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Quality control of solar shortwave and terrestrial longwave radiation for surface radiation measurements at two sites in Cyprus

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A B S T R A C T

Routine measurements of irradiance are valuable for many research fields such as energy applications. However, ground data of solar global radiation can present questionable values. In this study, a set of check procedures is used to test the quality of shortwave and longwave radiation measurements taken at two actinometric stations in Cyprus (Athalassa-inland location and Larnaca-coastal location), during the period November 2012–July 2014. The testing procedures include physically possible limits for all the radiation components and comparisons between global radiation and the sum of direct and diffuse radiation. The quality process is implemented to both the 10-min averaged irradiances, hourly irradiation and the respective daily values. This paper reviews the currently available procedures for quality assessment of the solar shortwave and longwave irradiation data. In the present study, the first level of test includes physical possible limits which are determined by the Daylight Research Group and the Baseline Surface Radiation Network of the World Meteorological Organisation (WMO). The second level of test is a semi-automated procedure that is based on the creation of an envelope in the clearness index and the diffuse to global irradiance ratio. The third level of test is based on the comparison of various radiation parameters including comparison of measured extreme values with theoretical estimations from clear sky-models. The fourth level of test of the quality control procedure refers to the analysis of daily and annual variations of the radiation parameters.

1. Introduction

The amount of solar radiation received in an area at the ground level is the main source of energy for the development of many natural processes, such as heating of the ground and the air layers near the ground and in the atmosphere, evapotranspiration and photosynthesis; to some extent it constitutes one of the climatic parameters of the area. Therefore, the knowledge of the solar radiation climate of a region is of paramount importance in assessing the potential use of solar energy, converted to either thermal or electrical energy. Such information is a prerequisite for the design of solar energy conversion systems. Solar radiation data are, therefore, required in many research fields.

Compared to measurements of other meteorological variables, the measurement of solar radiation is more prone to errors and often encounters more problems such as technical failure and operation-related problems [1]. Different sources of errors related to solar radiation measurements can be categorised into two classes: equipment and operation-related problems [2]. With any kind of measurements there exist errors, some of which are systematic, while others are random inherent of the equipment employed. The most common sources of error arise from the sensors and their construction. The cosine response is rated as the most important instrumental error. However, the random errors are considered more important due to operational problems or maintenance processes of the instruments. According to Younes et al. [3], the following operational errors are common: shade-ring misalignment; dust, snow, dew, water-droplets, bird droppings on the surface of the glass dome; incorrect sensor levelling; shading caused by building structures or trees; electric fields in the vicinity of cables; mechanical loading of cables; orientation of the sensors and electricity blackout.

Therefore, the quality control (QC) of measured data has been a main concern of most radiometric network operations. A number of researchers have proposed different methods for quality control. The World Meteorological Organisation (WMO) has published guidelines on the quality control of data from the World

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Radiometric Network [4]. The proposed checks cover instantaneous, hourly, daily and monthly mean values. The Daylight Research Group [5] has proposed physically possible limits for the main radiation components and comparisons between them [6]. Later, Long and Shi [7] have extended the testing procedure by including extremely rare limits and configurable climatological limits for all radiation parameters.

Younes et al. [3] developed a new procedure for controlling the quality of larger solar irradiation data sets. They proposed a set of physical and statistical indices to develop a semi-automated procedure. Their method is based on the creation of an envelope in the clearness index and the diffuse to global irradiance ratio. The method was implemented successfully by a number of researchers using data from different parts of the world [8,9,10].

Molineaux and Ineichen [11] have developed a web-based facility for quality control of solar radiation data. Their computer programmes allow validation limits to be set on the tests so as to enable the user to increase the precision of the tests. Their programme carries out a series of coherence tests, which is then followed by the creation of a number of plots based on comparisons between modelled/calculated and measured values. A web-based service to perform a fine and precise QC was also developed by Geiger et al. [12]. The method is based on the quality control procedures proposed during the development of the European Solar Radiation Atlas project [13]. The SERI QC software has been developed by NREL for assessing the quality of solar radiation data by comparing measured values with expected ones. This procedure is based on the relationship between global and direct components of solar radiation [14]. Page model [15] sets upper and lower boundaries for diffuse radiation and an upper boundary for global radiation. For the diffuse component, the overcast and clear-sky irradiance set the upper and lower limits, respectively. For the global component, the upper limit is set by the global clear-sky model. The clear-sky model is based on the estimation of the direct-beam radiation using the Linke turbidity factor, the air mass and the Rayleigh optical depth of the atmosphere. Bird and Hulstrom [16] have also proposed a clear-sky model. Detailed quality control procedures were applied to radiation data by the European project ENDORSE which are based on extreme and rare observations and include range and consistency checks [17], as shown in Table 1.

Journée and Bertrand [18] have developed detailed procedures and software for the quality control of radiometric sub-hourly data (i.e., 10-min and 30-min averaged data) of the Belgium network. The quality criteria of radiometric data include physical limits, step, persistence, quality envelope, spatial consistency and sunshine duration tests.

More recently, Ineichen [19] in order to detect time shift in the data, checked the symmetry of the irradiance values (with respect to solar noon) for very clear days by plotting *GHI* and *BNI* versus the sine of the solar elevation angle. If the time stamp is correct, the afternoon curve should normally lay over the morning curve. He further tested the sensor's calibration coefficient by introducing the concept of the modified clearness index, k_t', which was defined by the following equation [20]:

$$k_t' = k_t/(1.031 \exp(-1.4/(0.9 + 9.4/AM)) + 0.1 \quad (1)$$

where, *AM* is the optical air mass as defined by Kasten [21]. This modified clearness index has the advantage of being relatively more independent from the solar elevation angle than k_t. This modified global clearness index is also used to delineate three k_t' zones to characterise the sky condition:

Clear-sky conditions $0.65 < k_t' \leq 1.00$
Intermediate sky conditions $0.30 < k_t' \leq 0.65$
Cloudy sky conditions $0.00 < k_t' \leq 0.30$

The consistency of the solar components was tested by plotting the diffuse fraction (k_d) and the direct beam clearness index (k_b) against the clearness index (k_t) including the predictions from the Solis radiative model [19] using 4 different aerosol loads. Any important deviation between the predicted and measured clear-sky values indicates calibration uncertainties, pyrheliometer misalignment, shaded sensors or miss-categorisation of clear-sky conditions.

The aim of this study is to control the quality of 10-min, hourly and daily solar and terrestrial data using different quality tests obtained from the literature. The testing procedures have three different levels and include physically possible limits for all the radiation components and comparisons between them. The data after the quality control are used for statistical analysis for both the short and longwave radiation components in order to assess the radiation climate characteristics of the two locations in Cyprus, Athalassa-inland location and Larnaca-coastal location as shown in Fig. 1.

2. Solar shortwave and terrestrial longwave measurements

2.1. Climate characteristics of the two sites

The radiation data on which this study is based are being monitored at two meteorological stations: one located at Athalassa, an inland plain location and the other one at Larnaca Airport which is near the coast. The climate of both stations is typical Mediterranean with mild winters (mean seasonal air temperature of about 12 °C at Larnaca and 10.5 °C at Athalassa) and warm summers (mean seasonal air temperature of 27.5 °C at Larnaca and 29.5 °C at

Table 1
Quality Control Procedures (QCP) for the daily and hourly radiation variables used in the ENDORSE Project.

Component	QCP based on	Daily	Hourly
GHI (Wm^{-2})	Extremes	$0.03GHI_{toa} < GHI < 1.2I_0$	$0.03GHI_{toa} < GHI < \min(1.2I_0, 1.5I_0(\cos\theta_z)^{1.2} + 100$
	Rare obs.	$0.03GHI_{toa} < GHI < GHI_{toa}$	$0.03GHI_{toa} < GHI < \min(1.2I_0(\cos\theta_z)^{1.2} + 50$
BNI (Wm^{-2})	Extremes	$0 < BNI < I_0$	$0 < BNI < I_0$
	Rare obs.		$0 < BNI < 0.95I_0(\cos\theta_z)^{0.2} + 10$
DHI (Wm^{-2})	Extremes	$0.03GHI_{toa} < DHI << 0.8I_0$	$0.03GHI_{toa} < DHI < \min(0.8I_0, 0.95I_0(\cos\theta_z)^{1.2} + 50$
	Rare obs.		$0.03GHI_{toa} < DHI < 0.75I_0(\cos\theta_z)^{1.2} + 30$
Consistency checks		$DHI \leq 1.1GHI$	For $GHI > 20$ W m^{-2} $GHI/(BHI+DHI) \leq 0.15$ $DHI \leq 1.1GHI$

GHI = Global horizontal irradiance, *BNI* = Direct-beam normal irradiance, *DHI* = Diffuse horizontal irradiance, *BHI* = Direct-beam horizontal irradiance, GHI_{toa} = Global horizontal irradiance at the top-of-the-atmosphere, I_0 = Extraterrestrial irradiance (Solar constant corrected for the actual sun-earth distance), θ_z = solar zenith angle.