

User Guide For Gridded Water Balance Model Dataset

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Purpose

This document describes the characteristics of a gridded (GIS-based) water balance model data set covering the Continental United States (CONUS) at 1km resolution in both daily and monthly timesteps for the period 1980 - 2099. The data are available in Network Common Data Format (NetCDF) files that can be downloaded from the following URL:

<http://www.yellowstone.solutions/thredds/catalog.html>

In addition to providing downloads, the THREDDS server just referenced will also make spatial subsets of the data, produce maps, and provide time series extracts for point locations. Scripts for extracting data from the server can be obtained from the authors.

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Description of the Water Balance Model

Water balance modeling is a tool for increasing our understanding of climate influence on natural resources. Like balancing a check book, it is a way of tracking the balance of nature's most important asset. Most natural resources we manage are either water itself (springs, rivers, wetlands), or life that depends on water. Water and temperature interactions are based in physics that we can mathematically model. We find (and many others before us have too) that these modeled values are more strongly correlated with the things we manage than simple measures of temperature or precipitation.

We use a simple model based on methods described by Thornthwaite and Mather (1955) and Lutz et al. (2010). The model tracks the fate of precipitation after it falls. After precipitation (snow or rain) hits the ground it has three options: (1) Stay put temporarily as stored snow pack or soil moisture, (2) Go up, via evaporation or through plants via transpiration. (3) Go down and become either ground water or runoff to wetlands, lakes, streams, rivers. Temperature determines the time water is stored as snow and when it melts, as well as the rate of evapotranspiration. The movement of water between compartments depends on the amount of energy (heat) in the system and the amount of water available.

Versions of the Model

Dataset Versions:

Ver	Dates	Aggregates	Data inputs	Source
1	1980 - present	Daily	Daymet	Excel, R
1.5	2006-2099	Daily, monthly, annual	Future MACAv2MetData	http://www.yellowstone.solutions/thredds/catalog/daily_or_monthly/gcm/catalog.html
1.5	1979 - present	Daily, monthly, annual	Historical Gridmet	http://www.yellowstone.solutions/thredds/catalog/daily_or_monthly/v2_historical/gridmet_v_1_5_historical/catalog.html
2	1980-2019	Daily, Monthly	Daymet,	http://www.yellowstone.solutions/thredds/catalog/daily_or_monthly/v2_historical/catalog.html

Version 2 of the model uses Daymet historical data as input for daily temperature and precipitation. Snow Water Equivalent (SWE) is estimated using temperature-indexed equations (Lutz et al. 2010) in which the melt threshold temperature used in the snow estimation equations is different for each 1km grid cell, using values supplied by Jennings et al. 2018. Actual Evapotranspiration (AET) is calculated based on 30-year daily NDVI values, using methods provided by the USGS (Gabriel Senay, personal communication). Daily precipitation is adjusted into “effective precipitation” using an Igrid vegetation structure layer provided by Senay et al. (personal communication). During each day of model run, all soil water is available for AET, rather than being removed at a rate governed by equations found in Lutz et al. (2010).

Version 1.5 of the model For the historical period, this version of the model uses GRIDMET for its temperature and precipitation inputs. For the future period, it uses [MACA GCM](#) as its inputs for temperature and precipitation. Importantly, the MACA data were downscaled with Gridmet, so time series generated from 1980 – 2099 will be commensurate for this version of the model, with no breaks between the past and future. This version further differs from version 2 by **not** using the Senay NDVI correction to AET or the IGRID precipitation adjustment. During each day of the model run, water is removed from the soil at a rate governed by equations found in Lutz et al. 2010. These changes were made because it was realized that the NDVI / veg structure assumptions could not be easily extended into the future.

Output Variables

The output parameters of the model (available for download from the URL above) are defined as follows:

Potential Evapotranspiration (PET, mm): The amount of evaporation and transpiration (movement of water into the atmosphere by plants) that would occur if soil moisture were unlimited. Temperature, wind, solar radiation, cloudiness and a variety of other factors affect PET. Sixty to ninety percent of annual precipitation is evapotranspired back to the atmosphere, mostly through plant leaves. There are many ways to calculate PET. In the current model, we used methods described by Oudin et al (2005)

and Oudin et al. (2010). We also used a heat load correction that incorporated slope and aspect for each grid location, as described by Lutz et al. (2010).

Actual Evapotranspiration (AET, mm): AET is the water balance value that is most closely related to vegetation growth. When plants transpire vigorously they are alive and growing. If the water in the soil is insufficient to meet the evaporative demand of the atmosphere, then $AET < PET$. In version 2 of the model, AET will sometimes exceed PET because of the NDVI correction, which incorporates field data on vegetation structure and greenness.

Moisture Deficit (Deficit, mm): Use simple subtraction, i.e., $Deficit = PET - AET$. Deficit is the amount of water vegetation would use if it was available. Deficit can never be negative.

Soil water: The amount of water that is held in the soil. The model treats the soil like a bucket that can be filled by inputs (e.g. rain, snowmelt) and emptied by outputs (e.g. evaporation, transpiration). If the soil gets full, then runoff to streams results. Water holding capacity is the amount of water soil retains after it is saturated then drains. Think of a saturated sponge left on a counter without squeezing. Soil typically fills with water in winter and spring. As plants use water from soil it can be replenished by rain. If rain doesn't fall, deficit or summer drought occurs. Plants "drink" water from soil and soil stores water, but not all soils are equal. Some are shallow, some rocky, sandy, or loamy, thus different soils store different amounts of water. In the current model, we used SSURGO soil data from the Natural Resources Conservation Service to determine the water holding capacity for each area (Soil Survey Staff, NRCS, 2018). Units = mm.

Runoff (mm): When the soil water bucket overflows, the water is lost as runoff.

Accumulated Growing Degree Days (AGDD, mm): This is a traditional measure of heat for growing plants, calculated here with a base temperature of 10 °C. Plants develop through annual phenological stages (germination, first leaf or bud, flowering) based on availability of plant nutrients, water and heat. A single day's growing degree days is $GDD = ((\text{Daily Maximum Temperature} + \text{Daily Minimum Temperature}) / 2) - 10$. AGDD is the sum of all GDD for the water year. Water years run from October 1 – September 30 of the following year. Units = Degrees C.

Rain (mm): Rain = total daily precipitation – daily snow accumulation, where snow is taken directly as Snow Water Equivalent (SWE) increase from the Daymet input dataset.

Accumulated Snow Water Equivalent (SWE, mm): total SWE at each location. Estimated using equations described by Tercek and Rodman (2016) with melt threshold temperatures at each 1km grid cell provided by Jennings et al. (2018).

Technical Details of the Data Files

Output Data Characteristics

In all versions of the model, we have copied the NetCDF data structure used by Daymet. Details of the structure appear in Appendix 1. See also the Daymet documentation link above. Importantly,

both Daymet and our version 2 output data maintain 365 days in every year, regardless of leap years. During leap years, December 31 is omitted. Version 1.5 output data includes February 29 during leap years, but all the input and output grids have been reprojected and resampled to match version 2 (Daymet). The projection is Lambert Conformal Conic.

Functions Used to Make Monthly Summaries

The model was run on a daily time step and monthly summaries were generated by applying the following summary functions to the daily values for each month separately.

Soil Water = Mean

AET = Sum

PET = Sum

Deficit = Sum

Melt = Sum

Rain = Sum

Water input to soil = Sum

Runoff = Sum

Accumulated Precip = Last value of month

Accumulated SWE = Last value of month

Source Code Availability

The analytical code was written in Python version 3.6 (Millman and Aivazis 2011) using the Numpy and Scipy libraries (van der Walt et al. 2011) and run as parallel processes on the Amazon cloud. The source code can be downloaded here: [v2_code](#). And [v1.5 code](#).

Literature Cited

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Appendix 1 – Metadata for the 1980 Deficit file. All files have the same structure, which follows the structure used by Daymet. See

https://daac.ornl.gov/DAYMET/guides/Daymet_V3_Annual_Climatology.html for more detail.

Dataset type: Hierarchical Data Format, version 5

```
netcdf file: 1980_Deficit.nc4 {
  dimensions:
    x = 7814;
    y = 8075;
    time = 365;
    nv = 2;
  variables:
    float x(x=7814);
      :units = "m";
      :long_name = "x";
      :standard_name = "projection_x_coordinate";
      :_ChunkSize = 7814; // int

    float y(y=8075);
      :units = "m";
      :long_name = "y";
      :standard_name = "projection_y_coordinate";
      :_ChunkSize = 8075; // int

    float lat(y=8075, x=7814);
      :units = "degrees_north";
      :long_name = "lat";
      :standard_name = "latitude";
      :_ChunkSize = 1010, 977; // int

    float lon(y=8075, x=7814);
      :units = "degrees_east";
      :long_name = "lon";
      :standard_name = "longitude";
      :_ChunkSize = 1010, 977; // int

    float time(time=365);
      :long_name = "time";
      :calendar = "standard";
      :units = "days since 1980-01-01 00:00:00 UTC";
      :bounds = "time_bnds";
      :_ChunkSize = 365; // int

    short yearday(time=365);
      :long_name = "yearday";
      :_ChunkSize = 365; // int

    float time_bnds(time=365, nv=2);
      :long_name = "time_bnds";
      :_ChunkSize = 365, 2; // int
```

```

short lambert_conformal_conic;
:grid_mapping_name = "lambert_conformal_conic";
:longitude_of_central_meridian = -100.0; // double
:latitude_of_projection_origin = 42.5; // double
:false_easting = 0.0; // double
:false_northing = 0.0; // double
:standard_parallel = 25.0, 60.0; // double
:semi_major_axis = 6378137.0; // double
:inverse_flattening = 298.257223563; // double
:long_name = "lambert_conformal_conic";

float Deficit(time=365, y=8075, x=7814);
:cell_methods = "area: mean time: minimum";
:_FillValue = -9999.0f; // float
:long_name = "Deficit";
:units = "mm";
:missing_value = -9999.0f; // float
:coordinates = "lat lon";
:grid_mapping = "lambert_conformal_conic";
:_ChunkSize = 12, 279, 270; // int

// global attributes:
:_NCProperties = "version=1|netcdf5libversion=4.4.1|hdf5libversion=1.8.17";
}

```