ENVIRONMENTAL INFORMATION SUMMARIES C-23

# 1971-2000
# United States Climate Normals

**Monthly, Daily, and Divisional Products**

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## Overview

Climate is an important factor in such activities as agriculture, commerce, industry and transportation, to name just a few. It affects human activities such as farming, fuel consumption, structural design, building site location, trade, analysis of market fluctuations and the utilization of other natural resources. The influence of climate on our lives is endless. The National Climatic Data Center (NCDC) is charged to fulfill the mandate of Congress "...to establish and record the climatic conditions of the United States," an important provision of the Organic Act of October 1, 1890 (15 U.S.C. 311) which established the Weather Bureau, subsequently the National Oceanic and Atmospheric Administration (NOAA), as a civilian agency.

The mandate to describe the climate was combined with guidelines established through international agreement. The end of a decade has been set by the World Meteorological Organization (WMO) as the desirable term for a 30-year period from which to calculate climatic conditions. The average value of a meteorological element over the 30 years is defined as a climatological normal. The normal climate helps in describing the climate and determining climatic time trends by comparing the current 30-year period with earlier periods.

The average value of a meteorological element over 30 years is defined as a climatological normal. These normal values help in describing the climate and are used as a base to which current conditions can be compared. Every ten years, NCDC computes new thirty-year climate normals for selected temperature and precipitation elements for a large number of U.S. climate and weather stations. These normals are summarized in daily, monthly, divisional, and supplementary normals products.

This document provides information on the primary normals products released by NCDC for the 1971-2000 period, including the following:

*A. Climatography of the United States Number 81*
*Monthly Station Normals of Temperature, Precipitation, and Heating and Cooling Degree Days, 1971 - 2000*

*B. Climatography of the United States Number 84*
*Daily Normals and Precipitation Probabilities, 1971 - 2000*

*C. Climatography of the United States Number 85*
*Divisional Normals and Standard Deviations of Temperature, Precipitation, Heating and Cooling Degree Days, 1931 - 2000 (1931 - 1960, 1941 - 1970, 1951 - 1980, 1961 - 1990, 1971- 2000.)*

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## Products

### A. Climatography of the United States No. 81

*Climatography of the United States, No. 81 / Monthly Station Normals of Temperature, Precipitation, and Heating and Cooling Degree Days, 1971-2000*

**See Also:** *Climatography of the United States, No. 81, Supplement No. 1 / Precipitation Probabilities and Quintiles, 1971-2000* and *Climatography of the United States, No. 81, Supplement No. 2 / Annual Degree Days to Selected Bases, 1971-2000*

The Climatography of the United States Number 81 series (Clim81) provides monthly climatic normals data for a total of 7,937 sites which record temperature and/or precipitation data, of which 5,556 record temperature data. The sites record data from National Weather Service (NWS) offices (known as First Order stations), principal climatological stations, and volunteer "cooperative" observer stations across the United States and its territories.

Units used in this publication are degrees Fahrenheit (°F) for temperature and inches for precipitation. Heating and cooling degree day (base 65°F) normals are derived from the monthly normal temperatures using a modification of the technique developed by Thom (1954a, 1954b, 1966), or, for most First Order stations, are computed directly from daily degree day values. Note: Degree day normals have also been computed to other bases and are available in *Climatography of the United States, No. 81, Supplement No. 2 (Annual Degree Days to Selected Bases, 1971-2000)* or in digital data set DOC/TD-9641-G.

The climatological normals presented in this publication are based on monthly maximum, minimum, and mean temperature and monthly total precipitation records for each year in the 30-year period 1971 - 2000, inclusive. Most stations were operating as of December 2000. In order to be included in the normals, a station had to have at least 10 years of monthly temperature data or 10 years of monthly precipitation data for each month in the period 1971 - 2000. In addition, a station had to be active since January 1, 1999 OR had to be included as a normals station in the 1961 - 1990 normals.

A climate normal is defined, by convention, as the arithmetic mean of a climatological element computed over three consecutive decades (WMO, 1989). Ideally, the data record for such a 30-year period should be free of any inconsistencies in observational practices (e.g., changes in station location, instrumentation, time of observation, etc.) and be serially complete (i.e., no missing values). It is important to note that several adjustments were made to the data before the normals were calculated. These adjustments include estimating missing data, adjusting for time of observation bias, and adjusting for inhomogeneities. When present, inconsistencies can lead to a non-climatic bias in one period of a station's record relative to another. In that case, the data record is said to be inhomogeneous. Since records are frequently characterized by such data inhomogeneities, statistical methods have been developed to identify and account for them. In the application of these methods, adjustments are made so that earlier periods in the data record more closely *conform to the most recent period*. Likewise, techniques have been developed to estimate values for missing observations. After such adjustments are made, the climate record is said to be homogeneous and serially complete. The climate normal can then be calculated simply as the average of the 30 values for each month observed over a normals period like 1971 to 2000. By using appropriately adjusted data records, where necessary, the 30-year mean value will more closely reflect the actual average climatic conditions at all stations.

The methodology used to address problems at stations with inhomogeneities and missing data values is comprised of several steps. As with all automated quality control and statistical adjustment techniques, only those data errors and inhomogeneities falling outside defined statistical limits can be identified and appropriately addressed. In addition, even the best procedures can occasionally apply corrections where none are required or misidentify the exact year of a discontinuity. In the 1971 - 2000 monthly normals calculations, the sequential year-month data were adjusted to conform to a common midnight-to-midnight observation schedule. This is necessary since changes in observation time also can lead to non-climatic biases in a station's record. The data were then quality controlled to identify suspect observations and missing or erroneous values were estimated. Finally, the serially complete data series were adjusted for non-climatic inhomogeneities. In the 1971 - 2000 normals, all stations were processed through the same procedures, whereas in the 1961 - 1990 normals only First Order stations were evaluated for inhomogeneities.

In order to effectively compare records among various stations, the time of observation bias, if present, must be removed. While the practice at all First Order stations is to use the calendar day (midnight recording time) for daily summaries, cooperative network station observers record observations once per day summarizing the preceding 24-hour period ending generally in the local morning or evening hours. Observations based on observation times other than midnight can exhibit a bias relative to those based on a midnight observation time (Baker, 1975). Moreover, observation times at any one station may change during a station's history resulting in a potential inhomogeneity at that station. To produce records that reflect a consistent observational schedule, the technique developed by Karl et al. (1986) was used to adjust the monthly maximum and minimum temperature observations to conform to observations recorded on a midnight-to-midnight schedule. However, no time of observation bias adjustments were applied to stations in Alaska, Hawaii, or the United States possessions since no model for adjustment presently exists for these regions.

All monthly temperature averages and precipitation totals were cross-checked against archived daily observations to ensure internal consistency. In addition, each monthly observation was evaluated using an adaptation of the quality control procedures described by Peterson et al. (1998). In this approach, observations at each station are expressed as a departure from the long-term monthly mean. Then, monthly anomalies at a candidate station are compared with the anomalies observed at neighboring stations. Where anomalies at the candidate disagree substantially with those of its neighbors, the observations at the candidate are flagged as suspect and an estimate for the candidate is calculated from neighboring observations. If the original observation and the estimate differ by a wide margin (standardized using the observed frequency distribution at the station), the original is discarded in favor of the estimate. Very few observations were eliminated based on the quality control evaluation.

To produce a serially complete data set, missing or discarded temperature and precipitation observations were replaced using the observed relationship between a candidate's monthly observations and those of up to 20 neighboring stations whose observations exhibited the highest correlation with those at the candidate site. Monthly estimates are calculated using the climatological relationship between candidate and neighbor as well as a weighting function based on the neighbor's correlation with the candidate. For temperature estimates, neighboring stations were drawn from the pool of stations found in the United States Historical Climatology Network (USHCN; Karl et al. 1990) whereas for precipitation estimates, all available stations were potentially used as neighbors in order to maximize station density for estimating the more spatially variable precipitation values.

Peterson and Easterling (1994) and Easterling and Peterson (1995) outline the method that was used to adjust for temperature inhomogeneities. This technique involves comparing the record of the candidate station with a reference series generated from neighboring data. The reference series is reconstructed using a weighted average of first difference observations (the difference from one year to the next) from neighboring stations with the highest correlation with the candidate. The underlying assumption behind this methodology is that temperatures over a region have similar tendencies in variation. For example, a cold winter followed by a warm winter usually occurs simultaneously for a candidate and its neighbors. If this assumption is violated, the potential discontinuity is evaluated for statistical significance. Where significant discontinuities are detected, the difference in average annual temperatures before and after the inhomogeneity is applied to adjust the mean of the earlier block with the mean of the latter block of data. Such an evaluation requires a minimum of five years between discontinuities. Consequently, if multiple changes occur within five years or if a change occurs very near the end of the normals period (e.g. after 1995), the discontinuity may not be detectable using this methodology.

The methodology employed to generate the 1971 - 2000 normals is not the same as in previous normals calculations. For example, in the calculation of the 1961 - 1990 normals, no attempt was made to adjust cooperative network observer data records for inhomogeneities other than those associated with the time of observation bias. Therefore, serial year-monthly data for overlapping periods between normals (e.g., for the 20 years in common between the 1961 - 1990 and 1971 - 2000 normals) will not necessarily be identical.

Temperature normals are provided for mean monthly maximum temperature (HIGHEST MEAN), mean monthly minimum temperature (LOWEST MEAN), and mean monthly average temperature (NORMAL). The median (50th percentile) monthly average temperature is shown as MEDIAN. The median is the middlemost value in an ordered series of values. Half of the values are greater than the median and half are less than the median. Monthly normals for February are based on a 28-day month. For HIGHEST MEAN and LOWEST MEAN, the year of occurrence is also provided.

Degree day normals were computed in two (2) ways. For 250 selected NWS First Order locations, heating and cooling degree day normals were computed directly from daily values for the 1971 - 2000 period. For all other stations, the rational conversion technique developed by Thom (1954, 1966) was modified by using a daily spline-fit assessment of mean and standard deviations of average temperature. The Thom methodology allows the adjusted mean temperature normals and their standard deviations to be converted to degree day normals with uniform consistency. The modification eliminates an artificial month-by-month 'step' in the data output. In some cases this procedure will yield a small number of degree days for months when degree days may not otherwise be expected. The annual degree day normals were calculated by adding the corresponding monthly degree day normals.

When historical climate data are accumulated and examined, they generally follow a certain pattern called a statistical distribution. For example, if 30 years of March temperature data were assembled and examined, the data would have a pattern that consisted of most of the March values having temperatures close to the normal or average value, a few March values having very warm temperatures, and a few March values having very cold temperatures. This kind of statistical pattern is called a "Gaussian" distribution. Temperature data typically follow a Gaussian distribution, but precipitation frequently does not. This is because precipitation is zero-bounded. When historical precipitation data are examined, most of the values will be close to the middle of the distribution, and some values will be considerably higher than the middle range. But on the low end of the scale, the smallest values will never be less than zero, since negative precipitation is not possible. In particularly arid regions, the pattern can be drastically skewed to the left-hand side of the scale, with most of the values being near zero and a few very wet values spread far to the right. This kind of pattern is called a "Gamma" distribution. Once the statistical distribution is identified, the statistical properties of the distribution can be used to estimate the probabilities that certain values will occur, and which values can be expected at certain probability levels. The probability levels desired can be preselected at certain individual levels or at regular intervals. The 0 - 20%, 20 - 40%, 40 - 60%, 60 - 80%, and 80 - 100% intervals are called the quintile levels.

In this data set, the Gamma distribution was used to estimate the precipitation values at 15 probability levels (0.005, 0.01, 0.05, 0.10, 0.20, 0.30, 0.40, 0.50, 0.60, 0.70, 0.80, 0.90, 0.95, 0.99, and 0.995). For example, if 1.77 inches corresponds to the 0.20 probability level, that means that, *on average*, 2 out of 10 years will have 1.77 inches **or less** of precipitation in that month. It also means that, *on average*, 8 out of 10 years will have **more than** 1.77 inches of precipitation in that month.

The following table shows the expected precipitation values at the five (5) quintile levels for each of the 12 months and for the year:

| LVL | Quintile | Range |
|---|---|---|
| 1 | First Quintile | 0 - 20% |
| 2 | Second Quintile | 20 - 40% |
| 3 | Third Quintile | 40 - 60% |
| 4 | Fourth Quintile | 60 - 80% |
| 5 | Fifth Quintile | 80 - 100% |

For example, if 2.91 and 4.07 inches are the bounds for the second quintile (level 2), then a monthly total precipitation amount for that month falling in the range 2.91 to 4.07 would be classified as a second quintile precipitation amount and that month would be considered relatively dry. In addition, two (2) *extreme* quintile levels are also computed: Quintile level 0 is defined for monthly precipitation totals less than the 1971 - 2000 minimum monthly value, while quintile level 6 is defined for monthly precipitation totals greater than the 1971 - 2000 maximum monthly value.

The individual monthly station values of average (maximum, minimum, and mean) temperature and total precipitation used to calculate the normals for the 1971 - 2000 period are available from the National Climatic Data Center and may be obtained in digital media (TD-9641). In addition, extremes of monthly total precipitation and mean temperature are included, along with the standard deviations of the monthly temperatures. The median (i.e., 50th percentile), 11-year (*e.g.*, 1990 - 2000) and 21-year (*e.g.*, 1980 - 2000) means are also provided for both temperature and precipitation.

When working with the precipitation normals, note that values less than .005 inch are shown as zero. Precipitation includes rainfall and the liquid water equivalent of frozen precipitation (snow, sleet, hail).

## B. Climatography of the United States No. 84

*Climatography of the United States No. 84 / Daily Normals and Precipitation Probabilities 1971 - 2000*

The Climatography of the United States Number 84 series, (Clim84), provides daily climatic normals data from a total of 7,937 sites which record temperature and/or precipitation data, of which 5,556 record temperature data. The sites record data from National Weather Service (NWS) offices (known as First Order stations), principal climatological stations, and volunteer “cooperative” observer stations across the United States and its territories. The data include daily normals for each day of the year, four seasonal averages (Winter, Spring, Summer, and Autumn), and the annual average or total. A climate normal is defined, by convention, as the arithmetic mean of a climatological element computed over three consecutive decades (WMO, 1989).

There have been several issues of the Clim84, each covering a different normals period. Daily normals for the 1921 - 1950, 1931 - 1960, and 1941 - 1970 periods included maximum, minimum and average temperature. Heating and cooling degree day normals were added with the 1951 - 1980 issue. The 1961 - 1990 issue included two sets of tables: (i) the daily normals for maximum, minimum and average temperature, heating and cooling degree days, and precipitation; and (ii) precipitation probabilities and quintiles. The 1971 - 2000 issue contains the same two sets of tables. However, with the inclusion of the cooperative observer sites, many more stations are available than in the past.

Units used in this publication are degrees Fahrenheit (°F) for temperature and inches for precipitation. Heating and cooling degree day (base 65 °F) normals are derived from the monthly normal temperatures using a modification of the technique developed by Thom (1954a, 1954b, 1966), or, for most First Order stations, are computed directly from daily degree day values. Degree day normals have also been computed to other bases and are available in *Climatography of the United States, No. 81, Supplement No. 2 (Annual Degree Days to Selected Bases, 1971 - 2000)* or in digital data set DOC/TD-9641-G.

Generally, the daily values adhere to two (2) rules. First, the sum of the maximum and minimum temperature divided by two (and rounded OR truncated) should equal the average temperature. Second, the functional relationship TAVG - 65 + HDD - CDD = 0, where TAVG is the average temperature, HDD is the daily heating degree days, and CDD is the daily cooling degree days, should be valid. There can be exceptions to the latter rule (and there is flexibility in the first rule in allowing truncation or rounding) in order to assure that the arithmetic average or sum of the daily values is equivalent to the monthly values presented in data set DOC/TD-9641-C *(Climatography of the United States, No. 81 Monthly Station Normals of Temperature, Precipitation, and Heating and Cooling Degree Days, 1971-2000)*. In other words, values in this data set are subordinated to those found in the monthly normals.

Daily Normals: The daily normal values presented in the first set of tables are simple means of the observed daily values. They are interpolated from the monthly normals by use of the cubic spline function as described by Greville (1967). The series of daily values resulting from the cubic spline yields a smooth curve throughout the year that represents the annual cycle of the climatological element for a station.

There were several reasons for using a cubic spline fit of the monthly normals instead of averaging the daily data. First, simply averaging the observed daily values would result in a daily normal curve that has considerable variability from day to day (e.g. the annual temperature cycle would be considerably jagged or ragged.) This climatological raggedness could result in daily normals that trend in the opposite direction from what is expected (e.g. in the seasonal march of temperature). Using a cubic spline fit of the monthly normals eliminates this raggedness from the daily normal curve. Furthermore, a complete and homogeneous (i.e. no change in siting, instrumentation, exposure or observation practices) set of data is necessary for the analysis to be accurate. There are very few stations that have complete and homogeneous daily records. Any change of the types indicated above would introduce a non-climatic effect which would make the data inhomogeneous. The techniques for estimating missing daily data and adjusting daily data for inhomogenities are complex and for many stations are difficult to apply. However, the estimation and adjustment techniques for monthly data are not as complex or troublesome. Hence, the official daily normals are based on monthly normals which incorporate inhomogeneity adjustments.

The daily normal curve begins on January 1 and ends on December 31. The cubic spline function requires data past these end points to serve as an anchor for the computations (so the end points themselves can be fitted properly by the interpolating function.) The procedure involves constructing a cumulative series of monthly sums calculated from the monthly normals. The monthly normals were treated as sums in order to facilitate the interpolation of the daily values. For precipitation and degree days, the treatment is straightforward. For maximum, minimum and average temperature, the monthly sum was computed by multiplying the monthly normal by the number of days in the month. The cumulative series was for a 24-month period (July, ..., December, January, ..., December, January, ..., June) so the end points could be determined. This process was applied independently to all six climatological elements (i.e. maximum, minimum and average temperature, heating and cooling degree days, and precipitation.) No normal values for February 29 are included; in common practice, the normal values for the 28$^{th}$ are used for the 29$^{th}$ in each leap year. Thus, for leap years, the February monthly total degree days or precipitation are calculated by adding the daily value for the 28$^{th}$ to the monthly total. February temperature averages are likewise not adjusted for leap years. For most stations, the monthly heating and cooling degree day normals (base 65°F) are derived from monthly normal temperature using an estimation technique developed by Thom (1954a, 1954b, 1966). Spurious values of 1 are indicated by a -99 or an asterisk (*) in this data set. Such values are designated as spurious because of their separation from the major rise and fall of non-zero degree day values over the course of a heating/cooling degree day season, yet their presence assures consistency between the monthly total and the sum of the daily total. For applications emphasizing accumulation and computations on a day-by-day basis, such spurious values should often be excluded.

## C. Climatography of the United States No. 85

*Climatography of the United States No. 85 / Divisional Normals and Standard Deviations of Temperature, Precipitation, Heating and Cooling Degree Days, 1931 - 2000 (1931 - 1960, 1941 - 1970, 1951 - 1980, 1961 - 1990, 1971 - 2000.)*

The Climatography of the United States Number 85 series (Clim85) includes normals and standard deviations for the five 30-year normals periods and the 70-year period between 1931 - 2000 for each climate division. The normals and standard deviations include values for each of the 12 calendar months and an annual value. The divisional data are displayed by name and number for a state or territory. Data for the conterminous United States are presented alphabetically, followed by data for Alaska, Hawaii, Puerto Rico, the Virgin Islands, and Pacific trust territories. The data elements, presented in separate sections, include time of observation-corrected mean temperature (degrees Fahrenheit), precipitation (inches), and heating and cooling degree days (base 65 degrees Fahrenheit.)

A *climate division* represents a region within a state that is as climatically homogeneous as possible. Furthermore, divisional boundaries generally coincide with county boundaries except in the western U.S., where they are based largely on drainage basins. Divisional data are used to assess large-scale climatic features with respect to a long period of time (*i.e*., decadal, 30-year period, *etc*.). There are 344 climate divisions in the conterminous U.S., with additional divisions in Alaska, Hawaii, Puerto Rico, the U.S. Virgin Islands, and Pacific trust territories. Climate divisions are numbered from 01 to 10. Most states have fewer than 10 divisions. Rhode Island (state 37) is comprised of a single division. There is no division 04 in Nebraska, and no division 01 in the Pacific Islands. The District of Columbia is included in division 04 of Maryland (state 18). The Virgin Islands (state 67) data from St. Thomas, St. Croix, and St. John have been combined into a three-island average. The divisions have been established for the benefit of researchers in hydrology, agriculture, energy supply, etc., who require data averaged over an area of a state rather than for a point (station). Divisional data have been found to be useful for building larger area averages (e.g., for entire states or regions). The data presented have many applications, but like all climatological products they must be used within the framework for which they were designed.

The monthly divisional average temperature and total precipitation data are derived by giving equal weight to all stations reporting both temperature and precipitation within a climatological division, except for Hawaii, where any available stations (including precipitation-only stations) are used. The number of reporting stations within a division varies from month-to-month and year-to-year. Station data are *not* adjusted for inhomogeneities.

Temperature values are corrected for time of observation in the conterminous U.S. as the observers at National Weather Service cooperative stations often take one observation per day, and the ending time of the climatological day can vary from station-to-station as well as year-to-year. Differences of the 24-hour period over which maximum and minimum temperature (as well as average temperature) is reported impact the calculated monthly mean temperature. These potential biases are rectified by adjusting for varying observation times using a model (Karl et al., 1986) to adjust the climate division averages such that all stations end their climatological day at midnight (i.e., climatological and calendar day coincide).

Monthly divisional temperature normals and 70-year averages are computed by adding the yearly values for a given month and then dividing by the number of years in the period. The annual normal and 70-year average are computed by adding all of the monthly normal or long-term average values and then dividing by 12. Precipitation normals and long-term means are computed in a similar manner, except for the annual, which is the sum of monthly values.

Sequential monthly degree days are derived using a modification of the Rational Conversion Formulae developed by Thom (1954, 1966). This technique utilizes the historical monthly average temperature and its corresponding standard deviation (over the standardizing period 1931- 2000) to compute degree days. The modified Thom technique derives the monthly degree days using a spline fit of the monthly mean temperature and standard deviations to ameliorate the month-to-month step function that is inherent with only a single monthly input. The procedure for the computation of the divisional degree day normals involves i.) Calculation of the standard deviations of the temperatures for each of the 12 calendar months over the standardizing period; ii.) Use of the modified Thom technique to compute the heating and cooling degree days for every month and year in the period 1931 - 2000; and iii.) Calculation of the 30-year normals and 70-year (1931 - 2000) long-term averages of the degree days using the procedure discussed above. Standard deviations are computed using the sum and sum square values from the corresponding period of month-year sequential values. For annual temperature, the sum and sum square of the annual values are used, while for annual precipitation, the sum and sum square of monthly values are used.

The monthly normals for a division were computed by adding the values from the appropriate time period for a given month and then dividing by the number of years in the period. For temperature, the annual normals and annual long-term averages were computed by adding all of the monthly normal or monthly long-term average values and then dividing by 12. For precipitation and degree days, the annual normals and annual long-term averages were computed by adding the 12 monthly normal or long-term monthly average values. Be aware of the fact that if an annual normal were computed by averaging the annual values obtained for each year in the period, it may be slightly different from the sum of the 12 monthly normals (long-term averages) because of rounding differences.

It is important to note that the monthly and annual temperature and precipitation normals and standard deviations for 1931 - 1960, 1941 - 1970, 1951 - 1980, and 1961 - 1990 for some divisions may differ from the corresponding normals and standard deviations printed in earlier editions of *Climatography of the United States, No. 85*. This is due to two reasons. First, station data were *not* adjusted for inhomogeneities in the 1931 - 2000 release. Second, the composition of the divisional data base changed in the 1980s due to the need to include corrected and late station reports. These updates made for a more complete and accurate release of values in the 1931 - 1990 publication, in which difference from previous publications were indicated with an comparison indicator flag ('*').

The 1931 - 2000 release includes supplemental divisional data for Hawaii. Hawaiian hydrological divisions were included in the data set to better summarize the impact of varied topography and the locations of the observation stations in Hawaii on highly localized precipitation patterns. These patterns are at a finer resolution than the island-by-island climate divisions. Research by the National Weather Service's Hydrometeorological Design Studies Center (NOAA, 2002) has led to the establishment of regional divisions for precipitation frequency studies. Data based on these divisions are included in the publication *Climatography of the United States, No. 85* at the end of the precipitation section.

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