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Assessment and recalibration of the Heliosat-2 method in global horizontal irradiance modeling over the desert environment of the UAE

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Abstract

Remote estimation of global horizontal irradiance (*GHI*) by Heliosat-2 model has been benchmarked against ground-based measurements in different locations. The obtained results have shown that the level of agreement between ground-based and model-based *GHI* values are location dependent. To our knowledge no similar studies have been carried out over the Arabian Peninsula. The unique climatic condition in the Peninsula, characterized by high concentrations of airborne dust particles and high humidity makes the region a particularly interesting case.

In this study Heliosat-2 method was used to derive the ground surface *GHI* in the United Arab Emirates. Inputs to the model were monthly Linke turbidity factor normalized to an air mass of 2 and a cloud index derived from SEVIRI sensor onboard the European satellite Meteosat. The Linke turbidity factor was obtained from a ground network of seven stations distributed across the UAE. A SEVIRI-based technique was developed and used to derive cloud index from high-resolution visible channels. Ground surface *GHI* measurements were collected from four inland stations for a period ranging from mid-2007 to mid-2010. The obtained results show that the Heliosat-2 model underestimates the *GHI*. The obtained root mean square error (RMSE) and mean bias error (MBE) values ranged from 16.3% to 18.5% and −13.6% to −15.8%, respectively. A constant bias was observed between modeled and measured *GHI* throughout the four stations. To correct this bias, the empirical equation used in Heliosat-2 to estimate the clear sky diffuse horizontal irradiance (DHI_{clear}) was recalibrated. With the new DHI_{clear} empirical equation, the modified Heliosat-2 model becomes more adapted to desert and dusty environments such as that of the UAE. By applying the modified DHI_{clear} equation, the RMSE and MBE values dropped to 9.5–10.3% and −1.2 to +0.8%, respectively.

Keywords: Heliosat; Solar resource assessment; Linke turbidity; Global horizontal irradiance; Diffuse irradiance

1. Introduction

Depletion of fossil fuel resources and fluctuations in their market price, together with an increasing awareness of the need to reduce greenhouse gas production and fossil fuel usage has led to an increasing effort around the globe to develop new and environmentally friendly energy resources. Solar technologies have emerged as a promising candidate in supplying power and other heating and cooling applications. Cost of power generation from solar plants is expected to decline as generation increases along with continuous advancements in the technology.

Countries within the Arabian Peninsula have high potential for solar technologies, since their locations receive long hours of sunlight and the frequency of clouds is modest. The United Arab Emirates (UAE), for example,

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Nomenclature

GHI	global horizontal irradiance in (W/m^2)
DNI	direct normal irradiance in (W/m^2)
DHI	diffuse horizontal irradiance in (W/m^2)
GHI_{clear}	clear sky global horizontal irradiance in (W/m^2)
DNI_{clear}	clear sky direct normal irradiance in (W/m^2)
DHI_{clear}	clear sky diffuse horizontal irradiance in (W/m^2)
n	cloud index
T_L	Linke turbidity factor
$T_L(2)$	Linke turbidity factor normalized to air mass of 2
θ_Z	solar zenith angle
δ	optical thickness of whole atmosphere
δ_R	optical thickness of Rayleigh atmosphere
δ_{ozone}	optical thickness of ozone
δ_{gas}	optical thickness of gases
δ_{H_2O}	optical thickness of water vapor
$\delta_{aerosol}$	optical thickness of aerosols
I_0	solar constant of 1,367 (W/m^2)
ε	Earth–Sun distance correction
m	air mass
Z	elevation of a site in meters
k_t	hourly clearness
k_t'	corrected hourly clearness
K_t	daily clearness
$\rho^t_{(i,j)}$	instantaneous reflectance for pixel (i,j)
$\rho^t_{min(i,j)}$	surface albedo for pixel (i,j)
ρ_{max}	maximum reflectivity
k_T^*	clear sky index

already set a target of 7% share of electricity production capacity from renewable energy sources by the year 2020. The UAE has already taken action towards the implementation of its objectives by realizing a 10 MW photovoltaic (PV) plant operating in Masdar City and a concentrated solar power (CSP) plant, Shams 1, currently under construction, that will have a capacity of 100–125 MW. Those large scale power production plants come in addition to the PV rooftop program that has the goal to reach 500 MW installed capacity around the UAE within 20 years.

An accurate assessment of the solar radiation resources reaching the surface becomes necessary for decision makers and stakeholders in the region. Schillings et al. (2004a) developed a model to derive direct normal irradiance (*DNI*) from Meteosat images, which was tested over eight sites in Saudi Arabia. Over eight stations, results for the yearly sum of *DNI* values had a root mean square error (RMSE) of 8.1%, hourly values show an RMSE of 36% and a mean bias error (MBE) of +4.3% (Schillings et al., 2004b). Maxwell et al. (1998) also applied the climatological solar radiation (CSR) model for global, direct and diffuse irradiation modeling over Saudi Arabia. Their results show RMSE and MBE values ranging from 187 to 511 Wh/m^2/day and −47 to +691Wh/m^2/day, respectively, for the monthly mean total global horizontal irradiation over 11 ground-based measurement stations (Maxwell et al., 1998). Available solar maps generally overestimate the solar radiation reaching the surface because the models are not tuned for the specific climatologic characteristics represented in the region. Conditions such as high aerosol concentrations in the atmosphere are common due to the desert environment. High humidity is also frequent in the vicinity of the coast.

The Heliosat model has been proposed by Cano et al. (1986) and has evolved since then from an empirically based model to a hybrid model, comprising of atmospheric physical parameters. Heliosat has the capability to model the global horizontal irradiance (*GHI*) reaching the surface at a specific location using Meteosat satellites. The performance of this model is location dependent (Rigollier et al., 2004), but no published studies were found on its application in the Arabian Peninsula.

This study assesses the performance of Heliosat-2 model to estimate the *GHI* over the desert climate of the UAE at temporal and spatial resolutions of 30 min and 3 km, respectively. Ground-based measurements collected from mid-2007 to mid-2010 were used to determine physical parameters of the atmosphere. Also, the high-resolution visible (HRV) channel of the SEVIRI instrument onboard of Meteosat Second Generation (MSG) satellite was employed to derive cloud index n. Due to the unique climatic condition in the Peninsula, characterized by high concentrations of airborne dust particles and high humidity, the empirical equation used in Heliosat-2 to estimate the clear sky diffuse horizontal irradiance was recalibrated to become more adapted to desert and dusty environments.

2. Background on solar radiation and its modeling

Solar radiation, also known as short wave radiation, is the radiation from the Sun in the solar spectrum range of 0.3–3 μm (Duffie and Beckman, 2006). Irradiance is defined as the rate at which radiant energy is incident on a unit area measured in W/m^2, while irradiation is the integration of the irradiance over a time period (hour or day) measured in J/m^2 (Duffie and Beckman, 2006).

Solar radiation reaching the surface of the Earth is broken down into two main components: (a) the *DNI* which is the radiant flux density incident on a surface normal to the Sun; and (b) the diffuse horizontal irradiance (*DHI*) which is the diffuse radiant flux density reaching the surface of the Earth. *GHI* is the total radiant flux density in the solar