



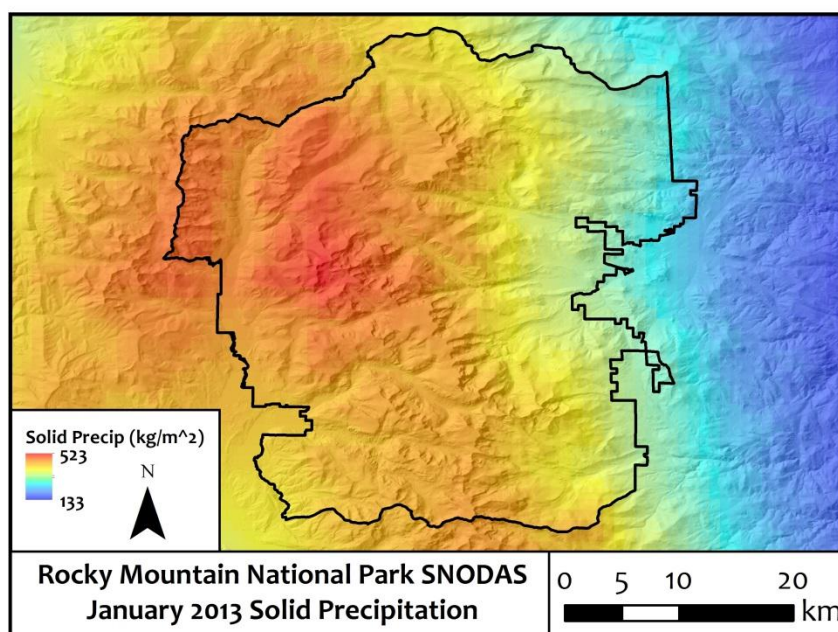
National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

NOTE: There may be revised processes and documentation available.

For the most current version check, please check the following:
<https://irma.nps.gov/App/Reference/Profile/2210281/?lnv=true>

NPScape Climate Grid Analysis Toolset



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Version History

Version	Changes
20150105	Revised GUI Added count
20141217	Added count statistic to summary statistics Added overlapping polygon processing capability to zonal statistics
20140519	Switched from functions to objects Added daily aggregation methods Multiple bugs addressed
20130830	Added support for DAYMET data; Add BioClimatic variables calculation
20130219	Updated code to match new PRISM file names; clarified output file format
20130306	Code Modifications; Bug fix with CRU file Names; Added appendices to explain optional use of Python scripts; Added links for software dependencies involving older versions of Python.
20131210	Added support for DAYMET daily and monthly PRISM climatology data for HI Increased number of available summary statistics Provided ability to aggregate by season Added support for BioClimatic variables Added ability to preview graphics in ArcMap

Overview

NPScape is a landscape dynamics monitoring project that provides landscape-level data, tools, and evaluations for natural resource management, planning, and interpretation (NPS 2013). The goal of the NPScape Climate Grid Analysis Toolset (CGAT) is to provide landscape-scale climate monitoring support to I&M networks and parks; climate which is one of the top ranked vital signs among all of the NPS I&M networks ([Fancy & Bennetts 2012](#)). This document provides guidance for using the Climate Grid Analysis Toolset (CGAT). Currently CGAT is designed to facilitate the efficient analysis of CRU, DAYMET, PRISM4K, SNAP, and SNODAS gridded climate datasets. CGAT offers various options for aggregation and statistical analysis.

Data Sources

To meet the needs of the National Park Service, we have opted to focus on five publically available datasets from five different sources (Table 1).

Table 1. Temporal and spatial extent of datasets supported by CGAT.

Datasets	Geographic Extent	Spatial Resolution (km)	Temporal Resolution	Temporal Extent	Source
CRU	Global	8-17	Monthly	Climatology (1961-1990)	New et al. 2000
DAYMET	Lower 48, Mexico, Canada	1.0	Daily	1980-Present	DAYMET 2013
PRISM 4k	Lower 48	4.0	Monthly	1895-Present	PRISM Climate Group 2012
SNAP	Alaska, Western Canada, Northwestern U.S.	0.771 and 2.0	Monthly	1901-2009	SNAP 2012
SNODAS	Lower 48	1.0	Daily	10/1/2003-Present	National Operational Hydrologic Remote Sensing Center 2004

Our decision to support these five datasets is based on the following:

- *Spatial Resolution* – Where possible, we opted for the highest spatial resolution.
- *Geographic Extent* – We wanted to ensure that each NPS unit was adequately represented.
- *Measured Variables*- The measure variables should have clear application to ecological and physical issues faced by the parks.
- *Scientific Rigor* – The methods to produce the source datasets should be adequately documented and the use of the datasets should be accepted within the broader scientific community.

The following section describes each dataset in more detail.

CRU CL2.0

CRU CL2.0 is a ten-minute (approx. 8-17 km, depending on latitude), global-scale climatology for 1961-1990 reference period (New et al, 2002; <http://www.cru.uea.ac.uk/cru/data/hrg/tmc/>). While CRU is spatially coarser than the other data sources (Figure 1) and is only provided as a climatology (i.e., not as a time series), it offers a number of unique variables that have direct bioclimatic application (Table 2). More detailed information about CRU variables can be found at <http://www.cru.uea.ac.uk/>.

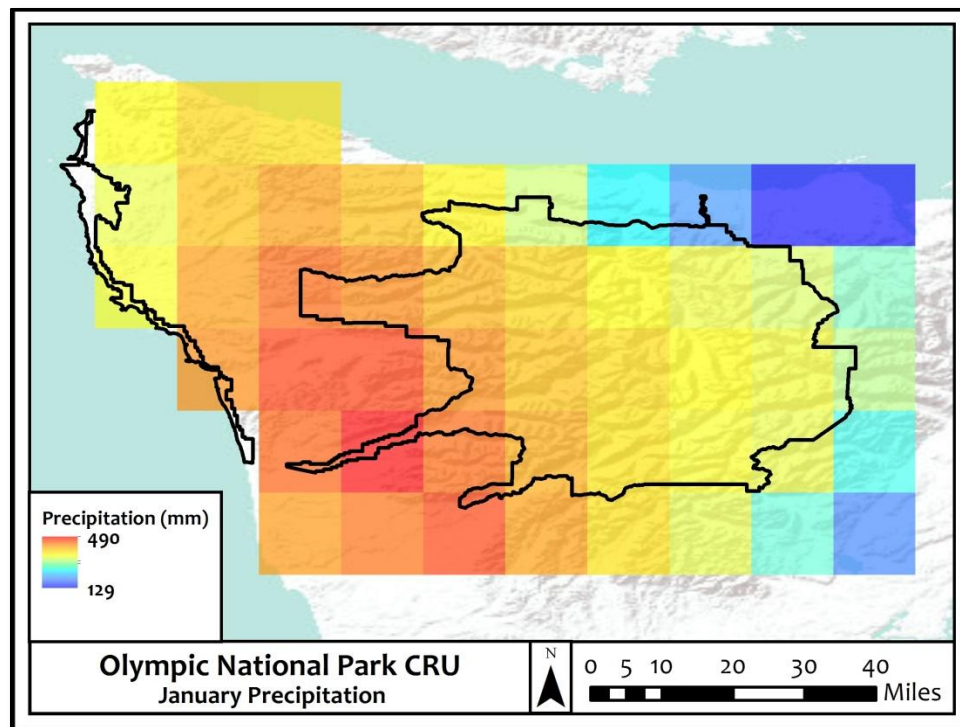


Figure 1. Figure 1: CRU precipitation (mm) in January for Olympic National Park.

Table 2. CRU CL2.0 variables and related information.

Variable Code	Info
pre	Precipitation (mm/month)
rd0	Wet-days (number of days with >0.1mm rain per month)
tmp	Mean temperature (Degrees Celsius)
dtr	Mean diurnal temperature range (Degrees Celsius)
reh	Relative humidity (percent)
sunp	Sunshine (percent of maximum possible (percent of day length)
frs	Ground-frost (number of days with ground-frost per month)
wnd	10m wind speed (meters/second)

DAYMET

DAYMET is a set of 1-km daily gridded weather parameter estimations derived from daily meteorological observations (Table 2; Figure 2; Table 3). Primary sources for the creation of the DAYMET grids include the NOAA National Climate Data Center Global Historical Network (GHCN) and NRCS Snowpack and Telemetry (SNOTEL) stations. Detailed information about input specifications and other related information of DAYMET data can be found at <http://daymet.ornl.gov/overview>.

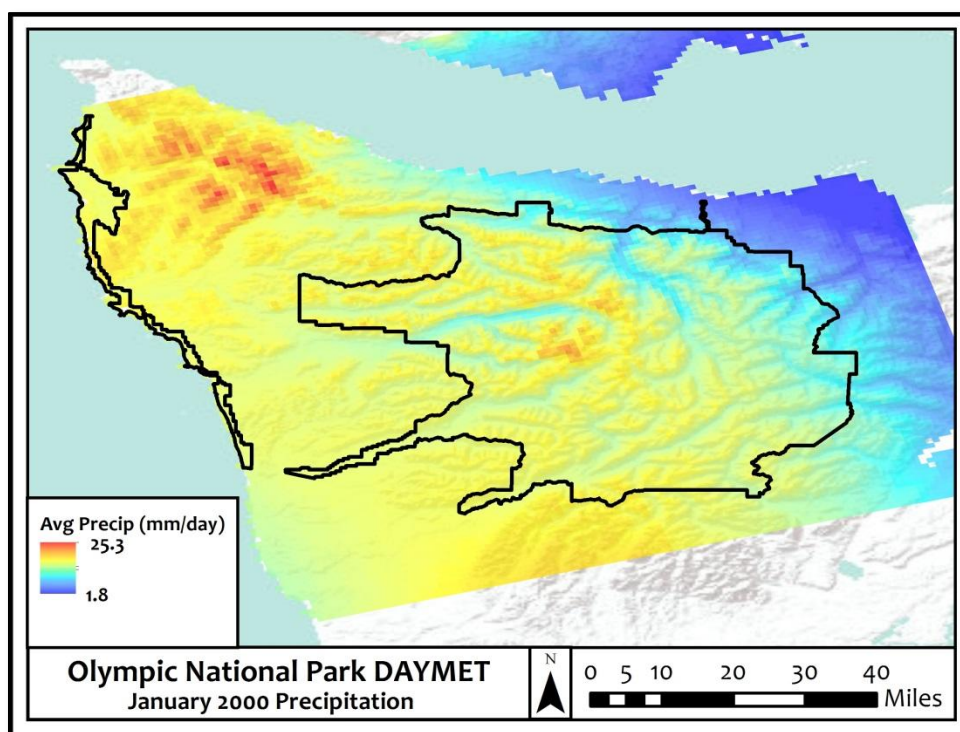


Figure 2. DAYMET January 2000 precipitation (mm/day) for Olympic National Park.

Table 3. DAYMET variables and related information

Variable Code	Info
Tmax	Maximum temperature (degrees C)
Tmin	Minimum temperature (degrees C)
Srad	Shortwave radiation (W/m ²)
Vp	Vapor pressure (Pa)
Swe	Snow-water equivalent (kg/m ²)
Prcp	Precipitation (mm/day)
Dayl	Day length

PRISM 4k

PRISM (Parameter-elevation Regressions on Independent Slopes Model) uses an advanced algorithm that factors in numerous regional controls including rain shadows, coastal effects, and temperature inversions. PRISM data are spatially continuous for the continental U.S., and have been modeled from 1895 to present. The spatial resolution of the free monthly PRISM data is 2.5 arc-minutes (~4 km). More detailed information about PRISM data is available at <http://www.prism.oregonstate.edu/>

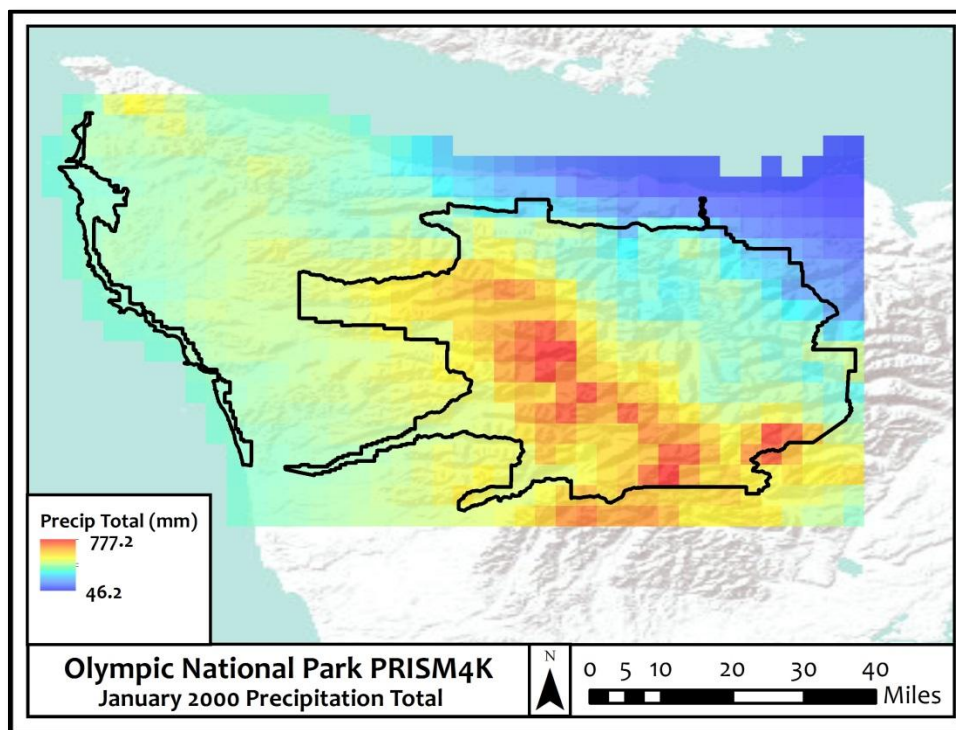


Figure 3. PRISM4K precipitation (ppt) values for Olympic National Park for January of 2000.

Table 4. PRISM variables and related information.

Variable Code	Info
ppt	Total Precipitation (millimeters*100)
tmax	Average Maximum Temperature (degrees Celsius *100)
tmin	Average Minimum Temperature (degrees Celsius *100)
tmean	Average Dew point Temperature (degrees Celsius *100)

SNAP

SNAP (Scenarios Network for Alaska and Arctic Planning) products include historical and projected monthly climate data for temperature and precipitation across **Alaska** (771 m) and **Western Canada** (2 km data only) (SNAP, 2012). SNAP data are derived from CRU TS 3.0 / 3.1 (<http://www.cru.uea.ac.uk/cru/data/hrg/>); downscaling methods are described in detail at <http://www.snap.uaf.edu/downscaling.php>.

Derived data products include potential evapotranspiration, vegetation, fire, permafrost, day of freeze, day of thaw, subsequent length of growing season, as well as decadal seasonal and annual averages. For detailed information on each of the datasets, please refer to the metadata in their respective sections.

Currently, the CGAT model has been tested to support the 771 m and 2 km historical SNAP data for the four variables listed in Table 5.

NOTE: Due to the extremely large file sizes, it is necessary to manually download the SNAP data files from the website <http://www.snap.uaf.edu/data.php>.

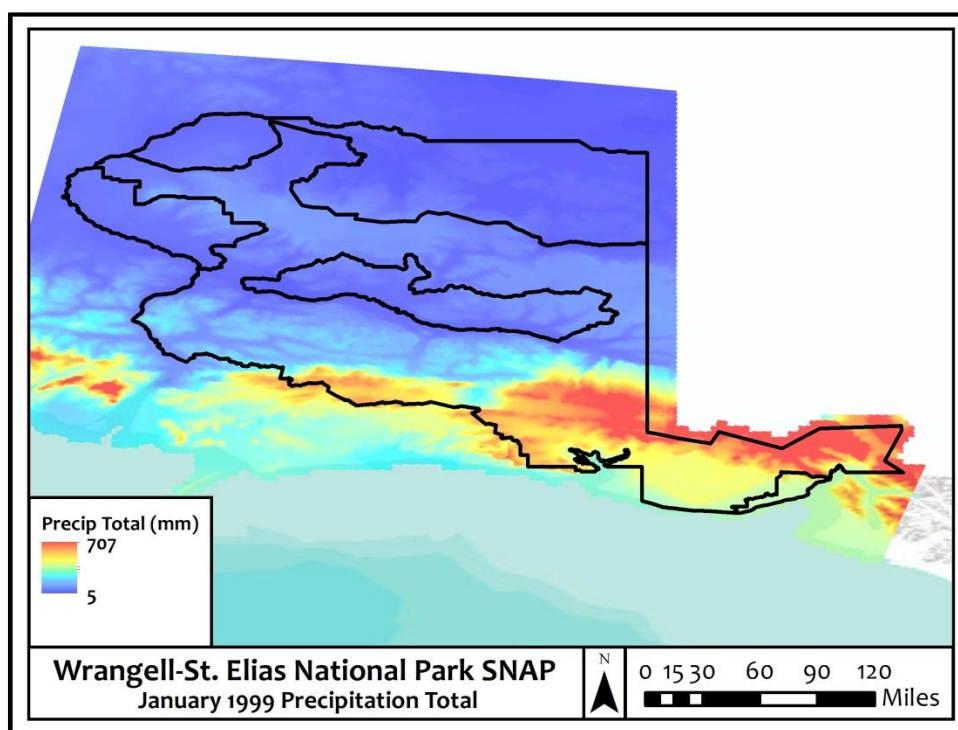


Figure 4. SNAP 771m CRU TS31 January 1999 historical precipitation (mm) for Wrangell-St. Elias National Park, Alaska.

Table 5. Supported SNAP variables and related information.

Variable Code	Info
tas	Mean air temperature (degrees Celsius)
pr	Total Precipitation (millimeters)
dof	Day of Freeze (Julian Day; 0 = Primarily Frozen and 365 = Rarely Freezes)
dot	Day of Thaw (Julian Day; 0 = Rarely Freezes and 365 = Primarily Frozen)

SNODAS

The National Weather Service's National Operational Hydrologic Remote Sensing Center (NOHRSC) offers Snow Data Assimilation System (SNODAS), a daily 1 km gridded dataset for a number of hydrologically relevant variables (Figure 5; Table 6). SNODAS data are derived from point-based observations (e.g., SNOTEL) and remotely-sensed imagery (NOHRSC 2012).

<http://nsidc.org/data/g02158.html>

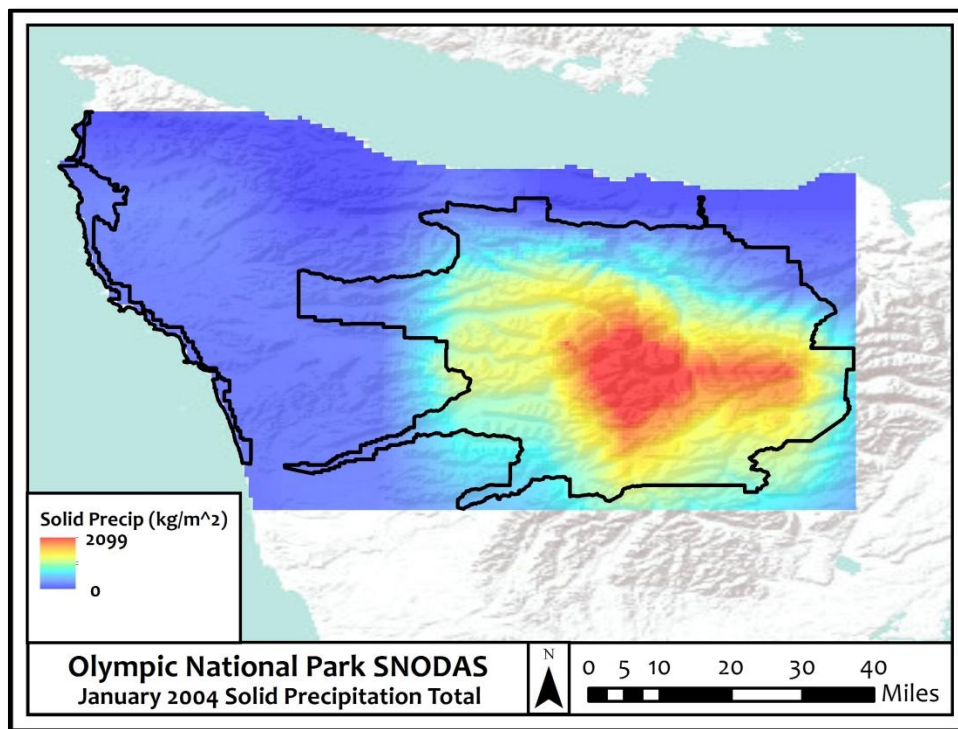


Figure 5. SNODAS January 2004 solid precipitation (kg/m²) for Olympic National Park.

Table 6. SNODAS variables and related information.

Variable Code	Info
1025S	Solid Precipitation (kg/m ²). 24 hour total, 06:00 UTC-06:00 UTC
1025L	Liquid Precipitation (kg/m ²). 24 hour total, 06:00 UTC-06:00 UTC
1034	Snow Water Equivalent (meters). Snapshot
1036	Snow Depth (meters). Snapshot
1038	Snow Pack Average Temperature (kelvin)
1039	Sublimation of Blowing Snow (meters). Total of 24 per hour sublimation rates, 06:00 UTC-06:00 UTC
1044	Snow Melt Runoff at the Base of the Snow Pack (meters). Total of 24 per hour melt rates, 06:00 UTC-06:00 UTC
1050	Sublimation from the Snow Pack (meters). Total of 24 per hour sublimation rates, 06:00 UTC-06:00 UTC

Aggregation

CGAT provide a set of aggregation tools intended to facilitate rapid processing, especially when there is a need to aggregate across numerous years.

- **Days to Months** - Aggregates daily grid by the respective calendar month and year.
- **Months to Calendar Years** – Aggregates monthly grids to the respective calendar year.
- **Months to Climate Seasons** – Aggregates monthly grids to the climatological seasons (DJF, MAM, JJA, SON). Note that the December month is for the year prior.
- **Months to Water Years** – Aggregates the monthly grids to the respective water year. Note that the October, November and December months are for the year prior (http://water.usgs.gov/nwc/explain_data.html).

Table 7. Recommended Aggregation Methods By Data Source

Dataset	Aggregation			
	Days to Months	Months to Calendar Years	Months to Climate Seasons	Months to Water Years
PRISM4K				
SNAP				
CRU				
SNODAS				
DAYMET				

Recommended	
Not Recommended	

Statistics

The CGAT tool provides four statistics for the purpose of summarizing the gridded data. General Summary Statistics and Bioclimatic variables all produce new grids summarize the results spatially while zonal statistics summarizes the grid values for a defined region as a table.

- **General Summary Statistics**¹ (using the numpy statistical libraries*)
 - Average (avg)
 - Minimum (min)
 - Maximum (max)
 - Sum (sum)
 - Variance (var)
 - Median (med)
 - Standard Deviation (stdev)
 - Percentile (percentile = number 0-100)
 - Range (range)
 - Count (count) – Count of grids above/below a specified threshold
 - Percentile Rank - Percentile rank is the value of a variable below which a certain percentage of observations fall. The advantage of percentile over other common means of representing departures from a common baseline (e.g., departure from normal) is that percentile does not depend on the underlying data being normally distributed. Furthermore, percentile is unit independent and bound by the range of 0 to 100%².
- **Zonal Statistics** - Calculates summary statistics for specific areas of interest. Example areas could include fire boundaries, watersheds, park boundaries, etc. This tool **does** support overlapping polygons as input features. Zonal statistics includes the calculation of the following statistics: minimum (MIN), maximum (MAX), range (RANGE), mean (MEAN), standard deviation (STD), sum (SUM), variety (VARIETY), majority (MAJORITY), minority (MINORITY), and median (MEDIAN). Output from zonal statistics is a .csv table with the zonal statistics by zone per climate grid. Statistical zones are defined by the specified field in either a feature class or grid layer zone dataset³
- **BioClimatic Variables** – Aggregate a set of monthly grids to the respective bioclimatic metrics (<http://www.worldclim.org/bioclim>). Note that this aggregation currently requires the installation of R.
 - BIO1 Annual Mean Temperature
 - BIO2 Mean Diurnal Range (Mean of monthly (max temp - min temp))
 - BIO3 Isothermality (BIO2/BIO7) (* 100)
 - BIO4 Temperature Seasonality (standard deviation *100)
 - BIO5 Max Temperature of Warmest Month
 - BIO6 Min Temperature of Coldest Month
 - BIO7 Temperature Annual Range (BIO5-BIO6)
 - BIO8 Mean Temperature of Wettest Quarter
 - BIO9 Mean Temperature of Driest Quarter
 - BIO10 Mean Temperature of Warmest Quarter
 - BIO11 Mean Temperature of Coldest Quarter
 - BIO12 Annual Precipitation
 - BIO13 Precipitation of Wettest Month
 - BIO14 Precipitation of Driest Month
 - BIO15 Precipitation Seasonality (Coefficient of Variation)
 - BIO16 Precipitation of Wettest Quarter

¹<http://docs.scipy.org/doc/numpy/reference/routines.statistics.html#order-statistics>

²<http://docs.scipy.org/doc/scipy-0.7.x/reference/generated/scipy.stats.percentileofscore.html>

³<http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#//009z000000w8000000.htm>.

- BIO17 Precipitation of Driest Quarter
- BIO18 Precipitation of Warmest Quarter
- BIO19 Precipitation of Coldest Quarter

Table 8. Recommended Statistics By Data Source.

Dataset	Statistic			
	Summary	Percentile Rank	Zonal Stats	BioClimatic Variables
PRISM4k				
SNAP				
CRU				
SNODAS				
DAYMET				

Recommended	
Not Recommended	

Processing Steps and Tools

Included with this document is an ArcGIS toolbox named NPScape Climate Grid Analysis Toolset (CGAT), as well as the supporting python code. **For the toolset to run without error, it is crucial that the CGAT subfolder be located in the same folder.**

CGAT requires the following software and installations:

- **ArcGIS 10.2** with the **Spatial Analyst License** enabled.
- **Python 2.7** - 32 bit (installed with ArcGIS). Note that stand-alone installations of Python may have difficulty finding the ArcGIS arcpy module.
- **Numpy** (1.6.2+) - Note that installation and updating of Numpy will require administrative privileges ([NumPy for Python 2.7 32 bit](#))
- **Scipy** ([0.13.3 for Python 2.7 32bit](#))
- **R** (Version 3.0.1) with the following libraries (raster, dismo, and ncdf) – Installation of R is only required if you plan to calculate the bioclimatic variables [R Version 3.0.1](#)
- **Python for Windows Extensions** - download latest executable for Python 2.7 32 bit from [here](#). The latest build will be at the top, open that directory and select pywin32-(Build number).win32-py2.7.exe. Installation only required for zonal statistics tool.

In addition, although not a requirement, this code has only been tested on a Windows operating system. Because there are some data conversions between UNIX and dos (especially for SNODAS), there may be compatibility issues if this module is run under another operating system.

General Workflow

Gridded climate data are challenging to work with because they not only are provided in various but also include the entire geographic extent, making the files unnecessarily large. Therefore, one key utility of CGAT is to generate a local archive of the climate data in a standard and efficient format (netCDF) for the desired geographic extent.

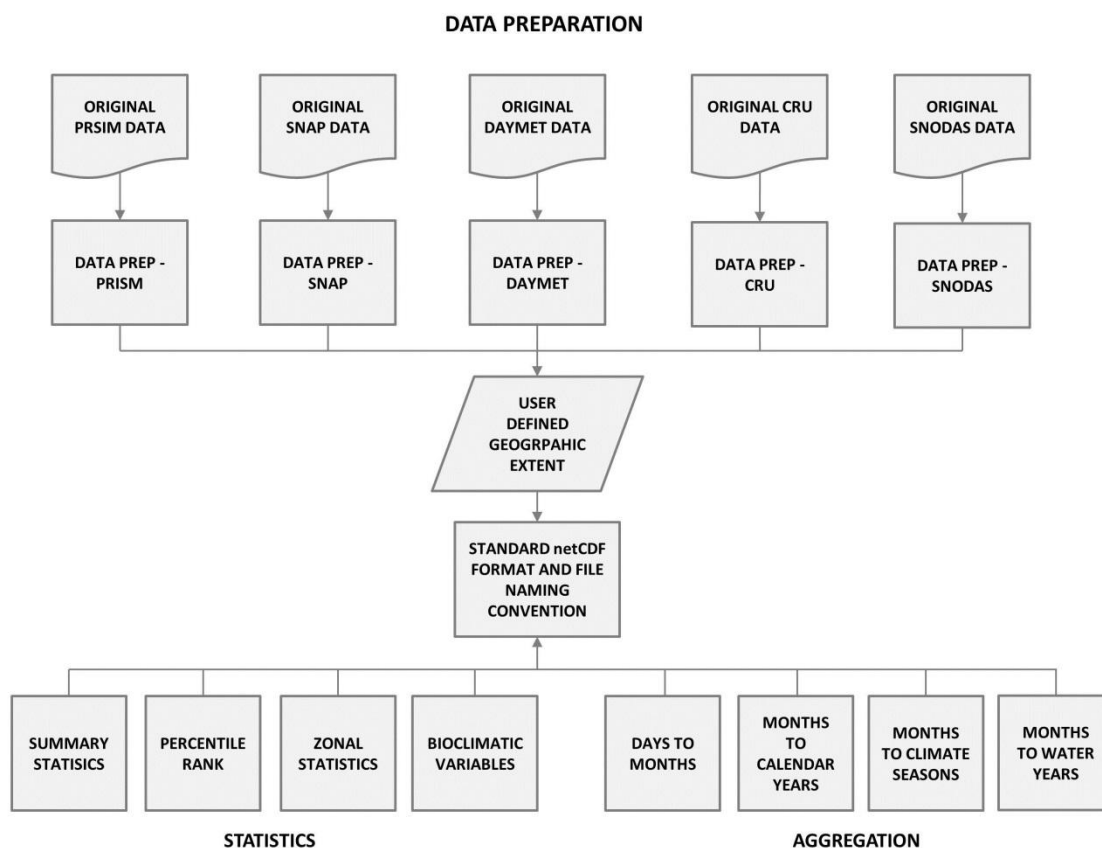


Figure 6. Climate grid Analysis Toolset-- Analysis Flow Chart.

Once in the standard format, statistical analyses are substantially faster, and data source independent. Furthermore, because netCDF is a non-proprietary and accepted data model – especially and increasingly so for climate data – other statistics not covered by CGAT can be readily calculated from the netCDFs.

Note: the one downside to using netCDF files is that ArcGIS does not natively support reading and writing of the grids. Please refer to the section below which shows how to read the files.

To begin processing, open ArcMap and access the NPScape Climate Grid Analysis Toolset toolbox through ArcCatalog by navigating to the folder that the toolset is stored under (Figure 7).

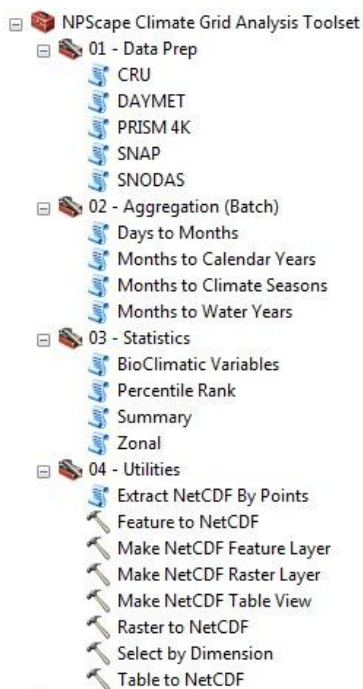


Figure 7. The NPScape CGAT Toolset in ArcCatalog

Data Prep

Except for SNAP, the Data Prep tools automatically pull the data directly from the source and save the files locally. Thus, the entire process is completely automated.

All tools will generally require the following:

- **Working Directory** – The folder where you intend to set up your data archive.
- **Geographic Extent** – The input geographic extent that includes the maximum area to process. Note: When using a feature class to define the geographic extent, be sure to project the feature class to a Geographic Coordinate System as specified by a shapefile, display extent, or other extent as desired for the outputs
- **Geography Code** – The geographic code given to the reformatted grids. If you choose the entire extent for the US, we recommend using 'US'. Otherwise, for park, network or regional extents, we recommend using the respective unit codes. Please note that underscores are never allowed.
- **Parameters** – Specify one or more of the climate variables. Note that the variable codes will differ among the climate sources.
- **Dates** – Years, months, and sometimes days, depending on source data
- **Keep Original Files** – You can indicate whether to preserve or discard a local copy of the original files downloaded from the source. Unless space is a real issue, we recommend keeping a copy locally.
- **Preview Grids** – If checked, **ALL** of the processed grids will be added as a layer to the ArcMap session.

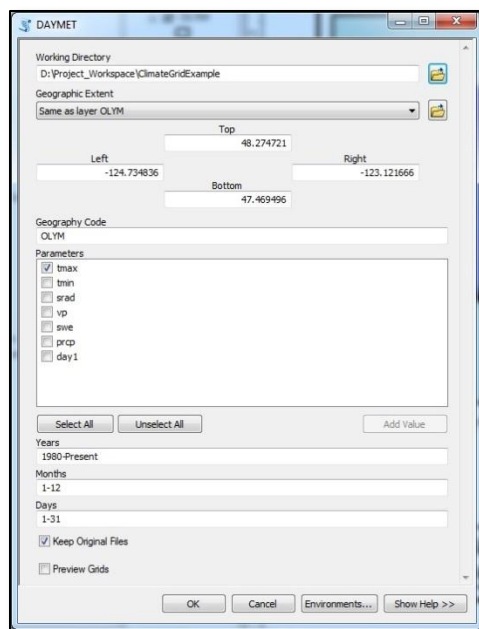


Figure 8. Example of the Data Prep tool for the DAYMET data.

Defaults are set to retrieve the maximum data available. Please be aware that some data sources (e.g., SNODAS, DAYMET) will take a long time to process if you accept the defaults.

General Notes

- **Geographic Extent** – When using a feature class to define the geographic extent, be sure to project the feature class to a Geographic Coordinate System.
- **Overwrite Errors** – Multiple runs with the same parameters will yield an error message. There is not an overwrite function written into this tool. Therefore, the initial layer generated needs to be deleted in order to create an additional one (dependent on file location as well).

Source-Specific Notes:

- **CRU** - Since CRU is a 30-year climatology, there is no ability to specify a range of years.
- **PRISM4K** - The month of 14 pertains to the annual average.
- **SNAP**
 - The archive location is the folder in which the SNAP.zip files are stored as well as the location that the new .nc files will be written to.
 - There is no option in the script to automatically remove the downloaded files. If you want them removed after processing, you will need to delete them manually.
- **SNODAS**
 - For the parameter input “1039” pay close attention to the high and low values in the output raster layer: If there are values that are inconsistent, it is indicative of the absence of snow sublimation data for the day/month/year input in the data prep toolbox.
 - If you are processing numerous grids, be sure you have enough disk space. Each SNODAS archive is initially 22 MB in size. Because all archives are downloaded before processing, if you process all grids for all years, that is approximately 8.1 GB per year. The good news, however, is that once you process the grids and clip them to a smaller extent, the size will likely decrease.

As the data sources are processed, they will be converted to a [netCDF](#) format with an extension of “*.nc”. We chose to standardize on netCDF because it is not proprietary, is frequently used by the climate community, and can be easily processed using a number of different tools.

All files are named according to our own naming convention:

geographyCode_dataSource_variable_statistic_date.nc

Geography code represents the geographic extent of the processed data. For example, if PRISM data were clipped to the extent of Rocky Mountain National Park, an appropriate geography code might be ‘ROMO’ or ‘RMNP’.

Data Source is the originating source of the processed data.

Table 9. Source codes and data sources used by CGAT.

Source Code	Data Source
CRUCL20	CRU Version 2.0
DAYMET	Daymet
PRISM4K	PRISM 4 kilometer monthly/annual grids
SNAP	SNAP
SNODAS	SNODAS

Variable is the variable being measured (e.g., ‘ppt’ for PRISM precipitation). Variable codes are identical to those used by the respective data sources (see above).

Statistic represents analysis or aggregation of the source variable by the respective data sources. For example, PRISM calculates averages (avg) for their temperature grids and totals (tot) for monthly precipitation. Table 10 indicates what each code represents.

Table 10. Statistics codes used by CGAT to name the processed grids.

Statistic Code	Statistic Description
avg	average
obs	Instantaneous observation/snapshot
avg[time]	Average for a larger time step (e.g., 30 year avg)
tot	Total
wyAvg	The average for a water year (October-September)

The date is always represented by YYYYMMDDHH. If time divisions (day, hour) are irrelevant (e.g., for monthly data), the values are represented by ‘00’. In cases where there is a multi-year aggregation (e.g., 30 year averages), only the begin date is represented.

Aggregation (Batch)

The aggregation tools do not require you to specify one or more grids to process. Instead, you will need to provide some criteria to automatically select files. Thus, a critical step before running the aggregation tools is ensuring that the correct files are present (most often by running a Data Prep routine prior) and ensure that the file names conform to the naming standards defined above.

Aggregation tools will require most, if not all, of the following inputs:

- **Aggregation Statistic** – The statistic to be applied to the set of grids being aggregated
- **Operator** – Operator symbol when using count or percentile statistics
- **Value** – Threshold value related to statistic and operator when using count and percentile
- **New Statistic Name** – The label to call the aggregated set of grids. For example, when determining the maximum of seasonal precipitation (originally represented as totals), an appropriate statistic name might be *SeasonalMaxOfMonthlyTotals*.
- **Location of NC Grids** – The folder containing all of the netCDF grids to aggregate.
- **Grid Geographic Code** – This is the geographic code applied to the naming of the netCDF grids during the Data Prep process.
- **Year Range** – Range of years (e.g., 2005-2010)
- **Month Range** – Range of Months (e.g., 1-12)
- **Day Range** – Range of Days (e.g., 1-31)
- **Grid Data Source** – The data source of the grids being aggregated (e.g., PRISM, DAYMET)
- **Grid Parameter** – The parameter being represented in the grids to be aggregated (e.g., tmin, tmax, ppt, etc)
- **Grid File Statistic** – The statistic used to represent the original parameter in the files to be aggregated (e.g., tot, avg, etc.)
- **Extract Points** – (Optional) input that extracts values from resulting aggregation netCDF to provided points attribute table.
- **Extract Points Simple Field Names** – (Optional) input related to Extract Points. If checked, reports values at points with simple short field names in points attribute table.

Figure 9 provides an example of the aggregation tool. In this case, PRISM4K grids (e.g., ROMO_PRISM4k_ppt_tot_2002100000.nc) are used to calculation minimum annual precipitation values.

Figure 9. Example Aggregation: Months to Calendar Years

Statistics

The grid statistics tools all require the specification of multiple files to calculate the desired statistics. In most cases, new summary grids are created. For example, Figure 10 shows the calculation of the maximum of the annual minimum precipitation values. Tool inputs are well explained in the ArcGIS Tool Help sidebar.

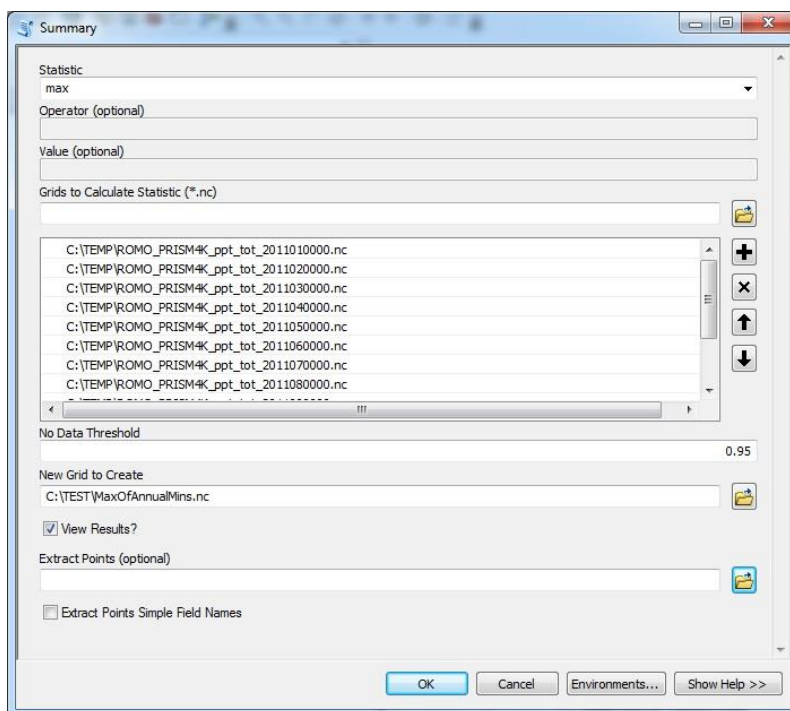


Figure 10. Example Summary Statistics

BioClimatic Variables, Percentile Rank, and Summary tool results can be previewed in ArcMap if the “View Results?” argument is checked. Keep in mind that if this argument is checked when calculating BioClimatic Variables, all 19 grids will be previewed. BioClimatic Variables and Summary tools have the optional input of a point feature class for data extraction of the resulting grid(s). In contrast to the other statistic tools which generate grids, Zonal creates a summary table (**Error! Reference source not found.**)

Table 11. Zonal Statistics Summary Table Fields.

<u>Field</u>	<u>Description</u>
UNIT_CODE	The name of this column is the same as the field defined in the shapefile or feature
ZONE_CODE	
COUNT	Number of cells intersecting the zone
AREA	The area of the zone
MIN	Minimum grid value found
MAX	Maximum grid value
RANGE	Range of grid values
MEAN	Average of grid values
STD	Standard deviation of grid values
SUM	Sum of grid values
VARIETY	Number of unique values for all cells
MAJORITY	Grid value that occurs most often
MINORITY	Grid value that occurs least often
MEDIAN	Median of grid values

FileName	Input netCDF file name
----------	------------------------

Utilities

The Utilities toolbox contains one custom script tool and all of the ArcGIS Multidimensional Toolbox tools. The custom script tool is named “Extract NetCDF By Points”. This tool extracts values for all provided netCDF files at provided point locations and reports them in the attribute table of the points. The values are reported in the attribute table with a field name that matches the file name of the netCDF file. Points should be a geodatabase point feature class because netCDF file names produced by the CGAT toolbox are longer than allowed field name lengths in a shapefile. There is an option for simplifying the field names that are added to the point attribute table when reporting the netCDF values so results could be exported to other table formats like .dbf and .xls. If simple field names are desired a new geodatabase table is created within the same geodatabase that logs the netCDF filename and its simple field name reported in the point attribute table.

ArcGIS 10.2 does not currently support automatic reading and writing netCDF (version 3) files. Therefore, to view a netCDF grid in ArcGIS, use the ‘Make netCDF raster layer’ within the Utilities toolbox. Keep in mind this is a temporary raster and will be deleted once the ArcMap session is terminated. Once a temporary raster layer is created it can be exported to any raster format.

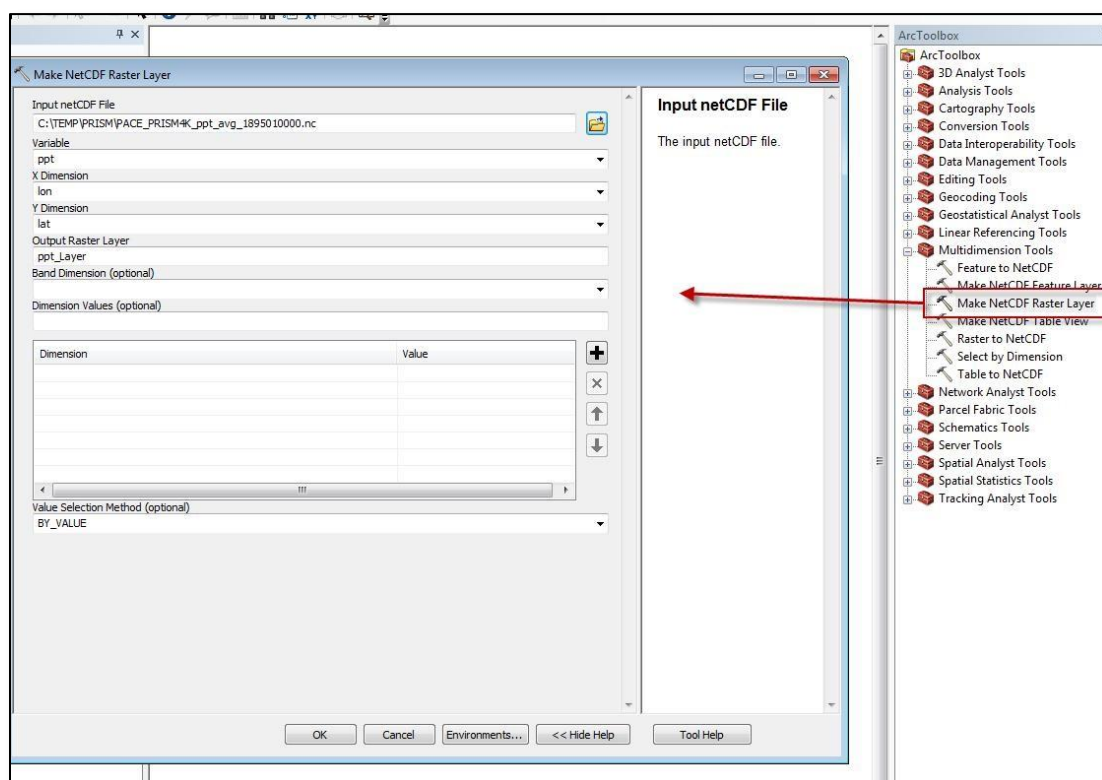


Figure 11. ArcToolbox window displaying how to create Raster layers from netCDF (.nc) files.

Troubleshooting

Questions, comments, concerns, and feedback are welcome and encouraged. Please contact Brent Frakes (brent_frakes@nps.gov).

Literature Cited

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