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A non-parametric method for correction of global radiation observations

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Abstract

This paper presents a method for correction and alignment of global radiation observations based on information obtained from calculated global radiation, in the present study one-hour forecast of global radiation from a numerical weather prediction (NWP) model is used. Systematical errors detected in the observations are corrected. These are errors such as: tilt in the leveling of the sensor, shadowing from surrounding objects, clipping and saturation in the signal processing, and errors from dirt and wear. The method is based on a statistical non-parametric clear-sky model which is applied to both the observed and the calculated radiation in order to find systematic deviations between them. The method is applied to correct global radiation observations from a climate station located at a district heating plant in Denmark. The results are compared to observations recorded at the Danish Technical University. The method can be useful for optimized use of solar radiation observations for forecasting, monitoring, and modeling of energy production and load which are affected by solar radiation.

Keywords: Global solar radiation; Solar energy; Observations; Correction; Quality control; Statistical clear-sky model

1. Introduction

The transition to a reliable and secure energy system based on weather dependent production technologies, especially wind and solar, will require new methods for automated handling of climate data recorded at, in most cases, unsupervised and uncalibrated stations. Reliable observations of solar radiation are an important source of information for operation of the energy system, especially for the energy production and load which are dependent on the solar radiation, for example production from photovoltaics and solar collectors, and load from heating and cooling of buildings.

Observations of solar radiation are exposed to many sources of errors. Younes et al. (2005) list the most important types of errors and divide the errors into two major categories: equipment errors and operation related errors. The present solar radiation sensor technology makes it easy and cheap to install and connect sensors to the Internet, both for professional and amateur applications. Web sites already provide on-line data (DMI, 2012), which can become an important source of information for operation of energy systems. Such, mostly unsupervised and unvalidated installations, will be highly exposed to different error sources.

In the present study observations of global radiation from a station at a district heating plant in Sønderborg, Denmark, are used. Three types of errors are found in

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Nomenclature

G_t	observed global radiation (W/m^2)
G_t^{nwp}	numerical weather predictions (NWPs) of global radiation (W/m^2)
G_{cs}	clear-sky global radiation (W/m^2)
B_{cs}	direct clear-sky global radiation (W/m^2)
D_{cs}	diffuse clear-sky global radiation (W/m^2)
G	global radiation (W/m^2)
I_{ext}	extraterrestrial radiation (W/m^2)
G_t^{pr}	projection of global radiation to the plane normal to the direct solar radiation (W/m^2)
$\widehat{G}_t^{\text{pr,cs}}$	estimated clear-sky radiation on a plane normal to the direct solarradiation (W/m^2)
$\widehat{G}_t^{\text{cs}}$	estimated clear-sky global radiation (modeled based on observations) (W/m^2)
$\widehat{G}_t^{\text{nwp,cs}}t$	clear-sky global radiation for numerical weather predictions (NWPs) (W/m^2)
$\widehat{G}_t^{\text{co}}$	corrected global radiation (W/m^2)
θ_t^{zenith}	solar zenith angle (rad)
$\tau_{\text{a,B}}$	transmittance function of the atmosphere for direct radiation under clear-sky conditions
τ_{c}	transmittance function of clouds in the atmosphere
β_t	parameter vector for the local quantile regression
$\rho_q(u)$	the quantile regression objective function
q	sample quantile to be estimated in the local quantile regression
i	counter of days (days)
j	counter in samples
t	time (h)
t_{sp}	sample period (h)
h_{doy}	bandwidth of kernel function in the *day of year* dimension (days)
h_{tod}	bandwidth of kernel function in the *time of day* dimension (h)

the observations: tilt in the leveling of the sensor, shadowing from surrounding objects, and clipping at a maximum level. A method is presented for correction of the observations on the basis of information extracted from global radiation calculated using a model based on physical principles. The method is based on a non-parametric statistical clear-sky model and requires no further information about the installation and sensor than the observed values and the location of the station. With the statistical clear-sky model the sensor output level under clear-sky conditions is modeled directly from the observations. This is compared to solar radiation calculated with a clear-sky model based on physical modeling of the optical effects through the atmosphere, such as the models described by Davies and McKay (1982), Bird (1984), Rigollier et al. (2000), Mueller et al. (2004), and Ineichen (2006). In the preset study forecasts from a numerical weather prediction (NWP) model is used. The result after correction of the observations is compared to high quality measurements recorded at the Danish Technical University.

Studies on quality control of measured solar radiation data can be found in the literature. The procedures are semi-automatic and are mostly based on comparison to physical models for detection of erroneous measurements (Geiger et al., 2002; Younes et al., 2005; Isaac and Moradi, 2009; Journée and Bertrand, 2011).

The paper is organized as follows: the data used in the study is presented in the next section. This is followed by a section in which the statistical clear-sky model is described and a section where the correction is presented. The paper ends with a discussion of the method and a conclusion.

2. Data: observations and numerical weather predictions of global radiation

The data used in this study consists of time series of global radiation observed at two weather stations: one located in Sønderborg (54.91°N and 9.80°E) and one located at DTU Byg in Lyngby (55.79°N and 12.52°E), both in Denmark. In addition NWPs of global radiation for the same locations are used. All values are hourly averages. All times are in UTC and the time points are set to the end of the hour.

2.1. Observations

The observations from Sønderborg are recorded with a weather station, which is located at a district heating plant. The weather station is mounted on a pole on a single-storey building as seen on the image in Fig. 1. No information about the type of the solar radiation sensor was available. The time series from Sønderborg is

$$\{G_t; \quad t = 1, \ldots, N\} \tag{1}$$

where $N = 17520$ and G_t is the observed average global radiation between time t and $t-1$. The upper plot in Fig. 2 shows the series which spans from 2009-01-01 to 2011-01-01. From this plot it is readily seen that the observations are not without systematic errors, for example it can be seen that the values are clipped at a maximum level. This and other types of systematic errors are corrected for the Sønderborg observations using the method described in this paper.