Paper Title:Skill evaluation of the inter-sectoral impact model intercomparison

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RESEARCH ARTICLE | JUNE 16 2023

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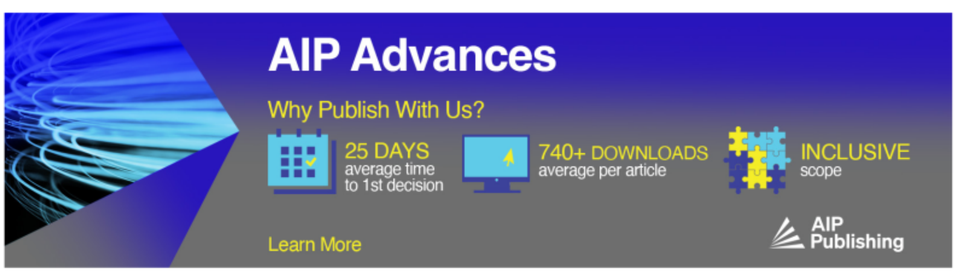
AIP Conference Proceedings 2614, 040063 (2023)
https://doi.org/10.1063/5.0125743



Skill Evaluation of the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP) Method for Earth System Model (ESM) Output Bias Correction

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Abstract. Earth System Models (ESM) output still has a low resolution. The scale-down Climate imprint (CI) method and the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP) bias correction method were applied to improve ESM resolution. BNU-ESM, MIROC-ESM, and MIROC-ESM-CHEM were selected to represent the ESM and ERA-Interim data as proxies for the observation data. The variables used in this study were the maximum temperature and rainfall. This study aims to evaluate the ability of the ISI-MIP bias correction method in three climate regions (rainfall patterns) in Indonesia (Monsoon, Local, Equator). Evaluation of ISI-MIP ability using Taylor Diagram and correlation map. The results obtained by ISI-MIP work well at the maximum temperature variable compared to rainfall with a correlation coefficient of 0.8 and 0.5, respectively. In addition, the Monsoon region has better results compared to the local and equatorial regions. Of the three ESM models, the MIROC model is the model that has the best performance.

INTRODUCTION

The impacts of climate change tend to be multi-sectoral and differences between rural and urban areas. Extreme rainfall causes urban areas to experience flooding due to many buildings and a lack of water drainage. Meanwhile, the agricultural sector is vulnerable to climate change in rural areas. Changes in the planting calendar are effects of climate change and disproportionate water requirements (excess or insufficient). The decrease in rainfall and the increase in temperature are other impacts of climate change[1]. Indonesia has experienced a decrease in the frequency of cold days (TX10p) and cold nights (TN10p). In addition, a significant increase of 0.18 and 0.30°C occurred in the average daily maximum temperature (TXmean) and daily minimum temperature (TNmean) [2]. Meanwhile, extreme temperatures indirectly affect stress levels in urban areas.

The variability of climate change that occurs in Indonesia in the future requires new strategies and risk management. The government needs to pay attention to sustainable development by considering climate change variability. A climate model is needed that can simulate various future climate changes [3]. The Earth system model (ESM) is the latest climate simulation by including the representation of the biogeochemical cycle in the simulation

The 8th International Conference on Mathematics, Science and Education 2021
AIP Conf. Proc. 2614, 040063-1–040063-6; https://doi.org/10.1063/5.0125743
Published by AIP Publishing. 978-0-7354-4549-9/$30.00

model[4]. Simulations are carried out numerically involving the atmosphere, oceans, and land surfaces. However, the ESM is still rugged and has a low resolution. Low resolution can cause considerable bias, so a scale-down method is needed to correct it. The downscaling method produces high-resolution ESM and has low computational costs is statistical downscaling[5]. The Climate Imprint (CI) or delta method is a simple downscaling method with good performance[6]. Several other studies on downscaling statistics [7]–[10] .

Although the statistical method of downscaling can change the resolution of the ESM to a higher level (local scale), there is still a systematic bias. There is a bias between the statistical scale-down results and the observational data set. Inadequate quality of observational data and imperfect parameterization is one source of bias. A bias correction method is needed to minimize the bias of downscaling results [9]. The IS-IMIP method is designed to synthesize impact projections in agriculture, water, biomes, health, and infrastructure at various levels of global warming[12]. Gusev also applied the ISI-MIP method to investigate the possible changes in various annual riverbed characteristics (mean value, standard deviation, extreme annual runoff frequency) up to 2100 based on the application of the SWAP ground surface model and meteorological projections simulated by five GCMs according to four scenarios RCP[13]. The ISI-MIP bias correction method was also applied by Casanueva et al. [4] to project climate from the heat stress index. The study used the ISI-MIP bias correction method[15],[4].

This study focuses on evaluating the skills of the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP) bias correction method on ESM output data. Skill evaluation was carried out in three climate regions in Indonesia [2]. Skill evaluation based on correlation map and Taylor Diagrams. The statistical downscaling method used in this research is climate imprint. Evaluation of the performance of the ISI-MIP bias correction method was carried out on three ESM models, namely BNU-ESM, MIROC-ESM, and MIROC-ESM-CHEM. Era-Interim reanalysis dataset was used as observational data. The maximum temperature and rainfall were chosen as the observed variables.

METHODS

The steps to achieve the objectives of this research are (1) preprocessing data and descriptive analysis, (2) Downscaling with CI methods, (3) The results of downscaling CI bias correction using the ISI-MIP method, (4) Division of the results of the correction bias into three climate regions, (5) evaluation of the ability of ISI-MIP correction bias in 3 climate regions using correlation map and Taylor diagrams.

Study and Data

This study evaluates the ISI-MIP bias correction method in three climate regions in Indonesia. The climate region includes region 1 (monsoon), region 2 (anti-monsoon), and region 3 (equator) (see Figure 1). In this study, ESM and Era-Interim outputs were used (as of observation proxies) with coordinates 6.79°-12.55°LS and 92.81°-143.43°BT. The variables used in this study were maximum temperature and rainfall. The scenario used is historical.

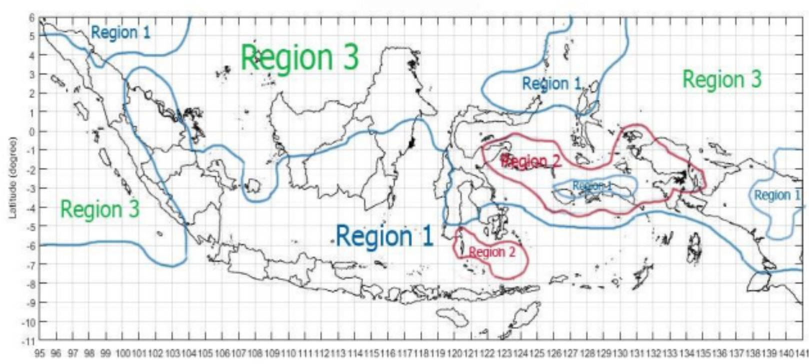

FIGURE 1. The three climate regions

TABLE 1. Data resource description

Model	Resolution	Scenario	Scale
BNU-ESM	2.8° × 2.8°	Historical	Daily
MIROC-ESM	2.8° × 2.8°	Historical	Daily
MIROC-ESM-CHEM	2.8° × 2.8°	Historical	Daily
Era Interim	0.25° × 0.25°	Reanalysis	Daily

ERA-Interim was developed by European Center for Medium-Range Weather Forecasts (ECMWF). The interim period is 1979-2019. The ESM output dataset is taken from the Coupled Model Intercomparison Project Phase 5 (CMIP5) dataset source. The ESM period are 1950-2005 for BNU-ESM, 1850-2005 for MIROC-ESM, and 1850-2005 for MIROC-ESM-CHEM. Evaluation of ISI-MIP capability will be carried out separately between the maximum temperature and rainfall variables.

Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP)

The correction of bias using the ISI-MIP method consists of two stages, namely long-term monthly average correction and daily variability adjustment [12]. Thus, X_{ijk}^{data} represents data for the *i*-th day, *j*-month and *k*-year, on a particular grid cell of the simulation time series (ESM data) or observation, where T is the daily average temperature data, and P is the data for rainfall. A nonlinear (exponential) approach was chosen for the rainfall case, so the correction formula in the rainfall data is shown in Equation (1).

$$\tilde{P}_{ijk}^{ESM} = \left[a + b\left(P_{ijk}^{ESM} - P_{mean}^{ESM}\right)\right]\left[1 - \exp\left\{\frac{-\left(P_{ijk}^{ESM} - P_{mean}^{ESM}\right)}{c}\right\}\right] \quad (1)$$

The linear portion of the function above is represented by the offset a and the slope of b, while c is the decay constant for the exponential part, which must be adjusted. While correcting the bias in temperature variables apply the linear function as shown in Equation (2).

$$\tilde{T}_{ijk}^{ESM} = \delta_j + b\Delta T_{ijk}^{ESM} + \tilde{\bar{T}}_{jk}^{ESM} \quad (2)$$

Where δ_j is the long-term mean temperature in the j-th month, $\tilde{\bar{T}}_{jk}^{ESM}$ is the average corrected monthly temperature, ΔT_{ijk}^{ESM} is the residual ESM output and b is the slope.

RESULT AND DISCUSSION

Indonesia's climate zones are divided into three regions based on proximity and characteristics [17]. Region 1 is a monsoon-type region with a clear period between the dry and rainy seasons. The type of rainfall in region 1 is unimodal. Region 2 is a local type region (local) opposite of region 1. Region 3 is an equatorial region with a bimodal rain distribution (two peaks of the full rainy season) almost throughout the year, which is included in the rainy season criteria. Before conducting the three ISI-MIP areas in Indonesia, we ensured that the downscaling and bias correction methods could match local climate patterns. The following is a map of raw data, observation data (ERA-Interim), and downscaling and bias correction results.

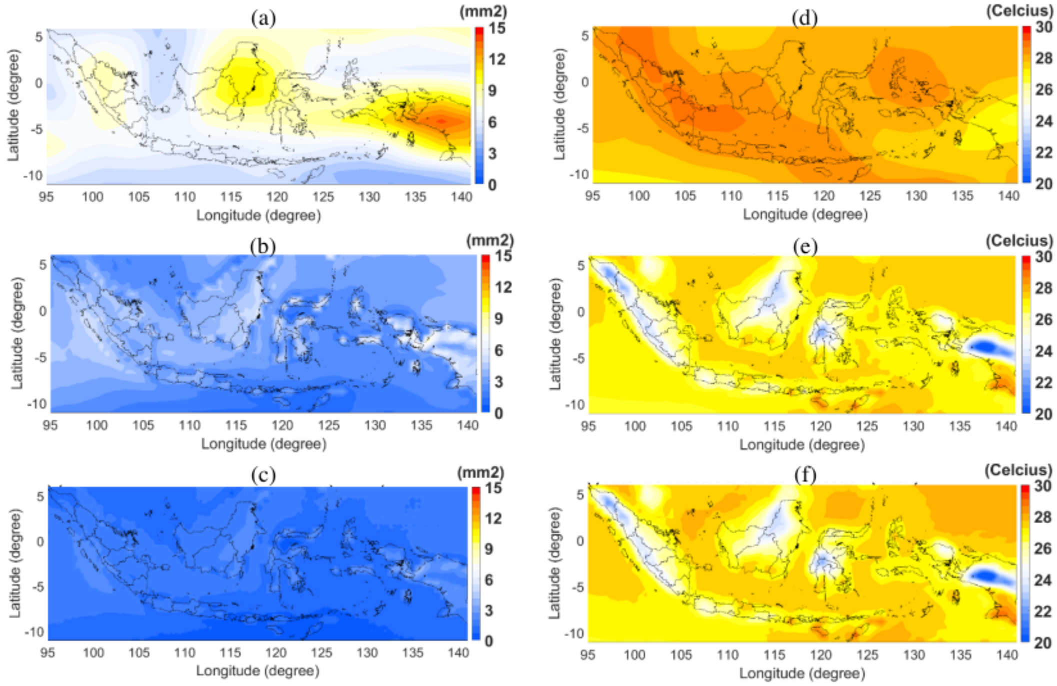

FIGURE 2. Effect of Downscaling and Bias Correction for ESM Output (BNU-ESM Model) of (a) Before Downscale and Bias Correction (Rainfall). (b) ERA-Interim ECMWF (Rainfall). (c) After Downscale and Bias Correction (Rainfall). (d) Before Downscale and Bias Correction (Maximum Temperature). (e) ERA-Interim ECMWF (Maximum Temperature). (f) After Downscale and Bias Correction (Maximum Temperature)

The ISI-MIP bias correction method can equate the BNU-ESM model with the ERA-Interim, shown in Figure 2. The dark blue ISI-MIP method map indicates that the rainfall intensity is slightly below the ERA-Interim ECMWF. The MIROC-ESM and MIROC-ESM-CHEM models after downscaling and bias correction have the same results as the BNU-ESM models. In comparison, the maximum temperature variable produces not much different from the rainfall variable, where the ISI-MIP method can bring the ESM output to the local climate. Part of the island of Papua, East Kalimantan province, has a high rainfall intensity. High rainfall intensity and reduced green area can cause flood in [18]. The lowest temperatures are along the highlands in Indonesia, the island of Papua, parts of the island of Sumatra, northern Kalimantan, and Central Sulawesi. To determine how well the results of the bias correction using the ISI-MIP method were performed, a correlation test was conducted between the results of the correction bias and the ERA-Interim [19]. The higher the correlation coefficient value indicates that the bias correction results can follow the local climate (ERA-Interim). The following is a map of the correlation between the results of the bias correction and the ERA-Interim.

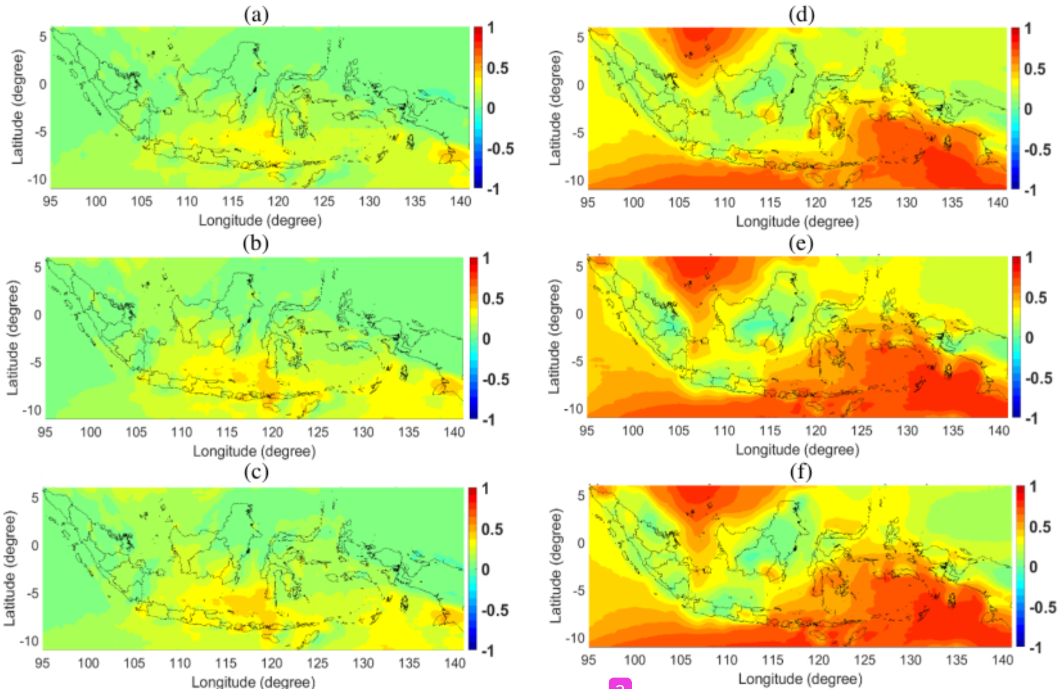

FIGURE 3. Correlation Between Bias Correction Results and ERA-Interim (a) BNU-ESM (Rainfall). (b) MIROC-ESM (Rainfall). (c) MIROC-ESM-CHEM. (d) BNU-ESM (Maximum Temperature). (e) MIROC-ESM (Maximum Temperature). (f) MIROC-ESM-CHEM (Maximum Temperature)

The correlation between the results of the correction bias with the Interim ERA on the maximum temperature variable looks better than the rainfall variable based on Figure 3. The highest correlation coefficient on the rainfall variable is 0.4 and is in region 1. While the maximum temperature variable has the highest correlation coefficient of 0.8, it is located in region 1. However, the highest coefficient for each variable is mostly located in the ocean area. The MIROC-ESM and MIROC-ESM-CHEM models are better than the BNU-ESM models. Taylor's diagram contains three statistical measures: correlation, RMSE, and standard deviation [2]. The Taylor diagram in this study is used to evaluate the ISI-MIP method on climate zones in Indonesia. The best performance is for certain climate zones close to the "observed" point. Figure 4 shows that in region 1 with the MIROC-ESM and MIROC-ESM-CHEM models, the maximum rainfall and temperature variables are close to the observed point, meaning that the skill of the ISI-MIP bias correction method is best in region 1 with the MIROC-ESM and MIROC-models. ESM-CHEM. Maximum temperature yield is better than rainfall.

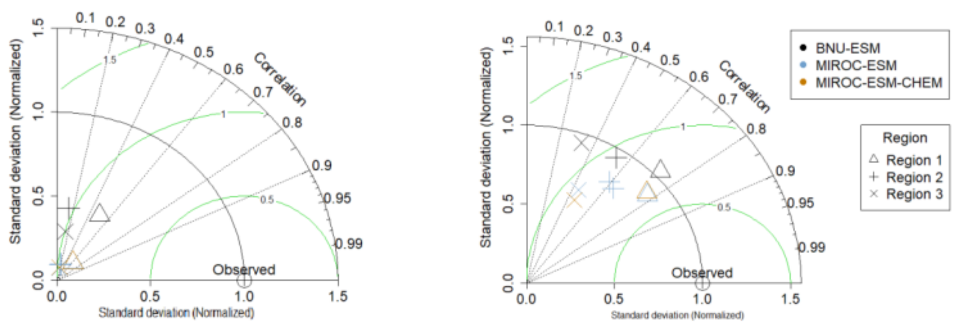

FIGURE 4. Taylor Diagram for (a) Rainfall and (b) Maximum Temperature

CONCLUSION

The downscaling (CI) method and the ISI-MIP bias correction have good expertise in equalizing Interim Era pattern data. The correlation value between the results of the ISI-MIP and ERA-Interim bias correction methods is the highest maximum for the temperature variable compared to the rainfall variable. Overall, region 1 was better than region 2 and region 3. The MIROC-ESM and MIROC-ESM-CHEM models were better than the BNU-ESM models. Overall, the ISI-MIP bias correction method has good performance but needs improvement, especially for the rainfall variable. Several method approaches can improve performance, one of which is the Ensemble method.

ACKNOWLEDGMENT

Acknowledgements to the Research and Development Board of Higher Education (DIKTILITBANG) PP Muhammadiyah for financial support in this research. (0842.305/PT/I.3/C/2021).

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