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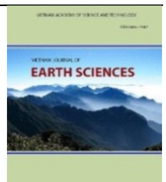

Performance of SEACLID/CORDEX-SEA multi-model experiments in simulating temperature and rainfall in Vietnam

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ABSTRACT

The study examined the performance of six regional climate experiments conducted under the framework of the Southeast Asia Regional Climate Downscaling/Coordinated Regional Climate Downscaling Experiment-Southeast Asia (SEACLID/CORDEX-SEA) project and their ensemble product (ENS) in simulating temperature at 2 m (T2m) and rainfall (R) in seven climatic sub-regions of Vietnam. The six experiments were named following the names of their driving Global Climate Models (GCMs), i.e., CNRM, CSIRO, ECEA, GFDL, HADG and MPI. The observation data for the period 1986–2005 from 66 stations in Vietnam were used to compare with the model outputs. Results showed that cold biases were prominent among the experiments and ENS well reproduced the seasonal cycle of temperature in the Northeast, Red River Delta, North Central and Central Highlands regions. For rainfall, all the experiments showed wet biases and CSIRO exhibited the best. A scoring system was elaborated to objectively rank the performance of the experiments and the ENS experiment was reported to be the best.

Keywords: SEACLID/CORDEX-SEA; RegCM; climate downscaling; climate change; Vietnam.

1. Introduction

Climate change has been one of the most important topics of global concern in recent decades, as evidenced in the Conferences of the Parties (COP) from the first-1995 (COP 1 in Berlin, Germany) to the latest-2018 (COP 24 in Katowice, Poland). This has also been demonstrated in the Assessment Reports (AR) of the Intergovernmental Panel on Climate Change (IPCC). In the fifth AR of IPCC, Christensen et al., (2013) reported that the Southeast Asia region (SEA) suffered from persistent changes on regional climate, which resulted in explicit consequences for citizens' life in this region (Hijioka et al., 2014). It was also shown in these reports that there were a limited number of studies on regional climate change and its impacts in the SEA region. To provide the latest climate information at the regional level, a cooperation on regional climate downscaling in SEA was established under the framework of the Coordinated Re-

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gional Climate Downscaling Experiment (CORDEX) of the World Climate Research Program (WCRP) (Giorgi et al., 2009), known as the Southeast Asia Regional Climate Downscaling (SEACLID)/CORDEX-SEA (Juneng et al., 2016; Cruz et al., 2017; Ngo Duc et al., 2017). The Regional Climate Model (RegCM) Version 4.3, developed by the Earth System Physics section of the Abdus Salam International Centre for Theoretical Physics (Giorgi et al., 2012) was used to downscale the outputs of several Global Climate Models (GCMs) to a finer spatial resolution for the CORDEX-SEA domain. Though regional climate models (RCMs) could provide more detailed information on local or regional climate than GCMs, there always exist biases related to model simulation compared to observation data. Thus, evaluation of model performance is always crucial before any further assessment and/or application using the model's outputs is implemented. To date, there is no such study for Vietnam using the SEACLID/CORDEX-SEA experiments.

Up to this time a number of studies on evaluation of model performance have been carried out in the SEA region (e.g. Aldrian et al., 2004; Torsri et al., 2013; Raktham et al., 2015; Juneng et al., 2016; Raghavan et al., 2016; Ngo Duc et al., 2017; Ratna et al., 2017, etc.). Aldrian et al. (2004) used the Max Planck Institute RCM (REMO) to simulate rainfall in Indonesia. They reported that the REMO model well reproduced the spatial pattern of monthly and seasonal rainfall over land, but overestimated rainfall over the ocean. The quality of the driving data significantly affected the performance of the REMO experiment. Torsri et al. (2013) characterized the regional means and variability of temperature and precipitation in 1961–2000 for Thailand using the RegCM3 model. They concluded that the model was appropriate for climate studies in Thailand, and could well simulate seasonal features and tendencies but with a lower level. Juneng et al. (2016) and Ngo Duc et al. (2016) analyzed the sensitivity of precipitation and extremes to cumulus and air-sea flux parameterizations using the RegCM4. Their results showed dry biases in the equatorial area and rather wet biases in the mainland Indo-China, except for the experiments with the MIT Emanuel cumulus schemes. The performance of the Weather Research and Forecasting (WRF) model in simulating major weather phenomena over the East Asia and SEA regions was evaluated by Raktham et al. (2015). Their study concluded that the simulated tropical cyclones displayed a high sensitivity to the cumulus schemes and a low sensitivity to the microphysical schemes. Ratna et al. (2017) used the WRF model and reported an overestimation of boreal summer precipitation in the SEA mainland and an underestimation of boreal winter precipitation in Indonesia. A WRF simulation at the resolution of 25 km was also used by Raghavan et al. (2016) to analyze the present - day (1961–1990) climate over Vietnam. The model was able to represent the observed spatial patterns of the climate with some biases. It was underlined that improvements in modeling should be implemented to reproduce the realistic patterns of climate at a better spatial resolution before the model information can be applied for impact studies at a local scale.

In Vietnam, a number of studies related to the assessment of RCM performances have been conducted (e.g. Phan Van et al., 2009; Mai Van et al., 2014; Ngo Duc et al., 2014; Nguyen Xuan et al., 2016; Trinh Tuan et al., 2019, etc.). Phan Van et al. (2009) studied the seasonal and inter-annual variations of surface climate elements in Vietnam using the RegCM3 model. The observed annual cycle and the inter-annual variability of surface air temperature and precipitation were well reproduced. The model systematically underestimated air temperature over most of seven climatic sub-regions of Vietnam, although the lapse-rate correction for elevation differences between the model grids and the locations of the observed stations was implemented beforehand. The precipitation of rainy and dry seasons were respectively underestimated and overestimated. Ho et al. (2011) also used the RegCM3 to study extreme climatic events in Vietnam. They reported the projected increase of hot summer days and the projected decrease of cold winter nights in the future. Ngo Duc et al. (2014) simulated and projected the climate of Vietnam using three RCMs with the A1B emission scenario. It was shown that an ensemble mean of the three RCMs performed better than any individual RCM in reproducing the climatological mean state and some extreme climate indices for temperature and precipitation. Mai Van et al. (2014) evaluated the performance of the PRECIS RCM in simulating seasonal climate in Vietnam. They reported that the model could well simulate the spatial patterns, annual cycles and inter-annual variability of precipitation and temperature. Nguyen Xuan et al. (2016) used observed data from 481 rain gauges to build a gridded rainfall dataset for Vietnam, called the Vietnam Gridded Precipitation (VnGP) dataset. The VnGP could serve as a very good reference dataset for the evaluation of model performance in Vietnam. Trinh Tuan et al. (2019) used the VnGP to bias-correct model rainfall in Vietnam and then analyzed the future changes of the bias-corrected products in the mid-future period 2046–2065.

The present study investigates the performances of the six regional climate downscaling experiments and their ensemble average (ENS) under the framework of the SEACLID/CORDEX-SEA project. The research question is whether the SEACLID/CORDEX-SEA experiments can well represent rainfall and temperature for the reference period 1986–2005 over the seven climatic sub-regions of Vietnam.

2. Observed data and numerical experiments

2.1. Observed data

Observed daily rainfall and 2 m temperature data for the period 1986–2005 from 66 meteorological stations over the seven climatic sub-regions of Vietnam were used to evaluate the model performance. The period 1986–2005 was chosen, as this period usually served as the reference one in the fifth AR (AR5) of IPCC. Observed daily rainfall and 2 m temperature data for the period 1986–2005 from 66 meteorological stations over the seven climatic sub-regions of Vietnam were used to evaluate the model performance. The 66 stations belong to the meteorological station network of the Vietnam Meteorological and Hydrological Administration. The data were quality-checked by using the 3-sigma and 5-sigma rules for identifying the outlier values of temperature and precipitation, respectively. Among the 66 stations, there are six stations located in Northwest (NW), 13 stations in Northeast (NE), 13 stations in Red River Delta (RRD), 11 stations in North Central (NC), nine stations in South Central (SC), seven stations in Central Highlands (CH) and seven stations in the Southern region of Vietnam (SV) (Fig. 1).

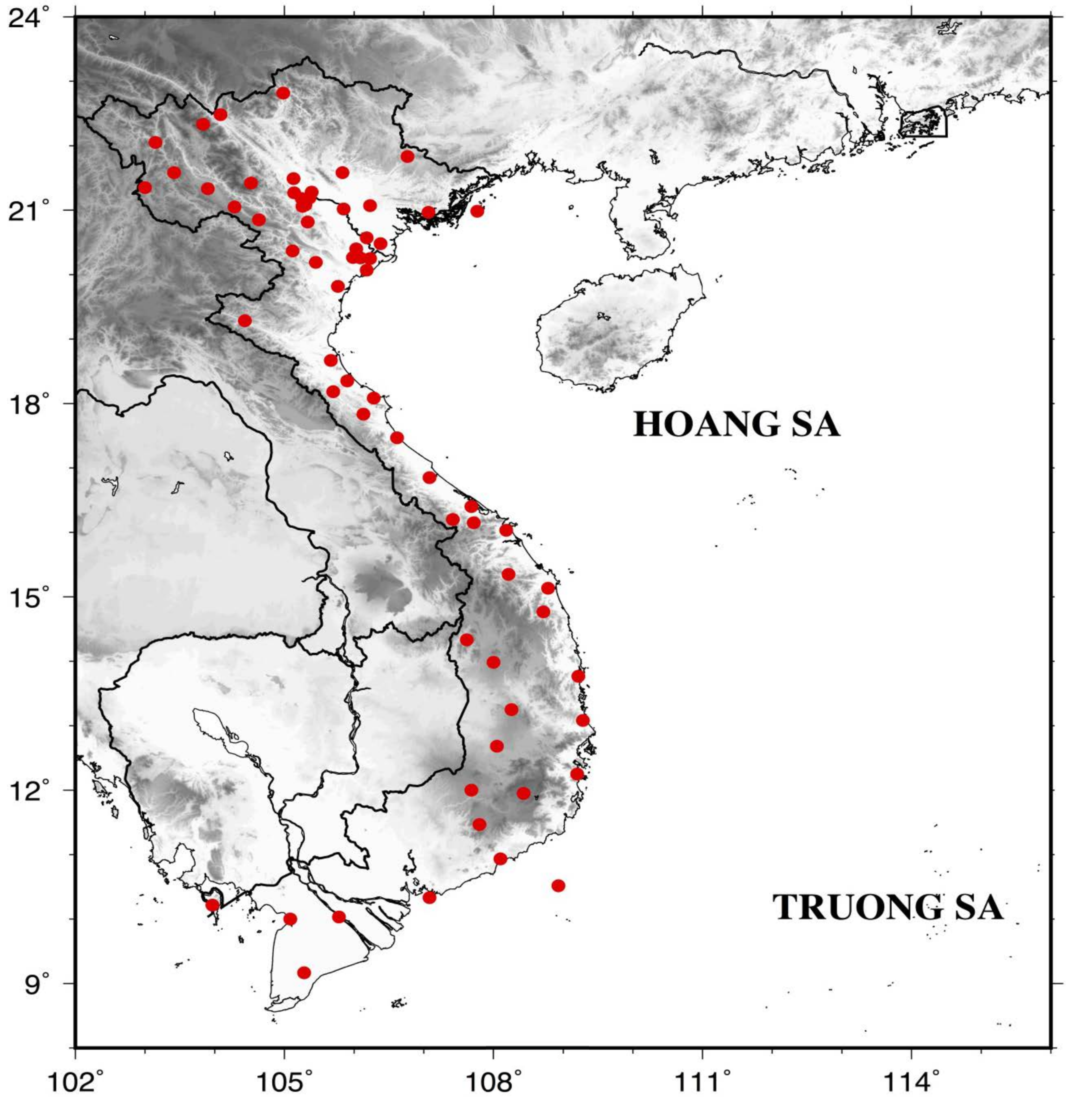

Figure 1. Research domain with red circles showing the locations of the meteorological stations used in this study. Topography over Vietnam is obtained from the Global 30 Arc-Second Elevation (GTOPO30) dataset (gray shading, in m)

2.2. Numerical experiments

Outputs from six numerical experiments under the framework of the SEA-CLID/CORDEX-SEA project using the RegCM4.3 model (Giorgi et al., 2012) were used (Table 1). The RegCM was developed and maintained in the Earth System Physics section of the Abdus Salam International Centre for Theoretical Physics (ICTP), Italy. The model is flexible, portable and can be applied to any region of the world and for a wide range of studies. The SEACLID/CORDEX-SEA experiments downscaled the outputs of six GCMs to a resolution of 25 km for the SEA domain of 15°S–27°N, 89.5°E–146.5°E and for the baseline period 1986–2005 and the future period 2006-2100 under the two greenhouse gas concentration scenarios RCP4.5 and RCP8.5. The physical parameterizations of the experiments were chosen based on previous sensitivity studies (Juneng et al., 2016; Cruz et al., 2017; Ngo Duc et al., 2017). In the analyses of this study, we additionally defined an ensemble experiment, called ENS, which was obtained by taking a simple arithmetic average of the six RCM experiments. Two model variables, i.e. daily rainfall and temperature, were extracted and interpolated by using the nearest point method to the locations of the observed stations used in this study.

Table 1. Names of seven downscaling experiments

Experiment number	Initial and boundary conditions	Short abbreviation
EXP1	N/A	ENS
EXP2	CNRM-CM5	CNRM
EXP3	CSIRO-MK36	CSIRO
EXP4	EC-EARTH	ECEA
EXP5	GFDL-ESM2M	GFDL
EXP6	HadGEM2	HADG
EXP7	MPI-ESM-MR	MPI

3. Results

Figure 2 shows the seasonal variability of the monthly means of temperature averaged over the seven climatic sub-regions for the period 1986–2005. In general, all the experiments underestimate T2m. The underestimation of temperature is prominent in the NW and SC regions in the late winter and in CH and SV in spring. The ENS is in a good agreement with the observation; especially in NE, RRD, NC and CH. HADG and CSIRO show a better performance in NW and HADG is better in SC than the other models (Fig. 2). It should be noted that Phan Van et al. (2009) also reported the cold bias characteristic of the RegCM model in simulating temperature over the climatic sub-regions of Vietnam.

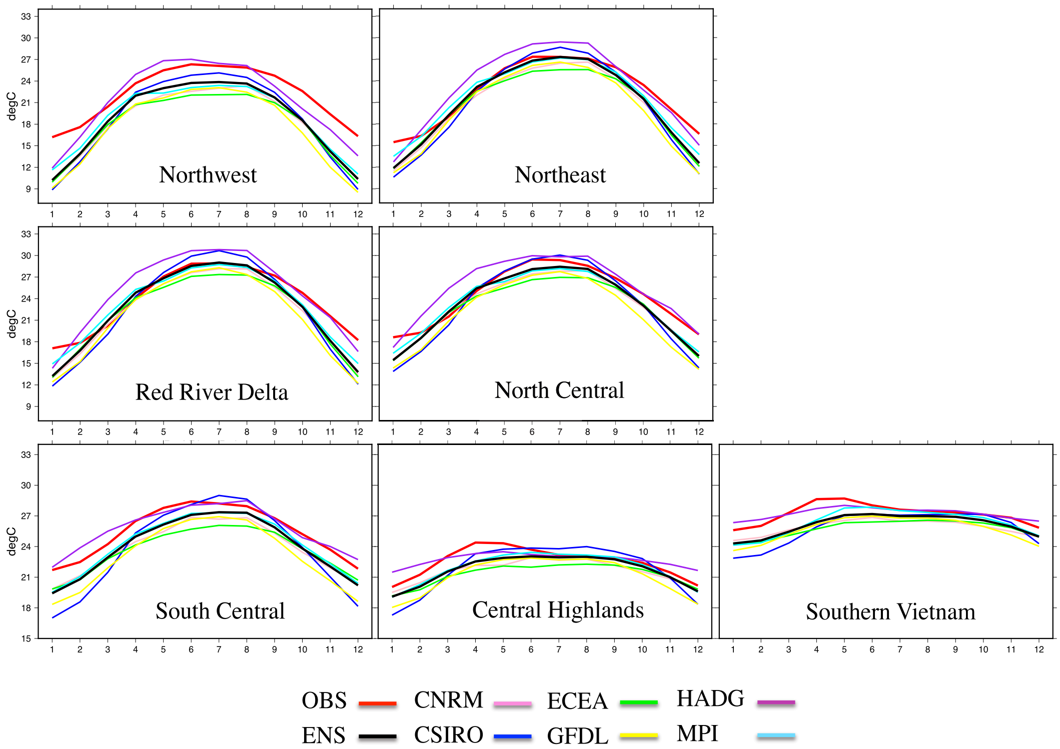

Figure 2. Seasonal cycles of T2m observation data (red lines) and simulated data of CNRM (pink), CSIRO (blue), ECEA (green), GFDL (yellow), HADG (purple), MPI (cyan) and ENS (black). The data are monthly averaged for the period 1986–2005 over the stations in the seven climatic sub-regions of Vietnam

Rainfall was not simulated as well as temperature due to its high spatial and temporal variability (Fig. 3). It is generally overestimated by the experiments, e.g. ECEA, MPI, GFDL and ENS. CSIRO seems to perform the best in representing the observed seasonal variations and amplitude of rainfall in all the subregions in Vietnam. The wettest bias is obtained with ECEA and MPI in the seven regions while GFDL also largely overestimates rainfall in NW, NE, RRD and NC. Conversely, HADG shows a dry bias in late winter, spring and summer in those four regions. In SC, all the models overestimate rainfall from January to September and underestimate rainfall for the rest of year (Fig. 3).

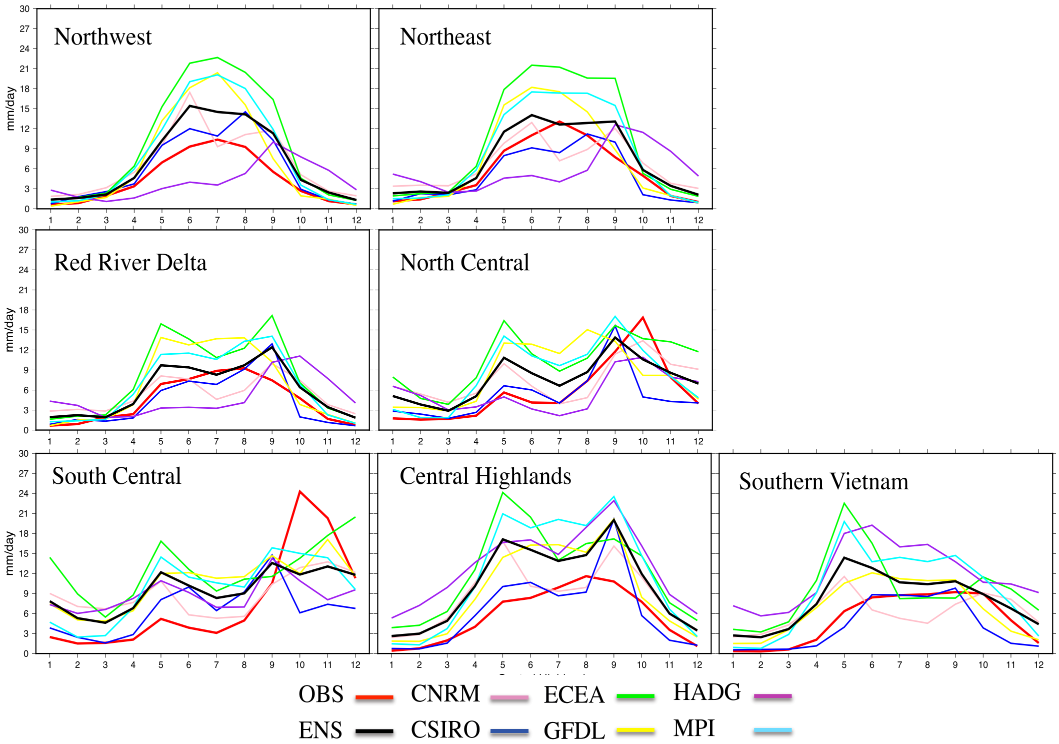

Figure 3. As in Fig. 2 but for rainfall

The relationships between the observed temperature and the simulations are described in Fig. 4. Data were averaged at each station for the whole reference period 1986–2005. The area between two grey lines denotes the place where the model data are within +/-2°C from the observation. When the model data at one station is found within this area, that station is considered as a "good" station (Ngo Duc et al., 2014). In general, the experiments show high percentages of "good" stations in SV and CH with the range of 86–100% and 71–86%, respectively (Fig. 4, Table 2). However, only 17% of the stations in NW (except for HADG–50%) are qualified as "good" ones. Among seven regions, HADG exhibits the highest percentage of good stations, while GFDL shows the lowest one. Most of experiments lie in the right half of the diagonal line in all regions (except for NE), which indicates the cold bias characteristics of the RegCM model, as shown in Fig. 2.

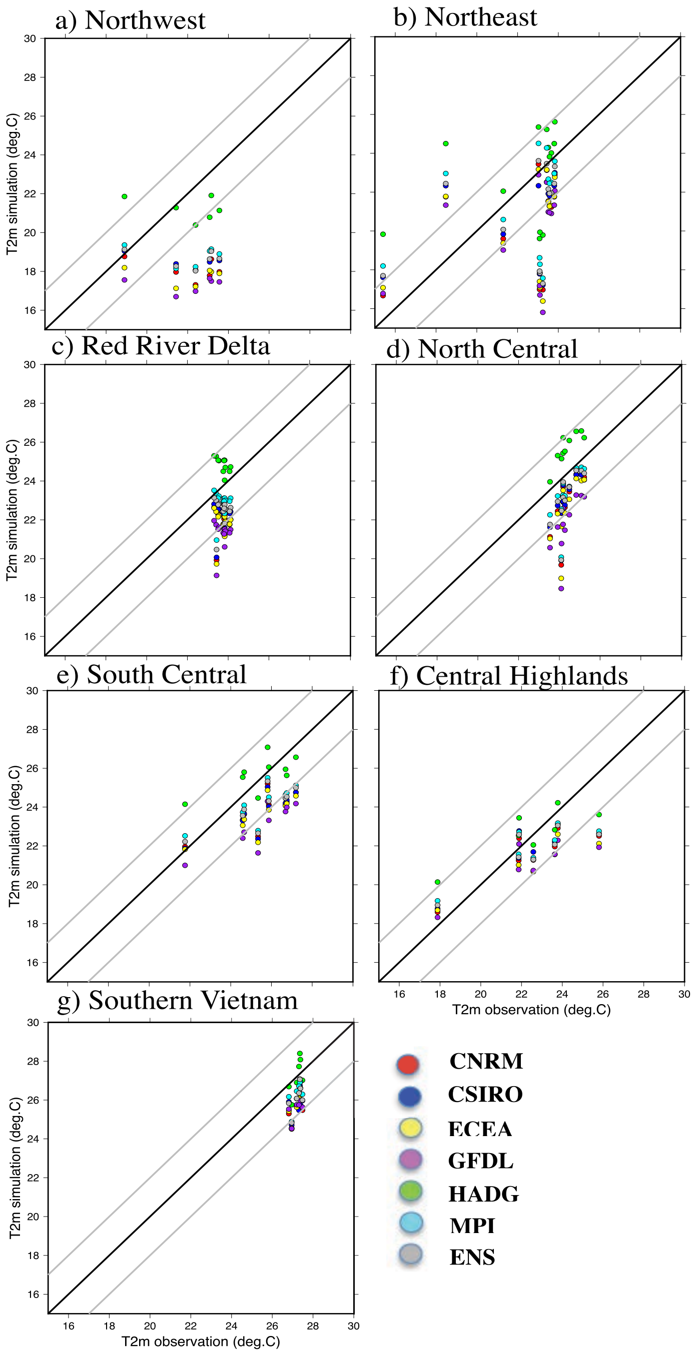

Figure 4. Relationship between 1986–2005 observed 2 m temperature and the different model outputs, i.e. CNRM (red), CSIRO (blue), ECEA (yellow), GFDL (violet), HADG (green), MPI (blue) and ENS (grey). The dots indicate the stations located in a) Northwest, b) Northeast, c) Red River Delta, d) North Central, e) South Central, f) Central Highlands and g) Southern Vietnam. Black line denotes the ideal cases in which simulated data are equal to the observation. Two grey lines define the area where simulated data are within +/-2°C from the observed one

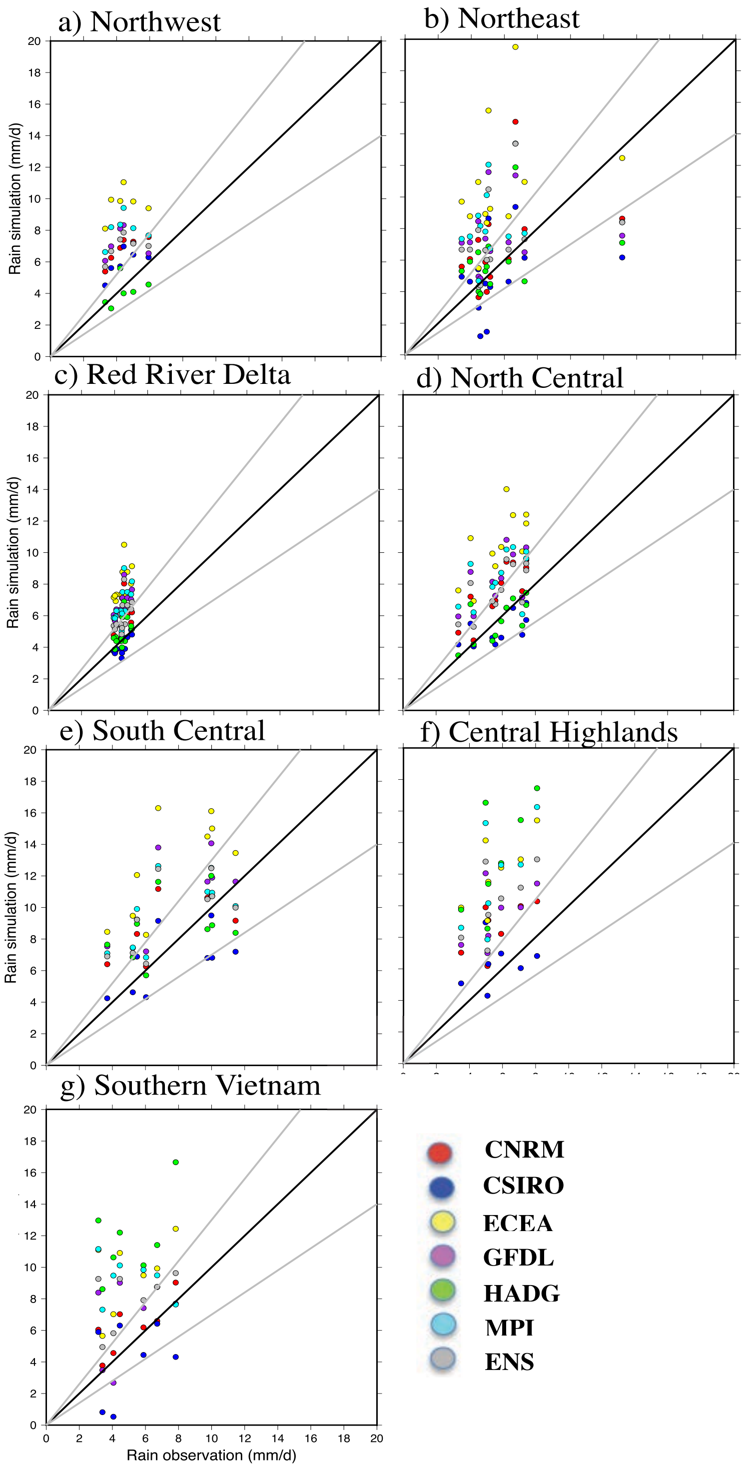

Figure 5. As in Fig. 4 but for rainfall. Two grey lines define the area where simulated data are within +/-30% from the observed one

Rainfall stations are identified to be "good" if they lie in the area defined by two grey lines where their values are within +/-30% from the observation ones. Wet biases are found in all regions as more stations lie in the left half of the diagonal black line. The number of "good" rainfall stations is generally small and lower than that of temperature stations (Table 4). HADG shows the best results in NW and NC with the percentage of good stations to be 83% and 91%, respectively. In RRD and CH, CSIRO well simulates precipitation with 92% and 71% of stations being "good", respectively. In contrast, ECEA shows a poor performance with 0% good stations in NW, RRD, NC, CH and SV. In CH, good stations of five experiments also account for 0%. This reveals that simulating precipitation in CH is challenging.

Table 2. The number and percentage of "good" T2m and R stations of six experiments and their ENS in the seven climatic sub-regions in Vietnam

Model		CNRM		CSIRO		ECEA		GFDL		HADG		MPI		ENS	
Region (No. of stations)	Var	No. of good stations	%	No. of good stations	%	No. of good stations	%	No. of good stations	%	No. of good stations	%	No. of good stations	%	No. of good stations	%
NW (6)	T2m	1	17	1	17	1	17	1	17	3	50	1	17	1	17
	R	1	17	2	33	0	0	1	17	5	83	1	17	1	17
NE (13)	T2m	6	46	8	62	6	46	4	31	7	54	8	62	8	62
	R	7	54	6	46	3	23	5	38	6	46	3	23	6	46
RRD (13)	T2m	9	69	11	85	9	69	4	31	13	100	12	92	11	85
	R	11	85	12	92	0	0	1	8	11	85	1	8	6	46
NC (11)	T2m	9	82	10	91	8	73	3	27	10	91	10	91	10	91
	R	6	55	9	82	0	0	2	18	10	91	2	18	7	64
SC (9)	T2m	5	56	5	56	4	44	3	33	8	89	5	56	5	56
	R	5	56	5	56	1	11	4	44	5	56	5	56	5	56
CH (7)	T2m	6	86	6	86	5	71	5	71	5	71	6	86	6	86
	R	2	29	5	71	0	0	0	0	0	0	0	0	0	0
SV (7)	T2m	6	86	6	86	6	86	6	86	7	100	6	86	6	86
	R	5	71	2	29	0	0	3	43	0	0	1	14	1	14

The absolute T2m biases were estimated for the period 1986–2005 at each station (Fig. 6). Cold biases (0–4°C) are prominent in mostly Vietnam (except for HADG), which agrees with the results shown in Fig. 2 and Fig. 4. Several stations in NW and CH display warm biases (0 to 2°C) in all the experiments (Fig. 6). In general, there is a high agreement among the experiments (excluding HADG) in simulating T2m.

Dry biases are found with CSIRO and HADG in simulating rainfall in NW, RRD and NC. Conversely, ECEA and MPI display wet biases (Fig. 7). For the whole Vietnam, wet biases (10–90%) are popular among the experiments, which is also consistent with the results shown in Fig. 3 and Fig. 5.

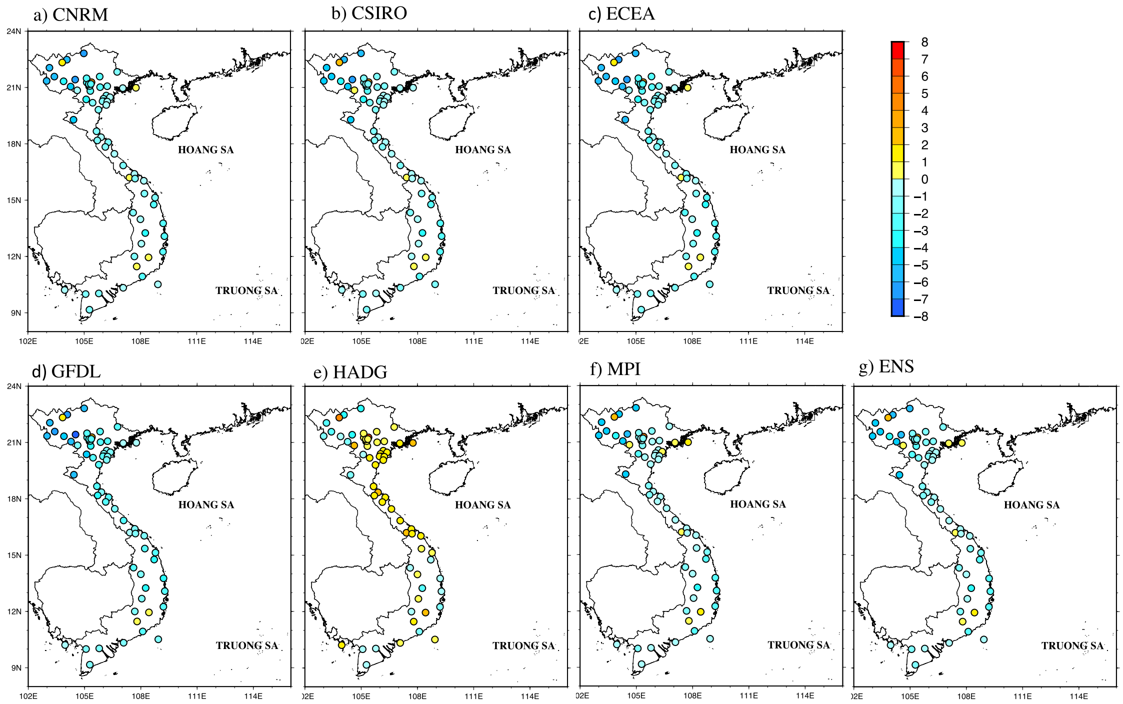

Figure 6. T2m biases (°C) simulated by the experiments a) CNRM, b) CSIRO, c) ECEA, d) GFDL, e) HADG, f) MPI and g) ENS for the period 1986–2005 in Vietnam. Warm (cold) biases are represented by warm (cold) colored circles

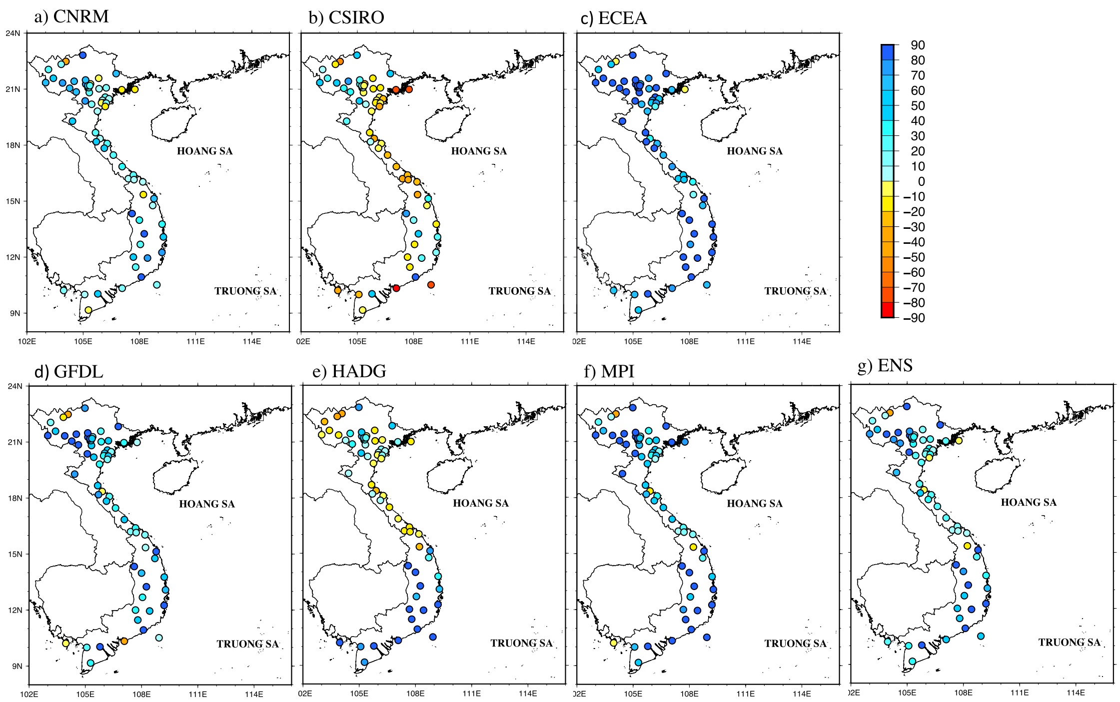

Figure 7. As in Fig. 6 but for precipitation biases (%). Wet (dry) biases are represented by cold (warm) colored circles

Fig. 8 shows the relationship between the monthly simulated T2m and the monthly observation by using Taylor diagrams (Taylor, 2001). In a Taylor diagram, the radius distance represents the ratio of standard deviation (RSTD) of the simulated data to that of observation, while the polar angle expresses the correlation (CORR) between them. The point OBS on the horizontal axis displays the observation where the CORR and RSTD values equal to one. The linear distances between the simulated points and the OBS point are proportional to the centered root mean square difference (RMSD) between the simulated and observed data.

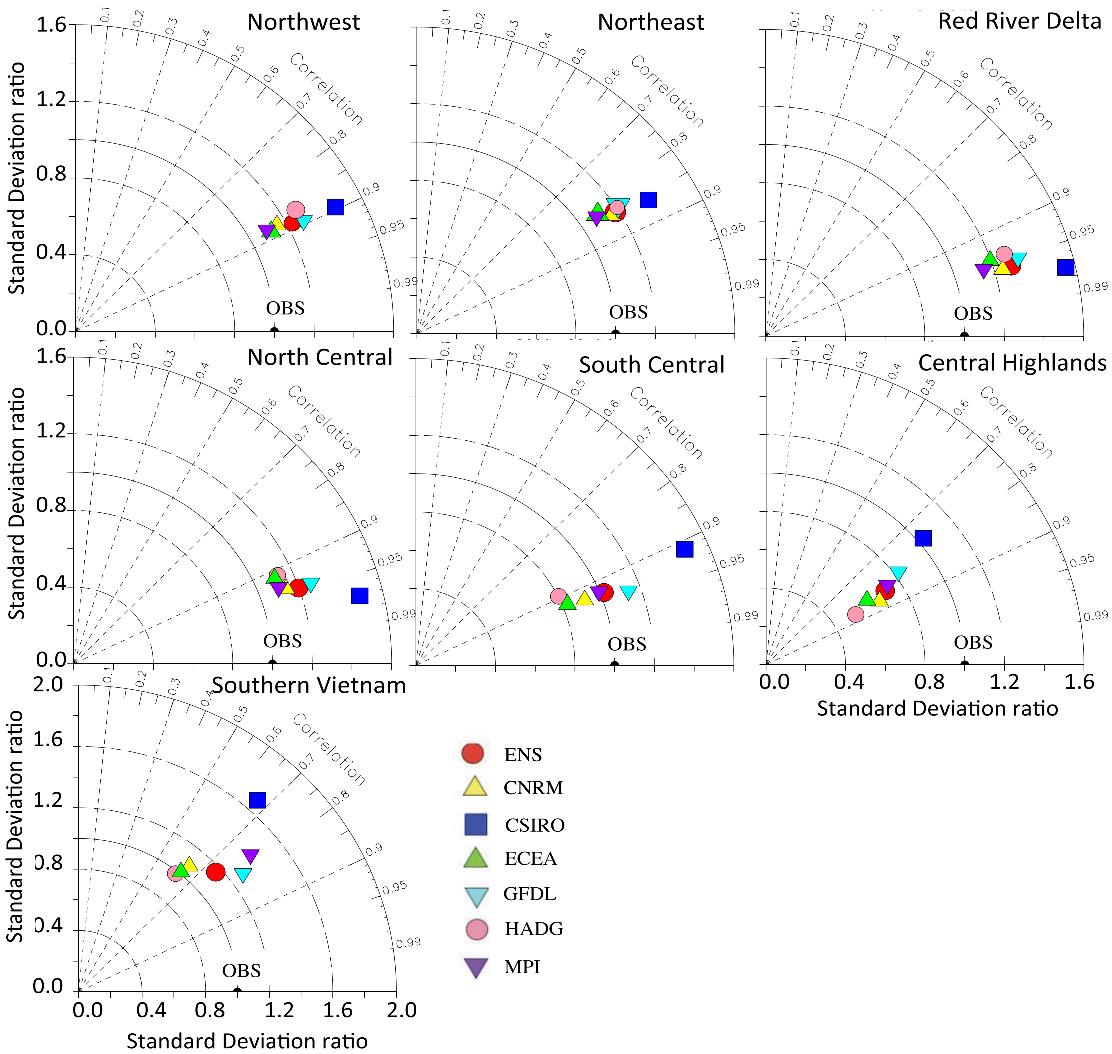

Figure 8. Taylor diagram for the 1986–2005 climatological monthly time series of temperature over the stations of the seven climatic sub-regions in Vietnam with six regional experiments and their ENS

In NW, the experiments show high CORRs (over 0.85) and RSTDs of around 1.2. Among them, ECEA and MPI display the best performance. SV shows the lowest CORRs while the highest are in RRD, NC and SC. HADG and ECEA in SV and ENS and MPI in SC have the best RSTD and RMSD. Among the regions, SC generally exhibits the best performance (Fig. 8).

The performance of simulated precipitation is not as good as that of temperature (Fig. 9). This can be attributed to the high variability of RCMs' precipitation (Juneng et al., 2016). While SC shows the best result with simulated temperature, it is the worst for simulated rainfall with low CORRs (0.3–0.7) and low RSTDs (0.5–0.7). In NE and RRD, HADG displays the lowest CORR (~ 0.1). ENS exhibits a relatively better performance in NE, RRD and SV.

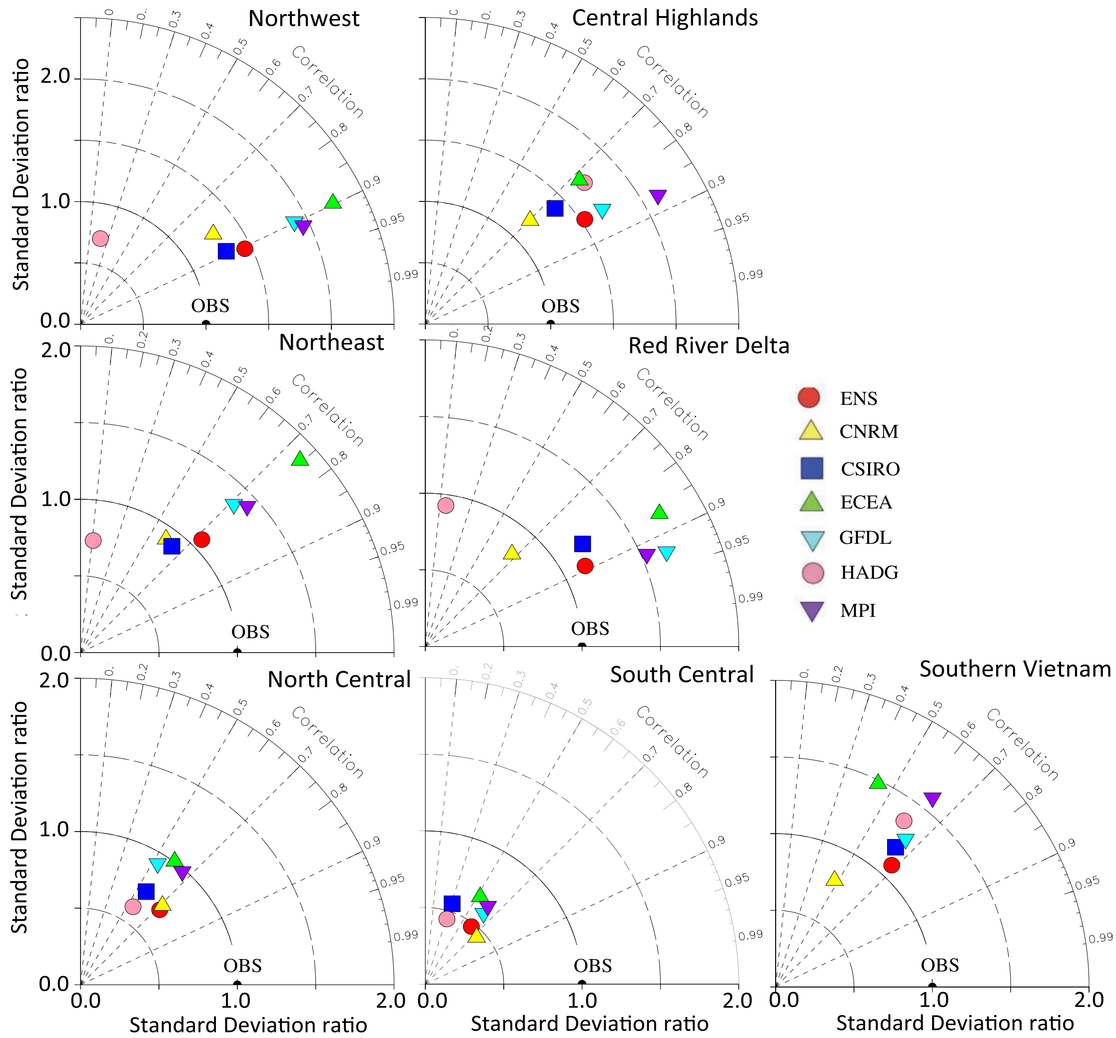

Figure 9. As in Fig. 8 but for precipitation

The above-mentioned different evaluation methods showed that the performance of the experiments depended on the climate variables, the climatic sub-regions, and the used evaluation matrix. Thus, it is not always obvious to conclude which experiment is the best in all cases.

In order to obtain an objective ranking of the overall performance of the experiments, the following method was implemented based on four criteria: (1) minimum absolute bias, (2) minimum RMSD, (3) maximum CORR and (4) RSTD closest to 1. For each criterion, the experiment performing the best gets the score of 6, the second-best gets the score of 5 and so on. The worst experiment gets the score of 0. The final score of each region is the average of the temperature score and the precipitation one. Figure 10 shows the sum of the scores over the seven sub-regions for each experiment. It can be noted that ENS has the highest score, followed by CNRM and MPI. Thus, the ENS ensemble mean outperforms each individual experiment in representing temperature and rainfall in the seven climatic sub-regions of Vietnam.

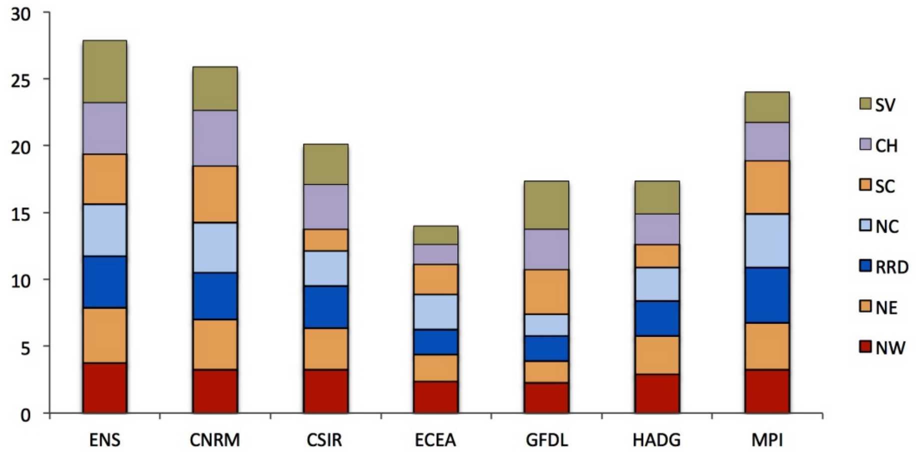

Figure 10. The ranking scores of the seven experiments based on the statistic values of (1) absolute bias, (2) CORR, (3) RMSD and (4) RSTD between monthly model and observation values in the seven climatic sub-regions of Vietnam

4. Conclusions

This study evaluated the performance of six SEACLID/CORDEX-SEA regional downscaling experiments for the period 1986–2005. The experiments were conducted using the RegCM4.3 model with the ICBC obtained from 6 GCMs, including CNRM, CSIRO, ECEA, GFDL, HADG and MPI. The ENS ensemble experiment was obtained by averaging the outputs of the six experiments. The analysis was performed for the seven climatic sub-regions of Vietnam.

It was shown that there was a systematic cold bias in the RCM temperature. ENS exhibited the best in simulating temperature in NE, RRD, NC and CH. For precipitation, the experiments showed a wet bias tendency and CSIRO exhibited the best. The number of "good" stations varied with the experiments and with the variables. For example, CH had a high percentage of "good" T2m stations but a very low percentage of "good" precipitation ones. HADG well exhibited in NW and NC, CSIRO well performed in RRD and CH while ECEA showed the poorest performance in NW, RRD, NC, CH and SV. Finally, a scoring system was elaborated to objectively rank the performance of the experiments. ENS had the highest score, followed by CNRM and MPI. The results suggest that the ensemble mean of the multi-model SEACLID/CORDEX-SEA experiments could be an appropriate and useful data source for assessing future climate scenarios of Vietnam.

Acknowledgements

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