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Trends in downward surface solar radiation from satellites and ground observations over Europe during 1983–2010

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ABSTRACT

Trends of all-sky downward surface solar radiation (SSR) from satellite-derived data over Europe (1983–2010) are first presented. The results show a widespread (i.e., non-local dimension) increase in the major part of Europe, especially since the mid-1990s in the central and northern areas and in springtime. There is a mean increase of SSR of at least 2 W m^{-2} per decade from 1983 to 2010 over the whole Europe, which, taking into account that the satellite-derived product lacks of aerosol variations, can be mostly related to a decrease in the cloud radiative effects over Europe. Secondly, residual series have been derived as the result of the difference between ground-based and satellite-derived all-sky SSR data. The residual mean series points to a significant increase during the period 1983–2010, with higher rates of around 2 W m^{-2} per decade over central and eastern Europe. The spatial variation of these residual time series, which are in line with clear-sky SSR trends over Europe reported in the literature, seem to suggest that these differences in the residual series are not just explained by calibration issues in the satellite-derived product.

1. Introduction

Downward surface solar radiation (SSR) is a critical part of the Global Energy Balance and the climate system, and consequently, the understanding of changes in SSR are crucial for an improved understanding of climate change issues (IPCC, 2013; Wang and Dickinson, 2013; Wild, 2012). A widespread decrease of SSR from the 1950s to the 1980s has been observed (Liepert, 2002; Stanhill and Cohen, 2001; Wild, 2009), followed by an increase of SSR since the mid-1980s, especially in developed regions such as Europe (Wild, 2009). These periods of decrease and increase of SSR have been named as global dimming and brightening (Stanhill and Cohen, 2001; Wild et al., 2005), respectively. Changes in the transmission of the atmosphere due to variations in cloud properties and aerosols have been suggested as the main causes of these SRR trends (Mateos et al., 2014; Stanhill and Cohen, 2001; Wang et al., 2012; Wild, 2009, 2016).

However, both global dimming and brightening phenomena still have some uncertainties, due to for example the lack of long-term SSR series, especially under clear-sky conditions, which limit the spatial representativeness of the observed changes (Hakuba et al., 2013; Hinkelman et al., 2009; Wild, 2009). Satellite-derived SSR offers an alternative to fill these gaps, at least since the 1980s, as they have a better coverage than ground-based observations. Nevertheless, these satellite datasets are also frequently affected by non-climatic factors due to the use of different instruments to derive the datasets and the temporal degradation of satellite sensors (Sanchez-Lorenzo et al., 2013b; Zhang et al., 2015).

Hinkelman et al. (2009) analyzed the trends of the SSR derived from the GEWEX-SRB project (1° resolution) during the period 1983–2004. Their results show a slight increase of 0.25 W m^{-2} on global scale, with a similar decadal evolution over Europe, which it is not in line with the ground-based observations (Chiacchio and Wild, 2010; Sanchez-Lorenzo et al., 2015). Pinker et al. (2005) used a different product (2.5° resolution) and found that the derived global mean SSR series underwent a significant increase of 1.6 W m^{-2} per decade from 1983 to 2001. Their results highlighted that the positive trends are mainly concentrated over the oceans and not over land areas, in disagreement with the brightening detected in surface observations over land (Wild, 2009). On the other hand, Hatzianastassiou et al. (2005) derived a SSR product from 1984 to 2000 (2.5° resolution) and reported a significant increase of +2.4 W m^{-2} per decade in the global mean series, which is considerably higher than the results from Pinker et al. (2005) and

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Hinkelman et al. (2009). Overall, the increase in SSR shown by Hatzianastassiou et al. (2005) is more in line with the brightening period observed in the surface measurements since the late 1980s (Wild, 2009; Wild et al., 2005), although it is worth noting that trends over different regions, such as Europe, are not reported. Recently, Zhang et al. (2015) and Wang et al. (2015) reported a disagreement between ground-based records and different satellite-derived products over China.

The Satellite Application Facility for Climate Monitoring (CM SAF) has generated a product of SSR based on the instruments on-board the geostationary Meteosat First Generation satellites covering the period 1983–2005 (Mueller et al., 2011; Posselt et al., 2011a). Over Europe, considering a subset of grid points, this dataset shows a significant annual increase of 1.8 W m^{-2} per decade over the whole period which increases up to 4.5 W m^{-2} per decade if only the 1994–2005 period is considered (Sanchez-Lorenzo et al., 2013b). More recently, this dataset has been extended by using records from the Meteosat Second Generation satellites until 2010 by Posselt et al. (2014), who reported a mean increase of 4.4 W m^{-2} per decade over the whole Europe during the 1994–2010 period, but without an analysis of the spatial and seasonal differences in the trends (Posselt et al., 2014).

The main goal of this work is to study the changes of the annual and seasonal SSR over Europe by using the CM SAF SSR product extended until 2010, with special emphasis on the spatial and seasonal differences of these trends as previous literature mainly focused on the average over the whole of Europe on an annual basis. In addition, this work studies the residual series obtained by subtracting the high spatial resolution satellite-based all-sky data from a homogeneous dataset of ground-based of all-sky SSR on monthly basis. The datasets used in this study are described in Section 2. The trends of all-sky SSR over Europe are detailed in Section 3, whereas the residual series are shown in Section 4. Finally, conclusions of this paper are presented in Section 5.

2. Datasets and analysis

The satellite-based data set used in this study is based on the CM SAF Surface Radiation data set derived from the Meteosat geostationary satellites of the First Generation (MFG, Meteosat 2-7 in operation between 1982 and 2005) (Posselt et al., 2011b, 2012) and the Second Generation (MSG, >2005) (Posselt et al., 2014) and covers the time period from 1983 to 2010 with a spatial resolution of 0.03° in latitude and longitude. The MFG and MSG satellites, which are located at a longitude of 0° over the equator in an altitude of around 36,000 km, are equipped with the Meteosat Visible and Infrared Imager (MVIRI) radiometers and Spinning Enhanced Visible and Infrared Imager (SEVIRI), respectively. In brief, the satellite-derived SSR is first derived by making use of the Heliosat algorithm (e.g., Hammer et al., 2003) that determines the effective cloud albedo, which afterwards is combined with estimated clear-sky irradiances using the Mesoscale Atmospheric Global Irradiance Code (MAGIC) (Mueller et al., 2009). To derive the clear-sky irradiances monthly-averages of the integrated water vapour from the ERA-Interim reanalysis (Dee et al., 2011) as well as a monthly climatology of the aerosol properties based on Kinne et al. (2006) have been used (Posselt et al., 2011b; Mueller et al., 2015). Particular care was taken in Posselt et al. (2014) to ensure a homogeneous transition from the MVIRI instruments (until 2005) and the SEVIRI instruments (starting 2006). The broadband visible channel information from MVIRI was reproduced by a linear combination of the two narrow band visible channels available from SEVIRI following the methodology of Cros et al. (2006). Additional details about the dataset can be found in Posselt et al. (2011b, 2012, 2014).

The ground-based all-sky SSR measurements used to be compared with the satellite-derived product were obtained from the Global Energy Balance Archive (GEBA, http://www.geba.ethz.ch/), which is a database maintained at ETH Zurich that stores worldwide monthly means of different energy fluxes measured at the surface, mainly SSR measurements (Gilgen and Ohmura, 1999). A subset of series over Europe with monthly homogenized records of SSR (expressed in W m^{-2}) was considered. This dataset has been previously checked for temporal homogeneity by Sanchez-Lorenzo et al. (2013b), and contains the longest SSR series over Europe, with series starting before 1971 and with at least 30 years of data up to 2007. For this study, the records have been updated from January 2008 to December 2010 where possible by using the data available in the World Radiation Data Center (WRDC, http://wrdc.mgo.rssi.ru/). For more details about the name of the stations, and homogenization and gap filling procedures, we refer to Sanchez-Lorenzo et al. (2013b).

In order to compare the satellite-derived and the ground-based datasets, a subset of 47 time series was selected over the 1983–2010 period (Fig. 1). We have excluded the stations at both high altitudes and latitudes as in Sanchez-Lorenzo et al. (2013b) due to the well-known problems to derive SSR in mountain areas (Posselt et al., 2012), as well as the limitations of the geostationary satellites to observe high-latitude areas (Schulz et al., 2009). In addition, we have also excluded some stations that were subjected to numerous statistical corrections (e.g., Rome) during the homogenization of the series (Sanchez-Lorenzo et al., 2013b). The 47 satellite-derived grid points closest to the 47 ground-based stations have been extracted in order to compare both SSR datasets. December 1988 that is missing in the satellite-derived records was not considered in the ground-based series, as well as all the months missing in the ground-based stations (which have no complete records for all stations after 2000), in order to use the same number of months for the comparison of both datasets.

The linear trends of the series shown in this paper were calculated by means of least squares linear fitting and where required their significance assessed by the Mann-Kendall nonparametric test (Kendall, 1955) at the 95% confidence level. Gaussian low-pass filters were used in order to smooth time series, which improves the visualization of the decadal variability when plotted together. The filter only considers the values on one side at the start and end of the series in order to filter the full period.

3. Trends of the satellite-derived all-sky SSR over Europe

Trends of the annual and seasonal SSR derived from the satellite data over Europe (from 35° N to 60° N and 15°W and 35° E) are presented for both the 1983–2010 and 1994–2010 periods. This is due to the fact that data previous to 1994 suffer from temporal inhomogeneities, which has been suggested to be the result of artifacts in the raw data and instrument failures (Krähenmann et al., 2013; Posselt et al., 2011a). Nevertheless, the neglect of time varying aerosols, both from anthropogenic and natural (e.g., derived from large volcanic eruptions such as the Pinatubo) sources in the satellite-derived product has been also suggested as a reason in order to explain the observed breaks, among other possible causes (Sanchez-Lorenzo et al., 2013b). Consequently, and taking into account the results shown in Section 4, we show also the trends over the whole 1983–2010 period.

Time series of annual and seasonal mean values of SSR were derived for each grid point. The seasons are defined as spring (MAM), summer (JJA), autumn (SON), and winter (DJF). Winter is dated according to the year in which January and February fall, and for 1983 is calculated only considering January and February, as well as for 1989 as December 1988 is missing in the satellite-derived dataset. Then, the linear trends of the series were calculated by means of least squares linear fitting and annual and seasonal maps have been produced with the obtained trend rates. The grid values have been regridded from the 0.03° resolution to 0.1° in order to improve the visualization of the maps as the original trends show evidences of artifacts (not shown), which was the result of the regridding of the data from the original satellite grid to the 0.03° long-lat grid on which the data is provided. We confirm that these artifacts do not affect the following results and regridding was just performed for visualization purposes.