Normals Calculation Methodology 2020

The science and methodologies used to generate official climate normals for the United States were well established during the creation of the 1981-2010 U.S. Climate Normals. At that time, a team of NCEI researchers spent considerable time and effort improving and automating processes to calculate normals, especially with regards to daily and hourly normals. The 19812010 normals methods are documented in a series of five peer-reviewed publications (Applequist et al. 2012; Arguez et al. 2012; Arguez and Applequist 2013; Durre et al. 2013; Durre and Squires 2015).

With the effort to build conventional normals for 1991-2020, the same methodologies and basic algorithms were followed. Therefore, it was appropriate to place the technical reports for the previous effort in Appendix_I in this document, as this work forms the basis of the 2020 U.S. Climate Normals Project.

In 2017, the document *WMO Guidelines on the Calculation of Climate Normals (No. 1203)* was released. The *Guidelines* largely agreed with the overall approach taken by NCEI in generating climate normals and provided tolerance for certain variations in criteria and methods applied by WMO Member countries. However, there were some meaningful redirections regarding calculations that led to a number of small changes in the current NCEI normals calculation software. In addition, there were some user requests to change some calculations and produce new normals variables. Therefore, this document will describe the changes made to the previously approved methodologies in preparation for generating the 1991-2020, and 20062020, U.S. Climate Normals for stations.

Four types of changes will be described. First, a number of technical changes were made to existing calculations to incorporate the updated WMO guidelines, and still more changes were made to accommodate new compilers and improved coding approaches. Second, some alterations were made to the consideration of station completeness and the flags used to describe it. Third, additional variables and changes to calculated statistics were introduced. Fourth, output formats for the normals were adapted to modern technology, the requirements of NCEI's Data Access Branch, and the needs of the product's primary users in the National Weather Service.

Technical Calculation Changes

One of the primary changes to calculations involved the adoption of Banker's rounding, where a decimal value ending in 5 rounds to the nearest even integer. Calculations are performed in the original metric units of the source GHCN datasets. Numbers are retained at machine precision until rounding is performed for the final output. Users may notice small apparent inconsistencies between different normals variables that result whenever any rounding is applied. For example, the reported average temperature normal may not be identical, but within rounding error, of the sum of the corresponding maximum and minimum temperature normals.

Two methodological changes affect the calculation of monthly, seasonal, and annual counts of threshold exceedances. First, as stipulated by the updated WMO guidelines, an average monthly count is now calculated using the following procedure: (1) counting the number of exceedances in each year/month, (2) converting these counts to percentages of the total number of observations in each year/month, (3) averaging these percentages to obtain a climatological average percentage for each calendar month, and (4) multiplying the climatological percentage by the maximum number of days in the month. For records with significant within-month data gaps, this change in methodology can yield a significantly different result compared to the 1981-2010 method. In most cases, however, the two methods provide very similar results. Second, in the previous normals cycle, daily values were constrained to agree with the homogenized monthly temperature data before counts were made. The NWS requested that we go back to simply counting the raw exceedances as was done in the past, and this change was agreed to by NCEI.

Further, following James and Arguez (2015), a slight correction was made to the algorithm for calculating daily temperature range (DTR) that results in small differences in the calculated values compared to the previously-used method.

Another rule adopted from the WMO is that each month is treated equally in calculating seasonal and annual averages; they are not weighted by the length of month. Monthly values of most variables are output to one decimal place in customary units, except for precipitation reported to the nearest hundredth of an inch, as illustrated in Table 1. A final technical decision involved allowing normals that are close to zero and round to zero to be written as 0.0 or 0.00 and accompanied by a new flag to indicate this situation, rather than placing a large negative integer in the output as was done for the 1981-2010 normals.

Table 1. Precision of final output for variables in Customary and metric units.

F° - 1	Examples: 71.1, -10.2
inches - 2	Example: 0.00, 0.01, 0.02, 0.14, 1.34, 18.46
counts - 1	Example: 11.3, 45.5, 97.1 (days/month)
C° - 1	Example: 12.3, -9.7
mm - 1	Example: 0.1, 9.4, 15.5

The calculation of percentiles was also changed to match the WMO *Guidelines*. The recommendation was to calculate a value with a fractional rank by using linear interpolation between the integer values on either side (for example, the 6.8-th ranked value is calculated as (0.2 × sixth ranked value + 0.8 × seventh ranked value)). This was important as many percentile thresholds in a 30-year period are fractional.

Flags for Normals

As in the 1981-2010 normals, a flag is used to indicate the completeness of the underlying data and the consequent calculation method used. For the 2020 normals, three substantial changes were made to this flag. First, in the updated WMO guidelines, the definition for a "standard" normal (flag "S") were loosened, now requiring that 24 years (or 80%) of a 30-year period needed to be available. In the 2006-2020 normals, "S" indicates that at least 12 years are available. Second, rather than identifying normals based on entirely complete records with a "C" flag, the "S" flag is now also used when all 30 years are available. Third, the flag identifying socalled estimated normals, also referred to as quasi-normals or pseudonormals, was changed from "Q" to "E".

According to the WMO guidelines, a minimum of 10 years is required for calculating any normal. Using the same convention as in the 1981-2010 normals, 1991-2020 and 2006-2020 normals that meet this criterion, but cannot be considered WMO standard normals, are identified as Representative, "R", when values in missing years can be filled in and as Provisional, "P", when such filling is not possible. Gap filling, which uses regression relationships with nearby stations, is only applied to monthly temperatures and precipitation when sufficient suitable neighboring stations are present. The "E" flag is used when stations do not meet the minimum WMO requirement, and statistical methods can be applied to estimate the normal from surrounding stations.

The possible values of the completeness flag are summarized in Table 2.

Table 2. Completeness Flags for Normals.

S Standard - meets WMO standards for data availability for 24 or more years

R Representative - meets WMO standards for data availability for 10 or more years, but not for 80% completeness; gaps in monthly temperature or precipitation are filled in

P Provisional - meets WMO standards for data availability for 10 or more years; gap filling not possible or not applicable

E Estimated - meets WMO standards for data availability for 2 or more years for all months (nearby stations with "P", "R", or "S" normals are available to estimate normals)

In previous normals cycles, NCEI represented a variety of special conditions using large negative integers. In this cycle, it was decided to treat these conditions with a new calculation flag and appropriate assignment of 0 or -9999 (missing) to the variable field, as noted in Table 3.

Table 3. Calculation Flags

Flag	Former Code	Meaning
M	-9999	Missing
W	-8888	Not Used in 2020
X	-7777	Nonzero value that rounds to zero
Y	-6666	Not enough values to perform a computation
Z	-5555	Zero value is inconsistent with another parameter or value is set to zero to be consistent with other calculations

<u>New and Changed Normals Variables</u>

The WMO *Guidelines* called for production of precipitation quintiles, and some in the user community requested precipitation terciles, so values were calculated at 20th, 40th, 60th, 80th, 33.3rd and 66.7th percentiles, in addition to the traditional 25th, 50th, and 75th percentiles, or quartiles.

The other area of change involved the introduction of new thresholds for daily, monthly, seasonal, and annual frequencies. Some metric thresholds following the recommendations of WMO (2017). These included several high thresholds that were also added to the set of Customary units thresholds. The new sets of thresholds are listed in Tables 4 and 5; native Celsius and Millimeter units for temperature (Table 4) and precipitation (Table 5), respectively. Several larger thresholds were added, too.

Table 4. Temperature thresholds for number of monthly, seasonal, and annual occurrences

Degrees Fahrenheit:
Max Temp: >= 40, 50, 60, 70, 80, 90, 100, and <= 32
Min Temp: <= 0, 10, 20, 32, 40, 50, 60, 70

Degrees Celsius:
Maximum temperature >= 25, 30, 35, 40
Maximum temperature < 0
Minimum temperature < 0

Table 5. Precipitation, snowfall, and snow depth thresholds for daily, monthly, seasonal, and annual frequencies of occurrence.

Precipitation: >= 0.01, 0.10, 0.25, 0.50, 1.00, 1.50, 2.00, 4.00, 6.00 inches
Precipitation: >= 1, 5, 10, 50, 100, 150 mm
Snowfall: >= 0.1, 1.0, 2.0, 3.0, 4.0 5.0, 10.0, 20.0 inches
Snowfall: >= 5, 10, 25, 100, 500 mm
Snow Depth: >= 1, 2, 3, 4, 5, 10, 20 inches

Computational Procedures for the 1981-2010 Normals: Precipitation, Snowfall, and Snow Depth

Preliminary Documentation
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1. Overview

The 1981-2010 U.S. Climate Normals being released by NOAA's National Climatic Data Center (NCDC) during 2011 include a suite of descriptive statistics based on precipitation, snowfall, and snow depth measurements at several thousand stations from across the United States and its Caribbean and Pacific territories. Three groups of statistics are provided: 30-year averages, frequencies of occurrence, and percentiles (Table 1). Thirty-year averages of month-to-date, year-to-date, monthly, seasonal, and annual totals of precipitation and snowfall serve as basic descriptors of a location's climate. Daily relative frequencies and average number of days per month for precipitation, snowfall, and snow depth exceeding various thresholds (e.g., precipitation >= 0.01 inches) provide a starting point for estimating the present-day and future likelihood of those threshold exceedances (Table 2). Finally, percentiles of both daily values and monthly totals offer distributional information that can be useful when placing a particular amount of precipitation or snow into historical perspective.

Table 1. Statistics Produced for the 1981-2010 Normals

Precipitation	Average monthly/seasonal/annual totals
	Average month-to-date totals
	Average year-to-date totals
	Average number of days per month exceeding various thresholds
	Daily relative frequencies exceeding various thresholds
	25^{th}, 50^{th}, and 75^{th} percentiles of monthly totals
	Daily 25^{th}, 50^{th}, and 75^{th} percentiles
Snowfall	Average monthly/seasonal/annual totals
	Average month-to-date totals
	Average year-to-date totals
	Average number of days per month exceeding various thresholds
	Daily relative frequencies exceeding various thresholds
	25^{th}, 50^{th}, and 75^{th} percentiles of monthly totals
	Daily 25^{th}, 50^{th}, and 75^{th} percentiles
Snow Depth	Average number of days per month/season/year exceeding various thresholds
	Daily relative frequency exceeding various thresholds
	Daily 25^{th}, 50^{th}, and 75^{th} percentiles

Table 2. Element Dependent Thresholds for ***Relative Frequency*** **and** ***Number of Days per Month*** **Statistics**	
Precipitation	>= .01”, .10”, .50”, 1.00”
Snowfall	>= 0.1”, 1.0”, 3.0”, 5.0”, 10.0”
Snow Depth	>= 1”, 3”, 5”, 10”

The above-mentioned suite of statistics are referred to as "traditional normals" and are calculated directly from the available data. For active stations whose records are too short for such calculations, average monthly, seasonal, annual, month-to-date, and year-to-date totals are estimated and provided as "quasi-normals".

The remainder of this document describes the procedures used to compute the various parameters. Section 2 provides a brief description of the data and the station selection criteria for traditional normals. The computational procedures for traditional normals are explained in section 3, and a brief description of the quasi-normals is provided in section 4. Figures and other material will be incorporated into a forthcoming Journal article on all of these computations.

2. Data

A. Source data

The statistics are computed from the Global Historical Climatology Network - Daily (GHCN-Daily) data set (Menne et al., submitted). The data in GHCN-Daily originate from more than 20 sources and are processed through a carefully designed suite of quality-control (QC) procedures (Durre et al. 2010). The U.S. component of GHCN-Daily is an integrated version of NCDC's holdings of daily surface observations, including those from the U.S. Cooperative Observer Network (Coop) and the Automated Surface Observing System (ASOS), among others, and thus represents the most complete historical record of daily data for the United States.

For the calculations described herein, 24-hour precipitation totals, 24-hour snowfall totals, and once-a-day snow depth measurements are considered. Data from NCDC's Global Summary of the Day, a GHCN-Daily source based on synoptic messages, are not included in the normals calculations because they tend to be less accurate and apply to 24-hour periods different from the reporting periods in other data sources. Also excluded are data flagged as erroneous by the GHCN-Daily QC system and multi-day accumulations of precipitation and snowfall extending over more than three days.

B. Station selection for traditional normals

In order to be included in the calculations, a station must meet the following criteria:

(1) It must be part of a network operated by the National Weather Service (NWS).

(2) It must be located in one of the 50 U.S. states or on one of the Caribbean or Pacific Islands where the NWS operates stations.
(3) Its record of precipitation measurements not flagged as erroneous by the GHCN-Daily QC system must be sufficiently long and complete to allow for each of the statistics included in the normals to be based on at least 10 years of data during 1981-2010; i.e.,
  (a) each of the 12 calendar months must be complete in at least 10 of the 30 years and
  (b) for each day of the year, there must be at least 10 years in which at least 20 values are available within plus or minus 14 days of that day.
(4) Its entire suite of calculated normals parameters must pass various consistency checks intended to identify stations with significant biases in the data (e.g., snowfall reported as zero rather than missing).

The above data completeness requirements are based on recommendations in WMO (1989) as well as on sensitivity tests conducted for each of the statistics computed.

Since records of snowfall and snow depth observations are not sufficiently complete at all stations that meet the data completeness requirements for precipitation, statistics for these two elements are provided for appropriate subsets of the chosen precipitation stations. As a result, statistics for all three variables are available at approximately 5300 stations, precipitation and snowfall statistics are available for another 1100 stations, and statistics for precipitation alone are provided for a further 1100 stations.

3. Computational procedures for traditional normals

A. Averages

1) Averages of monthly, seasonal, and annual precipitation and snowfall totals

The average monthly, seasonal, and annual totals of precipitation and snowfall require as a first step the computation of monthly totals for each station/year/month. Following WMO (1989), a monthly total is calculated for every station/year/month in GHCN-Daily that is complete when daily values, two-day accumulations, and three-day accumulations are considered. Accumulations that extend from the end of one month to the beginning of another are excluded. February 29 is included in the monthly totals for February in leap years. For precipitation, an attempt is made to fill in monthly totals that are missing during the normals period using a previously developed method based on median absolute deviation regression relationships between stations and qualifying neighbors. Monthly snowfall totals are not estimated because of the large number of zeros that degrade the quality of the regression relationships in many locations and because of the temperature dependence and larger spatial variability of snowfall compared to precipitation. A description of the estimation procedure is provided in the appendix.

For each calendar month, the average monthly total then is the arithmetic mean of all observed and, for precipitation, estimated totals available during the 30-year period. Thus, any given average can be based on a complete record of observed monthly totals, an incomplete record of observed monthly totals when estimates could not be produced, or, in the case of precipitation, a record that is complete when both observed and estimated values are considered.

Also provided are average totals for the year as well as for the seasons of December-February, March-May, June-August, and September-November. Seasonal and annual averages are obtained by summing the appropriate average monthly totals.

2) Average month-to-date and year-to-date totals

Average month-to-date and year-to-date totals of precipitation and snowfall are calculated from daily data in complete months, smoothed to reduce spurious variations in day-to-day increases, and scaled to match the corresponding average monthly totals described in the previous section. Specifically, the procedure works as follows:

First, for each calendar month, those years are identified during which daily precipitation observations are available for the entire month. For each day (*i)* of the month, "raw" average month-to-date totals are obtained by summing the daily precipitation measurements between day 1 and day *i* of the month across all qualifying years and dividing the resulting grand sum by the number of qualifying years. (February 29 is excluded from this calculation.) The results directly reflect the available data, but have two shortcomings:

> (a) Sampling variability results in significant short-term variations in the day-to-day increases in month-to-date totals.
>
> (b) The end-of-month totals may not match the corresponding average monthly totals described in the previous section which are based not only on daily precipitation observations, but also on two-day and three-day accumulations and estimated monthly totals.

These issues are addressed by the subsequent smoothing and scaling steps.

In preparation for smoothing, raw average year-to-date totals are formed by summing the average month-to-date totals accordingly. For example, the year-to-date total for March 26 is the sum of the end-of-month total for January, the end-of-month total for February, and the month-to-date total for March 26. The resulting average year-to-date totals are then further aggregated into three-year-to-date totals in order to allow for smoothing across the beginning and end of the year. A 29-day running mean is then applied to the three-year series before the middle of the three years is disaggregated again into smoothed average month-to-date totals. The 29-day filter was chosen after testing various shorter running means and was found to remove variations that are likely to be the result of sampling variability while preserving changes in the rate of increase on the time scale of weeks such as those seen during the onset of the southwest monsoon. Although the smoothing may significantly change the average end-of-month total, this effect will be eliminated by the subsequent scaling step.

Finally, the smoothed average month-to-date totals are scaled to match the corresponding average monthly totals in order to achieve consistency between the two statistics. In most cases, this is done by multiplying the month-to-date total for each day of the month by the ratio of the average monthly total to the month-to-date total on the last day of the month. However, two cases need to be addressed in which this "ratio scaling" does not apply:

> (a) If the average month-to-date total at the end of the month and the average monthly total both equal zero, no scaling is necessary because the statistics already match. This situation most commonly arises for snowfall during the snow-free season. For precipitation, it only arises at a few locations in the Southwest during summer months.
>
> (b) If the average month-to-date total at the end of the month is zero, while the average monthly total is greater than zero, the average month-to-date total is set equal to the average monthly total on the last day of the month and set to zero on all other days of the month. This was found to occur only once for snowfall when the average monthly total was equal to 0.1 inches due to the inclusion of months containing two-day and three-day accumulations which are not considered in the month-to-date totals.

B. Frequencies of occurrence

The frequencies of occurrence of several types of events (Table 2) are expressed in terms of two quantities: (1) average (or expected) number of days per month, season, and year on which the event occurs and (2) relative frequencies of occurrence (in percent of available values) during 29-day windows centered on each day of the year. The daily relative frequencies are intended as a supplement to the monthly frequencies that provides an indication of major changes in relative frequency within a month, such as the increase in the frequency of precipitation during the onset of the southwest monsoon at stations in the southwest.

1) Average number of days per month, season, and year

For a particular station and calendar month, the expected number of days per month on which precipitation, snowfall, or snow depth exceed a specific amount is calculated as follows:

First, all years are identified in which the daily observations of the element of interest are missing on nine or fewer days of the month. In other words, up to approximately 1/3 of the month is allowed to be missing. Next, for each of the qualifying years, the number of days on which the variable of interest is greater than or equal to the specified threshold (e.g., precipitation >= 0.01 inches) is counted. Third, the counts for each year are summed, and the result is divided by the total number of days with data in the qualifying years to obtain the probability of the threshold exceedance for the calendar month. This relative frequency is then multiplied by the number of calendar days in the month to obtain the corresponding expected number of days per month on which the threshold is exceeded. (For February, the number of calendar days in the month is set to 28+7/30 to account for the seven leap years during 1981-2010.)

Assume, for example, that the average number of days with precipitation >= 0.01 inches during January is to be calculated. If only 25 days are available in one of the years during January, and January is complete in all other 29 years, the total number of days available would be 29 years*31 days + 25 days = 924 days. If 308 of those days have precipitation >= 0.01 inches, then the probability of this event during January would be 308/924, or 0.33, and the event would be expected to occur on an average of 0.3333*31, or 10.33, days during the month.

2) Daily relative frequencies of occurrence

The relative frequencies for each day of the year are calculated in a manner that is consistent with the computation of monthly frequencies. In this case, however, the values are chosen from a 29-day window centered on each day of the year, and the frequency is expressed as a percent of available values. Specifically, the computation works as follows:

> a) For each day of the year except February 29, an empirical relative frequency is first calculated using data from all years that have values on at least 20 of the 29 calendar days within the applicable window. For example, if the relative frequency of measurable precipitation is to be computed for January 1, data for 2010 are used if there are at least 20 values available during January 1-15 and December 17-31 of that year. The pool of values considered then consists of all available values on those 29 days during all qualifying years, and the relative frequency is equal to the percentage of values within the pool that are greater than or equal to 0.01 inches.
>
> b) Due to the limited sample size, the relative frequency for February 29 is not calculated directly. Rather, it is set to the average of the frequencies for February 28 and March 1.
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> c) In order to reduce short-term fluctuations in the resulting frequencies that are likely to be associated with sampling variability, the empirical frequencies are smoothed with a 29-day running mean. After several other types of filters as well as shorter running means had been tested, this particular filter was found to yield the desired level of smoothing while retaining variations on the time scale of weeks.

For a particular station and element, relative frequencies are produced only if there are at least 10 qualifying years for each of the 365 windows. The 29-day window was chosen to increase the sample size from what it would be if only the values reported on the calendar day of interest were considered; with a minimum of 20 values in at least 10 years, each frequency is calculated from at least 200 values.

C. Percentiles

Since precipitation, snowfall, and snow depth follow distributions that are positively skewed, the medians and quartiles of both monthly totals and daily observations are also provided as an indication of the variability of these values. The percentiles of monthly precipitation and snowfall totals are calculated for each calendar month. The same percentiles are also computed within moving 29-day windows centered on each day of the year for precipitation on days with measurable precipitation, for snowfall on days with measurable snowfall, and for snow depth on days with snow on the ground.

1) Medians and quartiles of monthly totals

For each calendar month, all available monthly totals (including estimates in the case of precipitation) are sorted from lowest to highest, and the lower quartile (i.e., 25th percentile), median (50th percentile), and upper quartile (75th percentile) are calculated following standard procedures. If values from all 30 years are available, then the lower quartile is the eighth lowest value, the median is the average of the 15th and 16th lowest values, and the upper quartile is the 23rd lowest value. The calculation is performed only if there are at least 10 values available for the calendar month, a condition that is ensured by the station selection criteria described in section 2b above.

2) Medians and quartiles of nonzero daily observations

Percentiles are calculated for a station, element, and day of the year using the same pool of values from which the daily relative frequencies are produced, and the same level of smoothing is also applied. However, since the percentiles are based only on nonzero values, some additional considerations are required with a sample of these values is limited as is the case when the climate is dry or snow is rare. A full description of the procedure follows.

> a) For each day of the year except February 29, an empirical percentile is first calculated using data from all years that have values on at least 20 of the 29 calendar days within the applicable window. The nonzero amounts within this set of values are sorted from lowest to highest, and the median and quartiles are identified as described for monthly totals in the previous subsection. If not at least 10% of the chosen values are nonzero, the median and quartiles for that day of the year are set to missing at this stage.
>
> b) The median and quartiles for February 29 are set to the average of the corresponding percentiles for February 28 and March 1.
>
> c) The resulting sets of medians and quartiles are each smoothed with a 29-day running mean. Since percentiles may only have been calculated for parts of the year, the running mean is not always based on the full 29 days: In order to allow for the smoothing of even those percentiles that directly precede or follow a time

of the year during which percentiles are missing, the running mean is calculated whenever percentiles are available on at least 15 of the 29 days; percentiles that cannot be smoothed in this manner are set to missing.

d) Some additional steps are taken to address the potentially discontinuous nature of the resulting percentiles in relatively dry and relatively snow-free regions. First, gaps in the percentiles that are shorter than 15 days are filled in using linear interpolation between the corresponding percentiles immediately preceding and following the gap. Second, for a particular station and element, the resulting set of percentiles is retained only if there is a continuous stretch of (empirical and interpolated) percentiles that is at least 30 days long. Third, any remaining continuous stretches of percentiles shorter than 15 days are removed. Two final cosmetic steps are taken to address some special cases. The entire set of precipitation percentiles for a particular station are retained only if they contain no more than two gaps after the preceding three steps. In addition, at locations in the northern Great Plains, mid-winter gaps in snowfall percentiles are filled in using linear interpolation even when they extend over more than two weeks since the percentiles before and after the gap typically do not differ much from each other.

As a result of all of the above steps, precipitation percentiles are provided at approximately 5900 locations year-round as well as at another 1600 stations where precipitation is sufficiently frequent only during part of the year. Percentiles of snowfall in snow depth are available during the central portions of the snow season at approximately 2500 and 2600 stations, respectively.

4. Quasi-normals

A subset of the statistics described in the previous section are provided for approximately 1800 active stations whose precipitation records did not meet the completeness requirements for the traditional normals. Although the statistics are not expected to be as accurate as those based on more complete records, they are intended as guidance for a basic assessment of the precipitation climatology at NWS and Climate Reference Network (CRN) stations that were operational in 2010 end for which no statistics would otherwise be available.

The "quasi-normals" are available for precipitation only (not snowfall or snow depth) and include the following parameters:

- Estimated average monthly totals, or "pseudo-normals," computed closely following the neighbor-based estimation approach of Sun and Peterson (2005, 2006);
- seasonal and annual totals calculated from the monthly pseudo-normals as described in Section 3a above; and
- average month-to-date and year-to-date totals computed from the daily data and scaled by the monthly pseudo-normals in a manner analogous to the method described in Section 3b.

For quasi-normals, a less restrictive completeness requirement applies than for traditional normals: All 12 calendar months must have complete precipitation records in at least two, rather than 10, of the years between 1981 and 2010. However, the station must also report at least one precipitation total during 2010 in order to be considered "active." a final selection criterion is imposed by the pseudo-normals methodology: In order to be able to calculate monthly pseudo-normals, a station must have at least 10 neighbors within 500 km for which traditional normals are available. This number is close to the 11 neighbors used by Sun and Peterson (2006). As a result of these criteria, quasi-normals are available for 1741 NWS stations and 84 CRN stations.

Appendix: procedure for estimating monthly precipitation totals

The estimation procedure works as follows:

Regression relationships are developed separately for every station/calendar month for which such estimation is necessary, using all available monthly totals during the normals period that overlap with qualifying neighbors. Neighboring stations used are not required to be located in the United States or its territories and do not have to meet the network affiliation criteria for inclusion in the normals, thus increasing the possibility for estimates in border areas, on islands, and in data-sparse regions. However, when estimates are required for a particular target station and calendar month, qualifying neighbors have to meet the following criteria: (1) they must be located within 500 km of the station for which the estimates are to be produced; (2) they must have at least 10 monthly totals for that calendar month during the normals period that overlap with totals available at the target station; and (3) they must have monthly totals during all years for which an estimate is needed at the target station for that particular calendar month.

Qualifying neighbors are sorted in order of descending index of agreement between their monthly totals for the calendar month of interest and overlapping monthly totals at the target station. The index of agreement provides a measure of similarity in terms of both correlation and amplitude.

A regression model and accompanying estimates are then developed as follows. The neighbor with the highest index of agreement is used to develop a regression model. Next, the neighbor with the second highest index of agreement, if available, is added, and a two-neighbor regression model is established. If the estimates based on the two-neighbor model has a lower index of agreement with the available monthly totals at the target location than the one-neighbor model, the one-neighbor model is used. If the two-neighbor model is in better agreement than the one-neighbor model, the neighbor with the third-highest index of agreement is added, and a three-neighbor model is developed. This iterative procedure continues until no more qualifying neighbors are available or the maximum allowable number of neighbors has been reached. The maximum number of neighbors allowed depends on the number of observations at the target but cannot exceed five. (Any negative precipitation estimates are set to zero for each model developed before its agreement with the observations is evaluated.)

Estimates are not produced for a particular station and calendar month if any of the following conditions apply: the monthly totals at the target station are all equal to zero, thus making the development of a regression relationship impossible; there are no qualifying neighbors; or no valid regression model can be produced because all possible combinations of input data results in degenerate or non-unique solutions. Therefore, there are some stations whose record of monthly totals is not complete for all calendar months even after the attempt to estimate the missing monthly totals.

The requirement of a minimum number of 10 years of overlap for the development of regression models is chosen to be consistent with the minimum completeness requirement for inclusion in the normals products. Increasing the minimum number of years required to 15 decreases the number of stations for which estimates can be produced by about 15% and yields only a slight improvement in the error statistics.

The neighbor search radius of 500 km leaves only a few island stations for which no suitable neighbors can be found. Increasing the radius to 1000 km does not yield estimates for those stations. At the same time, sensitivity tests suggest that smaller radii (75, 150, or 225 km) would increase the number of stations and calendar months without estimates and slightly increase the overall error in the estimates.

References

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NOAA's 1981-2010 Climate Normals
Methodology of Temperature-related Normals

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Overview

This report describes the methodology used to compute daily, monthly, seasonal, and annual normals for numerous temperature-related variables at about 7,500 weather stations for the 1981-2010 Normals period. A climate normal is typically defined as a 30-year average of an atmospheric quantity, such as maximum temperature. However, advanced statistical techniques are used to account for missing data values, inhomogeneities, station moves, etc. and therefore the normals presented here are much more than 30-year averages. This report offers a preliminary description of all procedures used to compute the new normals for temperature-related variables. We intend to submit a journal article on this matter which, if and when accepted, would replace this report as the authoritative reference for the computations done on temperature-related variables for the 1981-2010 Normals. For information regarding precipitation-related normals or hourly normals (including hourly temperature normals), please review the accompanying documentation.

Source Data

The underlying values used to compute the 1981-2010 Normals come from the Global Historical Climatology Network - Daily (GHCN-Daily) dataset (Menne et al., submitted). As its name suggests, this dataset contains daily observations for many atmospheric variables worldwide, and is the most comprehensive set of daily climate data for the United States. The data values have undergone extensive quality control (QC) as described by Durre et al. 2010. The backbone of the stations used in the 1981-2010 Normals come from the U.S. Cooperative Observer Network. First Order stations as well as the U.S. Climate Reference Network are also included, however we do not report climate normals for CoCoRaHS stations.

As described by Menne and Williams (2009) and Menne et al. (2009), NCDC provides monthly temperature data values that have undergone robust quality control and standardization at the monthly timescale. For the 1981-2010 Normals, the approaches described in these papers were applied to monthly maximum and minimum temperature values that were in turn computed from GHCN-Daily values. Monthly values were computed for station-months for which no more than nine missing or suspect daily values were present in GHCN-Daily. The standardization procedures account for both documented and undocumented station moves and other changes in observing practices. Therefore, we give precedence to normals computed from monthly temperature data.

Product Portfolio

The temperature-related products in the 1981-2010 Normals are listed in Table 1. Normals of maximum, average, and minimum temperature; diurnal temperature range; and heating and cooling degree days are provided at the daily, monthly, seasonal, and annual timescales. Part of the standardization performed on monthly temperature values involves application of a time of observation (TOB) adjustment that strives to make it as if the observations at a particular station had been taken at local midnight. We adjust the Normals back to local observation time, but also provide the midnight observing time offsets. Standard deviations of monthly mean temperatures as well as daily temperature values are also reported. Finally, we also provide "count" normals at the monthly, seasonal, and annual timescales. These are parameters such as the normals of the number of days in July where the maximum temperature exceeds 90F.

Table 1. **Temperature Normals Released July 1, 2011**

Daily	Tmax, Tmin, Tavg, DTR
	Heating and Cooling Degree Days
	Standard Deviations
Monthly	Tmax, Tmin, Tavg, DTR
	Midnight observing time offsets
	Heating and Cooling Degree Days
	Count Normals
	Standard Deviations
Seasonal	Tmax, Tmin, Tavg, DTR
	Heating and Cooling Degree Days
	Count Normals
Annual	Tmax, Tmin, Tavg, DTR
	Heating and Cooling Degree Days
	Count Normals

Table 1 only shows the normals that will be released July 1, 2011. Later installments of the 1981-2010 Normals will provide several other product classes. This includes agricultural related climate normals such as frost/freeze dates and growing degree days; all normals that require gridding or aggregation including at the climate division level; as well as any climate normals that involve population data such as our population-weighted monthly heating and cooling degree day product.

For the vast majority of stations, we compute the normals using a "traditional approach" that uses 30 years of data wherever possible. However, for about 1100 short-record stations, we employ a "pseudonormals" approach as described by Sun and Peterson (2005). These pseudonormals are based on linear combinations of the normals from neighboring stations computed using the traditional approach. In this report, we focus on the traditional approach. For more information about the pseudonormals approach, please consult the Sun and Peterson (2005) paper.

Computation of Tmax, Tmin, Tavg, and DTR Normals and Standard Deviations

As described earlier, we give precedence to monthly temperature values and therefore first compute monthly normals of maximum and minimum temperature (see the flowchart in Figure 1). Missing or suspect monthly values are filled using a regression technique based on index of agreement with neighboring values. For more information on the filling analysis, please consult the accompanying precipitation methodology. Once we arrive at filled monthly values for all 30 years, the monthly normals of maximum and minimum temperature are computed as the simple averages of the 30 values for each station-month. We report a completeness flag with each normals value describing the relative completeness of each data record (before filling). The completeness criteria are an extension of the guidelines provided by the World Meteorological Organization (WMO 1989). The monthly average temperature (diurnal temperature range) normal is computed as the mean (difference) of the monthly maximum temperature normal and the monthly minimum temperature normal. We also compute the standard deviations across the 30-year period for the four variables.

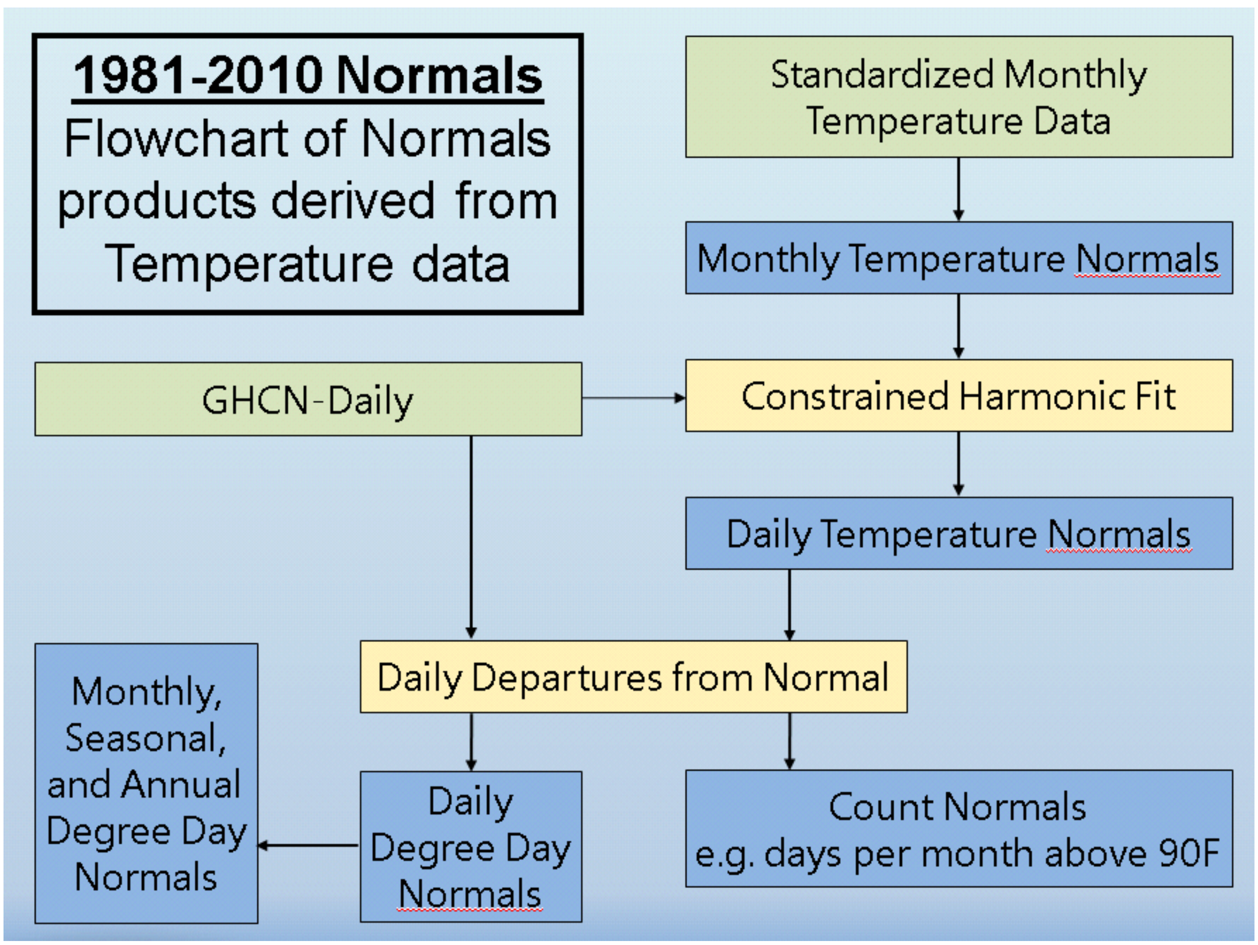

Figure 1. Flowchart of temperature-derived climate normals. Monthly temperature values are given precedence. Datasets are shown in green, methods are shown in orange, and products are shown in blue.

The computation of daily normals of maximum and minimum temperature involves a constrained harmonic least squares fit. We begin by first computing the "raw" daily normals from GHCN-Daily. Let $y(t)$ represent the *raw* daily normals:

$$y(t) = \frac{1}{30}\sum_{k=0}^{29} x(t + 365k) \qquad (1)$$

Here, t ranges from 1 to 365. For Julian days where there are less than 10 non-missing and non-suspect values from 1981-2010, we use a windowing technique as needed to yield at least 10 values for the average. We can model the daily temperature normals function as a linear combination of harmonics. As described in Wilks (2006), a single harmonic can sometimes provide a reasonable representation of the annual cycle, but additional harmonics are needed in order to account for features that deviate from a single sinusoidal shape, such as asymmetries between summer and winter, or between transition seasons. On the other hand, over-fitting must be guarded against as well. The equation for the harmonic fit, $h(t)$, is as follows:

$$h(t) = A_0 + \sum_{k=1}^{M}\left[A_k \cos(\omega_k t) + B_k sin(\omega_k t)\right] \qquad (2)$$

where t ranges from 1 to N=365 and $\omega_k = 2\pi k/N$. If $M=N$, then $h(t)=y(t)$; if $M<N$ then $h(t)$ represents a smoothed version of $y(t)$. If no constraints are applied, we can solve for the coefficients in (2) via least squares minimization of the following cost function:

$$J_u(\vec{A},\vec{B}) = \sum_{t=1}^{N}\left[y(t) - A_0 - \sum_{k=1}^{M}\left[A_k \cos(\omega_k t) + B_k sin(\omega_k t)\right]\right]^2 \qquad (3)$$

Setting partial derivatives to zero, we have $2M$+1 equations and $2M$+1 unknowns. This system of linear equations can be solved fairly easily using singular vector decomposition (SVD) to arrive at the coefficients (A_0, A_1, B_1, etc.). The coefficients are then plugged into (2) to define the unconstrained harmonic fit. However, because we give precedence to the monthly temperature values, we need to constrain the coefficient values such that the mean monthly normals are consistent with the means of the daily normals for a particular month. Therefore, we need to impose 12 constraints, one for each month:

$$J_c(\vec{A},\vec{B},\vec{\lambda}) = \sum_{t=1}^{N}\left[h(t) - A_0 - \sum_{k=1}^{M}\left[A_k \cos(\omega_k t) + B_k sin(\omega_k t)\right]\right]^2 \qquad (4)$$

$$+\lambda_{jan}\left[T_{jan} - A_0 - \frac{1}{31}\sum_{t=1}^{31}\sum_{k=1}^{M}[A_k\cos(\omega_k t) + B_k sin(\omega_k t)]\right]$$

$$+\lambda_{feb}\left[T_{feb} - A_0 - \frac{1}{28}\sum_{t=32}^{59}\sum_{k=1}^{M}[A_k\cos(\omega_k t) + B_k sin(\omega_k t)]\right]$$

$$\dots +\lambda_{dec}\left[T_{dec} - A_0 - \frac{1}{31}\sum_{t=335}^{365}\sum_{k=1}^{M}[A_k\cos(\omega_k t) + B_k sin(\omega_k t)]\right]$$

T_{jan} is the monthly temperature normal for January, T_{feb} is the monthly temperature normal for February, etc. The λ terms are Lagrange multipliers that impose the constraints. Now, setting partial derivatives to zero, we have 2M+13 equations and 2M+13 unknowns. Once again, we can solve this linear system of equations using SVD.

In order for the constraint to be imposed exactly, M must be greater than or equal to 6. Otherwise, there are more constraints than coefficients. However, to guard against over-fitting, we need to restrict the number of harmonics. Therefore, **we set *M* to 6 for all computations.** Daily maximum and minimum temperature normals are computed in this fashion. As before, the average temperature and DTR normals are derived from these.

To compute the standard deviations of daily temperature values, we use a 15-day window about the centered Julian day. In practice, this results in a time series of at least 100 good data values. We then simply take the standard deviation of these values. To smooth out considerable noise in these estimates, we employ a running 29-day equal-weight filter. Note that standard deviations (both monthly and daily) are not computed for pseudonormal stations.

Computation of Heating and Cooling Degree Day Normals

The 1971-2000 climate normals of monthly heating and cooling degree days (HDD/CDD) were originally computed for all stations using a modification of the Thom Method (Thom 1954; Thom 1966), which is based on monthly means and standard deviations. Daily degree day normals were computed as a spline fit through the monthly degree day values. After receiving feedback from NWS and industry, it was decided that HDD/CDD calculations for 1971-2000 would be done 'directly' for the first-order stations for which relatively complete daily records were available. For 1981-2010, we compute degree days in a 'more direct' fashion for all stations, leveraging off of the improvements to the daily temperature normals.

For computation of degree days, we utilize the daily mean temperature normals for a particular station, which is ultimately derived from the constrained harmonic fit analysis described above. The key step is to estimate the spread of daily temperature values about the daily normal. This is critical since the definition of HDD/CDD is constructed as an asymmetric sum. Let us first consider this definition. Suppose $T_j(t)$ represents 30 mean temperature values, one for each year from t=1981 to t=2010, for a particular Julian day j, which ranges from 1 to 365. H_j and C_j represent the daily heating and cooling degree days, respectively, as follows:

$$H_j(t) = \left\{\frac{0 \; if \; T_j(t) > 65F}{65F - T_j(t) if \; T(t)_j \leq 65F}\right\} \quad (5)$$

$$C_j(t) = \left\{\frac{0 \; if \; T_j(t) < 65F}{T_j(t) - 65F \; if \; T(t)_j \geq 65F}\right\} \quad (6)$$

The most direct way to compute daily normals of H_j and C_j would be to average the 30 annual values for each j. That poses three major issues: (1) the normals would be quite noisy, (2) missing values would have to be accounted for somehow, and (3) the HDD/CDD normals would not be consistent with the daily mean temperature normals which are consistent with the monthly values. Since we already know the daily mean temperature normal from the harmonic analysis, we just need an estimate of the distribution about this average to estimate the daily HDD/CDD normals, preferably in such a way that smoothes out sampling variability.

Analogous to the approach for daily standard deviations, we use a 15-day window centered on j (and allowing it to extend across the beginning/end of the year) across all 30 years, for a maximum distribution of 450 values. The anomalies with respect to the distribution mean are computed for all non-missing values, and then the corresponding daily mean temperature normal is added to each of these anomaly values. Then, the individual HDD/CDD values are computed following the equations above. Finally, these values are averaged (over the number of non-missing values in the window) to arrive at a normal value of HDD/CDD for that Julian day. This process is repeated for all Julian days. These daily normals are smoothed lightly using up to 11 passes of a 1-2-1 filter (the number of passes is based on the time series). Monthly HDD/CDD normals are computed by summing up the corresponding daily normals. Annual HDD/CDD normals are computed as the sums of the 12 monthly values.

Computation of Count Normals

Count normals, such as the number of days per month in which the minimum temperature drops below 32F, is computed using an analogous windowing strategy as that used for standard deviations and HDD/CDD, except that instead of a centered window we use the days in a given month. All available daily values are adjusted such that the daily average for each day is equal to the relevant daily temperature normal. The percentage of values that meet the particular criterion (e.g., tmax greater than 70F) is calculated, and that percentage is scaled to account for missing values and arrive at the count normal for that month. From the monthly values, seasonal and annual count normals are computed.

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NOAA's 1981-2010 Climate Normals: Supplemental Normals

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Introduction

This report describes the methodology used to compute supplementary products to the 1981-2010 NOAA Climate Normals that were released in July 2011 (Arguez et al. 2012). These new "supplemental normals" consist of four additional normals products: (1) growing degree day normals, (2) frost-freeze date probabilities, (3) probabilities of frost-freeze occurrence, and (4) growing season length normals. Because these products are most commonly utilized by farming interests, they are often referred to collectively as "agricultural normals", although they are utilized in many other industries including, but not limited to, construction, architecture, and pest control. This report offers a preliminary description of all procedures used to compute these products. A journal article on this topic is currently being drafted. If published, the journal article would replace this report as the authoritative reference for the computation of NOAA's 1981-2010 Supplemental Normals.

Source Data

The underlying values used to compute the 1981-2010 Supplemental Normals come from the Global Historical Climatology Network - Daily (GHCN-Daily) dataset (Menne et al., 2012). The data values have undergone extensive quality control (QC) as described by Durre et al. 2010.

Homogenized Monthly Temperature Data

Even though GHCN-Daily goes through rigorous quality control, it is not homogenized like the monthly temperature dataset. As described by Menne and Williams (2009) and Menne et al. (2009), NCDC provides monthly temperature data values that have undergone robust quality control and standardization at the monthly timescale. For the 1981-2010 Normals, the approaches described in these papers were applied to monthly maximum and minimum temperature values that were in turn computed from GHCN-Daily values. The standardization procedures account for both documented and undocumented station moves and other changes in observing practices. The new Supplemental Normals are calculated such that they are consistent with the homogenized monthly temperature data.

Serially-Complete Daily Minimum Temperature Data

Frost-freeze date probabilities and growing season length normals are based on the first and last "killing freeze" of the growing season. A killing freeze is essentially a cold snap that hinders plant growth; the temperature threshold varies from one plant species to another. In order to compute these values, missing daily minimum temperature values must be accounted for. Very few stations (<5%) have complete daily minimum temperature data over any thirty year period,

including 1981-2010. Missing values occur either because no observation exists in our records, or because an observation was flagged as erroneous by the GHCN-Daily QC.
We fill in missing values using a simple anomaly-based approach. For each missing value in a station's daily time series from 1981-2010, the five nearest neighbors whose daily observations are non-missing are identified. Anomalies are computed by taking each of the five minimum temperature observations and subtracting each station's daily temperature normal for that day of the year. Then, the mean of the five anomalies is added to the target station's daily temperature normal for that day of the year.

The serially-complete daily minimum temperature data are adjusted, if necessary, to be consistent with the serially-complete homogenized monthly temperature values used to compute the 1981-2010 Climate Normals released in July 2011. For example, if the 31 daily minimum temperature values from January 2000 average to 45.5F, but the monthly homogenized mean minimum temperature value for January 2000 is 44.5F, the 31 daily minimum temperature values are each reduced by 1.0°F. In relatively few cases, the adjustments result in inter-month discontinuities. These discontinuities are suppressed using an iterative smoothing approach. This helps ensure that frost-freeze date probabilities are not disproportionately concentrated near the beginning or end of a month.

Bootstrapped simulations

Even with serially-complete daily data from 1981-2010, frost-freeze date probabilities and growing season length normals can be quite “noisy” or “jagged” due to the irregularity of first and last freeze events from year to year. To remedy this, a bootstrapping approach is used to generate 10,000 simulations of the 365-point annual cycle of daily minimum temperature. This results in substantially less “jagged” results, for example, in the frost-freeze date probabilities.

To create each simulation of 365 daily values, 12 segments of daily minimum temperature values for each month are pieced together. There are three randomized components: (1) the year from which each 28-31 day sequence is drawn, (2) an offset of ±14 days in the date the sequence begins, and (3) the monthly mean imposed on the sequence. To guard against implausible simulations, an extremes check and a monthly transition check are utilized. If either check fails, a new sequence is generated.

The resulting 10,000 simulations per station compare favorably with the serially-complete data from 1981-2010. Further, the resulting supplemental normals computed using the simulations versus the 30-year dataset also compare favorably. The primary difference is an increase in statistical confidence (and an associated suppression of jaggedness) of the results from the bootstrapping approach.

The bootstrapped simulations are utilized to compute frost-freeze date probabilities, probabilities of frost-freeze occurrence, and growing season length normals. As explained below, neither the bootstrapped simulations nor the serially-complete minimum temperature values are used to compute growing degree day normals.

Frost-Freeze Probabilities of Occurrence

Frost-freeze probabilities are the likelihood that a given minimum temperature will be experienced at least once during a month or year. Probabilities are calculated for the following threshold temperatures: 16°F, 20°F, 24°F, 28°F, 32°F, and 36°F. For example, there is a 15.7% chance that the temperature will drop to 36°F or below at least one day of the year at Miami (FL) International Airport. These probabilities are calculated as the percentage of the 10,000 simulations in which the threshold is reached at least once during a particular month or for the full year.

Frost-Freeze Probability Dates

Frost-freeze probability dates represent the likelihood that a given minimum temperature will be experienced before or after a given date. Probability dates are provided for the beginning of the growing season (i.e., the probability that the last spring freeze will occur on or after the specified date) and the end of the growing season (i.e., the probability that the first autumn freeze will occur on or before the specified date). Probability dates are calculated for the following threshold temperatures: 16°F, 20°F, 24°F, 28°F, 32°F, and 36°F. The probability levels are 10, 20, 30, 40, 50, 60, 70, 80, and 90%. The terms “spring” and “autumn” are used loosely in this sense as not all dates will strictly occur during spring or autumn months for some of the warmer and colder stations across the United States.

The computation of frost-freeze date normals is based on conditional probabilities. This only affects a minority of stations in warmer climates where the probability of occurrence (see example in previous section) is not 100%. The dates represent the probabilities of frost-freeze occurrence before or after the specified date provided the minimum temperature is reached at least once during the cold season. In order to provide frost-freeze date normals, the probability of occurrence must be at least 10%; otherwise the values are shown as the special value -6666, indicating that the minimum temperature is too rare (or never occurs) to compute frost-freeze date normals.

At the other extreme, some stations have some degree of frost-freeze risk year-round. Following NCDC precedent, frost-freeze dates are calculated over the August 1 – July 30 period. Year-round frost-freeze risk occurs for a portion of northern or high elevation stations where reaching the minimum temperature threshold in July or August is not out of the question. Using the 10,000 simulations, a station is given a special value of -4444 if at least one occurrence at or below the minimum temperature threshold is present for each day of the year.

Growing Season Length Normals

Growing season length normals are the likelihood that the growing season (i.e., the number of days between the last spring frost-freeze and the first autumn frost-freeze) will be at least the specified number of days. They are calculated by taking the longest period for each of the 10,000 simulations for which the minimum temperature is above the threshold. Growing season length normals are reported for the same temperature thresholds and probability levels as listed above for the frost-freeze probability dates.

Growing Degree Day Normals

Growing degree days are a measure of agricultural output based primarily on the mean daily temperature (as opposed to the products described above which rely solely on minimum temperature). Computationally, growing degree days are equivalent to cooling degree days, which is a metric of temperature-based cooling demand (primarily in the warm season). For the computation of cooling degree days, see the following documentation:

http://www1.ncdc.noaa.gov/pub/data/normals/1981-2010/documentation/temperature-methodology.pdf

Growing degree days are available for the following base temperatures: 40°, 45°, 50°, 55°, 57°, 60°, 65°, 70°, and 72°F. In addition, growing degree days are provided for a pair of "truncated bases" specifically related to the growth cycle of corn: 48/86 and 50/86. For the 48/86 truncated base computation, minimum temperatures below 48°F are replaced with 48°F, and maximum or minimum temperatures above 86°F are replaced with 86°F. After this adjustment, the growing degree days are computed as they are for the other bases. An analogous computation is done for the 50/86 truncated base.

For more information

To obtain additional information on the 1981-2010 Supplemental Normals or to acquire them, please contact NCDC's User Engagement and Services Branch by sending an email request to NCDC.Orders@noaa.gov or calling 828-271-4800 and selecting option 2.

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Computational Procedures for the 1981-2010 Normals: Hourly Products

Preliminary Documentation
July 1, 2011

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1. Overview

The 1981-2010 U.S. Climate Normals being released by NOAA's National Climatic Data Center (NCDC) during 2011 include a suite of descriptive statistics based on hourly observations at a few hundred stations from across the United States and its Pacific territories. Statistics are provided as 30-year averages, frequencies of occurrence, and percentiles (Table 1) for each hour and day of the year.

We encourage use of these products for examination of the diurnal change of a particular variable. Temperature and precipitation normals created for the daily, monthly, seasonal, and annual time scales are also available.

Table 1. Statistics Produced for the 1981-2010 Hourly Normals	
Temperature, Dew Point, Mean Sea Level Pressure	Average hourly value
	10th and 90th percentiles of hourly values
Heating and Cooling Degree Hours	Average hourly value (base 65°F)
Heat Index and Wind Chill	Average hourly value
Clouds	Hourly percent frequency of clear, few, scattered, broken, and overcast conditions
Wind	Prevailing and secondary wind direction and percent frequency
	Average wind speed and percentage of calm winds
	Mean wind vector direction and magnitude

The above-mentioned statistics are referred to as "traditional normals" and are calculated directly from the available data.

The remainder of this document describes the procedures used to compute the various parameters. Section 2 provides a brief description of the data and the station selection criteria for traditional normals. The computational procedures for traditional normals are explained in section 3. Figures and other material will be incorporated into a forthcoming Journal article on all of these computations.

2. Data

The statistics are computed from the ISD-lite dataset for which more information can be found here: (http://www.ncdc.noaa.gov/oa/climate/isd/index.php?name=isd-lite).

262 stations were selected from the ISD-lite data based on their completeness and membership in a list of what were known as "first order stations." These are typically airport locations with the needed 24 hours/day observations to make hourly normals meaningful. All stations had at least 27 of the 30 years represented.

3. Computational procedures for traditional normals

Data configuration

Each hourly normal is computed on the basis of 450 possible values. This is the aggregation of the value for a particular date and time, plus and minus 7 days, over each of 30 years. If fewer than 350 valid values are present, the output is given as the special value -9999. No normals are computed for February 29, but data for February 29 is included in the 15 day window for leap years. The original data has been shifted from Greenwich Mean Time to an end product in local standard time.

Quality control

The following conditions will cause a value to be flagged as invalid prior to the computation of normals:

- Any value exceeding the world record for that variable.
- Streaks of constant values longer than 24, 48, 72, and 24 hours for temperature, dew point, mean sea level pressure, and wind speed respectively.
- Mean sea level pressures that exhibit "wrap-around" values where, for example, values in excess of 1059 hPa are recorded as 960 hPa.
- A dew point value exceeds the temperature value. Both are flagged as invalid.
- Within a 450 observation sample, temperature and dew point values outside 7 standard deviations of the mean value are removed. This process iterates up to 10 times until there are no values outside the 14 standard deviations range.

Derived variables

Heat index was computed when the temperature exceeded 80°F and relative humidity was greater than 40%. In instances when these criteria were not met, the temperature replaced the heat index in the sample set. Thus the heat index normal is a temperature as influenced by heat index.

Similarly, wind chill was computed when the temperature was less 50°F and the wind speed was greater than or equal to 3 mph. The wind chill value is set equal to the temperature if these conditions are not met. The wind chill normal is a temperature as influenced by the wind chill.

Wind normals are comprised of the following:

The average speed of all wind speed values.

The frequency of winds less than or equal to 3 mph.

The direction and magnitude of the mean wind vector. These are computed by first decomposing the wind observation into u and v components. The average of each component is computed. A mean wind vector is then assembled from the average components.

For winds greater than 3 mph, each is counted in a 45° wide directional bin centered on 0, 45, 90, …, 315 degrees. Counts in these bins are rescaled to account for a bias introduced by wind directions being even multiples of 10. The identity of the two bins with the highest counts, along with their overall frequencies, is provided.

Cloud frequencies in categories clear, few, scattered, broken, and overcast. These are computed from valid observation values from 0 to 8 inclusive representing eighths of sky coverage. An obvious observational preference was noticed to reporting values 0, 2, 4, 7, and 8. We therefore included any reports of 1, 3, 5, and 6 with the next higher category.

Cooling degree hour normals were computed by subtracting 65 from each valid temperature in the sample of 450. Positive differences were summed and divided by the number of valid values. Heating degree hour normals were computed in a similar manner.

4. Summary

Averages (normals), percentiles, and frequencies of occurrence of the above at the hourly time scale are available at 262 locations in the US and its territories. The recommended use of these products is in examination of the diurnal change of a particular variable and how that change may shift over the annual cycle. For daily, monthly, and seasonal values, please use the normals products created for those time scales.

Hourly Normals: Changes for 2014

This document details the changes in procedures used to produce the hourly normals between the original 2011 run and the update released in 2014. There are two differences in the processing discussed in the next two sections, followed by a comment regarding other differences that may be found in the end product. The new procedures were utilized to refresh the 1981-2010 hourly normals, as well as to release a new 2001-2010 version (e.g., 10-year averages) of the same hourly normals products. It is assumed that the reader is familiar with the concept of normals in general (Arguez et al., 2012) and particularly the hourly normals (Applequist et al., 2012). Please see the second of these references to put the following in proper context.

Station selection and dataset composition

In 2011 for our first effort at hourly normals, we chose a list of stations that were known as "first order stations," a collection of locations typically at major airports for which hourly observations were taken from 1981 to 2010. This was meant to be a representative, rather than comprehensive, sampling of US data. Beginning with a list of 273 stations, we attempted to find complete records in the ISD-lite data. 262 stations were found, though these were not entirely from the original list of 273. For example, the current Denver International Airport opened in the mid-1990s and lacked sufficient data to compute 30 year normals. The nearby Buckley Air Force Base was introduced as a substitute. Additionally, the airport in Austin, TX was also relocated in the mid-1990s. To establish a nearly complete 30 year record representative of the hourly values in the center of Austin, we combined records for Mueller Airport and Camp Mabry. A second site south of the city uses merged records from the former Bergstrom Air Force Base and current commercial airport. All stations were required to have data in 27 of the 30 possible years, but no further checks for data completeness were performed.

The primary reason to re-compute the 1981-2010 normals in 2014 was to make then compatible with the results of a parallel effort to compute normals for the years 2001-2010. We wished to use as many stations as possible while avoiding the ad hoc and manual process used to compile station datasets for the 2011 version of the 30 year normals. An automated method was designed and applied to the entire set of US controlled ISD-lite records. First, the entire catalog of ISD-lite stations was searched for candidates with data in the desired year range. Data file names sharing the same valid AWS and WBAN identifiers were combined. For example, these three data files would be merged into one record: 123456-12345-1990, 123456-99999-1990, 999999-12345-1990. No other combinations were made. As such, for the period 1981-2010, the previously mentioned Buckley Air Force Base was automatically selected and no location had sufficient data for Austin, TX.

Assuming that hourly temperature normals were the most popular products, locations that were candidates for normals were required to have valid hourly observations more than 70% of the time. Furthermore, after computing the normals, those stations with less than 95% of the hourly temperature normals computed were discarded. The locations for which normals were computed in 2011 but failed the new criteria were still included (e.g. two locations in Austin, TX and Mt Washington, NH). Hourly normals for 1981-2010 are now provided for 457 stations, up from 262 in the original 2011 release. In addition, 2001-2010 hourly normals are available for 887 stations.

Percentage of calm winds

In 2011 when sampling the wind values to compute the frequency of calm winds, the calculation was done in conjunction with wind direction frequencies. As such, we required that for a wind vector to be considered, it must have valid values for both speed and direction. This resulted in discarding valid wind cases of the "light and variable" variety for which the wind speed was valid and the direction was reported with the "missing" flag value. In the 2014 version, the aforementioned requirement to have a valid direction was removed resulting in small, typically a few percent, increases in the frequency of calm winds. Average wind speed calculations were not affected.

Other differences

Other differences that might be found between the 2011 and 2014 versions of 1981-2010 normals are attributed to the dynamic nature of the ISD-lite database. Typically, however, there are no differences in the normals values, or differences of 0.1 or 0.2°F and similar differences for other computed values.

References

Applequist, S., A. Arguez, I. Durre, M. F. Squires, R. S. Vose, and X. G. Yin, 2012: 1981-2010 U.S. Hourly Normals. *Bull. Amer. Meteor. Soc.*, **93,** 1637-1640.

Arguez, A., and Coauthors, 2012: NOAA'S 1981-2010 U.S. CLIMATE NORMALS An Overview. *Bull. Amer. Meteor. Soc.*, **93,** 1687-1697.