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Original Article

Climate Analog Locations of Cities and Disappearing Climate in Viet Nam

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Abstract: The study defined climate analog locations of cities and disappearing climate in Viet Nam at the end of the 21st century under the Representative Concentration Pathways 4.5 (RCP4.5) and 8.5 (RCP8.5) scenarios. Outputs from six regional climate experiments conducted under the Southeast Asia Regional Climate Downscaling/Coordinated Regional Climate Downscaling Experiment – Southeast Asia (SEACLID/CORDEX-SEA) were used, covering the domain of 15S - 27N, 89.5E - 146.5E. Results showed the general southward tendency of climate analog locations from the original sites. The climate distances between the reference cities and their analog locations were greater under the RCP8.5 than those under the RCP4.5. The analog locations of Ha Noi, Hai Phong and Da Nang were closer to the original cities than those of Ho Chi Minh and Can Tho. Under the RCP8.5, 2.39% of land in Viet Nam, mainly located in some small parts of the Central Highlands and Southern Viet Nam, was projected by the ensemble (ENS) experiment to experience disappearing climate at the end of the 21st century.

Keywords: Climate analog, disappearing climate, regional climate model, Viet Nam.

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1. Introduction

The notion of climate analog was well introduced in previous studies [e.g. Hallegatte et al., 2007; Ishizaki et al., 2012; Bos et al., 2015; Hibino et al., 2015] [1-4]. Briefly, a climate analog location of a reference site A is the place where its present climate being similar to the projected future climate in A. The reference site A is considered to experience disappearing climate if its present climate is found at nowhere within the study area in the future. Williams et al. [2007] [5] showed that disappearing climates generally located in tropical mountainous regions and the poleward areas of continents. The percentage of global terrestrial surface that might experience disappearing climate was projected to be 10 – 48% and 4 – 20% for the high (A2) and low (B1) emission scenarios by 2100, respectively. Besides, disappearing climates could occur in the northern high-latitudes, Andes, Central America, sub-Saharan Africa and South-East Asia (SEA) [Fabienne et al., 2017] [6]. They showed that the projected disappearing land fraction was about 14%, 20%, and almost 40% at the 1.5°C, 2°C, and 4°C global warming levels, respectively.

In Viet Nam, a number of researches on climate and climate change have been conducted [e.g. Nguyen Duc Ngu and Nguyen Trong Hieu, 1991; 2004; Nguyen Viet Lanh, 2007; Tran Viet Lien et al., 2007; Nguyen Duc Ngu, 2008; Phan-Van et al., 2009; Ho et al., 2011; Mai Van et al., 2014, Nguyen et al., 2014; Ngo-Duc et al., 2014; 2016; Ngo-Thanh et al., 2017; Trinh-Tuan et al., 2019] ([7-19]). In 2009, the Ministry of Natural Resources and Environment (MONRE) published the report on Climate Change and Sea Level Rise Scenarios for Viet Nam [MONRE, 2009] [20]. This report was updated in 2012 and 2016 [MONRE, 2012; 2016] [21-22] and has been considered as a reference document for supplying the basis for climate change-related studies in various sectors. It is worth noting that no research on climate analog has been published in Viet Nam to date.

The present study identifies for the first time the best analog locations of cities in Viet Nam within the SEA domain by using the outputs of six regional climate experiments resulted from the Southeast Asia Regional Climate Downscaling/Coordinated Regional Climate Downscaling Experiment – Southeast Asia (SEACLID/CORDEX-SEA) project [Ngo-Duc et al. 2017, Juneng et al. 2016, Cruz et al. 2017, Tangang et al. 2018] ([17], [23-25]). Projected disappearing climate in the future in Viet Nam is also analyzed in the study.

2. Data and methodology

Two climate variables used for the analysis in this study are monthly 2m-temperature and precipitation of the reference period 1986 - 2005 and the future period 2080 - 2099 under the Representative Concentration Pathways 4.5 (RCP4.5) and 8.5 (RCP8.5) scenarios. The data were obtained from the outputs of six regional downscaling experiments of the SEACLID/CORDEX-SEA project and from their ensemble average (ENS). The Regional Climate Model version 4.3 (RegCM4.3) [Giorgi et al. 2012] [26] was used to dynamically downscale six global climate models (GCMs) of the Coupled Model Intercomparison Project Phase 5 (CMIP5) to 25 km horizontal resolution over the SEA domain of 15S - 27N, 89.5E - 146.5E. The downscaled experiments are respectively called 1) CNRM, 2) CSIRO, 3) ECEA, 4) GFDL, 5) HADG and 6) MPI, following the names of the six driving GCMs.

In order to identify climate analog locations, a formulation to estimate the climate distance d from a location B to a target point A was proposed as follows:

$$d = \frac{1}{2} \times (d_T + d_P) \qquad \text{(Eq.1)}$$

where d_T and d_P are the distances of temperature and precipitation, respectively.

$$d_T = \frac{1}{\beta} \times \frac{1}{12} \sum_{n=1}^{n=12} \sqrt{\frac{(T_{f,n} - T_{p,n})^2}{\sigma T_{f,n}{}^2 + \sigma T_{p,n}{}^2}} \qquad \text{(Eq.2)}$$

$$d_P = \alpha \times \frac{1}{\beta} \times \frac{1}{12} \sum_{n=1}^{n=12} \sqrt{\frac{(P_{f,n} - P_{p,n})^2}{\sigma P_{f,n}{}^2 + \sigma P_{p,n}{}^2}} \qquad \text{(Eq.3)}$$

where T (P) is the 20-year monthly mean temperature (precipitation) in the future (f) in A or at the present period (p) in B for month n (from January to December); σT (σP) is the standard deviation of the monthly temperature (precipitation) values; β is an ENS weighting factor, equals to 1 if an individual experiment is considered and equals to 2.0 (1.8) under RCP4.5 (RCP8.5) for the ENS values; α is a scaling factor related to the ratio between the variability of precipitation and temperature within the SEA domain. α varies from 3.5 to 4.9, depending on the experiments and scenarios. It should be noted that the climate distance from B to A could be different with that from A to B.

The best analog location of the target point A is the point located within the SEA land region at which the climate distance to A is the minimum. Based on this, the best analog locations of 78 cities in Viet Nam (Figure 1, Table 1) are identified. For illustrative purposes, analyses for five central cities including Ha Noi, Hai Phong, Da Nang, Ho Chi Minh and Can Tho are conducted in Section 3.1. When the climate distance to A from the best analog location is smaller than or equal to 1 (or $1 < d \leq 2$), A is considered as a good-analog (or poor-analog) point. When the climate distance from A to each location within the SEA land region is greater than the arbitrary threshold of 2, i.e. there is no location within SEA at which the future climate is similar to the present climate in A, the point A is considered to experience disappearing climate in the future.

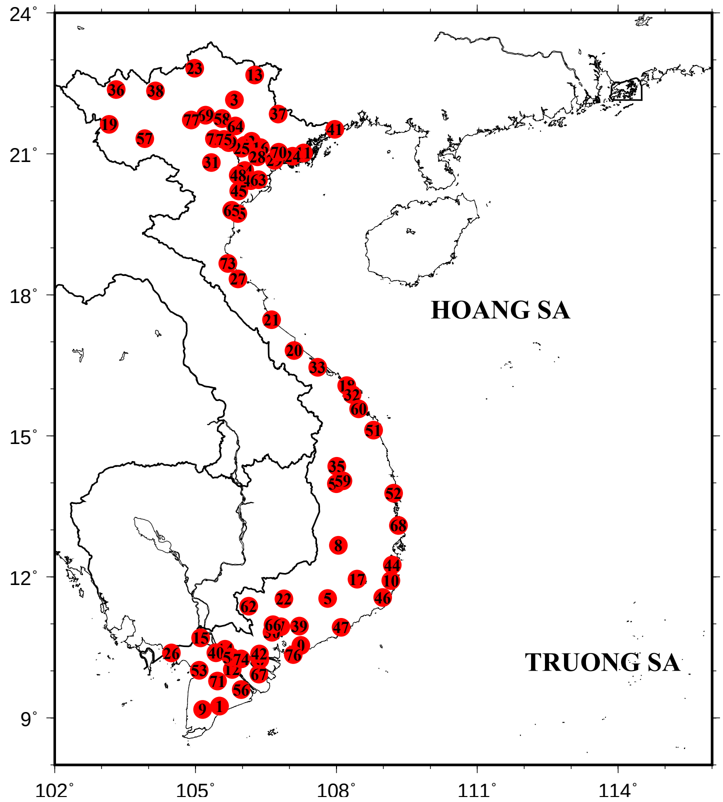

Figure 1. Locations of 78 cities in Viet Nam (displayed with red circles and numbered from 1 to 78 according to the respective order of cities in the Table 1) analyzed in this study.

A ranking method based on the central root mean square difference was implemented and showed the superior performances of ENS, CNRM and the poorest one of ECEA compared to the remaining experiments (not shown). Thus, to illustrate the results clearly and less confusing, the present study only carries out the analysis for the ENS, CNRM and ECEA experiments.

3. Results and discussions

3.1. Climatic relocation of five central cities in Viet Nam

Figure 2 shows the locations of the best climate analogs (with minimum climate distances) of the five central cities in Viet Nam projected by the CNRM, ECEA and ENS experiments. The best analog locations tend to be located southward from the reference cities. Those of Ha Noi, Hai Phong and Da Nang are close to their original cities except for the RCP8.5 scenario with the ENS experiment while those of Ho Chi Minh and Can Tho are at far distances from their origins. The ECEA future climates of both Ho Chi Minh and Can Tho under the RCP8.5 are similar to the present climate of Illoning, Maluku, Indonesia (131.375E, 4.125S). The ENS future climate of Can Tho is analogous to the present climate of Penang island, Malaysia (100.125E, 6.125N) for both the scenarios (Table 1). The climate distances under the RCP8.5 are greater than those under the RCP4.5 (Table 1, Figure 2).

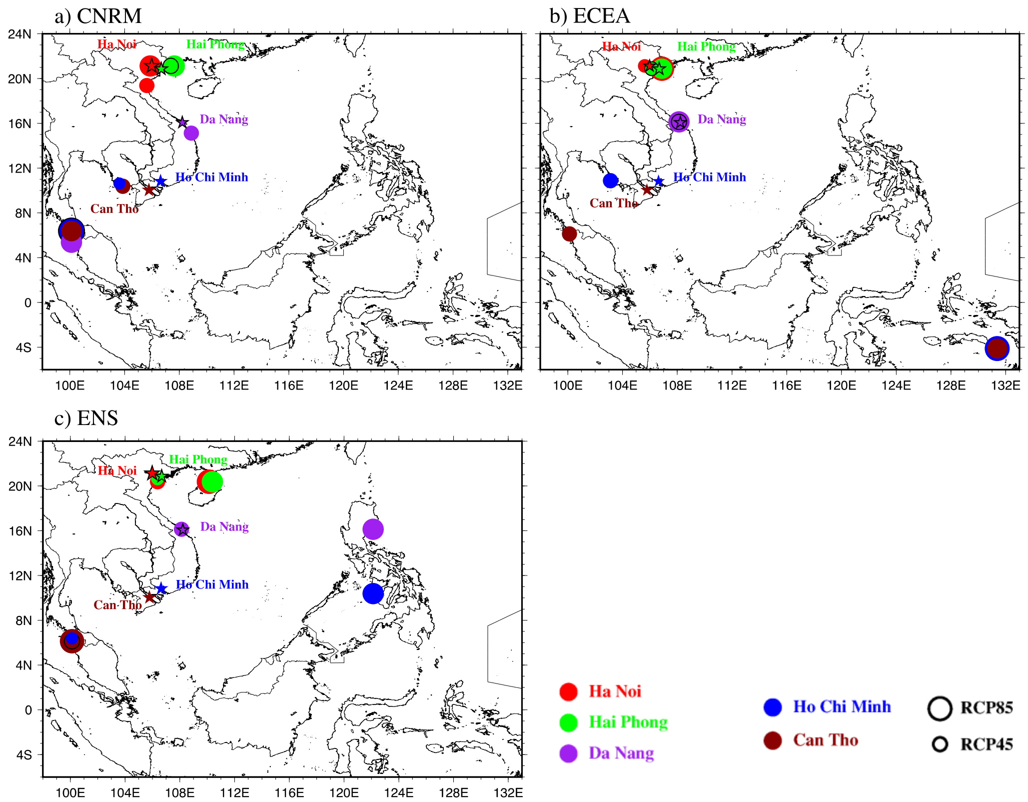

Figure 2. Climatic relocation of the 5 central cities in Viet Nam (Ha Noi – red, Hai Phong – green, Da Nang – purple, Ho Chi Minh – blue, and Can Tho – dark-red circles) at the end of the 21st century under the RCP4.5 (smaller circles) and the RCP8.5 (larger circles) scenarios with the a) CNRM, b) ECEA and c) ENS experiments. The original locations of the 5 cities are marked with star symbols.

Table 1. The original and best analog locations within the SEA domain of 78 cities in Viet Nam and their respective climate distances (CD) under the RCP4.5 and RCP8.5 scenarios, obtained with the ENS experiment.

No.	**Reference city**	**Original locations**		**Best Analog RCP4.5**			**Best Analog RCP8.5**		
		Lon	**Lat**	**Lon**	**Lat**	**CD**	**Lon**	**Lat**	**CD**
1	Ba Ria	107.243	10.542	99.625	7.125	0.758	122.125	10.375	1.763
2	Bac Lieu	105.510	9.250	99.375	6.625	1.570	124.125	6.125	2.469
3	Bac Giang	106.190	21.270	105.875	21.125	0.859	110.125	20.375	1.567
4	Bac Kan	105.830	22.150	108.625	21.875	0.419	110.375	21.375	0.817
5	Bac Ninh	106.050	21.180	106.375	20.625	1.058	110.125	20.375	1.667
6	Bao Loc	107.812	11.542	107.125	12.375	0.581	99.375	11.375	0.768
7	Ben Tre	106.370	10.240	100.125	6.375	1.011	100.125	6.375	1.737
8	Bien Hoa	106.820	10.940	100.125	6.375	0.852	100.125	6.375	1.691
9	Buon Ma Thuot	108.040	12.670	107.375	12.875	0.944	99.875	12.875	1.255
10	Ca Mau	105.150	9.180	99.875	6.375	1.010	99.875	6.375	1.780
11	Cam Ranh	109.160	11.920	97.625	5.125	1.234	108.125	4.125	1.551
12	Cam Pha	107.300	21.020	109.375	19.875	1.096	110.375	20.875	1.770
13	Can Tho	105.780	10.030	100.125	6.125	0.760	100.125	6.125	1.890
14	Cao Bang	106.260	22.680	109.375	21.875	0.450	111.625	21.625	0.890
15	Cao Lanh	105.630	10.460	100.125	6.125	0.803	100.125	6.375	1.870
16	Chau Doc	105.108	10.702	100.125	6.375	0.776	100.125	6.375	1.759
17	Chi Linh	106.383	21.133	106.375	20.625	0.953	106.375	20.375	1.632
18	Da Lat	108.440	11.950	108.375	14.125	0.800	107.625	12.625	0.870
19	Da Nang	108.220	16.068	108.125	16.125	1.430	122.125	16.125	2.370
20	Dien Bien Phu	103.160	21.630	105.375	22.375	0.750	106.875	21.375	0.820
21	Dong Ha	107.100	16.816	107.625	16.625	1.076	109.125	14.625	1.777
22	Dong Hoi	106.620	17.469	106.875	17.125	1.070	108.375	15.875	1.812
23	Dong Xoai	106.880	11.530	98.875	8.125	0.959	123.875	7.625	1.557
24	Ha Giang	104.980	22.823	104.875	22.625	0.391	114.125	22.875	0.977
25	Ha Long	107.070	20.950	110.125	18.375	1.403	106.875	20.625	2.049
26	Ha Noi	105.980	21.120	106.375	20.375	1.100	110.125	20.375	1.660
27	Ha Tien	104.487	10.380	99.625	7.125	1.284	98.375	9.625	2.459
28	Ha Tinh	105.905	18.340	105.875	18.375	1.084	106.875	17.375	1.699
29	Hai Duong	106.320	20.938	105.625	20.875	1.007	106.375	20.375	1.737
30	Hai Phong	106.680	20.860	106.375	20.625	1.170	110.375	20.375	1.710
31	Ho Chi Minh	106.630	10.820	100.125	6.375	0.780	122.125	10.375	1.780
32	Hoa Binh	105.337	20.817	105.625	20.875	1.007	110.375	20.375	1.621
33	Hoi An	108.335	15.879	108.375	15.875	1.380	122.375	18.125	2.236
34	Hue	107.600	16.460	108.875	15.125	1.050	108.625	15.625	1.540
35	Hung Yen	106.050	20.646	106.375	20.375	0.998	106.375	20.375	1.758
36	Kon Tum	108.008	14.350	106.375	15.375	0.718	107.875	12.875	0.809
37	Lai Chau	103.310	22.368	105.375	22.375	0.746	109.625	21.875	0.826

38	Lang Son	106.760	21.850	105.375	20.875	0.523	106.125	20.375	0.934
39	Lao Cai	104.148	22.338	107.875	22.125	0.501	105.125	21.375	0.822
40	Long Khanh	107.211	10.951	98.875	8.125	0.838	122.125	10.375	1.646
41	Long Xuyen	105.435	10.386	100.125	6.125	0.789	100.125	6.375	1.797
42	Mong Cai	107.966	21.524	110.125	21.375	1.003	110.625	19.625	1.442
43	My Tho	106.360	10.360	98.875	8.125	0.984	100.125	6.375	1.538
44	Nam Dinh	106.177	20.430	106.375	20.375	1.040	106.125	20.125	1.801
45	Nha Trang	109.190	12.250	108.625	15.625	1.160	118.375	9.125	1.610
46	Ninh Binh	105.920	20.210	106.375	20.375	1.006	106.125	20.125	1.722
47	Phan Rang - Thap Cham	108.988	11.560	109.125	14.125	0.982	122.375	18.375	1.195
48	Phan Thiet	108.100	10.928	104.875	9.625	0.541	123.625	9.625	1.390
49	Phu Ly	105.910	20.545	106.125	20.375	0.983	110.375	20.375	1.596
50	Phuc Yen (Vinh Phuc)	105.705	21.237	105.625	21.125	1.115	110.125	20.375	1.797
51	Pleiku	108.000	13.983	107.625	13.625	0.277	120.125	15.125	0.907
52	Quang Ngai	108.790	15.120	108.875	15.125	1.440	118.625	9.375	2.117
53	Quy Nhon	109.220	13.780	108.625	15.625	1.220	122.375	18.125	1.640
54	Rach Gia	105.080	10.012	100.125	6.375	0.913	99.875	6.375	1.907
55	Sa Dec	105.756	10.290	100.125	6.125	0.803	100.125	6.375	1.936
56	Sam Son	105.899	19.733	105.875	19.375	1.154	110.625	20.375	1.808
57	Soc Trang	105.970	9.600	100.125	6.125	0.750	100.125	6.375	1.810
58	Son La	103.918	21.325	101.375	20.875	0.829	95.875	23.875	0.848
59	Song Cong	105.565	21.749	105.625	21.125	0.844	111.375	21.375	1.479
60	Tam Diep	108.138	14.041	106.125	15.375	0.872	105.125	14.375	0.806
61	Tam Ky	108.474	15.573	108.875	15.125	1.224	108.625	15.625	1.910
62	Tan An (Long An)	106.405	10.538	100.125	6.375	0.793	100.125	6.375	1.739
63	Tay Ninh	106.131	11.375	99.625	7.125	0.814	99.625	7.125	1.852
64	Thai Binh	106.340	20.450	105.875	19.625	1.171	110.625	20.375	1.872
65	Thai Nguyen	105.848	21.594	105.625	21.125	0.820	111.375	21.375	1.473
66	Thanh Hoa	105.770	19.800	106.875	20.625	1.090	110.625	20.375	1.700
67	Thu Dau Mot	106.650	10.980	100.125	6.375	0.776	122.125	10.375	1.783
68	Tra Vinh	106.349	9.933	100.125	6.375	0.763	123.875	7.625	1.976
69	Tuy Hoa	109.320	13.095	101.625	6.875	1.403	104.125	2.875	1.864
70	Tuyen Quang	105.214	21.823	105.375	21.125	0.723	109.875	21.125	1.421
71	Uong Bi	106.770	21.034	105.625	19.625	0.905	110.375	20.375	1.387
72	Vi Thanh (Hau Giang)	105.470	9.784	100.125	6.125	0.805	100.125	6.125	1.721
73	Viet Tri	105.401	21.322	105.625	21.125	1.041	110.375	20.375	1.619
74	Vinh	105.690	18.670	106.875	17.375	0.880	106.875	17.375	1.470
75	Vinh Long	105.972	10.253	100.125	6.125	0.803	100.125	6.375	1.936
76	Vinh Yen (Vinh Phuc)	105.604	21.308	105.625	21.125	1.065	107.875	20.875	1.648
77	Vung Tau	107.080	10.345	99.625	6.875	0.948	122.375	9.625	2.167
78	Yen Bai	104.911	21.723	105.125	21.375	0.914	110.125	20.625	1.700

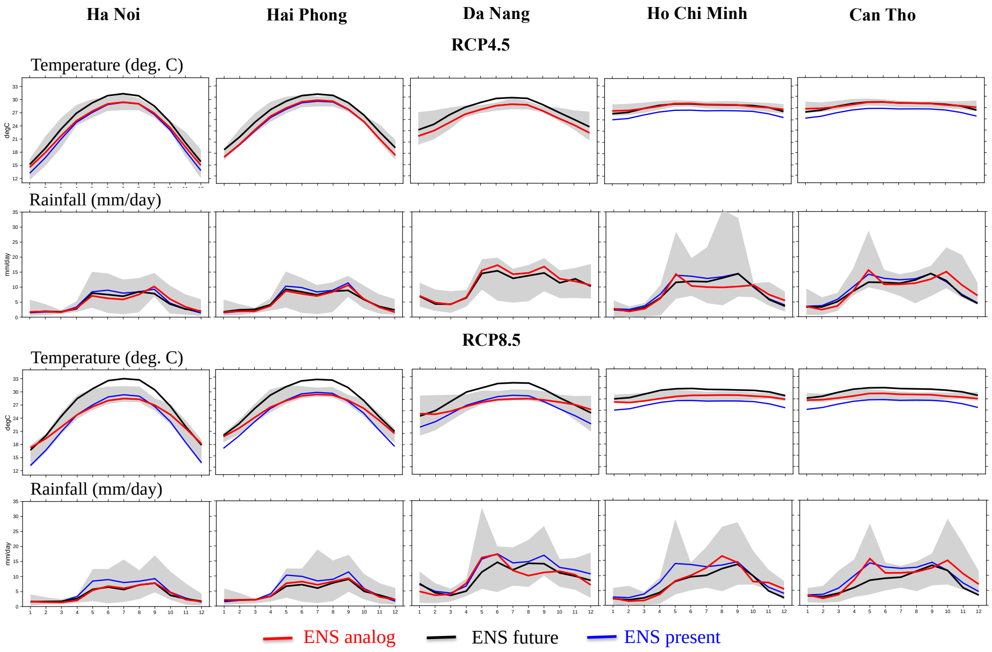

Figure 3. Seasonal cycles of temperature and precipitation of the five central cities (Ha Noi, Hai Phong, Da Nang, Ho Chi Minh and Can Tho) in Viet Nam. Blue and black lines show the present and future projected cycles of a reference site, respectively. Red lines represent the present cycles of the respective best analog location with the ENS experiment. Grey shading displays the value range of the 6 RCMs at the best analog location.

Figure 3 describes the future seasonal cycles of temperature and precipitation of the five central cities (black lines), which generally fit well with the present cycles of the analog locations (red lines). There is a better similarity for temperature than precipitation, and for the RCP4.5 than the RCP8.5. The future precipitation in Ho Chi Minh and Can Tho is not in good agreement with the present one at the analog locations under both the scenarios. This is also appropriate for Da Nang under the RCP8.5 (Figure 3). The results shown in Figure 3 are in line with those shown in Figure 2c, i.e. the distances between Ho Chi Minh and Can Tho and their analog locations are large for both the RCP4.5 and the RCP8.5.

3.2. Disappearing climate in Viet Nam

The land fractions of disappearing climate in Viet Nam are 0.66%, 1.75% and 2.39% for the CNRM, ECEA and ENS experiments under the RCP8.5, respectively. This means that we can almost find a location within the SEA region at which its projected future climate is close to the present climate of a given place in Viet Nam. The present climate in only a few small parts in the Southern Viet Nam and the Central Highlands of Viet Nam (red parts in Figure 4) is projected to disappear in SEA in the future. This agrees with the results of *Williams et al.* [2007] [5], which showed that disappearing climate located in the mountainous tropical areas. The good-analog percentage is high (~80% - 90%) under the RCP4.5 and lower (~53% - 62%) under the RCP8.5. The poor-analog percentage accounts for 37% - 44% of the Viet Nam land under the RCP8.5, which mainly lies in the Central and the Southern Viet Nam (Figure 4). This indicates that the warmer regions at present tend to be poor analog or disappearing climate locations in the future while the cooler ones (e.g. the Northern Viet Nam) show the good-analog characteristic.

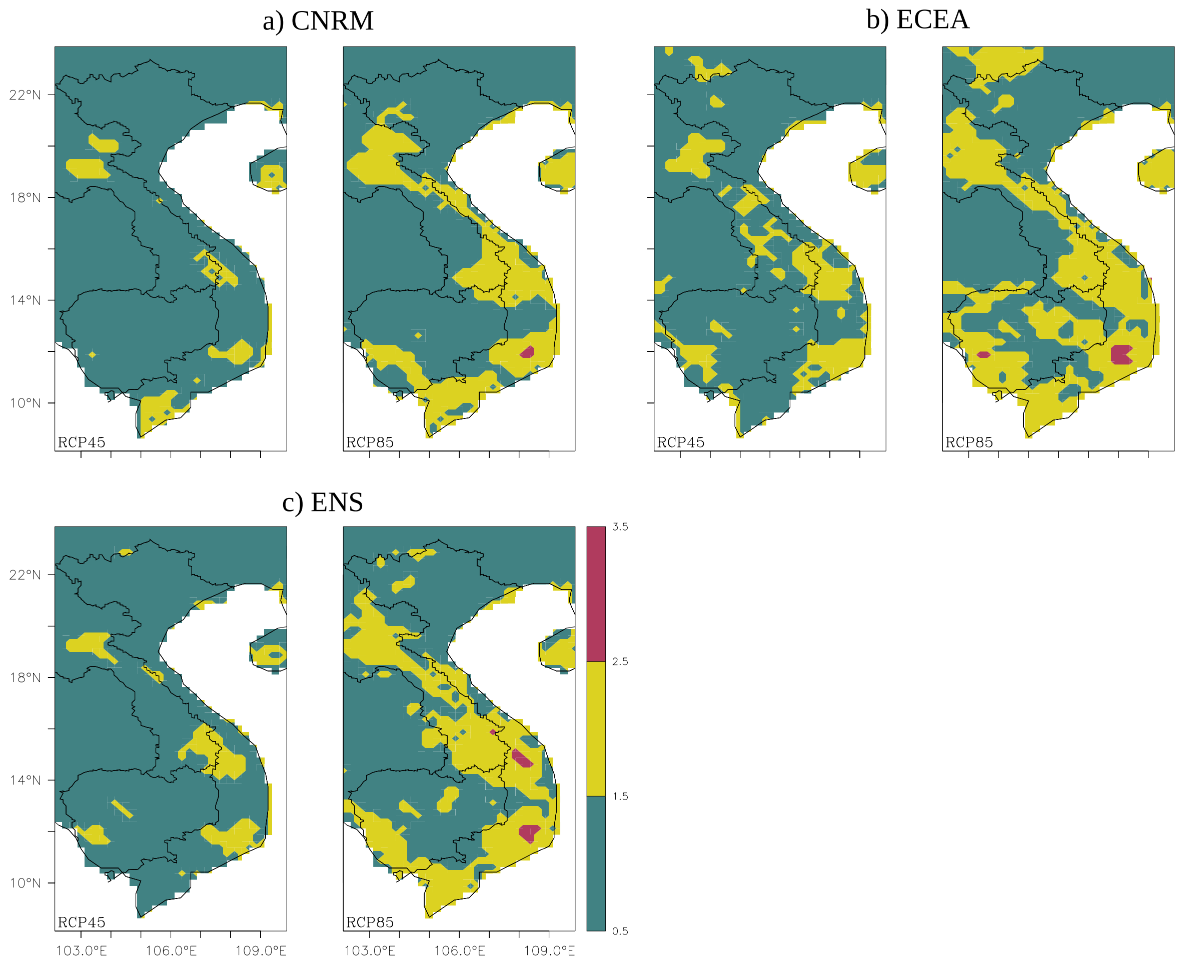

Figure 4. Locations of good analog (green), poor analog (yellow), and disappearing climate (red) in Viet Nam. Results are obtained under the RCP4.5 and RCP8.5 scenarios at the end of the 21st century with the a) CNRM, b) ECEA and c) ENS experiments.

Table 2. Land ratio of disappearing climate, poor- and good-analogs within the Viet Nam domain projected from the CNRM, ECEA and ENS experiments for the RCP4.5 and RCP8.5 scenarios at the end of the 21st century

Experiment	Scenarios	Disappearing (%)	Poor-analog (%)	Good-analog (%)
CNRM	RCP45	0.00	11.79	88.21
	RCP85	0.66	37.93	61.41
ECEA	RCP45	0.00	23.15	76.85
	RCP85	1.75	44.33	53.92
ENS	RCP45	0.00	13.88	86.12
	RCP85	2.39	40.72	56.89

4. Conclusion

The study used the model data from six downscaled climate experiments and their ensemble product, which were conducted under the framework of the SEACLID/CORDEX-SEA project. The results showed the climatic relocations of 78 cities in Viet Nam in the future under the RCP4.5 and RCP8.5 scenarios, which generally exhibited a southward tendency. The climate distance under the RCP8.5 was larger than that under the RCP4.5. The climate analog locations of Ha Noi, Hai Phong and Da Nang were closer to their original cities than those of Ho Chi Minh and Can Tho. In the future, about 2.39% of Viet Nam land, mainly located in the Central Highlands and Southern Viet Nam, was projected to experience disappearing climate by the ENS experiment under the RCP8.5. The poor-analog locations are prominent in the Central and Southern Viet Nam while the good-analog areas are mainly in the Northern Viet Nam. The results of the present study would provide worthwhile inputs for further climate change impact assessment and adaptation research.

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