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PVMAPS: Software tools and data for the estimation of solar radiation and photovoltaic module performance over large geographical areas

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ABSTRACT

A set of computational tools and climatic data, tentatively named PVMAPS, is presented which makes it possible to calculate solar radiation and photovoltaic system power on inclined and/or sun-tracking surfaces over large geographical areas at arbitrarily high spatial resolution. Calculations of solar radiation and photovoltaic performance are done using validated models published in the scientific literature.

The software has been implemented as modules in the open-source GRASS Geographical Information System and is delivered together with scripts to perform the calculations for any geographical region in the area covered by the data.

The accompanying data set includes information about elevation, horizon height, average temperatures, solar radiation (direct and diffuse components) as well as data to calculate the effects of wind and spectral variations on PV performance. The geographical extent of the data at present includes Europe, Africa and most of Asia.

All tools and data are freely available at no cost.

1. Introduction

1.1. Solar radiation data availability

In recent years a number of freely available solar radiation data sets have become available based on satellite data, which have both high spatial and temporal resolution. The CM SAF collaboration (www.cmsaf.eu) provides a number of different solar radiation data sets at hourly time resolution and spatial resolution of a few km, covering Europe and Africa. The LSA-SAF collaboration (landsaf.meteo.pt) likewise makes data from the Meteosat Second Generation satellites available at 15 min resolution. Geospatial solar radiation data for the Americas can be downloaded from the National Oceanic and Atmospheric Administation (www.class.ngdc.noaa.gov). Time series of solar radiation data are available from the SODA web site (www.soda-is.com) for single sites, as well as from the National Solar Radiation Database covering the Americas (from which limited area solar radiation maps at hourly resolution are also available). This list is not exhaustive, and only covers products that are free of charge.

One problem with these solar radiation products is the very large amount of data, often running into terabytes for a time series covering several years. The time series for individual sites require less storage but it becomes very cumbersome to build up maps of larger areas from these data.

Having data sets on solar radiation available in a tractable format will be useful not just for studying the solar energy potential. Solar radiation data can be used for building design, for agricultural studies and for many studies regarding biology and the environmental sciences.

1.2. Mapping of photovoltaic system performance

For a number of years the Renewable Energy Unit of the European Commission's Joint Research Centre has been involved in research on estimating the solar resource and mapping the geographical variability of solar irradiation and solar energy system performance. This research has produced a number of scientific outputs, starting with Šúri et al. (2005, 2007). Another result of this work has been the online PV estimation tool PVGIS:

http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php

The software developed for this research has made it possible to produce digital maps describing the performance of PV systems of various types. Some of these data are available online:

http://re.jrc.ec.europa.eu/pvgis/download/download.htm

However, there has so far been no single source of software and data that would allow users to produce their own calculations

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using the software tools developed for the PVGIS project. The aim of this document and the accompanying software and data sources is to present tools and data that allow users to do this.

The data used in this project are inherently geospatial. They are therefore well suited to be used in a Geographical Information System (GIS) environment. In order to make all the methods and data freely available and accessible to all potential users the software has been implemented as modules in the open-source GRASS GIS (grass.osgeo.org) (Neteler and Mitasova, 2008), version 7. The advantage of working in a GIS environment like GRASS is that it becomes very easy to combine data sets with different spatial resolution and to select geographical areas of interest. In addition, GRASS has a very large number of functions to do calculations with raster (gridded) data. Finally, many of the methods described in the following have already been implemented in the GRASS module r.sun, and the new software tools described in this paper have been developed as derivatives of `r.sun`.

The structure of this paper is as follows: Section 2 describes the sources of the data used in PVMAPS. Section 3 gives an overview of the models used in the software. All models have been previously described and validated in the peer-reviewed literature. Section 4 describes the software modules and scripts that make up the software package. A case study is presented in Section 7 for a high-resolution map of solar radiation and PV performance for South Africa. Finally the conclusions are presented.

Instructions on how to download the software and data are found at this link:

http://re.jrc.ec.europa.eu/pvmaps/index.html

This paper is not intended as a manual for the software, which instead can be found at:

http://re.jrc.ec.europa.eu/pvmaps/pvmaps_manual.pdf

2. Data sources

2.1. Solar radiation data

2.1.1. Hourly solar radiation data

The solar radiation data in this database cover Europe, Africa, Asia except the easternmost part, as well as the eastern part of South America. For Europe, Africa and South America, the solar radiation data have been obtained from the CM SAF Collaboration (www.cmsaf.eu), who have calculated hourly global and direct solar irradiance from satellite data. Two different data sets are available from CM SAF with hourly data, in the following named the SARAH data set and the Operational data set.

The algorithms used for the Operational data are described in Müller et al. (2009), see also Huld et al. (2012) for more validation of the data. The data used here cover the time period 2007–2015 with a spatial resolution of 1′30″. The SARAH data set has been calculated using the SPECMAGIC algorithm (Müller et al., 2012; Posselt et al., 2014). The spatial coverage is the same as for the Operational data, with spatial resolution of 3′. The data set covers the period 1983–2015, but for this work, the data used cover the period 2005–2015.

Also for Asia the solar radiation data are retrieved from satellite data, using the SPECMAGIC algorithm. Details about the processing and validation are found in Gracia Amillo et al. (2014). The data used here cover the period 1999–2015 (except 2006), with a spatial resolution of 3′. The hourly data are now available from the CM SAF web interface.

2.1.2. Data for calculating the interannual variability of solar radiation

For the Western section of the solar radiation data, the year-to-year variability has been calculated using the monthly averages of the SARAH data set from CM SAF (Müller et al., 2012; Posselt et al., 2014). These data cover the time period 1983–2014 and have a spatial resolution of 3′. For the Eastern section the data used are the same as for the hourly solar radiation data described above. The interannual variability is given as the relative standard deviation of the global horizontal irradiation.

2.2. Ancillary climatic data

The mathematical models used to calculate solar radiation on inclined planes and to calculate PV performance use a number of climatic parameters, for which data must be available throughout the geospatial domain. The parameters used to prepare the data in PVMAPS are:

- Air Temperature (2 m temperature). This is used for calculating PV module temperature which is subsequently used to calculate PV power (Section 3.6.2).
- Wind speed data (10 m wind speed). Wind cools the PV modules and modifies the temperature and hence the PV power (Section 3.6.3).
- Water vapour content of the atmosphere, used to calculate clear-sky solar radiation (Section 3.1).
- Aerosol content of the atmosphere, used to calculate clear-sky solar radiation.

Air temperature and wind speed data have been obtained from the European Centre for Medium Range Weather Forecast (ECMWF, www.ecmwf.int), using the "ERA-interim" reanalysis data (Dee et al., 2011), available at:

http://http://apps.ecmwf.int/datasets/data/interim-full-daily/levtype=sfc/

The data have worldwide coverage at a spatial resolution of 45′ (0.75°) latitude/longitude and a time resolution of 3 h.

The total column water vapour data are taken from the 3-hourly operational forecast data of the European Centre for Medium-range Weather Forecast (www.ecmwf.int) (European Centre for Medium-Range Weather Forecasts, 2006). The spatial resolution is 7′30″. The monthly average values were calculated from the 3-hourly data using the period 2010–2015. Note that these data are not publicly available.

Aerosol data were obtained from the MACC reanalysis data (Schroedter-Homscheidt et al., 2013; European Centre for Medium-Range Weather Forecasts, 2006). The spatial resolution is 45′ (0.75°) latitude/longitude, and the data used are daily values for the period 2013–2015.

2.3. Terrain elevation and horizon data

The terrain elevation is needed to calculate accurately the clear-sky radiation as well as improving the estimate of the air temperature. Furthermore, the calculation algorithms for solar radiation and PV performance can make use of the height of the local horizon to take into account the effect of shadowing on the solar irradiance and hence PV output power.

The software comes with two different sets of data on elevation and horizon height. One data set has a relatively low spatial resolution of 30 arc-seconds and contains both the digital elevation model (DEM) and the horizon height calculated in 48 directions. The other data set has been obtained from the Shuttle Radar Topography Mission (SRTM) digital elevation model data covers the earth land surface between 60°N and 60°S (Farr et al., 2007) at a spatial resolution of 3 arc-seconds. These data have been imported as GRASS raster files and a set of horizon height raster