RECONSTRUCTION OF DAILY 1820-1872 MINNEAPOLIS-ST. PAUL, MINNESOTA TEMPERATURE OBSERVATIONS

by

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ABSTRACT

Utilizing multiple regression conversion models generated from hourly 1961-1980 local weather bureau observations, the military and civilian volunteer 1820-1872 Minneapolis-St. Paul fixed-time scheme daily temperature data are transformed to midnight to midnight daily absolute maximum and minimum estimates. This unifies the old data as to observation method internally and creates a match with the method used at the local St. Paul and Minneapolis first-order weather bureau stations from 1873 on. Preliminary testing of the models on the same 1961-1980 empirical data determines that reasonably accurate conversions are possible. The major monthly mean temperature features of the 1820-1872 era are described using conversion model derived figures.

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I. INTRODUCTION

The Minneapolis-St. Paul, Minnesota pre-weather bureau era daily temperature record is one of the lengthiest and most complete in the United States, 98 percent intact from January 1, 1820 to December 31, 1872. Included are observations by the military at or near Fort Snelling, January 1820 through April 1858, and by the St. Paul Smithsonian observer, Reverend A. B. Paterson, January 1859 through December 1872. In addition to providing insight as to the general character of this period's temperatures, the data set, when merged with official weather bureau data from 1873 on, enlarges the observational volume by nearly 50 percent. Given these qualities, it is a very attractive object of study for one interested in nineteenth century climate or consolidation of a local climatological history.

Unfortunately, analysis and interpretation of ninteenth century records of these kind along with comparisons with more recent periods have to be accompanied with qualifications, namely references to the unknown exposure techniques, uncertain instrumentational qualities, changes in the environment, site changes, and discrepancies in monthly mean averaging methods. The first four complications are very difficult to objectively correct for a single locality's data. Indeed, some of these factors complicate interpretation of official weather bureau temperature data as well. The last factor, however, different averaging methods, presumably generates systematic discrepancies in monthly mean computation which should be adjustable using suitable statistical techniques.

The purpose of this study is to convert the pre-1873 Minneapolis-St. Paul fixed-time scheme daily temperature observations to midnight to midnight absolute maxima and minima estimates. The approximated maxima and minima will be generated from multiple regression models representing 1961-1980 relationships between meteorological variables at the pre-1873 observation times. To evaluate the regression models' potential for producing accurate results, conversions will first be done on the 1961-1980 empirical data itself, with comparisons made between the estimated and actual maxima and minima.

Assuming that such a conversion on the modern data is found to be feasible and that the models' application on the 1820-1872 data is a reasonable and valid exercise, the old data will be effectively homogenized as to observation method, both internally and in relation to the post-1872 first-order station weather bureau data.

Mean temperatures for calendar periods in which data are missing will also be estimated, using substitution of contemporaneous mean temperature data from other nearby military or civilian observations into linear regression models of modern-era temperature relationships between Minneapolis-St. Paul and present-day stations corresponding to the former military/civilian observers' locations.

In addition to unifying the temperature record as to observation method, results of the study might serve as a guide or method for future analyses of other localities' pre-weather bureau era temperature data. No such conversion of fixed-time scheme temperature observations has been previously attempted.

2. HISTORICAL BACKGROUND

The first organized national weather observing network was initiated by the military in 1814, when the Physician and Surgeon of the U.S. Army directed hospital, post, and regimental surgeons to keep weather diaries. The War of 1812, lasting into 1815, prevented perfection of the system, but in 1818, the Surgeon General issued another order for each Army post surgeon to "keep a diary of the weather . . . noting everything of importance relating to the medical topography of his station" (National Archives 1981, p. vii).

2.1 The Fixed Time Scheme Methods of Observing Temperature During the Pre-Weather Bureau Era

Owing to the time and effort involved in taking hourly temperature readings and the absence of self-registering thermometers, the military in 1818 first adopted the method of taking daily observations at 7 am, 2 pm, and 9 pm local time (National Archives 1981, p. vii). This scheme along with several other fixed format methods were the bases for observing and averaging temperatures throughout the pre-weather bureau era. The military's initial choice was probably influenced by a study done by Professor Chester Dewey of the New York Academy System a few years earlier. Analysis of hourly New York temperature data over the three-year period 1814-1816 determined that the best hourly grouping representing daily means of the 24 hours without correction was the 7 am/2 pm/9 pm "set." Results of Dewey's research established the 7 am/2 pm/9 pm scheme as the standard method, and most American observers subsequently began using it for daily readings and monthly mean computations (Alexander 1924, p. 120).

Blodget, in a more geographically comprehensive study found that the 7 am/2 pm/9 pm method also approximated most accurately the mean of the 24 hours for a collection of seven named (Toronto, Philadelphia, Washington, Key West, Mobile, Galveston, and El Paso) and other unnamed coastal and interior locations. The 6 am/2 pm/ 10 pm and Sunrise/9 am/3 pm/9 pm methods were also found to be "sufficiently near for most purposes." Daily extreme temperatures, however, were less satisfactorily represented, noted as "correct only in the middle latitudes, being much in error in Canada, and at parts of the Gulf Coast." Blodget wrote that while the 7 am/2 pm/9 pm method sometimes yielded averages too high for certain locations and "generally a little too great for the summer months in the United States" it was "much more nearly correct than any other which may be used for simultaneous observation over the entire area of the United States" (Blodget 1857, p. 37). The findings of this report resulted in the Smithsonian Institution, which had organized a volunteer observational network in 1847, adopting the 7 am/2 pm/9 pm method in 1853. The Surgeons General's office, overseers of the military post observations, readopted it in 1855 after having officially dropped it in favor of the Sunrise/9 am/3 pm/9 pm method in 1843 (Alexander 1924, p. 120).

From the above, it is evident that the 7 am/2 pm/9 pm and other fixed time scheme procedures were expedient methods, appropriate under the existing circumstances but not without recognized deficiencies. The major consequence of these deficiencies, of course, is that the reported monthly means and extremes for stations of the era contain geographically related data biases.

2.2 The Fort Snelling Data

Fort Snelling was established in 1820 on a 100 foot bluff above the junction of the Minnesota (then St. Peter) and Mississippi Rivers, as part of a planned system of forts along the Louisiana Purchase fringe. Its initial purpose was to secure the frontier from British influence, capture fur-trading profits for the United States, and keep peace between the skirmishing Sioux and Chippewa Indians (Ziebarth & Ominsky 1970, p. 27). Meteorological observations were part of the earliest activities of the post, as the chief medical officers of the army were interested in the effect of climate on the health of soldiers (National Archives 1981, p. vii).

2.2.1 Early Variations in Observational Site

The initial military encampment, established in August 1819, was not located on the bluff overlooking the two rivers but in the bottom-lands on the right bank of the St. Peter river near the southeast end of the present-day Mendota bridge (Ziebarth & Ominsky 1970, p. 7). Temperature observations evidently commenced as early as October 1819, but for this month, as well as November and December 1819, only records of the reported monthly means survive. The encampment, along with the meteorological observations, remained here until mid-May

1820, when a move was made across the river to a location northwest of the permanent site of the fort. As the new location was situated near a spring, it was named "Camp Coldwater" (Ziebarth & Ominsky 1970, p. 11). The move must have taken about three days as evidenced by the fact that there are no weather observations in the meteorological diary for May 21-23, 1820. Instead, it reads: "moving from St. Peter's to Cold Water Camp." While the cornerstone for Fort Snelling was laid in September 1820, the fort was not completed until 1824 (Ziebarth & Ominsky 1970, p. 11); thus, there is also some uncertainty as to when the thermometer readings actually began being taken within the enclosure. These historically documented site changes indicate that the 1820-1824 observations were made in at least three places, including both valley and hilltop terrain.

Evidence also exists, both in the diaries themselves and from independent sources, that exposure directions of the thermometers were not constant. For example, in the weather diary for the third quarter of 1820, the Fort Snelling surgeon noted that the thermometer had been placed in the shade with a northwest exposure. However, for the first quarter of 1821, it was described as standing in the shade with a northeast aspect. In 1823, the explorer William H. Keating visited the post and observed that the thermometer was exposed to the southwest (Ludlum 1968, p. 179).

These early indications of exposure inconsistencies, all before 1824, possibly relate to the fact that the fort was still under construction, and a permanent spot inside the stockade had not yet been selected for the thermometer. While there may have been other exposure direction changes at the fort, no other such references appear in the diaries after the first quarter of 1821.

In addition to these exposure direction uncertainties, no information is recorded in any of the diaries regarding observation heights of the thermometers.

2.2.2 General Quality of the Data

Much of the criticism regarding the early pre-weather bureau temperature observations concerns the questionable instrumentation and uncertain exposure techniques (Ludlum 1968, p. 179). As to thermometers, some information is available regarding the nature of the instruments at Fort Snelling. The explorer Keating, during his 1823 visit at the post, inspected the thermometer and found it to be a glass tube attached to a brass plate with marked gradations. This type instrument, which reportedly was supplied to all the military posts of the time, was manufactured by a Mr. Fisher of Philadelphia, who was well-regarded as a thermometer-maker. Curious about the effects of the sun's rays on heating the brass back plate, Keating performed some tests and found the contamination effect to be ten degrees or more (Ludlum 1968, p. 179). While no mention is made of an assessment of the Fort Snelling thermometer's placement (Fort Snelling was actually called Fort St. Anthony in 1823), he did report that some posts of the observing network had their thermometers facing into the rays of the sun (Ludlum 1968, p. 179).

Twenty years later in 1843, the military reorganized its weather observing activities. In addition to changing the times of temperature observations to Sunrise, 9 am, 3 pm, and 9 pm, the military posts were all issued new standardized instruments. Again, these were reportedly made by a reputable manufacturer, George Tagliabue of New York City (National Archives 1981, p. viii).

The above accounts indicate that at least some of the Fort Snelling temperature observations were made with instruments that were up to contemporary standards. The level of these technological standards is, of course, uncertain, but there does seem to have been an effort to supply the fort with good thermometers.

Exposure methods and their influences on the post temperature observations are impossible to assess directly, although the enclosed nature of the fort and its site on a steep bluff one hundred feet above the junction of two rivers had the potential for producing occasionally peculiar readings. For instance, a surgeon resident at Fort Snelling in 1826 noted: "thermometer two miles from post on several occasions reads 10° to 11° lower -- compared and found to agree -- believe the fort with its 60 fires responsible." This of course, was an early observation of "heat island" influences on temperature observations (Ludlum 1968, p. 179). In another account, relating to the effects of cold air drainage in producing hill/valley temperature discrepancies: "Mr. Prescott's thermometer at his home near Ft. Snelling ranges 2 to 7 degrees lower than at the fort, the difference increasing with the intensity of the cold. On the morning of

18 February 1849, the Ft. Snelling instrument read -30°, Mr. Prescott's -37°, and that of Dr. Williamson, who lived on a level with the Mississippi River, -40°" (Ludlum 1968, p. 179).

Other influences on the quality of temperature observations at Fort Snelling, of course, relate to the competency of the observers themselves. While the head surgeon was evidently entrusted with the responsibility for making the observations, signatures on the diaries include those of Surgeons, Acting Surgeons, Acting Assistant Surgeons, Hospital Stewards, and even Indian agents. A total of 28 names appear in the reports from 1820 to 1858, probably representing a wide range of personal interests and skills in making meteorological observations. In spite of the observational quality uncertainties, the mere existence of an early temperature record of this kind for a location so far into the interior is regarded as very fortunate for historical meteorology (Ludlum 1968, p. 180).

2.2.3 Other Complications Involved with The Fort Snelling Data

A problem concerning the application of the temperature estimation models on the Fort Snelling data, especially before 1843, was the fact that daily wind and sky cover observations were qualitative and did not coincide directly with the time of the temperature observations. To illustrate, for the 1820-1835 period, wind direction and sky conditions received only one entry daily in the diaries, the sky cover observations being expressed as either "cloudy" or "fair." Moreover, daily wind speed observations were recorded only intermittently and in qualitative Beaufort scale terms. For lack of other information, the once-daily wind direction and sky cover observations were assigned to each of the thrice-daily temperature observation times. Quantification of the sky cover data and estimation of the missing wind speed information were done using mean 1961-1980 statistics, generated by calendar month for each of the 7 am, 2 pm, and 9 pm observation times.

Another complication was the fact that the Fort Snelling observation times were not at standard time, but at some form of local time. If the discrepancies between 1961-1980 standard time and Fort Snelling local time were large, this might adversely affect the accurate estimation of overnight minima, especially from 7 am temperatures in summer. Also, one had to assume that the observers actually took the temperature readings at the specified times. Peculiar average daily ranges or differences between observation times might suggest evidence to the contrary. A rather glaring example of deception is seen for the October 1827 diary, which was copied line-for-line from the October 1826 report.

2.2.4 Variation in the Times of Observation

Four observational formats covering five separate time periods are displayed in the Fort Snelling weather diaries. These are the 7 am/2 pm/9 pm method for January 1820-December 1835, the "A.M."/"P.M."/"EVENING" method for January 1836-December 1840, the Sunrise/2 pm/Sunset/9 pm method for January 1841-December 1842, the Sunrise/

9 am/3 pm/9 pm method for January 1843-June 1855, and the 7 am/2 pm/ 9 pm method again for July 1855-April 1858. Based on comparative analysis of the 7 am/2 pm/9 pm and Sunrise/2 pm/Sunset/9 pm formats' inter-observational times temperature differences, the "A.M"/"P.M."/ "EVENING" method's selection of hours was assumed for analysis purposes to be Sunrise/2 pm/9 pm.

2.3 Data of the Reverend A. B. Paterson, 1859-1872

Daily 7 am/2 pm/9 pm method meteorological observations by the St. Paul Smithsonian observer, Reverend A. B. Paterson, were used to generate daily maxima and minima temperature estimates for the 1859-1872 period. The Smithsonian system for taking meteorological observations, established in 1847, was the most important of its kind in the United States in the mid-nineteenth century. Based on the voluntary cooperation of private observers, who were supplied with standardized instruments and report forms, the system's effectiveness was such that it gradually absorbed other private and state weather services, leading to the eventual establishment of the National Weather Service (National Archives 1981, p. viii).

Paterson's observations from January 1859 to May 1862 and from January to February 1863 were taken from personal meteorological notes, and for the period June 1862 to December 1872, excepting January and February 1863, from official Smithsonian forms. Evidently Paterson became a Smithsonian observer in June 1862. Reverend Paterson was keenly interested in meteorology, as he was also author of a monthly column in the local newspaper describing the weather of the past month and its influence on life in the community. Minneapolis also had a Smithsonian observer, William Cheney, who began his observations in 1864 and like Paterson, had a monthly newspaper column.

The only significant complication encountered with the Paterson data was for the non-Smithsonian observations, in which wind data were either absent or in the 1820-1835 form of a single designated daily direction. For those periods without any wind data, direction or force, daily maxima and minima temperature estimates were derived from 1961-1980 regression models that excluded winds. Periods with wind direction but no force information had average 1961-1980 wind speed statistics substituted.

A validity check of the Paterson daily minima estimates was made possibly by the availability of concurrent daily minima observations from a nearby unofficial observer's self-registering thermometer. These readings, which appeared with some interruptions in the local newspaper from 1862 on, provided an invaluable means of evaluating the general appropriateness of using the 1961-1980 data-derived regression models on mid-nineteenth century data.

Paterson's wind force observations were not in Beaufort scale terms but in a different hierarchy of values called the Smithsonian scale. Also, the 7 am, 2 pm, and 9 pm observations were still at some form of local time. The site of Paterson's observations was on sloping terrain, about 3/8 mile from the Mississippi River and approximately 50 feet above it (Minnesota State Geological Survey 1983).

3. THE CONVERSION TECHNIQUE

Conversion of temperature observations from the fixed-time scheme methods to midnight-to-midnight absolute maxima and minima approximations involved essentially two steps. First, using the prediction models, estimates were made on a day-to-day basis of midnight temperatures, "overnight minimum" temperatures, and "afternoon maximum" temperatures. Under certain conditions, "special case maxima" temperature estimates were also generated. Second, each day's set of estimated temperatures was examined, with the highest and lowest figures identified as the estimated maximum and minimum, respectively, for the day. In a few rare instances, extra temperature observations for a given day would disclose readings which were more extreme than those estimated. For these cases, the observed extreme would replace the estimated extreme as the designated daily maximum or minimum.

3.1. The Need for More Than One Set of Conversion Models

Due to the fact that the 1820-1872 observations were taken under four different fixed time formats, two sets of multiple regression models were needed to accomplish the conversion of all the data. One set was designed explicitly for the 7 am/2 pm/9 pm method, and the other for the Sunrise/9 am/3 pm/9 pm method. However, since the other two methods had observation times common to each of these first two, estimation of maxima and minima from these formats could be accomplished by "borrowing" appropriate models from each of the 7 am/2 pm/9 pm and Sunrise/9 am/3 pm/9 pm sets.

3.2 Independent Variable Choices for the Conversion Models

Independent variable choices for the midnight, overnight minimum, afternoon maximum, and special case maximum prediction models consisted of such information as temperature changes between observation times, sky cover, and wind components (north/south and east/west). Depending on which temperature type was being estimated, the number of independent variables ranged from one to seven. The predictor variables chosen for the four applications had individual and marginal estimating utilities that were largely unknown at the outset; hence, some predictors were selected whose individual or marginal contributions to estimating accuracy were subsequently found to be minor. For example, the marginal contribution to estimating precision of wind component information over and above that of temperature change and sky cover data was slight for all model types (See Table 22).

The dependent variable for each model type was a temperature change, and this predicted value was added or subtracted from an observed temperature at a specified time (7 am, Sunrise, 2 pm, 3 pm, or Sunset) to yield a midnight, overnight minimum, afternoon maximum, or special case maximum estimated temperature.

3.3 Empirical Data Used to Generate the Conversion Models

Empirical data to generate the multiple regression conversion equations were taken from 20 years of hourly observations (January 1, 1961 to December 31, 1980) at the Minneapolis-St. Paul International

Airport. Hourly data for the years 1961-1964 were available on published reports ("Local Climatological Data Supplement"), while hourly observations for the 1965-1980 period were taken from microfiche forms available by special order from the National Climatic Center in Asheville, North Carolina. Observational site for the temperature readings was virtually constant over the twenty-year period. According to the 1981 Minneapolis-St. Paul Local Climatological Data Annual Summary, the only major shift in location of the temperature instruments (hygrothermograph commissioned on 1/1/60) was an 800 foot move to the west northwest on May 24, 1963 (change in elevation +12 feet). Thus, the empirical data represented observations taken at essentially the same local spot for about 90 percent of the record. In the 1961-1964 data set, no information was given in the published reports as to the exact times of the official hourly observations, the assumption for analytical purposes being made that they were taken at the top of the hour, exactly. In the 1965-1980 microfiched records, observations were usually noted as taken three to five minutes before the designated hour. Given these relatively minor discrepancies between actual observation time and designated observation time (5 to 8 percent), the 1965-1980 readings were, for analytical purposes, also assumed to have been taken at the top of the hour. The effects of this "rounding" on regression model parameter generation and resulting nearest integer temperature estimating precision would likely be negligible.

3.3.1 Data Gathering and Processing Procedures of the Empirical Data

From the 20 years of official reports, observed hourly temperature data were copied onto paper forms, by month (240 forms). Additional hourly meteorological data such as cloud cover, wind direction, and wind speed which corresponded to the nineteenth century observation hours (7 am, 2 pm, 3 pm, and 9 pm), or immediately preceded or followed sunrise times (4 am, 5 am, 6 am, 7 am, or 8 am) were also included on the forms with the temperature data. To get the observations in final form suitable for generation of the various prediction model regression coefficients, three additional pre-processing tasks were required: calculation of the inter-observational time temperature changes and wind components, along with interpolation of sunrise conditions.

3.3.1.1 Interpolation of Sunrise Conditions

Sunrise was an official observation time for some of pre-weather bureau era data, in particular from January 1841 through June 1855 and likely from January 1836 through December 1840. Since meteorological conditions are not currently taken at sunrise, these empirical data had to be interpolated. Using hourly conditions read at the designated hours immediately preceding and following sunrise for given days, sunrise conditions such as temperature, sky cover, and wind components were linearly interpolated. To illustrate, if sunrise occurred on a given day at 5:45 am and the official sky cover statistics were eight-tenths at 5:00 am and four-tenths at 6:00 am, respectively, the interpolated cloudiness figure at sunrise would be five-tenths. Additional observer information in the 1965-1980 microfiche records sometimes permitted more refined sunrise temperature estimations. For example, in the microfiche data, observer notes as to the time or times of the daily minima were usually recorded daily. Frequently, these observed daily minima corresponded closely to the time of sunrise, and as a result the temperature and recorded time of the daily minimum could be substituted as one of the interpolation boundary temperatures. To illustrate, if a daily minimum of 50°F was observed at 5:30 am on a morning with a sunrise time of 5:40 am, given a subsequent 6:00 am temperature observation of 56°F, the interpolated sunrise temperature would be 52°F.

3.3.1.2. Processing of the Data

Following completion of the data gathering and the pre-processing jobs described above, prediction models for each of the key temperature types were generated for the 7 am/2 pm/9 pm and Sunrise/9 am/3 pm/9 pm observational schemes.

4. DESCRIPTION OF THE CONVERSION MODELS, BY MAJOR APPLICATION

4.1 Midnight Temperature Estimation Models

In converting fixed-time scheme daily temperature observations to midnight-to-midnight absolute maxima and minima estimates, a useful procedure was approximation of midnight temperatures. Most midnight-to-midnight absolute maxima and minima, of course, are observed in the late afternoon and early morning respectively; however, nondiurnal influences (e.g., frontal passages) occasionally result in midnight-to-midnight extremes being recorded at the demarcation hours themselves. Analysis of the 1961-1980 Minneapolis-St. Paul hourly data revealed that midnight temperatures as daily absolute maximum or minima were not uncommon, particularly during the colder months of the year (see Table 1).

4.1.1 Methods Used in Developing Estimation Models for Midnight Temperatures

Temperature interpolation was the method used to estimate midnight temperatures, based on analysis of conditions at a pre-midnight and post-midnight standard observation time, and/or changes in conditions over their interval. Applied to the nineteenth century observational formats encountered in this study, the intervals bounded by the times 9 pm and 7 am for the 7 am/2 pm/9 pm format, and the times 9 pm and sunrise for the Sunrise/9 am/3 pm/9 pm format

TABLE 1

PERCENT OF DAYS IN WHICH OBSERVED MIDNIGHT TEMPERATURES (0000 & 2400 STANDARD TIME) WERE 24 HOUR MAXIMA, MINIMA, OR BOTH -- MINNEAPOLIS-ST. PAUL, MINNESOTA (1961-1980)

Month	Daily Maximum At Midnight (% of Days)	Daily Minimum At Midnight (% of Days)	Both Extremes for Same Day at Successive Midnights (% of Days)
January	22	26	6
February	18	24	5
March	10	28	4
April	7	21	4
May	5	21	2
June	3	17	2
July	1	18	*
August	2	18	1
September	4	26	3
October	7	24	4
November	12	33	6
December	27	32	10
ANNUAL MEANS:	10	24	4

*Less than 0.5%.

served this purpose most usefully. Meteorological data to generate the multiple regression interpolation models accordingly were extracted from observations at these hours/times.

4.1.1.1 Independent Variable Selection for the Midnight Temperature Estimation Models

Seven independent variables, 7 am (sunrise) temperature less 9 pm temperature of the night previous, 7 am (sunrise) sky cover, 7 am (sunrise) North-South wind component, 7 am (sunrise) East-West wind component, 9 pm night previous sky cover, 9 pm night previous

North-South wind component, and 9 pm night previous East-West wind component were chosen to estimate the independent varible, 7 am (sunrise) temperature less midnight temperature of the night previous. The dependent variable, usually a negative number (reflecting the usual overnight net decline of temperature), was subtracted from the 7 am (sunrise) temperature to produce a midnight previous temperature estimate. Table 2 lists and describes these variables in more detail. The same selection of independent variables shown in Table 2 was used to generate midnight to mid-morning "overnight minima" models, described in a later section.

4.1.1.2 Calendar Periods Chosen to Generate Models for The Sunrise/9 am/3 pm/9 pm Format

Midnight temperature interpolation models for the Sunrise/9 am/3 pm/9 pm observational format were generated by calendar month. This was convenient in that the time unit of analysis conformed to the time units covered in most meteorological reports. Also, a relatively small number of equations (12) were required, and the resulting empirical data sample sizes were large (565 to 620 days).

In analyzing calendar month "blocks" of daily data under this format, however, the potential biasing effects of first day to last day discrepancies in sunrise time on regression model accuracy had to first be assessed. The sunrise time variable, not incorporated into the regression equations, modifies the relationship of midnight to sunrise elapsed time with that of 9 pm the night previous to sunrise elapsed time. Since temperature change over the 9 pm to sunrise

TABLE 2

VARIABLES USED IN GENERATING MIDNIGHT TEMPERATURE INTERPOLATION EQUATIONS

	Variable Name	Remarks
	Dependent Variable:	
	7 am or sunrise temperature less midnight temperature	Usually a negative number. Subtracted from the 7 am or sunrise temperature to yield a midnight temperature estimate
	Independent Variables:	
a)	7 am or Sunrise temperature less previous night's 9 pm temperature	Usually a negative number (morning temperatures are generally lower than previous evening 9 pm temperatures).
b)	7 am or Sunrise Cloudiness	Expressed in tenths of sky cover: 0 for cloudless, 10 for overcast.
c)	7 am or Sunrise North/South wind component	'+' sense for southerly components, '-' sense for northerly components.
d)	7 am or Sunrise East/West wind component	'+' sense for easterly components, '-' sense for westerly components.
e)	9 pm night previous cloudiness	Expressed in tenths of sky cover, 0 for cloudless, 10 for overcast.
f)	9 pm night previous North/South wind component	'+' sense for southerly components, '-' sense for northerly components.
g)	9 pm night previous East/West wind component	'+' sense for easterly components, '-' sense for westerly components.

interval was used to interpolate temperature change over the midnight to sunrise interval, first day to last day discrepancies in the two intervals' time lengths relative to one another would have to be minor in order to assure insignificant biasing of the daily midnight temperature estimates.

Comparative analyses, by month, of first day to last day ratios of 9 pm to sunrise elasped time versus midnight to sunrise elapsed time confirmed this, the largest discrepancy (6 percent), observed for March, was hardly large enough to have an appreciable biasing influence on nearest integer approximations of daily midnight temperatures for the month (See Table 3).

TABLE 3

COMPARISON, BY CALENDAR MONTH, OF THE FIRST TO LAST DAY RATIOS OF ELAPSED TIME FROM MIDNIGHT TO SUNRISE VERSUS ELAPSED TIME FROM 9 PM NIGHT PREVIOUS TO SUNRISE, MINNEAPOLIS-ST. PAUL, MINNESOTA

Month	Midnight to Sunrise Elapsed Time ÷ 9 pm to Sunrise Elapsed Time, First Day of Month	Midnight To Sunrise Elapsed Time ÷ 9 pm to Sunrise Elapsed Time, Last Day of Month
January	0.72	0.72
February	0.72	0.70
March	0.70	0.66
April	0.66	0.63
May	0.63	0.60
June	0.60	0.60
July	0.60	0.62
August	0.62	0.65
September	0.65	0.67
October	0.67	0.69
November	0.70	0.71
December	0.71	0.72

4.1.1.3 Calendar Periods Chosen to Generate Models for the 7 am/2 pm/9 pm Format

In developing midnight temperature interpolation equations for the 7 am/2 pm/9 pm format, data for the months January, February, November and December were also analyzed in calendar month units. For the other months, however, a different and more serious complication existed, beginning-of-the-month to end-of-the-month discrepancies in sunrise to 7 am elapsed time and the corresponding effect on daylight temperature rises from previous night minima. Accumulated insolation, of course, would affect a given day's temperature rise by 7 am and its relation to the previous night's midnight temperature. In Minneapolis, sunrise occurs before 7 am from February 25 to November 7, maximum sunrise to 7 am elapsed time reaching 154 minutes in mid-June. As some months have pronounced first to last day differences in this variable (see Table 4), potentially large contrasts between first and last day relationships with preceding night's midnight temperatures are created.

Assuming enough data, the ideal approach in handling this problem would be to generate the regression models on a day-to-day basis, in effect transforming the sunrise to 7 am elapsed time variable into a day-to-day constant and eliminating the need to consider it directly. A day-to-day March-October analysis in this study would have required 245 equations, with comparatively few observations available per equation (20) relative to the number of variables (8). Practical considerations (number of regression equations required,

TABLE 4

FIRST AND LAST DAY OF THE MONTH TIME INTERVALS BETWEEN SUNRISE AND 7 AM, IN MINUTES, FOR MARCH THROUGH OCTOBER, MINNEAPOLIS-ST. PAUL, MINNESOTA

Month	Elapsed Time from Sunrise to 7 am on First Day of Month (Minutes)	Elapsed Time from Sunrise to 7 am on Last Day of Month (Minutes)	Net Change (Minutes) First Day to Last Day
March	8	64	+56
April	65	115	+50
May	117	150	+33
June	150	150	0
July	150	124	-26
August	122	87	-35
September	85	51	-34
October	49	10	-39

resulting sample sizes per equation, and general precision desired) called for some kind of trade-off, and to this end, the calendar months March to October were broken up and analyzed in one-third month segments. The first two partitions were ten days each in length, and the last partition ten or eleven days long, depending on the month.

The effect of segmenting the March-October data was to reduce the largest sunrise to 7 am elapsed time discrepancy over a given analysis period to 19 minutes (March 21-31). Another effect was to increase the number of interpolation models from 12 to 28. Sample sizes for the partitioned months were still large, varying from 200 to 220 days; calendar month unit sample sizes, as before, ranged from 565 to 620 days.

In addition to reducing the biases generated from time-of-sunrise changes, partitioning of the March to October data undoubtedly reduced the unfavorable influences on model accuracy of other variables that might have a tendency to be subject to rapid changes over certain calendar month periods (e.g., ground condition changes over March and April from snow-covered to soggy to dry).

4.2 Overnight Minimum Temperature Estimation

While midnight temperature interpolation had usefulness in estimating adjacent day demarcation temperatures, a few of which might in certain situations be good approximations of daily extremes (see Table 1), direct estimation of diurnal maxima and minima was obviously of far greater importance.

4.2.1 Methods Used in Developing Estimation Models for Overnight Minimum Temperatures

Development of regression models for overnight minima temperature estimation consisted of analyzing 1961-1980 data from days in which the observed midnight to midnight low fell between midnight and 9 am. The 9 am boundary time is at least an hour after sunrise on all days of the year; however, some mid-winter days (particularly in January) experienced "overnight" lows at this hour. The selection criterion of daily minima occurring between midnight and 0900 could usually be verified by inspection of hourly readings, although the 1965-1980 microfiched reports, as mentioned earlier, usually included observer notes of the actual time or times of this event. Subjective judgement had to be used only infrequently in choosing from the 1961-1964 data. Table 5 shows the percentage of 1961-1980 days, by month, in which the daily midnight-to-midnight absolute minimum was observed between 0000 and 0900 hours.

TABLE 5

PERCENTAGE OF DAYS IN WHICH THE MIDNIGHT-TO-MIDNIGHT ABSOLUTE MINIMUM WAS OBSERVED BETWEEN 0000 AND 0900 HOURS, BY MONTH, 1961-1980, MINNEAPOLIS, MINNESOTA

Month	Number of Days	Percentage
January	428	69
February	411	73
March	455	73
April	457	76
May	487	79
June	480	80
July	505	81
August	490	79
September	427	71
October	434	70
November	395	66
December	403	65

4.2.1.1 Sunrise/9 am/3 pm/9 pm Overnight Minimum Estimating Procedures

The approach here was the same as for midnight temperature estimation, independent variable selection being unchanged (see Table 2), along with the choice of the analytical time unit (the calendar month). The dependent variable, however, was now sunrise temperature less overnight low temperature, and this figure (always a non-negative number) was subtracted from a given sunrise temperature to yield an overnight low estimate.

4.2.1.2 7 am/2 pm/9 pm Overnight Minimum Estimating Procedures

Multiple regression estimates of midnight to 9 am minimum temperatures for the 7 am/2 pm/9 pm format were probably the most important of the sets generated for this study. Midnight temperature estimates would just occasionally be selected as daily lows, and overnight minima estimated under the Sunrise/9 am/3 pm/9 pm format would generally differ only slightly from same day sunrise temperatures or pre-sunrise midnight temperature estimates. Overnight minima under the 7 am/2 pm/9 pm format, however, had a seasonal disposition to differ by many degrees from 7 am temperatures, especially in summer. On June 10, 1965, for example, the observed airport 7 am temperature was 16°F higher than the overnight minimum, recorded shortly before sunrise. Numerous other examples are present in the 20-year record, particularly on clear, relatively calm mornings in May or June in which temperature rises of 12°F or more were experienced. Given these potentially large contrasts between 7 am and overnight low temperatures, multiple regression prediction models could be very useful in producing representative approximations of these minima.

Independent variable selection remained unchanged from the Sunrise/9 am/3 pm/9 pm application, the dependent variable now being 7 am temperature less overnight minimum temperature. For the same reasons discussed above in the section on midnight temperature interpolation, the sunrise to 7 am elapsed time variable made it necessary that data for the months from March to October be partitioned (see

Table 4). Repeating the procedure used with midnight temperature interpolation, March to October data were analyzed in one-third month units. Sample sizes were less than those for the midnight temperature interpolation; however, reflecting exclusion of days in which the midnight-to-midnight minimum did not occur between 0000 and 0900 hours. The advantages of using a 20-year data set were realized in this application, sample size figures still ranging from 137 days to 178 days for the partitioned months, and 395 to 428 days for the calendar months units (See Appendices E through H, P, and Q).

4.3 Afternoon Maxima Temperature Estimation

Data chosen to generate "afternoon maxima" estimation models were taken as a first criterion from days in which the twenty-four hour midnight-to-midnight maximum occurred between 1 pm and 6 pm. Similar to overnight minima data selection, this could be verified for a given day by inspecting the hourly temperature readings or observer notes in the microfiche reports. Three independent variables, 2 pm (3 pm) sky cover, 2 pm (3 pm) north/south wind component, and 2 pm (3 pm) east/west wind component were chosen to estimate the dependent variable, temperature difference from the 2 pm (3 pm) observation to the absolute daily maximum. This figure would be added to the 2 pm (3 pm) temperature observation to yield an absolute afternoon maximum estimate. Time unit of analysis for each format type was the calendar month (See Appendixes I through L, R, and S).

4.3.1 Problems Associated with Estimation of "Afternoon Maxima"

One complication peculiar to afternoon maxima estimation, especially for the months May to September, was the potential effect of early afternoon showers or thunderstorms on observed 2 pm or 3 pm temperatures. Impending or actual occurrence of rain, of course, can occasionally cause sharp drops in temperature from previous levels (temporary plunges of 15-20°F are recorded in the 1961-1980 record). An occurrence shortly before or at the time of a 2 pm or 3 pm temperature reading could result in the official observation being very unrepresentative of pre-shower temperature conditions, and a regression model generated primarily from data in which these phenomena did not occur would likely produce very inaccurate estimates of daily maxima in these situations. To insure exclusion of rain-induced influences from the afternoon maxima analysis, the additional daily selection criterion of no measurable rain between the hours ending 1 pm to 4 pm was applied to months May to September. Table 6 displays the sample sizes, by month, of days selected, under these criteria, to generate the "afternoon maxima" regression models.

The general problem of daily maximum estimation for days in which mid-afternoon temperatures appeared conspicuously low relative to those at previous daylight hours (e.g., 7 am and 9 am) would be handled through "special case maxima" multiple regression estimation equations described below.

TABLE 6

SAMPLE SIZES OF DATA USED IN GENERATING MULTIPLE REGRESSSION ESTIMATION EQUATIONS FOR "AFTERNOON MAXIMA," BY MONTH

Month	Number of Days	Percentage of Possible Days Selected
January	382	62
February	411	73
March	512	83
April	510	85
May	512	83
June	503	84
July	559	90
August	545	88
September	520	87
October	523	84
November	452	75
December	366	59

4.4 Special Case Maximum Temperature Estimation

Special case maximum temperature estimation was used in instances in which peculiar net temperature changes between observation times hinted that daily maxima likely occurred outside the 1 pm and 6 pm interval, or were significantly different from the official readings at 2 pm or 3 pm. Accurate estimation of maxima in these relatively uncommon situations would be better accomplished through separately derived multiple regression models.

4.4.1 "Non-Summer" Cases

A non-diurnal phenomenon that occasionally produces midnight-to-midnight maxima in late fall to early spring is the successive warm sector/cold sector passage of a cyclone. If the timing is right and the system intense enough, temperatures may exhibit a net overnight rise from 9 pm to 7 am or sunrise, then show a net decline in daylight to 2 pm or 3 pm. Inspection of the 1961-1980 hourly data for such events revealed the rather obvious fact that temperature "crests" seldom passed 7 am, sunrise, or 9 am exactly. Instead of assigning the official morning reading as the estimated daily maximum, a more accurate approach would be to objectively estimate between hours crest temperatures. Using selected cases from the months November to April for 1961-1980, multiple regression equations were generated to estimate this non-diurnal type of maximum. Five independent variables, net temperature rise to 7 am (sunrise), net temperature fall to 2 pm (3 pm), 7 am (sunrise) sky cover, 7 am (sunrise) north/south wind component, and 7 am (sunrise) east/west wind component, were chosen to predict the dependent variable, net difference between the hours maximum temperature and the 7 am (sunrise) temperature. Empirical cases chosen were those days in which the overnight temperature rise was at least 1°F and the morning to afternoon fall at least 2°F. Examples in which crest temperatures occurred prior to 7 am or sunrise were not distinguished from those whose maxima occurred after 7 am or sunrise. The selection process yielded 49 days' data for the 7 am/2 pm/9 pm format (about 2.5 days per year, each).

4.4.2 "Spring-Summer" Cases

As discussed previously, data from May to September in which measurable rainfall was recorded between the hour periods ending 1 pm to 4 pm were excluded from the generation of multiple regression "afternoon maxima" models. This was because accurate approximation of daily maxima from 2 pm and 3 pm observation was potentially hindered in situations of impending for actual rainfall. Another phenomenon of timing that complicated daily maxima estimation from single afternoon observations, particularly in April-September, was the passage of late morning cold fronts; these might or might not be associated with rain. A strong cold front passing through a given location between 10 am and noon would have allowed time for an appreciable diurnal temperature rise, but also correspondingly ample time for a pronounced accumulated temperature fall by the time of the official 2 pm or 3 pm observation. An example of this is the related events of April 27, 1962: A vigorous cold front moved through the Minneapolis-St. Paul area between 11 am and noon, following a temperature rise to 72°F from 7 am and 9 am readings of 54°F and 62°F, respectively. Subsequent to the frontal passage, temperatures declined to 54°F by 2 pm and 47°F by 3 pm. Ordinary multiple regression "afternoon maxima" estimates would have yielded temperatures only a few degrees higher than the respective 2 pm and 3 pm observations, hence the selected maximum for the day would have been either 7 am or the 9 am temperature, 18°F and 10°F in error, respectively. Obviously, in this instance and other similar situations, a more specialized regression model was needed to better estimate the daily maxima.

An objective inspection method had to be devised for identifying likely cases of these phenomena from available data at nineteenth century observational times, and from examination of April to September 1961-1980 hourly temperatures on days in which these events were experienced, it appeared that two mutually inclusive temperature conditions were good indicators of these daily maxima types: (1) a morning observation to afternoon observation net temperature change below a certain value and (2) the given afternoon temperature observation being above a certain level. These approximate "critical" values, especially the afternoon temperature figures, showed apparent seasonal changes, and to allow for this variation, the selection criteria were arbitrarily differentiated by calendar month.

4.4.2.1 7 am/2 pm/ 9 pm Format Selection Criteria

Table 7 lists the criteria, by month, for selecting daily data to generate the 7 am/2 pm/9 pm format's "spring-summer" special case maxima estimation model.

Based on the above criteria, 82 days' data from April-September 1961-1980 (about 4 days per year) were chosen to generate the regression model for these special case maxima. Seven independent variables, net temperature change to 2 pm from 7 am, 7 am north/south wind component, 7 am east/west wind component, 7 am sky cover, 2 pm north/south wind component, 2 pm east/west wind component, and 2 pm sky cover, were used to estimate the dependent variable, daily absolute maximum less 2 pm temperature. The dependent variable was added to the 2 pm temperature to yield a daily absolute maximum estimate.

TABLE 7

SELECTION CRITERIA FOR GENERATION OF THE MULTIPLE REGRESSION ESTIMATION EQUATION FOR "SPRING-SUMMER" SPECIAL CASE DAILY MAXIMA UNDER THE 7 AM/2 PM/9 PM OBSERVATIONAL FORMAT

Month	Criteria
April	Temperature ≥50°F at 2 pm, 7 am temperature equal to or higher than 2 pm temperature.
May	Temperature ≥55°F at 2 pm, 7 am temperature equal to or higher than 2 pm temperature.
June-August	Temperature ≥65°F at 2 pm, 7 am temperature higher, equal to or ≤2° lower than 2 pm temperature.
September	Temperature ≥60°F at 2 pm, 7 am temperature equal to or higher than 2 pm temperature.
All months: For all 2 pm temperatures ≥ 70°F	Temperature ≥70°F at 2 pm, 7 am temperature higher, equal to or ≤2°F lower than 2 pm temperature.

4.4.2.2 Sunrise/9 am/3 pm/9 pm Format Selection Criteria

Table 8 shows the criteria, by month, for selecting 1961-1980 daily data to generate the Sunrise/9 am/3 pm/9 pm format's regression model.

TABLE 8

SELECTION CRITERIA FOR GENERATION OF THE MULTIPLE REGRESSION ESTIMATION EQUATION FOR "SPRING-SUMMER" SPECIAL CASE DAILY MAXIMA UNDER THE SUNRISE/9 AM/3 PM/9 PM OBSERVATION FORMAT

Month	Criteria
April	Temperature ≥45°F at 3 pm, 9 am temperature equal to or higher than 3 am temperature.
May	Temperature ≥55°F at 3 pm, 9 am temperature equal to or higher than 3 pm temperature.
June-July	Temperature ≥65°F at 3 pm, 9 am temperature equal to or higher than 3 pm temperature.
August-September	Temperature ≥60°F at 3 pm, 9 am temperature equal to or higher than 3 pm temperature.
All months: For all 3 pm temperatures ≥ 70°F	Temperature ≥70°F at 3 pm, 9 am temperature higher, equal to, or ≤2°F lower than 9 am temperature.

From these selection criteria, 183 days' data (about 9 days per year) were picked to generate the Sunrise/9 am/3 pm/9 pm format's regression model for spring-summer special case maxima estimation. The sample size was more than double that for the 7 am/2 pm/9 pm format's model; however, this was largely an unavoidable consequence, as data from the format's other morning reading (sunrise) would have been much more difficult to use effectively with 3 pm data in discriminating spring-summer special case maxima occurrences. Independent variable selection rationale was unchanged from that used for the

7 am/2 pm/9 pm format model and as shown in Table 8, the 7 am and 2 pm observational times' data were replaced by observations from 9 am and 3 pm, respectively (See Appendices M and T).

5. EVALUATION OF THE CONVERSION MODELS, BY APPLICATION

While generation of the multiple regression conversion model sets was only a means to an end, of some interest were their individual estimating precisions, and the extent to which they represented actual physical influences on temperature changes.

5.1 Midnight Temperature Interpolation Models

Multiple regression estimating precision for midnight temperature interpolation varied only slightly among analysis periods and between formats. In the set of 28 equations generated for the 7 am/2 pm/ 9 pm format, mean daily absolute errors ranged from 1.3°F (March 11-20) to 1.8°F (May 11-20). Median and modal absolute errors were with one exception all 1°F, the exception being a 2°F median error for the May 11-20 period (See Appendix N). For the Sunrise/9 am/3 pm/9 pm format, mean absolute errors varied from 1.4°F (several calendar month periods) to 1.8°F (January). Median and modal absolute errors were all 1°F (See Appendix O).

Comparing zero-order correlation coefficients, the independent variable net temperature change from 9 pm (night previous) to 7 am (or sunrise) was by far the most important individual estimator in this application. The "preeminence" is explainable by the fact that the time interval considered (9 pm the previous night to 7 am or 9 pm the previous night to sunrise) overlapped considerably with that of the dependent variable (midnight to 7 am or midnight to sunrise), producing an autocorrelative effect. Thus, most of the collective influences of the other six independent variables were already incorporated in that of the first independent variable (See Appendices B and D).

Examining the signs of the other six independent variables zero order correlation coefficients separately, one could get an appreciation of the direction in which they influence temperature change from midnight to 7 am (or sunrise). For example, in the January Sunrise/ 9 am/3 pm/9 pm regression model, the computed zero order correlation coefficient for sunrise sky cover was +.454 (See Appendix D). Interpreting the positive sign, this indicated that as sky cover increased (became more positive on 0 to 10 scale), the net temperature difference from sunrise to midnight (usually negative) was influenced in the positive direction (less negative). This, of course, reflected the effect of cloud cover on inhibiting overnight temperature decline. In this same regression model, sunrise north/south and east/west wind components were also related positively (r = +.451 and +.377, respectively) to the dependent variable. Since southerly and easterly component winds had been given positive signs by convention (see Table 2), this indicated that these winds also had an inhibiting effect on net midnight temperature to sunrise temperature decrease. This made physical sense, as these winds are generally associated with warm air and moisture advection, which oppose nocturnal temperature declines in winter. The above wind component variables also displayed maximum correlations in winter, reflecting the greater importance of advective processes on temperature movements at these times.

5.2 Overnight Minima Estimation Models

Multiple regression estimation accuracies for overnight minima showed slightly more model to model variation than was displayed for midnight temperature interpolation. In the 28 regression models generated for the 7 am/2 pm/9 pm format, mean daily absolute residuals ranged from 1.3°F (March 21-31) to 2.2°F (May 11-20). Median absolute residuals were mostly 1°F but nine were 2°F. All but one of the modal residuals were 1°F, the exception being a 2°F figure. Smallest and largest mean residuals were seasonally concentrated in groups of adjacent analysis periods. For example, the five ranking largest mean absolute residuals were confined to the successive periods May 1-10 to June 11-20 (average 2.1°F) while the lowest eight values (those with averages less than 1.4°F) were restricted to the adjacent periods March 11-20 to March 21-31 and September 1-10 to October 21-31 (See Appendix P).

For the Sunrise/9 am/3 pm/9 pm format, variation in mean absolute residuals was more pronounced, figures ranging from 0.8°F (August) to 2.1°F (January). Median errors were 1°F for the months March to November and 2°F for December to February. Modal errors were all 1°F. In general, estimation was best in the warmest months and poorest in the coldest months (See Appendix Q).

Examining the relative importances of individual independent variables in this application, the following patterns were evident. For the 7 am/2 pm/9 pm format, the independent variable net temperature change from 9 pm the night previous to 7 am was again the most significant predictor for the periods October 1-10 to March 21-31, and July 11-20 (See Appendix F). For the other periods, sky cover at either 7 am or 9 pm was the most significant individual estimator. Wind influences, while not predominating for any one analysis period, showed interesting seasonal inclinations. North/south 7 am components, for example, exceeded 7 am east/west components in absolute correlation magnitude for the thirteen consecutive analysis periods September 21-30 to April 11-20, the opposite being shown for the other fifteen intervals April 21-30 to September 11-20. This seasonal reversal in correlation magnitudes might be due to two factors. First, north/south regional temperature gradients are less over late-April to mid-September than they are over late-September to early April. Since winds advect temperature contrasts from one region to another, one might therefore expect the effect on early morning temperature rises during late April to mid-September to be less pronounced than during late-September to early April. Second, the influence of air moisture is likely greater during late April to mid-September, the warmer air at these times of the year having a much greater capacity to hold it in vapor form. It is a well known fact that the West is generally less humid than the East in the warmer months of the year, so a westerly component wind is advecting air from comparatively dry regions and an easterly wind is advecting air from relatively moist areas. Since humid air warms more slowly than dry air due to the greater scattering and reflecting of the more numerous haze and cloud particles, perhaps this explains the increased importance of east/west components on early-morning temperature rises in late-spring through late-summer. East/west temperature gradients are probably too insignificant to explain this seasonal predominance over north/south winds.

Inspecting the signs of the independent variables' zero-order correlation coefficients (See Appendix F), it was possible to associate likely physical meanings to the statistics. For instance, the 7 am and 9 pm night previous sky cover coefficients were nearly all negative, indicating a logical association between greater (less) cloudiness and less (greater) temperature difference between 7 am and the overnight minimum. The oppositely signed exceptions, positive 7 am sky cover correlations for October 1-10 to March 21-31, probably reflected the greater tendency at these times of the year for greater (less) cloudiness to be associated with warm (cold) advection, producing greater (less) differences between 7 am temperatures and overnight minimum temperatures.

A few possible physical interpretations of the wind component correlation signs can be made also (See Appendix F). For the 7 am components, the north/south signs were all positive from October 1-10 to June 21-30, indicating that greater temperature rises to 7 am were associated with more southerly (positively signed) winds. The exception to the rule, the negatively signed correlations for July 1-10 to September 1-10, may be a reflection of southerly winds being more moisture-laden at these times, actually inhibiting morning temperature rises by the above-mentioned humid atmosphere properties. For the 7 am east/west components, signs were all negative from April 1-10 to September 21-30, indicating a warm season association between decreased temperature rises to 7 am and easterly (positively signed) winds; possibly this relates to the air moisture variable also. Finally, signs were all positive for the net temperature change from 9 pm the night previous to 7 am variable. Interpreted, this meant that 7 am/overnight minimum temperature differences were greater (less) when net overnight temperature declines from 9 pm the night previous to 7 am were less (greater).

For the Sunrise/9 am/3 pm/9 pm format (see Appendix H), net temperature change from 9 pm the night previous to sunrise was the most important individual predictor of sunrise temperature/overnight low temperature difference for the months July-March. Signs, as with the 7 am/2 pm/9 pm format, were all positive, indicating a tendency for sunrise temperatures to be closer to the overnight minima on nights that experienced greater 9 pm to sunrise net temperature declines. For the other months (April-June), multiple correlation coefficients were rather poor (all less than +.30) and each month had a different "primary" independent variable.

Examining other independent variable signs for the months July-March, it appeared that small sunrise temperature/overnight minima differences were consistently associated with: less sunrise cloudiness, more northerly sunrise winds (exception: August), more 9 pm night previous cloudiness, and more northerly 9 pm night previous northerly winds (exception: August).

5.3 Afternoon Maxima Equations

Estimating precision for the afternoon maxima equations was the best of the four different applications, although collectively, the multiple correlation coefficients were the lowest. For the 7 am/2 pm/9 pm format (see Appendix R), average absolute residuals ranged from 0.7°F (November-January) to 1.1°F (May-June). Median and modal errors were all 1°F, the November equation also having a 0° mode. The Sunrise/9 am/3 pm/9 pm format (see Appendix S) showed an identical range in average absolute errors, the lowest figure, 0.7°F, being shown for December-February, the highest, 1.1°F, displayed for May. Median and modal absolute residuals were all 1°F.

Inspection of the zero-order correlation coefficients for the 7 am/2 pm/9 pm format (see Appendix J) showed that for the months December-May, 2 pm north-south wind component was the predominant independent variable influence on the 2 pm temperature/afternoon maximum temperature difference. For the other months, June to November, 2 pm sky cover was the most important independent variable. In each of these cases, the primary independent variable estimator was positively signed, indicating a tendency for larger differences between 2 pm temperatures and afternoon maxima to be associated with southerly winds and cloudier skies, respectively.

The Sunrise/9 am/3 pm/9 pm pattern was somewhat different (see Appendix L), 3 pm sky cover showing the highest individual association for all the calendar month units except February. The correlation coefficient signs for this variable were all positive, reflecting the direct relationship between cloudier 3 pm skies and greater maximum temperature/ 3 pm temperature differences. This association between cloudiness and temperature difference probably related to resident air mass types, warm air masses with their cloudier but not necessarily overcast skies encouraging (along with other meteorological influences such as southerly winds) relatively larger temperature rises from 2 pm or 3 pm readings.

5.4 Special Case Maxima Equations

Special case maxima estimation equations were developed for daily situations in which ordinary afternoon maxima estmation models would likely have yielded poor approximations of midnight-to-midnight maxima. The best measure of these special case models' effectiveness would not only be inspection of regression residuals, but also examination of daily errors in maxima estimation that would have resulted if they hadn't been employed at all in situations justifying their use. Table 9 shows the average absolute residual errors for each model and the mean error reduction in daily maxima estimation that resulted from their application.

TABLE 9

AVERAGE ABSOLUTE RESIDUALS AND MEAN ERROR REDUCTION FOR "SPECIAL CASE" MAXIMA REGRESSION MODELS (1961-1980)

Model Type	Sample Size	Average Absolute Residual (°F) of Special Case Model	Average Net Reduction in Daily Estimating Error (°F) From Ordinary Regression Models
Non-Summer (7 am/2 pm/9 pm)	51	1.9	0.4
Non-Summer (Sunrise/9 am/3 pm/9 pm)	49	2.1	0.9
Spring-Summer (7 am/2 pm/9 pm)	82	3.3	1.5
Spring-Summer (Sunrise/9 am/3 pm/9 pm	183	2.5	1.5

As Table 9 shows, the special case models all resulted in net improved estimating precision, more so for the "Spring-Summer" variety.

While "Special Case Maxima" estimated seldom influenced a given 1961-1980 monthly mean by more than 0.2°F, if at all, its use was consistent with one of the objectives of this study, namely to utilize regression models to a maximum extent in producing representations of the actual midnight-to-midnight daily maxima and minima.

6. TESTING THE COLLECTIVE PRECISION OF THE REGRESSION MODELS IN PRODUCING DAILY MAXIMA AND MINIMA ESTIMATES

With the multiple regression conversion equations generated for the individual temperature types, the next step was to test their collective accuracy in producing midnight-to-midnight absolute maxima and minima estimates on the same 1961-1980 data.

Accordingly, midnight-to-midnight (0000 and 2400 hours), overnight minimum, afternoon maximum, and in appropriate instances, special case maximum temperature estimates were generated by format for each day of the empirical record (January 1, 1961 to December 31, 1980). Then, by inspection of each day's set of temperature estimates, the highest and lowest figures were selected as approximations of the daily maximum and minimum, respectively. In a few rare cases observed 7 am, 9 am, 9 pm, or estimated sunrise readings were still identified as daily extremes (mostly minima), even after comparison with the regression model generated temperature estimates.

Following this, the general precision of the estimates in representing the known official maxima, minima, and means were compared on a day-to-day, monthly, and 20-year basis for a variety of statistics.

6.1 Day-to-Day Comparisons

Table 10 lists various error statistics, by month, for estimation of daily maxima, minima, and means for the 7 am/2 pm/9 pm format.

TABLE 10

ERROR STATISTICS, BY MONTH, FOR ESTIMATION OF 1961-1980 DAILY MAXIMUM, MINIMUM AND AVERAGE TEMPERATURES(7 AM/2 PM/9 PM FORMAT)

Month	Mean Error (MAX) °F	Median Error (MAX) °F	Modal Error (MAX) °F	Mean Error (MIN) °F	Median Error (MIN) °F	Modal Error (MIN) °F	Mean Error (AVG) °F	Median Error (AVG) °F	Modal Error (AVG) °F	Both max and min correctly estimated for the same day (% of time)
January	1.1	1	1	1.8	1	1	1.4	1	1	4
February	1.0	1	1	1.8	1	1	1.3	1	1	4
March	1.1	1	1	1.4	1	1	1.2	1	1	3
April	1.2	1	1	1.6	1	1	1.3	1	1	3
May	1.3	1	1	1.9	2	1	1.5	1	1	3
June	1.3	1	1	1.9	2	1	1.5	1	1	2
July	1.2	1	1	1.8	2	1	1.3	1	1	3
August	1.1	1	1	1.5	1	1	1.2	1	1	3
September	1.1	1	1	1.4	1	1	1.2	1	1	3
October	0.9	1	1	1.4	1	1	1.1	1	1	4
November	0.9	1	1	1.5	1	1	1.1	1	1	5
December	1.1	1	1	1.7	1	1	1.3	1	1	5
Means	1.1			1.6			1.3			

From Table 10, it appeared that collective use of the regression models provided satisfactory day-to-day conversion approximations of 1961-1980 absolute maxima and minima. About 80 percent (29 of 36) of the mean monthly absolute estimating errors of daily maxima, minima, and averages fell between 0.9°F and 1.5°F. Daily maxima estimation (1.1°F average error) was superior to daily minima estimation (average error: 1.6°F), with daily mean estimation about midway between (1.3°F average error). Median and modal daily estimating accuracies were also good, all but three of the values being 1°F.

Table 11 lists the corresponding statistics for estimation of 1961-1980 daily maxima, minima, and means under the Sunrise/9 am/3 pm/ 9 pm format.

For this method, the combined regression models showed a slightly better day-to-day collective estimating precision. All but three of the 36 mean absolute error figures were 1.5°F or less, this being due, of course, to the fact that the sunrise and 3 pm observation times are generally closer to those of the absolute minima and maxima, respectively, than those at 7 am and 2 pm. Mean estimating precision for the daily minima was improved from 1.6°F to 1.3°F, and that for daily means improved from 1.3°F to 1.1°F. Mean estimating accuracy for daily maxima remained unchanged at 1.1°F with median and modal errors for each of the 36 models being 1°F.

TABLE 11

ERROR STATISTICS, BY MONTH, FOR ESTIMATION OF 1961-1980 DAILY MAXIMUM, MINIMUM, AND AVERAGE TEMPERATURES (SUNRISE/9 AM/3 PM/9 PM FORMAT)

Month	Mean Error (MAX) °F	Median Error (MAX) °F	Modal Error (MAX) °F	Mean Error (MIN) °F	Median Error (MIN) °F	Modal Error (MIN) °F	Mean Error (AVG) °F	Median Error (AVG) °F	Modal Error (AVG) °F	Both max and min correctly estimated for the same day (% of time)
January	1.1	1	1	1.8	1	1	1.4	1	1	3
February	1.0	1	1	1.8	1	1	1.3	1	1	4
March	0.9	1	1	1.3	1	1	1.3	1	1	3
April	1.2	1	1	1.1	1	1	1.1	1	1	6
May	1.2	1	1	1.2	1	1	1.2	1	1	4
June	1.1	1	1	1.0	1	1	1.0	1	1	6
July	1.1	1	1	0.9	1	1	1.0	1	1	6
August	1.0	1	1	0.9	1	1	0.9	1	1	7
September	1.0	1	1	1.1	1	1	1.0	1	1	6
October	0.9	1	1	1.4	1	1	1.1	1	1	5
November	1.0	1	1	1.5	1	1	1.2	1	1	3
December	1.1	1	1	1.8	1	1	1.3	1	1	4
Means	1.1			1.3			1.1			

6.2 Month-by-Month Evaluations

Monthly average temperature estimation was a primary objective of this study so an assessment was needed also of the daily maxima and minima estimates' collective "performance" in producing representative monthly means. Table 12 shows the average discrepancies, by month and by format, between estimated and official 1961-1980 monthly means.

TABLE 12

AVERAGE DISCREPANCIES, BY MONTH, BETWEEN ESTIMATED AND OFFICIAL 1961-1980 MONTHLY MEANS, BY FORMAT

Month	Average Absolute Error, Combined Regression Models, 7 am/ 2 pm/9 pm Format °F	Average Absolute Error, Combined Regression Models Sunrise/ 9 am/3 pm/9 pm Format - °F	Average Error Using Means of 7 am, 2 pm & 9 pm (7 am/2 pm/ 9 pm mean less official mean) - °F
January	.22	.25	+1.26
February	.31	.35	+1.07
March	.20	.26	+0.64
April	.35	.18	+0.68
May	.28	.19	+1.37
June	.33	.19	+1.38
July	.29	.20	+1.03
August	.22	.15	+0.60
September	.27	.21	+0.38
October	.24	.20	+0.41
November	.18	.18	+0.58
December	.26	.24	+0.86
Annual Means	.26	.22	+0.86

From Table 12, the average absolute estimating discrepancies by month were also low, never exceeding .35°F. Comparison of the absolute error figures, by month, with those resulting from estimation via the 7 am/2 pm/9 pm methods shows that in all 24 comparisons, the collective regression model method was superior. Next, the individual month-to-month discrepancies were evaluated statistically (480 comparisons) using the t-test for significance between two sample means. Table 13 lists the average monthly t-values, by format.

TABLE 13

AVERAGE t-VALUES, BY MONTH, FOR DISCREPANCIES BETWEEN ESTIMATED AND OFFICIAL 1961-1980 MONTHLY MEANS, BY FORMAT

Month	Average Absolute t-Value 7 am/2 pm/9 pm Format	Average Absolute t-Value Sunrise/3 pm/9 pm Format
January	.09	.08
February	.10	.12
March	.11	.11
April	.13	.09
May	.13	.09
June	.20	.10
July	.21	.16
August	.14	.10
September	.15	.11
October	.10	.09
November	.07	.07
December	.09	.09

From Table 13, the t-statistics as monthly groupings are far below the level necessary to reject the null hypothesis at the .05 level (critical value about 1.96). More importantly, on an individual basis, the null hypothesis was not rejected for any of the 480 comparisons, largest computed absolute t-statistic being only .66. From this it appeared that the monthly means derived from multiple regression estimated daily maxima and minima were good representations of the official 1961-1980 monthly mean data.

6.3 Twenty-Year Evaluations

Finally, from a longer term perspective, monthly comparisons were made of the 20-year estimated versus official averages of the following statistics: average daily mean, average daily maximum, average daily minimum, average daily range, standard deviation of daily means, average day-to-day variability in maxima, average day-to-day variability in minima, and average day-to-day variability in daily means. Utilizing the same t-test for differences between two sample means, the discrepancies were evaluated. Table 14 lists the variables' t-values, by month for the 7 am/2 pm/9 pm format.

Using the .05 level of significance (critical t-values: 1.73 for 18 degrees of freedom), the null hypothesis was not rejected for any of the official-estimated disparities except one (July day-to-day variability in daily minima). While 95 of the 96 t-values were not significant statistically, persistence in sign for some of the variables over the monthly intervals suggest that there were some biases inherent in the collective use of the models. For example, the signs of the average daily ranges are all negative, indicating that the regression model-estimated maxima and minima represented

TABLE 14

t-VALUES, BY MONTH, FOR DISCREPANCIES BETWEEN 1961-1980 OFFICIAL AND ESTIMATED AVERAGES OF EIGHT TEMPERATURE STATISTICS, 7 AM/2 PM/9 PM FORMAT (ESTIMATED MEANS MINUS OFFICIAL MEANS)

Month	Avg. Daily Mean	Avg. Daily Max.	Avg. Daily Min.	Avg. Daily Range	Std. dv of Daily Means	Day-to-Day Max.	Day-to-Day Min.	Day-to Day Avg.
JAN	-.08	-.20	+.06	-1.17	+.02	- .06	- .20	-.09
FEB	0	-.09	+.06	- .38	-.41	- .02	- .79	-.37
MAR	-.02	-.06	+.01	- .17	+.08	+ .13	- .33	0
APR	-.04	-.11	+.07	- .27	+.10	+ .56	- .03	+.31
MAY	-.16	-.26	-.04	- .49	+.16	+ .83	- .95	+.45
JUN	+.05	-.27	-.02	- .39	+.23	+1.47	- .42	+.32
JUL	-.09	-.09	-.09	- .06	+.14	+1.01	-1.95	+.05
AUG	-.07	-.17	+.05	- .30	-.14	+ .87	-1.50	+.45
SEP	-.16	-.33	+.10	- .59	+.04	+ .37	-1.10	-.42
OCT	-.03	-.20	+.21	- .67	-.23	+ .03	- .11	-.50
NOV	-.06	-.25	+.19	- .54	-.08	+ .09	- .61	-.55
DEC	0	-.16	+.14	- .80	-.19	0	- .96	-.29

slightly "smoothed" versions of the official data. This smoothing is also reflected in the day-to-day minima variability (eleven out of twelve months showing negative signs). Interpreting other "runs" of like sign, the regression equations slightly understated day-to-day variability in daily mean temperatures from August to March, and overstated it for April to July.

Table 15 lists the corresponding data, by month for the Sunrise/ 9 am/3 pm/9 pm format. From Table 15, the t-values were all, without exception, not rejected at the .05 level. The slight smoothing bias of the regression equations was again evidenced in the negative signs displayed under the average daily range variable. Also, the average day-to-day variability in mean temperatures were seasonally biased again, negatively so for August to March, and positively for April to July.

To summarize, from the analyses above, it appeared that the groups of multiple regression conversion equations were an essentially accurate method of changing temperature data from a fixed time scheme of several daily temperature observations to one of midnight-to-midnight absolute maxima/minima equivalent estimtes. The day-to-day estimating errors for example, compare favorably with the discrepancies in temperature readings that are commonly observed from one part of a city to another on a given day. Assuming that the 1820-1872 Minneapolis-St. Paul data were relatively free of other inhomogeneities, the groups of regression models should be able to yield useful estimates of daily extremes and derived monthly means.

TABLE 15

t-VALUES, BY MONTH, FOR DISCREPANCIES BETWEEN 1961-1980 OFFICIAL AND ESTIMATED AVERAGES OF EIGHT TEMPERATURE STATISTICS, SUNRISE/9 AM/3 PM/9 PM FORMAT (ESTIMATED MEANS MINUS OFFICIAL MEANS)

MONTH	Avg. Daily Mean	Avg. Daily Max.	Avg. Daily Min.	Avg. Daily Range	St. Dev. of Daily Means	Day-to-Day Max.	Day-to-Day Min.	Day-to-Day Avg.
JAN	-.03	-.09	+.03	-.56	-.03	- .11	-.12	-.15
FEB	+.01	-.06	+.05	-.26	-.53	- .28	-.72	-.45
MAR	-.03	-.09	+.50	-.36	-.27	- .06	-.46	-.34
APR	+.03	-.04	+.16	-.21	+.03	+ .47	+.36	+.03
MAY	-.01	-.06	+.05	-.23	-.05	+ .45	-.20	+.09
JUN	-.16	-.08	+.20	-.32	+.11	+1.08	+.74	+.34
JUL	+.02	-.06	+.10	-.21	+.10	+ .67	+.05	+.10
AUG	+.06	+.01	+.09	-.10	-.10	+ .19	+.31	-.23
SEP	+.04	-.04	+.14	-.21	-.06	+ .22	-.41	-.41
OCT	-.01	-.15	+.20	-.57	-.19	- .12	+.07	-.59
NOV	-.05	-.23	+.21	-.53	-.07	+ .17	-.67	-.39
DEC	+.01	-.13	+.14	-.71	-.17	0	-.78	-.15

7. APPLICATION OF THE CONVERSION MODELS ON THE 1820-1872 DATA

Now that it was evident that the sets of multiple regression conversion models could provide reasonable approximations of daily maxima and minima from relatively homogeneous modern data, it should be a straight-forward procedure to apply them mechanically on the pre-weather bureau era observations. Unfortunately, there were complications: namely, the fact that many of the sky cover and wind observations (particularly before 1843) did not conform to the temperature observation times, the data were qualitative, or were intermittent. The following sections describe in more detail these non-conformities, and the steps that were taken to make the non-temperature observations compatible for substitution into the conversion models. Also described are the procedures used to handle the relatively few missing daily temperature observations.

7.1 The 1820-1835 Fort Snelling Data

Temperature readings for the 1820-1835 period followed the "standard" method of that time, observations at 7 am, 2 pm, and 9 pm local time. However, daily observations of other pertinent regression model variables such as sky cover and wind usually consisted of single-entries only, these evidently representing the most typical conditions for the day.

7.1.1 Sky Cover Observations at Fort Snelling For the 1820-1835 Period

Daily sky cover observations for the 1820-1835 period (as well as the 1836-1842 interval) were expressed qualitatively, either as "cloudy" or "fair." Data in this form obviously could not be substituted in the regression models directly, so an objective method of quantification had to be devised. Utilizing the 1961-1980 empirical data again, frequency distributions of 7 am, 2 pm, and 9 pm sky cover observations were generated by month (36 total distributions). Next, using the arbitrary definition of "fair" as a sky cover of four-tenths or less and "cloudy" as sky cover of five-tenths or greater, the 36 frequency distributions were each subdivided, with average sky cover statistics calculated for the "fair" and "cloudy" subgroups. These subcategory means served as the quantitative sky cover representations, by month, or "fair" and "cloudy" daily observations. Table 16 lists the average sky cover statistics, by month, for "fair" and "cloudy" conditions at 7 am, 2 pm, and 9 pm. Most of the rounded figures are either 1's or 9's, indicating "fair" skies to be essentially cloud-free and "cloudy" skies to be essentially overcast. This also reflects the well-known U-shaped frequency distribution tendencies of sky cover observations.

In a few instances, observers would indirectly provide data on sky cover that differed from the official single-entry daily description. For example, on September 9, 1826, Surgeon Robert E. Wood, in the remarks column of the weather diary, noted "fog at 8 am" on a day that was denoted as "fair". Obviously, in this instance, the appro-

TABLE 16

AVERAGE CLOUD COVER IN TENTHS FOR "FAIR" (0 TO 4 TENTHS CLOUD COVER) AND "CLOUDY" (5 TENTHS TO OVERCAST) CONDITIONS, BY MONTH, FOR THE HOURS 7 AM, 2 PM, AND 9 PM, MINNEAPOLIS-ST. PAUL, MINNESOTA 1961-1980

MONTH	7AM "FAIR" COND.	7AM "CLOUDY" COND.	2PM "FAIR" COND.	2PM "CLOUDY" COND.	9PM "FAIR" COND.	9PM "CLOUDY" COND.
JAN	0.59	9.36	0.89	9.24	0.57	9.44
FEB	0.91	9.27	0.93	9.25	0.62	9.29
MAR	0.91	9.41	1.13	9.37	0.72	9.43
APR	0.88	9.39	0.96	9.26	0.87	9.23
MAY	0.89	9.21	1.39	8.81	0.87	9.13
JUN	1.03	9.01	1.71	8.60	1.24	8.65
JUL	0.93	8.77	1.85	8.13	1.02	8.38
AUG	0.94	9.04	1.42	8.31	0.72	8.72
SEP	0.72	9.11	1.21	8.81	0.66	9.16
OCT	0.83	9.26	1.13	8.90	0.64	9.03
NOV	1.08	9.43	0.93	9.31	0.55	9.52
DEC	0.92	9.53	1.09	9.48	0.71	9.53

priate sky cover description at 7 am was "cloudy", and in cases like these in which it was possible to deduce hourly sky covers that were likely to be opposite than those of official daily designations, changes for the affected hours were made.

7.1.2 Wind Observations at Fort Snelling for the 1820-1835 Period

Wind direction data, like cloudiness data, consisted of one daily entry, usually to the nearest eight-point compass direction. Wind speed (or force) data were in Beaufort scale terms, but appeared only occasionally in some Surgeon's diaries and not at all in the others. The Beaufort scale observations, when they did appear, could readily be quantified, but to resolve the problem of days which had no wind force readings, 1961-1980 average 7 am, 2 pm, and 9 pm hourly wind speeds, by month (See Table 17), were substituted in their place. The use of these "plugged" wind speed averages allowed the actually observed wind direction data to be incorporated into the models.

Undoubtedly, the absence of hourly specificity for the cloudiness and wind direction observations, and the frequent total absence of wind speed data caused some regression model accuracy to be lost from daily maxima and minima estimates in the 1820-1835 data. Spread over a calendar month period, however, similar to that for ordinary day-to-day regression model errors, an appreciable cancelling out effect was likely accumulated and monthly means were probably considerably less affected. In the 1961-1980 test data, for example, the mean absolute errors in estimating the official monthly means for both the 7 am/2 pm/9 pm and Sunrise/9 am/3 pm/9 pm formats were only about 20 percent of those shown in estimating the daily means (See Tables 10, 11, and 12).

TABLE 17

AVERAGE WIND SPEEDS FOR 7 AM, 2 PM, AND 9 PM, BY MONTH, MINNEAPOLIS-ST. PAUL, MINNESOTA, 1961-1980 (TO NEAREST KNOT)

Month	Average Wind Speed at 7 am (Knots)	Average Wind Speed at 2 pm (Knots)	Average Wind Speed at 9 pm (Knots)
January	8	10	9
February	8	10	8
March	9	12	9
April	9	12	9
May	9	12	8
June	8	11	7
July	7	10	7
August	7	10	7
September	7	11	7
October	7	12	8
November	8	11	8
December	8	10	8

7.1.3 Time Gaps in the 1820-1835 Data

Two major interruptions (28 and 31 days in length) in the Fort Snelling 1820-1835 temperature observations necessitated mean temperature regression estimates using contemporary data from nearby military posts. The first gap, October 5 to November 1, 1820, was "filled" for October 5-31 utilizing Fort Crawford (Prairie Du Chien, Wisconsin) mean temperature data for October 5 to 31, 1820, substituted into a regression model based on the derived 1899-1981 linear relationship between Prairie Du Chien and Minneapolis mean temperatures for the 27 day period. Since Prairie Du Chien temperature observations were made by cooperative observers and not on a midnight-to-midnight basis (usually 6 pm to 6 pm or 5 pm to 5 pm), correction factors were first applied to the data, based on comparative relationships between monthly mean temperatures derived at Minneapolis-St. Paul for one hour-incremented twenty-four hour observational periods (Baker, 1975). After these preliminary Prairie Du Chien data adjustments, a linear regression model was generated for the two localities, the model taking the form Y = 2.8316 + .9066 X, where X was the Prairie Du Chien (Fort Crawford) October 5 to 31 mean temperature and Y the estimated Minneapolis (Fort Snelling) October 5-31 mean temperature (r = .892, standard error, 1.98°F for the model). The computed mean for the October 5 to 31, 1820 data at Fort Crawford was 41.4°F. Substituting this into the October 5-31 regression model and incorporating the 7 am/2 pm/9 pm mean at Fort Snelling for October 1 to 4, 1820, an estimated October 1820 monthly mean temperature at Fort Snelling of 43.4°F was derived.

The second data gap, October 1-31, 1827, existed because the Fort Snelling observer for the month, J.P.C. McMahon, copied data from the October 1826 diary in its place. This lapse was filled using October 1827 monthly mean temperature data from Fort Howard (Green Bay, Wisconsin) substituted into a regression model based on 1891-1948 relationships between Minneapolis and Green Bay October mean temperatures. The model took the form Y = .9743 + 1.031 X, where X was the Green Bay (Fort Howard) October mean temperature and Y the estimated Minneapolis (Fort Snelling) October mean temperature (r = .932; standard error 1.48°F). The computed mean using 7 am, 2 pm, and 9 pm data at Fort Howard for October 1827 was 46.9°F, and substitution into the regression model yielded a Fort Snelling October 1827 monthly mean estimate of 47.4°F. Two other time gaps, several days in length apiece, were the before mentioned May 21-23, 1820, and July 13 and 15-16, 1822 periods; no steps were taken to estimate the mean temperature for these days.

7.2 The 1836-1840 Fort Snelling Data

At the beginning of January 1836 and lasting through 1840, headings of the temperature observation columns took the form "A.M.", "P.M.", and "evening." Sky cover data was still in "cloudy" and "fair" terms, but the number of observation times was increased to two, an "a.m." and a "p.m." reading. Wind direction observations, also, were converted to this twice daily scheme (for regression model estimation purposes, "p.m." sky cover and wind direction observations were assumed to apply to both the "p.m." and "evening" temperature observation times). Wind speed observations, however, were still intermittent, and as before, only shown once each day, when recorded. The same quantification techniques used on the 1820-1835 data were applicable here, but uncertainty existed as to what the actual "a.m.", "p.m.", and "evening" times represented.

A comparison of the average differences between 7 am and 2 pm temperatures for the 1820-1835 data versus the average differences between the "a.m." and "p.m." temperature observations for the 1836-1840 suggested that the "a.m." time was one other than 7 am, probably sunrise. Table 19 shows the average temperature differences, by month, between the 7 am and 2 pm temperature observations for the 1820-1835 period, "a.m." and "p.m." observations for 1836-1840, and the sunrise and 2 pm observations for 1841 and 1842.

TABLE 18

AVERAGE DIFFERENCES BY MONTH BETWEEN 7 AM AND 2 PM TEMPERATURES (1820-1835), "A.M." AND "P.M." TEMPERATURES (1836-1840), AND SUNRISE AND 2 PM TEMPERATURES (1841-1842), FORT SNELLING

Month	2 pm T - 7 am T (1820-1835) °F	"P.M." T - "A.M." T (1836-1840) °F	2 PM T - Sunrise T (1841-1842) °F
January	13.7°F	13.7°F	14.5°F*
February	16.3	18.9	15.8
March	14.7	21.1	17.0
April	13.4	20.6	15.1
May	12.0	22.1	18.9
June	10.3	21.4	16.0
July	10.0	20.4	17.0
August	11.5	19.1	17.8
September	12.9	18.6	15.3
October	14.6	16.4	15.5
November	11.0	12.5	8.6
December	11.5	13.9**	8.1

*1842 only.
**Excludes 1840.

As Table 18 shows, the greatest disparities between the 1836-1840 and 1841-1842 schemes, and the 1820-1835 method were in the warmer months of the year. This seasonal disparity would make sense if "a.m." was indeed sunrise, the earlier sunrise time in the warmer months causing the mean "p.m." temperature minus "a.m." temperature figures to be larger. In contrast, the figures for the 1820-1835 period (with the morning observation time known) are smaller in the warmer months, probably due to the fact that the period of greatest diurnal temperature rise has shifted to the hours before 7 am.

Regarding identification of the "p.m." observational time, given the fact that the afternoon observations for the immediately following years 1841 and 1842 were made at 2 pm (as well as those during the preceding 1820-1835 era), it was assumed that the 1836-1840 "p.m." observational time was 2 pm also. Lastly, since 9 pm was the standard evening observational time for 1820-1835 and for 1841-1872, for lack of other evidence, it was similarly assumed that the 1836-1840 "evening" observation time was 9 pm as well.

The 1836-1840 cloudiness and wind force data, as stated above, were in qualitative terms. Thus, to make the "a.m." data compatible for regression model input, statistical representations, by month, of "cloudy" and "fair" sunrise sky cover conditions, as well as average interpolated sunrise wind speeds were also required from the 1961-1980 data. Table 20 shows the average sky cover figures for "cloudy" and "fair" sunrise conditions, based on the same "cloudy" and "fair" definitions used for Table 16. Table 20 displays, by month, the average interpolated 1961-1980 wind speeds at sunrise.

TABLE 19

AVERAGE INTERPOLATED CLOUD COVER IN TENTHS FOR "FAIR" (0 TO 4 TENTHS CLOUD COVER) AND "CLOUDY" (5 TENTHS TO OVERCAST) CONDITIONS AT SUNRISE, MINNEAPOLIS-ST. PAUL MINNESOTA (1961-1980)

Month	Sunrise "Fair" Conditions	Sunrise "Cloudy" Conditions
January	0.90	9.14
February	1.09	9.18
March	0.93	9.32
April	0.85	9.19
May	1.10	8.90
June	1.08	8.70
July	1.02	8.47
August	1.05	8.72
September	0.88	8.96
October	0.92	8.98
November	1.14	9.38
December	1.13	9.42

TABLE 20

AVERAGE INTERPOLATED WIND SPEEDS AT SUNRISE, BY MONTH, MINNEAPOLIS-ST. PAUL, MINNESOTA, 1961-1980 (NEAREST KNOT)

Month	Average Interpolated Wind Speed at Sunrise (Knots)
January	8
February	8
March	8
April	8
May	7
June	6
July	6
August	6
September	6
October	7
November	8
December	8

No data gaps were present in the 1836-1840 diaries but due to some peculiarly high temperature observations in December 1840, suggesting of some instrumentation problems, a regression model estimated December 1840 mean temperature figure, using temperature observations from Fort Howard was substituted instead. To explain, during December 1840 at Fort Snelling, "p.m." temperature readings of 64, 65, 72, 83, 65, 64, and 56°F were scattered in the weather diary following same day "a.m." readings of 22, 18, 11, 24, 12, 6 and 5°F, respectively. Obviously, these unreasonably high observations could not be taken as valid and temperature data from the month were best disregarded entirely. The regression model, derived from analysis of Green Bay and Minneapolis December mean temperatures for 1891-1948, took the form $Y = 3.975 + 1.059 X$, where X was the observed Fort Howard (Green Bay) December mean temperature, and Y the estimated Fort Snelling (Minneapolis) December mean temperature ($r = .946$, standard error 1.83°F). The December 1840 Fort Howard mean, 21.1°F, substituted into the equation, yielded an estimated Fort Snelling monthly mean temperature of 18.3°F.

Owing to the difficulty of devising selection criteria for identifying Special Case spring-summer maxima from sunrise and 2 pm observations, no special case maxima of this kind were estimated for the 1836-1840 period.

7.3 The 1841-1842 Fort Snelling Data

At the start of 1841 and continuing through the end of 1842, the sunrise/2 pm/sunset/9 pm method of temperature observations was used at Fort Snelling. Sky cover and wind direction data were still twice daily (an "A.M." and a "P.M." reading), and wind speed information continued to be intermittent and in qualitative Beaufort scale terms. The same statistical measures employed previously were used on the 1841-1842 data to make it compatible for regression model input. In January 1841, however, possibly relating to a continuation of the December 1840 instrumentation problem, 2 pm temperature observations were unrecorded at Fort Snelling. Sunset temperatures for the month, though, were read, and since they didn't appear to be unreasonably high relative to the sunrise observations and sunset is only a few hours after 2 pm in January, the decision was made to estimate January 1841 maxima using empirical 1961-1980 relationships between January sunset temperatures (interpolated from the 1961-1980 data by the same methods discussed previously) and January afternoon maxima. Employing the independent variables sunset sky cover (tenths), sunset north/south wind components, and sunset east/west wind components, the dependent variable, temperature difference from the sunset temperature to the afternoon maximum was estimated (See Appendices M and T for regression coefficients and zero-order correlation co-efficients). The use of this regression model permitted direct estimation of the January 1841 mean temperature at Fort Snelling

(12.3°F), regression processed data from nearby military posts not having to be used.

For the same reasons discussed in the previous section on the 1836-1840 data, no special case spring-summer maxima were estimated for this period.

7.4 The January 1843 to June 1855 Fort Snelling Data

In 1843, and continuing through June 1855, the sunrise/9 am/ 3 pm/9 pm method was used by the military posts, Fort Snelling included. The year 1843 was an important one in the development of the country-wide network of temperature observations, as beginning in January observers were furnished with standard thermometers made by George Tagliabue, an instrument-maker from New York City (National Archives 1981, p. viii). Prior to 1843, thermometers issued by the military reportedly had not been carefully constructed or standardized; however, these new instruments had to meet Naval Observatory specifications before being issued (National Archives 1981, p. viii). At Fort Snelling, the new instrument evidentally did not arrive until after the first of the year, as no observations appear in the record until January 11, resulting in a ten day data gap from January 1st. Fortunately, observations were taken at Fort Crawford for these missing days and regression model Fort Snelling estimates were thus possible. Using 1899-1981 data for Prairie Du Chien (temperature data adjusted for time of observation) and Minneapolis-St. Paul for the period January 1-10, a model of the form $Y = 3.377 + .951\ X$

was generated, where X was the Fort Crawford (Prairie Du Chien) observed mean temperature for January 1-10, and Y the estimated Minneapolis-St. Paul (Fort Snelling) mean temperature for the same period (r = +.940, standard error 3.01°F). The estimated January 1843 monthly mean at Fort Snelling resulting from combined regression substitution of Fort Crawford data for January 1-10 and ordinary regression model estimation of the absolute maxima and minima for January 11-31 was 15.1°F.

The year 1843 was a significant one for non-temperature observations as well, as cloudiness and wind data (direction and speed) in the registers were now expressed in quantitative form, and were observed synchronously with temperature (at sunrise, 9 am, 3 pm, and 9 pm). Moreover, wind speeds for the first time were expressed in quantitative Beaufort scale terms, and these, of course, could easily be converted to knots by taking the mean value of the intervals described by the designated force numbers.

Special case spring-summer maxima were not estimated for the 1843-1855 interval, as for much of the period's April-September data, 9 am temperatures (possibly owing to over-exposure to the sun) were higher than corresponding 3 pm temperatures a conspiciously frequent number of times.

7.5 The July 1855 to April 1858 Fort Snelling Data

In July 1855, the military switched back to the 7 am/2 pm/9 pm scheme. This observational method continued at Fort Snelling until the meteorological observations ceased at the end of April, 1858. Coincident hourly observations of cloudiness, wind direction, and wind speed data continued, but the cloudiness data reverted back to being expressed in "cloudy" and "fair" terms again. As was done with the sky cover data prior to 1843, these observations were quantified using the mean cloudiness statistics from Table 16.

7.6 The May to December 1858 Data Interruption

From May to December 1858 there were apparently no daily meteorological observations made in Minneapolis or St. Paul by individuals affiliated with the military or the Smithsonian Institution. Evidence of this is shown in the U.S. Department of Commerce publication "Climatic Summary of the United States" (1930), which included a list of pre-1873 reported monthly mean temperatures at Fort Snelling (October 1819 to April 1858) and by Reverend Paterson (January 1859 to December 1872). For the months May to December 1858 no actually observed monthly mean temperatures are recorded, only "plugged" long-term May to December average mean temperatures (U.S. Department of Commerce 1930, p. xvi). A private citizen, Dr. C.L. Anderson, is noted in the 1981 Local Climatological Data Summary for Minneapolis-St. Paul as being a Minneapolis temperature observer from January 1856 through December 1859; however, inquiries to the National Climatic Center, the Minnesota State Historical Society, the Smithsonian Institute, and National Archives were all unsuccessful attempts to locate 1856-1859 materials under his name. Daily notes (about 60 percent complete) of temperatures at 6 am, noon, and 4 pm made by a St. Paul druggist do appear in the St. Paul Daily Pioneer for May to December 1858, but in addition to the intermittency their quality is uncertain.

In view of the above, regression model estimation of mean temperatures for the months in question was a sensible approach to take. Utilizing the 7 am/2 pm/9 pm method monthly mean temperature computations for May-December 1858 made by the Smithsonian observer in Dubuque, Iowa, substituted into regression models derived from 1891-1949 May-December monthly mean temperature relationships between Dubuque and Minneapolis, estimated May to December 1858 monthly mean temperature figures for Minneapolis were generated. Table 21 lists, by month, the May to December regression models, their standard errors, correlation coefficients, the observed Dubuque monthly means, and the estimated Minneapolis monthly means.

7.7 Data of the Reverend A.B. Paterson 1859-1872

As stated earlier, Paterson's observations from January 1859 to May 1862 and from January to February 1863 were taken from personal meteorological notes, and for the period June 1862 to December 1872 (excepting January and February 1863) from official Smithsonian forms. Unfortunately, in the meteorological notes prior to June 1862 (and for about half of July 1862 on a Smithsonian form), observations of wind directions and force were either totally absent or in the 1820-1835 method form of a single designated daily direction.

TABLE 21

REGRESSION MODELS GENERATED FOR ESTIMATING MAY TO DECEMBER 1858 MINNEAPOLIS-ST. PAUL MONTHLY MEAN TEMPERATURES

Month	Regression Model (Y = Estimated Minneapolis-St. Paul Monthly Mean, X = Observed Dubuque Monthly Mean	Standard Error of Model	Correlation Coefficient	Observed Dubuque 7 am/2 pm/9 pm Method 1858 Monthly Mean	Estimated Minneapolis-St. Paul 1858 Monthly Mean
May	Y = -1.16 + .983 X	1.40°F	+.935	56.2°F	54.1°F
June	Y = .94 + .960 X	1.33	+.921	72.9	71.0
July	Y = -3.15 + 1.022 X	1.24	+.916	73.5	71.9
August	Y = 2.35 + .946 X	1.26	+.900	72.3	70.7
September	Y = - .30 + .968 X	1.42	+.907	64.2	62.1
October	Y = -1.87 + .983 X	1.34	+.944	51.2	48.5
November	Y = -5.82 + 1.035 X	2.05	+.892	32.9	28.2
December	Y = -4.94 + .979 X	2.06	+.930	23.4	17.9

For periods without any wind data (direction or force), daily maxima and minima estimates were derived from regression model coefficients generated from 1961-1980 meteorological data excluding winds (See Appendices U through Z). Table 22 compares these regression model's average absolute residuals, by month and by temperature type, with those of the corresponding models generated with wind data included.

From Table 22, regression model precision was reduced somewhat for Midnight temperature and Overnight Minimum temperature estimation as a result of exclusion of wind data as a predictor variable. The day-to-day precision losses were so insignificant, however, averaging less than 0.1°F, that monthly mean estimation could hardly be adversely affected. Regarding the special case maxima equations, exclusion of wind data resulted in the average absolute residuals for the winter and non-winter cases to decrease from 1.94°F to 1.93°F and increase from 3.27°F to 3.51°F, respectively.

For cases in which wind direction but no forces were observed, the 1961-1980 average hourly wind speeds that were used with the Fort Snelling data were utilized as "plugs". Subsequent to May, 1862, when Paterson's Smithsonian reports appear, sky cover, wind direction, and wind forces were all synchronous with temperature observations and no statistical substitutions had to be made. One minor change was a shift from the Beaufort Scale method of estimating wind forces to the "Smithsonian" scale. As before, these observed force numbers could be easily converted to knots by taking the mean value of the intervals described by the designated force numbers.

TABLE 22

COMPARISON OF AVERAGE ABSOLUTE RESIDUALS FOR REGRESSION MODEL ESTIMATES OF MIDNIGHT, OVERNIGHT MINIMA, AND AFTERNOON MAXIMA TEMPERATURES, BY MONTH, WIND DATA INCLUDED AND EXCLUDED

Month*	Midnight Temperatures (With Wind Data)	Midnight Temperatures (Without Wind Data)	Overnight Minimum Temperatures (With Wind Data)	Overnight Minimum Temperatures (Without Wind Data)	Afternoon Maximum (With Wind Data)	Afternoon Maximum (Without Wind Data)
January	1.78°F	1.87°F	2.00°F	2.06°F	0.75°F	0.75°F
February	1.69	1.74	2.00	2.08	.89	.95
March	1.44	1.46	1.49	1.56	.99	1.01
April	1.56	1.59	1.67	1.75	1.01	1.01
May	1.72	1.76	2.08	2.18	1.14	1.14
June	1.75	1.78	1.96	2.00	1.11	1.11
July	1.53	1.58	1.85	1.97	1.05	1.05
August	1.50	1.55	1.57	1.74	1.02	1.03
September	1.50	1.51	1.38	1.41	.95	.95
October	1.63	1.66	1.38	1.42	.84	.84
November	1.45	1.46	1.63	1.67	.66	.65
December	1.56	1.62	1.87	1.88	.71	.69
Annual Mean	1.59	1.63	1.74	1.81	.93	.93

*Partitioned data combined to create monthly units,

7.7.1 A Fortunate Opportunity to Test the General Accuracy of the Models in Estimating Nineteenth Century St. Paul Daily Minima

Daily temperature observations by another local druggist, E.H. Biggs, including readings from a self-registering minimum thermometer, provided an invaluable data set that could be used to test the general precision of the twentieth-century data derived regression models in producing daily minimum temperature estimates from the mid-nineteenth century Paterson data. The Biggs observations, which appeared in the St. Paul Daily Pioneer (with some interruptions) back to 1862, included a minimum temperature reading, along with 6 am, noon, and 4 pm observations. While it is uncertain for what time intervals the self-registering minimum thermometer was set, a comparison of the Biggs actually observed data with that of the estimated Paterson minima would likely prove useful. To this end, means and standard deviations of available Biggs observed minima and the corresponding estimated Paterson "overnight minima" were computed, by month, for the period 1868 to 1872. Then, using the t-test for differences between two sample means, the discrepancies were evaluated for statistical significance. Table 23 lists, by month, the Biggs observed mean minima, standard deviations, the Paterson estimated mean "overnight minima," standard deviations, and the resulting t-test figures.

TABLE 23

t-VALUES FOR DIFFERENCES BETWEEN OBSERVED E.H. BIGGS "MINIMUM" TEMPERATURES AND REGRESSION MODEL ESTIMATED A.B. PATERSON OVERNIGHT MINIMUM TEMPERATURES, BY MONTH, 1868-1872

Month	N (Days)	Mean of Biggs Minima	Std Dv of Biggs Minima	Mean of Estimated Paterson Minima	Std Dv of Estimated Paterson Minima	t-Value for Paterson Means Minus Biggs Means
		°F	°F	°F	°F	
January	154	5.77	12.77	4.53	12.15	-0.87
February	133	9.15	14.97	7.68	14.24	-0.82
March	154	17.34	12.03	18.35	13.17	+0.70
April	143	33.18	9.42	33.90	9.73	+0.63
May	152	48.40	8.08	48.09	8.00	-0.34
June	150	56.45	7.80	56.43	8.17	-0.02
July	154	61.60	7.11	61.39	6.68	-0.27
August	146	58.92	6.66	58.55	7.13	-0.46
September	149	49.32	9.27	49.95	10.19	+0.56
October	123	36.85	9.33	36.93	9.61	+0.07
November	120	24.84	10.61	24.82	10.96	-0.01
December	152	7.65	14.38	7.37	15.14	-0.17

From Table 23, all the t-values fall short of the level necessary to reject the null hypothesis at the .05 level ($t = 1.64$), indicating that the two groups of minima were essentially equivalent statistically. This further reinforces the results of the 1961-1980 regression model tests which found regression model estimated minima to be good representations of official minima.

7.7.2 A Few Similar Opportunities with the Fort Snelling Observations

Reverting back to Fort Snelling briefly, observers at the post would occasionally record temperatures at times other than the customary official ones. These usually involved temperature extremes that might or might not differ significantly from the designated times' readings. In any case, these observations also afford an opportunity to evaluate the regression models' precision in estimating extreme temperatures. Table 24 lists the dates of these infrequent special readings, the temperature at the nearest official time of observation for the day of the "unofficial" observation, and the day's regression model estimated maxima (minima).

TABLE 24

COMPARISON OF "NON-OFFICIAL" EXTREME TEMPERATURE OBSERVATIONS AT FORT SNELLING WITH PERTINENT SAME DAY OFFICIAL READINGS AND SAME DAY REGRESSION MODEL ESTIMATED EXTREMES

	Maxima		
Day	2 pm (3 pm) Official Temperature Observation	"Non-Official" Temperature Observation	Ordinary Regression Model Estimated Maximum for Day
July 17, 1820	88°F (2 pm)	93°F (no time specified)	90°F
June 11, 1821	95°F (2 pm)	98°F (no time specified)	97°F
March 4, 1826	48°F (2 pm)	52°F at 2:30 pm	50°F
April 16, 1826	60°F (2 pm)	68°F at 6:00 pm	62°F
June 7, 1826	86°F (2 pm)	88°F at 12:00 pm	88°F
June 2, 1829	80°F (2 pm)	92°F at 12:00 pm	82°F
June 15, 1829	88°F (2 pm)	92°F at 4:00 pm	90°F
June 25, 1843	89°F (3 pm)	90°F at 5:00 pm	90°F
June 29, 1846	87°F (3 pm)	88°F at 3:35 pm	88°F
July 26, 1846	88°F (3 pm)	91°F at 2:50 pm	89°F
August 6, 1846	91°F (3 pm)	93°F at 2:00 pm	92°F
August 8, 1846	88°F (3 pm)	93°F at 2:00 pm	89°F
October 3, 1847	90°F (3 pm)	91°F at 3:30 pm	91°F

	Minima		
Day	Sunrise, "AM." or 7 am Temperature Observation	"Non-Official" Temperature Observation	Regression Model Estimated Minimum for Day
June 17, 1829	61°F (7 am)	50°F at sunrise	52°F
August 31, 1832	48°F (7 am)	34°F at 4:00 am	42°F
February 14, 1838	-38°F (a.m.)	-40°F at 2:00 am ("mercury believed to have frozen")	-41°F
November 23, 1844	8°F (sunrise)	2°F at 7:15 am	8°F
January 6, 1854	-21°F (sunrise)	-26°F at 3:00 am	-26°F

8. ANALYSIS OF THE REGRESSION MODEL DERIVED MONTHLY MEAN TEMPERATURES

Table 27 displays the estimated 1820-1872 monthly mean temperature figures for Minneapolis-St. Paul, Minnesota, with Table 28 listing the figures in standardized form. Also, Tables 29 and 30 show the estimated monthly extremes and the estimated daily ranges, respectively. Grouping the mean temperature data by decade (1820-1869), the following comparative generalizations can be made (Table 25).

From Table 25, the 1860's were easily the coldest of the five decades considered. The annual 1860-1869 average mean temperature (41.5°F) was a full 1.2°F lower than the next coldest decade, the 1850's, and 2.7°F lower than the 1961-1980 figure. Seven of the calendar months (March through September) had their coldest decade means represented by the 1860-1869 averages. In comparison, three months, (November through January) had their coldest means shown by the 1850's, and one month (October) had its lowest mean displayed by the 1840's. The 1850's and 1860's each had the coldest February means. The 1830-1839 period, conversely, was the five decades' warmest, but only 0.5°F warmer than the 1961-1980 period. Six months (January, March, April, July, November, and December) showed their highest averages for this decade, with three showing maxima for the 1820's (May, June, and August), two for the 1850's

TABLE 25

AVERAGE ESTIMATED MONTHLY MEAN TEMPERATURES BY DECADE, 1820-1869, AND 1870-1872, MINNEAPOLIS-ST. PAUL, MINNESOTA -- °F

Decade/ Period	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1820-1829	11.0	15.2	30.7	45.6	59.6	70.1	72.9	70.8	59.3	46.6	31.4	14.8	44.0
1830-1839	14.0	17.1	31.1	47.9	58.3	67.9	74.2	70.1	58.1	46.9	32.8	17.5	44.6
1840-1849	13.6	17.2	29.7	45.5	57.4	65.8	71.0	67.9	57.8	44.6	30.3	16.1	43.1
1850-1859	9.1	14.5	27.7	42.8	56.4	67.4	73.2	69.4	60.4	48.5	29.6	13.7	42.7
1860-1869	10.2	14.5	24.8	42.1	55.7	65.2	69.4	66.6	57.4	44.8	31.0	16.0	41.5
1870-1872	12.2	18.3	26.8	48.0	61.5	69.4	72.0	68.5	61.1	48.0	29.8	10.7	43.8
1820-1872	11.6	15.9	28.7	45.0	57.7	67.4	72.1	69.0	58.7	46.4	30.9	15.3	43.2
1961-1980	9.5	16.3	29.6	45.5	58.0	67.9	72.9	70.0	60.1	49.2	33.3	18.1	44.2

TABLE 26

AVERAGE ESTIMATED MONTHLY MEAN TEMPERATURES, BY THREE DECADE GROUPS, 1820-1869 AND 1951-1980, MINNEAPOLIS-ST. PAUL, MINNESOTA -- °F

Three-Decade Period	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1820-1849	12.9	16.5	30.5	46.3	58.4	67.9	72.7	69.6	58.4	46.0	31.5	16.1	43.9
1830-1859	12.2	16.3	29.5	45.4	57.4	67.0	72.8	69.1	58.8	46.7	30.9	15.8	43.5
1840-1869	11.0	15.4	27.4	43.5	56.5	66.1	71.2	68.0	58.5	46.0	30.3	15.3	42.4
1951-1980	11.2	17.5	29.2	46.0	58.5	68.1	73.1	70.6	60.6	49.6	33.2	19.2	44.7

TABLE 27

ESTIMATED MONTHLY MEAN TEMPERATURES, MINNEAPOLIS-ST. PAUL, MINNESOTA, 1820-1872

°F

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	YEAR
1820	0.3	19.7	26.1	52.7	59.3	69.3	69.5	67.4	61.2	43.4	31.3	9.6	42.4
1821	5.8	13.0	29.0	40.4	54.9	73.0	71.1	74.5	59.9	48.9	30.0	9.5	42.5
1822	11.0	18.9	37.5	43.4	60.0	68.9	73.8	71.8	60.4	42.5	30.4	1.7	43.4
1823	11.8	5.0	29.8	48.4	55.9	73.2	75.4	71.6	55.6	46.9	31.2	12.5	43.1
1824	16.6	12.8	23.9	41.6	55.0	64.6	72.2	70.1	61.0	42.2	29.7	21.5	42.6
1825	14.0	27.6	37.7	55.2	60.1	68.9	74.5	70.4	62.2	46.2	33.7	15.1	47.1
1826	9.3	14.0	29.4	37.0	65.3	71.0	72.7	68.8	55.4	48.5	34.7	18.5	43.7
1827	16.4	23.6	31.8	44.8	61.0	70.7	73.3	69.7	61.3	47.4	31.9	12.6	45.4
1828	8.9	15.9	31.9	45.1	58.8	70.1	74.5	73.6	58.7	49.7	34.6	23.2	45.4
1829	15.5	2.0	29.6	47.2	66.0	71.6	71.9	70.2	57.0	50.1	26.0	24.2	44.3
1830	12.3	23.2	33.3	51.0	57.8	67.2	80.2	72.2	56.9	54.4	41.8	15.1	47.3
1831	8.0	13.7	32.1	44.8	59.5	68.8	72.7	71.1	54.8	47.8	31.1	2.5	42.2
1832	15.8	6.3	37.8	53.6	55.1	71.4	73.2	67.0	60.2	50.0	33.2	24.8	45.7
1833	20.4	20.0	33.3	51.3	60.2	67.0	73.3	70.0	62.4	40.9	36.6	30.6	47.2
1834	2.0	30.1	32.2	50.2	60.1	64.7	76.3	72.9	56.3	45.0	38.8	20.2	45.7
1835	22.7	8.7	32.6	43.6	61.1	66.8	69.4	67.5	54.6	45.7	23.9	16.4	42.8
1836	11.3	15.8	18.9	43.0	63.5	67.8	72.2	65.6	55.9	41.0	33.2	17.4	42.1
1837	18.4	23.8	22.9	40.4	53.8	64.9	71.9	68.8	58.6	46.6	36.8	16.9	43.6
1838	9.3	4.8	38.5	42.9	53.9	71.6	77.4	73.9	61.8	42.8	22.4	10.1	42.4
1839	20.1	24.5	29.5	58.4	57.9	68.7	75.6	72.3	57.2	54.5	30.1	21.1	47.5
1840	11.6	20.9	35.8	48.0	64.0	70.6	71.8	66.5	57.0	40.8	28.7	18.3	44.5
1841	12.3	17.3	33.2	39.8	59.8	70.4	72.5	68.4	54.3	45.1	31.2	20.6	43.7
1842	15.3	17.1	37.9	48.4	50.9	56.0	67.2	67.7	57.4	47.5	22.0	16.8	42.0
1843	15.1	1.0	3.9	43.0	52.2	62.5	69.8	66.6	57.5	36.4	25.8	22.0	38.0
1844	8.5	21.7	32.8	51.3	55.5	62.2	69.5	64.5	54.7	41.4	28.4	16.7	42.2
1845	19.1	25.1	34.2	47.2	59.9	67.8	74.6	69.5	60.5	46.3	29.9	14.1	45.7
1846	28.8	19.3	38.8	46.4	63.9	67.2	74.4	74.1	63.3	45.5	40.1	21.6	48.6
1847	4.1	19.4	23.4	46.4	52.3	65.3	72.2	67.1	58.1	47.0	30.3	15.8	41.8
1848	17.3	19.0	27.7	44.6	60.6	67.6	66.8	67.4	53.8	49.5	25.0	7.4	42.2
1849	3.6	11.6	29.7	40.0	55.3	68.2	71.2	67.5	61.4	46.8	41.6	7.7	42.0
1850	12.5	17.0	23.4	38.0	55.7	71.4	75.9	74.1	60.5	49.0	33.6	11.7	43.6
1851	14.0	21.8	39.6	49.4	56.8	66.4	75.3	68.5	67.9	50.7	29.5	10.9	45.9
1852	11.4	22.4	25.8	42.0	57.6	68.5	72.8	71.1	53.6	52.8	24.9	10.8	42.8
1853	13.2	6.6	22.2	43.9	53.2	67.3	70.0	70.4	59.6	44.5	28.3	17.6	41.4
1854	0.8	14.7	30.6	48.4	57.4	69.6	74.9	70.5	61.4	51.6	32.1	20.5	44.4
1855	11.0	9.2	23.6	49.5	61.3	65.4	72.2	65.7	60.5	46.3	33.0	8.9	42.2
1856	-0.5	11.1	19.4	46.5	58.5	70.8	74.7	67.4	58.8	51.2	30.7	8.6	41.4
1857	-4.1	15.1	23.7	31.6	53.1	62.5	74.1	68.6	61.3	48.0	25.2	24.8	40.3
1858	21.0	11.6	36.9	42.2	54.1	71.0	71.9	70.7	62.1	48.5	28.2	17.9	44.7
1859	11.3	15.7	31.5	36.2	56.8	60.6	70.6	67.4	57.8	42.0	30.1	5.0	40.4
1860	12.5	16.5	37.0	43.6	58.5	65.0	67.8	65.1	54.4	47.2	28.8	13.9	42.5
1861	8.4	16.6	24.9	45.4	50.1	66.9	66.6	66.8	57.9	46.3	29.5	20.0	41.6
1862	4.1	2.1	25.7	39.3	57.8	64.1	69.1	65.9	57.8	45.4	28.1	20.8	40.0
1863	18.6	14.4	26.5	47.7	58.4	63.9	67.7	66.6	57.5	38.8	29.4	19.1	42.4
1864	9.7	19.9	26.0	42.6	57.9	67.3	72.6	70.1	58.0	43.7	29.9	10.7	42.4
1865	12.3	22.7	24.6	42.8	57.1	66.5	65.0	65.7	66.3	47.4	36.8	9.2	43.0
1866	9.0	7.9	17.9	41.0	53.3	62.2	72.0	63.5	53.4	49.4	32.2	16.1	39.8
1867	6.4	15.1	12.1	39.4	48.0	66.6	66.7	67.2	56.4	47.1	34.1	14.6	39.5
1868	3.2	11.9	32.5	38.5	58.7	66.5	77.6	66.4	50.9	43.2	31.6	15.9	41.4
1869	18.2	17.6	20.4	41.0	56.7	63.2	68.7	68.6	61.2	40.0	29.6	19.8	42.1
1870	11.2	16.2	27.0	50.6	64.1	72.1	73.9	66.3	65.5	48.4	37.6	18.7	46.0
1871	12.5	19.4	31.7	47.2	63.8	67.5	70.3	68.8	58.9	47.8	26.8	8.2	43.6
1872	12.8	19.3	21.7	46.1	56.5	68.6	71.8	70.4	59.0	47.8	25.0	5.1	42.0
MEAN	11.6	15.9	28.7	45.0	57.7	67.4	72.1	69.0	58.7	46.4	30.9	15.3	43.2

TABLE 28

STANDARDIZED ESTIMATED MONTHLY MEAN TEMPERATURE DATA, BY MONTH, 1820-1872

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1820	-1.77	+.58	-.38	+1.51	+.40	+.56	-.35	-.59	+.73	-.78	+.08	-.93
1821	-.91	-.43	+.05	-.39	-.72	+1.64	-.34	+2.06	+.35	+.66	-.21	-.95
1822	-.10	+.48	+1.24	-.30	+.58	+.44	+.53	+1.06	+.49	-1.02	-.12	-2.21
1823	+.03	-1.64	+.16	+.67	-.46	+1.70	+1.05	+.98	-.92	+.14	+.06	-.46
1824	+.78	-.46	-.67	-.66	-.69	-.82	+.02	+.43	+.67	-1.10	-.27	+1.00
1825	+.38	+1.78	+1.27	+2.00	+.60	+.44	+.76	+.54	+1.02	-.05	+.61	-.04
1826	-.36	-.28	+.10	-1.55	+1.93	+1.05	+.18	-.06	-.98	+.56	+.84	+.51
1827	+.75	+1.17	+.44	-.03	+.83	+.97	+.37	+.28	+.76	+.27	+.21	-.45
1828	-.42	+.01	+.45	+.03	+.27	+.79	+.76	+1.73	-.01	+.88	+.81	+1.27
1829	+.61	-2.10	+.13	+.44	+2.11	+1.23	-.08	+.46	-.51	+.98	-1.09	+1.44
1830	+.11	+1.11	+.65	+1.18	+.02	-.06	+2.59	+1.21	+.05	+2.11	+2.41	-.04
1831	-.57	-.33	+.48	-.03	+.45	+.41	+.18	+.80	-1.15	+.37	+.04	-2.08
1832	+.66	-1.45	+1.28	+1.69	-.67	+1.17	+.37	-.72	+.44	+.95	+.50	+1.53
1833	+1.38	+.63	+.65	+1.24	+.63	-.12	+.41	+.39	+1.08	-1.44	+1.26	+2.48
1834	-1.51	+2.15	+.50	+1.02	+.60	-.79	+1.34	+1.47	-.71	-.36	+1.74	+.79
1835	+1.74	-1.08	+.55	-.27	+.86	-.17	-.88	-.54	-1.21	-.18	-1.56	+.17
1836	-.05	-.01	-1.38	-.38	+1.47	+.12	+.02	-1.24	-.83	-1.41	+.50	+.33
1837	+1.07	+1.20	-.81	-.89	-1.00	-.73	-.11	-.06	-.03	+.06	+1.30	+.25
1838	-.36	-1.67	+1.38	-.40	-.97	+1.23	+1.69	+1.84	+.91	-.94	-1.89	-.85
1839	+1.33	+1.31	+.12	+2.62	+.04	+.38	+1.11	+1.24	-.45	+2.14	-.18	+.93
1840	0	+.76	+1.00	+.59	+1.60	+.94	-.08	-.91	-.51	-1.47	-.49	+.48
1841	+.11	+.22	+.64	-1.91	+.53	+.88	+.12	-.21	-1.30	-.34	+.06	+.85
1842	+.58	+.19	+1.30	+.67	-1.74	-3.33	-1.59	-.47	-.39	+.30	-1.98	+.24
1843	+.55	-2.25	-3.49	-.38	-1.41	-1.43	-.75	-.87	-.36	-2.63	-1.14	+1.08
1844	-.49	+.88	+.58	+1.24	-.57	-1.52	-.85	-1.65	-1.18	-1.31	-.56	+.22
1845	+1.18	+1.40	+.78	+.44	+.55	+.12	+.79	+.20	+.52	-.02	-.23	-.20
1846	+2.70	+.52	+1.43	+.28	+1.57	-.06	+.73	+1.91	+1.35	-.23	+2.03	+1.02
1847	-1.18	+.54	-.74	+.28	-1.38	-.61	+.02	-.69	-.18	+.16	-.14	+.07
1848	+.89	+.48	-.14	-.07	[illegible]	+.06	-1.72	-.58	-1.45	+.82	-1.32	-1.29
1849	-1.26	-.64	+.14	-.97	-.62	+.24	-.30	-.54	+.79	+.11	+2.37	-1.24
1850	+.14	+.17	-.74	-1.36	-.52	+1.17	+1.21	+1.91	+.52	+.69	+.59	-.59
1851	+.38	+.90	+1.54	+.87	-.24	-.29	+1.02	-.17	+2.70	+1.14	-.32	-.72
1852	-.03	+.99	-.41	-.58	-.03	+.32	+.21	+.80	-1.51	+1.69	-1.34	-.74
1853	+.25	-1.40	-.91	-.21	-1.15	-.03	-.69	+.54	+.26	-.49	-.58	+.37
1854	-1.70	-.18	+.27	+.67	-.08	+.64	+.89	+.57	+.79	+1.38	+.26	+.84
1855	-.10	-1.91	-.72	+.89	+.91	-.58	+.02	-1.21	+.52	-.02	+.46	-1.05
1856	-1.90	-.72	-1.31	+.30	+.20	+1.00	+.82	-.58	+.02	+1.27	-.05	-1.09
1857	-2.47	-.12	-.70	-2.61	-1.18	-1.43	+.63	-.13	+.76	+.43	-1.27	+1.53
1858	+1.47	-.64	+1.17	-.54	-.92	+1.05	-.08	+.65	+1.00	+.56	-.61	+.41
1859	-.05	-.02	+.40	-1.71	-.24	-1.99	-.50	-.58	-.27	-1.15	-.18	-1.68
1860	+.14	+.10	+1.16	-.27	+.20	-.70	-1.40	-1.43	-1.27	+.22	-.47	-.23
1861	-.50	+.11	-.53	+.09	-1.84	-.14	-1.78	-.80	-.24	-.02	-.32	+.76
1862	-1.18	-2.08	-.42	-1.11	+.02	-.98	-.98	-1.13	-.27	-.26	-.63	+.89
1863	+1.10	-.22	-.31	+.53	+.17	-1.02	-1.43	-.87	-.36	-1.99	-.34	+.61
1864	-.30	+.61	-.38	-.46	+.04	-.03	+.15	+.43	-.21	-.70	-.23	-.75
1865	+.11	+1.04	-.57	-.42	-.16	-.26	-2.30	-1.21	+2.23	+.27	+1.30	-1.00
1866	-.41	-1.20	-1.52	-.77	-1.13	-1.52	-.05	-2.02	-1.57	+.80	+.28	+.12
1867	-.82	-.12	-2.34	-1.09	-2.48	-.23	-1.75	-.65	-.68	+.19	+.70	-.12
1868	-1.32	-.60	+.54	-1.26	+.25	-.26	+1.76	-.95	-2.30	-.84	+.15	+.09
1869	+1.04	+.26	-1.17	-.77	-.26	-1.23	-1.11	-.13	+.73	-1.68	-.30	+.72
1870	-.06	+.05	-.24	+1.10	+1.62	+1.38	+.57	-.98	+2.00	+.53	+1.48	+.54
1871	+.14	+.54	+.43	+.44	+1.55	+.03	-.59	-.06	+.05	+.37	-.92	-1.16
1872	+.19	+.52	-.97	+.22	+.31	+.35	-.11	+.54	+.08	+.37	-1.32	-1.66

TABLE 29

ESTIMATED MONTHLY TEMPERATURE EXTREMES, 1820-1872
(MAXIMUM/MINIMUM)
°F

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1820	30/-34	48/-20	69/-12	67/9	84/33	94/42	95/47	93/46	71/27	-	57/-7	33/-23
1821	41/-34	48/-14	56/3	80/11	85/30	98/49	94/51	93/54	84/34	73/25	55/8	38/-25
1822	47/-29	43/-24	70/13	85/14	86/38	91/47	95/56	94/48	69/32	81/13	64/-24	47/-32
1823	43/-28	41/-26	55/-2	81/24	88/32	102/36	98/48	94/49	88/25	83/20	61/9	45/-20
1824	43/-24	45/-28	59/-12	75/25	91/19	87/45	98/53	94/47	85/40	69/20	57/-1	54/-1
1825	40/-19	52/-18	63/18	84/29	85/34	89/52	96/54	90/48	80/39	83/15	70/8	41/-2
1826	43/-27	52/-24	58/-6	68/2	91/26	94/53	92/52	88/47	79/36	83/19	61/15	49/-20
1827	45/-25	48/-11	58/-9	67/25	88/37	94/50	98/53	94/49	91/29	-	63/0	35/-16
1828	39/-28	52/-22	58/-18	80/16	82/28	94/46	95/53	89/53	85/41	81/26	56/17	49/-3
1829	43/-20	35/-33	68/-2	86/25	92/34	92/50	90/53	87/47	80/35	81/18	53/-7	53/-8
1830	48/-21	58/-22	66/2	83/30	82/28	87/48	96/63	92/55	85/33	83/34	66/26	54/-28
1831	33/-20	52/-21	60/2	81/22	90/36	86/48	94/55	94/49	82/30	83/18	60/-9	37/-28
1832	47/-29	38/-32	76/-4	82/27	84/31	90/48	92/56	85/34	84/32	79/27	65/7	50/-13
1833	46/-21	49/-15	72/-22	82/24	88/35	92/37	96/51	88/46	83/39	63/17	59/13	46/-14
1834	41/-36	53/0	57/7	82/26	92/34	88/47	96/56	91/52	54/26	71/23	68/13	48/-12
1835	45/-19	51/-33	64/-11	79/15	83/30	90/47	94/49	90/47	77/30	77/14	61/-14	43/-14
1836	41/-26	54/-26	62/-16	79/12	89/39	90/41	95/53	87/44	75/32	68/15	57/11	49/-28
1837	43/-8	55/-10	52/-12	80/6	85/24	89/47	94/49	96/46	86/34	71/20	56/11	42/-22
1838	48/-24	37/-41	77/2	83/18	94/28	98/48	102/53	97/51	87/36	83/19	60/-4	47/-22
1839	44/-19	54/-28	74/-16	86/35	88/28	98/46	97/52	98/49	84/27	84/25	55/-4	48/-14
1840	41/-38	56/-30	61/-2	81/21	94/33	91/49	92/53	91/48	79/36	72/11	59/-3	-
1841	49/-35	61/-15	64/8	70/18	90/21	94/49	95/52	87/47	93/31	72/20	62/0	46/2
1842	50/-15	50/-25	75/1	88/24	85/27	83/37	92/40	91/45	87/34	77/20	68/-19	39/-13
1843	-	31/-26	28/-22	80/-1	74/25	90/34	91/49	82/49	85/32	71/8	42/4	40/-6
1844	36/-19	46/-16	66/2	81/29	78/31	84/40	91/54	86/43	82/30	72/19	60/-7	43/-10
1845	43/-14	53/-5	80/1	83/14	87/37	92/47	95/52	90/50	83/33	73/16	69/-13	47/-15
1846	60/7	53/-19	65/19	86/17	86/42	88/43	96/56	96/54	90/39	77/18	63/5	43/1
1847	41/-25	42/-18	75/-14	83/18	83/31	87/41	94/49	90/46	89/38	91/13	74/8	45/-20
1848	46/-24	45/-8	65/-12	77/17	83/38	91/40	89/49	88/47	80/32	71/26	45/-3	30/-19
1849	37/-32	41/-31	57/4	61/22	84/21	88/45	95/49	87/46	84/43	75/25	73/17	33/-25
1850	37/-18	44/-26	48/-7	76/15	88/30	89/54	99/57	92/50	80/46	71/31	58/13	31/-15
1851	47/-29	51/-13	77/7	80/19	80/28	88/42	95/51	90/49	92/34	77/20	63/7	47/-26
1852	45/-32	58/-13	58/-10	68/3	90/31	97/34	95/45	92/46	86/29	84/25	57/-3	46/-29
1853	57/-17	47/-24	59/-16	68/12	85/31	87/47	89/54	92/42	90/39	74/7	55/1	48/-16
1854	46/-37	46/-20	60/1	87/7	85/30	94/40	95/53	96/49	86/37	81/26	60/9	46/-8
1855	56/-27	39/-25	50/-18	89/14	92/31	96/39	98/47	84/44	89/40	80/20	60/5	45/-35
1856	33/-35	44/-32	46/-16	69/24	93/31	97/43	97/56	97/47	90/25	86/21	56/2	36/-17
1857	31/-37	44/-35	59/-19	66/1	86/20	92/38	93/53	92/45	87/35	76/21	54/-14	48/1
1858	45/-17	55/-25	70/-5	87/18	-	-	-	-	-	-	-	-
1859	44/-25	46/-18	50/15	75/7	85/29	86/32	95/44	89/46	79/35	78/19	70/4	39/-28
1860	45/-41	46/-14	72/15	71/16	87/20	87/43	87/47	88/42	80/34	71/24	58/-16	38/-21
1861	37/-19	43/-27	50/-1	82/22	78/29	88/46	91/49	94/46	87/31	76/20	55/-20	46/-17
1862	32/-37	35/-36	50/-3	55/6	85/33	85/43	90/51	83/47	87/35	80/16	58/6	44/-16
1863	41/-17	42/-33	49/1	78/17	89/32	92/38	93/40	93/33	92/30	67/16	56/-11	46/-32
1864	50/-38	51/-23	58/-9	73/26	90/24	93/35	94/50	95/47	86/25	69/22	51/-1	47/-24
1865	39/-19	48/-4	59/-26	79/3	89/28	94/39	86/46	96/45	86/43	80/19	64/17	37/-28
1866	38/-23	40/-31	42/-11	78/15	88/22	86/42	92/51	82/39	79/26	84/15	56/-1	44/-16
1867	32/-30	43/-25	44/-25	62/13	78/21	89/45	85/46	87/41	83/35	74/23	66/-8	35/-17
1868	31/-39	47/-29	72/-14	74/5	89/34	96/38	99/56	89/44	73/19	78/14	58/9	37/-19
1869	38/-9	42/-16	57/-20	70/9	85/35	91/37	92/47	86/51	88/28	72/15	66/4	42/-10
1870	34/-24	40/-24	47/-11	85/23	92/40	100/43	97/50	92/41	83/50	82/18	65/12	53/-19
1871	41/-18	45/-16	55/6	92/27	94/33	94/46	92/48	95/42	86/29	81/22	58/-13	44/-26
1872	40/-19	50/-19	47/-12	85/14	91/33	93/47	96/48	93/45	93/31	77/23	55/-16	41/-34

TABLE 30

AVERAGE DAILY RANGES FOR ESTIMATED MONTHLY MEAN TEMPERATURES
1820-1872
°F

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
1820	19.8	22.7	20.5	21.9	25.4	25.9	25.3	22.9	19.0	-	15.9	19.2	21.7
1821	22.7	24.7	20.6	20.4	26.4	23.3	23.3	19.5	20.0	19.7	14.0	19.0	21.1
1822	24.5	21.8	21.0	22.3	24.2	19.4	21.4	23.3	23.6	19.9	17.8	22.9	21.8
1823	22.5	23.2	20.1	23.3	26.0	29.8	24.5	21.7	24.4	25.5	18.0	18.7	23.1
1824	22.4	20.7	21.8	19.4	26.2	19.9	21.5	19.8	19.5	18.2	14.6	17.6	20.1
1825	21.7	21.2	16.5	21.8	20.2	18.0	18.4	17.8	15.6	18.2	17.6	15.9	18.6
1826	20.6	28.7	23.8	22.0	22.6	19.8	20.6	18.9	19.5	21.9	17.2	17.2	21.1
1827	20.0	23.6	20.6	18.1	22.4	18.4	19.5	20.6	18.7	-	17.5	18.0	19.8
1828	24.6	25.8	21.7	19.1	21.4	22.6	20.6	17.6	17.3	23.1	14.0	19.7	20.6
1829	21.9	23.8	21.8	21.8	23.7	22.1	20.8	19.2	18.0	18.8	17.2	20.6	20.8
1830	21.1	24.2	20.6	24.8	19.9	20.7	19.7	18.7	17.3	18.3	12.9	16.1	19.2
1831	22.4	24.9	17.6	19.1	23.1	19.1	19.6	19.1	20.0	19.4	15.1	21.4	20.1
1832	23.4	24.2	23.7	22.2	21.1	20.2	18.9	19.3	20.5	22.1	18.0	16.8	20.9
1833	18.8	23.2	22.1	24.1	23.5	24.1	21.8	20.0	17.4	15.8	15.9	13.5	20.0
1834	23.9	20.6	20.1	25.8	23.1	19.1	19.3	16.9	17.4	17.8	16.8	18.3	19.9
1835	17.5	23.9	20.6	20.9	22.5	19.1	21.0	17.4	17.8	17.0	16.5	21.0	19.6
1836	19.7	20.6	26.2	22.8	25.3	23.8	21.4	19.4	21.2	21.1	17.1	19.4	21.5
1837	19.1	21.3	23.8	25.1	25.1	23.5	23.7	23.6	19.3	21.3	19.0	21.1	22.2
1838	24.8	30.8	30.2	22.8	28.8	25.7	26.4	24.8	24.5	21.1	20.4	24.5	25.4
1839	21.1	27.6	26.2	27.7	26.6	29.0	26.8	25.7	24.7	19.8	18.5	17.9	24.6
1840	23.0	25.2	23.4	25.2	25.5	25.7	21.6	19.7	21.0	18.6	13.5	-	22.0
1841	22.0	22.8	20.6	17.0	23.7	19.1	20.0	21.3	20.0	17.7	16.9	14.6	19.6
1842	22.1	23.8	22.5	23.0	23.9	20.3	21.9	20.3	19.9	23.7	13.5	15.9	20.9
1843	-	20.1	25.7	21.4	21.7	18.6	19.8	18.4	17.1	17.0	12.7	15.0	18.9
1844	17.0	19.0	19.3	18.1	21.1	19.7	17.2	19.1	20.1	19.8	15.0	16.0	18.4
1845	18.4	17.2	22.0	19.0	20.9	17.6	19.1	21.0	21.5	19.9	18.5	18.0	19.4
1846	17.0	20.6	18.4	18.0	19.7	19.6	18.0	20.8	22.4	19.5	14.7	14.9	18.6
1847	22.2	19.1	23.0	25.2	22.5	18.7	17.7	19.7	20.4	24.1	15.2	19.5	20.6
1848	22.1	18.5	18.4	23.1	20.7	20.6	17.8	17.5	19.3	20.8	12.7	16.4	19.0
1849	19.4	20.7	18.3	17.1	18.4	16.2	19.5	17.3	18.6	18.5	16.6	16.4	18.1
1850	19.6	21.8	17.2	15.8	19.8	16.6	16.0	14.8	16.6	22.2	11.1	14.2	17.1
1851	21.5	21.8	21.8	27.6	22.1	21.2	15.4	17.2	21.5	22.2	14.6	15.4	20.2
1852	16.1	19.4	14.7	21.4	21.2	26.6	23.4	24.3	24.5	24.5	16.0	17.0	20.9
1853	15.6	17.3	17.3	21.1	20.8	16.0	16.9	19.4	17.7	25.2	15.5	16.6	18.3
1854	21.7	24.6	19.5	24.1	20.7	19.8	19.9	22.9	20.8	19.5	17.7	18.4	20.8
1855	22.2	22.2	21.9	25.1	28.1	24.2	23.5	18.9	17.2	22.0	17.6	19.1	21.8
1856	23.6	22.9	23.0	18.1	24.2	23.2	23.4	22.0	21.7	18.9	17.9	18.8	21.3
1857	22.8	21.8	21.3	19.6	25.4	23.0	24.3	21.3	19.7	17.5	16.9	16.1	20.8
1858	22.3	22.1	19.1	18.9	-	-	-	-	-	-	-	-	-
1859	19.9	21.0	12.6	20.2	20.9	20.2	21.2	19.6	20.4	18.3	16.1	19.3	19.1
1860	22.6	21.7	20.9	23.8	24.1	20.7	21.4	22.1	19.3	22.0	15.9	18.0	21.0
1861	18.8	19.2	17.9	19.3	20.3	21.1	20.9	19.4	18.9	20.1	15.2	19.8	19.2
1862	19.6	23.6	17.1	17.8	24.4	22.4	21.4	18.9	20.7	23.0	17.9	18.5	20.4
1863	15.0	18.8	16.7	22.9	23.8	23.7	23.7	20.8	22.3	15.9	17.2	14.5	19.6
1864	20.8	20.2	17.5	20.0	26.2	24.2	20.9	23.0	22.0	19.9	15.6	20.7	20.9
1865	21.3	16.1	18.7	20.1	24.5	21.1	19.3	18.5	19.6	16.9	19.9	20.1	19.7
1866	16.9	23.1	18.5	17.1	26.1	21.2	21.2	19.6	20.3	19.0	14.2	16.3	19.5
1867	19.8	22.6	25.9	20.1	19.7	20.3	19.3	20.7	20.3	21.9	19.2	20.1	20.8
1868	21.1	21.6	20.2	22.8	27.2	23.5	23.5	21.0	21.8	20.5	13.0	16.2	21.0
1869	18.8	20.4	22.1	19.6	24.4	23.7	23.1	18.8	19.4	18.4	14.9	14.6	19.8
1870	20.7	22.1	19.7	29.3	24.7	23.9	24.3	23.7	19.5	19.2	20.1	16.9	22.0
1871	17.7	22.7	17.2	20.6	27.3	24.9	22.8	23.5	23.4	22.1	15.4	16.4	21.3
1872	19.5	19.3	20.2	23.4	21.4	20.9	22.9	21.7	20.7	26.2	14.9	18.5	20.8
MEAN	20.6	22.1	20.6	21.5	23.3	21.6	21.1	20.3	20.1	20.3	16.2	17.9	20.3

(September and October), and one for the 1840's (February). Examining the annual averages, the trend of temperature was slightly warmer from the 1820's to the 1830's, and then sharply colder through the 1860's. Comparing the annual mean temperature of the entire 1820-1872 estimating period with that of 1961-1980, the former was 1°F colder. Greatest negative monthly disparities from 1961-1980 means were shown for the consecutive months October through December (departures of -2.8°F, -2.4°F, and -2.8°F respectively), with the largest positive discrepancy, +2.1°F shown for January. This January discrepancy was the only case in which a 1961-1980 average was not warmer than a corresponding 1820-1872 figure. Finally, as the thirty-year period is a well-established time unit for determining climatic "normals", Table 26 compares the average monthly mean temperatures for the intervals 1820-1849, 1830-1859, 1840-1869, and 1951-1980.

Inspecting the monthly mean temperatures in more detail, along with examining the standardized data in Table 28, the following major temperature movements, by decade, can be described.

8.1 The 1820-1829 Decade

The 1820's, second warmest of the five complete decades between 1820 and 1872, showed a mixed character of monthly mean temperature anomalies over the first half (years: 1820-1824; 31 of 60 or 51 percent above normal) and a predominantely above normal character of departures over the second half (years: 1825-1829; 45 of 60 or 75 percent above normal); from May 1826 on, 36 of the decade's remaining

43 monthly means were above 1820-1872 monthly averages. The decade's maximum annual means, 47.1°F for 1825, ranked as the fifth warmest of the 1820-1872 era, a three month spell of much above normal warmth from February to April of that year (from Table 28, average standardized departures for the three months: +1.68) in part responsible. Some shorter time-scale features of interest for the decade were the series of three alternating month well below normal monthly means over the five-month period October 1822 to February 1823, including the coldest December in recorded history (standardized departures for the five months: -1.02, -.12, -2.21, +.03, and -1.64, respectively), the ten consecutive months of above normal means from December 1824 through October 1825, and the great two-month temperature reversal between April and May 1826 (standardized departures shifting from -1.55 to +1.93.) Another interesting feature was the isolated, much below normal monthly mean temperature lapse of February 1829, a month that was 2.10 standard deviation units below average, yet was both preceded and succeeded by four months each of mostly well above average monthly means. This nine-month interval also included the most anomalously warm month of the decade, May 1829 (standardized departure: +2.11).

8.2 The 1830-1839 Decade

The 1830's, warmest of the pre-weather bureau era decades, included the second, third, and fourth warmest years of the 53-year era. These were 1839, annual mean temperature 47.5°F, and 1830 and 1833, annual mean temperatures 47.3°F and 47.2°F, respectively. Four of the first five years of the 1830's were above normal, continuing a tendency of above average annual means that had begun with 1825 (nine of the ten annual means over the 1825-1834 period were warmer than average, only 1831 showing a negative departure). On an individual basis, 73 percent (44 of 60) of the 1830-1834 monthly means were above average, similar to the proportion shown for the years 1825-1829. Following sharply colder and below average means for 1835 and 1836, a slightly above normal average for 1837, and a below normal figure for 1838, the annual mean temperature showed a 5.1°F rise to the decade's maximum for 1839.

As the 1830's were the warmest decade, there were a number of well above average mean temperature figures. April 1839 was the 2nd warmest month in relative terms of the 1820-1872 period, the 58.5°F monthly mean being 2.62 standard deviation units above the 53-year April average (January 1846 and September 1851 were each 2.70 standard deviation units warmer than their respective 1820-1872 means). This extreme departure statistic was followed in rank by July 1830's +2.59, December 1833's +2.48, and November 1830's +2.41. July and November 1830 were part of a five-month period that experienced three positive anomalies of more than two standard deviations (standardized departures for July to November 1830: +2.59, +1.21, +.05, +2.11, and +2.41, respectively). Coldest month of the decade in relative terms was December 1831, the mean temperature (2.5°F) being 2.08 standard deviation units below the 1820-1872 December average. This month was part of a 12-month period September 1831 to August 1832 that displayed scattered single month lapses of well below normal mean temperatures.

Another interesting short term feature of the decade was the great variability in temperature departures exhibited for the September 1833 to February 1834 interval. Over this six-month period, the succession of standardized mean temperatures was as follows: +1.08, -1.44, +1.26, +2.48, -1.51, and +2.15. In absolute terms, January 1834 was 28.5°F colder than December 1833, and February 1834 28.1°F warmer than January 1834.

Some other features of note were the nine straight months of well above normal means from September 1832 to May 1833, and the alternating 3 to 4 month long runs of much above and much below normal means shown over June 1838 to April 1839 (See Table 28).

8.3 The 1840-1849 Decade

The 1840-1849 decade, 1.5°F colder than the 1830's, showed great extremes in monthly mean temperature departures, mostly negative. From the 1840 annual average of 44.5°F (1.3°F above normal), the annual means displayed three consecutive declines to a 38.0°F figure for 1843, coldest in the history of Minneapolis-St. Paul temperature observations (1820-1983). From this absolute minimum, the yearly averages then exhibited consecutive warmings for three straight years, reaching the maximum annual mean for the 1820-1872 period (48.6°F) for 1846. From this peak, however, the yearly average plunged 6.8°F to 41.8°F for 1847 (1.4°F below average), and the means for 1848 and 1849 were each more than 1°F below average. The outstanding feature of the decade was the remarkably cold 19-month period May 1842-November 1843, averaging 1.22 standard deviation units below normal. This interval includes the coldest June (1842), the coldest November (1842), the coldest March (1843), and the coldest October (1843) in recorded history. The departure statistics for March 1843 and June 1842 (-3.49 and -3.33 standard deviation units, respectively) indicate return periods of thousands of years, so perhaps some forcing mechanism, peculiar in extent to the 1842-1843 period only was responsible. The December 1843 to April 1844 period, in which 4 of the 5 monthly means were above normal, was only a brief respite, as the next 7 monthly means ending with November 1844 were all well below normal again, showing average departures of -1.09 standard deviation units. Included in this interval is the 2nd coldest August in recorded history. Beginning with December 1844, however, the monthly means began to show a consistently above normal character, and 20 of the next 25 months ending with December 1846 were above average. This period included the most anomalously warm month of the decade, January 1846 (2.70 standard deviation units above average), warmest January in history.

Another cold lapse returned over July 1848 to January 1849, however, with 5 of the 7 months at least 1.2 standard deviation units below average, (standardized departures: -1.72, -.58, -1.45, +.82, -1.32, -1.29, and -1.26, respectively).

8.4 The 1850-1859 Decade

The 1850's, while only 0.4°F colder than the 1840's as a unit, showed less variability and a different seasonal pattern of anomalies. For example, while winter/early spring (December to March) monthly mean temperatures were about 3°F colder than those of the 1840's, the mid-summer to early fall (July to October) means of the 1850's were 2°F warmer than those of the 1840's. Above and below normal annual means were well scattered through the decade, the years 1850-1851, 1854, and 1858 showing warmer than normal averages. The latter above normal year was the last such classification until 1870.

Two noteworthy features of the decade were the relatively brief extreme cold periods of December 1855 to March 1856 (standardized departures: -1.05, -1.90, -.72, and -1.31, respectively) and December 1856 to June 1857 (standardized departures: -1.09, -2.47, -.12, -.70, -2.61, -1.18, and -1.43, respectively). January and April 1857 are the coldest months of their respective names in recorded history. September 1851, in contrast, (standardized departure: +2.70) matched January 1846 as the most anomalously warm monthly mean of the 1820-1872 period.

8.5 The 1860-1869 Decade

The 1860's, 1.2°F colder than the 1850's, and the coldest decade in recorded history, showed no annual means warmer than the 1820-1872 average (43.2°F). In all, 84 of the 120 individual monthly means (70 percent) were below average with only the months November and December not having consistently below normal readings (six of the Novembers and four of the Decembers had monthly means below average). The decade essentially consisted of three lengthy intervals (25 to 35 months) of predominately below normal temperatures, interrupted by brief several-month long periods of mostly above normal means.

The first cold period, June 1860 to November 1862, showed 25 of 30 monthly means below average, including two noteworthy series of anomalies for July to September 1860 (standardized departures: -1.40, -1.43, and -1.27, respectively) and January to April 1862 (standardized departures: -1.18, -2.08, -.42, and -1.11, respectively). Following a six-month respite, December 1862 to May 1863, in which 4 above normal means were recorded, the below normal regime returned, with 21 of the next 27 months, June 1863 through August 1865, showing negative anomalies. June to October 1863 began this period with a steady series of below normal statistics (standardized departures: -1.02, -1.43, -.87, -.36, and -1.99, respectively). A second break in the below normal pattern occurred during September to November 1865, with three straight months of above normal means, two of them well above normal. The standardized departures for September (+2.23) and November (+1.30), for example, were the most positive and third most positive of the decade, respectively, with September 1865 1.3°F warmer than July 1865, coldest July in recorded history. Consistently below normal conditions returned again in December 1865, however, with 27 of the next 35 months ending with October 1868 below average. The abnormality of the cold appeared to reach its depth during this period, with a number of far below normal monthly means, particularly in 1866 and 1867. The period February to September 1866, for example, experienced the following series of standardized departures over 8 months: -1.20, -1.52, -.77, -1.13, -1.52, -.05, -2.02, and -1.57, respectively; and the 5 month period March to July 1867 showed the following anomalies: -2.34, -1.09, -2.48, -.23, and -1.75, respectively. The yearly average temperatures for 1866 and 1867 were surpassed in cold by only 1843 over the 1820-1872 era.

A curious feature of the last below normal period was the "out-of-character" hot July of 1868 (standardized departure: +1.76), followed by a sharp two-month dropoff to a more typical for the decade and record cold September 1868 (standardized departure: -2.30).

The below normal temperatures departed again over the period November 1868 to February 1869, as four consecutive above normal means were shown, but the decade closed with eight of the last ten months below average.

8.6 The 1870-1872 Period

The annual mean for 1870 (46.0°F, 2.8°F above average) was the first above normal mean in twelve years and the warmest since 1846. This represented just a one-year respite from below normal temperatures, however, with 1871 and 1872 showing consecutive declines to a 42.0°F figure for 1972. While the pre-weather bureau era daily record ends here, further examination of official St. Paul weather bureau records for years subsequent to 1872 disclosed that the annual means declined further to 40.4°F in 1873, and 39.0°F in 1875, the latter figure being the second coldest in history.

8.7 Using Average Daily Range Statistics to Assess Validity of the Results

At the outset, it was stated that the usefulness of the regression models in converting the fixed time temperature observations to daily absolute maximum/minimum estimates was contingent on data inhomogeneities being of minor significance. While there was likely no completely objective way of identifying these inhomogeneities, one method of identifying possible time intervals of "contaminated" data was inspection of average daily ranges. Table 31 (from Table 30) summarizes, by month, the average daily ranges for each of the separate averaging method periods for the 1820-1872 era.

From Table 31, average estimated daily ranges for the 1820-1872 era compare favorably with those of the 1961-1980 period, average overall daily range for the former interval (20.5°F), being about 1°F higher than that for the latter (19.3°F).

Examining the mean daily range statistics for the individual averaging method periods in Table 31, a noticeable feature is the succession of relatively high temperature ranges for virtually all months of the 1836-1840 period ("a.m.", "p.m.", "evening" method). These might be due to overexposure to the sun for the "p.m." readings, or an unusually responsive thermometer (in which case net

TABLE 31

AVERAGE DAILY RANGES, BY MONTH, FOR THE VARIOUS AVERAGING METHOD PERIODS INCLUDED IN THE 1820-1872 ANALYSIS ERA (°F)

Period	Format	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.
1820-1835	7/2/9	21.7	23.6	20.8	21.4	23.2	21.3	21.0	19.5	19.1	19.7	16.2	18.5
1836-1840	AM/PM/EVE	21.5	25.1	26.0	24.7	26.3	25.5	24.0	22.6	22.1	20.4	17.7	20.7
1841-1842	SR/2/9	22.0	23.3	21.6	20.0	23.8	19.7	21.0	20.8	20.0	20.7	15.2	15.2
1843-1854/5*	SR/3/9	19.4	20.2	19.8	21.3	21.4	19.8	18.4	19.4	20.0	21.1	15.0	16.5
1855/6-1857/8**	7/2/9	22.9	22.3	21.1	18.9	24.8	23.1	23.8	21.6	20.7	18.2	17.4	17.4
1857-1872	7/2/9	19.5	20.9	18.9	21.2	23.9	22.3	21.8	20.8	20.6	20.2	16.4	18.0
1820-1872		20.6	22.1	20.6	21.5	23.3	21.6	21.1	20.3	20.1	20.3	16.2	17.9
1961-1980		18.2	18.3	16.8	20.2	21.9	21.2	21.1	21.2	20.8	20.3	15.8	15.4

*1855 from Jan. to June., 1854 from July to Dec.

**1856 to 1858 for Jan. to Apr., 1856 to 1857 for May to June, 1855 to 1857 for July to Dec.

contamination of the monthly means would be minor). Whatever the cause, they are especially evident for the years 1838 and 1839 (See Table 30), the average annual daily ranges for these years (25.4°F and 24.6°F, respectively) being at least 1.5°F higher than any other in the 1820-1872 record. Another noticeable feature from the grouped data is the comparatively low average daily ranges shown for the 1843-1854/5 era, particularly for the months May through August. Collectively, the range statistics for these months average about 2°F lower than the 1820-1872 means. This could have been due to cloudier than normal summers, or poor night-time ventilation at the site of the thermometer(s), inhibiting overnight temperature declines. Average annual daily ranges for the two consecutive years 1849 and 1850 (18.1°F and 17.1°F, respectively) are the lowest for the 1820-1872 period.

8.8 The Possibility of Overexposure to the Sun for 7 am Readings During the 1820-1835 Period

A noticeable characteristic of the Fort Snelling 1820-1835 data, particularly for the warmest months (May-August) of the year, was the relatively low average differences shown between 7 am and 2 pm temperatures. For the 1859-1872 period (same format), for example, average differences between these two hours was about 12.5°F, but for the 1820-1835 period, the differences were about 1.5°F less, and some years had figures that were much less (e.g., the average differences for June 1826 and June 1827 are 7.4°F and 6.9°F, respectively).

Table 32 lists these average 2 pm/7 am differences, along with those for the 9 pm/7 am hours, by month, for the 1820-1835 and 1859-1872 periods.

TABLE 32

COMPARISON, BY MONTH, OF MEAN 7 AM/9 PM and 7 AM/2 PM TEMPERATURE DIFFERENCES FOR THE 1820-1835 AND 1859-1872 PERIODS

Month	7 am Less 9 pm Temperature (1820-1835)	7 am Less 9 pm Temperature (1859-1872)	2 pm Less 7 am Temperature (1820-1835)	2 pm Less 7 am Temperature (1859-1872)
January	-5.0°F	-4.6°F	13.7°F	11.2°F
February	-6.1	-6.0	16.3	13.4
March	-4.7	-5.5	14.7	13.5
April	-2.2	-4.0	13.4	13.6
May	-0.5	-2.5	12.0	13.4
June	0.8	-1.3	10.3	11.9
July	1.1	-1.4	10.0	12.0
August	-0.8	-2.2	11.5	12.8
September	-2.2	-3.3	12.9	14.1
October	-4.9	-3.7	14.6	14.6
November	-3.6	-3.1	11.0	10.2
December	-4.1	-3.4	11.5	9.9

Inspecting the 7 am temperature vs. 9 pm temperature differences first, a curious relationhip between the 1820-1835 and 1859-1872 data is evident. For the months November through March, when sunrise is either after or shortly before 7 am, the figures are comparable; however, for the other months, especially May through July (when accumulated daylight at 7 am is at a seasonal maximum) the 7 am temperature at Fort Snelling (as indicated by a less negative or more positive difference) are higher relative to 9 pm temperatures than those for the 1859-1872 era. Looking at the 2 pm temperature vs. 7 am temperature relationships, a similar, seasonally reversed relationship is present. The 1820-1835 era has higher or nearly equivalent figures compared to the 1859-1872 period for the months October to April, but for the months May to September, the statistics are as much as 2°F lower. This reversed relationship seems peculiar, and considering the fact that the Paterson minima observations evidently are reasonable (recall the corroboration with the Biggs self-registering instrument minima for the 1868-1872 data) it is possible that the 1820-1835 data for roughly May to July are overstated by about 1°F due to sun contamination.

9. CONCLUSION

While it appears from the average daily range statistics in Table 31 and the between hours' average temperature differences in Table 32 that the 1820-1872 record may be of uneven quality, this is not an altogether unexpected result. As was discussed earlier, discrepancies in averaging methods are just one kind of inhomogeneity that can influence the reported temperatures in a lengthy record. Indeed, if not providing reasonable monthly mean temperature approximations, the mere exercise of estimating the daily maxima and minima was useful, as it permitted the calculation of the average daily range statistics, which in turn allowed the indirect identification of periods in which these other inhomogeneities might be more influential than in others.

One point that has been established by this study is that on relatively homogeneous data, it is feasible to convert fixed-time scheme temperature observations to midnight-to-midnight absolute maxima and minima approximations. While the choice of independent variables for the conversion models was in some respects guesswork, future studies of this kind might use more refined statistical techniques, such as stepwise regression. This might narrow down the number of independent variables per model considerably (recall the slight marginal contributions of wind component information). Also, if one was not overly concerned with individual days' estimating precision, a "special case maxima" set could likely be omitted without any serious effect on monthly mean accuracy.

BIBLIOGRAPHY

Alexander, William Henry. A Climatological History of Ohio, Bulletin No. 26, Engineering Experiment Station. Columbus, Ohio: Engineering Experiment Station at the Ohio University, 1924.

Baker, Donald G. "Effect of Observation Time on Mean Temperature Estimation." Journal of Applied Meteorology 14 (1975), pp. 471-476.

Blodget, Lorin. Climatology of the United States and of the Temperature Latitudes of the North American Continent. Philadelphia, Pennsylvania: J.B. Lippincott and Company, 1857.

Clark, Charles T. and Schkade, Lawrence L. Statistical Methods for Business Decisions. Cincinnati, Ohio: Southwestern Publishing Company, 1969.

Ludlum, David M. Early American Winters, II 1821-1870. Boston, Massachusetts: American Meteorological Society, 1968.

National Archives. Lists of Climatological Records in the National Archives. Washington, D.C.: Government Printing Office, Washington, D.C., 1981.

Richmond, Samuel B. Statistical Analysis. New York, N.Y.: Ronald Press, 1964.

U.S. Department of Commerce. Climatic Summary of the United States. Washington, D.C.: Government Printing Office, Washington, D.C., 1930.

Zeibarth, Marilyn and Ominsky, Alan. Fort Snelling: Anchor Post of the Northwest. St. Paul, Minnesota: Minnesota Historical Society, 1970.

GSA. Climatological Records of the U.S. Weather Bureau, Fort Crawford, Wisconsin, October 1820 and January 1843, Microfilm Publication T-907 Reel 546, National Archives, Washington, D.C.

GSA. Climatological Records of the U.S. Weather Bureau, Fort Howard, Wisconsin, October 1827 and December 1840. Microfilm Publication T-907 Reel 546, National Archives, Washington, D.C.

GSA. Climatological Records of the U.S. Weather Bureau, Dubuque, Iowa, May-December 1858. Microfilm Publication T-907 Reel 153, National Archives, Washington, D.C.

GSA. Climatological Records of the U.S. Weather Bureau, Fort Snelling, Minnesota, January 1820-April 1858. Microfilm Publications T-907 Reel 267, National Archives, Washington, D.C.

GSA. Climatological Records of the U.S. Weather Bureau, St. Paul, Minnesota, June 1862-December 1872. Microfilm Publication T-907 Reel 272, National Archives, Washington, D.C.

NOAA. Local Climatological Data Annual Summary with Comparative Data (1977), Dubuque, Iowa. National Climatic Center, Asheville, N.C.

NOAA. Local Climatological Data, Minneapolis-St. Paul, Minnesota, December 1961-December 1980. National Climatic Center, Asheville, N.C.

NOAA. Local Climatological Data Supplement, Minneapolis-St. Paul, Minnesota, December 1960-December 1964. National Climatic Center, Asheville, N.C.

NOAA. Surface Weather Observations (Microfilm) Minneapolis-St. Paul, Minnesota, January 1965-December 1980. National Climatic Center, Asheville, N.C.

NOAA. Local Climatological Data Annual Summary with Comparative Data, (1981), Minneapolis-St. Paul, Minnesota. National Climatic Center, Asheville, N.C.

NOAA. Cooperative Meterological Reports - Prairie Du Chien, Wisconsin, 1899-1981. National Climatic Center, Asheville, N.C.

Minnesota Historical Society, St. Paul Daily Pioneer, May-December, 1858, January 1868-December 1872 (Microfilm). Minnesota Historical Society, Research Center, St. Paul, Minnesota.

Minnesota Historical Society, Meteorological Records, St. Paul, Minnesota, January 1859-March 1876, Reverend A.B. Paterson, D.D.

APPENDIX A: MIDNIGHT TEMPERATURE INTERPOLATION REGRESSION COEFFICIENTS (7AM/2PM/9PM FORMAT)

PERIOD	N	A_0	7AM T-9PM T	7AM SKY	7AM N/S	9PM SKY	9PM N/S	7AM E/W	9PM E/W
JAN	620	+ .186	+.714	+.117	+.087	-.114	-.117	+.092	-.109
FEB	565	- .128	+.685	+.159	+.122	-.100	-.086	+.033	-.038
MAR 1-10	200	- .295	+.683	+.311	+.035	-.265	-.056	+.034	-.034
MAR 11-20	200	+ .952	+.714	+.061	+.039	-.102	-.048	+.066	-.062
MAR 21-31	220	+1.647	+.706	+.002	+.008	-.132	-.022	+.060	-.036
APR 1-10	200	+1.651	+.651	+.021	+.056	-.167	-.059	+.074	-.045
APR 11-20	200	+1.635	+.516	+.009	+.015	-.145	-.042	+.046	-.051
APR 21-30	200	+3.559	+.688	-.052	+.092	-.181	-.034	+.002	-.025
MAY 1-10	200	+4.138	+.547	-.172	+.056	-.217	+.015	-.051	+.027
MAY 11-20	200	+4.314	+.629	-.143	+.114	-.157	-.082	-.033	-.004
MAY 21-31	220	+4.540	+.645	-.156	+.091	-.166	-.100	-.021	-.017
JUN 1-10	200	+4.789	+.618	-.134	+.052	-.182	-.004	-.011	-.069
JUN 11-20	200	+4.709	+.668	-.196	+.106	-.101	-.064	-.050	-.008
JUN 21-30	200	+4.152	+.600	-.125	+.036	-.131	-.095	-.015	-.016
JUL 1-10	200	+4.162	+.619	-.137	+.042	-.129	-.037	-.060	+.007
JUL 11-20	200	+3.909	+.635	-.137	+.034	-.100	-.054	-.011	-.006
JUL 21-31	220	+2.983	+.617	-.064	+.115	-.076	-.097	*	+.005
AUG 1-10	200	+3.138	+.616	-.078	+.086	-.083	-.117	+.036	-.072
AUG 11-20	200	+2.292	+.569	-.114	+.074	-.041	-.054	+.033	+.018
AUG 21-31	220	+2.550	+.713	-.067	+.060	-.118	-.110	+.008	-.001
SEPT 1-10	200	+1.749	+.642	-.045	+.118	-.091	-.072	-.006	+.010
SEPT 11-20	200	+1.743	+.678	+.010	+.042	-.126	-.039	+.119	-.078
SEPT 21-30	200	+1.635	+.709	+.021	+.001	-.130	-.069	+.029	-.015
OCT 1-10	200	+1.373	+.712	+.046	+.031	-.170	-.023	+.011	-.031
OCT 11-20	200	+1.348	+.678	+.052	+.042	-.153	-.069	+.005	+.010
OCT 21-31	220	- .141	+.653	+.180	+.058	-.140	-.027	+.093	-.057
NOV	600	+ .704	+.702	+.090	+.039	-.124	-.010	+.047	-.057
DEC	620	+ .544	+.733	+.068	+.023	-.123	-.070	+.117	-.087

* less than +.0005

APPENDIX B: MIDNIGHT TEMPERATURE INTERPOLATION ZERO-ORDER CORRELATION COEFFICIENTS (7AM/2PM/9PM FORMAT)

PERIOD	N	R*	7AM T-9PM T	7AM SKY	7AM N/S	9PM SKY	9PM N/S	7AM E/W	9PM E/W
JAN	620	.922	+.898	+.430	+.418	-.063	+.343	+.384	+.315
FEB	565	.922	+.904	+.496	+.434	+.031	+.467	+.268	+.268
MAR 1-10	200	.916	+.884	+.634	+.316	-.092	+.311	+.380	+.257
MAR 11-20	200	.922	+.906	+.426	+.306	-.022	+.327	+.295	+.236
MAR 21-31	220	.908	+.893	+.286	+.380	-.073	+.207	+.361	+.276
APR 1-10	200	.877	+.843	+.041	+.278	-.107	+.081	+.202	+.046
APR 11-20	200	.717	+.677	-.015	+.166	-.160	-.011	+.040	-.053
APR 21-30	200	.886	+.844	-.211	+.242	-.233	+.051	-.201	-.160
MAY 1-10	200	.815	+.722	-.298	+.288	-.385	+.124	-.191	-.081
MAY 11-20	200	.830	+.743	-.339	+.400	-.327	+.048	-.121	-.051
MAY 21-31	220	.827	+.742	-.303	+.267	-.280	-.026	-.101	-.092
JUN 1-10	200	.802	+.730	-.391	+.233	-.335	-.008	-.149	-.115
JUN 11-20	200	.824	+.770	-.297	+.253	-.286	-.080	-.098	-.081
JUN 21-30	200	.776	+.718	-.326	+.184	-.280	-.124	-.088	-.030
JUL 1-10	200	.745	+.667	-.182	+.103	-.266	-.007	-.242	-.145
JUL 11-20	200	.795	+.753	-.344	+.075	-.216	-.021	-.111	-.039
JUL 21-31	220	.783	+.725	-.198	+.323	-.182	+.002	-.075	+.048
AUG 1-10	200	.694	+.622	-.212	+.227	-.212	-.113	-.078	-.046
AUG 11-20	200	.769	+.722	-.126	+.334	-.105	+.157	+.042	+.158
AUG 21-31	220	.843	+.799	-.059	+.216	-.153	-.020	+.110	+.087
SEPT 1-10	200	.854	+.824	+.043	+.433	-.104	+.155	+.182	+.311
SEPT 11-20	200	.854	+.821	+.097	+.381	-.123	+.046	+.106	+.192
SEPT 21-30	200	.852	+.837	+.345	+.248	+.058	+.155	+.147	+.219
OCT 1-10	200	.896	+.879	+.312	+.206	-.100	+.082	+.198	+.206
OCT 11-20	200	.866	+.849	+.310	+.148	-.027	+.086	+.200	+.239
OCT 21-31	220	.878	+.855	+.379	+.276	+.024	+.194	+.274	+.300
NOV	600	.907	+.894	+.401	+.302	-.013	+.257	+.227	+.267
DEC	620	.925	+.908	+.394	+.369	-.042	+.270	+.390	+.293

* MULTIPLE CORRELATION COEFFICIENT

APPENDIX C: MIDNIGHT TEMPERATURE INTERPOLATION REGRESSION COEFFICIENTS (SUNRISE/9AM/3PM/9PM FORMAT)

PERIOD	N	A_o	SR T - 9PM T	SR SKY	SR N/S	9PM SKY	9PM N/S	SR E/W	9PM E/W
JAN	620	+.121	+.732	+.142	+.097	-.131	-.127	+.076	-.103
FEB	565	-.102	+.700	+.162	+.121	-.098	-.084	+.035	-.056
MAR	620	+.634	+.689	+.123	+.047	-.149	-.045	+.048	-.041
APR	600	-.153	+.559	+.119	+.038	-.093	-.035	+.040	-.032
MAY	620	+.298	+.544	+.042	+.049	-.058	-.034	-.005	+.010
JUN	600	-.681	+.440	+.118	+.022	-.048	-.008	-.002	-.016
JUL	620	-.085	+.517	+.089	+.025	-.040	-.010	-.030	+.044
AUG	620	+.451	+.594	+.047	+.043	-.062	-.049	+.032	+.010
SEPT	600	+.532	+.654	+.082	+.055	-.094	-.042	+.039	-.028
OCT	620	+.596	+.667	+.101	+.041	-.137	-.037	+.045	-.030
NOV	600	+.734	+.707	+.089	+.044	-.125	-.014	+.052	-.062
DEC	620	+.460	+.750	+.093	+.046	-.132	-.083	+.098	-.082

APPENDIX D: MIDNIGHT TEMPERATURE INTERPOLATION ZERO-ORDER CORRELATION COEFFICIENTS (SUNRISE/9AM/3PM/9PM FORMAT)

PERIOD	N	R*	SR T – 9PM T	SR SKY	SR N/S	9PM SKY	9PM N/S	SR E/W	9PM E/W
JAN	620	.930	+.907	+.454	+.451	-.092	+.332	+.377	+.304
FEB	565	.923	+.906	+.488	+.444	+.023	+.472	+.243	+.306
MAR	620	.908	+.890	+.488	+.344	-.007	+.283	+.349	+.261
APR	600	.833	+.818	+.409	+.131	+.185	+.078	+.099	+.073
MAY	620	.797	+.790	+.396	+.186	+.257	+.092	+.089	+.148
JUN	600	.721	+.707	+.443	+.134	+.193	+.070	+.095	+.144
JUL	620	.788	+.777	+.471	+.227	+.205	+.262	+.038	+.265
AUG	620	.804	+.793	+.411	+.218	+.177	+.165	+.128	+.252
SEPT	600	.870	+.859	+.435	+.340	+.130	+.170	+.181	+.298
OCT	620	.871	+.856	+.378	+.205	+.005	+.135	+.216	+.255
NOV	600	.906	+.892	+.396	+.311	-.021	+.250	+.238	+.260
DEC	620	.931	+.915	+.394	+.402	-.060	+.264	+.397	+.287

* MULTIPLE CORRELATION COEFFICIENT

APPENDIX E: OVERNIGHT MINIMUM TEMPERATURE ESTIMATION REGRESSION COEFFICIENTS (7AM/2PM/9PM FORMAT)

PERIOD	N	A_0	7AM T-9PM T	7AM SKY	7AM N/S	9PM SKY	9PM N/S	7AM E/W	9PM E/W
JAN	428	+ 4.55	+.212	+.052	+.099	-.123	-.009	-.052	-.019
FEB	411	+ 3.90	+.206	+.050	+.084	-.078	-.015	-.099	-.034
MAR 1-10	147	+ 2.45	+.117	+.125	+.034	-.131	+.021	-.014	-.059
MAR 11-20	145	+ 3.03	+.138	*	+.084	-.112	+.003	+.018	-.099
MAR 21-31	163	+ 4.14	+.138	-.039	+.043	-.154	+.050	-.020	-.021
APR 1-10	148	+ 5.27	+.104	-.082	+.064	-.234	-.033	-.024	+.012
APR 11-20	149	+ 6.79	+.049	-.216	+.075	-.246	+.001	-.051	-.048
APR 21-30	160	+ 8.45	+.113	-.229	+.116	-.302	-.023	-.092	-.002
MAY 1-10	158	+11.05	+.129	-.438	+.025	-.328	+.101	-.008	-.067
MAY 11-20	137	+10.39	+.226	-.282	+.036	-.293	-.007	-.067	-.092
MAY 21-31	172	+11.45	+.280	-.385	+.037	-.376	-.070	-.047	-.011
JUN 1-10	163	+11.17	+.277	-.374	+.017	-.339	-.043	-.013	-.060
JUN 11-20	158	+10.54	+.321	-.380	+.026	-.226	-.034	-.063	+.019
JUN 21-30	159	+10.26	+.292	-.298	+.003	-.248	-.045	-.043	-.068
JUL 1-10	163	+10.64	+.413	-.363	-.001	-.244	-.060	-.055	-.007
JUL 11-20	164	+ 9.28	+.408	-.197	-.055	-.168	-.114	-.068	-.134
JUL 21-31	178	+ 8.78	+.277	-.215	-.004	-.254	-.100	-.084	-.076
AUG 1-10	161	+ 7.21	+.147	-.242	+.065	-.076	-.159	-.028	-.151
AUG 11-20	162	+ 6.82	+.131	-.218	**	-.082	-.115	-.047	-.130
AUG 21-31	167	+ 6.47	+.174	-.161	+.027	-.206	-.084	+.033	-.160
SEPT 1-10	144	+ 5.79	+.158	-.120	-.036	-.133	-.051	-.095	+.010
SEPT 11-20	141	+ 4.56	+.088	-.034	+.036	-.208	-.064	+.110	-.139
SEPT 21-30	142	+ 4.03	+.092	+.015	-.028	-.111	-.040	+.002	-.056
OCT 1-10	138	+ 3.66	+.134	+.057	+.139	-.159	-.069	-.049	+.002
OCT 11-20	137	+ 3.60	+.139	+.023	-.001	-.130	-.015	-.006	-.038
OCT 21-31	159	+ 2.88	+.155	+.076	+.104	-.100	-.078	-.037	-.026
NOV	395	+ 3.62	+.184	+.020	+.017	-.103	+.048	-.028	-.011
DEC	403	+ 4.31	+.221	+.024	+.002	-.158	-.007	-.053	-.002

*less than +.0005.
**greater than -.0005, but less than zero.

APPENDIX F: OVERNIGHT MINIMUM TEMPERATURE ESTIMATION ZERO-ORDER CORRELATION COEFFICIENTS (7AM/2PM/9PM FORMAT)

PERIOD	N	R*	7AM T-9PM T	7AM SKY	7AM N/S	9PM SKY	9PM N/S	7AM E/W	9PM E/W
JAN	428	.610	+.558	+.254	+.361	-.150	+.301	+.117	+.179
FEB	411	.561	+.496	+.232	+.300	-.084	+.247	-.023	+.043
MAR 1-10	147	.463	+.358	+.256	+.232	-.195	+.222	+.093	-.010
MAR 11-20	145	.529	+.342	+.053	+.322	-.231	+.195	+.058	-.121
MAR 21-31	163	.578	+.372	+.049	+.406	-.359	+.321	+.127	+.060
APR 1-10	148	.561	+.134	-.276	+.285	-.474	+.125	-.028	-.016
APR 11-20	149	.602	+.051	-.430	+.215	-.470	+.091	-.105	-.158
APR 21-30	160	.732	+.263	-.494	+.242	-.551	+.060	-.304	-.187
MAY 1-10	158	.751	+.246	-.574	+.119	-.584	+.121	-.245	-.204
MAY 11-20	157	.698	+.267	-.532	+.163	-.514	+.072	-.322	-.329
MAY 21-31	172	.770	+.303	-.617	+.087	-.591	-.034	-.260	-.282
JUN 1-10	163	.766	+.402	-.626	+.115	-.568	-.113	-.243	-.233
JUN 11-20	158	.710	+.438	-.554	+.064	-.398	-.020	-.279	-.196
JUN 21-30	159	.735	+.441	-.578	+.037	-.496	-.150	-.233	-.257
JUL 1-10	163	.735	+.351	-.551	-.157	-.464	-.208	-.302	-.332
JUL 11-20	164	.774	+.514	-.467	-.208	-.319	-.262	-.238	-.328
JUL 21-31	178	.680	+.285	-.507	-.035	-.483	-.177	-.277	-.312
AUG 1-10	161	.648	+.187	-.504	-.049	-.276	-.249	-.297	-.356
AUG 11-20	162	.597	+.022	-.479	-.120	-.221	-.234	-.232	-.323
AUG 21-31	167	.658	+.109	-.443	-.030	-.481	-.117	-.198	-.386
SEPT 1-10	144	.520	+.082	-.355	-.106	-.350	-.093	-.213	-.178
SEPT 11-20	141	.574	+.055	-.224	+.054	-.488	-.035	-.081	-.271
SEPT 21-30	142	.314	+.091	-.016	-.072	-.182	-.085	-.036	-.126
OCT 1-10	138	.591	+.401	+.106	+.372	-.313	+.085	+.125	+.106
OCT 11-20	137	.463	+.353	+.079	+.061	-.257	+.037	+.046	-.037
OCT 21-31	159	.521	+.402	+.188	+.197	-.121	+.047	-.023	+.049
NOV	395	.511	+.449	+.182	+.246	-.124	+.266	+.035	+.108
DEC	403	.546	+.483	+.208	+.179	-.200	+.176	+.056	+.088

* MULTIPLE CORRELATION COEFFICIENT

APPENDIX G: OVERNIGHT MINIMUM TEMPERATURE ESTIMATION REGRESSION COEFFICIENTS (SUNRISE/9AM/3PM/9PM FORMAT)

PERIOD	N	A_o	SR T– 9PM T	SR SKY	SR N/S	9PM SKY	9PM N/S	SR E/W	9PM E/W
JAN	428	+4.189	+.233	+.132	+.148	-.139	-.034	-.038	-.047
FEB	411	+3.939	+.217	+.069	+.084	-.089	*	-.116	-.043
MAR	455	+2.557	+.113	+.044	+.051	-.101	+.005	-.009	-.044
APR	457	+1.587	+.011	+.053	+.050	-.080	-.012	-.016	-.004
MAY	487	+2.248	+.055	-.003	-.025	-.053	+.026	+.009	-.037
JUN	480	+1.314	+.018	+.042	-.024	-.021	+.018	-.055	+.030
JUL	505	+1.926	+.083	+.045	-.033	-.050	+.005	-.060	+.001
AUG	490	+1.487	+.061	+.052	-.015	-.021	-.010	-.022	-.042
SEPT	427	+1.954	+.089	+.079	+.042	-.074	-.036	-.009	-.035
OCT	434	+2.879	+.128	+.067	+.070	-.110	-.039	-.061	+.017
NOV	395	+3.608	+.186	+.029	+.026	-.112	+.040	-.016	-.022
DEC	403	+4.254	+.244	+.074	+.058	-.190	-.034	-.057	-.010

*greater than -.0005 but less than zero.

APPENDIX H: OVERNIGHT MINIMUM TEMPERATURE ESTIMATION ZERO-ORDER CORRELATION COEFFICIENTS (SUNRISE/9AM/3PM/9PM FORMAT)

PERIOD	N	R*	SR T- 9PM T	SR SKY	SR N/S	9PM SKY	9PM N/S	SR E/W	9PM E/W
JAN	428	.686	+.621	+.365	+.438	-.158	+.307	+.175	+.193
FEB	411	.598	+.527	+.248	+.313	-.089	+.280	-.049	+.030
MAR	455	.427	+.323	+.149	+.262	-.178	+.189	+.077	-.012
APR	457	.292	+.063	+.036	+.198	-.186	+.109	**	-.008
MAY	487	.233	+.093	-.018	+.004	-.108	+.054	-.062	-.128
JUN	480	.211	+.082	+.110	-.026	+.026	+.052	-.089	+.045
JUL	505	.332	+.230	+.147	-.016	-.026	+.060	-.147	-.037
AUG	490	.309	+.197	+.181	-.039	+.052	-.006	-.094	-.107
SEPT	427	.387	+.298	+.236	+.140	-.039	+.044	+.047	+.017
OCT	434	.476	+.391	+.200	+.192	-.147	+.099	+.018	+.094
NOV	395	.511	+.448	+.189	+.253	-.136	+.251	+.054	+.099
DEC	403	.615	+.547	+.274	+.271	-.223	+.195	+.106	+.101

*MULTIPLE CORRELATION COEFFICIENT
**greater than -.0005, but less than zero.

APPENDIX I: AFTERNOON MAXIMUM ESTIMATION REGRESSION COEFFICIENTS (7AM/2PM/9PM FORMAT)

PERIOD	N	A_o	2PM CLOUDI-NESS	2PM N/S	2PM E/W
JAN	382	+1.197	-.005	+.028	+.001
FEB	411	+1.555	-.030	+.056	+.004
MAR	512	+1.666	-.026	+.022	-.009
APR	510	+1.926	-.009	+.010	-.005
MAY	512	+1.985	+.018	+.013	+.011
JUN	503	+1.445	+.081	+.003	-.009
JUL	559	+1.570	+.070	+.011	+.019
AUG	545	+1.412	+.089	-.015	+.008
SEPT	520	+1.047	+.092	+.011	+.004
OCT	523	+.974	+.052	-.002	-.004
NOV	452	+.694	+.033	+.010	-.014
DEC	366	+.744	+.021	+.018	*

*greater than -.0005, but less than zero.

APPENDIX J: AFTERNOON MAXIMUM ESTIMATION
ZERO ORDER CORRELATION COEFFICIENTS
(7AM/2PM/9PM FORMAT)

PERIOD	N	R*	2PM CLOUDINESS	2PM N/S	2PM E/W
JAN	382	.189	-.012	+.187	+.028
FEB	411	.335	-.052	+.321	+.045
MAR	512	.173	-.085	+.133	-.049
APR	510	.072	-.025	+.059	-.019
MAY	512	.111	+.053	+.087	+.070
JUN	503	.200	+.195	+.033	-.023
JUL	559	.210	+.177	+.078	+.120
AUG	545	.253	+.237	-.081	+.043
SEPT	520	.293	+.283	+.066	+.093
OCT	523	.178	+.175	-.034	+.009
NOV	452	.144	+.099	+.053	-.040
DEC	366	.158	+.090	+.136	+.055

* MULTIPLE CORRELATION COEFFICIENT

APPENDIX K: AFTERNOON MAXIMUM ESTIMATION REGRESSION COEFFICIENTS (SUNRISE/9AM/3PM/9PM FORMAT)

PERIOD	N	A_o	3PM SKY	3PM N/S	3PM E/W
JAN	382	+ .543	+.033	+.040	-.007
FEB	411	+ .535	+.035	+.017	-.020
MAR	512	+ .766	+.032	+.010	-.026
APR	510	+1.082	+.047	+.002	-.004
MAY	512	+1.185	+.073	*	-.003
JUN	503	+1.027	+.072	**	-.003
JUL	559	+ .773	+.116	-.006	-.003
AUG	545	+ .767	+.127	-.006	-.009
SEPT	520	+ .415	+.136	**	-.024
OCT	523	+ .722	+.060	-.021	-.006
NOV	452	+ .450	+.050	-.010	-.026
DEC	366	+ .605	+.022	-.006	-.009

*greater than -.0005, but less than zero.

**less than +.0005.

APPENDIX L: AFTERNOON MAXIMUM ESTIMATION
ZERO ORDER CORRELATION COEFFICIENTS
SUNRISE/9AM/3PM/9PM FORMAT

PERIOD	N	R*	3PM SKY	3PM N/S	3PM E/W
JAN	382	.143	+.133	+.022	+.003
FEB	411	.213	+.124	+.125	-.070
MAR	512	.187	+.063	+.053	-.125
APR	510	.137	+.134	+.024	**
MAY	512	.155	+.155	**	+.004
JUN	503	.192	+.191	+.014	+.014
JUL	559	.319	+.316	-.034	+.042
AUG	545	.333	+.329	-.059	+.014
SEPT	520	.404	+.386	-.048	-.039
OCT	523	.266	+.205	-.180	-.041
NOV	452	.232	+.149	-.106	-.114
DEC	366	.105	+.068	-.054	-.042

* MULTIPLE CORRELATION COEFFICIENT

** less than +.0005.

APPENDIX M: SPECIAL CASE MAXIMUM TEMPERATURE ESTIMATION REGRESSION COEFFICIENTS AND ZERO-ORDER CORRELATION COEFFICIENTS

REGRESSION COEFFICIENTS

TYPE:	N	A_o	NET OVER-NIGHT RISE TO 7AM	NET FALL FROM 7AM TO 2PM	7AM N/S	7AM E/W	7AM SKY
Non-Summer (7AM/2PM/9PM Format)	51	+7.20	+.067	-.067	+.006	+.044	-.482

TYPE:	N	A_o	NET OVER-NIGHT RISE TO 7AM	NET FALL FROM 7AM TO 2PM	7AM SKY
Non-Summer (7AM/2PM/9PM- without wind data)	51	+6.89	+.060	-.076	-.460

TYPE:	N	A_o	NET OVER-NIGHT RISE TO SR	NET FALL FROM SR TO 3PM	SR N/S	SR E/W	SR SKY
Non-Summer (Sunrise/9AM/3PM/9PM Format)	49	+8.75	+.091	-.036	+.072	+.020	-.661

TYPE:	N	A_o	NET CHANGE TO 2PM	7AM N/S	7AM E/W	7AM SKY	2PM N/S	2PM E/W	2PM SKY
Spring-Summer (7AM/2PM-9PM Format)	82	+6.75	-.783	+.026	+.219	-.136	-.071	-.107	-.141

TYPE:	N	A_o	NET CHANGE TO 2PM	7AM SKY	2PM SKY
Spring-Summer (7AM/2PM/9PM- without wind data)	82	+5.70	-.762	-.099	+.271

TYPE:	N	A_o	NET CHANGE TO 3PM	9AM N/S	9AM E/W	9AM SKY	3PM N/S	3PM E/W	3PM SKY
Spring-Summer (Sunrise/9AM/3PM/9PM Format)	183	+6.65	-.964	+.036	+.059	-.190	-.029	-.005	-.031

TYPE:	N	A_o	SUNSET SKY	SUNSET N/S	SUNSET E/W
January "Afternoon Maxima" (From sunset conditions)	382	+3.35	-.146	-.016	-.038

TYPE:	N	A_o	NET RISE TO SUNRISE	NET FALL TO 2PM	SR N/S	SR E/W	SR SKY
Non-Summer (Sunrise/2PM/9PM format)	44	+8.25	+.044	-.020	+.031	+.008	-.616

APPENDIX M: (CONTINUED)

ZERO ORDER CORRELATION COEFFICIENTS

TYPE:	N	R*	NET OVER-NIGHT RISE TO 7AM	NET FALL FROM 7AM TO 2PM	7AM N/S	7AM E/W	7AM SKY
Non-Summer (7AM/2PM/9PM Format)	51	.459	+.030	-.145	+.070	+.067	-.407

TYPE:	N	R*	NET OVER-NIGHT RISE TO 7AM	NET FALL FROM 7AM TO 2PM	7AM SKY
Non-Summer (7AM/2PM/9PM-without wind data)	51	.442	+.030	-.145	-.407

TYPE	N	R*	NET OVER-NIGHT RISE TO SR	NET FALL FROM SR TO 3PM	SR N/S	SR E/W	ST SKY
Non-Summer (Sunrise/9AM/3PM/9PM Format)	49	.511	+.140	-.026	+.160	-.014	-.407

TYPE:	N	R*	NET CHANGE TO 2PM	7AM N/S	7AM E/W	7AM SKY	2PM N/S	2PM E/W	2PM SKY
Spring-Summer (7AM/2PM/9PM Format)	82	.526	-.449	-.020	+.068	-.106	-.119	-.138	+.069

TYPE:	N	R*	NET CHANGE TO 2PM	7AM SKY	2PM SKY
Spring-Summer (7AM/2PM/9PM-without wind data)	82	.459	-.449	-.106	+.069

TYPE:	N	R*	NET CHANGE TO 3PM	9AM N/S	9AM E/W	9AM SKY	3PM N/S	3PM E/W	3PM SKY
Spring-Summer (Sunrise/9AM/3PM/9PM Format)	183	.698	-.683	+.087	+.119	-.098	-.044	-.001	+.101

TYPE	N	R*	SUNSET SKY	SUNSET N/S	SUNSET E/W
January "Afternoon Maxima" (From sunset conditions)	382	.360	-.355	-.074	-.223

TYPE:	N	R*	NET RISE TO SR	NET FALL TO 2PM	SUNRISE N/S	SUNRISE E/W	SUNRISE SKY
Non-Summer (Sunrise/2PM/9PM Format)	44	.486	+.004	-.039	+.009	-.064	-.466

*MULTIPLE CORRELATION COEFFICIENT

APPENDIX N: ERROR STATISTICS FOR MIDNIGHT TEMPERATURE INTERPOLATIONS, BY REGRESSION MODEL (7AM/2PM/9PM FORMAT)

PERIOD	STD ERROR	MEAN ERROR	MEDIAN ERROR	MODAL ERROR
JAN	2.463	1.780	1	1
FEB	2.274	1.685	1	1
MAR 1-10	2.427	1.681	1	1
MAR 11-20	1.669	1.289	1	1
MAR 21-31	1.822	1.350	1	1
APR 1-10	1.979	1.404	1	1
APR 11-20	2.392	1.736	1	1
APR 21-30	2.030	1.531	1	1
MAY 1-10	2.325	1.765	1	1
MAY 11-20	2.244	1.809	2	1
MAY 21-31	2.120	1.574	1	1
JUN 1-10	2.322	1.734	1	1
JUN 11-20	2.414	1.789	1	1
JUN 21-30	2.209	1.730	1	1
JUL 1-10	2.109	1.562	1	1
JUL 11-20	2.066	1.639	1	1
JUL 21-31	1.822	1.401	1	1
AUG 1-10	2.287	1.688	1	1
AUG 11-20	1.819	1.396	1	1
AUG 21-31	1.853	1.425	1	1
SEPT 1-10	1.974	1.524	1	1
SEPT 11-20	1.828	1.409	1	1
SEPT 21-30	2.212	1.579	1	1
OCT 1-10	1.996	1.519	1	1
OCT 11-20	2.236	1.696	1	1
OCT 21-31	2.273	1.675	1	1
NOV	1.941	1.452	1	1
DEC	2.201	1.555	1	1

APPENDIX O: ERROR STATISTICS FOR MIDNIGHT TEMPERATURE INTERPOLATIONS, BY REGRESSION MODEL (SUNRISE/9AM/3PM/9PM FORMAT)

PERIOD	STD ERROR	MEAN ERROR	MEDIAN ERROR	MODAL ERROR
JAN	2.518	1.820	1	1
FEB	2.321	1.729	1	1
MAR	1.974	1.421	1	1
APR	2.018	1.437	1	1
MAY	2.044	1.550	1	1
JUN	1.982	1.499	1	1
JUL	1.792	1.357	1	1
AUG	1.896	1.417	1	1
SEPT	1.961	1.449	1	1
OCT	2.189	1.667	1	1
NOV	1.956	1.463	1	1
DEC	2.267	1.604	1	1

APPENDIX P: ERROR STATISTICS FOR OVERNIGHT MINIMUM TEMPERATURE ESTIMATIONS, BY REGRESSION MODEL (7AM/2PM/9PM FORMAT)

PERIOD	STD ERROR	MEAN ERROR	MEDIAN ERROR	MODAL ERROR
JAN	2.591	1.998	2	1
FEB	2.590	2.004	2	1
MAR 1-10	2.619	1.754	1	1
MAR 11-20	1.996	1.384	1	1
MAR 21-31	1.809	1.323	1	1
APR 1-10	2.035	1.513	1	1
APR 11-20	2.484	1.828	1	1
APR 21-30	2.263	1.679	1	1
MAY 1-10	2.689	2.050	2	1
MAY 11-20	2.850	2.180	2	1
MAY 21-31	2.645	2.024	2	1
JUN 1-10	2.604	2.029	2	2
JUN 11-20	2.619	2.020	1	1
JUN 21-30	2.381	1.840	2	1
JUL 1-10	2.503	1.945	2	1
JUL 11-20	2.093	1.631	1	1
JUL 21-31	2.454	1.975	2	1
AUG 1-10	2.109	1.607	1	1
AUG 11-20	2.037	1.591	1	1
AUG 21-31	1.996	1.520	1	1
SEPT 1-10	1.785	1.398	1	1
SEPT 11-20	1.697	1.354	1	1
SEPT 21-30	1.850	1.386	1	1
OCT 1-10	1.774	1.372	1	1
OCT 11-20	1.776	1.369	1	1
OCT 21-31	1.833	1.398	1	1
NOV	2.155	1.626	1	1
DEC	2.529	1.871	1	1

APPENDIX Q: ERROR STATISTICS FOR OVERNIGHT MINIMUM TEMPERATURE ESTIMATIONS, BY REGRESSION MODEL, (SUNRISE/9AM/3PM/9PM FORMAT)

PERIOD	STD ERROR	MEAN ERROR	MEDIAN ERROR	MODAL ERROR
JAN	2.668	2.055	2	1
FEB	2.603	1.993	2	1
MAR	2.077	1.413	1	1
APR	1.484	1.049	1	1
MAY	1.489	1.107	1	1
JUN	1.312	.931	1	1
JUL	1.252	.909	1	1
AUG	1.150	.842	1	1
SEPT	1.440	1.119	1	1
OCT	1.775	1.323	1	1
NOV	2.205	1.685	1	1
DEC	2.652	1.980	2	1

APPENDIX R: ERROR STATISTICS FOR AFTERNOON MAXIMUM TEMPERATURE ESTIMATION, BY REGRESSION MODEL, 7AM/2PM/9PM FORMAT

PERIOD	STD ERROR	MEAN ERROR	MEDIAN ERROR	MODAL ERROR
JAN	.997	.748	1	1
FEB	1.197	.889	1	1
MAR	1.271	.990	1	1
APR	1.431	1.008	1	1
MAY	1.661	1.140	1	1
JUN	1.468	1.110	1	1
JUL	1.432	1.046	1	1
AUG	1.377	1.019	1	1
SEPT	1.241	.954	1	1
OCT	1.144	.838	1	1
NOV	.992	.660	1	0.1
DEC	1.041	.707	1	1

APPENDIX S: ERROR STATISTICS FOR AFTERNOON MAXIMUM TEMPERATURE ESTIMATION, BY REGRESSION MODEL, SUNRISE/9AM/3PM/9PM FORMAT

PERIOD	STD ERROR	MEAN ERROR	MEDIAN ERROR	MODAL ERROR
JAN	.927	.677	1	1
FEB	.960	.700	1	1
MAR	1.076	.778	1	1
APR	1.367	.970	1	1
MAY	1.689	1.103	1	1
JUN	1.322	.996	1	1
JUL	1.192	.917	1	1
AUG	1.326	.921	1	1
SEPT	1.202	.884	1	1
OCT	1.162	.809	1	1
NOV	1.045	.752	1	1
DEC	1.004	.725	1	1

APPENDIX T: ERROR STATISTICS FOR SPECIAL CASE AFTERNOON MAXIMUM TEMPERATURE ESTIMATION, BY REGRESSION MODEL

MODEL	STD. ERROR	MEAN ERROR	MEDIAN ERROR	MODAL ERROR
Non-Summer (7AM/2PM/9PM)	2.688	1.941	2	2
Non-Summer (7AM/2PM/9PM-- without wind data)	2.656	1.933	2	2
Non-Summer (Sunrise/9AM/3PM/9PM)	2.825	2.052	2	2
Spring-Summer (7AM/2PM/9PM)	4.173	3.266	3	1
Spring-Summer (7AM/2PM/9PM-- without wind data)	4.244	3.510	3	3
Spring-Summer (Sunrise/9AM/3PM/9PM)	3.460	2.492	2	1
January "Afternoon Maxima" from Sunset conditions	1.968	1.436	1	1
Non-Summer (Sunrise/2PM/9PM)	2.772	1.903	2	2

APPENDIX U: MIDNIGHT TEMPERATURE ESTIMATION REGRESSION COEFFICIENTS (7AM/2PM/9PM FORMAT - WITHOUT WIND DATA)

PERIOD	N	A_o	7AM-T - 9PM-T	7AM SKY	9PM SKY
JAN	620	+ .654	+.683	+.108	-.190
FEB	565	+ .167	+.682	+.155	-.152
MAR 1-10	200	- .057	+.678	+.304	-.289
MAR 11-20	200	+1.306	+.713	+.037	-.129
MAR 21-31	220	+1.823	+.711	+.008	-.150
APR 1-10	200	+2.013	+.672	+.002	-.183
APR 11-20	200	+1.744	+.513	+.001	-.161
APR 21-30	200	+3.732	+.705	-.059	-.204
MAY 1-10	200	+4.217	+.582	-.167	-.222
MAY 11-20	200	+4.785	+.680	-.157	-.190
JUN 1-10	200	+5.057	+.627	-.150	-.202
JUN 11-20	200	+5.050	+.708	-.204	-.120
JUN 21-30	200	+4.176	+.611	-.131	-.136
JUL 1-10	200	+4.342	+.636	-.137	-.152
JUL 11-20	200	+3.975	+.632	-.144	-.110
JUL 21-31	200	+3.232	+.644	-.067	-.102
AUG 1-10	200	+3.346	+.621	-.111	-.107
AUG 11-20	200	+2.408	+.581	-.100	-.064
AUG 21-31	220	+2.480	+.712	-.069	-.120
SEPT 1-10	200	+2.077	+.676	-.058	-.101
SEPT 11-20	200	+1.651	+.686	+.031	-.144
SEPT 21-30	200	+1.498	+.689	+.010	-.116
OCT 1-10	200	+1.507	+.714	+.033	-.174
OCT 11-20	200	+1.265	+.675	+.052	-.151
OCT 21-31	220	+ .185	+.667	+.160	-.148
NOV	600	+ .899	+.705	+.083	-.142
DEC	620	+ .880	+.727	+.048	-.156

APPENDIX V: MIDNIGHT TEMPERATURE ESTIMATION ZERO ORDER CORRELATION COEFFICIENTS AND ERROR STATISTICS
(7AM/2PM/9PM FORMAT - WITHOUT WIND DATA)

PERIOD	R*	7AM T - 9PM T	7AM SKY	9PM SKY	STD. ERROR	AVERAGE ABSOLUTE RESIDUAL	MEDIAN ABSOLUTE RESIDUAL	MODAL ABSOLUTE RESIDUAL
JAN	.907	+.898	+.429	-.063	2.656	1.874	1	1
FEB	.912	+.904	+.496	+.031	2.394	1.744	1	1
MAR 1-10	.914	+.884	+.634	-.092	2.433	1.673	1	1
MAR 11-20	.915	+.906	+.426	-.022	1.725	1.325	1	1
MAR 21-31	.906	+.893	+.286	-.073	1.831	1.370	1	1
APR 1-10	.866	+.843	+.041	-.107	2.036	1.427	1	1
APR 11-20	.706	+.677	-.015	-.159	2.408	1.727	1	1
APR 21-30	.876	+.844	-.211	-.233	2.091	1.609	1	1
MAY 1-10	.805	+.722	-.298	-.385	2.355	1.779	1	1
MAY 11-20	.811	+.743	-.339	-.327	2.327	1.853	2	1
MAY 21-31	.814	+.742	-.303	-.280	2.175	1.633	1	1
JUN 1-10	.794	+.730	-.391	-.335	2.338	1.762	1	1
JUN 11-20	.812	+.770	-.297	-.286	2.460	1.826	1	1
JUN 21-30	.761	+.718	-.326	-.280	2.246	1.766	1	1
JUL 1-10	.737	+.667	-.182	-.266	2.116	1.598	1	1
JUL 11-20	.792	+.753	-.344	-.216	2.060	1.651	1	1
JUL 21-31	.752	+.725	-.198	-.182	1.914	1.494	1	1
AUG 1-10	.665	+.622	-.212	-.212	2.347	1.778	1	1
AUG 11-20	.750	+.722	-.126	-.105	1.861	1.426	1	1
AUG 21-31	.827	+.799	-.059	-.153	1.920	1.457	1	1
SEPT 1-10	.839	+.824	+.043	-.104	2.043	1.518	1	1
SEPT 11-20	.839	+.821	+.097	-.123	1.893	1.438	1	1
SEPT 21-30	.845	+.837	+.345	+.058	2.233	1.581	1	1
OCT 1-10	.889	+.879	+.312	-.100	1.988	1.520	1	1
OCT 11-20	.861	+.849	+.310	-.027	2.248	1.728	1	1
OCT 21-31	.867	+.855	+.379	+.024	2.344	1.728	1	1
NOV	.903	+.894	+.401	-.013	1.967	1.462	1	1
DEC	.914	+.908	+.394	-.042	2.355	1.618	1	1

*Multiple Regression Coefficient

APPENDIX W: OVERNIGHT MINIMUM TEMPERATURE ESTIMATION REGRESSION COEFFICIENTS (7AM/2PM/9PM FORMAT - WITHOUT WIND DATA)

PERIOD	N	A_o	7AM T - 9PM T	7AM SKY	9PM SKY
JAN	428	+ 4.974	+.225	+.030	-.140
FEB	411	+ 4.183	+.203	+.027	-.106
MAR 1-10	147	+ 2.862	+.121	+.101	-.171
MAR 11-20	149	+ 3.622	+.166	-.027	-.132
MAR 21-31	163	+ 4.211	+.168	-.026	-.176
APR 1-10	148	+ 5.511	+.122	-.092	-.248
APR 11-20	149	+ 7.036	+.082	-.232	-.261
APR 21-30	160	+ 8.837	+.173	-.253	-.333
MAY 1-10	158	+11.019	+.175	-.397	-.360
MAY 11-20	157	+10.832	+.264	-.334	-.316
MAY 21-31	172	+11.559	+.286	-.408	-.378
JUN 1-10	163	+11.320	+.279	-.394	-.353
JUN 11-20	158	+10.707	+.344	-.393	-.225
JUN 21-30	159	+10.367	+.296	-.328	-.255
JUL 1-10	163	+10.832	+.416	-.401	-.262
JUL 11-20	164	+ 9.206	+.362	-.274	-.180
JUL 21-31	178	+ 8.935	+.254	-.273	-.256
AUG 1-10	161	+ 7.444	+.140	-.300	-.095
AUG 11-20	162	+ 6.489	+.067	-.277	-.060
AUG 21-31	167	+ 6.319	+.143	-.188	-.226
SEPT 1-10	144	+ 5.293	+.095	-.147	-.118
SEPT 11-20	141	+ 4.400	+.058	-.006	-.225
SEPT 21-30	142	+ 3.837	+.060	+.001	-.102
OCT 1-10	138	+ 4.167	+.156	+.028	-.170
OCT 11-20	137	+ 3.555	+.126	+.019	-.128
OCT 21-31	159	+ 2.990	+.137	+.070	-.112
NOV	395	+ 3.860	+.205	-.001	-.105
DEC	403	+ 4.363	+.209	+.012	-.161

APPENDIX X: OVERNIGHT MINIMUM TEMPERATURE ESTIMATION ZERO ORDER CORRELATION COEFFICIENTS AND ERROR STATISTICS (7AM/2PM/9PM FORMAT - WITHOUT WIND DATA)

PERIOD	R*	7AM T - 9PM T	7AM SKY	9PM SKY	STD. ERROR	AVERAGE ABSOLUTE RESIDUAL	MEDIAN ABSOLUTE RESIDUAL	MODAL ABSOLUTE RESIDUAL
JAN	.589	+.558	+.254	-.150	2.620	2.060	2	1
FEB	.517	+.496	+.232	-.084	2.665	2.077	2	1
MAR 1-10	.441	+.358	+.256	-.195	2.614	1.811	1	1
MAR 11-20	.444	+.342	+.053	-.231	2.077	1.472	1	1
MAR 21-31	.527	+.372	+.049	-.359	1.859	1.401	1	1
APR 1-10	.544	+.134	-.276	-.474	2.034	1.552	1	1
APR 11-20	.563	+.051	-.430	-.470	2.536	1.917	2	2
APR 21-30	.692	+.263	-.494	-.551	2.368	1.792	1	1
MAY 1-10	.722	+.246	-.574	-.584	2.783	2.172	2	1
MAY 11-20	.674	+.267	-.532	-.514	2.901	2.296	2	1
MAY 21-31	.763	+.303	-.617	-.591	2.651	2.065	2	1
JUN 1-10	.759	+.402	-.626	-.568	2.604	2.064	2	2
JUN 11-20	.705	+.438	-.555	-.398	2.602	2.042	2	1
JUN 21-30	.719	+.441	-.578	-.496	2.410	1.892	2	1
JUL 1-10	.727	+.351	-.550	-.464	2.504	1.987	2	1
JUL 11-20	.679	+.514	-.467	-.319	2.395	1.872	2	1
JUL 21-31	.633	+.285	-.507	-.483	2.561	2.060	2	1
AUG 1-10	.546	+.187	-.504	-.276	2.289	1.820	1	1
AUG 11-20	.495	+.022	-.479	-.111	2.176	1.790	2	2
AUG 21-31	.584	+.109	-.443	-.381	2.125	1.612	1	1
SEPT 1-10	.456	+.082	-.355	-.350	1.834	1.439	1	1
SEPT 11-20	.500	+.055	-.224	-.488	1.768	1.387	1	1
SEPT 21-30	.238	+.091	-.016	-.182	1.865	1.410	1	1
OCT 1-10	.522	+.401	+.106	-.313	1.847	1.443	1	1
OCT 11-20	.446	+.353	+.079	-.257	1.765	1.360	1	1
OCT 21-31	.457	+.402	+.188	-.121	1.885	1.468	1	1
NOV	.489	+.449	+.182	-.124	2.176	1.666	1	1
DEC	.537	+.483	+.208	-.200	2.532	1.877	2	1

*MULTIPLE REGRESSION COEFFICIENT

APPENDIX Y: AFTERNOON MAXIMUM TEMPERATURE ESTIMATION REGRESSION COEFFICIENTS (7AM/2PM/9PM FORMAT - WITHOUT WIND DATA)

PERIOD	N	A_o	2PM SKY
JAN	382	+1.176	-.003
FEB	411	+1.458	-.016
MAR	512	+1.693	-.027
APR	510	+1.929	-.009
MAY	512	+1.962	+.024
JUN	503	+1.475	+.080
JUL	559	+1.511	+.076
AUG	545	+1.347	+.090
SEPT	520	+1.061	+.092
OCT	523	+ .988	+.051
NOV	452	+ .799	+.024
DEC	366	+ .742	+.023

APPENDIX Z: AFTERNOON MAXIMUM TEMPERATURE ESTIMATION ZERO ORDER CORRELATION COEFFICIENTS AND ERROR STATISTICS (7AM/2PM/9PM FORMAT - WITHOUT WIND DATA)

PERIOD	2PM SKY	STD. ERROR	AVERAGE ABSOLUTE RESIDUAL	MEDIAN ABSOLUTE RESIDUAL	MODAL ABSOLUTE RESIDUAL
JAN	-.012	1.012	.752	1	1
FEB	-.052	1.266	.951	1	1
MAR	-.085	1.283	1.007	1	1
APR	-.025	1.431	1.006	1	1
MAY	+.053	1.666	1.135	1	1
JUN	+.195	1.467	1.110	1	1
JUL	+.177	1.439	1.052	1	1
AUG	+.237	1.380	1.031	1	1
SEPT	+.283	1.242	.948	1	1
OCT	+.175	1.143	.835	1	1
NOV	+.099	.996	.648	1	1
DEC	+.090	1.047	.694	1	1