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Validation and stability assessment of the monthly mean CM SAF surface solar radiation dataset over Europe against a homogenized surface dataset (1983–2005)

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ABSTRACT

This work presents a validation of the downwelling surface shortwave radiation, or surface solar radiation (SSR), derived from the Satellite Application Facility on Climate Monitoring (CM SAF) over Europe for a 23-year period of records on a monthly basis. This SSR product has been recently derived based on the visible channel of the Meteosat First Generation satellites, providing a dataset with a high spatial resolution (0.03° × 0.03°) covering the 1983–2005 period. The CM SAF SSR product is compared against a homogeneous dataset of surface observations from the Global Energy Balance Archive (GEBA) over Europe, which has been homogenized by means of the Standard Normal Homogeneity Test (SNHT). The results show a good agreement between both datasets ($r^2 = 0.86$, $p < 0.01$), with a slight overestimation (bias of +5.20 W m^{-2}) of the CM SAF records as compared to the surface observations on a monthly mean basis. Equally, there is a monthly mean absolute bias difference (MABD) of 8.19 W m^{-2} that is below the accuracy threshold defined by the CM SAF. There is a clear maximum and minimum MABD during summer and winter, respectively, with an opposite cycle if the relative MABD values are considered. Moreover, the temporal stability of the CM SAF SSR is checked against the GEBA stations for the mean time series over Europe, as well as for each individual series. The results point to possible inhomogeneities in the CM SAF records around 1987 and 1994, possibly due to changes in the satellite instruments, although other factors such as the lack of aerosol retrievals in the CM SAF SSR are also discussed. Consequently, the study of the means and trends in the SSR derived from CM SAF is only recommended for the records after 1994.

1. Introduction

Knowledge on the climatological averages and changes of the sunlight that reaches the Earth's surface, also known as downward surface shortwave radiation or simply surface solar radiation (hereafter referred to as SSR) is crucial for numerous processes in the climate system such as the water cycle (e.g. Allen & Ingram, 2002; Ramanathan, Crutzen, Kiehl, & Rosenfeld, 2001; Wang, Dickinson, Wild, & Liang, 2010; Wild & Liepert, 2010) or plant photosynthesis (e.g. Gu et al., 2002; Mercado et al., 2009). In fact, the climatological mean values of the SSR play a central role in the Surface Radiation Budget (SRB), especially due to the uncertainty in the estimation of its global annual mean value, and consequently also in the Global Energy Balance (e.g. Kim & Ramanathan, 2008; Stephens et al., 2012; Trenberth, Fasullo, & Kiehl, 2009; Wild et al., 2013). Moreover, it is a crucial variable for diverse socioeconomic sectors, such as the production of energy from solar energy systems (e.g., Hammer et al., 2003).

Equally, the study of the interannual and decadal variations of the SSR is fundamental for a better understanding of the climate variability and change (Wild, 2012). In fact, a widespread reduction/increase of the SSR from the 1950s to the 1980s/since the 1980s has been observed, a phenomenon that has been named as global dimming/brightening (Stanhill & Cohen, 2001; Wild et al., 2005). Changes in the transparency of the atmosphere due to variations in cloud characteristics and changes in anthropogenic aerosol emissions are considered the major causes of the dimming/brightening (e.g. Stanhill & Cohen, 2001; Wang, Dickinson, Wild, & Liang, 2012; Wild, 2009, 2012). However, both global dimming and brightening phenomena still have some uncertainties, due to for example the lack of long-term SSR series, especially over ocean and remote land areas, which limit the spatial representativeness of the observed trends (Wang et al., 2012; Wild, 2009, 2012). In addition, a comprehensive assessment of the temporal homogeneity of the SSR series, which are very often affected by spurious data and inhomogeneities (Hakuba, Sanchez-Lorenzo, Folini, & Wild, in press; Sanchez-Lorenzo, Calbó, & Wild, 2013; Shi et al., 2008; Wang,

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Dickinson, Ma, Augustine, & Wild, in press; You et al., 2013), is still lacking (Wild, 2009, 2012).

SSR derived from satellites offers an alternative to fill these gaps, at least since the 1980s (i.e. covering the brightening period), as they increase the availability of spatial information through a better coverage than surface observations. For a review of the methods used to derive SSR from satellites, we refer to Pinker, Frouin, and Li (1995). Nevertheless, products such as satellite-derived SSR datasets need to be validated, in order to ensure that the records are not affected by non-climatic factors, before they can be considered as useful for climate research (e.g. Cermak, Wild, Knutti, Mishchenko, & Heidinger, 2010; Evan, Heidinger, & Vimont, 2007). The most common causes of spurious changes in the satellite-derived products are the use of different satellites or instruments to derive the datasets, as well as the temporal degradation of satellite sensors during their lifetimes. Consequently, considerable effort has been devoted to generate homogeneous and stable datasets of satellite-derived quantities with high spatial and temporal resolution, which afterwards can be used for the generation of climatologies and the detection of trends (Ohring, Wielicki, Spencer, Emery, & Datla, 2005; Schulz et al., 2009).

With the aim of providing global-scale fields of radiative fluxes from satellite observations, the Global Energy and Water Cycle Experiment (GEWEX), which is a research program of the World Climate Research Program (WCRP), initiated the Surface SRB project in 1983. Since then, the GEWEX–SRB project lead by the NASA Langley Research Center has developed different physical models to derive SSR fluxes (Stackhouse et al., 2011). The main input data for the GEWEX–SRB algorithms are the radiances and cloud properties currently provided by the International Satellite Cloud Climatology Project (ISCCP) pixel level (DX) data, together with other products providing temperature and moisture profiles, column ozone amounts, etc. (Gupta et al., 1999; Raschke, Bakan, & Kinne, 2006; Stackhouse et al., 2011; Whitlock et al., 1995). The grid size for the different products of the GEWEX SRB project ranges from the 2.5° in the first version of the datasets (Whitlock et al., 1995) to 1° for the most recent releases (Hinkelman, Stackhouse, Wielicki, Zhang, & Wilson, 2009; Stackhouse et al., 2011).

The validation of the derived SSR in the last GEWEX–SRB product (version 3.0) showed an improvement over the previous versions (Stackhouse et al., 2011). Specifically, a slight underestimation has been found in the monthly derived SSR records of around -4 W m^{-2} and a root mean square (RMS) difference of 23 W m^{-2} as compared to selected surface measurements from the Baseline Surface Radiation Network (BSRN) (Ohmura et al., 1998). Hinkelman et al. (2009) analyzed the trends of the SSR derived from the GEWEX–SRB project (version 2.8) during the period 1983–2004. Equally, the time evolution of the mean series of the SSR obtained with around 100 surface station observations shows a good agreement with the GEWEX–SRB data, although an assessment of possible inhomogeneities in different continents and regions is not presented.

A similar approach to the GEWEX–SRB project based on ISCCP cloud inputs and radiative transfer models has been followed by other initiatives, typically using grid cells at a spatial resolution of around 2.5° (e.g. Hatzianastassiou et al., 2005, Lohmann, Schillings, Mayer, & Meyer, 2006; Pinker, Zhang, & Dutton, 2005). Pinker et al. (2005) pointed out the temporal stability and similarity of the trends of the derived SSR as compared with surface observations, although only using two stations located in high (Barrow, Alaska) and low (American Samoa) latitudes. In addition, Hatzianastassiou et al. (2005) derived SSR from 1984 to 2000 on a 2.5° longitude/latitude global grid, accounting for changes in the stratospheric aerosol content due to the large volcanic eruptions. It is worth to mention that the derived products described so far only used monthly climatological values for tropospheric aerosol, i.e. assuming constant values throughout the years. Overall, Hatzianastassiou et al. (2005) found a negative bias of around 10 W m^{-2} in the derived SSR as compared to surface observations. Equally, a significant increase in the global mean series was observed in line with the brightening period worldwide observed in the surface measurements since the late 1980s (Wild, 2009, Wild et al., 2005). Nevertheless, an assessment of the temporal stability of the derived SSR fluxes is also not presented in Hatzianastassiou et al. (2005).

Another dataset that contains radiative fluxes at global scales is the ISCCP-FD product (Zhang & Rossow, 2002), which is based on the cloud data offered by the ISCCP D-series datasets (Rossow & Duenas, 2004; Rossow & Schiffer, 1999), as well as the NASA Goodard Institute for Space Studies (GISS) radiative transfer model (Zhang, Rossow, Lacis, Oinas, & Mishchenko, 2004). The ISCCP-FD surface fluxes are derived for 280 km equal-area cells, and the validation against the high quality surface observations from the BSRN stations showed a slight bias (RMS) of around 2 W m^{-2} (18 W m^{-2}). However, to our knowledge, an exhaustive analysis of the temporal stability of the SSR ISCCP-FD fluxes is lacking.

In addition to the previous activities, the Satellite Application Facility on Climate Monitoring (CM SAF, for more details see Section 2.1) has recently generated a 23-year record of SSR data, including among other variables direct SSR and effective cloud albedo, covering the period 1983–2005 (Mueller, Trentmann, Träger-Chatterjee, Posselt, & Stökli, 2011; Posselt, Mueller, Stöckli, & Trentmann, 2012, Posselt, Müller, Stöckli, & Trentmann, 2011). These derived variables are based only on the visible channel (0.45–1 μm) of the instruments on-board the geostationary Meteosat First Generation satellites. The full disk reaches from 80° N to 80° S in latitude and 80° E and 80° W in longitude, and provides a dataset with a very high spatial resolution (0.03° × 0.03°). The derived CM SAF SSR has been validated against the surface observations from the BSRN available on the Meteosat full disk. The validation shows a good agreement between both datasets ($r = 0.89$) with only a slight overestimation ($+4.40$ W m^{-2}) of the CM SAF records, as well as the homogeneity of the derived SSR for the period covered by the BSRN stations (Mueller et al., 2011; Posselt et al., 2012). However, the validation and assessment of the temporal stability of the CM SAF SSR records have been limited to the years since the early 1990s, and to a small number of stations. In fact, the BSRN currently only includes around 10–12 stations with more than 10-years of data over the Meteosat full disk, only about half of them in Europe.

Summarizing, it is clear that the satellite-derived SSR records are needed in order to overcome some of the current gaps of knowledge, especially with the excellent spatial coverage not obtained with surface observations. Moreover, from the review of the literature that has been previously listed, a number of methodological issues related to the studies based on satellite observations remain, which can be summarized as follows:

- The surface observations since the 1980s used for the validation and temporal stability of the satellite records have not been tested in order to ensure their temporal homogeneity. In this respect, this step is crucial for long-term series before the 1990s, because the available SSR series are of variable quality and often have not been homogenized (Wild, 2012). Nevertheless, for shorter periods after the 1990s, high-quality data became more available from the networks such the BSRN.
- The validation and, specially, the temporal stability of the remote sensing products have been typically evaluated for short-time periods (e.g. Dürr et al., 2010; Lefèvre, Wald, & Diabaté, 2007; Posselt et al., 2012; Zelenka, Perez, Seals, & Renné, 1999), mainly due to the lack of high-quality records from surface observations as detailed above.
- The number of the surface observations, which is normally sparse or even zero over most of the studied area (e.g. Lohmann et al., 2006; Pinker et al., 2005; Posselt et al., 2012), should be increased in order to enhance the signal/noise ratio for a better detection of inhomogeneities in the remote sensing products.