First assessment of surface solar irradiance derived from Himawari-8 across China

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ABSTRACT

The Advanced Himawari Imager (AHI) aboard Himawari-8, a new generation geostationary satellite with high spatiotemporal resolution, was launched in 2014 and operated by the Japan Meteorological Agency. The released AHI surface solar irradiance (SSI) product by the Japan Aerospace Agency (JAXA) has great potential in application of study on energy budget, solar energy and ecosystem etc. In this study, the JAXA AHI SSI products are evaluated using the Chinese Ecosystem Research Network (CERN) pyranometer measurements during March-December 2016 at 36 sites in China. The AHI SSI products are correlated to surface measurements very well. The daily and monthly AHI SSI products on all-sky conditions show mean bias errors of 13.8 and 13.3 W m^{-2} relative to corresponding CERN measurements. The AHI SSI products are close to CERN data in summer, however they are significantly lower in winter. The significant positive bias of AHI SSI in the North China Plain very likely resulted from the underestimation of aerosol optical depth (AOD) by AHI. In contrast, the negative bias of SSI in high elevation stations is likely related to the improper input of atmospheric profile. All these error factors need further improvement in the AHI SSI algorithm.

1. Introduction

A Ground-based pyranometer is a relatively inexpensive way to measure surface solar irradiance (SSI). While it provides accurate estimates of SSI with high temporal resolution (for example, 1 min), networks of pyranometers are typically not available in sufficiently high spatial coverage. An alternative method is to use mathematical or empirical models to calculate SSI from meteorological observations, for example, temperature and sunshine duration, etc., which can improve the spatial coverage of SSI to some extent but with notable uncertainty. Calculations based on satellite-derived cloud and aerosol products have yielded surface SSI at global scale for the past three decades. Space-based platforms provide a global view of SSI and complement the sparse network of surface measurements regarding the spatial coverage. The methods can be separated into two broad classes: empirical method

and physical methods. The empirical methods are developed based on collocated satellite-radiance and ground-based SSI dataset or similar results from extensive atmospheric radiative transfer modeling, while the physical models interpret satellite-measured radiances in terms of properties of aerosols and clouds that are subsequently used in atmospheric radiative transfer models or parameterization models to determine SSI (Kleissl, 2013 and references therein).

A number of satellite SSI products have been created. They provide consistent estimations since the 1980s, with global coverage and resolutions up to a few kilometers and 15 min. Empirical or physical models are widely used to derive SSI products from either geostationary satellites (e.g. Meteosat, GOES and GMS), or polar-orbiting satellites (e.g. NOAA series and Metop) (Deneke et al., 2008; Castelli et al., 2014; Kleissl, 2013 and references therein). Geostationary-based products have higher temporal resolution (up to 15 min) but limited spatial

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coverage (± 65° latitude). In contrast, polar-orbiting products have global coverage but lower temporal resolution, limited to 1–2 times every day. Generally, SSI is intricately related to clouds, aerosols, water vapor, and other atmospheric constituents that show highly variability, therefore, it is a challenging task to retrieve SSI from space. Comprehensive comparison of satellite SSI products against ground truth is the first priority before these products are applied, which could reveal potential biases and show the way to improve satellite retrieval algorithms.

The Himawari-8, a new generation of geostationary meteorology satellite, was launched in 2014. The Advanced Himawari Imager (AHI), the primary instrument aboard Himawari-8, captures visible light and infrared images of the Asia-Pacific region, i.e., the latitude range from 60°S to 60°N and the longitude range from 80°E to 160°W. AHI has high spatial (0.5 km–2 km), spectral (16 wavelengths), and temporal (10 min–2.5 min) resolutions, which would be expected to show great promise for monitoring clouds and aerosols and thereby quantifying their influence on SSI. SSI and Photosynthetically Active Radiation (PAR) products have been released by the Japan Aerospace Exploration Agency (JAXA) but a comprehensive validation of these products are not reported (Bessho et al., 2016). Besides, Damiani et al. (2018) published another AHI SSI based on a fast-neural network algorithm, and the validation of SSI at four sites in Japan pointed that the half hourly mean bias was approximately 20–30 W m^{-2} on all-sky days.

China is characterized by various climate zones, terrains and aerosol loadings, which poses a good test bed for the validation of satellite SSI products. In this study, JAXA AHI SSI products in China are carefully validated through comparison against surface measurements. This is, as far as we know, the first attempt to validate AHI SSI products in China. It was shown that the AHI SSI data correlated to surface measurements very well. More important, we also noted that there was still room for improvement in the AHI SSI algorithm, for example, the aerosol module should be improved in polluted regions. A short description of the Himawari SSI algorithm as well as ground and satellite datasets are presented in Section 2. Section 3 presents the evaluation results. Finally, we provide a summary and a brief outlook in Section 4.

2. Data and method

2.1. Satellite SSI data

The JAXA AHI SSI retrieval algorithm is based on the framework of Frouin and Murakami (2007), which was used to estimate PAR at the ocean surface from Global Imager (GLI) data. The decoupled model is efficient and relatively accurate, eliminating the need for cloud screening and arbitrary assumptions about satellite sub-pixel cloudiness. One of the advantages of such a decoupled model is that it is simple, yet efficient and relatively accurate.

This SSI data are version 1.0, which have been available since March 2016. The data are available from JAXA P-Tree system (ftp. ptree.jaxa.jp). A detailed description of AHI product is provided on the website (http://www.eorc.jaxa.jp/ptree/userguide.html). The SSI data of full disk area have the spatial and temporal resolution of 5 km and 1 h, respectively.

2.2. Ground SSI data

The Chinese Ecosystem Research Network (CERN) is a comprehensive network engaging in monitoring on the water, soil, atmosphere and biological elements and processes of major ecosystems. The CERN stations are distributed over diverse geographic and topographic (in Fig. 1). A detailed description of the CERN stations can be found in Hu et al. (2007b). As one of important parameters of atmospheric watch, SSI is measured by a Kipp & Zonen CM11 pyranometer at 36 CERN stations across China (Hu et al., 2007a, b; Wang et al., 2015). SSI is sampled every minute but hourly values are saved in the data logger.

The quality-controlled CERN SSI data are available from 2004 to 2016. In this study, we use measurements from March to December 2016 to compare with corresponding AHI SSI products.

2.3. Aerosol and SSI data at Xianghe

The Xianghe (XH) site is a suburban station in the North China Plain (NCP). Aerosol optical depth (AOD) is measured by a CE318 sunphotometer (CE318), the standard instrument of the AErosol Robotic NETwork (AERONET). AOD is calculated from direct sun observations with an accuracy of 0.01 to 0.02 with a nominal 15-min temporal resolution (Xia, 2014; Zhu et al., 2017). SSI is measured by a Kipp Zonen CM21 with a 1-min temporal resolution. The data are quality-checked using the Baseline Surface Radiation Network (BSRN) quality control procedures and then submitted to the BSRN data archive (Xia, 2014). Measurements of AOD and SSI from March to December 2016 are used in this study.

The JAXA AHI AOD and the Moderate Imaging Spectro-radiometer (MODIS) AOD products onboard Terra are also used for explaining the errors of AHI SSI. This AHI aerosol retrieval algorithm is a heritage of Asian dust monitoring algorithm and a detailed description can be found in Uesawa (2016). Terra MODIS collection 6.0 level-2 dark target AOD products are used here.

2.4. Comparison between CERN and AHI SSI products

We evaluate the daily and monthly average of SSI. Hourly SSI values from AHI and CM11 have been aggregated into daily mean SSI. SSI at the closest AHI pixel to each CERN station is used to collocate to the station measurement. The AHI SSI performance is evaluated by using following statistical parameters: the mean bias error (MBE), mean absolute error (MAE), relative mean bias error (rMBE), root mean squared error (RMSE), and the slope (Slope) of linear regression. These parameters are calculated as follows.

$$MBE = \frac{1}{n} \sum_{i=1}^{n} (AHI_i - CERN_i) \tag{1}$$

$$MAE = \frac{1}{n} \sum_{i=1}^{n} |AHI_i - CERN_i| \tag{2}$$

$$rMBE = \frac{\sum_{i=1}^{n} (AHI_i - CERN_i)}{\sum_{i=1}^{n} CERN_i} \tag{3}$$

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (AHI_i - CERN_i)^2} \tag{4}$$

The AHI SSI products under clear-sky conditions are also compared to the corresponding CM11 measurements. The clear-sky days are selected based on CM11 measurements by the following simple method. The correlation between hourly CM11 SSI values and the cosine of the solar zenith angles (μ) is calculated. The day is defined to be clear-sky if the correlation coefficient exceeds 0.9.

3. Results

3.1. Overall picture of AHI SSI performance

The overview of the evaluation results is given in Fig. 2 on all-sky and clear-sky days, respectively. The monthly mean of clear-sky SSI is not discussed due to few samples. For all-sky days, The AHI SSI products perform very well compared to surface measurements. Daily and monthly all-sky AHI SSI show positive MBEs of 13.8 and 13.3 W m^{-2} relative to CERN data. RMSE of 32.0 W m^{-2} and 22.4 W m^{-2} are found for daily and monthly mean irradiance. The rMBEs of daily and monthly mean values are 8.0% and 7.7%. The MAE are 26.0 W m^{-2} and 21.2 W m^{-2}, respectively.