Production of solar radiation bankable datasets from high-resolution solar irradiance derived with dynamical downscaling Numerical Weather prediction model

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A B S T R A C T

A bankable solar radiation database is required for the financial viability of solar energy project. Accurate estimation of solar energy resources in a country is very important for proper siting, sizing and life cycle cost analysis of solar energy systems. During the last decade an important progress has been made to develop multiple solar irradiance database (Global Horizontal Irradiance (GHI) and Direct Normal Irradiance (DNI)), using satellite of different resolution and sophisticated models. This paper assesses the performance of High-resolution solar irradiance derived with dynamical downscaling Numerical Weather Prediction model with, GIS topographical solar radiation model, satellite data and ground measurements, for the production of bankable solar radiation datasets. For this investigation, NWP model namely Consortium for Small-scale Modeling (COSMO) is used for the dynamical downscaling of solar radiation. The obtained results increase confidence in solar radiation data base obtained from dynamical downscaled NWP model. The mean bias of dynamical downscaled NWP model is small, on the order of a few percents for GHI, and it could be ranked as a bankable datasets. Fortunately, these data are usually archived in the meteorological department and gives a good idea of the hourly, monthly, and annual incident energy. Such short time-interval data are valuable in designing and operating the solar energy facility. The advantage of the NWP model is that it can be used for solar radiation forecast since it can estimate the weather condition within the next 72–120 hours. This gives a reasonable estimation of the solar radiation that in turns can be used to forecast the electric power generation by the solar power plant.

1. Introduction

The financial issues have an important consideration in the deployment of the solar power plants. The financial considerations involve capital cost and system performance analysis, which is based on the availability of solar resource. The availability of long-time series of solar radiation is vital to meet the need of financial parties. Accurate prediction of solar energy resources over the potential location is very important for proper siting, sizing and life-cycle cost analysis of solar power plant. During the last decade an important progress has been made to develop multiple solar irradiance database (Global Horizontal Irradiance (GHI) and Direct

Normal Irradiance (DNI)), using satellite of different resolution and sophisticated models. The United States Department of Energy's (DOE's) National Renewable Energy Laboratory (NREL) and the Atmospheric Sciences Research Center (ASRC) at the State University of New York (SUNY)/Albany (USA) were the pioneers in the development of tools and data sources for solar energy during the past decade. The major current platforms used for estimating the solar radiation are based mainly on the Geostationary Operational Environmental Satellites (GOES), which were launched and maintained by the US National Oceanic and Atmospheric Administration (NOAA). Over the past two decades, a series of GOES satellites were launched to cover the entire Western Hemisphere. These satellites collect, every 30 min, high-spatial resolution (∼1 km) visible-channel images of the entire hemispheric, which are converted to hourly estimates of solar resources on a 10 km grid using a semi-empirical approach developed by ASRC. Solar resource data estimation includes both

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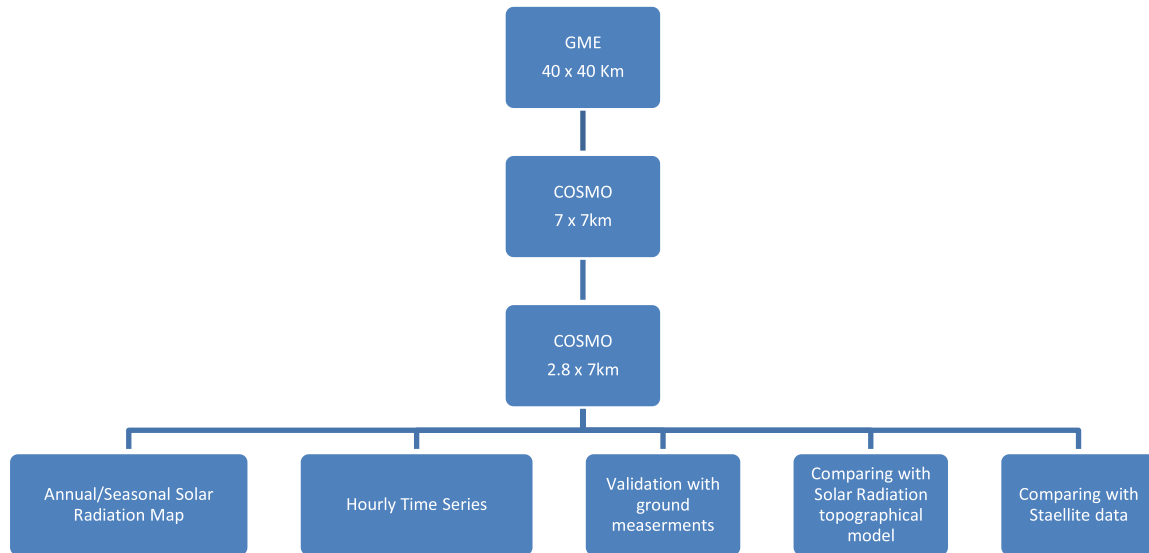
Fig. 1. Flowchart of the methodology used in this study.

GHI and DNI. The model was used to produce the 1998–2005 high-resolution data distributed as part of the US National Solar Resource Data Base (George et al., 2007). Later on and after launching the European Meteosat 5 and 7 geostationary satellites, SUNY adapted the model to estimate solar resources in the Eastern Hemisphere and several solar radiation maps were developed for some of the Eastern countries (Perez et al., 1977; Martins et al., 2007; NASA, 2014).

The solar radiation received at the surface of the ground is the result of energy interaction between the atmosphere and ground surface processes. In the past century, different physical models that formulate these interactions over topographic surfaces for a large spatio-temporal scale were developed (Dubayah, 1991). The first generation of such models, were the Atmospheric and Topographic Model (ATM) (Dubayah, 1992; Dubayah and Rich, 1995), Kumar et al. (1997) and SOLARFLUX (Hetrickw et al., 1993a,b). ATM is a raster based program and it was developed to provide inputs data for hydrological and snowmelt models in hilly area. Such model is explicitly concerned with atmospheric radiations problems. SOLARFLUX is a GIS based model that uses the information related to the topographic characteristics of the surface specified as grid of elevation, latitude, as well as the transmissivity of the atmosphere. Based on this inputs, SOLARFLUX, provides, direct radiation flux, duration of direct radiation, sky view factor, hemispherical projections of horizon angles, and diffuse radiation flux for each surface location. SOLARFLUX has been implemented in the first generation of GIS platform (ARCINFO and GRID GIS) (Hetrickw et al., 1993a,b).

The recent generations of ESRI'S GIS software have implemented the solar radiation analysis tools in the ArcGIS Spatial Analyst extension, which allow the calculation and analysis of the effects of the sun over selected geographic area and for specific periods of time. These analysis tools account for atmospheric effects (but not processes), site latitude and elevation, steepness (slope), compass direction (aspect), daily and seasonal shifts of the sun angle, and effects of shadows cast by surrounding topography.

Despite this sufficient progress in the accuracy of the solar radiation models, and remotely sensed data, the policy maker and the financing community, still consider solar radiation derived from models and satellite as non-bankable solar radiation datasets. The different actors of solar energy systems from engineering and the financing to the operating system, views bankable solar radiation only datasets from land-based measurement, during

10–15 years of datasets, to assess the viability and the capability of the solar power plant to repay its debt. The key consideration in the solar radiation bankable datasets is based on robust assessment of the temporal variability across all time scales of solar radiation that have a direct impact on the power generation and consequently the revenue stream. Therefore, it is crucial to have an accurate, and reliable solar radiation dataset, to reduce the risks associated with solar power plants.

This paper assesses the performance of High-resolution solar irradiance derived with dynamical downscaling Numerical Weather Prediction model with, GIS topographical solar radiation model, satellite data and ground measurements, for the production of bankable solar radiation datasets. Numerical Weather Prediction (NWP) Models, utilize a complex systems of partial differential equations based on the laws of physics, fluid motion, and chemistry, and use a coordinate system which divides the earth into 3D grid. For the purposes of forecasting weather condition, NWP models, calculate winds, heat transfer, solar radiation, relative humidity, and surface hydrology within each grid cell, and the interactions with neighboring cells are used to calculate atmospheric properties in the future.

Over the last decades, concerted efforts have been made to improve the resolution of the NWP models, through the exploitation of the increasing computing power (Ruby Leung et al., 2003). The typical resolution ranges from a few dozen km for General Circulation Models (GCMs) down to a few km for Limited Area Models (LAMs) (Al-Yahyai et al., 2010). GCMs used in meteorology and climatology are usually run at coarse spatial resolution and their output cannot be used for local effect studies, because they are unable to resolve important local scale features such topography and clouds. Downscaling approach were developed since nineties to obtain local scale weather conditions. Two different techniques for downscaling analysis are used. One technique is dynamical downscaling, based on using GCMs output to derive LAMs, which accordingly became able to simulate local weather condition in greater details (Von Storch et al., 1993; Wilby and Wigley, 1997). The other technics is statistical downscaling, where statistical relationship is constructed between observation of atmospheric parameters at large and local scale. Then, the statistical relationship is used on the GCMs data to obtain the atmospheric parameters at local scale form the output of GCMs (Kim et al., 1984; Hessami et al., 2004).

Due to this development, the outputs of NWP models are widely applied in applicable in different areas such as weather