**National Aeronautics and Space Administration**

**Goddard Earth Sciences Data and Information Services Center (GES DISC)**

# README Document for SRB/GEWEX Evapotranspiration (Penman-Monteith) Level-3 3-hour 0.5-degree

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Revision History

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| 01/27/17 | Some rewriting and editing from the original provided by Ming Pan | Bill Teng |
| 03/30/17 | Fixed two bad links | Bill Teng |

# Table of Contents

# 1.0 Introduction

This document provides basic information for using the SRB/GEWEX Evapotranspiration (Penman-Monteith) Level-3 3-hour 0.5-degree data set. This data set was generated with a focus on providing global scale land surface evapotranspiration estimates.

## 1.1 Data Set Description

The SRB/GEWEX Evapotranspiration (Penman-Monteith) Level-3 3-hour 0.5-degree data set was created as part of the "Developing Consistent Earth System Data Records for the Global Terrestrial Water Cycle" MEaSUREs Project. Evapotranspiration provides the critical link between the water and energy cycles within the Earth system. Better representation of the spatial distribution and temporal development of surface evapotranspiration is needed, not only to improve the description of water vapor exchanges for global water budget estimation, but also to advance our understanding of the climate system.

The Penman-Monteith (PM) algorithm uses a standard PM combination equation (Monteith, 1965) with a high level parameterization of the surface resistance to represent the vegetation response to environment factors. The PM equation is

$$\lambda ET = \left(\Delta(R_{net} - G_{flux}) + \rho_a \cdot C_p \cdot VPD / r_a\right) / \Delta + \gamma \cdot \left(1 + r_s / r_a\right) \quad (1)$$

where $\lambda ET$ is the latent heat flux (or evapotranspiration flux * unit latent heat of vaporization), $R_{net} - G_{flux}$ is net irradiance minus ground heat flux, $\rho_a$ is the air density, $C_p$ is the specific heat at constant pressure, $VPD$ is the vapor pressure deficit, $\Delta$ is the slope of the saturation vapor pressure-temperature curve ($de/dT$), $\gamma$ is the psychrometric constant, and $r_a$ and $r_s$ are the aerodynamic and surface resistances, respectively.

The surface resistance ($r_s$), which is primarily related to the stomatal resistance (Thorn, 1972), describes the biological control over the rate of transpiration. Jarvis (1976) suggested the use of a mechanistic model in which the stomatal conductance (inverse to stomatal resistance) was related to the $CO_2$ concentration, temperature, vapor pressure deficit, and photon flux density. This was widely applied in remote-sensing-based models. Cleung et al. (2007) parameterized the surface conductance based on the remote sensing retrievals of normalized difference vegetation index (NDVI), leaf area index (LAI), or fractional canopy cover. Mu et al. (2007) extended this parameterization by considering the constraints of VPD and minimum temperature on stomatal conductance and using LAI as a scalar for estimating canopy conductance, as described in the following equations:

$$C_l = c_L \cdot f_{T_{\min}} \cdot f_{VPD} \quad (2)$$

$$C_c = C_l \cdot LAI \quad (3)$$

where $C_l$ is the stomatal conductance, $c_L$ is the mean potential stomatal conductance per unit leaf area, $f_{T_{\min}}$ and $f_{VPD}$ are the constraints by minimum air temperature and VPD, respectively, to reduce the potential stomatal conductance, and $C_c$ is the canopy conductance.

The aerodynamic resistance ( $r_a$ ) describes the effect of the physical roughness of the vegetation on the transfer of heat and water vapor from the evaporative surface into the air above. This transfer is sensitive to wind speed and boundary layer stability conditions. We use the aerodynamic resistance parameterization from SEBS (Su, 2002), based on the Monin-Obukhov similarity theory (Monin and Obukhov, 1954) and the work of Massmam (1987). More details can be found in Vinukollu et al. (2011).

In addition to transpiration ( $\lambda E_t$ ), calculated with different resistance parameterizations (PM with surface resistance calculated as in Mu et al. (2007)), soil evaporation and evaporation from canopy interception are also estimated separately. Evaporation from bare soil and soil under the vegetation is calculated as

$$\lambda E_{soil} = \lambda E_{soil\_pot} \cdot f_{SM} \tag{4}$$

where $\lambda E_{soil\_pot}$ is the potential soil evaporation and $f_{SM}$ is the soil moisture constraint. The latter defines land-atmosphere interactions from vapor pressure deficit and relative humidity ( $RH$ , %):

$$f_{SM} = \left(RH/100\right)^{VPD/200} \tag{5}$$

The precipitation intercepted by canopy is calculated following the method in the Community Land Model (Thornton et al., 2004):

$$W_i = P \cdot \min(\,0.25, (1-\exp(-0.5LAI)) \tag{6}$$

where $P$ is precipitation. The evaporation from the water intercepted by canopy ( $\lambda E_c$ ) is calculated as follows:

$$\lambda E_c = \left(W_i/W_{im}\right)^{2/3} \cdot \lambda E_p \tag{7}$$

where $W_{im}$ is the maximum amount of water the canopy can intercepted, which is 0.2 times LAI (Dickinson, 1984); the power of 2/3 is as described by Deardorff (1978); and the term $\left(W_i/W_{im}\right)^{2/3}$ represents the wet fraction of the canopy. $\lambda E_p$ is the potential evaporation calculated from the PM equation.

Thus, the total evapotranspiration is the sum of soil evaporation, canopy interception loss, and transpiration:

$$\lambda E = \lambda E_{soil} + \lambda E_c + \lambda E_t \cdot \left(1-\left(W_i/W_{im}\right)^{2/3}\right) \tag{8}$$

To estimate global evapotranspiration based on the Penman-Monteith algorithm (1), the required data sets include (a) vegetation characteristics data derived from AVHRR or MODIS products (land cover, vegetation fraction, LAI, and vegetation height); (b) meteorology inputs including air temperature, wind speed, humidity, pressure, and precipitation collected from the latest version of the Princeton University global forcing data sets (Sheffield et al., 2006) and land surface temperature from the output of an off-line Variable Infiltration Capacity (VIC) land surface model simulation; and (c) radiative data such as incoming short wave and long wave radiation, surface emissivity, and albedo. A flow chart of the PM model with various inputs is

provided in Figure1. Information on the data inputs, including source and temporal and spatial resolutions, is summarized in Table 1.

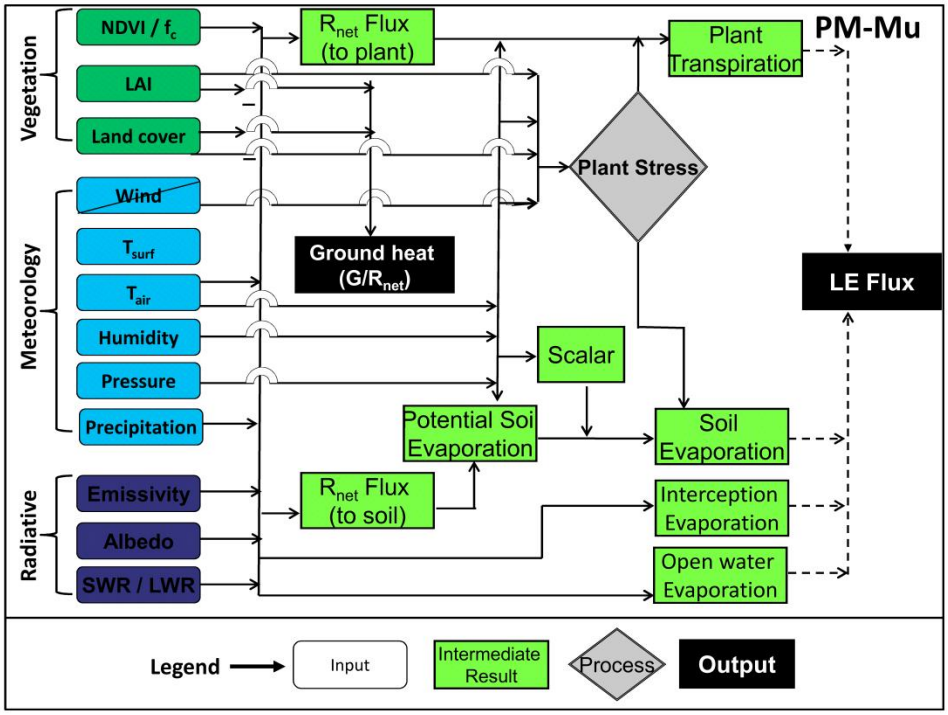


Figure1. Flowchart showing processes involved in the Penman-Monteith-based evapotranspiration algorithm and the required input variables.

Table 1. Summary of input variables to Penman-Monteith-based evapotranspiration algorithm.

| **Input variable** | **Source** | **Spatial** | **Temporal** |
|---|---|---|---|
| Net radiation | NASA/GEWEX SRB 3.0 | 1°x1° | 3 hourly, 1984-2007 |
| Near surface air temperature | Princeton University (PU) global forcing data sets (Sheffield et al., 2006) | 1°x1° | 3 hourly, 1984-2007 |
| Near surface specific humidity | PU global forcing data sets (Sheffield et al., 2006) | 1°x1° | 3 hourly, 1984-2007 |
| Near surface pressure | PU global forcing data sets (Sheffield et al., 2006) | 1°x1° | 3 hourly, 1984-2007 |
| Precipitation | PU global forcing data sets (Sheffield et al., 2006) | 1°x1° | 3 hourly, 1984-2007 |
| Near surface | PU global forcing data sets | 1°x1° | 3 hourly, 1984- |

| | | | |
|---|---|---|---|
| wind | (Sheffield et al., 2006) | | 2007 |
| Ground heat flux | VIC land-surface model (Sheffield and Wood, 2006) | 1°x1° | 3 hourly, 1984-2007 |
| Vegetation index | AVHRR Boston University GIMMS LAI/NDVI data set (Tucker et al., 2005) and MODIS (2007) | 0.5°x0.5° | Monthly (aggregated from bimonthly data), 1984-2006 |
| Land cover | MODIS-based UMD land cover data set | 0.5°x0.5° | 2004 (static) |
| Ocean/land mask | VIC land-surface model | 0.5°x0.5° | --- |

### 1.2 Data Disclaimer

This data set comes with no warranty, explicit or implied, to the extent permitted by applicable law. If you use this data set, please cite the following publication:

R.K. Vinukollu, E.F. Wood, C.R. Ferguson, and J.B. Fisher, 2011. Global estimates of evapotranspiration for climate studies using multi-sensor remote sensing data: Evaluation of three process-based approaches, *Remote Sens. Environ., 115*, 801-823, doi:10.1016/j.rse.2010.11.006.

For questions about the data set, please contact the data producer, Miaoling Liang (mliang@princeton.edu) or Ming Pan (mpan@princeton.edu).

## 2.0 Data Organization

The SRB/GEWEX Evapotranspiration (Penman-Monteith) Level-3 3-hour 0.5-degree data set consists of daily files, each containing the center latitude and longitude of 0.50° grid boxes and 8 three-hourly 360 (lat) x 720 (lon) arrays of evapotranspiration.

### 2.1 File Naming Convention

File names are formatted as follows:

WC_PM_ET_050_L3_V001_YYYYMMDDT00Z.nc4

where

- WC_PM_ET expands to **W**ater **C**ycle **P**enman-**M**onteith **E**vapo**T**ranspiration
- 050 indicates 0.50$^{o}$ spatial resolution
- L3 indicates Level-3 gridded data
- V001 indicates version 1 of data product
- YYYYMMDD indicates date of data acquisition

- T00Z indicates starting time (hour) for data contained in the file
- .nc4 indicates netCDF4 file format

Filename example: WC_PM_ET_050_L3_V001_19840101T00Z.nc4

### 2.2 File Format and Structure

SRB/GEWEX Evapotranspiration (Penman-Monteith) Level-3 3-hour 0.5-degree data files are in netCDF4 (http://www.unidata.ucar.edu/software/netcdf/docs/), which facilitates the creation, access, and sharing of array-oriented data in a form that is self-describing and portable.

Each daily file contains geolocation information (latitude and longitude of grid box centers) and one data field:

- evapotranspiration

There is also a set of global attributes defining the metadata for the data set. More details are provided in Section 3.0.

### 2.3 Key Science Data Fields

Satellite-derived evapotranspiration at land surface using the Penman-Monteith approach.

## 3.0 Data Contents

### 3.1 Dimensions

SRB/GEWEX Evapotranspiration (Penman-Monteith) Level-3 3-hour 0.5-degree data are stored in 3-dimensional arrays with dimensions (lat, lon, time), where lat = 360, the number of grid boxes in the north-south direction; lon = 720, the number of grid boxes in the east-west direction; and time = 8, the number of three-hourly lat x lon arrays.

### 3.2 Global Attributes

In addition to SDS (Scientific Data Sets) arrays containing variables and dimension scales, global metadata are also stored in the files. Some metadata are required by standard conventions; some are included to meet data provenance requirements; and others are provided as a convenience to users of the SRB/GEWEX Evapotranspiration (Penman-Monteith) Level-3 3-hour 0.5-degree data set. A summary of global attributes present in all files is shown in Table 2.

Table 2. Global metadata attributes associated with each SDS of the SRB/GEWEX Evapotranspiration (Penman-Monteith) Level-3 3-hour 0.5-degree data set.

| Global Attribute | Type | Description |
|---|---|---|
| Title | String | Full data set title |
| ProcessingCenter | String | Location of data set production |

| | | |
|---|---|---|
| ContactPersonName<br>ContactPersonRole<br>ContactPersonEmail<br>ContactPersonAddress | String | Contact information for dataset producers |
| Source | String | Algorithm basis for the data set |
| ProductReference | String | Citation information for reference on the data set |
| Identifier_product_doi | String | Digital object identifier of data set |
| Identifier_product_doi_authority | String | Digital object identifier host |
| ShortName | String | Product short name |
| ProcessingDate | String | Date of file creation, yyyy-mm-dd |
| VersionID | String | Product version number |
| Conventions | String | CF conventions followed |
| LocalGranuleID | String | File name |
| Format | String | File format |
| RangeBeginningDate | String | Start date of the data in the file |
| RangeBeginningTime | String | Time stamp of first temporal field |
| RangeEndingDate | String | End date of the data in the file |
| RangeEndingTime | String | Time stamp of final temporal field |
| NorthBoundingCoordinate | String | Center latitude of northernmost gridbox |
| SouthBoundingCoordinate | String | Center latitude of southernmost gridbox |
| EastBoundingCoordinate | String | Center longitude of easternmost gridbox |
| WestBoundingCoordinate | String | Center longitude of westernmost gridbox |
| LatitudeResolution | String | Latitudinal spatial resolution |
| LongitudeResolution | String | Longitudinal spatial resolution |

A list of key metadata fields can be found in Table 3. Global attributes in a SRB/GEWEX Evapotranspiration (Penman-Monteith) Level-3 3-hour 0.5-degree data file can be viewed with the *ncdump* software: ncdump –h -c <file>

Table 3. Key metadata fields

| **Name** | **Type** | **Description** |
|---|---|---|
| FillValue | float32 | Floating-point value used to denote missing data. Will normally be set to 1e15. |

| | | |
|---|---|---|
| | | Required by CF |
| long_name | String | Long descriptive variable name |
| standard_name | String | Standard description of the variable as defined in CF conventions |
| Units | String | Units of a variable. Must be a string that can be recognized by Unidata's UDUNITS package |
| Scale_factor | float32 | If variable is packed as 16-bit integers, this is the scale_factor for expanding to floating-point. |

### 3.3 Products/Parameters

This data set contains only one parameter: Evapotranspiration over land surface calculated from remotely sensed data using the Penman-Monteith approach.

## 4.0 Options for Reading the Data

The following are a few of the many command line and visualization tools available for reading netCDF4 format data, such as the SRB/GEWEX Evapotranspiration (Penman-Monteith) Level-3 3-hour 0.5-degree data files. For more comprehensive lists of tools, please see the following:

https://www.unidata.ucar.edu/software/netcdf/docs/

https://www.hdfgroup.org/products/hdf5_tools/

Most of the following tools (e.g., GrADS, NCO, CDO, NCL, IDL) can subset variables or subset data within specified temporal and/or spatial ranges. These tools can also calculate statistics like mean, standard deviation, maximum, minimum, etc. For further assistance on data use, please contact the data producer, Ming Pan, at email mpan@princeton.edu.

### 4.1 Command Line Utilities

*4.1.1 ncdump (free)*

The ncdump tool generates the CDL (Common Data Language) text (ASCII) representation of a netCDF or compatible file and writes to standard output. The tool can also be used as a simple browser for netCDF files, to display the dimension names and lengths; variable names, types, and shapes; attribute names and values; and, optionally, the values of data for all variables or selected variables. A common use of ncdump is with the –h option, with which only the header information is displayed. The ncdump tool comes with the netCDF library as distributed by Unidata.

http://www.unidata.ucar.edu/downloads/netcdf/

*4.1.2 n5dump (free)*

The h5dump tool enables users to examine the contents of an HDF5 file and dump those contents to an ASCII file or, optionally, as XML or binary outputs. It can display the contents of the entire HDF5 file or selected objects, which can be groups, data sets, a subset of a data set, links, attributes, or datatypes. The h5dump tool is included with the HDF5 distribution from The HDF Group.

https://www.hdfgroup.org/HDF5/release/obtain5.html

*4.1.3 NCO (free)*

The netCDF Operator (NCO) (http://nco.sourceforge.net/) toolkit manipulates and analyzes data stored in netCDF-accessible formats, including DAP, HDF4, and HDF5.

*4.1.4 CD) (free)*

CDO (Climate Data Operators) (https://code.zmaw.de/projects/cdo) is a collection of command line operators to manipulate and analyze Climate and Numerical Weather Prediction (NWP) model Data.

## 4.2 Visualization Tools

*4.2.1 Ncview (free)*

Ncview is a quick and easy way to visualize the contents of netCDF files.

http://meteora.ucsd.edu/~pierce/ncview_home_page.html

*4.2.2 ncBrowse (free)*

ncBrowse is a Java application that provides flexible, interactive graphical displays of data and attributes from a wide range of netCDF data file conventions.

http://www.epic.noaa.gov/java/ncBrowse/

*4.2.3 Panoply (free)*

Panoply is a Java application, developed by the NASA Goddard Institute for Space Studies (GISS), that plots geo-referenced and other arrays from netCDF, HDF, GRIB, and other data types. Among other capabilities, Panoply enables one to slice and plot geo-referenced latitude-longitude, latitude-vertical, longitude-vertical, time-latitude, or time-vertical arrays from larger multidimensional variables; combine two geo-referenced arrays in one plot by differencing, summing, or averaging; plot maps using various map projections; and access remote catalogs to retrieve data files.

http://www.giss.nasa.gov/tools/panoply/

*4.2.4 HDFview (free)*

HDFView is a Java-based visual tool created by The HDF Group for browsing and editing HDF4 and HDF5 files. It allows users to view all objects in an HDF file hierarchy, which is represented as a tree structure, and create, add, delete, and modify object contents and attributes.

https://www.hdfgroup.org/products/java/hdfview/

#### *4.2.5 IDL netCDFtools (commercial)*

Users familiar with the IDL programming language (http://www.exelisvis.com/ProductsServices/IDL.aspx) can use the netCDF functions available with the IDL software package to read and visualize the data.

#### *4.2.6 GrADS netCDFtools (free)*

Users familiar with the GrADS programming language (http://iges.org/grads/) can use the netCDF functions available with the GrADS software package to read and visualize the data.

#### *4.2.7 NCL (free)*

The NCAR Command Language (NCL) (http://www.ncl.ucar.edu/) is a free interpreted language designed specifically for scientific data processing and visualization.

# 5.0 Data Services

## 5.1 Mirador

Mirador is a GES DISC earth science data search and download tool. It provides a simple interface for users to make basic keyword, temporal, and spatial searches. More advanced, event-based searches are also possible. An interactive shopping cart offers various download options.

http://mirador.gsfc.nasa.gov/

The SRB/GEWEX Evapotranspiration (Penman-Monteith) Level-3 3-hour 0.5-degree data set can be keyword searched with "WC_PM_ET_050" or accessed via Mirador's "Projects" view.

http://mirador.gsfc.nasa.gov/cgi-bin/mirador/collectionlist.pl?keyword=WC_PM_ET_050

## 5.2 OPeNDAP

The Open-source Project for a Network Data Access Protocol (OPeNDAP) provides a means for requesting and accessing data across the internet, in a form usable by OPeNDAP clients, i.e., clients that can remotely access OPeNDAP-served data (e.g., Panoply, IDL, MATLAB, GrADS, IDV, McIDAS-V, Ferret). OPeNDAP provides the ability to retrieve subsets of files and to aggregate data from several files in one transfer operation.

The SRB/GEWEX Evapotranspiration (Penman-Monteith) Level-3 3-hour 0.5-degree data set is available from the GES DISC through OPeNDAP:

https://measures.gesdisc.eosdis.nasa.gov/opendap/TerrestrialWaterCycle/WC_PM_ET_050.1/

# 6.0 More Information

Detailed documentation of the Penman-Monteith approach can be found in the following publication:

R.K. Vinukollu, E.F. Wood, C.R. Ferguson, and J.B. Fisher, 2011. Global estimates of evapotranspiration for climate studies using multi-sensor remote sensing data: Evaluation of three process-based approaches, *Remote Sens. Environ., 115*(3), 801-823, doi:10.1016/j.rse.2010.11.006.

## 6.1 Other Evapotranspiration Resources

For other evapotranspiration and related data available at the GES DISC, please see

http://disc.sci.gsfc.nasa.gov/hydrology

For other evapotranspiration and related data available elsewhere, please search NASA's Global Change Master Directory (GCMD) at http://gcmd.nasa.gov/.

## 6.2 Point of Contact

Name: GES DISC Help Desk
URL: http://disc.sci.gsfc.nasa.gov/
E-mail: gsfc-help-disc@lists.nasa.gov
Phone: 301-614-5224
Fax: 301-614-5268
Address: Goddard Earth Sciences Data and Information Services Center
Attn: Help Desk
Code 610.2
NASA Goddard Space Flight Center
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USA

## 6.3 Acronyms

| | |
|---|---|
| AVHRR: | Advanced Very High Resolution Radiometer |
| GEWEX: | Global Energy and Water Exchange Project |
| LAI: | Leaf Area Index |
| MEaSUREs: | Making Earth System data records for Use in Research Environments |
| MODIS: | Moderate Resolution Imaging Spectroradiometer |
| PM: | Penman-Monteith |
| SRB: | Surface Radiation Budget |
| TOA | Top Of the Atmosphere |
| VIC: | Variable Infiltration Capacity |

# 7.0 Acknowledgments

The production of the SRB/GEWEX Evapotranspiration (Penman-Monteith) Level-3 3-hour 0.5-degree data set and related research was supported by NASA's Making Earth System Data Records for Use in Research Environments (MEaSUREs) Program and a separate NASA grant (NNX09AK35G) for "Development and diagnostic analysis of a multi-decadal global evaporation product for NEWS."

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