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PREPARATION OF A LARGE TESTING PROCEDURE FOR MODELS OF CLEAR SKY SOLAR IRRADIANCE COMPUTATION UNDER THE CLIMATE OF ROMANIA

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Abstract. *The paper reports on the preparation of a country-scale experiment aiming to foster the solar irradiance computation under the climate of Romania. The experiment refers to the performance of 53 models designed to simulate the global, diffuse and direct solar irradiance. We present the research strategy, suggest model classification criteria, propose a few testing procedures, and describe the datasets used. The results can fundament the modeling of solar irradiance in Romania, with major impact on the renewable energy and meteorological applications.*

Keywords: solar irradiance, Romania, modeling, renewable energy

1. Introduction

Detailed knowledge of solar radiation availability is of fundamental importance for the successful development of solar energy projects. The appropriate design of many solar energy devices requires solar global radiation input. There are some other devices which are using concentrated radiation. In this case estimates about the level of solar beam (direct) radiation are necessary. Quantitative information about the available diffuse solar radiation has special significance for the proper design of civil and industrial buildings illumination. Besides, a profound understanding of atmospheric processes makes intensive use of solar radiation information.

Although there are several world maps of solar radiation, they are not detailed enough to be used for the determination of available solar energy on small areas. For such regions, particular approaches are required. Moreover, in most countries the spatial density of the actinometrical stations is inadequate. For example, the ratio of weather stations collecting solar radiation data relative to those collecting temperature data in the USA is approximately 1:100, and worldwide the estimate is approximately 1:500. In Romania the ratio is about 1:20.

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These circumstances have prompted the development of calculation procedures to provide radiation estimates for areas where measurements are not carried out and for situations when gaps in the measurement records occurred.

2. Objectives

This study aims at a large scale testing of solar radiation computing models under the climate of Romania, at hourly scale. Here we report only on the preparation stage. We present a possible strategy to categorize the used models (a), we propose testing procedures (b), and describe the datasets available over the actinometrical and meteorological networks of Romania (c).

3. Models classification and performance

In the recent decades, different types of models have been developed to provide predictions of solar radiation. Fifty-three broad band models for computation of direct, diffuse and global irradiance on horizontal surface were selected for testing within this experiment. According to factors like input or output data, spatial, temporal and spectral resolution etc., nine types of radiation models can be recommended [1].

1. *Type of output data.* Outputs ideally consist of direct, diffuse and global irradiance, but frequently only one component is required (e.g., direct normal irradiance, or global irradiance on a tilted plane).

2. *Type of input data.* Inputs consist of meteorological variables, irradiance components and topographical characteristics. Generally, these inputs can be obtained from ground sites, or remote sensed from air- or space-borne sensors. In the experiment described here, the input consists of various meteorological data, but some local topography features were also considered, e.g. albedo. Aiming to provide results at hourly scale, the building of the meteorological database is a complex enterprise.

3. *Spatial resolution.* Some models provide predictions for a specific location (generally where the input data come from), others provide gridded results (generally when using satellite-based inputs).

4. *Time resolution.* Irradiance outputs can be of high-resolution (every minute or less), standard resolution (hourly), average resolution (specific day), low-resolution (average hour or average day for a specific month), or climatologic (average hour or day over a long-term period, such as 10–30 years). Typically, high-resolution data are needed for solar concentrators, hourly data are used for solar systems or building energy simulations, daily data are used in agricultural meteorology, while system design and climatology exploit long-term average data.

5. *Spectral resolution.* Most models are broadband (i.e. they evaluate the shortwave radiation transmitted by the atmosphere as if the solar spectrum was constituted only of one band, typically 300–4000 nm). Some models, however, consider two or more distinct bands for more resolution. For instance, there are models limited to the ultraviolet (below 400 nm) or the photosynthetic waveband (400–700 nm). For specific applications, such as atmospheric physics, remote sensing or prediction of the performance of spectrally-selective devices such as photovoltaic systems or coated glazings, spectral models are necessary.

6. *Type of methodology.* The model's methodology can be either deterministic or stochastic (also called "statistical"). A deterministic algorithm tries to determine irradiance for a specific time, which can be in the past, present or future. A stochastic algorithm "invents" solar radiation without this requirement, in a virtual way, but primarily tries to respect some statistical properties of the irradiance time series, such as variance, cumulative frequency distribution, persistence etc.

7. *Type of algorithm.* Another methodological distinction can be made between physical or semi-physical models, which are derived more or less directly from physical principles and empirical models, which are based only/mostly on measured irradiance data obtained for a specific location and period to predict irradiance at other locations and/or periods.

8. *Surface geometry.* Irradiance data may be needed for horizontal planes, tilted surfaces, or tracking surfaces that permanently point to the sun. Most solar energy and building applications involve receivers that are either fixed on a tilt or tracking the sun. Similarly, ecological applications often involve the modeling of topographic solar radiation over complex mountainous terrain. Solar radiation on such tilted surfaces can be obtained from horizontal radiation data by using so-called "transposition models".

9. *Type of sky.* Most models consider the effect of clouds, which is of primary importance. For some applications however, such as building energy load calculations or solar concentrator resource assessment, irradiance predictions are normally limited to clear-sky conditions, which may require a specific model.

According to the classification criteria presented above, the models used in our experiment can be assigned as described in Table 1.

Table 1

Models classification according to several criteria

Criterion	**Models feature**
#1—*Type of output data*	Direct, diffuse and global irradiance
#2—*Type of input data*	Meteorological variables, climatological data
#3—*Spatial resolution*	Specific location
#4—*Time resolution*	High resolution (instantaneous values)
#5—*Spectral resolution*	Broadband
#6—*Type of methodology*	Deterministic
#7—*Type of algorithm*	Physical and empirical models
#8—*Surface geometry*	Horizontal surface
#9—*Type of sky*	Clear sky models

Finally, the models will be tested in eight localities against meteorological data from stations owned by the National Meteorological Administration, well covering the Romania's territory (Fig. 1).

The model performance assessment will be performed by using qualitative and quantitative methods.

Qualitative Assessment. Most qualitative results appear in the form of scatter plots, which visually indicate the bias (systematic error) and scatter (random error) of predicted *vs.* measured values. Results from a perfect model would align on the 1:1 diagonal when compared to their perfectly measured counterparts.

Quantitative Assessment. Using qualitative information would be too difficult or subjective. A statistical analysis of the actual modeling errors must therefore be performed. The most common bulk performance statistics are the Mean Bias Error (*MBE*), the Root Mean Square Error (*RMSE*) and the Mean Absolute Bias Error (*MABE*). Another indicator is the t-statistic. Willmott's index of agreement, *d*, measures the degree to which a model's predictions are error free. Another statistical indicator is the coefficient of determination R^2.

A model designed to compute hourly solar irradiation provides good performance if the MBE, RMSE and the standard deviation have as low values as possible. For global irradiation, MBE within ±10% and RMSE within ±20% are considered satisfactory, while for diffuse irradiation MBE values within ±20%, and RMSE values within ±30% indicate good fitting between model results and measurements.

The 53 models will be ranked according to the statistical indicators, resulting in different hierarchies. An "accuracy score" that appropriately combines various statistical indicators may be used to provide an overall ranking for the models. However, a major inconvenience of the method is that each of its individual scores refers to the best performer, so that all calculations need to be redone each time a model is modified or added to the test pool.

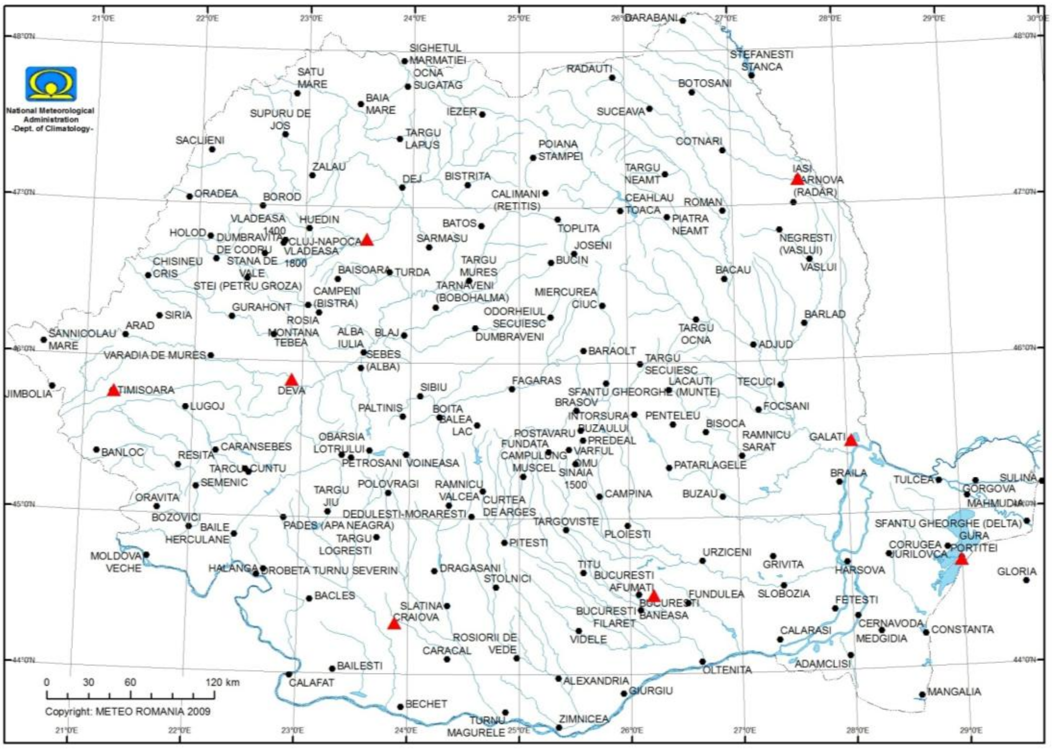

Fig. 1. Meteorological stations (black circles) and actinometrical stations (red triangles) of the National Meteorological Administration

4. The measurement databases

The input consists of several sub-databases, usable according to their content and requirements. The meteorological database refers to total cloudiness, air temperature, relative humidity, air pressure, wind speed and dew point temperature. They all are recorded at one hour lag at the eight test locations. A smaller database consists of values of column integrated ozone. Measurements are performed once per day in a single station (Bucharest-Băneasa), while satellite data are used for the other stations. Another database consists of column integrated precipitable water. Data are available for two stations (Bucharest-Afumaţi and Cluj-Napoca), and the measurements are performed once per day and twice per day, respectively.

Empirical relationships based on ground temperature and relative humidity will be used in case of the stations with missing precipitable water data. The turbidity coefficients α and β entering the Ångström's Law, as well as the values of the aerosol single-scattering albedo are obtained on a monthly basis from world maps recently published for all stations involved [2]. These are multi-yearly averaged values. The ground albedo is obtained from satellite images (MODIS[1]) on a monthly basis for all stations and all years with available meteorological data. The measured radiation data consist of global and diffuse hourly irradiations measured, and they are utilized for assessing the performance of the models.

5. Testing procedure

Models testing will be performed in stages. In the first stage, input data will be prepared by using the most accurate and reliable data. Only a few stations may provide such data. In next stages these constraints will be relaxed, and various considerations will be assumed. For example, Figure 2 illustrates the differences between the simulated global radiation resulted from the 53 models and the measured values at Cluj-Napoca Weather Station. The figure shows only those particular hourly values when the total cloud cover amount equals 0 and the relative sunshine equals 1. Different assumptions refer to instances when total cloud cover equals 0, but the relative sunshine duration is less than 1, or the reverse situation etc.

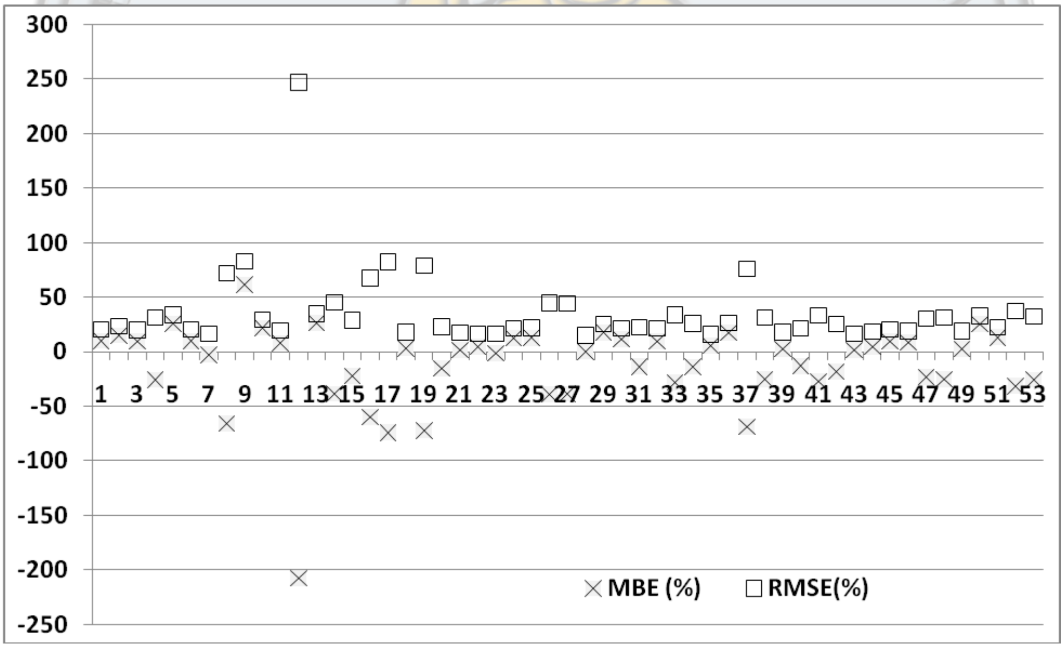

Fig. 2. MBE (%) and RMSE (%) values for the fifty-three models when applied to measured global solar radiation data in 2009 at Cluj-Napoca.

6. Concluding remarks

[1]http://modis.gsfc.nasa.gov/about/

Details are given herein about the preparation of a large scale testing of solar radiation computing models under the climate and latitudes of Romania.

Criteria to select the models are shown, and a formal model classification is adopted.

Information about the locations where the models are tested is provided, as well as details about the input and output databases.

A testing procedure is proposed and some results sampled.

The philosophy of the testing procedure is outlined in this paper, and detailed reports represent its follow-up.

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