THE ABILITY OF RCA4 REGIONAL CLIMATE MODEL TO SIMULATE AND PROJECT SURFACE SOLAR IRRADIATION OVER VIET NAM

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Abstract: *Currently, the application of numerical models in simulating, forecasting, and predicting meteorological factors and features of the atmosphere, including solar radiation combined using satellite data, is widely used. Therefore, comparing the difference between the parameters calculated from the model with the satellite is extremely necessary, thereby evaluating the quality of the model as well as the quality of the satellite products compared to the value of the satellite with monitoring or re-analysis, is the basis for making accurate forecasts/forecasts in the future.*

This study aims to assess the regional climate model RCA4 (RCP4.5 and RCP8.5) to simulate surface solar irradiation (SSI) based on estimated radiation data from the Himawari-8 satellite for Viet Nam using statistical indicators.

The results showed that the radiation values estimated from model correlated well with estimates from the satellite, which has been validated very close to the observation at the surface. In the spring and winter, the general correlation trend shows that the radiation at the stations in the North tend to be higher than the stations in the South of Viet Nam. Based on the assessment of the RCA4 model compared to satellites in the period (2016 - 2018), the results of model are used to analyze the progress of solar radiation during the year in 7 climate zones of Viet Nam between different versions. It can be seen that the maximum/minimum values of the month do not change much between versions. Comparing to the period 1976 - 2005, the estimated short-wave radiation at the surface in the period 2020 - 2050 decreases in most of Viet Nam for both scenarios RCP4.5 and RCP8.5. In contrast, the Central Highlands region shows an increase in short-wave radiation.

Keywords: *surface solar irradiation, satellite data, RCA4 regional climate model, solar radiation projection.*

1. Introduction

The solar radiation reaching ground level is often called surface solar irradiation (SSI). SSI clearly affects temperature and precipitation, drives large-scale atmospheric circulation, and also plays an essential role in some other processes such as global energy balance [24, 29], oceanic heat budget [30], photosynthesis [13], solar energy production [7] and power productivity [33], etc. SSI shows substantial spatial and temporal variability because it depends on the position of the sun and the cloud cover in the sky [18]. Observations in many regions over the globe indicate a decrease SSI from ~ 1950s to 1980s (“dimming”), followed by an increase SSI during 1990s (“brightening”) in all-sky conditions [12, 23, 32, 34]. There have been a lot of studies focusing on examining SSI using observations, re-analyses, satellite data, or climate models [4, 6, 11, 14] where it is beneficial to use numerical models in simulating

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SSI in the past and projecting SSI in the context of climate change according to climate change scenarios.

Brazel et al. (1993) showed that General Circulation Models (GCMs) are able to simulate the annual solar cycle [3]. However, the SSI seems to be underestimated for the southwestern United States. Solar radiation budgets from 20 GCMs are analyzed in the study of Wild (2005) [31]. The results showed that the global mean radiation budgets, especially at the surface, are significantly distinct between GCMs. The models seem to overestimate the land surface isolation of about 9 Wm^{-2} on average compared to surface stations, while the biases of the net solar fluxes at the top of the atmosphere are generally smaller. In the study of Romanou et al. (2007) [20], the ensemble simulations of SSI in the 20th century are analyzed using nine state-of -the-art coupled ocean-atmosphere-land-ice circulation models. The results show that all models estimate a global annual mean decrease in downward SSI of 1 - 4 Wm^{-2} while the Global temperature increases about 0.4 - 0.7°C.

Regional climate models are often used to dynamically downscale global model simulations for specific regions due to higher resolution. Some local features like topography and coastlines are more detailed by Rummukainen, (2010). Alexandri et al. (2015) [1, 21] used the RegCM4 regional climate model to simulate SSI patterns over Europe during the period of 2000 - 2009 and then evaluated against satellite-based observations from Satellite Application Facility on Climate Monitoring (CM SAF). Notably, the SSI bias between the RegCM4 and the CM SAF data depends significantly on the version used. In particular, the SSI bias for MFG (Meteosat First Generation) is +1.5%, while the SSI bias for MSG Meteosat Second Generation) is +3.3%. Recently, in the study of Tang et al. (2018) [27], the simulations of SSI of 5 Regional Climate Models (RCM, including CCLM4, HIRHAM5, RACMO22T, RCA4, and REMO2009) and ten driving GCMs over Southern Africa are compared to ground-based measurements, satellite-derived products, and reanalyses in the period of 1990 - 2005. The results show that SSI produced by GCMs over Southern Africa overestimates in term of their multi-model mean by about 1 Wm^{-2} in austral summer and 7.5 Wm^{-2} in austral winter when compare to that of the satellite-derived product SARAH-2. Besides, the RCMs driven by GCMs indicate underestimations of SSI in their multi-model mean in both seasons with mean bias errors of about -30 Wm^{-2} in austral summer and about -14 Wm^{-2} in winter compared to SARAH-2. The discrepancies of the simulated SSI of the RCMs are larger than those of the GCMs over Southern Africa.

Wild et al. (2015) used CMIP5 climate models to project long-term changes in SSI and their influence on energy yields of photovoltaic systems [33]. The RCP8.5 forcing scenarios of 39 GCMs have been implemented to see the decadal changes in all-and clear-sky SSI, cloud amount, and surface temperature projected up to 2050. The SSI of these models agree with the projection of the sign of the changes over almost the entire globe under clear-sky conditions, and still over a significant part of the globe when cloud effects are considered in addition. The statistically significant decreasing trend of clear-sky radiation is projected in most world regions, except for parts of China and Europe.

Viet Nam is a country located in the tropical region where solar energy is abundant. There are so differences in seasonal and annual SSI cycles due to the geographical extension from the North to the South as well as the effects of different weather phenomena. Presently, there are few publications on using climate model to simulated and projected SSI over Viet Nam. This paper aims to examine the ability of the RCA4 regional climate model in doing those above tasks. Section 2 will provide details of data sources and methodology. Section 3 describes results and discussions. Concluding remarks are given in Section 4.

2. Model description and Data

2.1. RCA4 Model

Because of the limitation of the public dataset for SSI, only the experiment of RCA4 RCM is chosen for downscaling to the CORDEX–SEA domain (89.49 - 146.51 E; 14.81 S - 26.96 N; http//www.cordex.org) with the resolution of 25 km. The model is given boundary conditions from the HadGEM2-ES global model from the Met Office Hadley Centre (MOHC). The RCA4 was built on its predecessor, RCA3 [17]. However, some physics parameterizations were improved to cater to simulations outside the European region [22]. For example, a new lake model (FLake) enhanced the land surface model and improved soil processes [22]. The Bechtold-KF scheme was used for cumulus parameterization [2]. Besides, the threshold of relative humidity for cloud formation was adjusted. The representation of the cloud-radiation parameterization was modified following Tiedtke (1996) [28] to account for in-cloud cloud-water heterogeneity [5]. A complete description of RCA4 can be found in Strandberg et al. (2015) [25].

The simulations are performed for i) 1951 - 2005 with historical forcing and ii) for 2006 - 2099 under different Representative Concentration Pathways (RCP) scenarios [19]. In RCA4, the RCP scenarios are expressed as changes in equivalent carbon dioxide concentrations as interpolated from one year to the next. Here, two different RCP scenarios are used, which have been assessed in IPCC (2013) [8] as follow:

- RCP 4.5: Strategies for reducing greenhouse gas emissions cause radiative forcing to stabilize at 4.5 Wm^{-2} before the year 2100.

- RCP 8.5: A scenario of comparatively high greenhouse gas emissions means that radiative forcing will reach 8.5 Wm^{-2} by 2100.

2.2. Satellite data

SSI AMATERASS is the solar irradiation product derived from the Himawari-8 satellite under the Japan Science and Technology Agency (JST) using the EXAM algorithm [26]. The algorithm is based on a fast neural network, accurately reproducing the radiative transfer model, using the Comprehensive Analysis Program for Cloud Optical Measurement (CAPCOM) [10, 15]; algorithm to retrieve cloud optical thickness and cloud-particle effective radius from Himawari-8 observations by a lookup table (LUT) based approach under a homogeneous plane-parallel and single-layer cloud model. Additional input information included in EXAM, such as water vapor and ozone, was acquired from external data sets (e.g., the Japanese Reanalysis and OMI/Aura satellite), and surface albedo was computed from Himawari-8 observations using a statistical method.

After membership registration, ISS Amaterass data with 30 min temporal resolution and 4 km spatial resolution downloaded from the website: ftp.amaterass.org. The AMATERASS data with 30 min time resolution were used to calculate daily data, and converted to a spatial resolution similar to the RCA4 model. The q uality of AMATERASS estimation was evaluated with the surface measurement at five stations in Viet Nam with a high correlation (over 0.95) in our previous study [16].

2.3. Method for evaluation

For comparison between RCA4 simulation and satellite estimation, a spatial validation was also performed by calculating the difference between RCA4 and AMATERASS at the grid scale. The indicators used here include: The CORR correlation index, The mean error (ME), the relative mean error (RME), the mean absolute error (MAR) and the relative mean absolute error (RMAE):

$$ME = \frac{1}{n}\sum_{i=1}^{n}(S_i - G_i) = \bar{S} - \bar{G} \qquad (1.1)$$

$$RME = 100\% * \frac{ME}{\bar{O}} \qquad (1.2)$$

$$MAE = \frac{1}{N}\sum_{i*1}^{N}|S_i - G_i| \qquad (1.3)$$

$$RMAE = 100\% * \frac{MAE}{\bar{O}} \qquad (1.4)$$

$$CORR = \frac{Cov(S,G)}{\sigma_S\sigma_G} \qquad (1.5)$$

In which, *S* is data from satellite, *G* is ground observation data, *N* is the number of samples;

CORR is dimensionless, *Cov(S,G)* is the covariance of the two variables, *σS* and *σG* are standard deviation of *S* and *G*, respectively.

Comparisons were carried out separately for seven different climate regions, namely the Northwest (B1), Northeast (B2), North Delta (B3), North Central (B4), South Central (N1), Central Highlands (N2), and the South (N3) and divided by four seasons (winter - DJF, spring - MAM, summer- JJA, and autumn -SON).

3. Results and discussions

3.1. Evaluation of RCA4 simulation against satellite data

Firstly, the relative mean errors RME (%) of SSI in winter (DJF), spring (MAM), summer (JJA), and fall (SON) of RCA4_RCP4.5 and RCA4_RCP8.5 model simulation data compared with AMATERASS satellite data over seven sub-regions in Viet Nam are shown in Figure 1. It can be seen that the two scenarios of the RCA4 model simulation show rather similar RME results. The overestimation of SSI values of the model is almost found in the North part of Viet Nam (B1-B4 sub-regions) during the year in which the most overestimated values are seen in wintertime and in the B2 sub-region. The underestimated values of RCA4 SSI are often observed in the N2 sub-region during the year. However, some small overestimated values of RCA4 SSI (under 20%) are found in some parts of N2 and N3 sub-regions in summer and autumn.

Figure 2 shows that RCA4's highest RMAE values are found in the B2-B4 subregions in DJF and SON in both RCP scenarios. The smallest RMAE values are observed in the N3 subregion in all seasons.

Monthly RME and RMAE in seven subregions and the whole of Viet Nam during 2016 - 2018 period are shown in Figure 3. It can be seen that RCA4 monthly RME values are normally overestimated in four North subregions (B1-B4) while underestimated in three south subregions (N1-N3) in which the highest values are observed in B2 in January, and the smallest deals are found in N3 in April.

In general, the RMAEs of the two scenario versions are similar and have higher errors in winter and spring. The RMAEs of RCA4 also show better results in the South than in the North of Viet Nam.

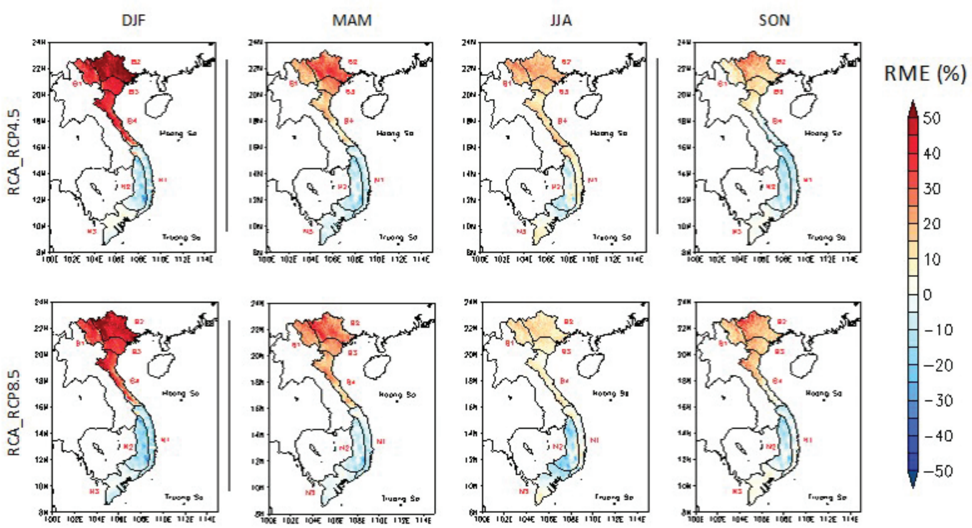

Figure 1. Distribution of relative mean errors RME (%) of SSI in winter (DJF), spring (MAM), summer (JJA) and fall (SON) of RCA4_RCP4.5 (middle) and RCA4_RCP8.5 (lower) compared with AMATERASS over seven sub-regions in Viet Nam during 2016 - 2018 period

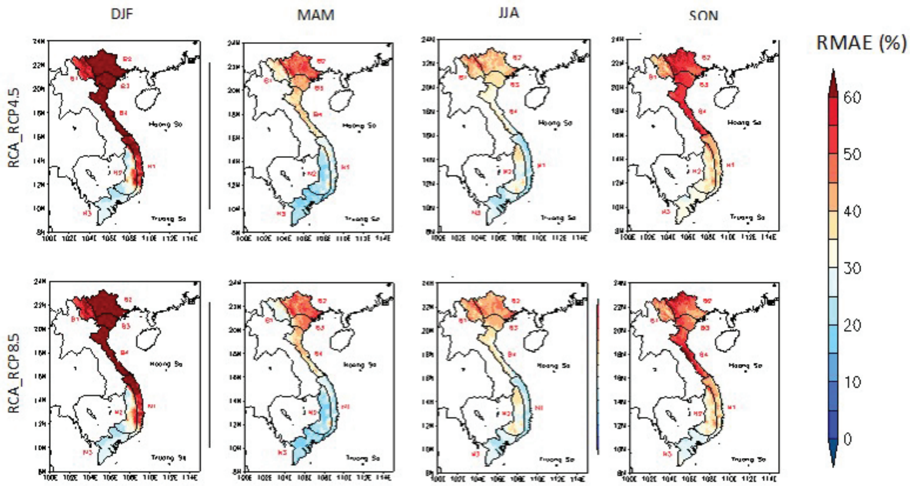

Figure 2. Distribution of relative mean errors RMAE (%) of SSI in winter (DJF), spring (MAM), summer (JJA) and fall (SON) of RCA4_RCP4.5 (middle) and RCA4_RCP8.5 (lower) compared with AMATERASS over seven sub-regions in Viet Nam during 2016 - 2018 period

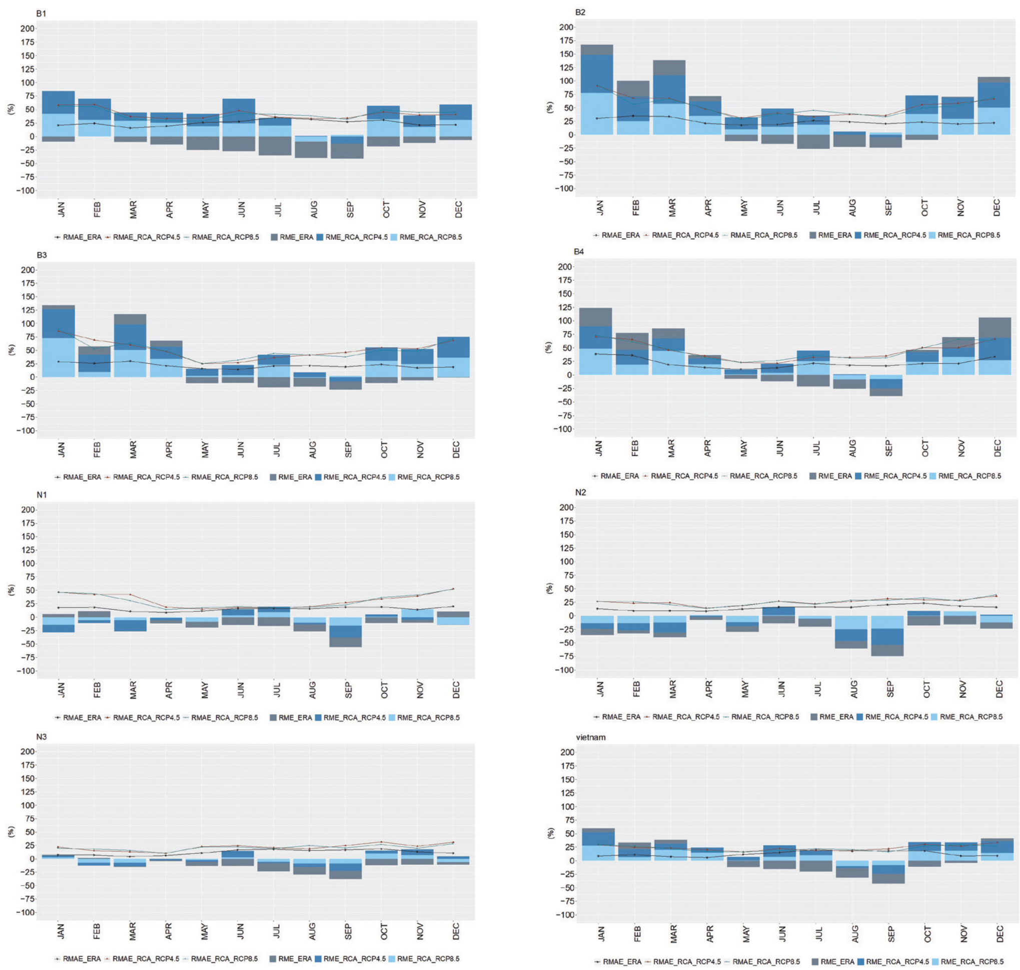

Figure 3. Monthly RME (%, columns) and RMAE (%, lines) of RCA4_RCP4.5 and RCA4_RCP8.5 compared with AMATERASS in seven subregions and the whole of Viet Nam during 2016 - 2018 period

3.2. RCA4 projection

Based on the comparative agreement between RCA4 and satellite estimations, we used the model projection to investigate the SSI change in the period 2005 - 2016 and the future 2021 - 2050 compared to the period 1976 - 2005 accordingly to climate change scenario RCP4.5 and RCP8.5.

The changes are non-uniformly distributed between 2006 - 2020 (Figure 4) and 2021 - 2050 (Figure 5) of the annual average short-wave radiation at the surface RCP8.5 scenarios. In the period 2006 - 2020, the average yearly short-wave radiation at the surface has an expected increase from 0.3 - 2.0 W/m² in the Northern region, Central Highlands and South Central regions, but the decrease in the North Central, Northern Delta and the Southern regions. In the period 2021 - 2050, the annual average short-wave radiation at the surface increases in the Southern region and Central Highlands regions. But the decrease of 1.0 - 3.0 W/m² in the remaining regions, including the Northern Delta, Central Coast, South Central and Southern regions. Therefore, the short-wave radiation at the surface rises in the Northern region, and in contrast, falls in the Southern region; except for the Central Highlands region that hasn't changed much.

Figure 6 and Figure 7 respectively show changes in the average short-wave radiation at the surface of the scenario RCP8.5 of the periods (2006 - 2020) and (2021 - 2050) compared with the period (1976 - 2005) in 4 seasons.

According to the RCP4.5 scenario, there are non-uniformly changes between 2006 - 2020 (Figure 8) and 2021 - 2050 (Figure 9) of the annual average short-wave radiation at the surface. In 2006 - 2020, the average yearly short-wave radiation at the surface increased from 1.0 to 5.0 W/m²; high concentration in the Central Highlands, with an increase of 3.0 - 5.0 W/m². Thus, this is the difference between the RCP4.5 scenario and the RCP8.5 scenario for 2006 - 2020. In contrast, in 2021 - 2050, the annual average short-wave radiation at the surface decreases by 1.0 - 5.0 W/m². Except for the provinces bordering China in the Northeast and the high-mountain areas in the Central Highlands, the value increased from 1.0 to 2.0 W/m². Thus, the short-wave radiation at the surface raises in the mountainous regions and decreases in the flat areas, similar to the RCP8.5 scenario.

Figure 10 and Figure 11 respectively show changes in the average short-wave radiation at the surface of the scenario RCP4.5 of the periods (2006 - 2020) and (2021 - 2050) compared with the period (1976 - 2005) in 4 seasons.

The relative mean deviation (RMB) of the short-wave radiation at the surface is negative in most of Viet Nam; apart from that the Central Highlands has a positive value. Thus, the short-wave radiation across Viet Nam decreases, meanwhile in the Central Highlands is increased. The change of short-wave surface radiation under the RCP8.5 scenario is more significant than the RCP4.5 scenario (Figure 12).

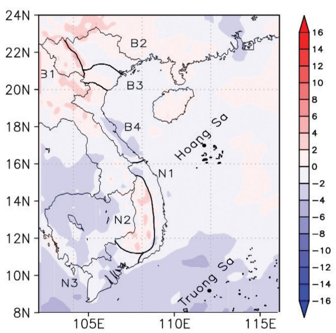

Figure 4. Changes in the annual average short-wave radiation (W/m²) at the surface in the RCP8.5 scenario for 2006 - 2020 compared to 1976 - 2005

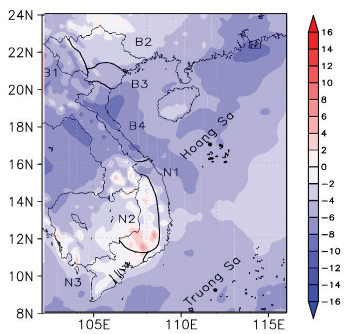

Figure 5. Changes in the annual average short-wave radiation (W/m²) at the surface in the RCP8.5 scenario for 2021 - 2050 compared to 1976 - 2005

The Winter (DJF)

The Spring (MAM)

The Summer (JJA)

The Autumn (SON)

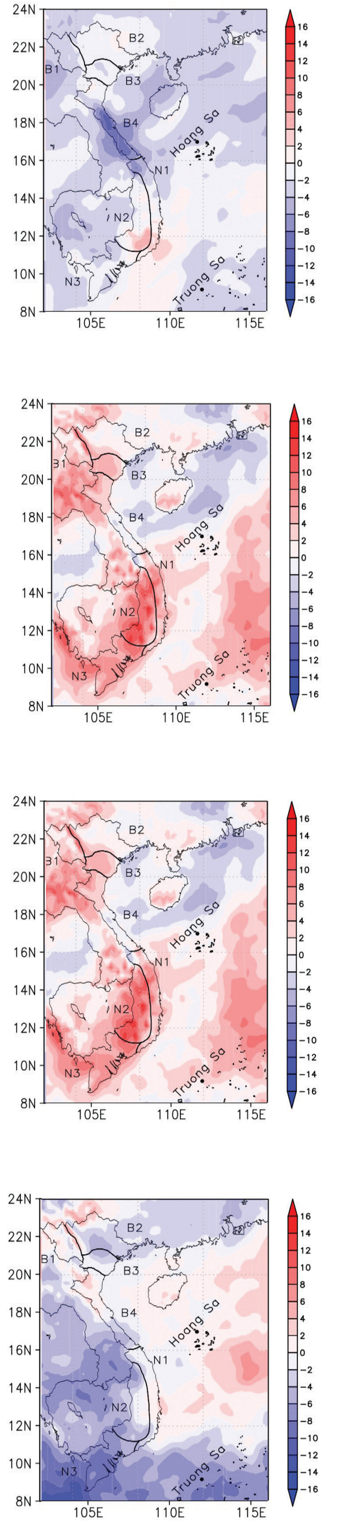

Figure 6. Changes in the average short-wave radiation (W/m²) at the surface of the RCP8.5 scenario of 2006 - 2020 compared to 1976 - 2005 in 4 seasons

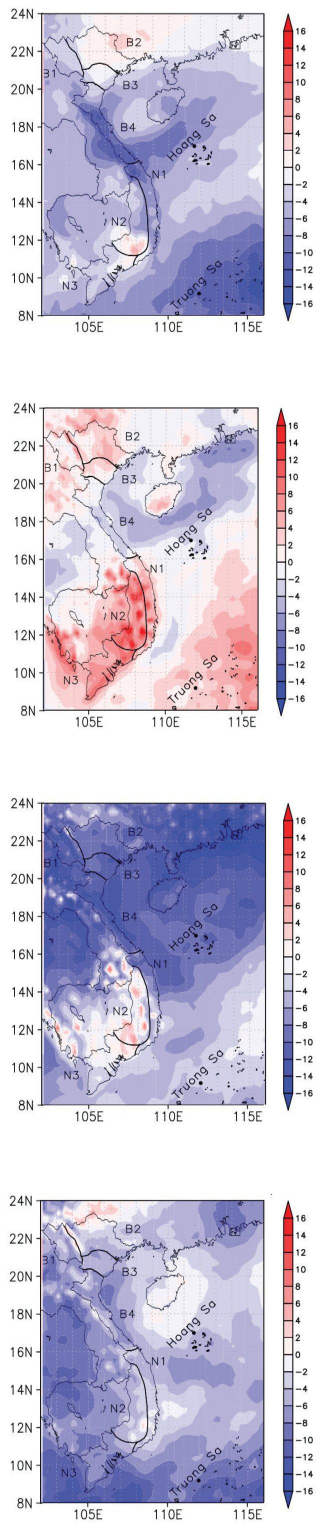

Figure 7. Changes in average short-wave radiation (W/m²) at the surface of the RCP8.5 scenario of 2021 - 2050 compared to 1976 - 2005 in 4 seasons

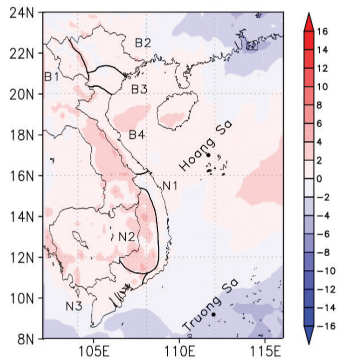

Figure 8. Changes in the annual average short-wave radiation (W/m²) at the surface in the RCP4.5 scenario for 2006 - 2020 compared to 1976 - 2005

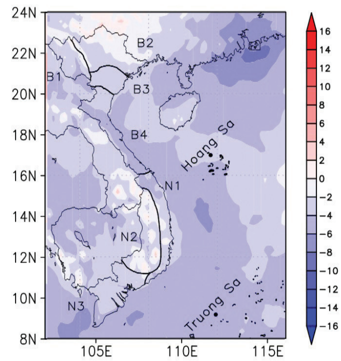

Figure 9. Changes in the annual average short-wave radiation (W/m²) at the surface in the RCP4.5 scenario for 2021 - 2050 compared to 1976 - 2005.

Winter (DJF)

Spring (MAM)

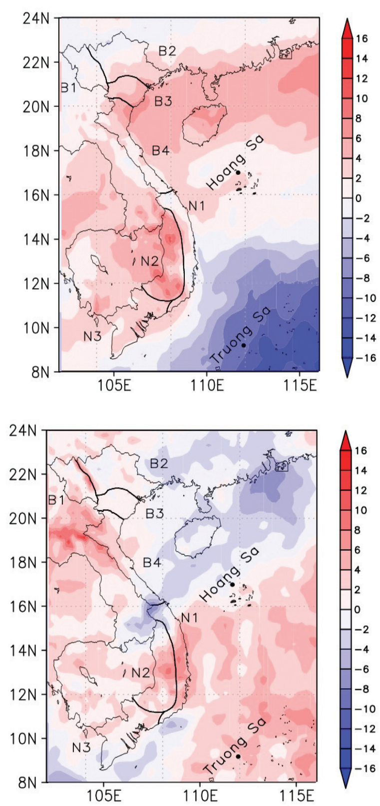

Figure 10. Changes in the average short-wave radiation (W/m²) at the surface of the RCP4.5 scenario of 2006 - 2020 compared to 1976 - 2005 in Winter (DJF) and Spring (MAM)

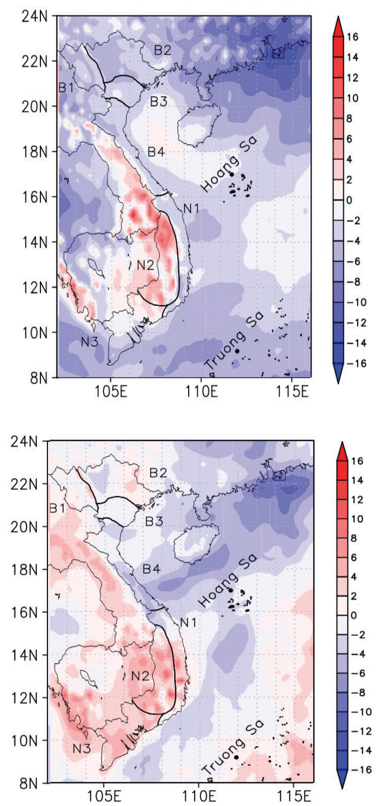

Figure 11. Changes in the average short-wave radiation (W/m²) at the surface of the RCP4.5 scenario of 2021 - 2050 compared to 1976 - 2005 in Winter (DJF) and Spring (MAM)

Summer (JJA)

Autumn (SON)

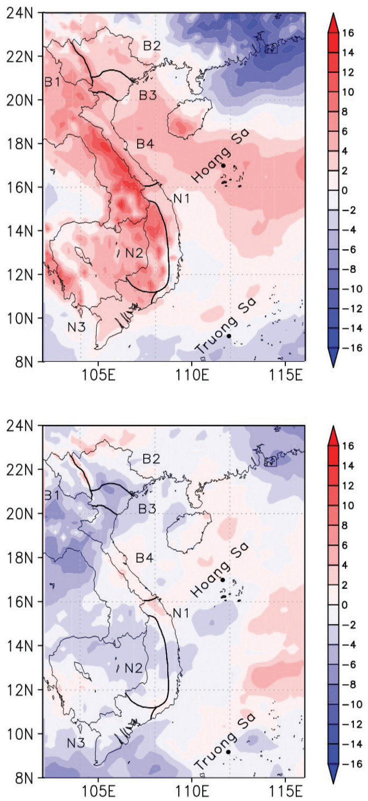

Figure 10. Changes in the average short-wave radiation (W/m²) at the surface of the RCP4.5 scenario of 2006 - 2020 compared to 1976 - 2005 in Summer (JJA) and Autumn (SON)

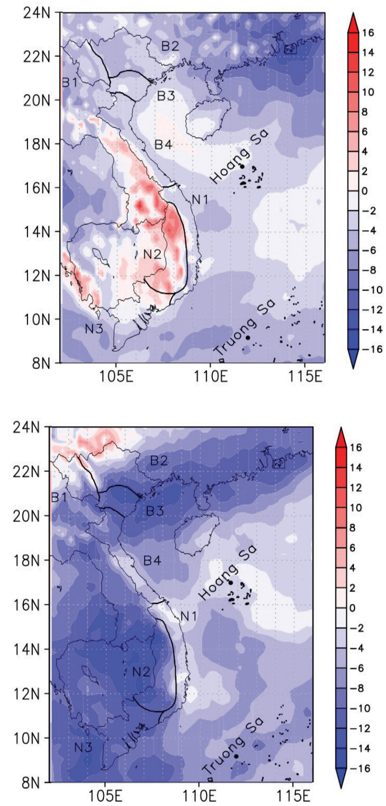

Figure 11. Changes in the average short-wave radiation (W/m²) at the surface of the RCP4.5 scenario of 2021 - 2050 compared to 1976 - 2005 in Summer (JJA) and Autumn (SON)

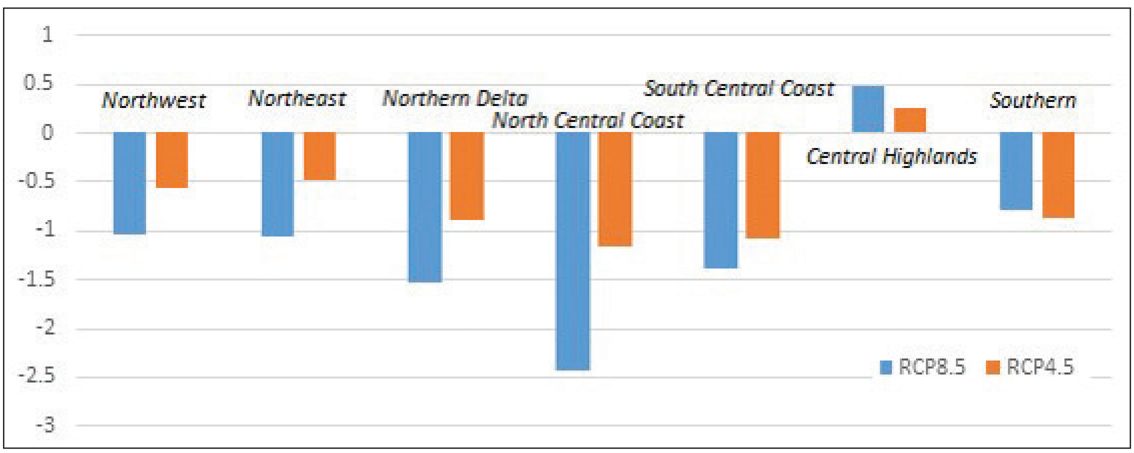

Figure 12. The relative mean bias RMB (%) of the short-wave radiation at the surface in Viet Nam

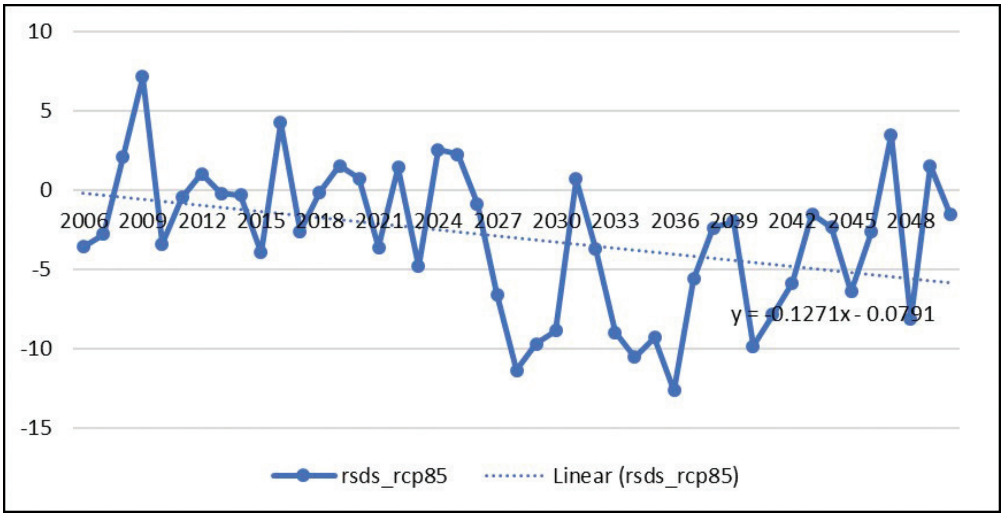

Figure 13. Future changes in annual short-wave radiation (W/m²) at the surface in Viet Nam in the RCP8.5 scenario for 2006 - 2050 compared to 1976 - 2005.

In general, the annual average surface short-wave radiation decreases in the future under both the RCP4.5 and RCP8.5 scenarios (Figure 13 and Figure 14). In the RCP8.5 scenario, the annual average shortwave radiation at the surface tends to fluctuate steadily around 0 for the period from 2006 to 2026, and negative during the period of 2027 to 2047, then the trend fluctuates slightly around 0 in the last 3 years. Meanwhile, in the RCP4.5 scenario, there is a decrease around the value of 0 in the 2006 - 2032 period and, it is a negative bias in the 2033 - 2050 period. The annual average short-wave radiation surface changes in the RCP 8.5 scenario are approximately in the RCP 4.5 scenario.

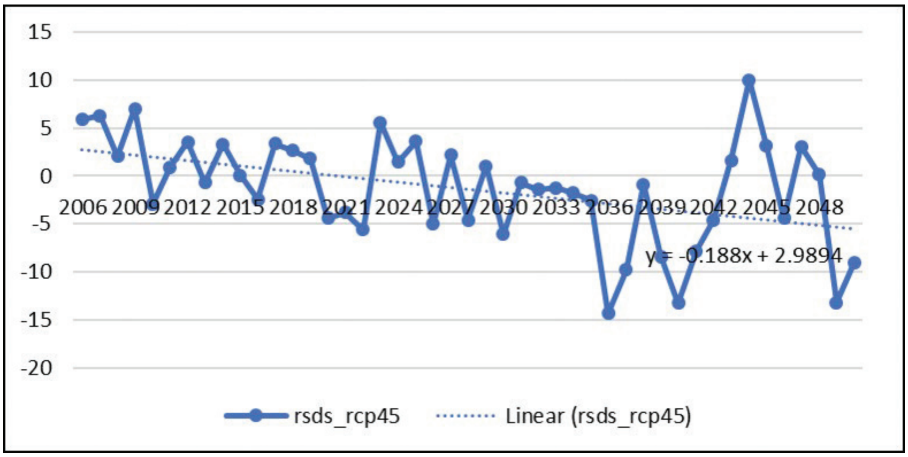

Figure 14. Future changes in annual short-wave radiation (W/m²) at the surface in Viet Nam in the RCP4.5 scenario for 2006 - 2050 compared to 1976 - 2005.

4. Conclusions

This study focuses on assessing the variation of solar radiation at the surface (SSI) in Viet Nam for the period 2006 - 2020 and the future period 2021 - 2050 compared with the period 1976 - 2005 using the regional climate forecasting model RCA4 RCM under high emission scenarios (RCP8.5) and medium emission scenarios (RCP4.5) [9]. Based on the evaluation of the error of the SSI from the model compared with the estimated data from the Himawari-8 satellite for the period 2016 - 2018, it shows the relative agreement of the model and satellite estimates to use model for assessing future volatility.

In general, in the spring, satellite data compared with model data for two scenarios shows that there is a markedly higher bias for RCP8.5 than RCP4.5. During the summer, the model estimation is more consistent with the satellite data in case of the RCP4.5 than the RCP8.5 scenario. The solar irradiance value in the RCP4.5 is higher than that in the RCP8.5. These high values are concentrated mainly in June and July. In the autumn, solar radiation has decreased markedly compared to the summer, and there is little difference between North and South Viet Nam. During the winter, solar radiation reduced significantly, especially in the Northern area affected by the strong Northeast monsoon during this time.

The relative mean bias (RMB) of short-wave surface radiation for the RCP8.5 scenario in the North Central region and the North is lower than in the RCP4.5 scenario. It is approximately equal from the South Central Coast region to the Southern. Compared to the period 1976 - 2005 (in both scenarios), the short-wave radiation at the surface in the period 2020 - 2050 decreases in most of Viet Nam, except for Central Highlands.

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