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 V002

Prepared by Suhung Shen, Justin Sheffield, Liqing Peng, and Ashley Heath
Last revision: October 22, 2021

Prepared By:

Suhung Shen
Name
GES DISC
GSFC Code 610.2

January 25, 2021
Date

Justin Sheffield
Name
Princeton University

Reviewed By:

Lena Iredell

October 10, 2021

Goddard Earth Sciences Data and Information Services Center (GES DISC)
http://disc.gsfc.nasa.gov
NASA Goddard Space Flight Center
Code 610.2
Greenbelt, MD 20771 USA

Reviewer Name Date
GES DISC
GSFC Code 610.2

Goddard Space Flight Center
Greenbelt, Maryland

Revision History

Revision Date	***Changes***	***Author***
Jan 25 2019	Initial version	Suhung Shen & Justin Sheffield
Jul 12 2019	revision	Justin Sheffield & Liqing Peng
Oct 6 2021	Revision to include Version 2 and update the algorithms	Liqing Peng & Ashley Heath

Table of Contents

Contents

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" 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 PGF v3 (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 radiation, 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), 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).

To produce a long-term surface radiation dataset up to the recent period, the surface radiation balance (SRB) rel3.0 shortwave and rel3.1 longwave radiation at 1.0° spatial resolution and 3-hourly time steps 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.

Ground heat flux (G) is estimated using a universal function of net radiation with a diurnal phase shift (Santanello & Friedl, 2003; Liebethal & Foken, 2006) when net radiation (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):

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

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):

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

where the day angle ($\mathit{\Gamma}$) is calculated in radians:

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

where doy is the day of year, N_{day} = 366 for leap years, N_{day} = 365 for common 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 steps 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 assumes 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 (m s^{-1}), T_a is the air temperature at 2-m (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. The dataset uses a short reference height (PET-short: C_n=900, C_d=0.34), which refers to a *short* crop with an approximate height of .12 m (such as clipped, cool-season grass).

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:

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

1.2 Specifications of PET_PU_3H025

1.2.1 PET_PU_3H025_001

The PET Version-1 global dataset is based on the Penman, PT, and FAO short-crop 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).

1.2.2 PET_PU_3H025_002

The PET Version-2 (PET V2) global dataset is based on the Penman, PT, and FAO equations spanning the 33-year period 1984-2016. The radiation data from the PET V2 dataset is extended to year 2016 using a scaled 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 Global LAnd Surface Satellite (GLASS) albedo. The ground heat flux is estimated based on a function of net radiation with a diurnal phase shift.

Table 1: Overview of the forcing datasets for V1 and V2

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

1.3 Data Disclaimer

1.3.1 Data Citation and Acknowledgement

If you use these 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. (2019). Variability of Atmospheric Evaporative Demand [Doctoral dissertation, Princeton University]. http://arks.princeton.edu/ark:/88435/dsp01tq57nt954
- Peng, L., Zeng, Z., Wei, Z., Chen, A., Wood, E. F., & Sheffield, J. (2019). Determinants of the ratio of actual to potential evapotranspiration. *Global change biology*, *25*(4), 1326-1343. 10.1111/gcb.14577

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 V002, Greenbelt, Maryland, USA, Goddard Earth Sciences Data and Information Services Center (GES DISC), Accessed: **[*Data Access Date*]**, 10.5067/R1O090COR372

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

1.3.2 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

1.4 What's New?

1.4.1 What is new about PET_PU_3H025_002?

The PET Version-2 global dataset is based on the Penman, PT, and FAO equations spanning the 33-year period 1984-2016. There are several improvements compared to the PET V1. The radiation data from the PET V2 dataset is extended to year 2016 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. The ground heat flux is estimated based on a function of net radiation with a diurnal phase shift.

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, compliant 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.V002.19850101T00Z.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°S-90°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 includes six input science variables and three-dimension variables listed in the following table.

Table 2.0: Data Fields in PET_MULTISEN_025 V1.

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

Table 2.1: Data Fields in PET_MULTISEN_025 V2.

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
ghflx	Ground Heat Flux from method of (Sellers, 1965)	W/m2	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 is shown in the following example:

PET_MULTISEN_025.L4.V002.19850104T00Z.nc

Global attributes:

SourceLongName = "Hybrid of NCEP/NCAR Reanalysis Model and Observations by Princeton University"
SourceShortName = "RM-OBS/PU"
ContactPersonName = "Justin Sheffield"
ContactPersonRole = "Data producer"
ContactPersonEmail = "justin@princeton.edu, justin.sheffield@soton.ac.uk"
ContactPersonAddress = "Dept CEE, Princeton University, Princeton NJ 08544 Dept Geography and Env. Sciences, University of Southampton, Southampton, UK"
RelatedURL = "http//hydrology.princeton.edu/data.php"
SpatialCoverage = "Global"
ProcessingDate = "2021-04-02"
ProcessingCenter = "Princeton University"
InputOriginalFile = "/home/air2/justin/projects/project_measures_pet"
ProductGenerationAlgorithm = "See Sheffield et al (2006)"
ProductGenerationAlgorithmVersion = "Last updated in February 2021"
ProcessingLevel = "Level 4"
ProductReference = "Peng, L., M. Pan, H. Beck, T. Roy, Z. Zeng, A. Chen, E. F. Wood, and J. Sheffield, in prep. A long-term global potential evapotranspiration dataset based on multisource observations; Shen, S., H. Rui, D. Ostrenga, C. Loeser, W. L. Teng, J. Sheffield, and D. L. Meyer, 2019 American Geophysical Union, Fall Meeting 2019, abstract #GC43J-1382; 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,";
OriginalFileVersion = "Last updated in May 2019"
OriginalFileProcessingCenter = "Princeton University"
DataQuality = "Assessment in progress"
Conventions = "CF-1.6"
VersionID = "2"
LocalGranuleID = "PET_MULTISEN_025.L4.V002.19850104T00Z.nc"
Format = "NetCDF4"
RangeBeginningDate = "1985-01-04"
RangeBeginningTime = "000000"
RangeEndingDate = "1985-01-04"
RangeEndingTime = "210000"
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, justin.sheffield@soton.ac.uk"
Processor = "GrADS v2.1.a2 and process_data.gs"
ProductionDateTime = "2021-04-02"
PGEVersion = "1.0.0"
LongName = "RM-OBS/PU Potential Evapotranspiration and Supporting Forcing L4 3-hourly 0.25x0.25 degree V002"
ShortName = "PET_PU_3H025"
IdentifierProductDOI = "10.5067/R1O090COR372"
IdentifierProductDOIAuthority = "http//dx.doi.org/"

4.0 Data Services

The data is stored online and may be found and accessed through several methods.

4.1 Direct data access

The data can be downloaded or remote accessed through HTTPS service:
PET V1: https://measures.gesdisc.eosdis.nasa.gov/data/PET_PU/PET_PU_3H025.001/
PET V2: https://measures.gesdisc.eosdis.nasa.gov/data/PET_PU/PET_PU_3H025.002/

or OPeNDAP service:
PET V1: https://measures.gesdisc.eosdis.nasa.gov/opendap/PET_PU/PET_PU_3H025.001/
PET V2: https://measures.gesdisc.eosdis.nasa.gov/opendap/PET_PU/PET_PU_3H025.002/

4.2 Download subsetted data

If a user is interested in 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 ranges, and select interested variables, then follow the instructions on the data download page

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)

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/

CDO

CDO is a collection of command line operators to manipulate and analyze Climate and NWP model Data. CDO is a large tool set for working on climate and NWP model data. NetCDF 3/4, GRIB 1/2 including SZIP (or AEC) and JPEG compression, EXTRA, SERVICE and IEG are supported as IO-formats. Apart from that CDO can be used to analyze any kind of gridded data not related to climate science.
CDO has very small memory requirements and can process files larger than the physical memory.

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&page=1

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&page=1

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's landing page:

PET V1: 10.5067/GPZDZYELYG1A
PET V2: 10.5067/R1O090COR372

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

7.0 Acknowledgements

This project is funded by NASA's Making Earth Science Data Records for Use in Research Environments (MEaSUREs) Program through the project entitled "Development of Consistent Global Long-Term Records of Atmospheric Evaporative Demand".

References

Peng, L. (2019). Variability of Atmospheric Evaporative Demand [Doctoral dissertation, Princeton University]. http://arks.princeton.edu/ark:/88435/dsp01tq57nt954

Peng, L., Zeng, Z., Wei, Z., Chen, A., Wood, E. F., & Sheffield, J. (2019). Determinants of the ratio of actual to potential evapotranspiration. *Global change biology*, *25*(4), 1326-1343. 10.1111/gcb.14577

Adler, R. F., Gu, G., & Huffman, G. J. (2012). Estimating Climatological Bias Errors for the Global Precipitation Climatology Project (GPCP). *Journal of Applied Meteorology and Climatology*, *51*(1), 84–99. https://doi.org/10.1175/jamc-d-11-052.1

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. *FAO, Rome*, *300*(9), D05109,

ASCE-EWRI. (2005). *The ASCE standardized reference evapotranspiration equation*. (R. G. Allen, I. A. Walter, R. Elliott, T. A. Howell, D. Itenfisu, & M. Jensen, Eds.) (p. 4). Reston, VA 20191: American Society of Civil Engineers.

Chaney, N. W., Sheffield, J., Villarini, G., & Wood, E. F. (2014). Development of a High-Resolution Gridded Daily Meteorological Dataset over Sub-Saharan Africa: Spatial Analysis of Trends in Climate Extremes. *Journal of Climate*, *27*(15), 5815–5835. https://doi.org/10.1175/jcli-d-13-00423.1

Choudhury, B. J. (1987). Relationships between vegetation indices radiation absorption, and net photosynthesis evaluated by a sensitivity analysis. *Remote Sensing of Environment*, *22*(2), 209–233. https://doi.org/10.1016/0034-4257(87)90059-9

Harris, I., Jones, P. D., Osborn, T. J., & Lister, D. H. (2013). Updated high-resolution grids of monthly climatic observations - the CRU TS3.10 Dataset. *International Journal of Climatology*, *34*(3), 623–642. https://doi.org/10.1002/joc.3711

Kalnay, E., Kanamitsu, M., Kistler, R., Collins, W., Deaven, D., Gandin, L., … Joseph, D. (1996). The NCEP/NCAR 40-Year Reanalysis Project. *Bulletin of the American Meteorological Society*, *77*(3), 437–471. https://doi.org/10.1175/1520-0477(1996)077<0437:tnyrp>2.0.co;2

Kustas, W. P., Daughtry, C. S. T., & Oevelen, P. J. V. (1993). Analytical treatment of the relationships between soil heat flux/net radiation ratio and vegetation indices. *Remote Sensing of Environment*, *46*(3), 319–330. https://doi.org/10.1016/0034-4257(93)90052-y

Liebethal, C., & Foken, T. (2006). Evaluation of six parameterization approaches for the ground heat flux. *Theoretical and Applied Climatology*, *88*(1-2), 43–56. https://doi.org/10.1007/s00704-005-0234-0

Mueller, B., Seneviratne, S. I., Jimenez, C., Corti, T., Hirschi, M., Balsamo, G., … Zhang, Y. (2011). Evaluation of global observations-based evapotranspiration datasets and IPCC AR4 simulations. *Geophysical Research Letters*, *38*(6), n/a–n/a. https://doi.org/10.1029/2010gl046230

New, M., Hulme, M., & Jones, P. (1999). Representing Twentieth-Century SpaceTime Climate Variability. Part I: Development of a 196190 Mean Monthly Terrestrial Climatology. *Journal of Climate*, *12*(3), 829–856. https://doi.org/10.1175/1520-0442(1999)012<0829:rtcstc>2.0.co;2

Penman, H. L. (1948). Natural evaporation from open water, bare soil and grass. *Proceedings of the Royal Society of London Series A*, *193*, 120–145.

Priestley, C. H. B., & Taylor, R. J. (1972). On the assessment of surface heat flux and evaporation using large-scale parameters. *Monthly weather review*, *100*(2), 81-92, DOI: 10.1175/1520-0493(1972)100<0081:OTAOSH>2.3.CO;2

Ran, H., Thomas, R., & Mavris, D. (2007). A Comprehensive Global Model of Broadband Direct Solar Radiation for Solar Cell Simulation. In *45th AIAA Aerospace Sciences Meeting and Exhibit*. American Institute of Aeronautics and Astronautics. doi.org/10.2514/6.2007-33

Santanello, J. A., & Friedl, M. A. (2003). Diurnal Covariation in Soil Heat Flux and Net Radiation. *Journal of Applied Meteorology*, *42*(6), 851–862. https://doi.org/10.1175/1520-0450(2003)042<0851:dcishf>2.0.co;2

Siemann, A. L., Chaney, N., & Wood, E. F. (2018). Development and validation of a long term, global, terrestrial sensible heat flux dataset. *Journal of Climate*. 31 (15), 6073-6095 DOI: 10.1175/JCLI-D-17-0732.1

Sheffield, J., Goteti, G., & Wood, E. F. (2006). Development of a 50-year high-resolution global dataset of meteorological forcings for land surface modeling. *Journal of Climate*, *19*(13), 3088-3111, DOI: 10.1175/JCLI3790.1

Shuttleworth, W.J. (1993). Chapter 4-Evaporation. In: *Handbook of Hydrology* (ed Maidment DR). McGraw-Hill, Sydney, Australia.

Wielicki B A, Barkstrom B R, Harrison E F, et al. (1996). Clouds and the Earth's Radiant Energy System (CERES): An earth observing system experiment. Bulletin of the American Meteorological Society, 77(5): 853–868, DOI: 10.1175/1520-0477(1996)077<0853:CATERE>2.0.CO;2