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Artificial neural network based model for retrieval of the direct normal, diffuse horizontal and global horizontal irradiances using SEVIRI images

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Abstract

A statistical model for the prediction of the solar irradiance components, utilizing six thermal channels of the SEVIRI instrument (onboard Meteosat Second Generation satellite), is presented. Additional inputs to the model include the solar zenith angle, solar time, day number and eccentricity correction. Treating the cloud-free and cloudy observations separately, the model employs two trained artificial neural network ensembles, one for estimating the direct normal irradiance and the other for estimating the diffuse horizontal irradiance. The global horizontal irradiance is then computed from the model's outputs. The model has been trained using reference data from three ground measurement stations for the full year of 2010 and tested over two independent stations for the full year of 2009. Over the two independent stations for all sky conditions, the relative root mean square errors for the direct, diffuse and global components are 26.1%, 25.6% and 12.4%, respectively, while the relative mean bias errors are −6%, +3.6% and −2.9%, respectively. The temporal and spatial variations of the direct, diffuse and global components are also presented for three days exhibiting different sky conditions in the year 2009.

Keywords: Solar resource assessment; Optical depth; Neural networks; Satellite images; Solar irradiance

1. Introduction

Applications utilizing solar radiation require accurate solar resource assessments. Not all applications require the same assessments though. Concentrating collectors require accurate direct normal irradiance (*DNI*) assessments, while models deriving the global tilt irradiance for fixed flat plate collectors require the *DNI*, diffuse horizontal irradiance (*DHI*), global horizontal irradiance (*GHI*) and ground albedo as inputs (Gueymard, 2009; Liu and Jordan, 1963). Assessments of the *DHI* and *DNI* are also useful for daylight applications in energy efficient homes (Hammer et al., 2003). Therefore, *GHI*, *DNI* and *DHI* assessments are important for a wide range of solar applications.

In the absence of sufficient ground measurements, planners' options become limited to spatial databases for solar resource information. Solar maps, derived from satellite images, have the ability to provide solar assessments over areas where no ground measurements are available. They provide much higher accuracies than simple interpolation of ground measurements (Zelenka et al., 1999). Yearly solar maps provide irradiation data showing the solar

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Nomenclature

DNI	direct normal irradiance (W/m^2)
DHI	diffuse horizontal irradiance (W/m^2)
GHI	global horizontal irradiance (W/m^2)
θ_Z	solar zenith angle (degrees)
ε	eccentricity correction
δ	total optical depth of the atmosphere
RMSE	root mean square error (W/m^2)
MBE	mean bias error (W/m^2)
rRMSE	relative RMSE (%)
rMBE	relative MBE (%)
I_0	solar constant: 1367 W/m^2
m	air mass
δ_R	rayleigh optical thickness
δ_{gas}	optical thickness due to air and carbon dioxide molecules
δ_{ozone}	optical thickness of ozone
$\delta_{aerosol}$	optical thickness of aerosols
δ_{water}	optical thickness of water vapor
T_L	Linke turbidity factor
$T_L(2)$	T_L normalized to an air mass of 2
n	cloud index
T04	SEVIRI T04 channel (3.9 μm) observed brightness temperature (K)
T05	SEVIRI T05 channel (6.2 μm) observed brightness temperature (K)
T06	SEVIRI T06 channel (7.3 μm) observed brightness temperature (K)
T07	SEVIRI T07 channel (8.7 μm) observed brightness temperature (K)
T09	SEVIRI T09 channel (10.8 μm) observed brightness temperature (K)
T10	SEVIRI T10 channel (12.0 μm) observed brightness temperature (K)
$T09_b$	SEVIRI T09 channel background clear sky brightness temperature (K)
$T10_b$	SEVIRI T10 channel background clear sky brightness temperature (K)
ΔT	pre-defined offset, 1.9 K for barren surfaces

potential in different areas for siting and performance pre-assessment purposes. They could also be used to show the annual variability of solar radiation. Additionally, if solar maps are developed from satellite measurements, historical irradiance estimations could be generated, since 2004 for SEVIRI (onboard Meteosat Second Generation satellite).

Several models were developed to estimate solar radiation at the surface of the earth using geostationary satellite images. Both empirical and physical based approaches were used in these models and in some cases hybrid-based approaches were proposed by integrating both physical and empirical characteristics (Perez et al., 2002). Physical model of Gautier et al. (1980) was used to estimate the *GHI* in North America using GOES images. This model was adapted for Meteosat images by Cogliani et al. (2007) to produce the physical model SOLARMET capable of measuring both the *GHI* and *DNI* over Europe, Africa and the Middle East. The Heliosat-2 model, a hybrid one, was developed to estimate the *GHI* using Meteosat images (Hammer et al., 2003; Rigollier et al., 2000, 2004). The original Heliosat model proposed by Cano et al. (1986) was also adapted for GOES images by Perez et al. (2002) to estimate the *GHI*, *DNI* and *DHI* over the USA. Another physical-based model was developed by Schillings et al. (2004a) to estimate the *DNI* from Meteosat images.

These models have been widely used in several locations for solar radiation estimations. Moradi et al. (2009) have applied Heliosat-2 to estimate the daily global horizontal irradiation in Iran. A relative root mean square error (rRMSE) of 11.7% and a relative mean bias error (rMBE) of +1.9% were obtained. More recently, Eissa et al. (2012a) have presented a recalibrated version of the Heliosat-2 model, adapted to the humid and dusty environment of the Arabian Peninsula. The authors have proposed the recalibration of the empirical clear sky *DHI* equation in Heliosat-2 using data collected from four stations in the UAE. The modified Heliosat-2 was successfully applied to estimate the *GHI* at a 30 min resolution. An rRMSE ranging between 9.5% and 10.3% and an rMBE ranging between −1.2% and +0.8% were obtained over the four stations. Vignola et al. (2007) tested the model developed by Perez et al. (2002) using an independent dataset of 1-year hourly ground measurements from Kimberly, Idaho, USA. The *GHI* and *DNI* are estimated from the model, while the *DHI* is calculated from those estimates. Their results show rRMSE values of 21.5%, 40.9% and 54.2% for the *GHI*, *DNI* and *DHI*, respectively, and rMBE values of −4.9%, +2% and +15.4% in the aforementioned order. Schillings et al. (2004b) tested the model of Schillings et al. (2004a) over eight stations in Saudi Arabia for hourly satellite-derived *DNI* values and obtained an rRMSE of 36.1% and an rMBE of +4.3% for all sky conditions.

Artificial neural networks (ANNs) have been used in a number of studies to model environmental applications, where they proved to be more successful than classical regression models (Chokmani et al., 2008; Ouarda and Shu, 2009). Furthermore, it was shown that ensemble of ANNs provide better generalization compared to using a single ANN (Freund and Schapire, 1996; Ouarda and Shu, 2009). ANNs have been used in several studies dealing with solar resource assessments. Tymvios et al. (2005) trained and validated an ANN to model the daily global horizontal irradiation over Athalassa, Cyprus using