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CONSTRUCTION OF A UNITED STATES HISTORICAL SNOW DATA BASE

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ABSTRACT

Construction of the first quality controlled historic snow data set for the United States will be completed by the end of this year. This daily set of approximately 1000 cooperative and first order stations will include records which in many cases extend back to the turn of the century. Daily maximum and minimum temperature and precipitation data will also be included. The data set will be of use in pure and applied research tasks and will obviate the need to draw conclusions based on short-term or suspect data.

1. Introduction

Across much of the heavily populated middle latitudes and in the polar regions the impact of snow on mankind and the environment is considerable. Falling snow or snow lying on the ground affect weather, climate, hydrology, biology, environmental chemistry, earth surface processes, engineering, agriculture, travel, recreation, commerce and safety, among others. In turn, the presence or state of snow is influenced by weather, climate, topography, proximity to water bodies, mankind, etc. Much remains to be learned regarding these associations and others. It is therefore critical that accurate information on snowfall and snow cover is available to investigators. Here, an historic ground station derived snow data set for the United States will be discussed. Included is a description of the set, a discussion of quality control procedures being employed and examples of its potential utility.

2. Identifying snow

Prior to looking specifically at the U.S. snow set it is useful to examine the variety of methods employed in gathering snow data.

a) Snow cover:

Ground station reports have the advantages of longevity of record and a measurement of depth. Negative aspects are the point nature of the measurement and limited spatial coverage, particularly outside of the lower elevations of the middle latitudes. Aerial surveys have good spatial resolution and permit the percent coverage of snow to be determined, however their overall spatial and temporal coverages are severely limited.

Satellite-derived snow cover products include those from shortwave and passive microwave sensors. Shortwave data provide continental coverage with a relatively high spatial resolution. Information on surface albedo and percent snow coverage are also gleaned from the data. Shortcomings include the inability to detect cover when solar illumination is low or absent or when skies are cloudy, the lack of all but the most general information on pack depth and the short two-decade long record (which has increased in quality with time) which is presently available.

Microwave-derived snow products provide continental coverage and the ability to recognize snow cover is independent of solar illumination or the absence of clouds. There is some indication that information on liquid water content can be obtained, although it remains uncertain as to just how accurate this is. Spatial resolution is lower than in the shortwave but is generally sufficient on continental scales, except where snow cover is patchy. It is difficult to identify shallow or wet snow using microwaves and no direct information on surface albedo can be obtained. Microwave products are only available for the past ten years.

b) Snowfall

Direct means of identifying where and how much snow is falling or has fallen include using ground-based radar and station observations. The former distinguishes between snow and liquid precipitation to some degree, but has difficulties identifying the presence of a light snowfall. Station observations remain the primary means of monitoring snowfall, despite the spatial limitations of the observing network.

Indirect means of assessing snowfall include satellite microwave recognition of precipitation in clouds, or identifying cloud patterns viewed in shortwave or infrared imagery which suggest the location of falling snow based on the location of a region with respect to a cyclonic system or water body. In both, some knowledge of the existing atmospheric temperature profile is needed. Finally, changes in satellite shortwave or microwave surface signatures can be used to estimate how much snow has fallen. These indirect methods presently have little or no utility in quantitative studies of snowfall.

3. Justification for construction of a U.S. historic snow data base

To provide the best information on regional or broader snow cover and snowfall, both station and satellite data must be included in the analysis. Station data also provide continuity between pre-satellite and satellite era snow products. This permits long time-series to continue to be expanded.

Unfortunately, from the standpoint of station data it is not as simple as going to an archive and blindly retrieving snow data. While snowfall and snow cover have theoretically been measured for the length of record at most recording stations, the availability and quality of the data for a number of stations is often quite poor in comparison with the other meteorological variables gathered. An example of the lack of attention paid to the documentation of snowfall and snow cover is shown in Table 1. Of the 38 New Jersey stations reporting temperature and precipitation data for January 1988, 13 had incomplete, missing or obviously inaccurate data on monthly snowfall totals and/or maximum depth of snow on the ground. This is not an unusual situation for any U.S. State or any country, and results in difficulties when analyzing snow for select events and, in particular, when evaluating time series of snow.

No doubt, as a partial result of the condition of snow data in climate archives, studies utilizing these data have been limited. For instance, only a few studies have dealt with secular variations of snow on a regional basis. Lengthy snowfall records were addressed by Namias (1960), who examined records at selected cities in the northeastern U.S., and by Thomas (1964), who studied Canadian and U.S. records in the Great Lakes region. Studies of regional snow cover over periods of 50 years or more are mainly limited to individual sites or regions in Europe (Uttinger, 1963; Manley, 1969; Lamb, 1969; Jackson, 1978; Pfister, 1978; 1985) or Japan (Arakawa, 1957) and a recent effort in the central U.S. (Robinson, 1987).

Fortunately, there are observers who diligently record snowfall and snow cover. As a result, there are a number of stations across the U.S. with long-term snow records. With a modest amount of quality controlling, these records will be extremely useful in any and all studies related to snowfall or snow cover across the U.S. An effort has recently begun to identify those stations and to create a snow data base. This project is being conducted by the author at the National Climatic Data Center (NCDC) in Asheville, NC during a year-long appointment as a visiting scientist.

4. Description of proposed set

The snow data set will be comprised of daily snowfall and snow cover data from approximately 800 cooperative stations which are presently active and have digital records extending back at least 50 years. For 200 first order stations, daily snow cover data extending back to the turn of the century, daily snowfall data since 1948 and daily water equivalent data since the early 1960's will be included. Coincident maximum and minimum temperature and precipitation data for the length of record for the cooperative stations and since 1948 for the first order stations will also be included in the set. In addition, information on station histories will be found in the set.

Table 1. Monthly summarized data of January 1988 snowfall and maximum depth of snow on the ground for New Jersey stations which record both daily temperature and precipitation. M = missing, data in inches (1" = 2.54cm). (Climatological Data, New Jersey, 1988).

	TOTAL SNOW, SLEET	MAX. DEPTH ON GROUND
Northern Division 01		
Belvidere Bridge	17.0	9
Boonton 1 SE	14.0	7
Canoe Brook	15.3	7
Charlotteburg Resvoir	15.5	8
Cranford	11.5	8
Essex Fells Serv Bldg	M 5.0	M
Flemington 5 NNW	13.5	7
High Point Park	M	16
Jersey City	M 6.5	M
Lambertville	12.0	7
Little Falls	M	M
Long Valley	17.0	M
Morris Plains 1 W	14.3	8
Newark WSO AP	15.4	9
Newton St Pauls Abbey	17.0	11
Plainfield	14.0	7
Somerville 3 NW	12.2	7
Sussex 1 SE	M	M
Wanaque Raymond Dam	12.3	6
Southern Division 02		
Atlantic City WSO AP	7.1	4
Audubon	12.0	8
Belleplain St Forest	5.0	5
Glassboro	M 0.0	6
Hammonton 2 NNE	7.5	0
Hightstown 2 W	10.6	6
Indian Mills 2 W	13.3	9
Millville FAA AP	6.0	7
Moorestown	M	M
New Brunswick 3 SE	15.8	8
Pemberton 3 S	12.0	11
Seabrook Farms	5.3	4
Shiloh	M	M
Toms River	M 0.0	0
Tuckerton	7.3	4
Woodstown	9.5	7
Coastal Division 03		
Atlantic City	M	M
Brant Beach	M 0.0	0
Cape May 2 NW	4.6	1

a) Daily data

It is important that the data base contain daily data. Owing to the transitory nature of snow, monthly data or end-of-month data alone are not sufficient to adequately address questions regarding snow dynamics, snow-climate interactions, major storms, etc. For instance, daily data are needed to calculate the duration of snow cover or the number of snowfall events. Using less than daily data may serve to mask significant snow events of days to a few weeks in length which may have a major influence on monthly or seasonal temperatures or it may give an inordinate weight to an isolated event which happened to occur at the time sampling took place.

b) Cooperative station data

Files were recently assembled at NCDC containing records from all cooperative stations which had previously been digitized and contained daily data prior to 1948. This amounts to approximately 1100 stations, most of which have digital records back to the early 1930's and in many cases to the early part of this century. Data for most stations include maximum and minimum temperature, precipitation, snowfall and snow cover. As these data were originally digitized for a variety of different studies and in some cases at locations other than NCDC, rigorous quality controlling is necessary as a part of this project (cf. section 5). A preliminary analysis to determine station starting dates, those no longer in operation and those with significant gaps in their records indicates that approximately 800 cooperative stations will be included in the snow set.

c) First order station data

Currently a digital set containing long-term daily snow cover data for approximately 200 first order stations is in the final stages of quality controlling at NCDC. This record has been compiled as part of a Department of Energy historical climate network program. Records for these stations go back to the turn of the century. Beginning in 1948, all climatic parameters reported by these stations are available in digital form, with the exception of water equivalent data which are available digitally since the early 1960's.

d) Station histories

Approximately one half of the cooperative stations in the data set are part of the U.S. Historical Climate Network and have detailed station histories available in digital form for the length of their existence. These histories include a record of station moves, observer changes and times of observation. The remaining cooperative and the first order stations have digitized histories beginning in 1948, with times of observation on file only since the early 1980's.

5. Development of quality control procedures

Six cooperative stations with records extending back to the turn of the century were selected for an initial assessment of data quality and to assist in the development of quality control procedures. Some disturbing problems with the snow data for several of the stations were noted, further emphasizing the need for a thorough quality control of all data going into the snow set.

For example, Grand Island, NE, with digitized records back to 1900, did not have any daily snow cover data flagged as missing. However, upon examination of graphs showing January totals for days with snow cover, a suspicious lack of snow cover days from 1915 through 1938 was noted (Figure 1). By including January snowfall totals in the figure, most snow cover errors were confirmed. Obviously, the observers during this period (Eli Barnes (1906-1921) and the American Crystal Sugar Company (1921-1938)) failed almost entirely to record snow on the ground. Six of the nine Januaries between 1906 and 1914 had no snowfall reported, making it unclear as to whether they actually had no snow cover or these data were missing. A check of the original records shows that only traces of snow fell in January 1907, 1909 and 1914. However 5.0" (12.7cm) fell in 1912 but was not entered into the digital file. No snow cover was listed on the original form for this month. A check of precipitation and temperature records suggests that Mr. Barnes failed to record snowfall events in 1910 and 1911. All of this confirms that he never kept records of snow on the ground and emphasizes the need to cross check data amongst several variables.

The first five years of Grand Island digital data were collected by Elbert Corbin. Here, the records for both snowfall and cover are essentially complete. Beginning in March 1938, Grand Island became a first order station manned by the National Weather Service. Records from then on appear to be accurate.

Napoleon, ND was intensively checked and found to have one of the best records of the study set. However, there are periods with missing data in the digital file, primarily in the early 1970s, which result in approximately 15% of the months having incomplete or suspect daily snowfall data and 10% with incomplete or suspect snow cover data. Of these months, about half were readily completed by going to the original forms and correcting keying errors made when the data were digitized or by comparing variables for a given day from the digital record. For instance, with precipitation measured and a snowfall report missing, the latter would be replaced by a zero if temperatures on the day in question were will above freezing.

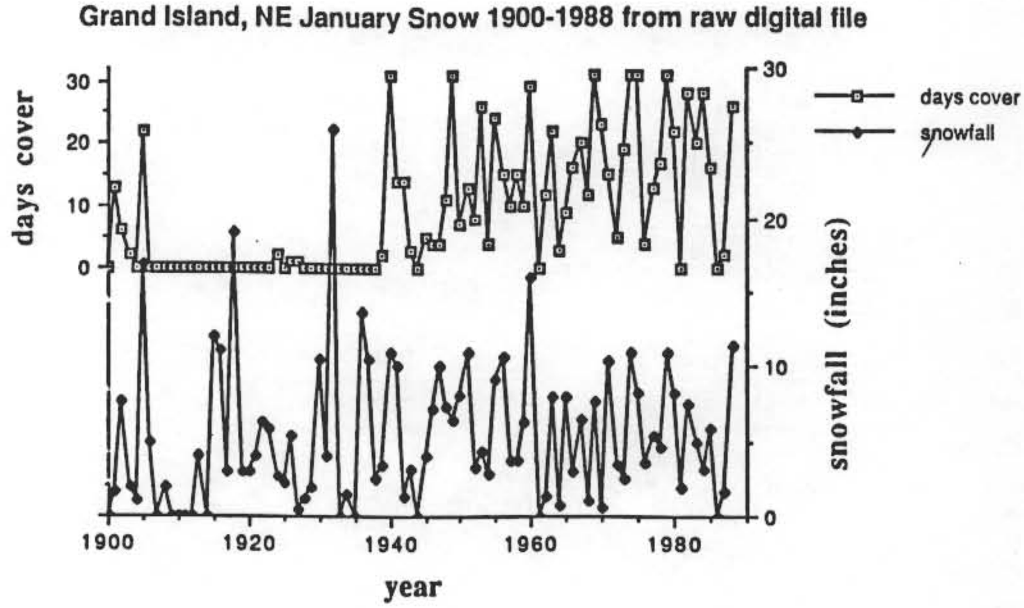

Figure 1. Grand Island, Nebraska snowfall and number of days with 1" (2.54cm) or greater snow cover for Januaries from 1901-1988 as found in the raw digital station file. See text for a discussion of the data quality.

Figure 2 shows a time-series of January snowfall and days with snow cover at Napoleon for the period with digital records (1901-1988). Here, the snow records were made complete by filling in missing snowfall data using temperature and precipitation reports and applying a 10:1 ratio of snow to liquid precipitation when temperatures were below freezing. For missing snow cover, gaps were filled in using snow cover data prior and subsequent to the gap and adjusting depths during the missing period using temperature, precipitation and snowfall records. Missing data such as this will not be completed in this manner in the digital set presently being constructed. More sophisticated approaches may be developed and applied to these gaps at a later date.

Changes in observers, observation times and station locations make if important to know a station's history before doing all but the most general investigations using it's data. Histories of the these variables for Napoleon are listed in Table 2. Changes are considered relatively minor in comparison with many other stations. For all but about 5 of the 99 years the station has been in operation (microfiche records go back to 1889), observations have been made by one of four observers. All station locations have been within a circle with a diameter of 1.5 miles (2.4km) and the station elevation has changed by no more than 25 feet (7.6m). The time of observation has varied considerably; fortunately these changes for the most part are well documented. Temperature observations, for which the timing is most critical (Karl et al., 1986) have oscillated between evening and morning hours several times during this century.

An additional problem with the temperature records has been discovered during the quality controlling of Napoleon data. During most of the 1911 to 1942 period when Charles Hoof measured temperature in the morning the official Weather Service files moved the maximum recorded for the previous 24 hours to the previous day, keeping the minimum on the present day. This resulted in numerous cases where the previous day's minimum exceeded the present day's maximum. This practice was observed until the middle of 1948 for all AM temperature stations. While it does not greatly affect monthly means, if not recognized, investigations examining individual events or relationships between temperature and the other variables would contain erroneous results.

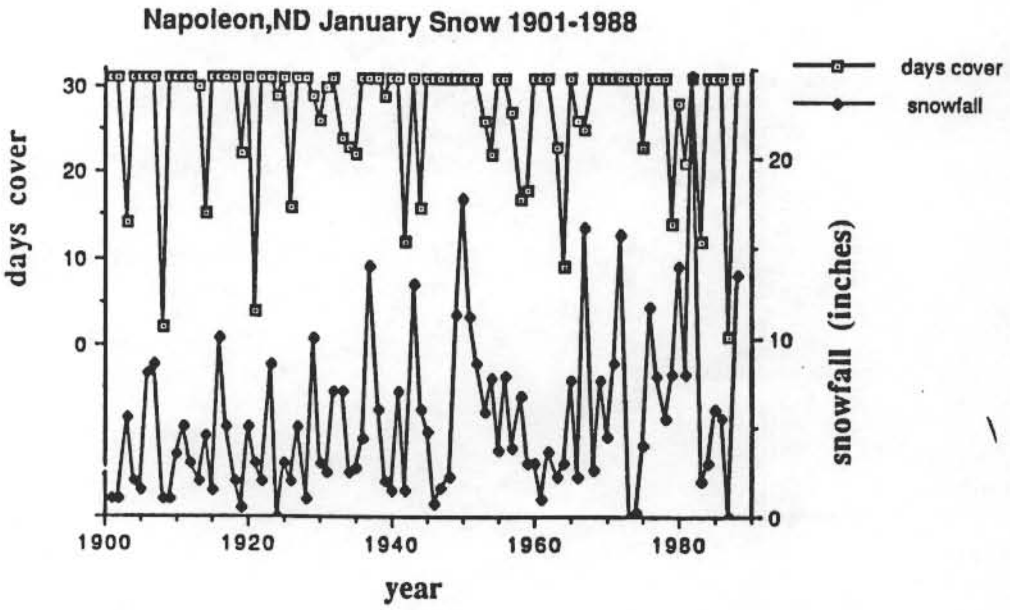

Figure 2. Napoleon, North Dakota snowfall and number of days with 1" (2.54cm) or greater snow cover for Januaries from 1901-1988. Following quality controlling of the digital file, records of snowfall for 1957-58, 1969-70, 1974-75 and 1988 and snow cover for 1975 were still found to be incomplete or missing. As described in the text, these variables were created for this figure using other parameters.

Table 2. Napoleon, North Dakota cooperative climate station history. Included are listings of; a) observers, b) station moves and c) time of day of measurement. Note that the station began recording data in 1889, while digitized records only extend back to 1901. Microfiche of the first 12 years are available at the National Climatic Data Center. (1 foot = 0.3048 meters, 1 mile = 1.61 kilometers)

a) OBSERVERS

1889-1899	Julius Hoof
1899-1944	Charles Hoof
1944-1945	Gladys Peterson
1945-1946	Joseph Hoof
1946-1954	Gladys Peterson
1954-1956	Ted Frank
1956-1957	Alvin Schuchard
1957	Warren Wentz
1957-1968	Gladys Peterson
1968-1973	Warren Wentz
1973-1974	Terry Wentz
1974-present	Warren Wentz

b) STATION MOVES

Year	Distance & direction	Change in elevation
1942	30 ft. S	none
1948	100 ft.?	none?
1949	70 ft. SE	none
1954	1.5 mi. NW	incr. 1 ft.
1957	4 blocks SE	decr. 1 ft.
1958	0.6 mi. W	none
1969	0.5 mi. E	incr. 9 ft.
1976	0.4 mi. NE	incr 16 ft.
1985	400 ft. SW	same

Table 2 c) TIME OF DAY OF MEASUREMENT

1889-1899	twice/day, times?
1899-May 1911	1800
June 1911-August 14, 1918	0700
August 15, 1918-July 1919	evening
August 1919-September 1919	0700
October 1919-April 1921	sunset
May 1921-June 1921	0700
July 1921	evening
August 1921-February 1923	0700
March 1923	1900
April 1923-October 23, 1942	0700
October 24, 1942-November 1942	1900
December 1942-May 1943	sunset
June 1943-July 1943	1900
August 1943-January 1944	sunset
February 1944-May 6, 1970	1730-1830
May 7, 1970-present	0700-0800

Differences in snow measurement methods or perhaps philosophy amongst the Napoleon observers are apparent when looking at the digital files and, in particular, when examining the original records. For instance, Mr. Hoof frequently reported the loss of the last three inches (7.6cm) or more of snow cover (often more than 8" (20.3cm)) in one day during the late winter/early spring. The original record would contain a notation of "only drifts remaining" on the next day and perhaps for several days thereafter. On the other hand, Gladys Peterson and Warren Wentz were more likely to report a more gradual demise of cover over a period of several days to a week. A comparison of records for a number of these episodes indicates that temperatures can not explain the difference. It is quite apparent that an investigation of variations in snow cover duration should disregard reports of less than three inches depth.

Differences were also noted in the frequency of snowfalls of less than one inch (2.54cm). In recent decades such events are much more common, although precipitation and snow cover records suggest this not to be so. While this should make little difference in monthly or seasonal totals, again care must be employed if time series of snowfall frequency are to be investigated.

6. Quality control

It is clear that extensive quality controlling of the data set variables is needed. A program has been developed to do so using data from the day in question (today) and the previous day (yesterday) along with State-specific thresholds. A variable for a particular day is flagged and a printout is produced which lists the type of flag and values for each variable in the set for yesterday, today and the following day. This will permit a preliminary assessment of the validity of the value and may avoid having to go to the original hard copy records to check the value. The program is designed to permit interactive adjustment of particular thresholds depending on the State, so that the operator is satisfied that erroneous data are being flagged yet an excessive amount of real data are not being flagged. A brief outline of the routine follows. Additional approaches utilizing more sophisticated statistics and comparisons with neighboring stations are recommended before detailed studies using small subsets of the set are conducted.

a) Temperature

Cases to be flagged include: 1) today's minimum exceeding the maximum, 2) today's minimum exceeding yesterday's maximum, 3) yesterday's minimum exceeding todays maximum, 4) a diurnal range of greater than a prescribed value (eg. 60°F (15.6°C) and 5) today's maximum or minimum falling above the state record maximum or below the record minimum.

b) Precipitation

Flagged values will include cases where daily precipitation exceeds: 1) a prescribed value (eg. 5.0" (12.7cm)), 2) a state's 24 hour precipitation record and 3) an estimate of the hundred year return period value (U.S. Weather Bureau, 1961).

c) Precipitation/snowfall

Situations to be flagged include days with: 1) no precipitation yet snowfall is reported, 2) no snowfall yet precipitation reported with a maximum temperature below 30°F (-1.1°C), 3) the ratio of snowfall to precipitation exceeding a selected ratio (partially dependent on temperature) and 4) the ratio of snowfall to precipitation less than 5:1 with a maximum temperature below 30°F. Also to be flagged are days: 5) when snowfall is reported yet the minimum temperature exceeds 39°F (3.9°C) and 6) when the day's snowfall exceeds the state 24 hour maximum.

d) Snow cover/snowfall

Days to be flagged include those where: 1) the snow cover exceeds a selected threshold, 2) no snowfall is reported yet an increase in depth occurs and 3) snowfall exceeds 2.0 inches (5.1cm) yet today's cover is less than yesterday's and today's maximum temperature is less than 30°F (-1.1°C). Also to be flagged are days: 4) when the snow cover is more than 5 inches (12.7cm) below yesterday's and 5) when today's cover is zero and yesterday's was 3 or 4 inches (7.6 or 10.2cm).

e) Extremes

As an additional check, a list of daily station extremes for the period of record will be produced with includes the top ten: 1) maximum maximum temperatures, 2) minimum maximums, 3) minimum minimums, 4) maximum minimums, 5) maximum precipitation events, 6) maximum snowfalls and 7) maximum snow depths.

Based on quality control efforts, data believed to be in error will either be replaced by a value obtained from an original data form (should the error have occurred in the digitization process) or they will be flagged as missing in the main set (if the original record shows the same value). In the latter case the flagged values will be stored in a separate file. Data originally shown as missing in the digital file will be checked against the original records and replaced whenever possible. At this point, no effort will be made to generate replacement values using physically-based algorithms.

7. Utility of the data set

The potential uses of the historic set for pure and applied research are considerable. Examining its utility in climate studies as an example, some questions which might be addressed include:

a) Have the frequency and intensity of snowfall events, the duration of snow cover of different depths and the water equivalent of the snow pack varied in the U.S. during the past century? If so, how?

b) How do anomalies of snowfall and snow cover correlate from region to region across the U.S.?

c) How do anomalies of snowfall and snow cover correlate with anomalies of temperature and precipitation?

d) To what extent, if any, does snow cover duration differ between urban and non-urban areas located in close proximity to each other?

e) How well do model simulations of snow accumulation and ablation perform? How may they be improved?

f) How important is it to accurately simulate snow cover in climate models in order to correctly model surface air temperatures?

Many of these climatic questions have begun to be addressed in a number of fine investigations (eg. Lamb, 1955; Namias, 1960; Namias, 1962; Clapp, 1967; Wagner, 1973; Dewey, 1977; Kukla, 1979; Afanas'eva et al., 1979; Robock, 1980; Wash et al., 1981; Walsh et al., 1982; Foster et al., 1983; Heim and Dewey, 1984; Namias, 1984; Johnson et al., 1984; Walsh and Jasperson, 1985; Walsh et al., 1985; Walsh and Ross, 1986; Trapasso and Simpson, 1988). However, in most cases these studies employ data which are limited in space or time, leaving too many uncertainties remaining concerning the representativeness of the study results. With a long-term national data base, multiple cases can be examined and statistical significance assigned to study results.

8. Conclusions

Construction of the first quality controlled historic snow data set for the United States will be completed by the end of this year. This daily set of approximately 1000 cooperative and first order stations will include digital records extending back to the turn of the century for many stations. Daily maximum and minimum temperature and precipitation data and station histories will also be included. The set will be designed so that additional data may be readily added once available. This not only includes updates in future years but also includes efforts to extend back records for stations which, while available in hard copy format, have yet to be digitized. The quality control routine designed for this study can be applied to these additions and can also be used to "clean up" the files for the thousands of stations with digital data from 1948 on. The data set will be of use to pure and applied research tasks and will obviate the need to draw conclusions based on short-term or suspect data.

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