Quality control of global solar radiation data with satellite-based products

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**A B S T R A C T**

Several quality control (QC) procedures are available to detect errors in ground records of solar radiation, mainly range tests, model comparison and graphical analysis, but most of them are ineffective in detecting common problems that generate errors within the physical and statistical acceptance ranges. Herein, we present a novel QC method to detect small deviations from the real irradiance profile. The proposed method compares ground records with estimates from three independent radiation products, mainly satellite-based datasets, and flags periods of consecutive days where the daily deviation of the three products differs from the historical values for that time of the year and region. The confidence intervals of historical values are obtained using robust statistics and errors are subsequently detected with a window function that goes along the whole time series. The method is supplemented with a graphical analysis tool to ease the detection of false alarms.

The proposed QC was validated in a dataset of 313 ground stations. Faulty records were detected in 31 stations, even though the dataset had passed the Baseline Surface Radiation Network (BSRN) range tests. The graphical analysis tool facilitated the identification of the most likely causes of these errors, which were classified into operational errors (snow over the sensor, soiling, shading, time shifts, large errors) and equipment errors (miscalibration and sensor replacements), and it also eased the detection of false alarms (16 stations). These results prove that our QC method can overcome the limitations of existing QC tests by detecting common errors that create small deviations in the records and by providing a graphical analysis tool that facilitates and accelerates the inspection of flagged values.

**1. Introduction**

Solar radiation has been historically recorded at ground level by different meteorological agencies in order to provide reliable data for the assessment of the solar resource. These records are not only the most accurate source of solar radiation data, but are also crucial for validating satellite-based models, which are swiftly becoming the most widely used option to obtain spatial estimates of solar radiation (McArthur, 2005; Polo et al., 2016; Sengupta et al., 2015). Different parameters can be used to measure the amount and type of solar radiation reaching the Earth. The most common one is the global horizontal irradiance (G), i.e. the total shortwave incoming radiation received by a horizontal surface. More specialized monitoring stations can also measure the radiation components, i.e. the direct normal irradiance (Bn) and diffuse horizontal irradiance (D), providing more information about the type of radiation being received. Other parameters also recorded are the longwave radiation (upwelling and downwelling) and the sunshine duration, a parameter historically used to indirectly estimate G. However, in most cases the parameter normally recorded is only the G and the Bn, and D are derived using decomposition models (Gueymard and Ruiz-Arias, 2015).

Measuring G is more prone to errors than other meteorological variables (Moradi, 2009). Younes et al. (2005) proposed the classification of these errors into two broad groups: equipment and operational errors. Equipment errors are inherent to the type of pyranometer used and the calibration applied, and include the zenithal error (cosine error), azimuthal error, stability, non-linearity, temperature dependence and spectral response. Highest-quality records are obtained with thermopile pyranometers, which are based on the thermoelectric effect. Within thermopiles, three levels of quality are established by the ISO...
Many QC methods have been proposed by meteorological agencies and independent researchers. Some well-known examples are the QC tests from the Baseline Surface Radiation Network (BSRN) (Long and Dutton, 2002), the MESOR recommendations (Hoyer-Klick et al., 2008), the NREL SERI QC procedure (NREL, 1993), the QCrad methodology (Long and Shi, 2008) or the web-based services from MINES ParisTech (Geiger et al., 2002) and AQC test (Molineaux and Ineichen, 2003). These QC procedures flag those samples identified outside of the normal ranges of data and usually leave the decision of removing flagged cases to the user. They can be classified in four broad categories (Ohmura et al., 1998): range tests (physically and extremely rare limits), across-quantities relationships, model comparisons and graphical analysis. The least restrictive level of most QC procedures is a range test based on the physically possible limits, with the upper limit being equal to the extraterrestrial irradiation (E) and a lower limit lying within −4 and 0 W/m² (Long and Dutton, 2002; Hoyer-Klick et al., 2008; Long and Shi, 2008). In a second step, the physical ranges are narrowed imposing more strict conditions. The upper limit is usually reduced with estimations from a clear-sky model (Geiger et al., 2002; Journée and Bertrand, 2011; Hoyer-Klick et al., 2008; Younes et al., 2005) such as the ESRA clear-sky model (Rigollier et al., 2000), the Page model (Page and Lebens, 1986) or the Bird clear-sky model (Bird and Hulstrom, 1980, 1981). Simulation with these clear-sky models are usually carried out under clean atmospheric conditions (aerosols and water vapor set to 0) instead of using estimated or climatological values. The lower limit is increased up to the level of extremely overcast conditions. This is typically imposed with the dimensionless clearness index (KT = K/E), with values around 0.03 (Geiger et al., 2002), or with the modified clearness index (Perez et al., 1990). Other approaches to reduce the acceptance ranges are to use climatological values (Long and Shi, 2008), to interpolate records from nearby locations or to use estimations from meteorological variables (Tang et al., 2010), mainly sunshine duration (Journée and Bertrand, 2011; Moradi, 2009; Munee and Fairouz, 2002). Other QC tests also check the stability of the time series generated, analyzing the step between consecutive samples (Journée and Bertrand, 2011). Besides, some authors have proposed QC methods tailored to detect time shifts by analyzing the symmetry between morning and afternoon records (Ineichen, 2013) and by using graphical analysis (Moreno-Tejada et al., 2015). When the diffuse or direct components are also available, coherence or consistency tests are commonly imposed (Long and Dutton, 2002). Some authors have proposed the use of envelope tests in a dimensionless k-space consisting of the clearness index, the direct-beam clearness index (KN = K/B) and the global-to-diffuse ratio (K = G/D). These envelope tests are based on setting empirical or statistical limits either on the KT–K space or the KT–KN one (Younes et al., 2005; Journée and Bertrand, 2011; NREL, 1993; Pashiardis and Kalogirou, 2016) and the subsequent graphical analysis of the envelopes obtained.

The majority of these tests are designed to detect only large deviations in ground records, while some of the most common errors just introduce small deviations from the real irradiance profile. These faulty records pass most tests because they are acceptable from a statistical or a physical perspective, but they still have a negative influence on the assessment of solar radiation. Our aim is to develop a new QC
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