

Response to Referee #1

We would like to thank the reviewer for the comments and suggestions, which are all valuable and very helpful for improving our paper. We have made revisions and a point-to-point response is present in the following.

Summary and comments:

Jiang et al. produced total and diffuse surface radiation over China using the geostationary satellite data and the deep learning network. I find the dataset of general interest. I have some concerns related to this manuscript.

Response:

We thank Referee #1 for the encouraging comments. All comments and suggestions have been considered carefully and well addressed.

Comments:

(1) the title suggests it is surface global solar radiation over China. I think “global” here should represent the whole earth. The title needs to be changed.

Response:

Thank you for your advice. In the revised manuscript, the title has been changed to “Surface solar radiation and the diffuse component in China acquired from geostationary Multi-functional Transport Satellite data”

Comments:

(2) scientific relevance: I do not think the authors provide enough details about how the new technique can address previous research problems/scientific questions. For example, what do the authors mean “no consideration of spatial collocation of surface radiation”, and how the proposed deep learning algorithm addresses this consideration remains unclear. What spatial patterns have been extracted from satellite images and how they are linked to target hourly radiation values are also not clear.

Response:

Thank you for your advice.

The expression of “no consideration of spatial collocation of surface radiation” might be incorrect and confusing. In fact, we meant that “takes no consideration of spatial adjacent

effects of surface radiation”. In general, the proposed deep learning algorithm addresses the spatial adjacent effects by dealing with spatial satellite image blocks of 16×16 pixels. Hierarchical features from low-level details (e.g., geometric shapes, sizes, orientations, edges and distribution) to high-level comprehensive abstract representations (e.g., intrinsic physical and optical properties of mixed clouds) are extracted from satellite images to handle the spatial adjacent effects. Then, the multi-layer perceptron is utilized to link extracted features to target hourly radiation values through implicit non-linear expressions, and their parameters are learnt from pre-prepared training samples in supervised manner. The details are described in the Introduction of the revised manuscript. The related parts are as “These methods are in theory based on an independent pixel approximation which assumes a plane-parallel horizontally homogeneous cloud. Thus, surface radiation retrievals from satellite imagers are pixel-based (from point to point), in other words, only (multi-band) satellite signals corresponding to the specific ground location are used for surface radiation estimation. However, in reality this idealized situation does not always exist, or even is uncommon. For example, in the presence of broken clouds, multiple reflections and scattering events off the sides of clouds or on the surface would lead to significant horizontal photon transport (Madhavan et al. 2017; Oreopoulos et al. 2000; Schewski and Macke 2003), which makes significant differences when the spatial resolution increases to several kilometres where the surface radiation of an individual footprint under inhomogeneous clouds is relevant to multiple adjacent satellite pixels (Huang et al. 2019). In fact, large biases and uncertainties occur frequently under broken clouds when comparing current high-resolution surface radiation products to quality-controlled ground observations (Deneke et al. 2009; Huang et al. 2016).”

Therefore, it seems that area-to-point retrievals are the optimal solutions. From this point of view, a practical effort has been made in our previous works, where a hybrid deep network mainly consisting of convolutional neural network (CNN) blocks and multi-layer perceptron (MLP) is built to retrieve hourly GSR/DIF from geostationary satellite data (Jiang et al. 2019). The CNN blocks takes image blocks as inputs thereby allowing for identical treatment of adjacent satellite pixels, and are further stacked to construct deep residual structure to extract hierarchical features from low-level details (e.g., geometric shapes, sizes, orientations, edges and distribution) to high-level comprehensive abstract

representations (e.g., intrinsic physical and optical properties of mixed clouds). It is believed that such hierarchical architecture of spatial features can fully expose the scattering effects, absorption effects as well as their interactions in the atmosphere, thus can be considered as substitutes for various input parameters representing atmospheric state in radiative transfer models. The MLP is utilized to link extracted features of CNN and additional auxiliary information defining the state in time and space to target measurements of hourly surface radiation through implicit non-linear expressions, whose parameters are learnt from pre-prepared training samples in supervised manner. The deep network is demonstrated to be effective in handling spatial adjacent effects and simulating complicated radiative transfer processes, and successful in achieving superior accuracy of GSR estimates.”

Comments:

The introduction gives an impression that the dataset is probably “over-produced” with no clear clue that how these datasets will be used specifically. Although they first paragraph in the introduction mentioned some possible applications of these datasets, further digging of these literatures would tell you the produced dataset here would be useless. I would suggest the authors further clearly identify, for example, how diffuse radiation are being used to forecast crop yield (if there is a crop model uses it, please name it), and how diffuse radiation are being used to simulate carbon dynamics (if there are Earth system models requiring these datasets, please list them in the paper) or any other specific applications that use this type of datasets either partly or over the whole part of China (rather than talk them general). Based on current descriptions, I think the produced datasets would be useless.

Response:

Thank you for your advice. More specific models (e.g., JULES, FöBAAR, YIBs, SWAP) and applications (e.g., modelling radiation-use efficiency of wheat, early yield assessment of soybean, wheat and sunflower) have been added into the first paragraph of the revised Introduction. The related parts are as follows: “The explicit knowledge on DIF is urgently required to assess its effects on plant productivity and carbon dynamics of terrestrial ecosystems that has become a popular issue in the field of ecology and environmental

sciences (Gu et al. 2002; Mercado et al. 2009; Zhang et al. 2011; Zhang et al. 2017). For instance, downward direct and diffuse radiation at the surface are necessary inputs for **JULES land-surface scheme and canopy radiation-photosynthesis scheme** to account for effects of diffuse radiation on sunlit and shaded photosynthesis thus impact on global primary production (Mercado et al. 2009) and land carbon sink (Rap et al. 2018), and also used to calculate photosynthetic photon flux density in the **Forest Biomass, Assimilation, Allocation, and Respiration (FöBAAR) model** for the purpose of simulating forest carbon cycle (Lee et al. 2018). The perturbations in diffuse solar radiation are needed to be quantified when using the **Yale Interactive terrestrial Biosphere (YIBs)** model to estimate the response of global carbon cycle to fire pollutions (Yue and Unger 2018). It also proves that satellite-based radiation data improve the performance of **Soil Water Atmosphere Plant (SWAP) model** during crop yield estimation (Mokhtari et al. 2018). Besides, the partitioning of diffuse and direct solar radiation as well as their diurnal variations are essential for **modelling radiation-use efficiency of wheat** during its vegetative phase (Choudhury 2000) and the **early assessment of crop (i.e., soybean, wheat and sunflower) yield** on a daily or shorter basis (Holzman et al. 2018).”

Comments:

(3) Methods and Comparisons with other products: I think throughout the manuscript, there is no scientific explanation that why we should correlate satellite images of five bands with total/diffuse solar radiation (I think the author also need to provide a definition in this manuscript what exactly data they are providing). I believe what you mean solar radiation here should be the integration of radiation over the whole wavelength rather just a few wavelengths.

Response:

Thank you for your advice. In fact, we directly link the satellite signals of visible channel to target shortwave solar radiation provided by ground measurements, without integration of radiation over different wavelengths. The utilization of other channels such as IR1-4 might add useful information about water vapor, cloud temperature etc. for final radiation estimation, but to assure the cross-sensor applications, only the visible channel of MTSAT data are used as it is available for almost all satellite images. We have made it clear in the

revised manuscript. The explanation is given in Section 2.1 as “The original MTSAT-1R satellite images are resampled to so-called hourly GAME products with a resolution of $1/20^\circ$; which is freely accessible at <http://weather.is.kochi-u.ac.jp/> (last accessed: 10 Dec., 2019). Herein, only the visible channel is used for the inference of shortwave or diffuse solar radiation provided by ground measurements.” and also in Section 2.2 as “In addition, for the convenience of cross-sensor applications, it is better to only depend on the visible channel which is available for nearly all satellite images. This is reasonable as the visible channel provides the most proportion of information on aerosols, clouds and other atmospheric properties (Lu et al. 2011).”

Comments:

Although the authors use the deep learning algorithm, it is necessary to explain what the mechanisms behind this correlation. Particularly, as the authors mentioned previously that spatial patterns are being extracted and correlated with target data from point locations, the authors should also explain what patterns are being used. Without sufficient explanations, the readers may concern about what are the error estimates and sources which the authors do not provide at all. For example, how reliable can we use the solar radiation estimates under cloudy conditions? Can the authors provide a quality flag for these areas and the confidence interval for us to use the dataset for regions under cloudy conditions? Does the authors separate comparisons/validation in accuracy for point locations between clear-sky and cloudy conditions? What is the accuracy level under clear-sky conditions and what is the accuracy level under cloudy conditions? IF the comparison in accuracy between this produced product and the other product under clear-sky conditions is the same or similar, what are the advantages of this produced product compared to previous ones?

Response:

Thank you for your advice. In the revised manuscript, we have explained the potential mechanisms in the Introduction and Section 2.2. More explanations are added into the first paragraph of Section 2.2. The related parts in the Introduction are as follows: “The CNN blocks takes image blocks as inputs thereby allowing for identical treatment of adjacent satellite pixels, and are further stacked to construct deep residual structure to extract hierarchical features from low-level details (e.g., geometric shapes, sizes, orientations,

edges and distribution) to high-level comprehensive abstract representations (e.g., intrinsic physical and optical properties of mixed clouds). It is believed that such hierarchical architecture of spatial features can fully expose the scattering effects, absorption effects as well as their interactions in the atmosphere, thus can be considered as substitutes for various input parameters representing atmospheric state in radiative transfer models.” The related parts in Section 2.2 are as follows: “Satellite image is regarded as a vivid portrayal of the atmosphere and the surface state, and its recorded signals usually contain information on cloud-radiation interactions and impacts among adjacent locations. Traditional physical algorithms retrieve surface radiation from satellite signals on the basis of various radiative transfer models or their simplified versions, where geometric conditions, atmospheric conditions, and aerosol types should be strictly defined, complex processes such as atmospheric absorption and scattering, and their interactions are needed to be precisely simulated, or clear-sky and cloudy retrieval modes are independently developed. Herein, we utilize deep learning technique to directly build the implicit correlations between satellite signals and surface radiation in view of its powerful approximation ability of continuous mapping function. Except that all-sky situations are under a unified framework and tedious intermediate simulations are avoided, different from classical pixel-based retrievals, the CNN blocks are able to deal with spatial adjacent effects of surface radiation, that is, the influence of neighboring pixels on the central point can be taken into account.” Although the spatially continuous error estimates are not provided, the validation results at site level shown in figure 8 can be used as a reference for the rational utilization of our datasets.

Different from the previous parameterization schemes, we didn’t develop independent clear-sky and cloudy retrieval modes separately. The deep network estimates solar radiation under all-sky conditions in a unified manner, and provides reliable results as indicated by Figure 6. As labels indicating a clear-sky or cloudy condition are unavailable for hourly measurements, we didn’t carry out separate comparisons during validation. In view of the high precision of our products under all-sky conditions, we suggest users in various fields to use it at ease, but limited within China

Comments:

In addition, for the deep learning part, I do not understand why we use 16*16 pixels. How you get the size determined? Plus, do the radiation measurements from point locations are across all these 16 pixels or just belong to only one of them? I have the impression that because the authors would like to use deep learning, they need to have an image used as input. So, this is a point to area comparison? If so, I would like to see the authors providing error estimates related to this misrepresentation of points as areas for the produced datasets.

Response:

Thank you very much for your advice. Actually, the CNN blocks deal with image blocks of 16*16 pixels to infer the surface radiation at the location corresponding to the central point of the input image block. Maybe we can call it area-to-point retrieval. We know that there exists a certain spatial scale for ground observations. Multiple reflections and scattering events off the sides of clouds or on the surface lead to significant horizontal photon transport, so that adjacent pixels also influence the measured radiation on the ground. Therefore, it is reasonable to take neighboring pixels into account during radiation estimation of the central location. Here, we expect the CNN blocks can approximate the spatial adjacent effects thereby improving the final accuracy of radiation estimation. We have made it clear in Section 2.2 as “The structure is shown in figure 1b and the detailed configurations are listed in table 1. There are two input pipes: *Input1* for MTSAT image blocks and *Input2* for additional attributes including the local time (month, day and hour) and location (longitude, latitude and altitude) corresponding to the central point of *Input1*. The *Output* can be either GSR or DIF associated with the central point of *Input1*.” and also in the Introduction as “For example, in the presence of broken clouds, multiple reflections and scattering events off the sides of clouds or on the surface would lead to significant horizontal photon transport (Madhavan et al. 2017; Oreopoulos et al. 2000; Schewski and Macke 2003), which makes significant differences when the spatial resolution increases to several kilometres where the surface radiation of an individual footprint under inhomogeneous clouds is relevant to multiple adjacent satellite pixels (Huang et al. 2019). In fact, large biases and uncertainties occur frequently under broken clouds when comparing current high-resolution surface radiation products to quality-controlled ground observations (Deneke et al. 2009; Huang et al. 2016). Therefore, it seems that area-to-point retrievals are the optimal solutions. From this point of view, a practical effort has been

made in our previous works, where a hybrid deep network mainly consisting of convolutional neural network (CNN) blocks and multi-layer perceptron (MLP) is built to retrieve hourly GSR/DIF from geostationary satellite data (Jiang et al. 2019). The CNN blocks takes image blocks as inputs thereby allowing for identical treatment of adjacent satellite pixels, and are further stacked to construct deep residual structure to extract hierarchical features from low-level details (e.g., geometric shapes, sizes, orientations, edges and distribution) to high-level comprehensive abstract representations (e.g., intrinsic physical and optical properties of mixed clouds).”

The previous studies revealed that time series of central point and its neighbouring pixels are most correlative within an extent of approximately 60km for hourly GSR, so the direct size of image block should be 12 *12. But it does not fit in with the classical size of CNN networks. So we choose the size of 16*16, thus extra pixels are included which are also helpful for extraction of edge features. More descriptions are added into Section 2.2 in the revised manuscript as “Considering the recommendation that time series of central point and its neighbouring pixels are most correlative within an extent of approximately 60km for hourly GSR (Wyser et al. 2005; Deneke et al. 2009), the input size for CNN is designed as 16×16 pixels ($\sim 80\text{km} \times 80\text{km}$) around the central location requiring for radiation estimation, slightly larger than recommended 60km to fit in with the classical CNN network structure and meanwhile ensure the extraction of edge features. In addition, for the convenience of cross-sensor applications, it is better to only depend on the visible channel which is available for nearly all satellite images. This is reasonable as the visible channel provides the most proportion of information on aerosols, clouds and other atmospheric properties (Lu et al. 2011).”

Comments:

(4) My last concern is that I think the manuscript has duplication issues: some of the figures have been seen previously in your other manuscripts. for example, figure 1, 2, etc (in your recent publications in Renewable and Sustainable Energy Reviews, Volume 114, October 2019, 109327). Also, I would like to mention here that previously you used the ResnetTL, and in this manuscript, it seems that you use a different network structure. So, what is the difference between them? what are the improvements?

Response:

Thank you very much for your advice. Actually, the structure of the network in this manuscript is similar to the ResnetTL. In this paper, we extend the ResnetTL to fit the estimation of diffuse radiation through transfer learning, an approach to reuse already gained knowledge to solve different but analogous problems. Therefore, a new deep network for DIF estimation is obtained by fine-tuning ResnetTL using new training samples consisting of ground measured diffuse radiation and the corresponding satellite image block. Both the trained ResnetTL and the network for diffuse radiation estimation are used together to generate our datasets. More explanations are added into the revised manuscript as in the Introduction “In this paper, we extend the previous network for GSR to fit the estimation of diffuse radiation through transfer learning, an approach to reuse already gained knowledge to solve different but analogous problems. A new deep network for DIF estimation is obtained by fine-tuning the GSR network using new training samples consisting of ground measured diffuse radiation and the corresponding satellite image block. After complete learning and optimization, the trained DIF network in combination with previous GSR network is used to generate radiation datasets (GSR and DIF) over China based on Multi-functional Transport Satellites (MTSAT) data.”, and also in Section 2.2 as “In the previous work (Jiang et al. 2019), we have built a hybrid deep network for GSR estimation. Herein, we further optimize the GSR model to fit the estimation of diffuse radiation by fine-tuning (refer to Section 2.3). The structure is shown in figure 1b and the detailed configurations are listed in table 1.”

The used radiation stations are all the same to that in our previous paper. To avoid the duplication issues, we have revised related figures, for example, the background of figure 2 is changed as land cover types that is a perfect way to demonstrate the representativeness of our stations, the graphical structure of the deep network (figure 1b) is expressed in another way. These changes are added into the revised manuscript.

Comments:

The authors also need to pay attention to the grammar of the manuscript and the language needs to be further edited.

Response:

Thank you very much for your advice. We have checked the grammar throughout the manuscript and corrected related errors.