National Aeronautics and Space Administration
Goddard Earth Science Data Information and
Services Center (GES DISC)

README Document for

RM-OBS/PU Potential Evapotranspiration and Supporting Forcing L4 3-Hourly 0.25x0.25 degree V001

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Jan 25 2019	Initial version	Suhung Shen & Justin Sheffield
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1.0 Introduction

This document provides basic information for using the dataset "RM-OBS/PU Potential Evapotranspiration and Supporting Forcing L4 3-Hourly 0.25x0.25 degrees V001" generated by Dr. Justin Sheffield from Terrestrial Hydrology Research Group at Princeton University.

This dataset consists of products of Potential Evapotranspiration (PET) based on near surface meteorology and surface radiation data derived from a combination of reanalysis, satellite and gridded gauge data. The rationale of the project is to reduce the error from the input meteorological forcing and provide a variety of widely used PET methods for different research and application purposes.

1.1 Algorithm Description

This gridded PET dataset is constructed from newly available near surface meteorology and radiation data using multiple physically-based PET methods. The baseline meteorology is taken from the updated Princeton Global Forcing dataset version 3 (PGF v3) and a newly developed long-term net radiation and ground heat flux dataset. The version 001 dataset is available at 3-hourly, 0.25-degree resolution for 1984-2006.

The PGF (Sheffield et al., 2006) dataset is developed at Princeton University primarily for driving off-line land surface models and hydrological models, and has been utilized successfully for regional climate and hydrological studies (e.g. Mueller et al., 2011; Sheffield et al., 2012; Chaney et al., 2014). It consists of 3-hourly, 0.25° resolution near-surface meteorology (including precipitation, temperature, pressure, downward surface shortwave, downward longwave radiation, specific humidity, and wind speed) for global land areas for the period of 1984-2016. PGF merges the NCEP- NCAR reanalysis (National Center for Environmental Prediction and National Center for Atmospheric Research; Kalnay et al., 1996) with the GPCP (Global Precipitation Climatology Project; Adler et al., 2012) and TMPA (TRMM Multi-Satellite Precipitation Analysis, Huffman et al., 2009) satellite-gauge precipitation, and CRU (Climatic Research Unit; New et al., 1999b; Harris et al., 2013) surface air temperature. All variables are spatially down- scaled to 0.25° using bilinear interpolation, with corrections to temperature and humidity based on elevation (Sheffield et al., 2006).

In order to produce long-term surface radiation up to the recent period, the SRB rel3.0 shortwave and rel3.1 longwave radiation at 1.0° spatial resolution and 3 hourly time step between 1984-2000 are merged with the surface downward shortwave radiation, downward longwave radiation, and upward longwave radiation from the CERES L3 SYN1deg Ed4A product spanning from 2000 to 2016. The relationship between the SRB and the CERES daily data for each month during the overlapping period of 2000-2007 is obtained by fitting a linear regression model. The grid-based regression parameters are applied to the daily SRB fluxes to remove the biases for the 1984-2000 period. The diurnal cycle of fluxes is corrected by shifting the 3-hourly SRB fluxes by the difference between the CERES and SRB daily values.

Liebethal & Foken (2006) evaluated six methods for ground heat flux (G) and found that the universal function of net radiation with a diurnal phase shift proposed by Santanello & Friedl (2003) works well when R_n is positive, as shown in Equation 1:

$$\frac{G}{R_n} = Acos\left[2\pi\frac{(\delta t + 10800)}{B}\right] \tag{1}$$

where *A* represents the maximum value of G/R_n, δt is time in seconds relative to solar noon, and *B* is an intercept parameter. A ranges from 0.31 for moist soil to 0.35 for dry soil, and B ranges from 74000 s for moist soil to 100000 s for dry soil.

To estimate 3 hourly G, the maximum of G/R_n (*A*) is first determined using vegetation cover fraction, which represents the extent of canopy and soil moisture condition, based on Choudhury (1987) and Kustas et al. (1993):

$$A = (G/R_n)_{max} = \begin{cases} 0.4 \cdot \exp(-0.5\text{LAI}) & \text{LAI} \leq 4 \\ 0.05 & \text{LAI} > 4 \end{cases} \tag{2}$$

The B parameter in Equation 1 is then estimated based on the linear regression relation found by Santanello & Friedl (2003):

$$B = 1729 \cdot \frac{A - 0.088}{0.0074} + 65013 \tag{3}$$

In order to calculate solar noon, the equation of time E_t (in minutes) is first estimated following Ran et al. (2007):

$$\begin{aligned} E_t = 229.18 \cdot (0.000075 + 0.001868cos\Gamma - 0.032077sin\Gamma \\ -0.014615cos2\Gamma - 0.040890sin2\Gamma) \end{aligned} \tag{4}$$

where the day angle (Γ) is calculated in radians:

$$\Gamma = \frac{2\pi(doy - 1)}{N_{day}} \tag{5}$$

where doy is the day of year, N_{day} = 366 for leap years, N_{day} = 365 for regular years.
Solar noon (SN) in minutes is then calculated for a given longitude (LON, in degrees, positive to the east of the Prime Meridian) and the equation of time (E_t) in minutes:

$$SN = 720 - 4 \cdot LON - E_t \tag{6}$$

Given an hour of the day, the relative difference δt (in seconds) in Equation 1 between the time $hour$ (=0, 3, 6, ..., 21 within one day) and solar noon SN can be calculated as:

$$\delta t = 60 \cdot (60 \cdot hour - SN) \tag{7}$$

$$\delta t = \begin{cases} 3600 \cdot \left(hour - \frac{SN}{60}\right) & \left|hour - \frac{SN}{60}\right| \leq 12 \\ 3600 \cdot \left(24 - \left|hour - \frac{SN}{60}\right|\right) & \left|hour - \frac{SN}{60}\right| > 12 \end{cases} \tag{8}$$

Finally, G is estimated according to the sign of R_n:

$$G = \begin{cases} 0.4 \cdot R_n & R_n \leq 0 \\ Acos\left[\frac{2\pi(\delta t + 10800)}{B}\right] \cdot R_n & R_n > 0 \end{cases} \tag{9}$$

PET at 3 hourly time step and 0.25 degree resolution is estimated with four widely used PET methods: open-water Penman equation, Reference crop evapotranspiration for high crop and low crop using the UN Food and Agricultural Organization (FAO) approach, and Priestley-Taylor equation.

Open-water Penman Equation (PET-OW)

The Penman method is a classical combined approach that estimates PET as the evaporation rate occurring from a wet surface without surface resistance (Penman, 1948). It requires observations of surface net radiation, near-surface air temperature, wind speed, and specific humidity. The OW equation assuming PET occurring from open water surface, is given by Shuttleworth (1993):

$$PET = \frac{\Delta}{\Delta + \gamma} \cdot \frac{(R_n - G)}{\lambda} + \frac{\gamma}{\Delta + \gamma} \cdot \frac{6.43(1 + 0.536u_2)D}{\lambda} \tag{10}$$

where PET is in mm d^{-1}, Δ is the slope of the saturation vapor pressure curve at the temperature of interest (kPa K^{-1}), γ is the psychrometric constant (kPa K^{-1}), $(R_n - G)$ is the available energy A (MJ m^{-2} d^{-1}), which is the difference between the surface net radiation and ground heat, λ is the latent heat of vaporization (MJ kg^{-1}), u_2 is the wind speed at 2-m height (m s^{-1}), and D is the vapor pressure deficit (VPD, kPa).

Reference Crop Evapotranspiration Penman-Monteith equation using FAO56 approach

The reference crop evapotranspiration equation is a specific application of the Penman-Monteith equation for the crop and short-grass reference surface and is also widely used for estimating PET. The FAO equation is given by ASCE-EWRI (2005):

$$PET = \frac{0.408\Delta(R_n - G) + \frac{C_n u_2}{T_a + 273}\gamma D}{\Delta + \gamma(1 + C_d u_2)} \tag{11}$$

where PET is in mm d^{-1}, Δ is the slope of the saturation vapor pressure curve at the temperature of interest (kPa K^{-1}), γ is the psychrometric constant (kPa K^{-1}), $(R_n - G)$ is the available energy A (MJ m^{-2} d^{-1}), u_2 is the wind speed at 2-m height(m s^{-1}), T_a is the air temperature at 2-m height (degree C), and D is the vapor pressure deficit (VPD, kPa). C_n (K mm s^3 Mg^{-1} d^{-1}) is a constant describing the effect of aerodynamic conductance that increases with canopy height. The denominator $\Delta + \gamma(1 + C_d u_2)$ is a special form of the denominator of the Penman-Monteith Equation $\Delta + \gamma(1 + r_s/r_a)$. C_d ($\frac{r_s}{r_a u_2}$, s m^{-1}) is a parameter that increases with the ratio of surface resistance to aerodynamic resistance. There are two sets of C_n and C_d: tall reference (PET-tall: C_n=1600, C_d=0.38) and short reference (PET-short: C_n=900, C_d=0.34) .

Priestley-Taylor Equation (PET-PT)

The Priestley-Taylor equation (1972) describes evaporation from a well-watered surface based on the equilibrium evaporation under conditions of minimal advection. It is a simplified form of the Penman equation and represents PET under "potential" atmospheric conditions when water is unlimited, given by

$$PET_{pt} = 1.26 \frac{\Delta(R_n - G)}{\lambda(\Delta + \gamma)} \tag{12}$$

This dataset consists of the following two versions:

PET Version-1 (PET V1): The global dataset based on the Penman, PT, and FAO equations spanning the 23-year period 1984-2006. The dataset uses satellite radiation data from the NASA/GEWEX Surface Radiation Budget (SRB) and meteorology from the Princeton Global Forcing dataset (Sheffield et al., 2006), which is updated to version 3 (PGF-V3). The ground heat flux is based on the dataset produced in Siemann et al. (2018).

PET Version-2 (PET V2): The global dataset is based on the Penman, PT, and FAO equations spanning the 33-year period 1984-2016. The radiation data from the PET V1 dataset is updated using a combination of the SRB radiation and the latest satellite radiation from the Clouds and the Earth's Radiant Energy System (CERES) satellite sensor and extended until the end of 2016. The upward short-wave radiation is estimated using the GLASS satellite albedo.

Table 1: Overview of the forcing datasets

Forcing	PET V1	PET V2
Radiation	CFSR	SRB rel3.0, 3.1
	SRB rel3.0, 3.1	CERES L3 SYN1deg Ed4A
		GLASS albedo v1.0
Air temperature	PGF V3	PGF V3
Specific humidity	PGF V3	PGF V3
Wind speed	PGF V3	PGF V3

1.2 Data Disclaimer

1.2.1 How to cite this dataset

If you use this data in a publication, we hope you will acknowledge the project appropriately. For instance:

> We thank the Terrestrial Hydrology Research Group at Princeton University for their efforts in producing the data records.

The appropriate reference(s) for the algorithms should also be cited:

- Peng, L., Wood, E. F., and Sheffield, J., Development of a long-term global atmospheric evaporative demand dataset, *Journal of Hydrometeorology*. To be submitted.

NASA requests that you include the following acknowledgment in papers published using this dataset:

> "The data used in this study were acquired as part of the mission of NASA's Earth Science Division and archived and distributed by the Goddard Earth Sciences (GES) Data and Information Services Center (DISC)."

Or add the following data citation as a reference:

> Sheffield, J. at Princeton University, NASA/GSFC/GES_DISC (2018), RM-OBS/PU Potential Evapotranspiration and Supporting Forcing L4 3-hourly 0.25x0.25 degree V001, Greenbelt, Maryland, USA, Goddard Earth Sciences Data and Information Services Center (GES DISC), Accessed: **[*Data Access Date*]**, 10.5067/GPZDZYELYG1A

We would appreciate receiving a copy of your publication, which can be sent to the GES DISC Help Desk by email: gsfc-dl-help-disc@mail.nasa.gov

1.2.2 Contact Information

If you have questions or feedback about this dataset and data access, please contact:

GES DISC Help Desk
Code 610.2 NASA/Goddard Space Flight Center Greenbelt, MD 20771
Phone: 301-614-5224 Fax: 301-614-5268
Email: gsfc-dl-help-disc@mail.nasa.gov

2.0 Data Organization

The variables in dataset are gridded, 3-hourly mean that are stored as a 3-dimensional array with dimension 600 x 1440 x 8 for each day.

2.1 Data Format and File Naming Convention

The data files are in NetCDF-4 format, complaint with CF convention version 1.6.

The file naming convention is as follows:

PET_MULTISEN_025.L4.<Version>.<DateTime>.nc

Where:

- Version = data processing version (e.g. V001 and V002)
  - V001 = PET V1
  - V002 = PET V2
- DateTime = the begin date and time in format YYYYMMDDT00Z (YYYY=4 digit year, MM=2 digit month, DD=2 digit day; e.g. 19850101T00Z)

Filename example: PET_MULTISEN_025.L4.V001.19850101T00Z.nc

2.2 Data Fields

The PET variables are estimated at a 3 hourly temporal resolution and 0.25x0.25 degree spatial resolution globally over land, covering latitude (60^{o}S-90^{o}N) and longitude (-180-180). The starting point is at (lat=-59.875, lon=-179.875, time=00Z). Missing values in the files are set to -9.99e+08. In addition to PET, the dataset include six input science variables and three dimension variables listed in the following table.

Table 2: Data Fields

SDS_name	Description	Unit	Datatype
Petpen	Potential Evapotranspiration from Penman method (Shuttleworth, 1993)	Mm	Float
Petpt	Potential Evapotranspiration from Priestley-Taylor method (Priestley and Taylor, 1972)	Mm	Float
Petref	Reference Crop Evapotranspiration (Allen, 1998)	Mm	Float
Rnet	Net Radiation from Surface Radiation Balance (SRB) data product (Stackhouse et al., 2011)	W/m2	Float
Rflag	Net Radiation infill flag (0=none, 1=filled)	-	Float
Ghflx	Ground Heat Flux from method of (Sellers, 1965)	W/m2	Float

Gflag	Ground Heat Flux infill flag (0=none,1=filled)	-	Float
Tas	Air Temperature at 2m height	Kelvin	Float
Shum	Specific Humidity at 2m height	Kg/kg	Float
Pres	Air Pressure at Surface	Pa	float
Wind	Wind speed at 10m height	m/s	Float
Lat	Latitude	degrees_north	Double
Lon	Longitude	degrees_east	Double
Time	Time (minutes since 1984-01-01 00:00)	minutes	Double

3.0 Metadata Contents

3.1 SDS Local Attributes

Each science data field contain its local attributes including missing value (_FillValue), Unit, long_name, and standard_name. For example:

```
float petpen(time, lat, lon) ;
        petpen:_FillValue = -9.99e+08f ;
        petpen:units = "mm" ;
        petpen:long_name = "3-hour Mean Potential Evapotranspiration from Penman
            method (Shuttleworth, 1993)" ;
        petpen:standard_name = "water_potential_evapotranspiration_amount" ;
```

3.2 Global Attributes

In addition to SDS arrays containing variables and dimension scales, global metadata is also stored in the files. Some metadata are required by standard conventions, some are present to meet data provenance requirements and others as a convenience to use this dataset. A summary of global attributes present in all files as in the following example:

PET_MULTISEN_025.L4.V001.19840101T00Z.nc

Global attributes:

SourceLongName = "Hybrid of NCEP/NCAR Reanalysis Model and Observations by Princeton University"
SourceShortName = "RM-OBS/PU"
ContactPersonName = "Justin Sheffield"
ontactPersonRole = "Data producer"
ContactPersonEmail = "justin@princeton.edu"
ContactPersonAddress = "Dept CEE, Princeton University, Princeton NJ 08544"
RelatedURL = "http://hydrology.princeton.edu/data.pgf.php"
SpatialCoverage = "Global"
ProcessingDate = "2018-12-09"
ProcessingCenter = "Princeton University"
InputOriginalFile = "/home/raid22/justin/global/forcings/V3/global/0.25deg/3hourly"
ProductGenerationAlgorithm = "See Sheffield et al (2006)"
ProductGenerationAlgorithmVersion = "Last updated in October 2018"
ProductReference = "Sheffield, J., G. Goteti, and E. F. Wood, 2006: Development of a 50-yr high-resolution global dataset of meteorological forcings for land surface modeling, J. Climate, 19 (13), 3088-3111"
OriginalFileVersion = "Last updated in August 2017" ;
OriginalFileProcessingCenter = "Princeton University"
DataQuality = "Assessment in progress"
Conventions = "CF-1.6"
VersionID = "1"
LocalGranuleID = "PET_MULTISEN_025.L4.V001.19840101T00Z.nc"
Format = "NetCDF4"
RangeBeginningDate = "1984-01-01"
RangeBeginningTime = "00:00:00"
RangeEndingDate = "1984-01-01"
RangeEndingTime = "21:00:00"
NorthBoundingCoordinate = "90.0"
WestBoundingCoordinate = "-180.0"
SouthBoundingCoordinate = "-60.0"
EastBoundingCoordinate = "180.0"
LatitudeResolution = "0.25"
LongitudeResolution = "0.25"
MapProjection = "Cylindrical Equidistant Projection"
GeodeticDatum = "WGS84"
Calendar = "standard"
ContactPerson2Name = "Justin Sheffield"

ContactPerson2Role = "Data producer"
ContactPerson2Email = "justin@princeton.edu"
Processor = "GrADS v2.1.a2 and process_data.gs"
ProductionDateTime = "2018-12-09"
PGEVersion = "1.0.0"
LongName = "RM-OBS/PU Potential Evapotranspiration and Supporting Forcing L4 3-hourly 0.25x0.25 degree V001"
ShortName = "PET_PU_3H025"
IdentifierProductDOI = "10.5067/GPZDZYELYG1A"
IdentifierProductDOIAuthority = "http://dx.doi.org/"

4.0 Data Services

The data is stored online that may be find and accessed through a number of methods

4.1 Direct data access

The data can be downloaded or remote accessed through HTTPS service:

https://measures.gesdisc.eosdis.nasa.gov/data/PET_PU/PET_PU_3H025.001/

or OPeNDAP service:

https://measures.gesdisc.eosdis.nasa.gov/opendap/PET_PU/PET_PU_3H025.001/

4.2 Download subsetted data

If a user is interested only a few variables over a region, the data can be downloaded through the subsetting service at GES DISC. For example:

- Start with GES DISC page: https://disc.gsfc.nasa.gov/
- Enter dataset name as keyword "**PET_PU_3H025**" to search under catalog "Data Collections"
- Click on "**Subset/Get Data**" button under the dataset name
  For more information about this dataset, click on the dataset name, which goes to the dataset landing page

- Provide interested temporal and spatial range, and select interested variables, then following instruction on the data download page

A tutorial of how to use the subset service can be found on the GES DISC web page under "How-to".

> How to use the Level 3 and 4 Subsetter and Regridder

4.3 Help resources

Online helps are available under Tools and Resources on GES DISC page (https://disc.gsfc.nasa.gov), such as HowTo and FAQ etc.

If you need assistance or wish to report a problem:

Email: gsfc-dl-help-disc@mail.nasa.gov
Voice: 301-614-5224
Fax: 301-614-5268

Address:
Goddard Earth Sciences Data and Information Services Center
NASA Goddard Space Flight Center
Code 610.2 Greenbelt, MD 20771 USA

5.0 Options for Reading the Data

5.1 Command Line Utilities

ncdump

ncdump is an easy use command line tool developed by the Unidata group that is able to review metadata and data in text format quickly.

The most common use of ncdump is with the –h option, in which only the header information is displayed.

> ncdump [-c|-h] [-v ...] [[-b|-f] [c|f]] [-l len] [-n name] [-d n[,n]] filename
> Options/Arguments:

[-c] Coordinate variable data and header information
[-h] Header information only, no data
[-v var1[,...]] Data for variable(s) <var1>,... only data
[-f [c|f]] Full annotations for C or Fortran indices in data
[-l len] Line length maximum in data section (default 80)
[-n name] Name for netCDF (default derived from file name)
[-d n[,n]] Approximate floating-point values with less precision filename File name of input netCDF file

For more information about install and usage of ncdump can be found from Unidata (https://www.unidata.ucar.edu/software/netcdf/netcdf-4/newdocs/netcdf/NetCDF-Utilities.html

NCO

NCO is a powerful command line toolkit developed by the Earth System Science group in University of California, Irvine, which can manipulate and analyzes data stored in NetCDF. More information can be found at http://nco.sourceforge.net/

5.2 Tools/Programming

This section lists some tools, but not limited, that may be used to read, visualize, and process this dataset:

Panoply

Panoply is a data viewer that displays geo-referenced arrays in NetCDF, HDF, and GRIB formats. The first time user may download the software from NASA Goddard Institute for Space and Studies (http://www.giss.nasa.gov/tools/panoply/). Examples to use Panoply for GES DISC archived data can be found in data HowTo:

https://disc.gsfc.nasa.gov/information/howto?keywords=panoply

GrADS

The Grid Analysis and Display System (GrADS) is an interactive tool developed by the COLA group (Center for Ocean-Land-Atmosphere Studies) at George Mason University (http://cola.gmu.edu/grads/), which can read, visualize, and analyze gridded (i.e. Level 3 and Level 4) data file in a number of formats, including NetCDF, HDF, binary, and GRIB, as well as station data in BUFR format. Examples at GES DISC data HowTo are:

https://disc.gsfc.nasa.gov/information/howto?keywords=grads

HDFView
HDFView is a Java based graphical user interface created by the HDF Group which can be used to browse data in HDF and NetCDF format. The utility allows users to view all objects in an HDF file hierarchy which is represented as a tree structure.
HDFView can be downloaded from: https://www.hdfgroup.org/downloads/hdfview/

ArcGIS
This dataset can be read easily with ArcGIS software as its metadata is CF complaint. Please follow the instruction in this HowTo to read the data:
How to Import Gridded Data in NetCDF Format into ArcGIS

6.0 More Information

Additional information related to this dataset can be found in the documentation section of the product landing page:

https://disc.gsfc.nasa.gov/datasets/PET_PU_3H025.001/summary

and Hydrology Project Web Site at Princeton University
http://hydrology.princeton.edu/data.pgf.php

7.0 Acknowledgements

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