DAYMET

Climatological Summaries for the Conterminous United States, 1980-1997

USER'S GUIIDE

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OVERVIEW

Daymet is a collection of algorithms and computer software designed to interpolate and extrapolate from daily meteorological observations to produce gridded estimates of daily weather parameters over large regions. These algorithms and software were developed by Peter Thornton while with the Numerical Terradynamic Simulation Group (NTSG) at the School of Forestry, University of Montana (www.forestry.umt.edu/ntsg). The climatological summaries described here are derived from a much larger database of daily weather parameters, produced on a 1 kilometer grid over the entire conterminous United States for the period of record 1980-1997. The daily observations used to produce the gridded surfaces came from approximately 6000 stations in the U.S. National Weather Service Co-op network and the Natural Resources Conservation Service SNOTEL network (automated stations in mountainous terrain). The gridded database of estimated daily weather parameters and the climatological summary maps can be accessed free of charge on-line at www.daymet.org.

This documentation describes the geographic and temporal characteristics of the climatological summary products available from the Daymet website. It also provides information on the file naming conventions for the binary (floating point) grids available for download from the website. A definition is provided for each of the climatological summary variables. Two appendices are included which describe the methods required to access and reproject the summary products using common Geographic Information System (GIS) software packages. A third appendix includes the references that should be used to cite this work.

If you have questions about the website content or methods used in creating the database, please contact:

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Geographic characteristics

All of the climatological summary products for the Daymet conterminous United States database (hereafter referred to as DaymetUS) cover exactly the same geographic area, using a single projection system and a single set of projection parameters. The projection system and relevant projection parameters are listed in Table 1.

Table 1. Projection system and parameters

Projection system	Lambert Azimuthal Equal Area
Latitude of central meridian	45.0° N
Longitude of central meridian	100.0° W
False easting	0.0 m
False northing	0.0 m
Spheroid	Sphere of radius 6370997.0 m

The spatial characteristics for all of the climatological summary products are identical, and are listed in Table 2.

Table 2. Spatial characteristics

Number of columns	4587
Number of rows	2889
Gridcell size (x-dimension)	1000 m
Gridcell size (y-dimension)	1000 m
Projected x-axis coordinate for the **center** of the upper-left gridcell	-2050000.0 m
Projected y-axis coordinate for the **center** of the upper-left gridcell	752000.0 m

The projection system, spatial resolution, and spatial coverage for the DaymetUS products are identical to those used by the Eros Data Center for the distribution of AVHRR biweekly composite satellite products for the conterminous United States. See Appendix A for information on importing the binary grids into ArcInfo or ArcView. See Appendix B for information on reprojecting these grids in ArcGIS.

Each of the summary products is presented as a complete spatial grid, where the summary results have been calculated separately for each gridcell. Gridcells that are mostly over the ocean, or over one of the Great Lakes, or outside the borders of the United States, have not been included in the calculations, and are assigned a value of zero in the data files.

Temporal characteristics

The DaymetUS climatological summary products are derived from a very large database of estimated daily weather parameters covering an 18-year period of record, from 1980 through 1997. The climatological summary products have been produced with three levels of temporal detail. First, the entire period of record has been summarized on an annual basis. Second, the entire period of record has been summarized on a monthly basis. Third, summaries have been produced for each individual year in the 18-year record. For each of the first two summary levels (the period of record summaries) both the means and the interannual standard deviations are provided as separate summary products.

To clarify, consider the case of a single summary variable, total precipitation. The first summary level for this variable consists of two products: the 18-year mean of the annual total precipitation, and the standard deviation around this mean calculated from the 18 individual annual precipitation totals. Each of these products is provided as a single 1 km grid, with values calculated independently for each gridcell from the underlying gridded database of daily weather parameters. The second summary level for this variable, the period of record monthly summaries, consists of 24 grids: 12 grids (one for each month) containing the 18-year mean of the monthly total precipitation, and 12 grids (one for each month) containing the standard deviations around these means calculated from the 18 individual monthly precipitation totals from the underlying daily database. So for example there will be one grid with the 18-year average of total July precipitation, and another grid with the interannual standard deviation of July total precipitation, calculated from the 18 individual July precipitation totals for the period 1980-1997. The third summary level for this variable, the single-year summary, consists of 18 grids, one for each of the individual years in the period 1980-1997. For example, one of the products will be the annual total precipitation for 1980. Since these products are based on a single year each, there are no interannual standard deviation grids associated with them.

Table 3 summarizes the temporal organization of the summary products. The number of grids shown in this table is for a single climatological variable, for example total precipitation.

Table 3. Temporal organization of summary products

Summary level	**Temporal basis for summary**	**File naming pattern[1]**	**Number of grids**
Period of record – annual	18-year mean	*_a_pa	1
	18-year interannual standard deviation	*_s_pa	1
Period of record – monthly	18-year mean	*_a_pm##	12
	18-year interannual standard deviation	*_s_pm##	12
Annual	Single-year	*_a_a##	18
Total number of grids per climatological variable			**44**

[1] The (*) in these patterns is replaced by the variable's abbreviation, as given in Table 4. The (##) in the patterns for period of record monthly products is replaced by a two-digit number for the month (01, 02, 03, … , 12). The (##) in the annual summary products is replaced by a two-digit number for the year (80, 81, 82, … , 97)

Climatological variables

The climatological summary variables are all derived from a much larger database of estimated daily weather parameters. This documentation does not contain a complete description of the underlying database of estimated daily weather parameters, but these parameters are listed for reference in Table 4.

Table 4. Daily weather parameters forming the basis for the DaymetUS climatological summaries

Parameter description	**Parameter abbreviation**
Daily maximum air temperature	Tmax
Daily minimum air temperature	Tmin
Daily total precipitation	Prcp
Daylight average shortwave radiant flux density	Srad
Daily average partial pressure of water vapor	VP

The climatological summary variables are separated into four categories: temperature, precipitation, radiation, and humidity. A number of summary variables are calculated for each category, using the daily weather parameters. The individual variables are listed in Table 5, and each variable is described in detail in the text that follows.

Table 5. DaymetUS climatological summary variables.

Category	Variable description	Units	Abbreviation for file naming
Temperature	Daily maximum air temperature	°C	tx
	Daily minimum air temperature	°C	tn
	Daily average air temperature	°C	ta
	Day-to-day variability in maximum temperature	°C	tvx
	Day-to-day variability in minimum temperature	°C	tvn
	Day-to-day variability in average temperature	°C	tva
	Number of frost days	days	tf
	Growing degree-days	degree-days	td
	Heating degree-days	degree-days	th
	Cooling degree-days	degree-days	tc
Precipitation	Precipitation frequency	proportion	pf
	Average precipitation event size	cm day^{-1}	pe
	Total precipitation	cm	pt

Radiation	Daily total shortwave radiation	MJ m^{-2} day^{-1}	rt
	Day-to-day variability in total shortwave radiation	MJ m^{-2} day^{-1}	rvt
Humidity	Daily average water vapor pressure	Pa	hv
	Day-to-day variability of water vapor pressure	Pa	hvv

There are 17 summary variables listed in Table 5, and there are 44 different temporal summary products for each variable (as described in the Temporal Characteristics section, Table 3), for a total of 748 summary climatological products.

Day-to-day vs. interannual variability

In addition to the categorization by main climatological variable type, as in Table 5, the 17 variables can also be divided into two groups depending on whether they are based on the daily values of individual weather parameters, or on the day-to-day variability of the individual weather parameters. There is some potential for confusion between the subset of climatological variables that summarize day-to-day variability, and the temporal summary products that describe interannual variability and are present for all of the climatological variables. The following example should help to clarify this distinction.

Consider a single gridcell in the database, and consider a single daily weather parameter, Tmax. The data for this parameter consists of records of the daily maximum air temperature for each day of the year for 18 years. The summary methods to generate climatological information from this weather parameter are straightforward. For the period of record annual summary products, first the average value of Tmax is calculated for each year, and then the 18-year mean of these values is recorded in the product tx_a_pa. The interannual standard deviation can be calculated from this set of 18 annual values for annual average Tmax, and this value is recorded in the product tx_s_pa. In a similar manner, average values of the daily Tmax are calculated for each month of each of the 18 years of record, and then the period of record mean values and the interannual standard deviations for each month are recorded in the products tx_a_pm## and tx_s_pm##, where ## stands for the month (01, 02, 03, …, 12). Finally, the single year mean values for each year, which were used to calculate tx_a_pa, are recorded as the products tx_a_a##, where here ## stands for the year (80, 81, 82, …, 97). It should be obvious that it is not possible to calculate an interannual standard deviation for the single year products. The individual monthly averages for each year are calculated for making the tx_a_pm## and tx_s_pm## products, but they are not being provided as summary products at this time.

The interannual standard deviation products summarize an important component of the climatological variability of the Tmax weather parameter, and the monthly period-of-record products capture important information about the seasonal cycle of the parameter. These products do not, however, capture the day-to-day variability of the Tmax weather parameter, which is a potentially important dimension of the total climatological variability of Tmax. In some climates, for example, the changes from day to day in Tmax might be small, perhaps buffered by a nearby body of water, while in other climates the variability might be large, perhaps reflecting the convergence of weather from different directions on different days. The mean and interannual standard deviation products for Tmax do nothing to characterize this variability, and so another climatological variable has been produced to summarize this day-to-day variation. For the case of Tmax, this variable is referred to as the day-to-day variability of daily maximum temperature, abbreviated tvx (Table 5). It is possible to summarize this new variable in all the same ways just described for Tmax, to produce period-of-record annual and monthly summaries of both the mean values for the day-to-day variability, as well as interannual standard deviations of this variability. There is an additional complication, however, which is that for annual and monthly summaries, the seasonal cycle in Tmax has a big influence on the variability of the daily Tmax values if that variability is calculated as a standard deviation of the daily Tmax values. To eliminate this influence, a new daily variable was calculated by removing the 18-year average seasonal cycle from the daily Tmax values.

Once the long-term average seasonal cycle has been removed, the new daily values are used to calculate standard deviations on an annual and monthly basis for all years, and these values are summarized as described above for Tmax, resulting in the same set of 44 temporal summaries. It may take a little thought to imagine the interannual standard deviation over 18 years of the monthly average of the day-to-day variability in daily maximum temperature, but that is what you have for the summary products tvx_s_pm##.

Not all of the summary climatological variables are amenable to this treatment of day-to-day variability. Notice in Table 5 that the precipitation summary variables do not have a day-to-day variability counterpart. The binary nature of precipitation occurrence makes it very difficult to interpret the day-to-day variability using standard deviations, and the identification and removal of the seasonal cycle is also problematic. Instead, the day-to-day variability in the precipitation process has been characterized on the basis of daily event frequency and event size, as explained in the descriptions of individual climatological summary variables that follows.

Description of climatological variables

This section includes a text description of each of the 17 climatological summary variables included in the DaymetUS database. Each variable described in this section has a total of 44 different summary products associated with it, corresponding to the temporal summary methods described in the section on Temporal Characteristics and summarized in Table 3. See Table 5 for units on all variables.

1. **Daily maximum air temperature (tx):** The average over either a monthly or annual period of the high temperature for a 24-hour period.
2. **Daily minimum air temperature (tn):** The average over either a monthly or annual period of the low temperature for a 24-hour period.
3. **Daily average air temperature (ta):** The average over either a monthly or annual period of the average air temperature for a 24-hour period. In practice, this variable is calculated in the Daymet daily database as (tx + tn)/2.0.

4. **Day-to-day variability in maximum temperature (tvx):** The standard deviation of daily maximum air temperature, calculated from either monthly or annual periods of daily data, after removing the long-term seasonal cycle from the data (see detailed description in previous section).
5. **Day-to-day variability in minimum air temperature (tvn):** The standard deviation of daily minimum air temperature, calculated from either monthly or annual periods of daily data, after removing the long-term seasonal cycle from the data (see detailed description in previous section).
6. **Day-to-day variability in average temperature (tva):** The standard deviation of daily average air temperature, calculated from either monthly or annual periods of daily data, after removing the long-term seasonal cycle from the data (see detailed description in previous section).
7. **Number of frost days (tf):** The number of days in either a monthly or annual period when the daily minimum air temperature is less than or equal to 0.0 °C.
8. **Growing degree-days (td):** The summation for either a month or a year of the daily average air temperatures for the period that are greater than 0.0 °C.
9. **Heating degree-days (th):** The summation for either a month or a year of the difference between 18.3 °C and the daily average air temperature, for days when that difference is positive (i.e. when the daily average air temperature is less than 18.3 °C).
10. **Cooling degree-days (tc):** The summation for either a month or a year of the difference between the daily average air temperature and 18.3 °C, for days when that difference is positive (i.e. when the daily average air temperature is greater than 18.3 °C).
11. **Precipitation frequency (pf):** The proportion of days in either a monthly or annual period that had any precipitation (i.e. a value from 0.0 to 1.0).
12. **Average precipitation event size (pe):** The average over either a monthly or annual period of the daily total precipitation for days with non-zero precipitation.
13. **Total precipitation (pt):** The total accumulated precipitation over either a monthly or annual period.
14. **Daily total shortwave radiation (rt):** The average over either a monthly or annual period of the total daily incident shortwave radiative flux.
15. **Day-to-day variability in total shortwave radiation (rvt):** The standard deviation of daily total shortwave radiation, calculated from either monthly or annual periods of daily data, after removing the long-term seasonal cycle from the data (see detailed description in previous section).
16. **Daily average water vapor pressure (hv):** The average over either a monthly or annual period of the daily average partial pressure of water vapor in air near the surface.
17. **Day-to-day variability in water vapor pressure (hvv):** The standard deviation of daily water vapor pressure, calculated from either monthly or annual periods of daily data, after removing the long-term seasonal cycle from the data (see detailed description in previous section).

Appendix A.

Using Daymet Summary Data in a GIS - ESRI Imports

General

The Daymet summary files are signed, 32 bit, floating point files and are most valuable recognized in this level of precision. Some GIS analysts may not be accustomed to working with raster data in this file format. For example, ESRI software users will find that the ArcInfo Grid format of signed, floating point files do not, and cannot, contain a Value Attribute Table (VAT). Each grid cell contains a unique, highly precise value.

ArcView

Rename the binary file name to a three character extension; for example tx_a_pa.flt. Import Daymet Summary files into ArcView using the "Import Data Source..." option found under the File pull down. Select "Binary Raster" as the import file type. Note: Binary Raster data can only be imported using the Spatial or 3D Analyst Extension.

ASCII headers file of the same name of the data file with a .hdr extension must accompany the IEEE floating-point file. The header files for the Daymet summary files include the following keywords and values:

<u>Sample ASCII Header File</u>
ncols 4587
nrows 2889
xllcorner -2050500.000
yllcorner -2136500.000
cellsize 1000
nodata_value -9999
byteorder msbfirst

For more help on this topic, see "binary files" in the ArcView on-line help.

Arc/Info

Rename the Daymet summary files to a three character extension, e.g. tx_a_pa.flt. Use the FLOATGRID command at the Arc prompt to import the Daymet summary files.
A header file of the same name of the data file with a .hdr extension must accompany the IEEE floating-point file. The header file for the Daymet summary files includes the following keywords and values:

<u>Sample ASCII Header File</u>
ncols 4587
nrows 2889
xllcorner -2050500.000
yllcorner -2136500.000
cellsize 1000
byteorder msbfirst

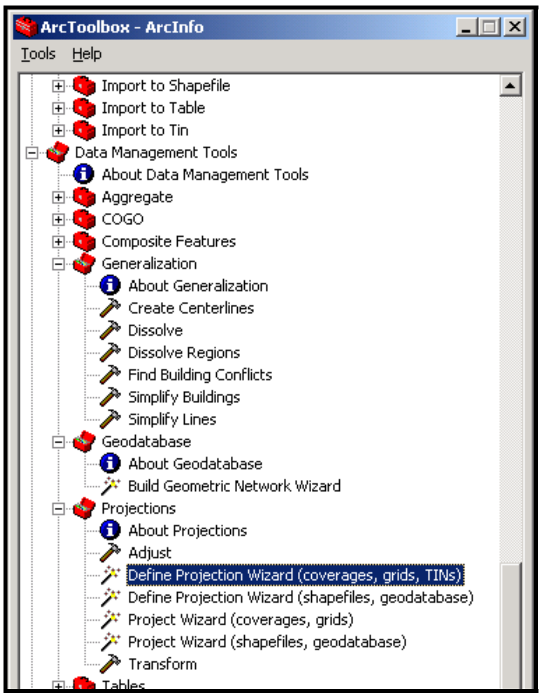
Appendix B.

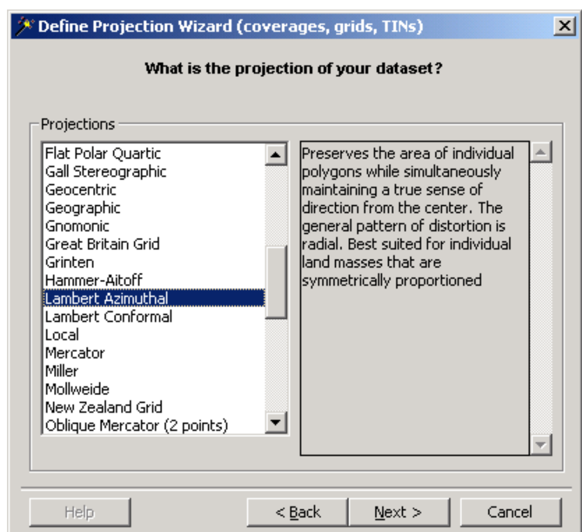
Reprojection of Data (Spheroid to Datum Conversion) in Arc

(Thanks to Matthew Hayes at the UNC-Chapel Hill Geography department for providing this summary)

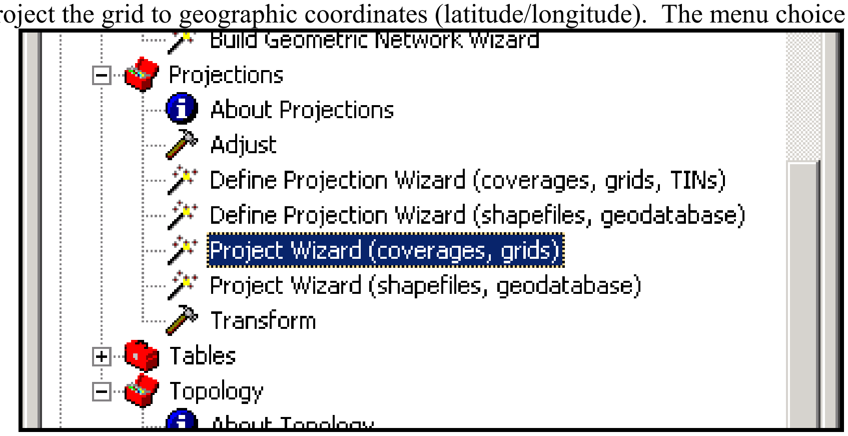
This Daymet data is projected as a Lambert Azimuthal spheroid. It may be necessary to re-project this data to a projection of your current dataset and also to a datum (if your set is projected on a datum). A few extra steps must be taken. It requires re-projecting to geographic coordinates and then to your projection rather than re-projecting directly to your specified projection. The steps can be taken in ArcGISToolbox or in ArcInfo workstation. The following instructions are using ArcGISToolbox and for converting from a spheroid to a datum.

1. First it is necessary to define the projection of the original binary data once you have converted it to a grid. Use the projection systems and parameters information found at the beginning of this document. The ArcToolbox menu choice is shown below.

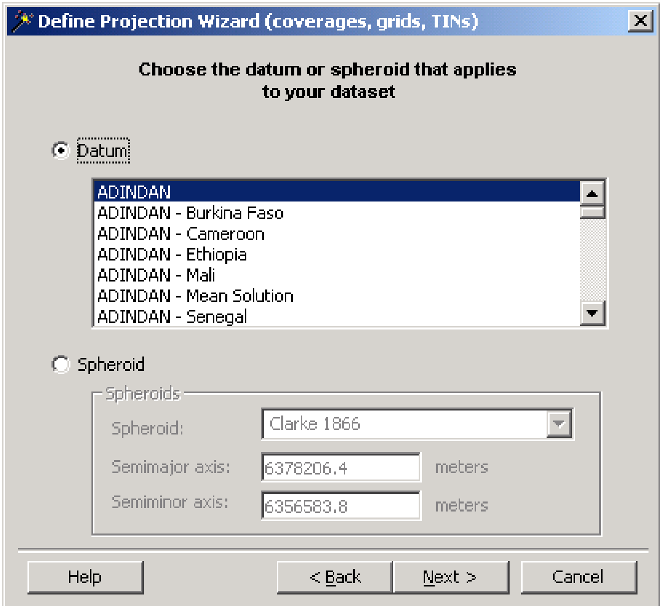




2. Reproject the grid to geographic coordinates (latitude/longitude). The menu choice is seen below.



3. Redefine the projection again, keeping it geographic coordinates, but *changing* the **spheroid** option to the **datum** you need. The screen below is where you will convert it to a datum of choice.



4. Reproject the grid from geographic coordinates on a datum to whatever projection you need, keeping the same datum.

Appendix C.

References to use in citing this work.

The following reference should be used as the general citation for the methods used to generate the Daymet U.S. database:

Thornton, P.E., Running, S.W. and White, M.A., 1997. Generating surfaces of daily meteorological variables over large regions of complex terrain. Journal of Hydrology, 190: 214-251.

For applications of the radiation and humidity climatological summary products, please include the following citations **in addition** to the general citation:

Thornton, P.E. and Running, S.W., 1999. An improved algorithm for estimating incident daily solar radiation from measurements of temperature, humidity, and precipitation. Agricultural and Forest Meteorology, 93: 211-228.

Thornton, P.E., Hasenauer, H. and White, M.A., 2000. Simultaneous estimation of daily solar radiation and humidity from observed temperature and precipitation: an application over complex terrain in Austria. Agricultural and Forest Meteorology, 104: 255-271.