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Regional and seasonal characteristics of global horizontal irradiance forecasts obtained from the Japan Meteorological Agency mesoscale model

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Abstract

To obtain accurate forecasts of photovoltaic power generation, the use of forecast datasets of meteorological elements from numerical prediction models, specifically global horizontal irradiance (GHI), is necessary. This study seeks to validate, and therefore improve GHI forecasts. Ground-based data from Japan Meteorological Agency (JMA) stations are used in a JMA mesoscale model (MSM) during the time period from 2008 to 2012 and temporal and spatial characteristics of forecast errors are analyzed. Statistical monthly evaluations show that associated errors vary between seasons, with monthly GHI mean bias error values ranging from −60 to +45 W/m^2 and root mean square errors (RMSEs) ranging from 95 to 170 W/m^2. Mapping of forecast errors show that underestimation of GHI forecast values and large RMSE values are significant in the southern part of Japan (a subtropical region located along the Pacific Ocean), particularly during summers. In winter, overestimation of GHI forecasts is found throughout the entire Japanese archipelago. The frequency of different cloud type occurrences over the Japanese islands indicate that regional and seasonal variations in cloud types are related to relatively large GHI forecast errors. High-level cirrus clouds, mid-level altocumulus, and low-level stratus are often observed during summer, when forecasted values are underestimated, and during winter, when values are overestimated.

Keywords: Mesoscale model; GHI; Forecast errors; Japanese islands

1. Introduction

Obtaining an energy supply from renewable sources is desirable for two important reasons: to match ever-increasing energy demands without relying on limited fossil fuel sources and to ameliorate the effects of climate change by decreasing carbon dioxide. Achieving these goals in Japan is important, and this makes the use of renewable sources vital in the management of power generation. In this scenario, photovoltaic (PV) power generation is expected to become an important source of renewable energy in Japan. As such, a PV energy source is strongly dependent on solar radiation (i.e., global horizontal irradiance; GHI), and its proper forecast and assessment have a fundamental role in PV power generation.

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PV power generation forecasts have been performed based on engineering techniques using meteorological forecast datasets (e.g., Fonseca et al., 2011). However, overall forecast accuracy is dependent on the forecast accuracy of each meteorological element, including GHI.

Moreover, large variations in PV power generation are mainly caused by variations in meteorological elements such as cloud cover and aerosols. Thus, it is clear that the production of a large amount of renewable energy in Japan is significantly dependent on the weather; therefore gaining an understanding of the characteristics of GHI forecast errors is important in the operation and integration of such systems in current power grids.

Output data from a numerical weather prediction model (NWP) has been considered useful in forecasting PV power generation and in energy management planning. The Japan Meteorological Agency (JMA) developed a mesoscale non-hydrostatic model (NHM, Saito et al., 2006, 2007) to use as an operational forecast model. Recently, many researchers and private-sector corporations in Japan have used grid point values from this model to develop PV power forecasts. GHI forecasts are also yielded by the model and can become very useful in PV power forecasts. However, GHI forecasts obtained from the NWP invariably contain errors. Therefore, in order to improve the MSM results it is necessary to first understand the characteristics of GHI forecast errors.

Intra-day solar irradiance (i.e., the downward shortwave component of radiation processes) forecasts obtained from different NWPs (e.g., Mathiesen and Kleissl, 2011) and regional GHI forecast error characteristics have been evaluated in previous studies (e.g., Zamora et al., 2005; Perez et al., 2010; Davy and Troccoli, 2011; and Pelland et al., 2011). Davy and Troccoli (2011) investigated seasonal GHI productivity and the relationship between regional forecast errors and climatic phenomena.

In addition, errors in forecasted regionally averaged GHI values throughout all the Japanese islands have been verified and have continuously improved. For example, Nagasawa (2008) investigated the mean bias errors (MBE) and root mean square errors (RMSE) in GHI forecasts using surface GHI values measured at 65 JMA stations over a four-year period between 2004 to 2007. Statistical evaluations showed significant negative bias in the GHI values and large monthly RMSE values (about 200 W/m^2), particularly during the summer. Yoshida et al. (2011) also verified GHI forecast errors using the NHM in the Tohoku region (northeastern Japan) and reported overestimated values during the summer. Ohtake et al. (2013a) examined errors in the MSM GHI forecasts using surface GHI observations from JMA stations in a specific region (i.e., Kanto region, central Japan) and found negative (positive) biases in the summer (winter) seasons.

In spite of these studies, regional variability in MSM GHI forecasts have not been addressed in the literature. Therefore, the present study analyzes the characteristics of both spatial and temporal (e.g., monthly, seasonal, and annual) errors characteristics in MSM GHI forecasts, and observed weather conditions.

In Section 2 of this paper, both the surface-measured JMA GHI dataset and the setting of the MSM analyzed in this study are described in detail. Annual and seasonal GHI forecast errors are analyzed in Section 3. Section 4 presents regional forecast error characteristics and analyzes the relationship between the errors and weather conditions (i.e., cloud types). Finally, Section 5 summarizes and discusses the findings of this study.

2. Data

2.1. Observational data

Pyranometers (Kipp & Zonen CM 3, CM 21, CMP 22, and EKO MS 62) were used to measure surface GHI from 2008 to 2011 at 47 JMA stations (see Table 1). In the middle of 2011, most of the pyranometers installed were replaced with EKO MS 402 units. In addition, the number of JMA stations measuring GHI decreased from 52 in January 2008 to 48 in December 2012. Five JMA stations, Sapporo (1), Tsukuba (47), Fukuoka (31), Ishigajikijima (42) and Minami-Torishima (Table 1), are Baseline Surface Radiation Network (BSRN) stations. Direct and diffuse solar irradiance are separately observed at these stations. Minami-Torishima JMA station (located at 153.98°E, 24.29°N) was removed from analysis because it was located outside of the MSM domain. Diffuse solar irradiance from direct sunlight was measured using a pyranometer with an automatic sun-tracking shadowing disk (to avoid direct solar irradiance).

The JMA performed quality control of all the measured GHI data. Maintenance of the GHI measurements is an important factor for the quality of the GHI observations. The glass domes of the measurements were routinely cleaned using a feather brush and a soft cloth (at least one a weak) to remove contaminants such as dust, ice and snow particles which can significantly affect the measurement by JMA operational staffs. Each pyranometer sampled GHI values at intervals of 10 s, and 1 min averages were calculated from the sampled data. Furthermore, in order to validate the MSM GHI forecasts, hourly-averaged GHI values were calculated using observed data.

2.2. Numerical model

Forecasted GHI values were calculated at each station using the MSM (the operational model in Japan developed from the non-hydrostatic model, e.g., Saito et al., 2006, 2007). The model was initialized using the same specifications as those described by Ohtake et al. (2013a). The model domain included a region surrounding the Japanese Island 3600 × 2900 × 21.8 km in size along the *x*, *y*, and *z* axes, respectively, with a horizontal grid spacing