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Evaluation of global horizontal irradiance estimates from ERA5 and COSMO-REA6 reanalyses using ground and satellite-based data

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ABSTRACT

This study examines the progress made by two new reanalyses in the estimation of surface irradiance: ERA5, the new global reanalysis from the ECMWF, and COSMO-REA6, the regional reanalysis from the DWD for Europe. Daily global horizontal irradiance data were evaluated with 41 BSRN stations worldwide, 294 stations in Europe, and two satellite-derived products (NSRDB and SARAH).

ERA5 achieves a moderate positive bias worldwide and in Europe of $+4.05\,W/m^2$ and $+4.54\,W/m^2$ respectively, which entails a reduction in the average bias ranging from 50% to 75% compared to ERA-Interim and MERRA-2. This makes ERA5 comparable with satellite-derived products in terms of the mean bias in most inland stations, but ERA5 results degrade in coastal areas and mountains. The bias of ERA5 varies with the cloudiness, overestimating under cloudy conditions and slightly underestimating under clear-skies, which suggests a poor prediction of cloud patterns and leads to larger absolute errors than that of satellite-based products. In Europe, the regional COSMO-REA6 underestimates in most stations (MBE = $-5.29\,W/m^2$) showing the largest deviations under clear-sky conditions, which is most likely caused by the aerosol climatology used. Above 45°N the magnitude of the bias and absolute error of COSMO-REA6 are similar to ERA5 while it outperforms ERA5 in the coastal areas due to its high-resolution grid (6.2 km).

We conclude that ERA5 and COSMO-REA6 have reduced the gap between reanalysis and satellite-based data, but further development is required in the prediction of clouds while the spatial grid of ERA5 (31 km) remains inadequate for places with high variability of surface irradiance (coasts and mountains). Satellite-based data should be still used when available, but having in mind their limitations, ERA5 is a valid alternative for situations in which satellite-based data are missing (polar regions and gaps in times series) while COSMO-REA6 complements ERA5 in Central and Northern Europe mitigating the limitations of ERA5 in coastal areas.

1. Introduction

Different methods have been developed to estimate surface irradiance in the absence of ground records (Urraca et al., 2017c). Satellite-based models using images from geostationary satellites are the most extended approach (Sengupta et al., 2015) nowadays. They provide gridded datasets of surface irradiance since the 1980s (Polo et al., 2016), with hourly or higher time resolutions and spatial resolutions down to few km. However, these products are not freely available for some regions such as Australia or Japan, while the spatial coverage of geostationary satellites is limited to latitudes within ± 65°. Products from polar-orbiting satellites have global coverage but they only provide daily data because these satellites pass over a fixed equatorial region only twice per day. Atmospheric reanalysis is an alternative that produces long-term irradiance data with global coverage (including the poles), intra-daily time resolutions, spatial resolutions around 30–80 km and no missing values. They are usually distributed at no cost and include a large number of weather parameters besides surface irradiance, making them an attractive option to assess surface irradiance. This is shown by the increasing number of research studies and industrial applications that incorporate reanalysis products (You et al., 2013; Juruš et al., 2013; Pfenninger and Staffell, 2016). However, the quality of irradiance data from reanalysis is generally lower than that of satellite-based products (Bojanowski et al., 2014; Urraca et al., 2017b)

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Nomenclature

B	beam (direct) surface irradiance received on a horizontal plane
B_N	beam (direct) surface irradiance received on a plane always normal to Sun rays
D	diffuse surface irradiance received on a horizontal plane
E	extraterrestrial irradiance received on a horizontal plane
E_N	solar constant adjusted to Earth - Sun distance
G	global surface irradiance received on a horizontal plane
KT	clearness index
BSRN	Baseline Surface Radiation Network
CM SAF	Satellite Application Facility on Climate Monitoring
ECMWF	European Centre for Medium-range Weather Forecast
HErZ/DWD	Hans-Ertel-Centre for Weather Research of Deutscher Wetterdienst
ITCZ	Inter Tropical Convergence Zone
JMA	Japan Meteorological Agency
MAE	Mean Absolute Error
MBE	Mean Bias Error
NASA's GMAO	NASA's Global Modeling and Assimilation Office
NCEP	National Centers for Environmental Prediction
NREL	National Renewable Energy Laboratory
NWP	Numerical Weather Prediction
PVGIS	Photovoltaic Geographical Information System
QC	Quality Control
rMAE	relative Mean Absolute Error
rMBE	relative Mean Bias Error
RTM	Radiative Transfer Model

Greek letters

θ	solar zenith angle

Subscripts

d	daily

Superscript

est	estimated values from radiation products
meas	measured values at ground station

and users should always evaluate if the loss of accuracy is acceptable for their particular application. Here, we examine whether two new reanalysis products, ERA5 and COSMO-REA6, are reducing this gap in terms of quality between reanalysis and satellite-based data.

Atmospheric reanalysis combines estimations from a Numerical Weather Prediction (NWP) model with ground observations and satellite data (Reanalyses.org, 2017). The core of a reanalysis model is the data assimilation model, which uses past records to limit and guide the predictions of a NWP model. This enables the extrapolation of the variables in space and time (Zhang et al., 2016), generating a coherent set of atmospheric parameters covering the whole Earth (global reanalysis), from the stratosphere to the ground. Variables assimilated typically include air temperature, wind speed, pressure or relative humidity (analyzed fields), but the NWP model also produces a vast list of parameters that are not directly observed and are just outputs of the NWP model (forecast fields). This is the case of the variable used in this study, the incoming shortwave irradiance, which is obtained with a Radiative Transfer Model (RTM) that simulates the attenuation of the irradiance from the top of the atmosphere (TOA) to the ground. Its quality depends on the RTM used and on the elements that attenuate the irradiance. Note that global reanalyses do not generally assimilate cloud, aerosol or water vapor data, increasing the uncertainty around the surface irradiance estimates (You et al., 2013; Zhao et al., 2013).

Reanalysis products can be classified into two groups, global and regional, reflecting their different spatial extent. Global reanalysis is the most common type and some of the currently available datasets are ERA-Interim (Dee et al., 2011) from the European Centre for Medium-range Weather Forecast (ECMWF), MERRA-2 from NASA's Global Modeling and Assimilation Office (NASA's GMAO), JRA-55 (Harada et al., 2016) from Japan Meteorological Agency (JMA) and CFSR (Saha et al., 2010) from National Centers for Environmental Prediction (NCEP). The ECMWF has recently released the first batch (2010–2016) of the new ERA5 (ECMWF, 2017), which will replace ERA-Interim by the end of 2019. On the contrary, regional reanalyses only cover a specific region of the Earth but at higher spatial resolutions. They are generated with a regional NWP model in a high-resolution grid that uses global reanalysis estimates as boundary conditions. Some examples are the COSMO-REA6 dataset (Bollmeyer et al., 2015) produced for Europe by the Hans-Ertel-Centre for Weather Research of Deutscher Wetterdienst (HErZ/DWD), the NARR (NCEP) (Messinger et al., 2006) for North America and the ASR (NCEP/UCAR and PMG, 2017) produced by the Polar Research Group for the Arctic.

The two most widely used reanalyses are probably ERA-Interim and MERRA with several validations published about their surface irradiance values. The quality of ERA-Interim values was checked against ground stations in Europe (Bojanowski et al., 2014; Urraca et al., 2017b), Spain (Urraca et al., 2017c) and in the Eastern Mediterranean (Alexandri et al., 2017), among other places. Besides, ERA-Interim was also compared against satellite products from CM SAF (Träger-Chatterjee et al., 2010; Bojanowski et al., 2014; Urraca et al., 2017b) and against the CERES-EBAF dataset (Alexandri et al., 2017). Most validations of the NASA's GMAO products (Yi et al., 2011; Zhao et al., 2013; Juruˇs et al., 2013) were based in the former MERRA dataset (Rienecker et al., 2011), as the new MERRA-2 was fully released on 2016 and only few works have already assessed the changes in surface irradiance data from MERRA to MERRA-2 (Draper et al., 2017; Pfenninger and Staffell, 2016). MERRA and ERA-Interim were directly compared by Boilley and Wald (2015), while for more general validations that compare global reanalysis from different organizations the authors refer to Wang and Zeng (2012), Decker et al. (2012) and Zhang et al. (2016).

All these studies found large biases in global horizontal irradiance (G) estimations from MERRA, MERRA-2 and ERA-Interim when the datasets were compared against ground and satellite data. The average bias worldwide was positive for MERRA and ERA-Interim (Decker et al., 2012; Zhang et al., 2016), and strong overestimations were observed in regions such as Europe, Asia and North America. This positive bias was related to an underestimation of the cloud fraction (Zhao et al., 2013; Zhang et al., 2016), although the opposite effect, small negative biases under clear-skies, was also described by Boilley and Wald (2015). This dependence of the bias on the clearness level evidences severe limitations of the reanalyses when modeling cloud patterns (Träger-Chatterjee et al., 2010; Yi et al., 2011; Alexandri et al., 2017). The biases under clear-skies were also related to aerosols and water vapor data (Zhang et al., 2016), but it is generally considered a secondary defect compared to clouds. Some authors have attempted to correct these biases. Zhao et al. (2013) corrected MERRA with ground data using an empirical relationship based on the daily cloudiness and the elevation. Jones et al. (2017) adjusted ERA-Interim to the satellite-based dataset HelioClim-3v5 (Blanc et al., 2011) using the clearness index and the cumulative distribution functions. These approaches may partly mitigate the consequences of using data with high average biases, but there is no method able to make a posteriori corrections of the large and highly variable errors caused by a poor modeling of

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