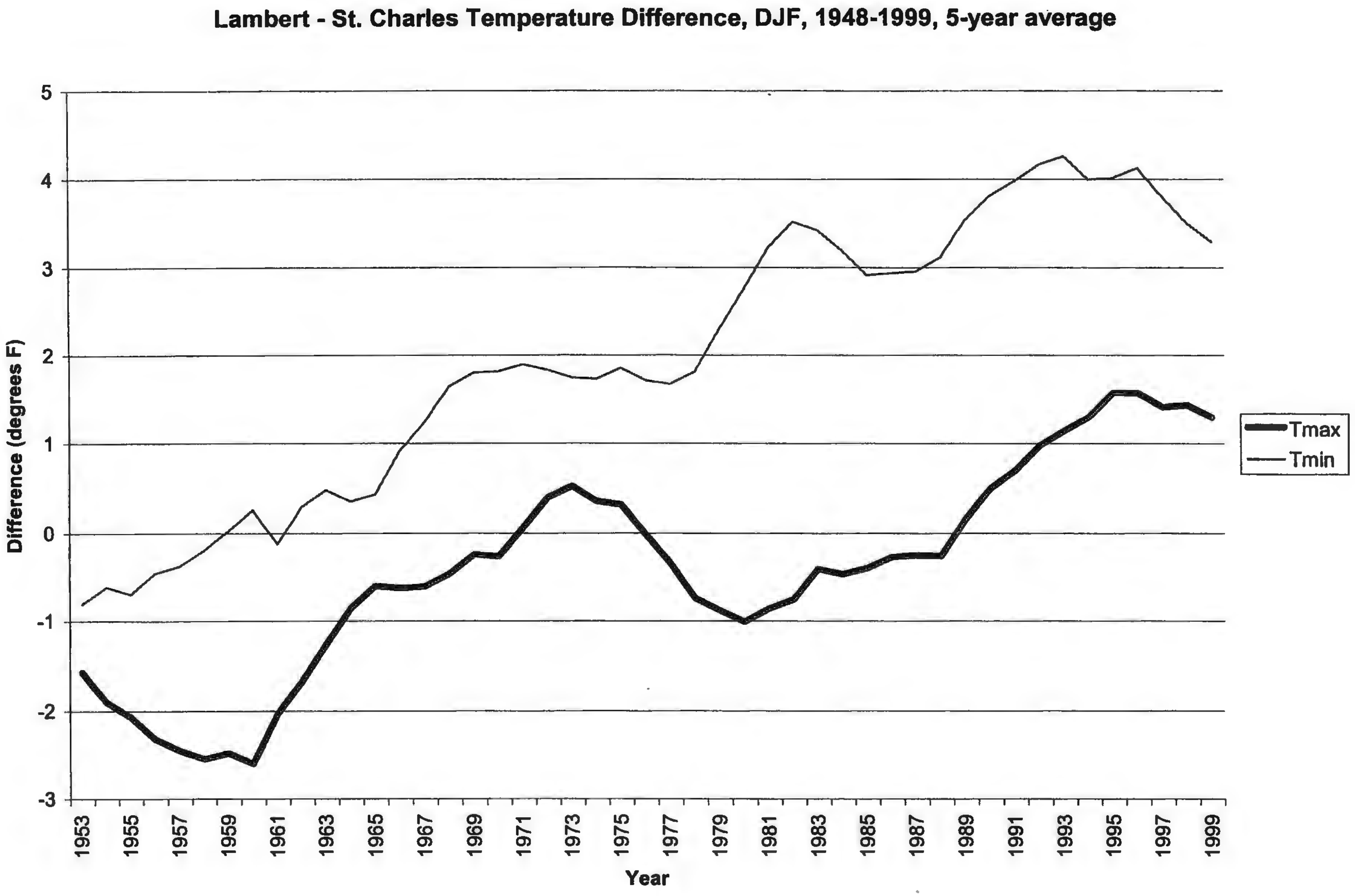

Figure 4b. Lambert Field – St. Charles temperature difference for winter (DJF) for 1948-1999 for 5-year average. Data points are midway between ticks.

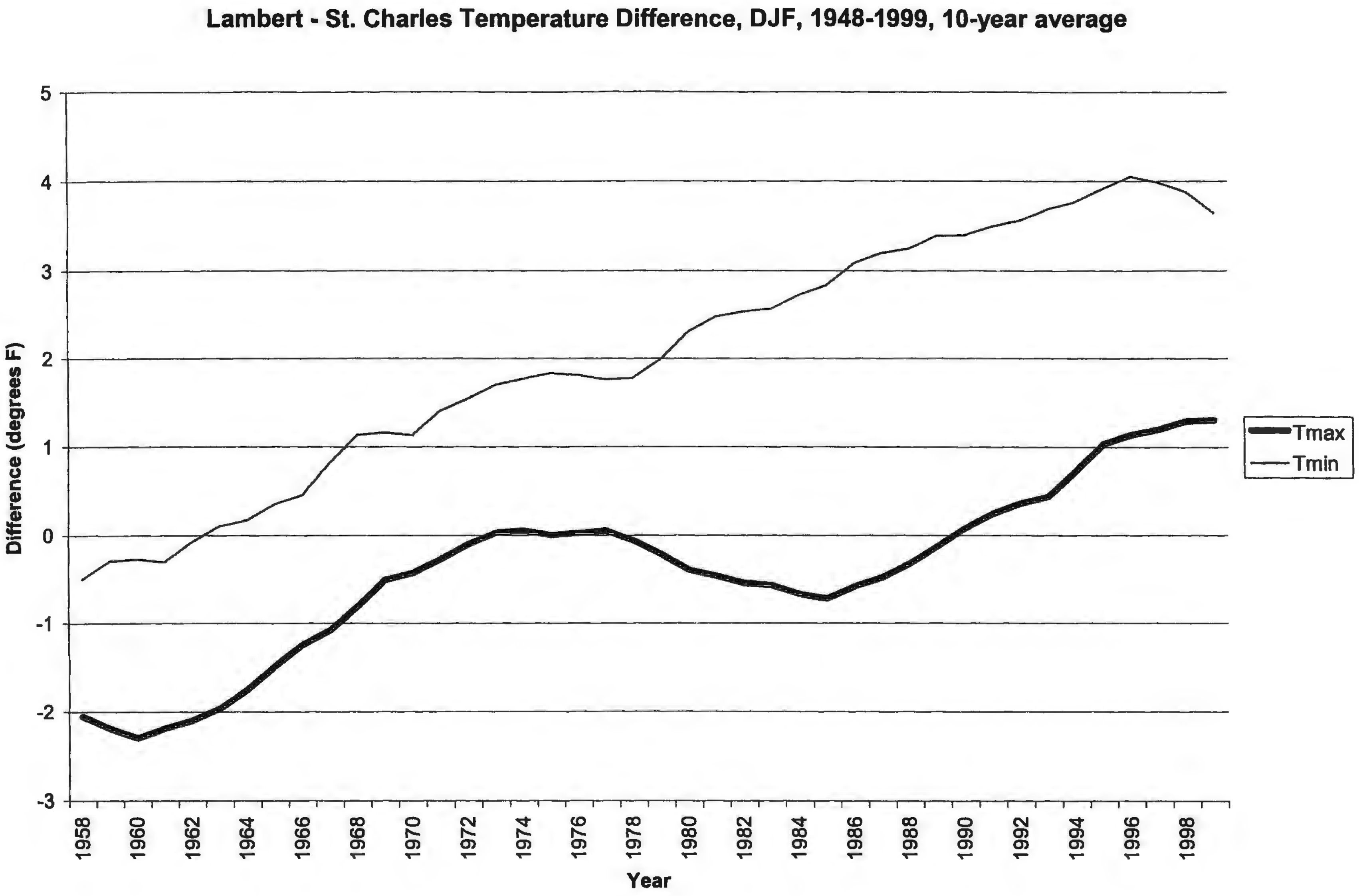

Figure 4c. Lambert Field – St. Charles temperature difference for winter (DJF) for 1948-1999 for 10-year average. Data points are midway between ticks.

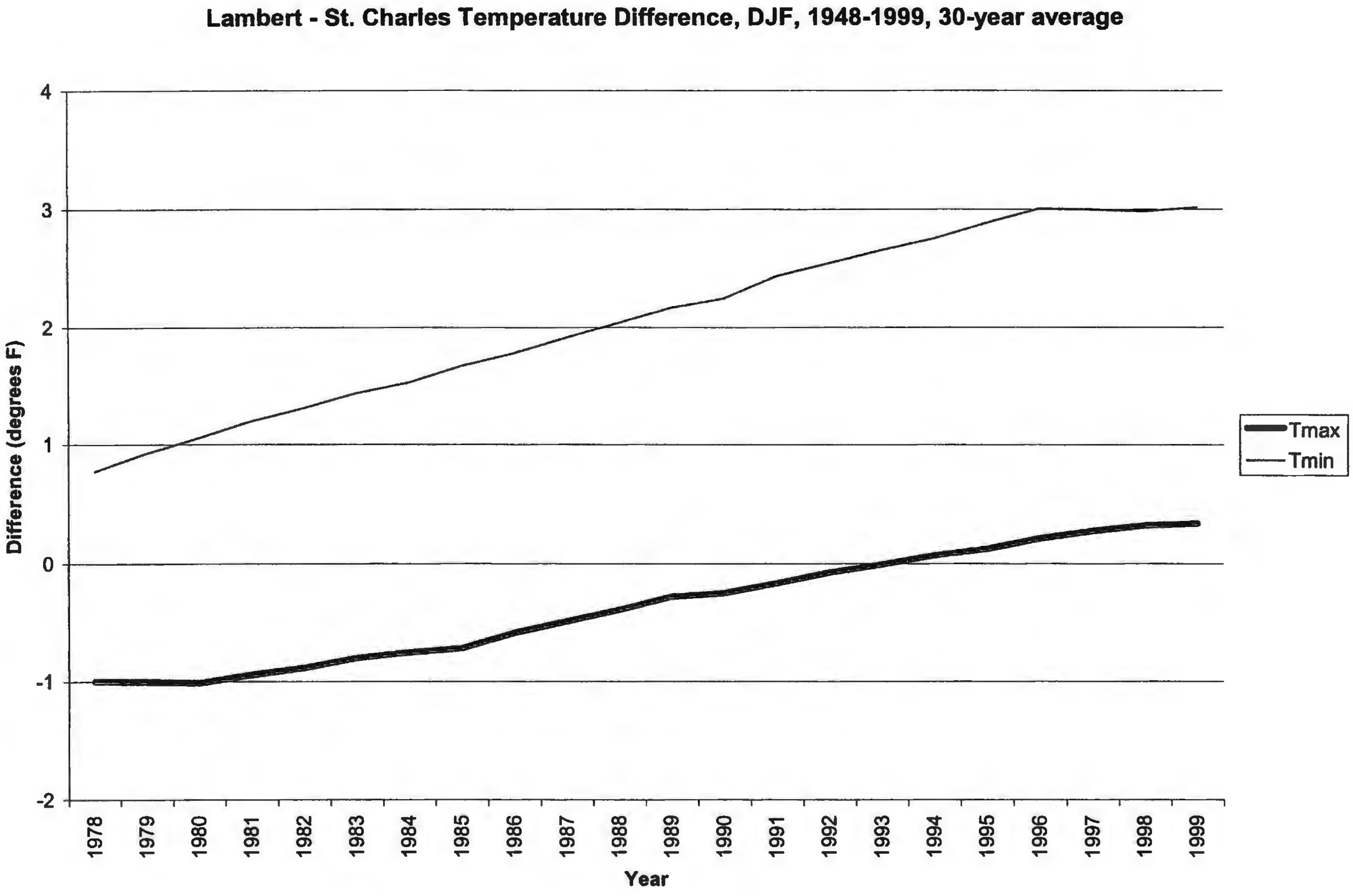

Figure 4d. Lambert Field – St. Charles temperature difference for winter (DJF) for 1948-1999 for 30-year average. Data points are midway between ticks.

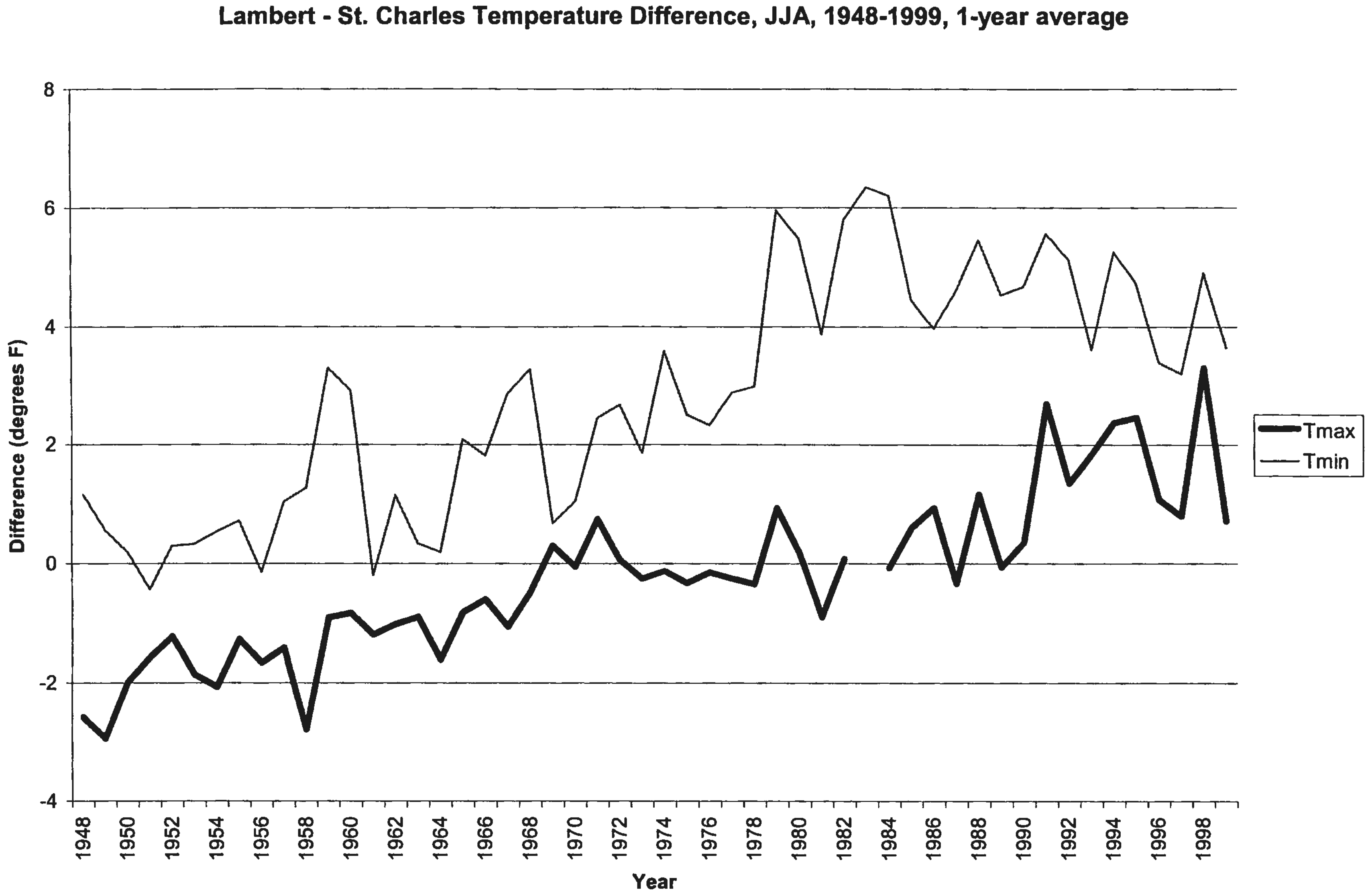

Figure 5a. Lambert Field – St. Charles temperature differences for summer (JJA) for 1948-1999 for 1 year.

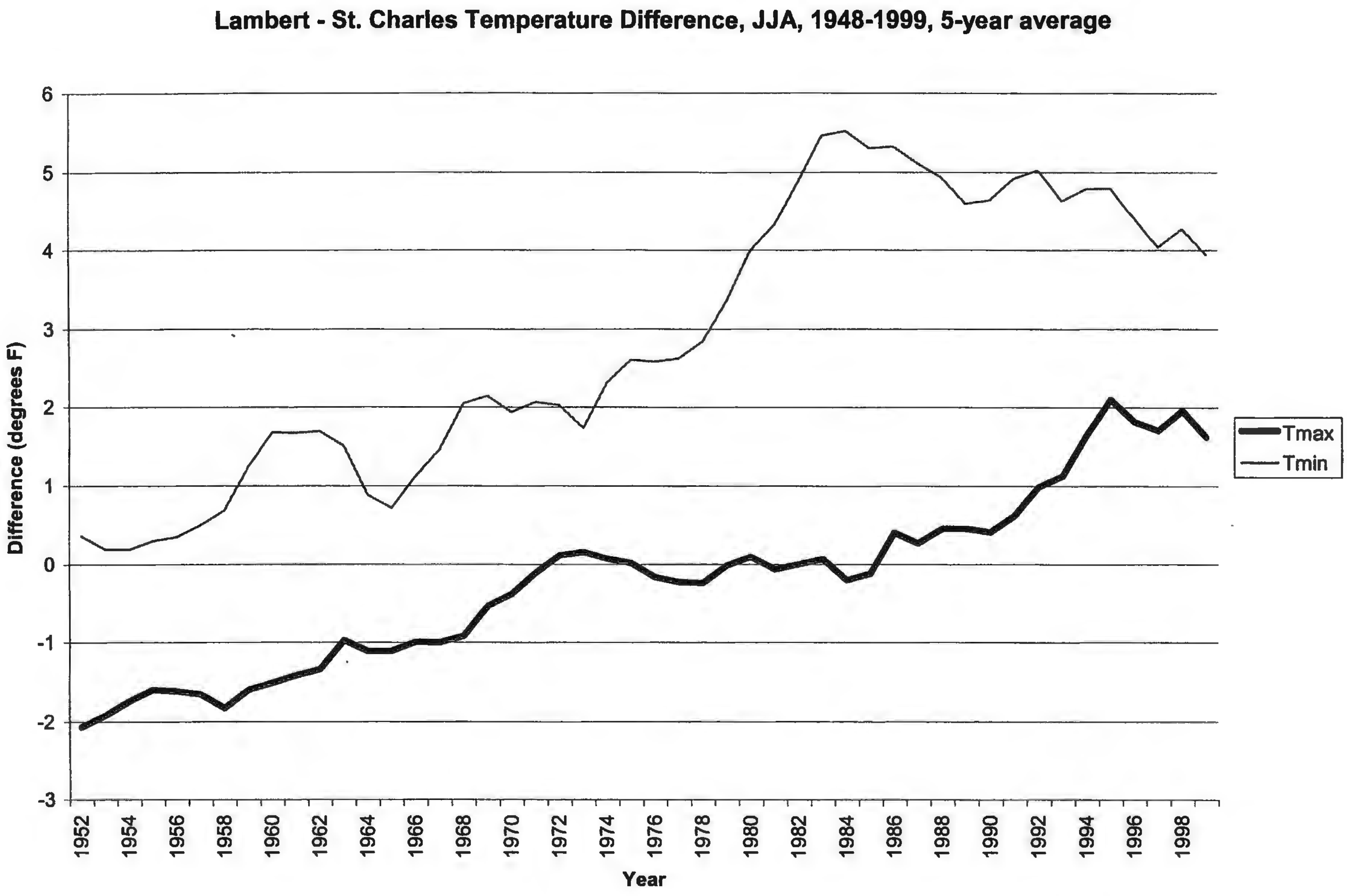

Figure 5b. Lambert Field – St. Charles temperature differences for summer (JJA) for 1948-1999 for 5-year average.

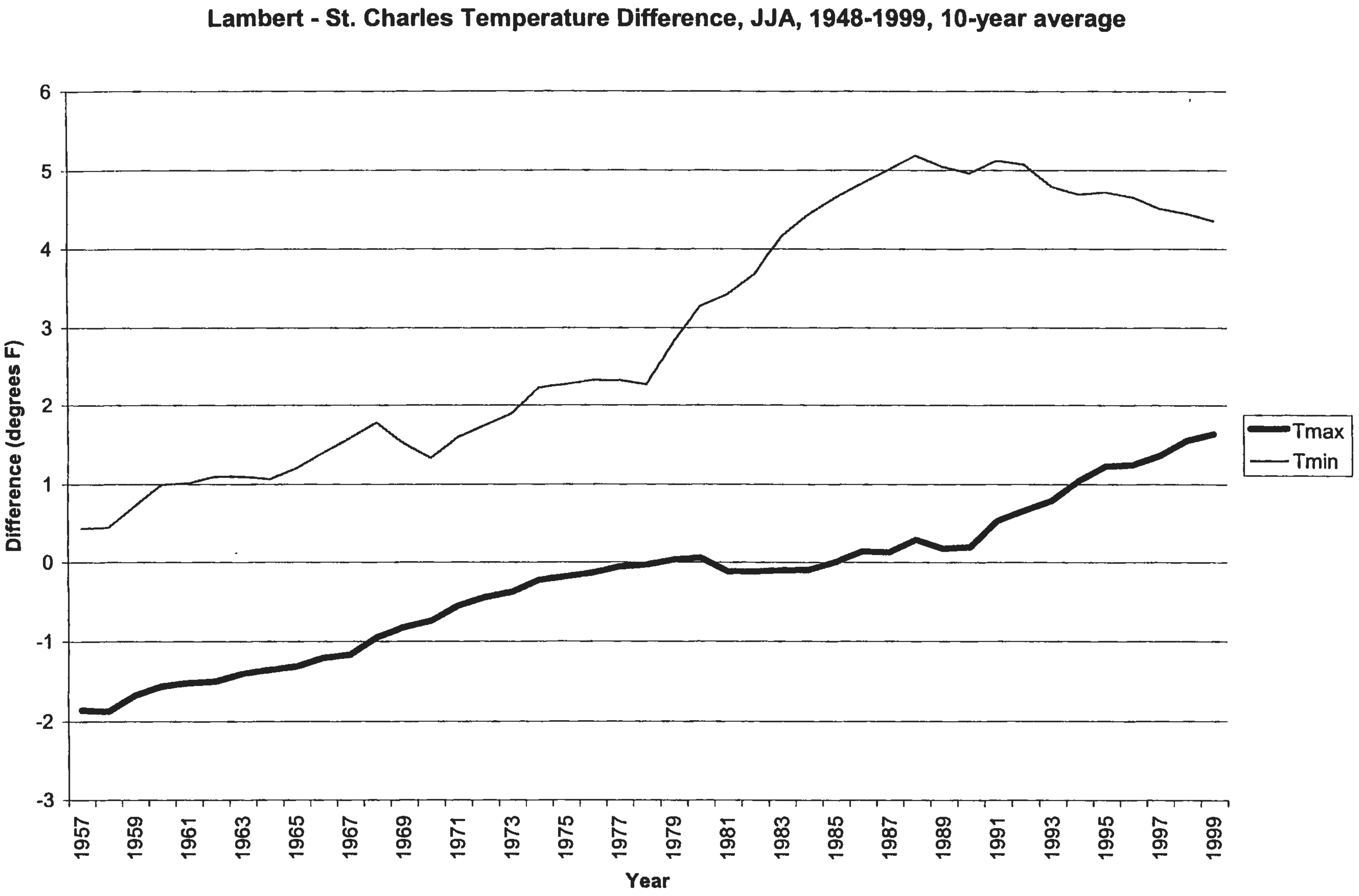

Figure 5c. Lambert Field – St. Charles temperature differences for summer (JJA) for 1948-1999 for 10-year average.

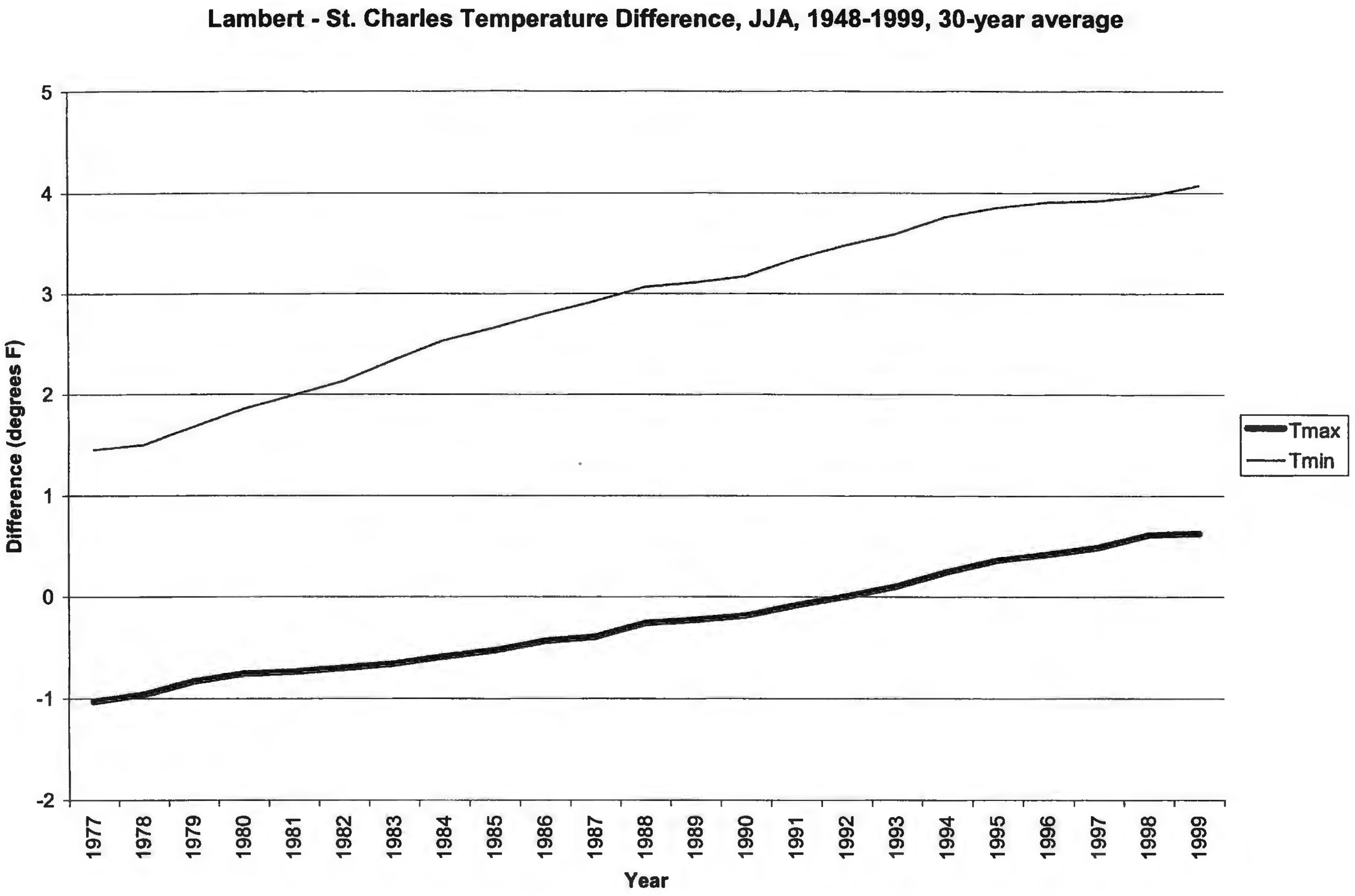

Figure 5d. Lambert Field – St. Charles temperature differences for summer (JJA) for 1948-1999 for 30-year average.

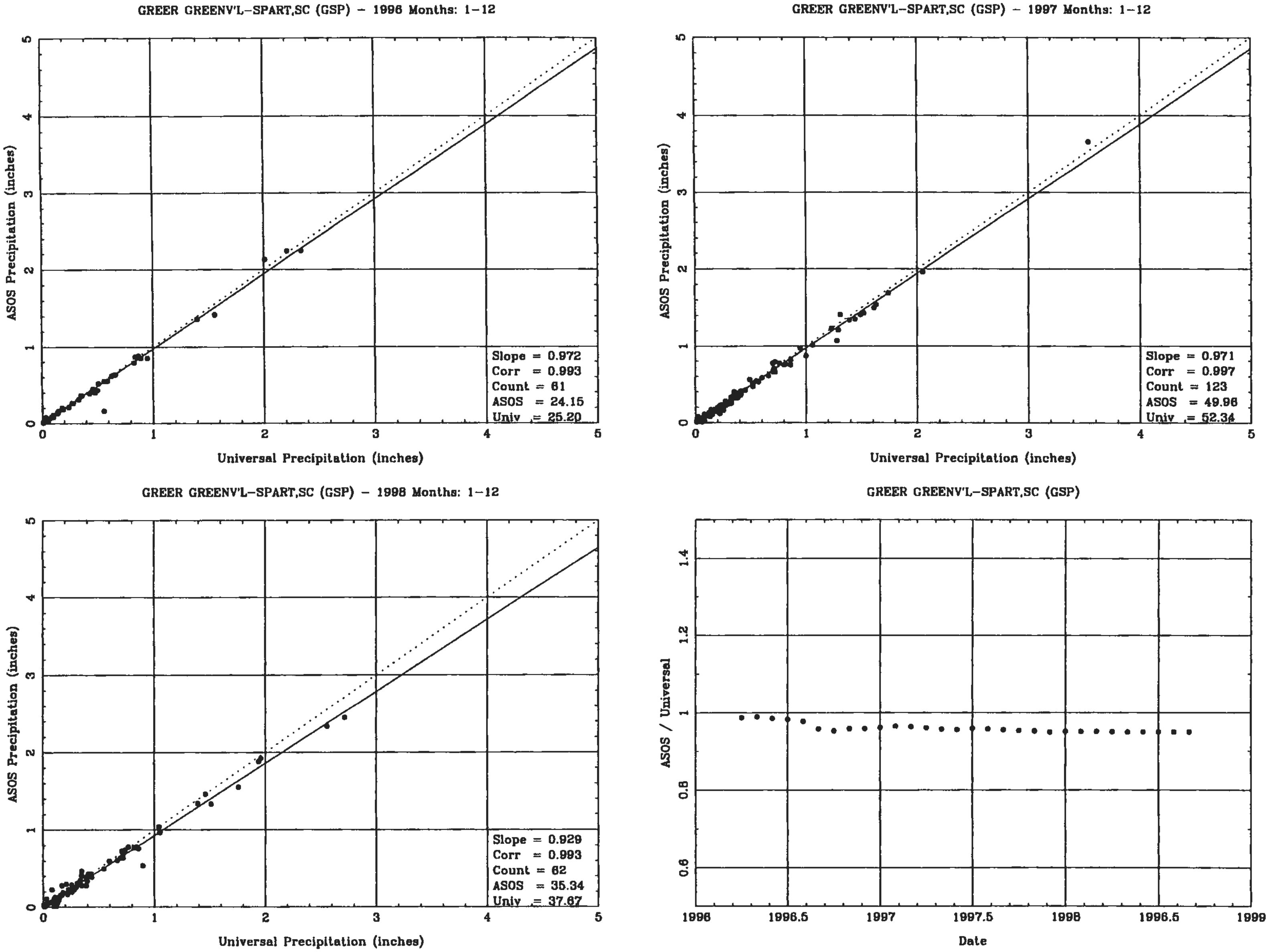

Figure 6a. Scatter diagram for 1996, 1997 and 1998 and the accumulated ratio of ASOS to Universal precipitation for Greenville-Spartanburg (GSP), SC.

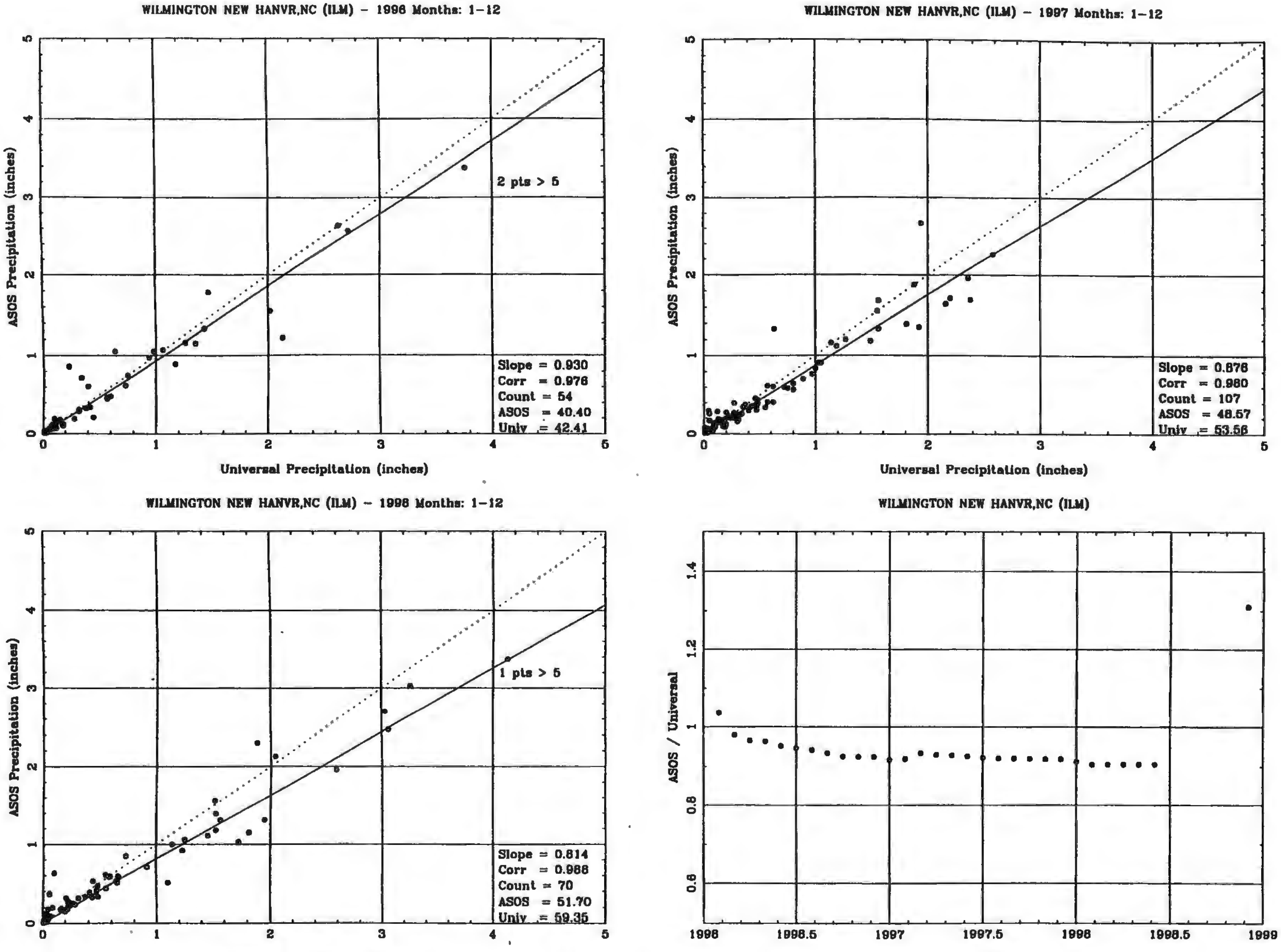

Figure 6b. Scatter diagram for 1996, 1997 and 1998 and the accumulated ratio of ASOS to Universal precipitation for Wilmington (ILM), NC.

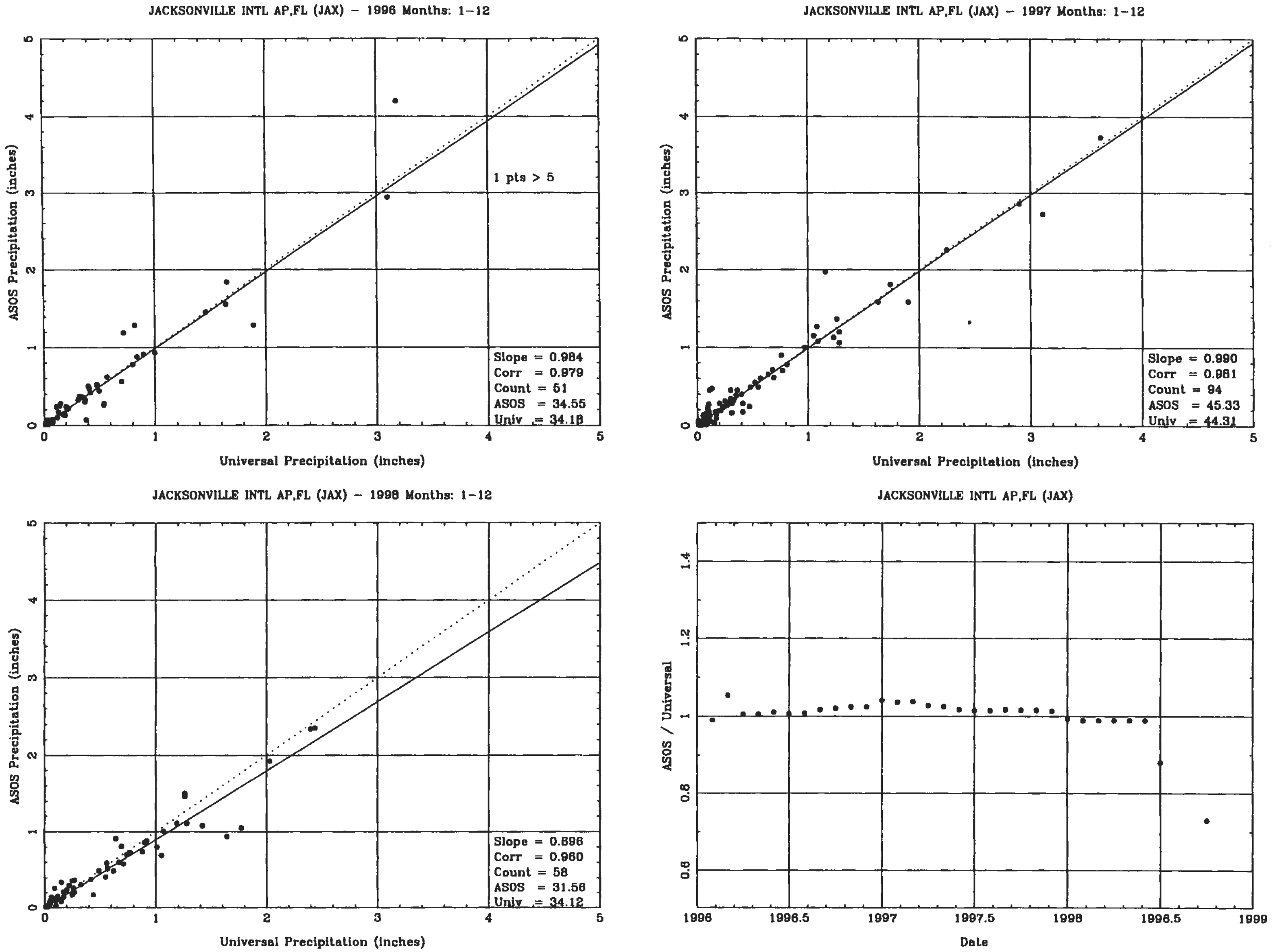

Figure 6c. Scatter diagram for 1996, 1997 and 1998 and the accumulated ratio of ASOS to Universal precipitation for Jacksonville (JAX), FL.

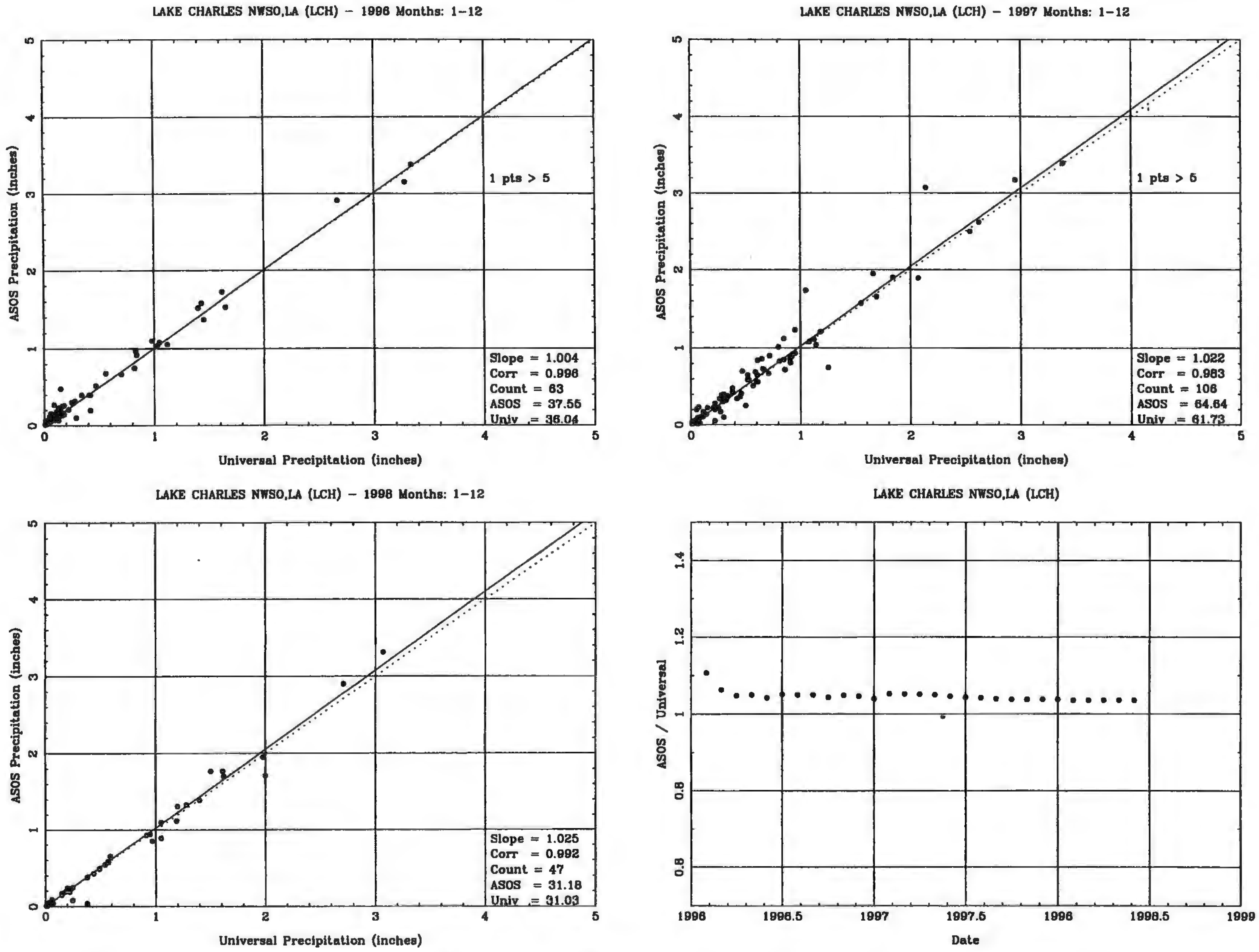

Figure 6d. Scatter diagram for 1996, 1997 and 1998 and the accumulated ratio of ASOS to Universal precipitation for Lake Charles (LCH), LA.

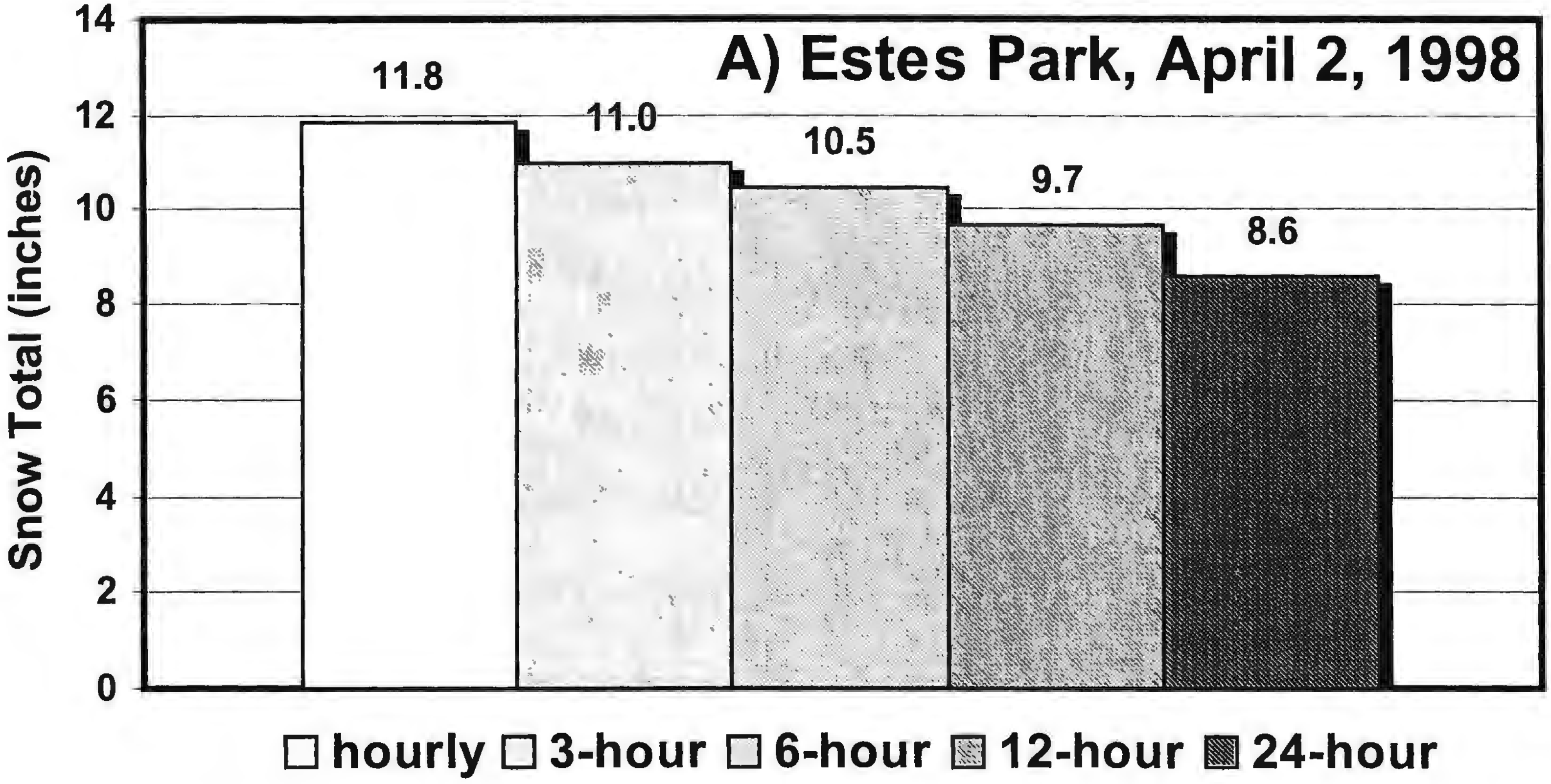

Figure 7a. Example showing the comparison of accumulated snowfall for different measurement intervals for Estes Park, Colorado, April 2, 1998.

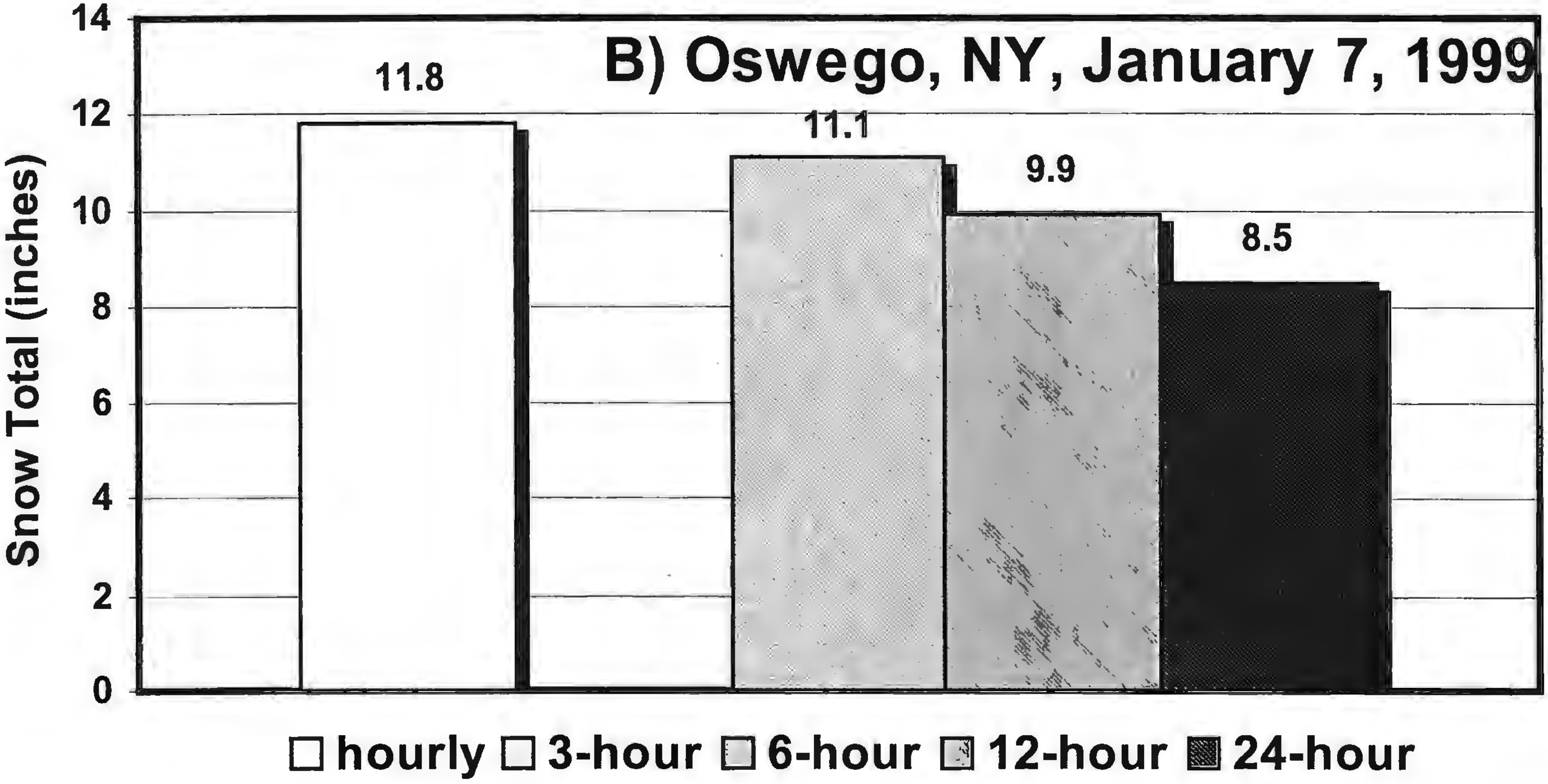

Figure 7b. Example showing the comparison of accumulated snowfall for different measurement intervals for Oswego, New York, January 7, 1999.

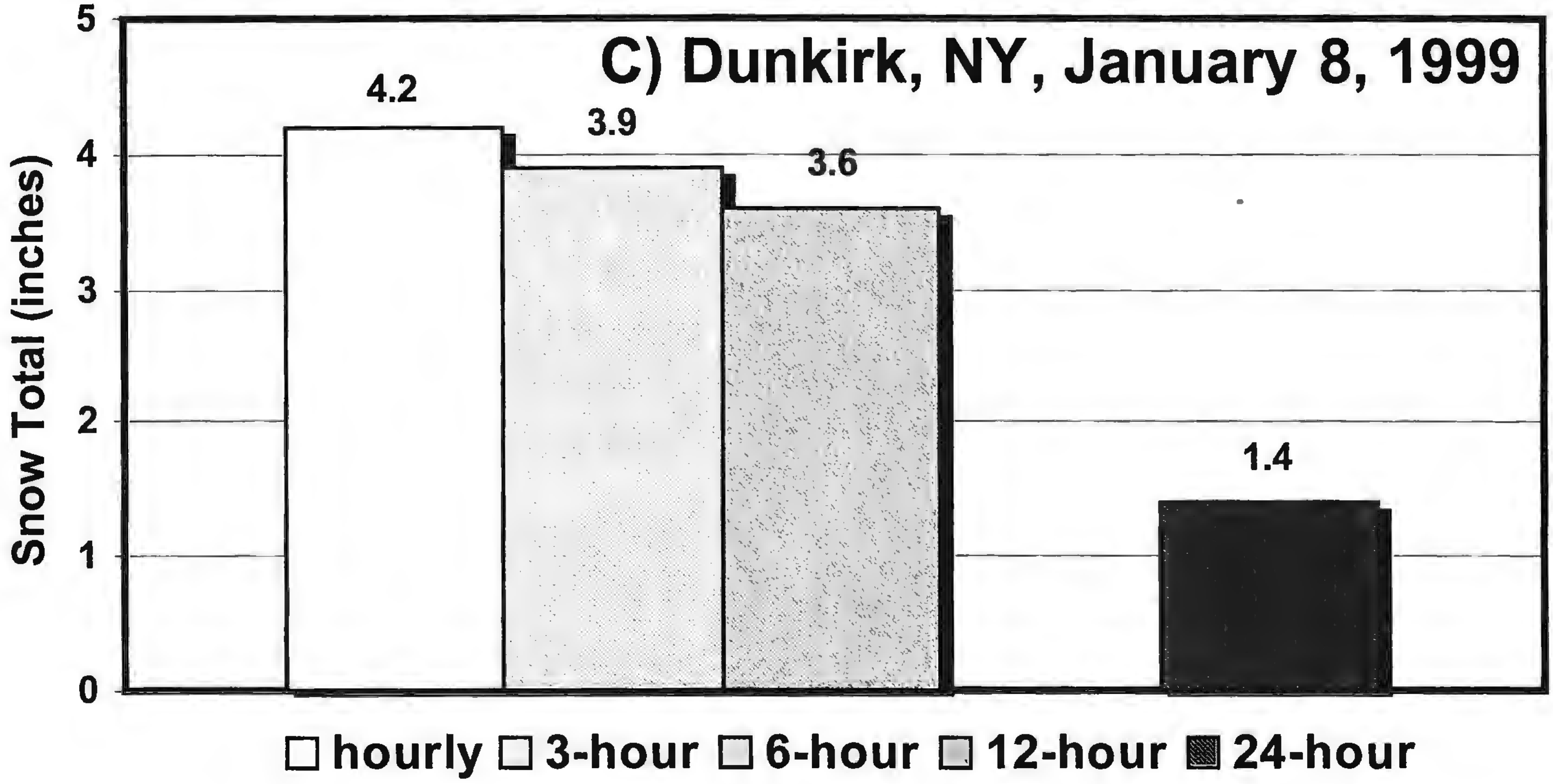

Figure 7c. Example showing the comparison of accumulated snowfall for different measurement intervals for Dunkirk, New York, January 8, 1999.

APPENDIX A.

- A Summary of Wind Climate Continuity with ASOS. 12th AMS Conference on Applied Climatology, 8-11 May 2000, Asheville, NC.

- Climate Data Continuity with ASOS in Precipitation and Temperature. 12th AMS Conference on Applied Climatology, 8-11 May 2000, Asheville, NC.

- Climate Data Continuity with ASOS Rain Observations. 16th AMS International Conference on IIPS for Meteorology, Oceanography and Hydrology, 9-14 January 2000, Long Beach, CA.

- Life After ASOS (Automated Surface Observing System) – Progress in National Weather Service Snow Measurement. Postprints, 68th Annual Western Snow Conference, April 18-20, 1999, Port Angeles, Washington.

- Climate Data Continuity with ASOS Rain Observations. 11th AMS Conference on Applied Climatology, 10-15 January 1999, Dallas, TX.

- Climate Data Continuity of Rain Observations with ASOS. 14th AMS International Conference on IIPS for Meteorology, Oceanography and Hydrology, 11-16 January 1998, Phoenix, AZ.

- A Comparison of Precipitation Measurements with the ASOS Heated Tipping Bucket Rain Gage and the Universal Rain Gage. 10th AMS Conference on Applied Climatology, 20-24 October 1997, Reno, NV.

- Climate Data Continuity with ASOS – Temperature. 13th AMS International Conference on IIPS for Meteorology, Oceanography and Hydrology, 2-7 February, 1997, Long Beach, CA.

Postprints, 68th Annual Western Snow Conference, April 18-20, 1999, Port Angeles, Washington

LIFE AFTER ASOS (AUTOMATED SURFACE OBSERVING SYSTEM)--PROGRESS IN NATIONAL WEATHER SERVICE SNOW MEASUREMENT

Nolan J. Doesken[1] and Thomas B. McKee

ABSTRACT

The National Weather Service is the primary source for snow measurements for areas of our country where most people live and work. Through its networks of first-order and cooperative stations, snowfall data are available for nearly every county of our country dating back many decades.

Important changes have occurred in NWS weather observations that are affecting the continuity of snowfall data. The single greatest change was the deployment of the Automated Surface Observing System (ASOS) at hundreds of airport weather stations across the country during the 1990s. ASOS does not measure snowfall or snow depth. It utilizes a heated tipping bucket rain gauge for measuring both rain and the water content of snow. This type of gauge tends to under measure the water content of precipitation that falls as snow, especially at temperatures well below the freezing point.

New snow measurement guidelines were implemented in 1996 to expand the use and consistency of snow data from cooperative observers. These guidelines allow snowfall measurements at intervals of no less than once daily to no more than once every six hours. Data were collected for two winters at volunteer locations in several states to assess the impact of measurement interval on measured snowfall. Results show that the time interval between measurements does affect the reported snowfall totals. Measurements taken every six hours produced snowfall totals 19% greater than measurements taken once each day. Similarly, measurements taken every hour produced snowfall totals 15% greater than if measured only once at the end of each 6-hour period. This suggests that data users must beware of this characteristic before analyzing time series or spatial snowfall patterns from different types of weather stations.

INTRODUCTION

This paper, on the subject of National Weather Service snow measurements, is written by someone outside of the National Weather Service as a direct result of the Climate Data Continuity Project (CDCP). The CDCP is a NOAA (National Oceanic and Atmospheric Administration) project funded since the early 1990s through NOAA's Environmental Services Data and Information Management program. The Climate Data Continuity Project was established to help provide collectors and users of NOAA climate data with information to help understand changes that may have been introduced during the 1990s. The National Weather Service deployed the Automated Surface Observing System (ASOS) beginning in 1992 as a part of their nationwide modernization program. Airport weather stations that previously had been staffed with professional round-the-clock weather observers turned over the function of surface weather observations to an array of electronic instruments.

The Colorado Climate Center has been a major contributor to the CDCP. The Center has conducted national evaluations of ASOS temperature and precipitation measurements. Comparisons of other basic climate elements have also been investigated. This paper looks at the impacts that ASOS has had on precipitation measurements across the country and on the measurement of snow in particular.

ASOS WINTER PRECIPITATION MEASUREMENTS

ASOS measures precipitation using a twelve-inch diameter heated tipping bucket (HTB) gauge. From the time of its initial deployment at a few stations on the Central Great Plains, this gauge was found to measure significantly less precipitation during the winter season than the conventional gauges that it replaced (McKee et al, 1994). ASOS gauge catch also decreased drastically as a function of temperature below 32 degrees Fahrenheit as shown in Figure 1.

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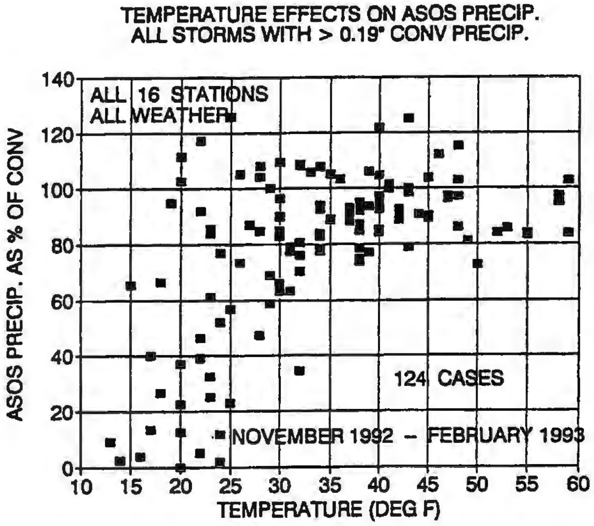

Figure 1. ASOS precipitation as a percent of Conventional measurements plotted as a function of temperature for each significant precipitation event (only events with greater than 0.19 inches from the conventional gauge were included), November 1992 through February 1993, from 16 stations (both commissioned and uncommissioned) ASOS comparison sites in the Central U.S. Temperature for each event was defined as a the mean ASOS temperatures, determined from hourly observations, for the 6-hour period with heaviest precipitation (from McKee et al, 1994).

Since initial deployment, some modifications have been made that improved the overall performance of the ASOS precipitation gauge for measuring rainfall (McKee et al, 1996). However, for the measurement of the water content of snowfall, it remains ineffective. Efforts are underway in the National Weather Service to replace the ASOS gauge with a better all-weather gauge for portions of the U.S. where snow accounts for a significant fraction of annual precipitation. Implementation could begin as early as 2002. However, many years of data from the HTB are already in the climatological archives meaning that data users will have to deal with years where winter precipitation readings are lower than they should have been for some stations.

Prior to the deployment of ASOS, snowfall and snow depth were measured by trained human observers following (hopefully) regulations established many years earlier for airways weather observations. A series of National Weather Service handbooks lays out the rules and regulations for these observations. Airport weather observers were directed to measure changes in snow depth every hour and report, by means of special remarks, snow depth increases if they equaled (when rounded) or exceeded one inch per hour. Actual snowfall was recorded every six hours at staffed weather stations. With the deployment of ASOS came a large and fundamental change. ***Snowfall was no longer measured.*** ASOS employed an electronic sensor for measuring the type and intensity of precipitation (rain or snow) but did not measure snowfall accumulations, total snow depth, or the snow water equivalent. ASOS was designed to serve the requirements of aviation as established by the Federal Aviation Administration. No specific requirements existed for snowfall measurement. This came as a surprise when the public and media realized snow observations at some major cities were no longer being taken by the National Weather Service. The winter of 1995-1996 really forced this issue as record snows fell over many eastern U.S. cities. The National Weather Service came face to face with a snow measurement crisis.

NWS SNOW MEASUREMENT GUIDELINES

At the same time, Doesken and Judson (1996) completed a book about snow and its measurement. Interest and use of snowfall data continued to grow greatly in the U.S. during the 1980s and 1990s. Snow is a major factor in the U.S. economy in both positive and negative ways. Snow is also a critical part of the global climate system. More and more research projects have sought out historic snowfall data. The primary sources for snow data in the U.S. for the locations where most people live and work are the National Weather Service first order stations (typically major airport weather stations) and thousands of cooperative stations that belong to the NWS Cooperative Program. Unfortunately, even from these official sources, snowfall data don't always stand up well to close scrutiny. The quality and continuity of historic snowfall data are sometimes questionable (Robinson, 1989).

The emerging snow measurement crisis led to a national snow measurement workshop sponsored by the National Weather Service and the Colorado Climate Center and held in Boulder, Colorado in September 1996. The results of this workshop were a new set of snow measurement guidelines for all National Weather Service weather stations (NOAA, 1996). No fundamental changes were made in how to measure snowfall. However, snowfall was more clearly defined as the greatest accumulation of new snow since the previous observation on a measurement surface prior to reduction by melting, compaction or other disturbance. The guidelines also attempted to achieve more uniformity between first order and cooperative observations. Through time, aviation observations had evolved such that some stations were measuring and clearing snow every hour while others measured every six hours. Most cooperative stations measure snowfall only once per day, either when snow ends or at a preset scheduled observation time. The new guidelines stated "This measurement should be taken minimally once-a-day (but can be taken up to four times a day).... Never sum more than four 6-hourly observations to determine your 24-hour total."

Findings by Doesken and Judson (1996) suggested that the frequency and timing of measurements of fresh snow accumulation could significantly affect data continuity. Since the new guidelines allowed a range of observational frequencies from a minimum of once per day to a maximum of once every six hours, some method of quantifying the effects was needed. Then, on January 11-12, 1997, extremely heavy snow fell in a narrow "lake-effect" band downwind of Lake Ontario. Subsequent reports from a snow spotter for the National Weather Service on the Tug Hill Plateau appeared to set a new national 24-hour snowfall record. With the new guidelines in place, the observation of 77 inches in 24-hours was not accepted as a new national record since it was the sum of six measurements from variable time increments, some of which were less than 6 hours (NOAA, 1997).

DOES THE MEASUREMENT INTERVAL AFFECT SNOWFALL TOTALS?

Unlike rain that lands in rain gauges and retains a constant volume after falling to the ground, snowfall is much trickier to measure. Snow melts, settles and may be redistributed by wind. Common sense tells us that the more frequently we measure and sum the accumulation of new deposits of snowfall, the more snow we will measure. Avalanche scientists have been aware of this for years (U.S. Dept. of Agriculture, 1961) but this has not been examined carefully when applied to National Weather Service data.

In the fall of 1997, a cooperative effort between the National Weather Service and the Colorado Climate Center was initiated to better document the effect of snow measurement interval on reported snow accumulations. Steve McLaughlin of the Buffalo, NY Weather Forecast Office and John Quinlan of the Albany, NY Weather Forecast Office each had a strong interest in this study and already had networks of trained snow spotters willing to help. Individual volunteers were identified from other states such as Colorado, Ohio, New Jersey, Maryland and North Carolina.

Participating snow spotters were asked to set up a series of snow boards for measuring snow accumulations for each of several different measurement intervals. During each snow event, snowfall was measured and then cleared from the appropriate board at intervals of one hour, three hours (at some stations), six hours, twelve hours (at some stations) and once daily. Observers also maintained a precipitation gauge for measuring snow water content. Additional information was recorded at the discretion of the observer including wind, temperatures and snow crystal type.

Despite a large number of participating volunteers, only 64 event data sets were obtained for the winters of 1997-1998, 1998-1999 and 1999-2000. Snow was nearly non-existent in the eastern U.S. for the winter of 1997-1998. Other potential storms could not be used if they included rain, freezing rain, ice pellets, or other conditions interfering with measurement interval comparisons. More than half of the candidate snow events from stations east of the Mississippi River were omitted due to rain and ice effects. We also learned how difficult it is for individual volunteers to maintain snow interval measurements for all intervals for the duration of a storm. Job and family responsibilities, plus the reality of sleep requirements, resulted in very few complete samples from storm beginning to end for all measurement intervals. Therefore, the data set is composed of some complete storm samples and many partial-storm segments.

Examples of snowfall measurements for different measurement intervals are shown in Figure 2 for three selected storms. For the majority of events, observed snowfall decreased as the interval between observations increased similar to the examples shown here.

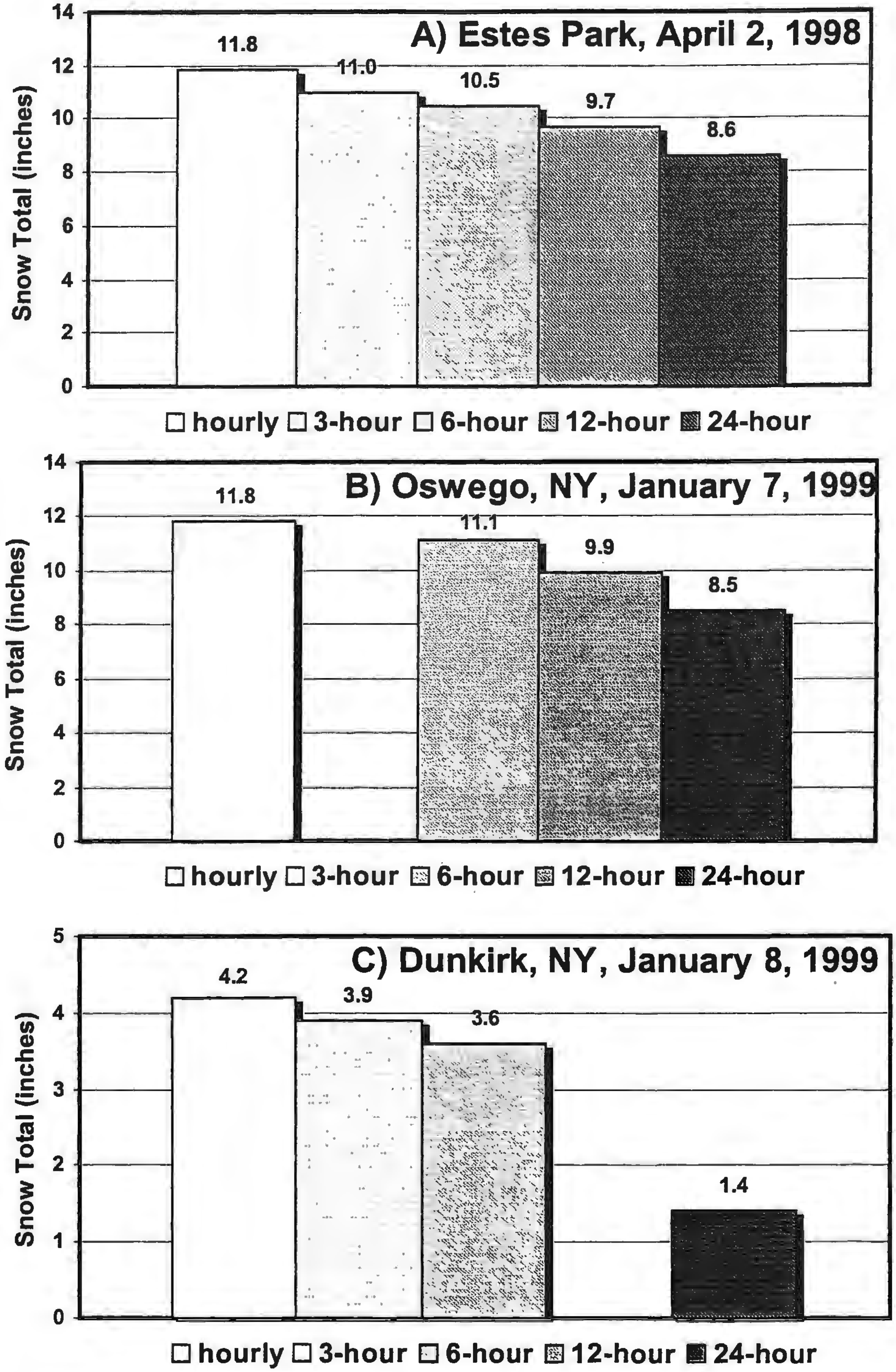

Figure 2. Examples showing the comparison of accumulated snowfall for different measurement intervals. A) Estes Park, Colorado, 4/2/1998, B) Oswego, New York, 1/7/1999, and C) Dunkirk, New York, 1/8/1999.

To quantify the relationship between measurement interval and accumulated snowfall, snowfall was summed for each measurement interval and compared to appropriate accumulations for coincident intervals. For example, if a storm (snow event) lasted 12 hours and all interval measurements were successfully taken, hourly measurements would be summed into four 3-hour totals, two 6-hour totals, one 12-hour total, and one 24-hour total. Likewise, each 3-hour interval measurement would be summed to form two 6-hour totals, one 12-hour total and one 24-hour total. The two six-hour interval measurements would be summed to form one 12-hour and one 24-hour total, and so on. Each sum would then be compared with the appropriate snow board accumulation for the matching period.

A summary of snowfall comparisons for different measurement intervals is shown in Table 1. Keep in mind that due to the volunteer nature of this effort the same storms may not be included in each sample. As a result, the measured snowfall and number of snow events vary from one category to the next. Despite these variations, it is very clear that the measurement interval does have a significant impact on snowfall totals. For the 28 snow events where measurements taken every six hours were summed and compared to the once-daily snowboard reading, the six-hour samples summed to 164.4 inches, 19% greater than the 138.4-inch total from once-daily observations. This is very relevant for the comparison of traditional first order station snow observations with that of surrounding cooperative stations. It clearly indicates that first order stations will likely report more snowfall than a nearby cooperative station for the same amount of new snow. Similarly, measurements taken every hour and summed into six-hour totals (327.9 inches) exceeded the six-hour measurements by 43.3 inches (15%) based on 45 events. Some professionally staffed weather stations have been measuring snowfall at hourly increments for many years. Such sites will report significantly more snow accumulation for the same actual snowfall than a station measuring less frequently. The largest differences were observed when measurements taken every hour and summed to form 24-hour totals were compared directly to once-daily readings. For 17 events, daily snowfall totals formed by summing hourly measurements equaled 118.6 inches, 30% greater than the 91.2 inches accumulation from coincident once-daily readings. Results are shown graphically in Figure 3.

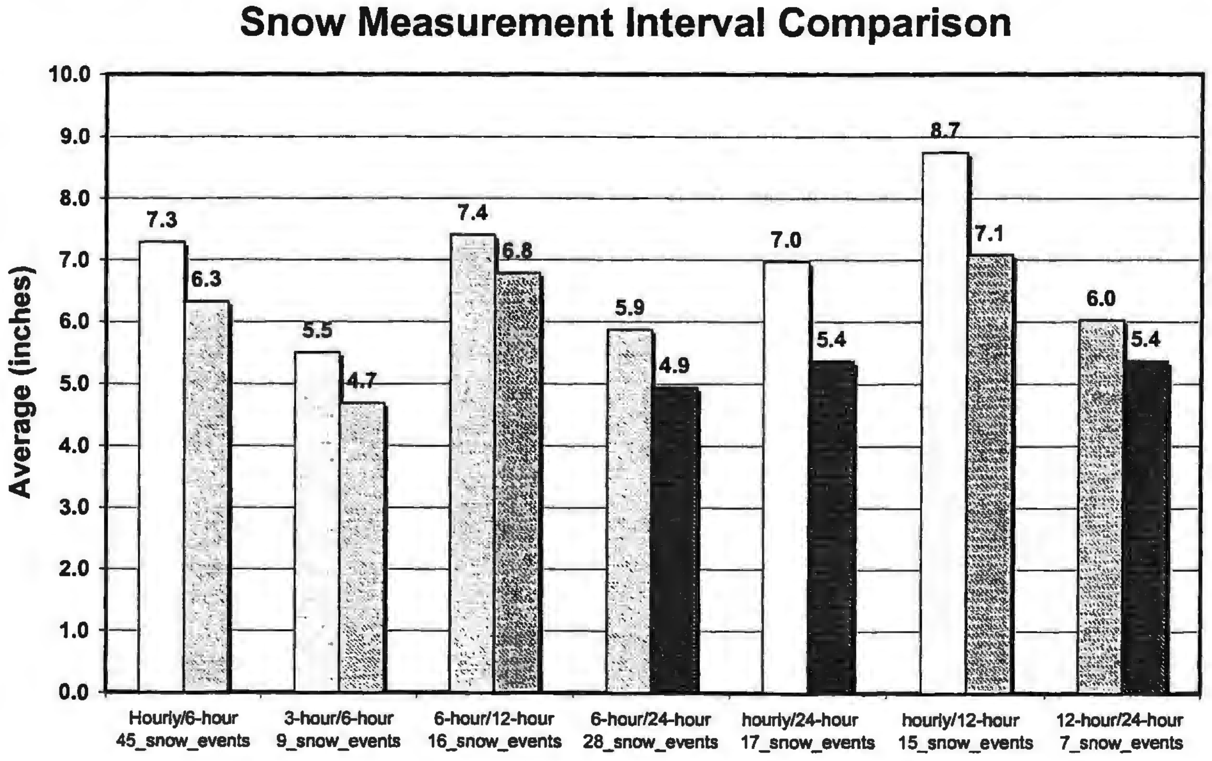

Figure 3. Snowfall comparisons for different measurement intervals. Values were normalized by dividing the total accumulated snowfall in each category by the number of events sampled.

Observed snowfall totals are a function of the measurement interval. While this may surprise some people, it is a logical outcome since snow changes over time. Measuring snowfall is similar to shooting at a moving target. While the accumulated totals appear to show systematic biases that are interval dependent, considerable variations were observed.

The small sample size for this study does not lend itself to meaningful discussions of variability, but more data will hopefully be gathered in the future. National Weather Service Offices in New York and Virginia continue to gather data from volunteer snow enthusiasts to extend this study.

Settling rates are nonlinear functions of time of day, temperature, wind, crystal structure, snow density, age of snow and other variables. Melting can obviously also contribute. In most subfreezing situations, snowfall totals obtained by summing short interval measurements (hourly or three-hourly) exceeded longer interval measurements. However, in some instances when snow fell at temperatures near the freezing point and especially during midday, snow accumulations on the one and three-hour interval snowboards were actually lower than for longer intervals. Melting occurred more quickly under these circumstances on the boards that were cleared the most often.

Table 1. Comparison of accumulated snowfall totals for specified measurement intervals for 64 snow events. This is a composite of all observations for all participating stations. Only periods with matching coincident measurements are included. The number of events in each comparison category is less than 64 since not all intervals were compared for each storm.

Snow Measurement Intervals Compared	**Number of Snow Events**	**Accumulated Snowfall in Inches**
6 Hours to 1 Hour	45	6: 284.6, 1: 327.9
6 Hours to 3 Hours	9	6: 42.2, 3: 49.5
6 Hours to 12 Hours	16	6: 118.5, 12: 108.6
6 Hours to 24 Hours	28	6: 164.4, 24: 138.4
1 Hour to 12 Hours	15	1: 131.2, 12: 106.3
1 Hour to 24 Hours	17	1: 118.6, 24: 91.2
12 Hours to 24 Hours	7	12: 42.2, 24: 37.6

DISCUSSION AND CONCLUSIONS

For snow experts accustomed to the deep snowpacks of the western mountains, this comparison of snowfall for different measurement intervals may seem trivial and irrelevant. However, for the millions of people who live and work in the cities, forests and agricultural lands of the valleys and plains of our country and whose lives are impacted briefly but dramatically by occasional snows, this project is far from trivial. Thousand of snow removal contracts are written each year based on official snowfall measurements. Urban snow removal budgets are set and adjusted according to snowfall measurements. Winter precipitation data from major cities across the country continue to be used in countless business applications. Teachers, students, researchers, businesses and the media routinely compare snowfall from one location to another and one year to another. Can the data truly be compared? It depends on how it is measured.

ASOS continues to under-measure winter precipitation at many stations across the country. This will continue until an all-weather precipitation gauge is deployed. Despite greater efforts during the past five years to standardize measurement procedures for snowfall, inconsistency is still a problem. As this study shows, even the best weather observers may report differences in accumulation per storm or for entire seasons by 15% to 30% simply due to differences in the time interval between measurements.

Snow data can be improved and should be. Understanding problems and data discontinuities has been accomplished with the help of NOAA's Climate Data Continuity Project. The 1996 National Weather Service Snow Measurement Guidelines were a large step in the right direction. However, by specifically allowing different measurement intervals, inconsistencies become inevitable. It is not easy to employ a single standard for measurement frequency, especially in a network that relies so heavily upon volunteers. Some volunteers are lucky to be home long enough to make a single measurement while others will eagerly measure as frequently as possible. There are still a few manual snowfall observations at first-order stations where most observers are measuring every six hours but some are measuring hourly. We hope that the information presented here will open people's eyes to the effects of observational differences. It is not trivial. With this knowledge in hand, improvements can be made leading to higher-quality long-term climate data.

REFERENCES

Doesken, N.J., and A. Judson, 1996: The Snow Booklet. *A Guide to the Science, Climatology and Measurement of Snow in the United States*. Atmospheric Science Department, Colorado State University, Fort Collins, CO, June, 84 pp.

McKee, T.B., N.J. Doesken and J. Kleist, 1994: Climate Data Continuity with ASOS - 1994 Annual Report. Climatology Report 94-1, Atmospheric Science Department, Colorado State University, Fort Collins, CO, December, 95 pp.

McKee, T.B., N.J. Doesken and J. Kleist, 1996: Climate Data Continuity with ASOS - Report for the Period September 1994 - March 1996. Climatology Report 96-1, Atmospheric Science Department, Colorado State University, Fort Collins, CO, December, 117 pp.

NOAA, 1996: Snow Measurement Guidelines (revised 10/28/96). U.S. Department of Commerce, National Weather Service, Silver Spring, MD, October.

NOAA, National Weather Service, 1997: Evaluation of the Reported January 11-12, 1997, Montague, New York, 77-Inch, 24-Hour Lake-Effect Snowfall. Special Report. Office of Meteorology, Silver Spring, MD, U.S. Government Printing Office, March, 41 pp.

Robinson, D.A., 1989: Evaluation of the collection, archiving, and publication of daily snow data in the United States. *Physical Geography*, 10, p. 120-130.

U.S. Dept. of Agriculture, 1961: Snow Avalanches: A Handbook of Forecasting and Control Measures. Agricultural Handbook No. 194. U.S. Government Printing Office, Washington, DC, 84 pp.

5B.1 A SUMMARY OF WIND CLIMATE CONTINUITY WITH ASOS

Thomas J. Lockhart, CCM, CMet

1. INTRODUCTION

This continuing project was first reported in October 1994 (Lockhart, 1995a), over five years ago. There have been many papers written by the author on this subject and how the changes effect different applications. Four papers were progress reports presented at both the National Weather Association and the AMS annual IIPS conference (Lockhart, 1996, 1997a, 1998a). One paper (Lockhart, 1997b) was the first to formally alert another technical community, wind engineering through ASME, of the consequences of the change to ASOS on the peak wind speed measurement. The next presentation (Lockhart, 1998b) was a report to the American Association of State Climatologists (AASC). At this meeting AASC adopted the standard 3-second running average as the definition of peak wind speed. The next paper (Lockhart, 1999b) reported these findings to the wind energy community through AWEA, the American Wind Energy Association. The last paper (Lockhart, 1999c) addressed international weather services converting to automatic weather stations.

Consequences of changing instrumentation and techniques measuring wind have been explored in the past, over and over again. In November, 1979, 21 years ago, the Electric Power Research Institute and the National Science Foundation jointly sponsored a Workshop on Wind Climate right here in Asheville. The purpose was to standardize wind measurements for the benefit of most applications using historical wind data. The recommendations included continuous 20-minute periods characterized by the means, 2-second peak speed, 1-minute peak speed (replacing the abandoned fastest mile speed), and standard deviation of fluctuations about the mean. In April 1992, 13 years later, OFCM (Office of the Federal Coordinator) sponsored a workshop the purpose of which was to find a standard characterization for wind measurements, the same goal. While a consensus was found by the 40 participants representing eight wind applications, OFCM chose not to adopt the consensus as a Federal Standard. The American Society for Testing and Materials Subcommittee D22.11, Meteorology, chose to advance the consensus as an ASTM standard (ASTM, 1996).

2. FINDINGS

Wind measurements are variable in space, time, and summarization methodology. If the pairs of instruments being compared are reasonably close together in a fairly flat location and use the same summarization methodology, the differences will be mostly random. Average speed differences can be expected to exceed ±0.2 m/s (0.4 kt.) and average direction differences can be expected to exceed ±2° unless the instruments introduce a bias (Lockhart, 1989). The wind part of the climate continuity study has concentrated on peak wind speed, average wind speed, and average wind direction.

2.1 Peak Wind Speed

Logic requires, given the shape of the speed distribution with time, that the longer the averaging time the smaller the average. When ASOS replaced the F420 with gust recorder the peak speed decreased. The 5-second clock average is longer than the approximately 2-second time constant (from an estimate of the combination of the frequency response of the galvanometer recorder and the distance constant of the cup anemometer). The size of the difference is a function of the time distribution of the speed. A sharp increase in speed, with a duration of about three seconds will be averaged to a smaller value if the algorithm is a 5-second average. The average will be even smaller if the gust peak occurs at the clock time for the 5-second average where part of the highest samples go in one 5-second bin and part go in the next. The gust recorder, on the other hand, follows the anemometer output continuously and the peak value is attenuated only by the response distance of the cups and the frequency response of the recorder.

One example, described in Lockhart (1997b), showed the difference to be between 8% and 35%. The range covers the 12 hours that were analyzed in ten minute periods. The important question is "what is the largest difference?" From an average speed of about 30 knots, one ten minute period had a difference of 13 knots. ASOS showed 45 knots while the gust recorder showed 58 knots. This 27% difference was for ASOS at 10m and the F460 at 6m. When the height difference is considered the difference increases to 35%. The important lesson of this case is the need to look at maximum differences and not average differences. When peak speeds build slowly over a minute or so there is no significant difference between the 5-second clock peak and gust recorder continuous value. It is the worst case, however, that is important.

The change to ASOS in the United States is one example of the change to automatic observing stations in the world. When digital systems are designed, decisions must be made about the details of sampling and averaging. The ASOS decision, based on commercial aviation applications, was to use a 5-second clock average speed from which the largest is kept as the peak speed. Many other organizations, sensitive to the need for a standard definition for peak speed, have chosen a 3-second running average as the definition. These include AASC, ASME, and the WMO (World Meteorological Organization). If peak wind speeds are to have meaning, the method used to sample and average the samples must be defined. The optimum solution is to have a standard method so data can be exchanged among different networks. The 3-second running mean leads.

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could be siting bias errors. It is possible, if the F420 were near a building at a lower height, that a siting bias could exist. Such a bias would be direction sensitive. An analysis of direction subsets was not conducted.

TABLE 1 Wind Direction Differences

Station		Average °	Std. dev. °
Binghamton, NY	BGM	2	17
Bismark, ND	BIS	-5	22
Columbia, SC	CAE	1	23
Cheyenne, WY	CYS	2	20
Fargo, ND	FAR	-4	15
Green Bay, WI	GRB	-4	18
Noctor, KY	JKL	1	27
Las Vegas, NV	LAS	-5	30
Lexington, KY	LEX	-23	24
Rapid City, SD	RAP	1	21
Russel, KS	RSL	-5	16
South Bend, IN	SBN	-7	19
Springfield, MO	SGF	16	21
Salina, KS	SLN	-8	19
Springfield, IL	SPI	-1	18
Tallahassee, FL	TLH	7	30
Tucson, AZ	TUS	-2	35
Valentine, NE	VTN	-2	29
Average		-2	22

3. REFERENCES

ASTM, 1996: Standard Practice for Characterizing Surface Wind Using a Wind Vane and Rotating Anemometer (ASTM D 5741-96). 100 Barr Harbor Drive, West Conshohocken, PA 19428

Lockhart, T.J., 1989: Accuracy of the Collocated Transfer Standard Method for Wind Instrument Auditing. *J. Atmos. and Oceanic Technol.*, **6**, 715-723.

Lockhart, T.J., 1995a: The Impact of Measurement Change on Climate Records. AMS 9th Conference on Applied Climatology, Dallas, TX, 16 Jan.

Lockhart, T.J., 1995b: Wind Climate Data Continuity Study. AMS 11th International Conference on Interactive Information and Processing (IIPS), Dallas, TX, 20 Jan.

Lockhart, T.J., 1996: Wind Climate Data Continuity Study II. AMS 12th International Conference on Interactive Information and Processing (IIPS), Atlanta, GA, 28 Jan. - 2 Feb.

Lockhart, T.J., 1997a: Wind Climate Data Continuity Study - III. AMS 13th International Conference on Interactive Information and Processing (IIPS), Long Beach, CA, 2-7 Feb.

Lockhart, T.J., 1997b: Wind averaging - the 5-second vs. 3-second vs. 1-second question. The 8th National Conference on Wind Engineering, Baltimore, MD, 5-7 June.

Lockhart, T.J., 1998a: Wind Climate Data Continuity Study - IV. AMS 14th International Conference on Interactive Information and Processing (IIPS). Phoenix, AZ, 16 Jan.

Lockhart, T.J., 1998b: Wind Climate Continuity with ASOS. American Association of State Climatologists, Duluth, MN, 6-7 Aug.

Lockhart, T.J., 1999a: Climate Continuity of Wind Speed With ASOS. AMS 11th Conference on Applied Climatology, Dallas, TX, 11 Jan.

Lockhart, T.J., 1999b: National Weather Service Data for Wind Energy Applications. Windpower 99, the American Wind Energy Association (AWEA) Annual Meeting, Burlington, VT, 22 Jun.

Lockhart, T.J., 1999c: Climate Continuity of Wind Speed With ASOS. 2nd International Conference on Experiences with Automatic Weather Stations, Vienna, Austria, 27-29 Sep.

Preprints, 12th AMS Conference on Applied Climatology, 8-11 May 2000, Asheville, NC

5B.2

CLIMATE DATA CONTINUITY WITH ASOS IN PRECIPITATION AND TEMPERATURE

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1. Introduction

Rainfall observations with the National Weather Service's Automated Surface Observing System (ASOS) are taken with the heated tipping bucket rain gage. The modified version of the gage was installed in the field starting in May 1996 and expanded through the network. A previous evaluation of the performance of the ASOS gage was reported by McKee et al. (1999) for data primarily based on one-minute observations. The results were that the ASOS rainfall values were within plus or minus 10% when compared to the Universal Rain Gage (UNIV) when the two gages were separated by less than one-mile. There were two sites where the ASOS reported much less rainfall which prompted the question – how well does the ASOS gage perform for daily precipitation compared to the UNIV gage at a larger number of sites? The current study addressed this question for all ASOS sites which have an operating UNIV gage and which produced enough rainfall for a comparison in the period 1996-1998 after the ASOS modifications were installed. McKee et al. (2000) have reported on a portion of this study. Dates for the installation of the modified ASOS gage were obtained from the National Weather Service. There are a few uncertainties about precise dates. Precipitation observations for the ASOS and UNIV were obtained from publications for the NOAA National Climate Data Center (NCDC) in Asheville, NC. One special note is that the ASOS observations published for the summary of the day (SOD) can be edited at the local National Weather Service Office and at the NCDC. This study is aimed at the continuity of climate so it is appropriate for examining the observations in the climate record.

2. Rain Comparison

A total of 44 National Weather Service sites are included in this study. Most sites are far enough north that frozen precipitation occurs, so only warm-season rainfall is included for most sites. As modified ASOS gages were installed, the number of sites increased. Table 1 shows the rain comparison for the number of sites with 3-year data from both gages for the summers of 1996, 1997 and 1998. Seven sites with three summers of data are summarized in Table 1. Each site is identified in location with the National Weather Service three-letter identifier. The date of the ASOS modification is given followed by the number of days with rain and the accumulated rain for ASOS and the UNIV. The ratio of the ASOS to UNIV rain is given. All of these sites were included in the previous study of 1-minute rainfall reported by McKee et al (1999) so the same ratio is given for that study. The current 1996-1998 summer results are quite similar to the previous results. The previous value of 0.87 at Wilmington, NC (ILM) was dominated by one large event. The three summers have increased that ratio now to 0.91. The ratios and the average of the ratios show the ASOS gage is performing quite well for the group. The exception is at Jackson, KY (JKL) where the ASOS observations are frequently edited to be the UNIV observations so the ratio of ASOS to UNIV is essentially 1.0.

Table 1. Comparison of ASOS to UNIV Daily Precipitation for Period Jun-Aug 1996, 1997, 1998

Location	Modification Date	No. Days	ASOS (in)	UNIV (in)	Ratio ASOS UNIV	Prev. 1 Min. ASOS UNIV '96-97
AMA	5/21/96	18	7.24	6.92	1.05	1.08
AST	5/9/96	49	11.66	11.08	1.05	1.06
GSP	5/14/96	82	32.09	34.33	0.93	0.97
ILM	5/6/96	70	52.26	57.43	0.91	0.87
JAN	5/6/96	61	31.48	30.81	1.02	0.95
JKL	5/6/96		AEU			
LCH	5/7/96	69	52.61	50.49	1.04	1.04
				Ave	1.00	

AEU = ASOS edited to Universal.

The 10 sites with 2 summers of observations had accumulated amounts of rain range from 11 inches to 25 inches with ratios ranging from 0.93 to 1.06 with the average of the ratios being 1.01. These comparisons show the ASOS gage is performing quite well. In this set one location is editing observations some of the time.

A total of 28 sites had one summer of data for June-August 1998. The average ratio of ASOS/UNIV was 0.98 with a range of 0.81 to 1.13. The accumulated rain amounts are smaller with some being less than 5 inches. Seven of the 28 sites did some editing of the ASOS data to match the UNIV.

A few comments on the data used for this study are noteworthy. The UNIV observations are published for hourly precipitation while the ASOS is the official daily observation for precipitation. Days with no value from

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the UNIV are not determined to have zero precipitation or to be missing. There were a number of days in this study in which ASOS had precipitation and the UNIV did not. These were not included in the analysis. Another rare observation occurred when ASOS and UNIV recorded the same rain amount on different but adjacent days. This analysis included only days on which both instruments reported rain.

Three warm sites including GSP, ILM and LCH have had daily data collection for all three years 1996-1998. Figure 1 shows a scatter diagram for each of the three years for GSP and the accumulated ratio of ASOS to the UNIV. A dotted line shows a ratio of one and the least squares fit to each year is the solid line which has the slope given in each graph. Approximately, 150 inches of precipitation are accumulated in the period with a ratio of 0.95 ASOS to UNIV. The accumulated ratio graph shows that the ratio does vary a small amount from year to year. This is an example of an ASOS gage that works well.

3. Temperature Comparison

The temperature portion of the study has been using Saint Louis, MO as a test site. Results of that portion will be included in the presentation.

References

McKee, T.B., Capt. R. Butler, N.J. Doesken, J. Kleist, N.L. Canfield, 1999: Climate data continuity with ASOS rain observations. Preprints, 11th Conference on Applied Climatology, 10-15 January, Dallas, TX, pp. 47-49.

McKee, T.B., N.J. Doesken, J. Kleist, N.L. Canfield, 2000: Climate data continuity with ASOS rain observations. Preprints, 16th Intl Conf IIPS for Meteor., Ocean., and Hydr., 9-14 Jan, Long Beach, CA, pp.318-319.

Acknowledgements

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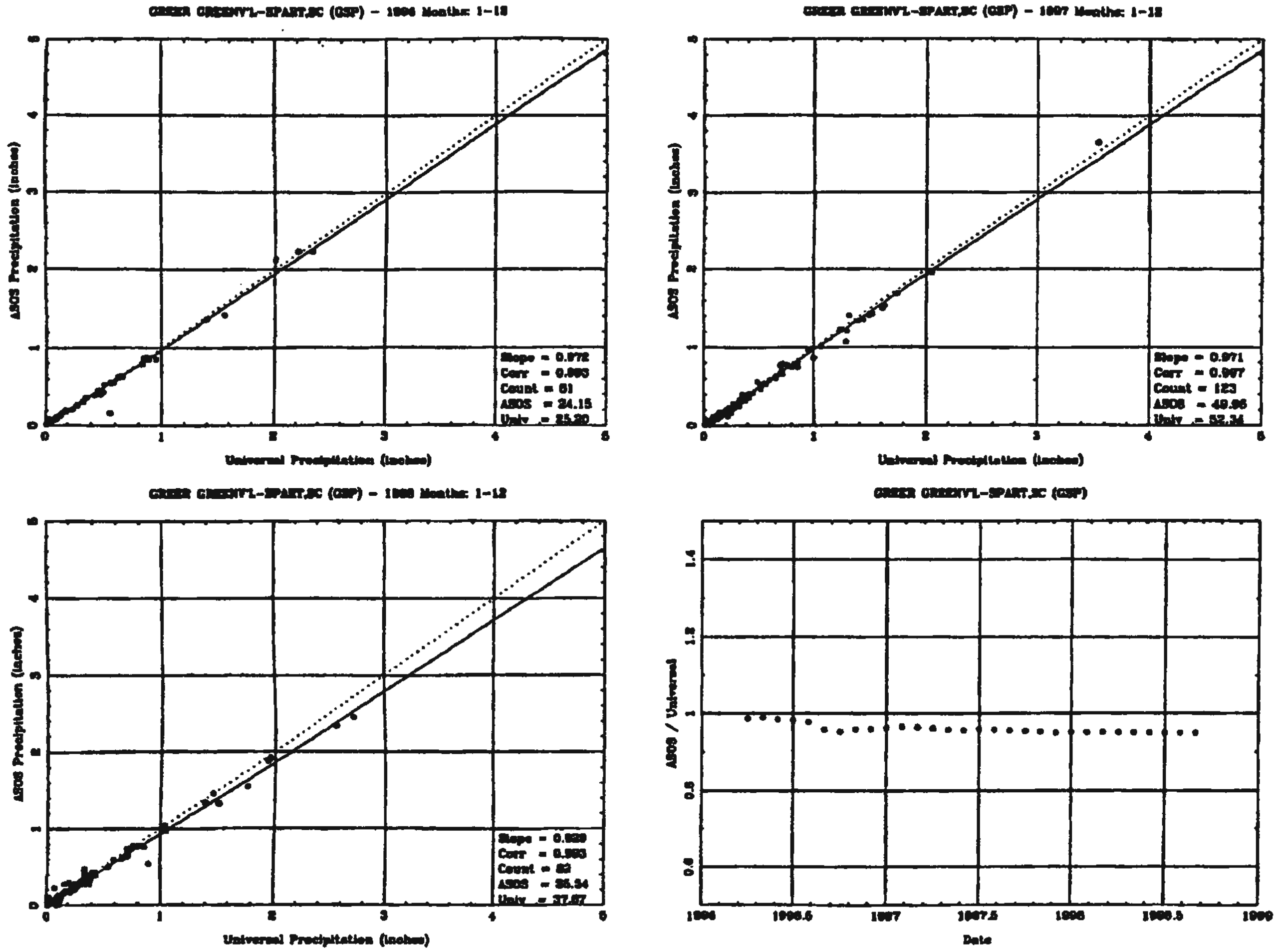

Figure 1. A comparison of ASOS to UNIV precipitation for Greer Greenville-Spartanburg (GSP), SC for 1996-1998.

16th International Conference on Interactive Information and Processing Systems (IIPS) for Meteorology, Oceanography, and Hydrology, 80th AMS Annual Meeting, 9-14 January 2000, Long Beach, Calif.

10.1

CLIMATE DATA CONTINUITY WITH ASOS RAIN OBSERVATIONS

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1. INTRODUCTION

Rainfall observations with the National Weather Service's Automated Surface Observing System (ASOS) are taken with the heated tipping bucket rain gage. The modified version of the gage was installed in the field starting in May 1996 and expanded through the network. A previous evaluation of the performance of the ASOS gage was reported by McKee et al. (1999) for data primarily based on one-minute observations. The results were that the ASOS rainfall values were within plus or minus 10% when compared to the Universal Rain Gage (UNIV) when the two gages were separated by less than one-mile. There were two sites where the ASOS reported much less rainfall which prompted the question – how well does the ASOS gage perform for daily precipitation compared to the UNIV gage at a larger number of sites? The current study addressed this question for all ASOS sites which have an operating UNIV gage and which produced enough rainfall for a comparison in the period 1996-1998 after the ASOS modifications were installed. Dates for the installation of the modified ASOS gage were obtained from the National Weather Service. There are a few uncertainties about precise dates. Precipitation observations for the ASOS and UNIV were obtained from publications for the NOAA National Climate Data Center (NCDC) in Asheville, NC. One special note is that the ASOS observations published for the summary of the day (SOD) can be edited at the local National Weather Service Office and at the NCDC. This study is aimed at the continuity of climate so it is appropriate for examining the observations in the climate record.

2. RAIN COMPARISON

A total of 38 National Weather Service sites are included in this study. Most sites are far enough north that frozen precipitation occurs, so only warm-season rainfall is included in the study. As modified ASOS gages were installed, the number of sites increased. Tables 1, 2 and 3 show the rain comparison for the number of sites with 3-year, 2-year and 1-year with data from both gages for the summers of 1996, 1997 and 1998. Seven sites have three summers of data summarized in Table 1. Each site is identified in location with the National Weather Service three-letter identifier. The date of the ASOS modification is given followed by the number of days with rain and the accumulated rain for ASOS and the UNIV. The ratio of the ASOS to UNIV rain is given. All of these sites were included in the previous study of 1-minute rainfall reported by McKee et al (1999) so the same ratio is given for that study. The current 1996-1998 summer results are quite similar to the previous results. The previous value of 0.87 at Wilmington, NC (ILM) was dominated by one large event. The three summers have increased that ratio now to 0.91. The ratios and the average of the ratios show the ASOS gage is performing quite well for the group. The exception is at Jackson, KY (JKL) where the ASOS observations are frequently edited to be the UNIV observations so the ratio of ASOS to UNIV is essentially 1.0.

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AMA	5/21/96	18	7.24	6.92	1.05	1.08
AST	5/9/96	49	11.66	11.08	1.05	1.06
GSP	5/14/96	82	32.09	34.33	0.93	0.97
ILM	5/6/96	70	52.26	57.43	0.91	0.87
JAN	5/6/96	61	31.48	30.81	1.02	0.95
JKL	5/6/96		AEU			
LCH	5/7/96	69	52.61	50.49	1.04	1.04
				Ave	1.00	

AEU = ASOS edited to Universal.

The 10 sites with 2 summers of observations included are given in Table 2. Accumulated amounts of rain range from 11 inches to 25 inches with ratios ranging from 0.93 to 1.06 with the average of the ratios being 1.01. These comparisons show the ASOS gage is performing quite well. In this set one location is editing observations some of the time.

The one summer data is shown in Table 3 for 1998. The accumulated rain amounts are smaller with some being less than 5 inches. Less than 15 days with rain were recorded at 2 locations. At 2 sites the date of the ASOS modification could not be determined or estimated. The range of the ratios has increased to 0.80 to 1.13 attributed in part to smaller total accumulations of rain. The average of the ratios remains quite close to 1.0 at 0.98. Seven out of 28 stations in this set (25%) are doing some editing of

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ASOS data to match the UNIV. Several of them have ratios at 1.0 or very close to it. The combination of ASOS observations and the editing appears to here to yield results quite similar to the UNIV observation which has been accepted standard for observations in the National Weather Service.

Table 2. Comparison of ASOS to Universal Gage (UNIV) Rainfall Period Jun – Aug 1997 & 98

Loc.	Mod. Date	No. Days	ASOS (in)	UNIV (in)	ASOS/ UNIV
ADQ	5/97	59	25.57	24.36	1.05 **
ANN	5/97	37	14.05	13.48	1.04
BIL	1/97	46	12.27	11.55	1.06
EWR	3/31/97	51	22.24	21.64	1.03
GLD	2/7/97	47	19.23	19.63	0.98
GRB	5/12/97	54	23.90	23.96	1.00
IND	5/19/97	49	19.45	20.94	0.93
MSN	3/97	56	26.48	25.53	1.04
PWM	3/28/97	50	22.44	21.87	1.03
SGF	5/19/97	49	20.71	21.92	0.95
				Ave	1.01

** Some AEU (ASOS edited to Universal)

A few comments on the data used for this study are noteworthy. The UNIV observations are published for hourly precipitation while the ASOS is the official daily observation for precipitation. Days with no value from the UNIV are not determined to have zero precipitation or to be missing. There were a number of days in this study in which ASOS had precipitation and the UNIV did not. These were not included in the analysis. Another rare observation occurred when ASOS and UNIV recorded the same rain amount on different but adjacent days. This analysis included only days on which both instruments reported rain.

REFERENCES

McKee, T.B., Capt. R. Butler, N.J. Doesken, J. Kleist, N.L. Canfield, 1999: Climate data continuity with ASOS rain observations. Preprints, 11th Conference on Applied Climatology, 10-15 January, Dallas, TX, pp. 47-49.

ACKNOWLEDGEMENTS

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Table 3. Comparison of ASOS to Universal Gage (UNIV) Rainfall Period of Jun – Aug. 1998

Location	Modification Date	Number of Days	ASOS (in)	UNIV (in)	ASOS/ UNIV	Comments
ABR	8/29/97	30	10.49	13.11	0.80	
BGM	11/23/97	28	8.36	8.33	1.00	AEU
BIS	10/97	20	4.79	4.80	1.00	AEU
BTV	11/26/97	48	24.74	23.90	1.03	
BUF	8/97	29	8.97	9.03	0.99	Some AEU
CDB	5/29/98	13	2.90	2.73	1.06	
CNK	7/31/97	37	12.37	11.92	1.04	Some AEU
CON	7/97	31	10.92	10.89	1.00	
DDC	3/17/98	21	7.51	6.68	1.12	All <1.0 in
DLH	10/6/97	25	10.31	10.69	0.96	Some AEU
FAI	2/18/98	30	4.65	4.10	1.13	
FSD	12/16/97	33	10.34	9.92	1.04	
GGW	10/97	26	6.69	6.84	0.98	
GTF	10/97	27	6.91	6.64	1.04	
HTL	7/30/97	17	2.88	2.88	1.00	AEU
ICT	10/28/97	26	7.10	7.03	1.01	
INL	9/24/97	35	8.41	7.86	1.07	Some AEU
ISN	9/16/97	21	4.75	4.50	1.06	
JAX	12/19/97	34	19.76	22.36	0.88	
JFK		10	5.79	5.04	1.07	
MOB	11/97	29	12.65	12.01	1.05	
MSO	11/6/97	29	7.39	7.01	1.04	
PHL	8/97	21	7.11	7.75	0.92	
SLC	7/24/97	16	4.86	4.46	1.09	
STC	7/24/97	28	10.70	10.58	1.01	
SYR		30	12.75	12.59	1.01	
TOP	11/97	23	14.00	13.18	1.06	
YAK	8/97	27	16.22	16.35	0.99	
				Average	0.98	

AEU = ASOS edited to Universal.

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Preprints, 11th Conference on Applied Climatology 79th AMS Annual Meeting 10-15 January 1999, Dallas, TX

2A.1

CLIMATE DATA CONTINUITY WITH ASOS RAIN OBSERVATIONS

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1. INTRODUCTION

The National Weather Service (NWS) has introduced the Automated Surface Observing System (ASOS) at more than 900 locations in the United States during the past few years. Rain is measured by a custom engineered heated tipping bucket rain gage (HTB). The initial HTB experienced problems, and a modified HTB was developed with installation at field sites beginning in May 1996. Most of the ASOS locations now have the modified HTB. The HTB is not an adequate gage for the measurement of frozen precipitation, and the NWS is actively pursuing an "all weather" precipitation gage for rain and snow.

The purpose of the present discussion is to compare the ASOS-HTB observations with other observations to evaluate performance for data continuity for weather and climate purposes. Two comparisons are included. One is the comparison of ASOS to another gage located very close to the ASOS gage. The colocated gages are not all identical but include a Universal Gage (UNIV), an 8 inch Standard Rain Gage (SRG), and a 4 inch rain gage. The intent of this comparison is to evaluate a few ASOS instruments in an absolute sense to a gage serving as a standard reference.

The second component is the comparison of the ASOS observations with concurrent observations from the UNIV which was the predecessor to ASOS. It is important to note that when ASOS was installed at each airport, the location of the weather station generally changed to be closer to landing and/or takeoff positions. Thus, the new ASOS gage and its predecessor generally are not colocated. Change of location can itself introduce a discontinuity in the climate record as well as adding variability to the ASOS-UNIV comparison, particularly during the convective season. For the purpose of this study, only sites where ASOS and the UNIV are within one mile or less of each other were included and where the UNIV had not been moved for some time prior to this comparison.

A total of 13 sites shown in Figure 1 with three letter identifiers have been used in this study. At each participating site, staff members of the local NWS Forecast Office operated the UNIV, filled out forms with total UNIV precipitation each six hours, and sent the forms to Colorado State University at the end of each month. Only a subset of the 13 sites were also able to install and maintain a colocated gage at the ASOS site. The ASOS observations are obtained from the National Climatic Data Center (NCDC) who upload the data directly from each site. Three ASOS data streams are used and compared. They include one-minute data, hourly data, and summary of the day (SOD) data. One-minute data are the original ASOS data and cannot be modified by a human at all. The hourly data can be edited operationally or at NCDC which is also the case with the SOD data. All three data sets must be examined to determine if ASOS data are being augmented.

2. RAIN COMPARISON

A comparison of the ASOS rainfall for one-minute, hourly, and daily observations with the observations from the colocated gages are given in Table 1. The four locations with colocated gages include Greenville-Spartanburg, SC (GSP); Jackson, MS (JAN), Lake Charles, LA (LCH) and Springfield, MO (SGF). The table includes the station identification, the period of the observations, the total accumulated rainfall for the colocated gage and the slope and ratio for each time period of minute, hour and daily. Slopes and ratios are very similar numerically. The consistency of minute, hourly and daily observations is very good indicating that ASOS was performing well and human augmentation was rare or nonexistent at these four sites. Three of the four sites had comparisons within ± 4 percent. One site (JAN) showed ASOS low by 7-8%. Figure 2 shows the relationship of ASOS and the colocated rain gage at GSP. This graph shows a stable relationship with small scatter.

A comparison of ASOS to the UNIV at all 13 sites is presented in Table 2. One minute and Summary of the Day (SOD) observations are included with the ratio of ASOS to UNIV and the slope of the line fitted to the observations. Total accumulated rainfall for one minute observations ranged from a low of 8.21 inches at AMA to more than 80 inches at JAN. The difference

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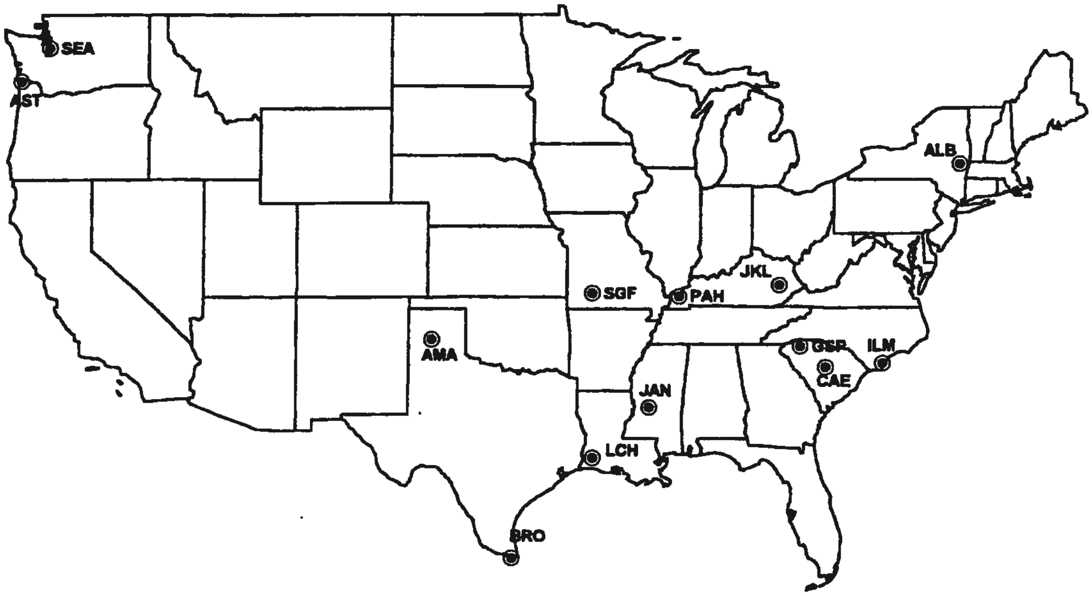

Figure 1. Station locations for the Climate Data Continuity Project.

Table 1. Comparison of ASOS (1 MIN, HRLY and SOD) to Colocated Rain Gage (CRG).

Station	Period	1 MIN to CRG			HRLY to CRG		SOD to CRG	
		CRG (m)	Slope	Ratio	Slope	Ratio	Slope	Ratio
GSP	7/96 - 5/97	32.81	0.97	0.97	0.96	0.97	0.96	0.96
JAN	7/96 - 11/97	44.50	0.92	0.93	0.92	0.93	0.92	0.93
LCH	7/96 - 5/97	12.43	1.01	1.02	1.01	1.01	1.01	1.00
SGF	7/96 - 11/97	25.86	1.03	1.02	1.01	1.01	1.02	1.02

CRG - Colocated Rain Gage; Slope - Least Squares Fit; Ratio - Ratio of ASOS accumulated rain to rain from the CRG.

Table 2. Summary of 1 MIN and SOD to UNIV.

Station	1MIN (in)	UNIV (in)	1 MIN / UNIV	Slope		SOD (in)	UNIV (in)	SOD / UNIV	Slope
ALB	11.74	11.83	0.99	0.96		5.47	5.27	1.04	1.00
AMA	8.21	7.60	1.08	1.08		5.21	4.88	1.07	1.05
AST	48.90	46.24	1.06	1.03		42.91	41.04	1.05	1.03
BRO	13.10	12.71	1.03	0.99		32.51	32.80	0.99	0.99
CAE	23.06	25.30	0.91	0.90		23.58	25.32	0.93	0.92
GSP	26.55	27.43	0.97	0.96		21.26	22.00	0.97	0.97
ILM	26.42	30.21	0.87	0.78		20.15	22.95	0.88	0.87
JAN	60.10	63.44	0.95	0.94		82.11	85.80	0.96	0.95
JKL	52.40	58.74	0.88	0.86		64.54	64.65	1.00	1.00
LCH	52.61	50.49	1.04	0.99		47.59	45.43	1.05	1.00
PAH	43.93	57.12	0.77	0.81		77.24	78.41	0.99	0.97
SEA	21.07	20.11	1.05	1.04		27.90	26.44	1.05	1.05
SGF	33.30	35.19	0.95	0.92		52.53	56.30	0.93	0.92
		Mean	0.97	0.94			Mean	0.99	0.98

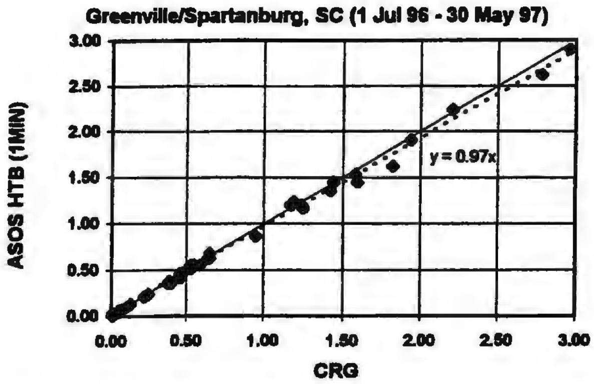

Figure 2. ASOS HTB (1 MIN) versus CRG (SRG) at GSP.

between the accumulated ratio and the slope are larger than the colocated analysis in Table 1. This is expected with the gages being up to one mile apart. The range of values of ratio or slope also vary more among the locations. In the one minute analysis three sites are of particular note. They are Willmington, NC (ILM), Jackson, KY (JKL) and Paducah, KY (PAH). These three have the lowest ratios of ASOS to UNIV. At ILM two large events caused the ASOS rain to be much smaller than UNIV and these also influenced the larger difference between the ratio and slope comparisons. No evidence indicates observing problems and one possibility is that spatial variation in convective storms is the cause. At JKL and PAH there is evidence that ASOS has a problem. Note the difference between the one minute and SOD ratios and slopes. Both JKL and PAH are augmenting ASOS observations on a few occasions and usually they use the UNIV observations so the SOD results have ASOS and UNIV in good agreement.

A general conclusion is that the ASOS rain gage is performing reasonably well at most locations with a range of ± 10% which includes differences in location of the gages. Two of the thirteen sites have gages that do not appear satisfactory. An important result is that the relationship of ASOS to the UNIV is quite stable.

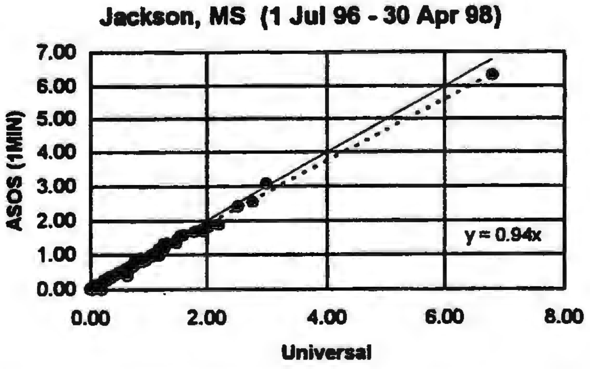

Figure 3. ASOS 1 MIN versus UNIV at JAN.

Figure 3 shows the observations from JAN. The stability of the relationship of ASOS to UNIV in Fig. 2 and Fig. 3 is a clear indication that ASOS could be evaluated relative to a fixed standard of the SRG. A recommendation is that each ASOS-HTB should have an 8 inch SRG placed beside it and that it should be read daily when rain occurs until a reasonable array of daily values have been recorded. The slope of the relationship then becomes a multiplier for that particular gage to allow the ASOS to have a known relationship to a standard. This would accomplish three goals. One is to provide the NWS with a known performance of ASOS. A second is to determine if ASOS is functioning properly. The NWS accepts only gages that pass a test with a fixed amount of rain to ± 4% prior to field installation. A third benefit is that if ASOS fails during a rain event (loss of power) the accumulated rainfall can be recorded in the SRG.

Planned future analysis of other rainfall and temperature intercomparisons will require more site-specific information about sensor exposures and system modifications, i.e., metadata. National Weather Service headquarters is taking steps to organize site-specific information gathered for management purposes into centralized databases that may improve accessibility for retrospective users of automated surface observations. Meanwhile, however, keeping accurate observational station histories for each and every observing site in its area of responsibility continues to be an important duty at each field weather office.

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10.15

CLIMATE DATA CONTINUITY OF RAIN OBSERVATIONS WITH ASOS

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1. INTRODUCTION

The National Weather Service (NWS) has introduced the Automated Surface Observing System (ASOS) during the past few years at most airport weather stations across the country. The introduction of ASOS has resulted in a new suite of instruments for measuring most meteorological elements. For the measurement of precipitation, ASOS uses a custom-engineered heated tipping bucket raingauge (HTB). After ASOS deployment began at a small number of sites in the central U.S., it did not take long to notice that the HTB often reported less precipitation than the Universal weighing-bucket raingauge (UNIV) that it replaced. The HTB was found to be inadequate for observing frozen precipitation (McKee et al, 1995) and, at many sites, it also undermeasured rainfall, particularly at greater rainfall rates.

After thorough studies of the HTB performance characteristics 1993-1995, several modifications to the gauge were proposed. Beginning in May 1996, a modified version of the gauge began to be phased in at selected sites and will eventually be in place at all ASOS sites. Rainfall data from this modified gauge are now being evaluated for data continuity for weather and climate observations. The preliminary results are presented below. In the meantime, the NWS is continuing to seek a satisfactory "all weather" precipitation gauge that can reliably measure both rain and the water content of snow.

The comparison of rainfall observed by ASOS and rainfall measured by the previous instrument has two components. The first component is to see how ASOS observations compare with concurrent observations from the Universal gauge (UNIV) which is the predecessor to ASOS. It is important to note that when ASOS was installed at each airport, the location of the weather station generally changed to be closer to landing and/or takeoff positions. Thus, the new ASOS gauge and its predecessor generally are not colocated. Change of location can itself introduce a discontinuity in the climate record as well as adding variability to the ASOS-UNIV comparison, particularly during the convective season. For the purpose of this study, only sites where ASOS and the UNIV stayed within one mile or less of each other were included and where the UNIV had not been moved for some time prior to this comparison.

The second part of the comparison involves a smaller number of sites where ASOS is easily accessible. An 8" diameter Standard Rain Gauge (SRG) has been installed beside the ASOS HTB and is read periodically by NWS local staff. For this purpose the SRG is considered an equivalent instrument to the UNIV. The intent of this part of the study is to verify ASOS gauge performance by comparing it to a colocated standard.

A total of 13 sites shown in Figure 1 with three letter identifiers have been used in this study. At each participating site, staff members of the local NWS Forecast Office operate the UNIV, fill out forms with total UNIV precipitation each six hours, and send the forms to Colorado State University at the end of each month. Only a subset of the 13 sites were also able to install and maintain a colocated 8" gauge at the ASOS site. The ASOS observations are obtained from the National Climatic Data Center (NCDC) who upload the data directly from each site. Three ASOS data streams are used and compared. They include one-minute data, hourly data, and summary of the day (SOD) data. One-minute data are the original ASOS data and cannot be modified by a human at all. The hourly data can be edited operationally or at NCDC which is also the case with the SOD data. All three data sets must be examined to determine if ASOS data are being augmented.

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2. RAIN COMPARISON

A comparison of the ASOS rainfall, as derived from one-minute, hourly, and daily data, with observations for a colocated SRG is shown in Table 1 for the period October 1996 through May 1997. Comparisons include only those periods when all data were available from each source. The four locations with colocated observations include Greenville-Spartanburg, SC (GSP), Jackson, MS (JAN), Lake Charles, LA (LCH), and Springfield, MO (SGF). The ratio of the accumulated ASOS rainfall determined from one-minute, hourly, and SOD data, respectively, to the accumulated SRG rainfall is shown in columns 2-4. Columns 5-7 give the slope of the least squares fitted line to the observations. These values can then be compared to the ratio of accumulated rainfall and the slope of the UNIV gauge to the SRG which are not colocated (columns 8 and 9). The consistency of minute, hourly, and daily observation is very good indicating that ASOS was performing well and human augmentation of observations was rare or non-existent at these four sites. The purpose of showing both ratios and slopes is to show if differences between gauge rainfall vary as a function of rainfall totals. In this case, the least square regression fit does give a different result, but the close similarity of the values shows that the relationship does not change much between smaller and larger values of precipitation.

Figure 2 shows the actual relationship of ASOS and SRG precipitation values at GSP for all individual events contributing to the totals in Table 1. For this station, ASOS has measured slightly less precipitation (95.6%) than the adjacent SRG, and differences have remained roughly the same regardless of rain amounts.

The original engineering specifications for ASOS precipitation measurements was stated to be ± 4%. These four locations show that ASOS agrees with the colocated SRG to within 5-6% with LCH being nearly identical. While some gauges are still slightly outside of the specified limits, ± 5-6% is a big improvement over the original ASOS HTB prior to modification. The ratios of ASOS to UNIV, which are not colocated, show a somewhat larger range from 0.92 to 1.10. These could be viewed as a measure of a local effect if the SRG and UNIV were assumed to be equivalent gauges. However, we have no firm evidence to conclude the gauges are identical. It is interesting to note that the average of the ratios across the four stations are within ± 2% of unity. No evidence is found in these data to indicate ASOS has a systematic bias.

A comparison of ASOS to the UNIV at all thirteen sites is presented in Table 2. These comparisons are for the ratio of accumulated precipitation for ASOS and UNIV where both observations are available. Columns (a) and (b) were developed independently but generally give similar results except for a few locations. AMA and ALB had less than 1 inch of accumulated rain in Column (b). CAE seems low in Column (a) for reasons which are not clear yet. JKL and PAH are different than any of the other locations and precipitation ratios are more similar to what had been experienced at many sites prior to making modifications to the gauge. They have many events in which ASOS is much lower than any of the other sites. The NWS staff at those offices augment the ASOS Summary of the Day data to make rainfall totals similar to UNIV. The impact of the changed values is seen in the last column which shows the ratio comparison for summary of the day ASOS observations for each site. The dramatic change in JKL and PAH is a strong indication that the ASOS has problems at these sites. The change at SGF is still being reviewed.

Many individual stations show ASOS precipitation to differ by more than the desired ± 4%. However, the average of the ratios of all sites is quite close to unity for each of the columns. The general conclusion is that the modified ASOS rain gauge is performing reasonably well at most locations with a range close to ± 10% including differences in location of the gauges.

ACKNOWLEDGMENTS

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REFERENCES

McKee, T.B., N.J. Doesken, J. Kleist, N.L. Canfield, 1995: Early results of climate data continuity with ASOS. Preprints, AMS 11th Conference for Meteorology, Oceanography and Hydrology, 15-20 January, Dallas, TX. Paper 16.3

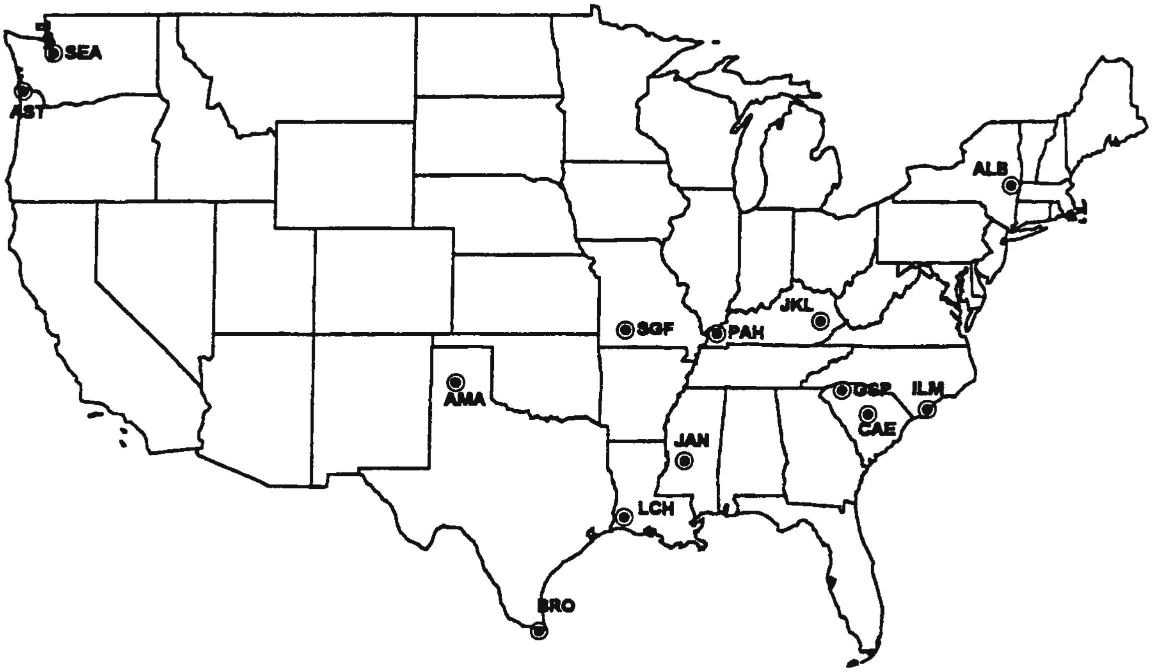

Figure 1. Station locations for the Climate Data Continuity Project.

Table 1. Comparison of Rain for ASOS, Colocated Standard Rain Gauge (SRG) and Universal Gauge (UNIV).

Station	Ratio of accumulated ASOS to SRG			Slope of least square fit for ASOS vs SRG			Ratio of accumulated UNIV to SRG	Slope of least square fit for UNIV vs SRG
	observation period			observation period				
	1 min	hour	day	1 min	hour	day	1 min	1 min
GSP	0.96	0.95	0.96	0.95	0.95	0.96	1.00	1.01
JAN	0.95	0.94	0.94	0.94	0.93	0.93	0.98	0.97
LCH	1.01	1.01	1.00	1.01	1.01	1.01	0.92	0.96
SGF (*)	1.05	1.05	1.05	1.04	1.04	1.04	1.10	1.09
Average	0.99	0.99	0.99	0.98	0.98	0.98	1.00	1.01

(*) = references 4" gauge.

Table 2. Comparison of the ratio of ASOS/UNIV accumulated rain derived from one minute ASOS observations and ASOS summary of the day observations.

Station	June - September 1996 (a)	June 1996 - March 1997 (b)	October 1996 - March 1997 (Summary of Day)
ALB	0.94	0.90	–
AMA	1.14	0.95	1.04
AST	1.13	1.10	1.04
BRO	–	1.09	1.03
CAE	0.85	0.94	0.94
GSP	1.01	0.99	0.95
ILM	0.90	0.97	0.88
JAN	0.95	0.95	0.96
JKL	0.91	0.86 (*)	1.02 (c)
LCH	1.06	1.08	1.05
PAH	1.06	0.75 (*)	0.97 (c)
SEA	–	0.96	0.98
SGF	0.94	0.96	1.09
Average	0.99	0.99 0.96 (*)	1.00

(*) = two sites included in average.
(a) = from all one minute data.
(b) = from 6 hour and 12 hour accumulation for one minute data.
(c) = these two change summary of day (SOD) observations from ASOS instrument.

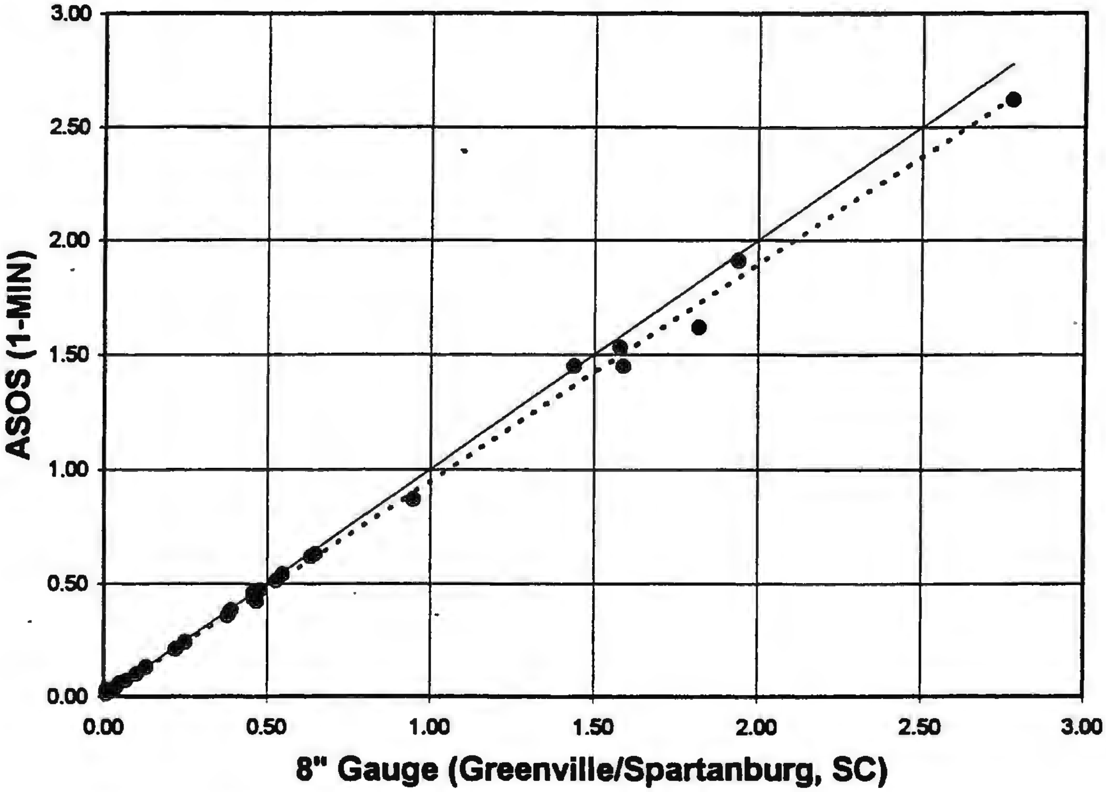

Figure 2. Comparison of rain events for ASOS and a colocated SRG for October 1996 - May 1997. Solid line is the equality and dashed line is least square line fit.

10TH CONFERENCE ON APPLIED CLIMATOLOGY, 20-24 October 1997, Silver Legacy Resort, Reno, NV

4B.4

A COMPARISON OF PRECIPITATION MEASUREMENTS WITH THE ASOS HEATED TIPPING BUCKET RAIN GAGE AND THE UNIVERSAL RAIN GAGE

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1. INTRODUCTION [1]

The National Weather Service (NWS) introduced the Automated Surface Observing System (ASOS) as part of the modernization of the NWS. The ASOS Heated Tipping Bucket precipitation gage was placed in the field in 1992. Modifications to the original gage were necessary and the final modified version of the gage now recognized as a rain gage began to be placed in service in May 1996. The replacement of gages continues at the present time. The NWS Climate Data Continuity Project is intended to assess the effect of changes in observing instruments and their location on the continuity of climate records.

The comparison of ASOS rain with the previous instruments has two components. The first is to compare ASOS observations with concurrent observations with the Universal gage (UNIV) which has not been moved for some time period. To accomplish this, the staff at each office operate the UNIV, fill out forms with precipitation each six hours, and send the forms to Colorado State University. The ASOS observations are obtained for the National Climatic Data Center (NCDC) who download the ASOS observations directly from each site. Three ASOS data streams are used. They include one-minute data, hourly data and Summary of the Day (SOD) data. One-minute data is the original ASOS data and cannot be modified by a human at all. The hourly data can be edited at ASOS and the SOD can also be edited. The second part of the comparison is to have a few sites place an 8" Standard Rain Gage (SRG) beside ASOS and read it periodically when someone can go from an office to ASOS located on the airfield usually less than a mile from the office. For this purpose the SRG is considered an equivalent instrument to the UNIV. The intent of this second portion is to verify that ASOS is making accurate observations which do not involve the instrument separation in space.

A total of 13 sites shown in Figure 1 have been used in the study for comparisons of rain. The comparisons presented here will include the ASOS SOD and co-located SRG and then the ASOS with the UNIV.

2. PRECIPITATION COMPARISON

A summary of the precipitation comparisons are presented in Table 1. The first column is the station identified. The second column is the comparison for June-September 1996 based on ASOS one-minute data accumulated to six-hourly periods or in some cases longer to complete a rain event. The third column is October 1996-March 1997 based on ASOS one-minute data accumulated to daily totals. Numbers in parenthesis to the right of the precipitation ratio is the percentage of total UNIV precipitation included. Some of the numbers are small due to incomplete recovery of ASOS one-minute data. The fourth column is the same October-March period but using the ASOS SOD data. The fifth column is the comparison of ASOS SOD data with the co-located SRG. AT GSP and JAN, the ASOS reports 0.95 of the SRG and LCH reports 1.03. The specification for ASOS is that it should measure 1.0 ± 0.04 for the ratio of ASOS to the UNIV gage. The results considered preliminary would indicate ASOS is very close to the specifications. At these three locations neither ASOS nor the SRG are shielded. At these three sites, the ratio information in the other columns reveal similar relationships which indicate no large local effects due to the location of the rain gage. In fact the pattern of comparison is quite consistent across the column with the exception of JKL and PAH. In both of these the ASOS-SOD values have been edited on occasion from the daily total accumulated from one-minute to be more like the UNIV observations. The collective

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set of all stations are used in each column to calculate the average of the ratios at the bottom of each column. This average of the ratios seems to indicate the ASOS gage is working relatively well at least for this data set. More complete analysis will be done in the coming months.

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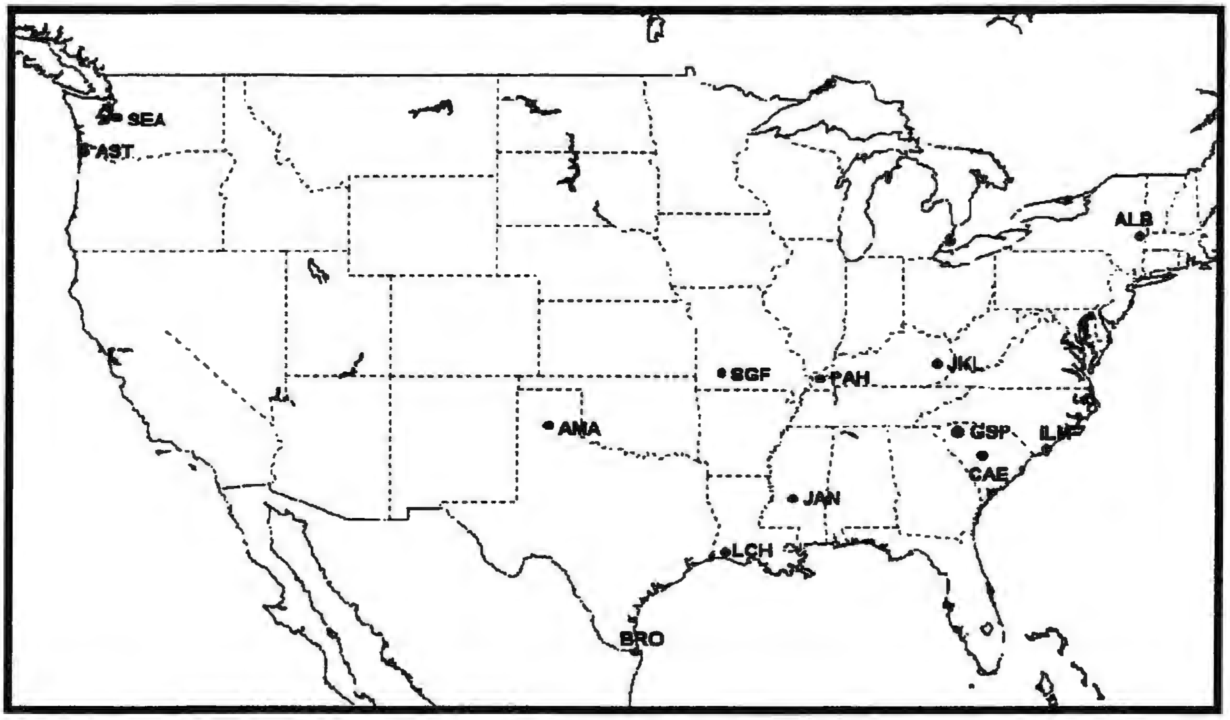

Figure 1. Station locations for the Climate Data Continuity Project

Table 1. Ratio ASOS/UNIV Precipitation

Station	Jun-Sep 96 (based on six-hourly)	Oct-Mar 97 (based on daily from 1-minute)	Oct-Mar 97 (based on SOD)	Oct-Mar 97 (ASOS-SOD vs. co-located 8" gage)	Comments
ALB	0.94	0.92 (39%)*	snow		ASOS biased low
AMA	1.14	1.03 (38%)	1.04		Variable
AST	1.13	1.05 (29%)	1.04		ASOS biased high
BRO	N/A	1.10 (24%)	1.03		Many ASOS 0.01 inch
CAE	0.85	0.95 (53%)	0.94		ASOS low at high end
GSP	1.01	0.97 (57%)	0.95	0.95	ASOS low at high end
ILM	0.90	0.87 (63%)	0.88		ASOS biased low
JAN	0.95	0.96 (55%)	0.96	0.95	ASOS low at high end
JKL	0.91	0.88 (57%)	1.02		Change SOD
LCH	1.06	1.09 (45%)	1.05	1.03	
PAH	1.06	0.76 (72%)	0.97		Change SOD
SGF	0.94	0.96 (37%)	0.98		
SEA	N/A	1.08 (39%)	1.09		Rooftop UNIV
Average	0.99	0.97	1.00		

* Percent of total UNIV precipitation included in the comparison.

13TH INTERNATIONAL CONFERENCE ON IIPS (13 IIPS)
77th AMS Annual Meeting 2-7 February 1997 Long Beach Convention Center Long Beach, California

1B.12

CLIMATE DATA CONTINUITY WITH ASOS – TEMPERATURE

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1. INTRODUCTION

The National Weather Service (NWS) has supported a program of Climate Data Continuity since the new automated Surface Observing System (ASOS) was implemented in 1992 to determine the impact of a new observing system on climate records. New ASOS's were commissioned beginning in the fall of 1992. In November 1993 a modified version of the ASOS hygrothermometer was introduced, and by summer of 1994 the modified instruments were located at all of the sites included in this study of temperature data continuity.

Temperature comparisons have now been made for two sets of sites. A preliminary report was given by McKee *et al.* (1996). The first group included the 15 sites shown in Fig. 1 based on midnight-to-midnight maximum and minimum temperature and on other observations during each day. Temperature comparisons were made between ASOS and the predecessor to ASOS which was the HO-83 hygrothermometer which is labeled as the conventional (CONV) instrument in this discussion. Data for this portion of the study are from June 1994 through August 1995 with minor exceptions. All of the ASOS instruments in this portion were commissioned, which means they were the official source of temperature data at the site.

A moratorium was placed on ASOS commissionings from the fall of 1994 until late spring 1995. The second set of comparisons came from sites which were not commissioned but for which 24-hourly temperature measurements were available from both the ASOS and the CONV HO-83 during the period September 1994 through August 1995. A total of 76 sites were included in the study. Since some were installed during the period and others were commissioned, which terminated the HO-83 data stream, there were 31 four-season sites (Fig. 2), 35 three-season sites, and 10 two-season sites. The twenty-four hourly observations were the data source for the comparisons since midnight-to-midnight maximum and minimum observations were not available.

2. DATA, DISCUSSION AND RESULTS

The introduction of the ASOS hygrothermometer introduced four issues to be considered in the analysis of temperature comparisons. Firstly and secondly, a new instrument has been installed which raises questions about the absolute accuracy of the ASOS temperatures and the relative difference between the ASOS and CONV temperatures. It would not be sufficient to determine a bias between them and not know which is closer to the true air temperature. Thirdly, the ASOS has been installed at airfields near take-off or landing areas which, at most sites, are distinctly different locations than the CONV instrument which was usually near the NWS office. A few sites have the ASOS and CONV co-located on the airfield. The change in locations allows for local effects to be important and to be quite different from site to site. The fourth issue is related to solar heating of aspirated hygrothermometers. In particular, there was a concern that the HO-83 could observe elevated temperatures during periods with light winds and high solar radiation.

The question of absolute accuracy was addressed by collecting information for the NWS test facility at Sterling, VA, and by taking a field standard temperature system to three ASOS instruments for a side-by-side comparison. An R.M. Young aspirated electronic temperature system, which was calibrated relative to a secondary standard at Sterling, VA, was used as the field standard. Our direct comparisons with ASOS at COS, OKC and TUL and the results of measurements by the NWS at Sterling, VA, show that ASOS does not have a temperature bias but does have a variability among ASOS sensors to the magnitude of ± 0.3°F.

The last three issues above lead to a formulation of the temperature difference of ASOS - CONV defined as ΔT with three possible contributors to give the equation:

$$\Delta T = \Delta T_i + \Delta T_\ell + \Delta T_s \qquad \text{(Eq. 1)}$$

where the subscripts of i, ℓ, and s are for ASOS - CONV instrument bias, local effect, and solar heating effect. The local effect could be different from day to night. Two analyses have been used to isolate ΔT_i. The first step considered only observations at night when ΔT_s is zero by definition. The local effect could be minimized by two meteorological conditions which include high winds to reduce temperature differences through mixing and advection and low overcast clouds to provide a rather uniform downward infrared radiation

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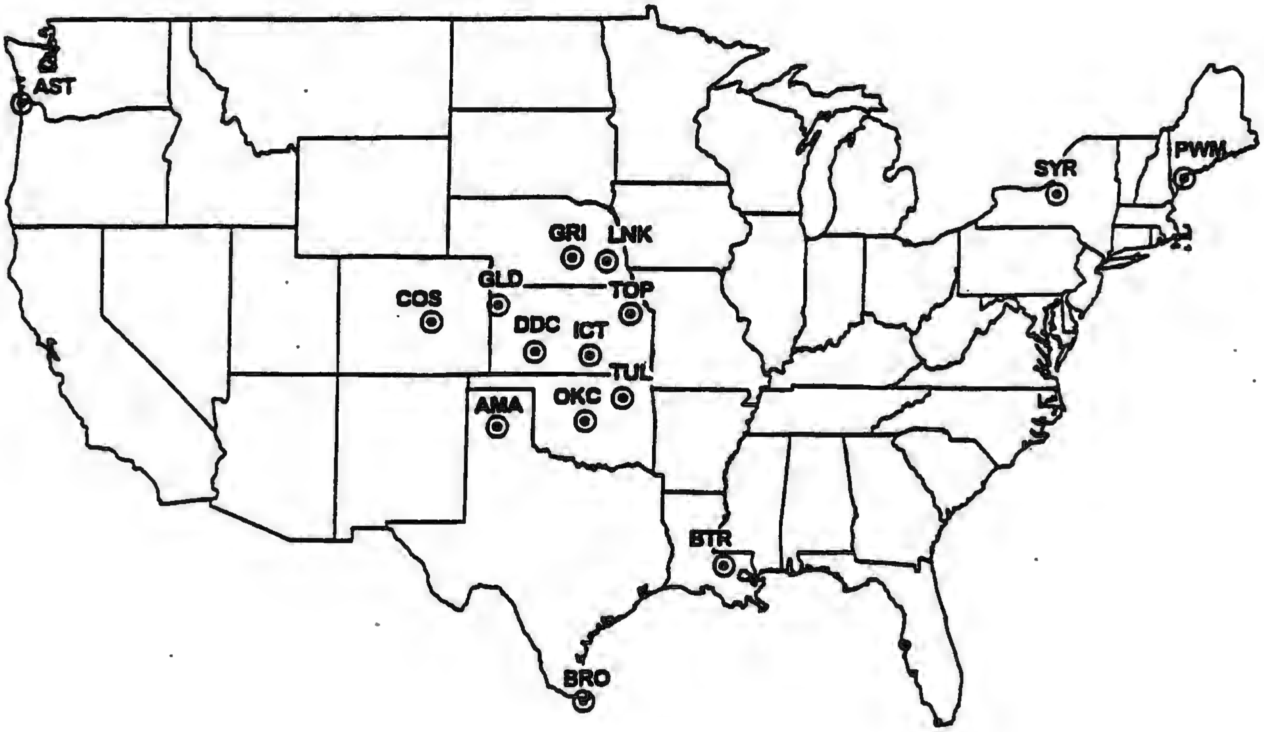

Fig. 1. *Location of 15 CDCP core sites.*

Fig. 2. *Location of CDCP four season expansion sites.*

source to reduce temperature differences. For the 15 sites in Fig. 1 the temperature at 0600 UTC and 1200 UTC for the entire period were used. Temperatures for these synoptic times were used only for the portion of the study to estimate ΔT_i.

If high winds or overcast skies isolate the effect of the instrument bias, the frequency distribution of the observations should become narrow. Since the ASOS and CONV instruments both report in whole degrees of temperature (Fahrenheit), the fraction of observations that are contained in the central three values has been used as a measure of the width of the distribution. Three was chosen simply by the logic that if the true value is near a whole degree, then that observation and one to either side should dominate the distribution. If the true value is near a half-degree point, one could argue for two points or four points. However, the number three has worked well. The results of the analysis with higher winds and overcast skies defined by ASOS showed that the condition of overcast skies yielded a narrower frequency distribution than higher winds. Thus, the overcast sky condition was used to define the instrument bias.

Results from this analysis showed that the fraction of the overcast observations contained in the central three group ranged from 0.94 to 0.99. The instrument biases were found to be negative at all sites (ASOS cooler than CONV) and are grouped by magnitude in Fig. 3. They range from -0.16 to -1.06°F and have a mean of -0.57°F. The confidence interval for the bias values at individual stations range from less than 0.1°F to nearly 0.3°F. These results show that the CONV instrument did have a warm bias and the range of the bias from instrument to instrument was quite large.

Once the ΔT_i is known, then the ΔT_ℓ at night is determined by rearranging the terms of Eq. 1 to

$$\Delta T_i = \Delta T - \Delta T_i \qquad \text{(Eq. 2)}$$

where the ΔT is the observed ΔT at minimum temperature where ΔT_s is assumed to be zero. The ΔT_ℓ for the 15 sites in Fig. 1 are shown in Fig. 4. The ΔT_ℓ can be positive or negative. The average of all 15 sites is -0.29°F. A few sites have quite large local effects at night. Four sites have ASOS cooler by 0.71°F to 1.10°F. Lincoln, NE, (LNK) is most interesting. The designation LNK-1 is the original ASOS location and ΔT_ℓ is -1.04°F. A number of problems were encountered with the instrument at this location, and the ASOS was moved in February 1996 to a location that is colocated with the CONV instrument. The local effect at night changed from a large negative value to less than -0.1°F for the new location which will be referred to as LNK-2. Notice also that the instrument bias in Fig.3 shows LNK-1 and LNK-2 to be virtually the same which should occur since the same instrument was used. The combination of instrument bias and nocturnal local effects made LNK-1 and Oklahoma City (OKC) very noticeable as ASOS minimum temperatures were about 2°F cooler.

The solar heating and daytime local effect can be isolated at the time of maximum temperature by subtracting the instrument bias from the observed maximum temperature which lead to the following expression

$$\Delta T_s + \Delta T_\ell = \Delta T - \Delta T_i \qquad \text{(Eq. 3)}$$

The combination of the solar heating and the daytime local effect is shown in Fig. 5. Most of the values are again negative with six sites having large values. These are interpreted as primarily due to solar heating of the CONV instrument. The two LNK sites are included along with Colorado Springs, CO, Tulsa, OK, Baton Rouge, LA, and Goodland, KS. The only surprise from a solar radiation point of view is Baton Rouge, LA. A close look at the observation shows that Baton Rouge is a weak wind location.

The study of the 76 sites with hourly observations prior to ASOS commissioning provided an independent evaluation of temperature data continuity with ASOS. Very similar results were obtained. The means of the instrument bias are -0.57°F (15 sites), -0.51°F (31 four-season sites) and -0.50°F (35 three-season sites). A total of 10 more sites had ASOS colder than CONV by more than 1°F. In nocturnal local effects, the majority of comparison sites showed ASOS cooler with some sites exceeding 1°F for some seasons. The solar and daytime local effects were also similar with large effects appearing at Albuquerque, NM, Jackson, KY, Madison, WI, and Tucson, AZ.

3. SUMMARY

The results of the climate data continuity study for temperature at 91 locations in the United States have shown the following results:

- ASOS has no temperature bias.
- The CONV instrument, the HO-83, has a warm bias of approximately 0.5°F.
- The average temperature change (ASOS - CONV) for minimum temperature due to local effects of the relocation of instruments is negative with several sites being cooler by 1°F or more.
- The average change (ASOS - CONV) for maximum temperature due to daytime local effects and reduction of solar heating from the HO-83 is negative with several sites being cooler by 1°F or more.

4. ACKNOWLEDGMENTS

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5. REFERENCES

McKee, T.B., N.J. Doesken, and J. Kleist, 1996: Climate data continuity of temperature, humidity and precipitation with ASOS. Preprints, 12th AMS Intl Conf on IIPS for Meteor., Oceanog. and Hydrol., 28 Jan - 2 Feb, Atlanta, GA, pp. 279-283.

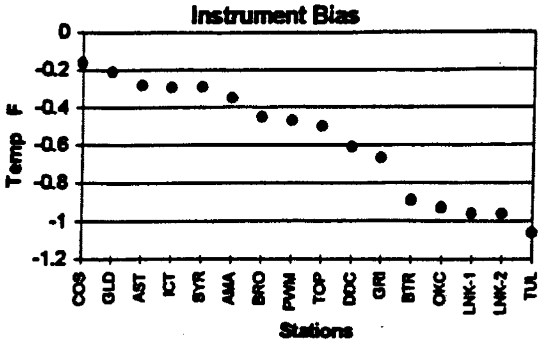

Fig. 3 *Instrument bias for 16 CDCP sites ranked in order of magnitude for ASOS - CONV*

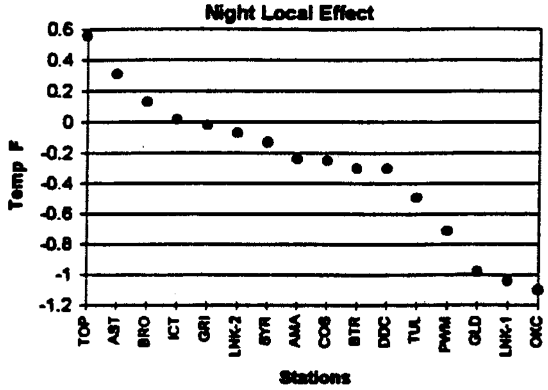

Fig. 4. *Night local effect of change in instrument location from 16 CDCP sites ranked in order of magnitude for ASOS - CONV.*

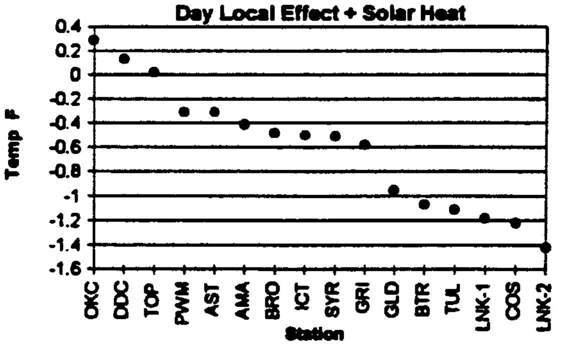

Fig. 5. *Combination of day local effect of change in instrument location and solar heating effect for 16 CDCP sites ranked in order of magnitude for ASOS - CONV.*

APPENDIX B.

Meteorological Standards Institute (MSI) Quarterly Reports for Wind Continuity for January 1998 through December 1999.

QUARTERLY REPORTS
for
January 1998 through December 1999

During the first quarter of 1998 consideration was given to the subject of peak wind speed sampling. Some data were being presented from Sterling which described average differences of sonic and Belfort anemometers. Given the variable frequency of wind measurements, the important measure is the maximum difference and not the average difference. Time was spent to prepare for a meeting with Dr. Bradley scheduled during the annual AMS meeting in Phoenix, Arizona. At this meeting the paper "Wind Climate Data Continuity Study - IV" was presented at the IIPS session. There were 56.3 hours charged during this quarter.

The second quarter was spent on data analysis (Sterling sonic and cup intercomparisons) of peak wind speed measurements. I was asked to review a "Test Plan for Comparing ASOS Five-second Wind vs. Three-second Wind" dated February 13, 1998. The document was reviewed in the form of a letter to Mr. Horvitz dated 10 April 1998 with copies going to Vickie L. Nadolski, Meka Laster, Richard Lewis, Mike Sturgeon, and Lynn Winans. Plans were started for a presentation to the annual meeting of the American Association of State Climatologists (AASC) in Duluth, MN on August 6 and 7. There were 89 hours charged during this quarter.

During the third quarter work was concentrated on the AASC presentation called "Wind Climate Continuity with ASOS." The paper was presented at the meeting in Duluth, MN. Data have shown that "hourly" wind speed values from the conventional F420/gust recorder system (1-minute average) and the ASOS systems (2-minute average) differ as a function of speed with ASOS reporting higher speeds at the high end and lower speeds at the low end. There were 28 ASOS cups calibrated in the Sterling wind tunnel and the results of these calibrations were examined to verify that ASOS was correct and the F420 was in error. A paper was written by Lockhart and Sturgeon called "Anemometer Calibration Methods." But it has not been submitted for publication as yet. There were 206 hours charged during this quarter.

The last quarter of 1998 started with additional work on the 28 cup analysis. Sterling was visited during 8/30 to 9/7/98 on ISO business. Some test data from Sterling were analyzed. The paper "Climate Continuity of Wind Speed with ASOS" was written and presented to the annual National Weather Association meeting in Oklahoma City, OK in October 20-22, 1998. Some work on requirement statements describing the 3-second running average appropriate for peak wind speed measurements was done. A request for an analysis of the differences in "calm" reports between the F420 and ASOS was requested. Data were reevaluated for calm comparisons and a graph was constructed describing the results. There were 255 hours charged during this quarter.

The first quarter of 1999 began with the presentation of "Climate Continuity of Wind Speed with ASOS" to the 11th Conference on Applied Climatology at the annual AMS meeting in Dallas, TX. Data from Sterling comparing sonic and cup anemometers were studied. The annual Workshop on Northwest Weather, sponsored by the National Weather Service, the University of Washington, and the local chapter of the AMS was attended. There were 112 hours charged during this quarter.

During the second quarter the analysis of Sterling data continued. There was an opportunity to bring the message of the value of ASOS data to another organization. The American Wind Energy Association met for its annual meeting in Burlington, VT during the 20-23 June period. A paper "National Weather Service Data for Wind Energy Applications" was presented. There were 48 hours charged during this quarter.

The third quarter of 1999 began with a trip to NCDC in Asheville, NC to contribute to the wind measurement part of the planning phase of the Climate Reference Network (CRN) meeting. The quarter included foreign travel for two projects. The 2nd International Conference on Experiences with Automatic Weather Stations met in Vienna, Austria during 27-29 September. A paper "Climate Continuity of Wind Speed with ASOS" was presented to bring information which had been presented in the United States to an international audience. Because of this opportunity to bring our experiences with ASOS to this new group of scientists, the paper originally intended for presentation at the National Weather Association meeting was canceled. There were 131 hours charged during this quarter.

There were no hours charged during the fourth quarter.

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