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Statistical analysis of cloud layers and solar irradiations for all seasons in Toyohashi city, Japan

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Abstract. Several solar irradiation forecasting methods are being developed toward economically efficient solar power generation. Among these, the method that utilizes all sky imagers to estimate the direction of cloud movement above certain observation points is able to forecast fluctuations in solar irradiation with localized temporal resolution (∼30 min) through observation of shadows cast by clouds. The one-layered cloud is usually assumed in forecasting the direction of cloud movement. However, in reality, multilayered clouds may move in different directions in the sky. While such multilayered clouds may have effect on forecast accuracy, the extent to which multilayered clouds affect the solar irradiation and the generated solar power has never been reported. Therefore, the purposes of this study are (1) to give the dataset to know the effect of multilayered clouds and (2) to decide whether the multilayered clouds have to be considered in forecasting of solar irradiation. We analyzed the number of cloud layers and their effect on the solar irradiation, the generated solar power, and the clearness index through statistical analysis for all seasons in Toyohashi city, Japan. The dataset used to analysis includes data with 4381 h. The analytical results show that multilayered clouds were observed for ∼40% of the daytime duration even in winter. In addition, the results show that multilayered clouds were observed even when the solar irradiation, the generated solar power, and the clearness index were high, which suggests that the effect of multilayered clouds must be considered. In addition, it will be shown that the maximum number of cloud layers to be considered is 3 from statistical analysis.

Keywords: Solar irradiation / clearness index / multilayered cloud / all sky imaging / statistical analysis

1 Introduction

The difference between forecasted and actual amount of generated solar power should be minimized to achieve economically efficient operation of solar power generation. In this context, an accurate forecasting of solar irradiation is necessary. Solar irradiation forecasting is performed by several methods [1–14] that use numerical weather prediction (NWP), satellite imaging, ground-based systems, which are characterized by temporal–spatial scales. NWP has an advantage that solar irradiation can be forecasted at any place up to more than one week. However, in prediction with NWP, it is difficult to forecast to variation of solar irradiation by clouds accurately because of the chaoticity in numerical prediction. The measurement with satellite imaging from the space covers the large area on the Earth and can provide the information of the position of clouds, the thickness of clouds, and the motion of the clouds, allowing the forecasting of variation of solar irradiation by clouds. However, the accurate estimation of solar irradiation from the space is still a challenging issue. Ground-based systems forecast fluctuations by cloud shadows [3,4,7–11,15,16] in solar irradiation for short duration of ∼30 min with the accurate solar irradiation measurement. The ground-based systems are divided into two types: the systems with pyranometer sensor networks [5,6] and the systems with all sky imagers (ASIs). The pyranometer sensor networks forecasts solar irradiations with one-dimensional data. On the other hands, the system with ASIs forecasts solar irradiations with two-dimensional data (sky images) as well as one-dimensional data. The systems with ASIs estimate the direction of cloud movements with optical flow [9,11–14]. In this context, the number of cloud layers is usually assumed to be unity [7].

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