

Estimating sea level rise for Vietnam East Sea

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Abstract:

Sea level rise for Vietnam East Sea in the 21st century was determined under both RCP 4.5 and RCP 8.5 scenarios. Changes in sea level of the Vietnam East Sea due to dynamic and thermosteric processes was estimated using results of different Atmosphere - Ocean General Circulation Model (AOGCMs) under the prescribed method in the IPCC's Fifth Assessment Report (AR5). Changes in sea level due to ice melting and land water storage was determined using a transfer function for global water balance based on the contribution of each sea level rise contributing component for different regions. Changes in sea level as a result of the vertical motion of the Earth's crust due to changes in the Earth's cryosphere was determined using the ICE5G models. The results showed that for the RCP 8.5 scenario, by the end of the 21st century, the average sea level rise is 76 cm, with estimated values varying between 52 cm and 106 cm at the 5% and 95% confidence intervals, respectively. For the RCP 4.5 scenario, the average sea level rise is 52 cm, with values of 33 cm and 75 cm at the 5% and 95% confidence interval, respectively. The sea level rise scenario determined for the Vietnam East Sea is slightly higher in comparison with the globally estimated results in AR5.

Keywords: climate change, sea level rise scenarios, Vietnam East Sea.

Classification number: 6.2

Introduction

Global average sea level has increased significantly between 1920 and 1950; especially after 1993 until now [1]. The significant increase after 1993 was also identified from the assessment of sea level using satellite data [2]. In Vietnam, tidal gauging data (between 1960 and 2013) showed an increase of sea level along the coast of Vietnam with levels of approximately 3 mm/year. On the other hand, satellite data (1993-2014) implied a sea level increase approximately 3.4

mm/year along the coast and 4.1 mm/year for the entire Vietnam East Sea [3]. The observed trend is slightly higher than the global average value for the same period.

Vietnam is assessed to be among the most severely impacted countries due to climate change and sea level rise. Estimating sea level rise in Vietnam is therefore, form scientific basis for climate change impacts assessment and adaptation measures.

There is a large number of approaches in determining sea level increase worldwide, especially after the publication of IPCC's Fourth Assessment Report (AR4) in 2007. The different studies have assessed the spatial distribution of the contributing components to sea level rise such as the thermosteric process, ice melts or changes in land water storage [1, 4, 5]. Estimated the increase in sea level in each region by assessing the different contributions under 3 emissions scenarios (B1, A1B, and A2) [4]. The thermosteric component was modelled based on CMIP3 while glacier melt component was determined based on the volume approach, and the ice in Greenland and Antarctica was determined based on the estimates from AR4. When accounting for the glacial isostatic adjustment (GIA) from the ICE-5G (VM2) model [6], it was determined that the thermosteric component and glacier melt contributed the most to overall sea level rise, with the thermosteric component being highly variable spatially. Using a different approach, Church came to the conclusion that the difference between sea level rise at the regional and global scale is due to the dynamical changes in the different regions as a result of water advection, temperature, salinity and wind circulation [1]. Slangen extended the research for the other contributing components using outputs of CMIP5 models [5]. In particular, the effects of the atmospheric loading (due to

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changes in the atmospheric circulation and changes in the column-integrated atmospheric moisture content) was estimated using the method proposed by Stammer & Huttermann [7]. The glacier melt component was determined using simulated temperature and precipitation data. The surface mass balance component of ice in Greenland and Antarctica was determined based on its relationship with the projected CMIP5 global mean surface temperature change using two total least squared fits [8]. The land water storage component was determined using data from Wada, et al [9], based on the difference between groundwater extractions and recharge using two different socio-economic projections in combination with population change. The method developed by Church and Slangen has been widely adopted for a number of nations in developing their own sea level rise scenarios [1, 5]. This includes Australia [10], Singapore [11], and the Netherlands [12].

This study applies the aforementioned approaches as well as results from IPCC's AR5 to estimate the sea level rise in Vietnam East Sea. The estimated sea level rise results were compared with observed data including data from tidal gauges and satellite data to assess reliability. Uncertainty in the total sea level rise estimation was also determined through determining uncertainties of each individual contributions.

Methodology

Estimating sea level rise contributing components

The method to determine sea level rise for Vietnam was developed based on IPCC's AR [1, 5], and sea level rise scenarios from Australia, the Netherlands and Singapore. The increase in sea level was determined as a sum of the contributing components in the region, this includes: sea level rise due to (i) thermosteric processes, (ii) melting of glaciers, (iii) ice mass balance in Greenland (GSMB), (iv) ice

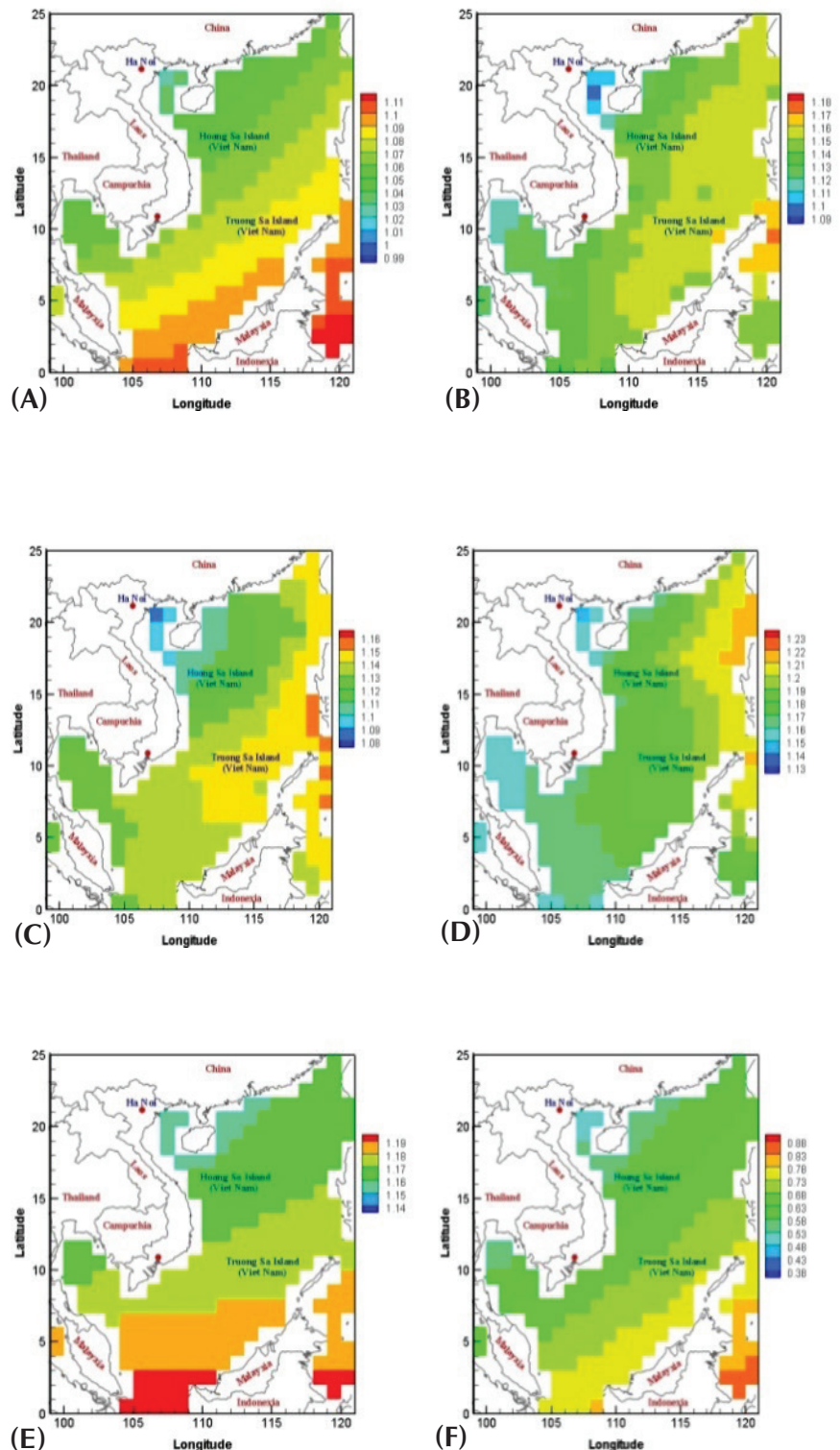


Fig.1. Spatial fingerprints of changes in: (A) Glaciers; (B) Surface mass balance in Greenland; (C) Surface mass balance in Antarctica; (D) Ice sheet dynamic in Greenland; (E) Ice sheet dynamic in Antarctica and (F) Land water storage.

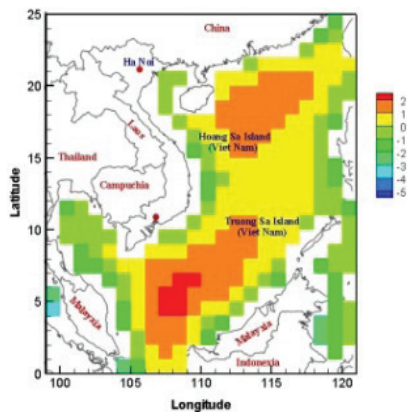


Fig. 2. The estimates of glacial isostatic adjustment from ICE5G model.

mass balance in Antarctica (ASMB), (v) ice sheet dynamic in Greenland (GDIS), (vi) ice sheet dynamic in Antarctica (ADIS), (vii) land water storage, and (viii) glacial isostatic adjustment (GIA).

Sea level rise due to dynamic and thermosteric components were determined using outputs from 21 Atmosphere- Ocean General Circulation Model (AOGCMs) published by IPCC. Both of these data were downloaded at monthly resolution and on the native model grids.

Other components such as glaciers, surface mass balance in Greenland and Antarctica; ice sheet dynamic in Greenland and Antarctica; land water storage; and glacial isostatic adjustment were determined based on the global mean time series published in IPCC's AR5 [13] and downscaled to the spatial fingerprint according to Slangen (Fig. 1A, 1B, 1C, 1D, 1E and 1F) [5].

Sea level change due to changes in the vertical motion of the Earth's crust in response to changes in the cryosphere were determined from the ICE5G models by Peltier [6] (Fig. 2).

Combining uncertainty of sea level rise

Level of uncertainty of the total sea level rise was determined based on the sum of the uncertainties of each individual component. For the dynamic and thermosteric components,

uncertainty was determined based on the models utilized. For the changes in surface mass balance, it is assumed that the component is heavily influenced by the magnitude of climate change. For the glaciers, uncertainty was determined based on IPCC [12].

Level of uncertainty of each component (except for the glacial isostatic adjustment) has a central estimate (median), an upper and lower estimates which are indicative of the 5th and 95th percentiles of the distribution and/or the likely range assessed in the IPCC's AR5 [12]. A sum of the estimates of the uncertainty of each component was determined so that a total value of the possible variation of the sea level rise for Vietnam could be calculated.

ice sheet in Antarctica; and dynamic ice sheet in Greenland respectively.

Results

Comparing the results with observed data

Figure 3 depicts the time series of sea level rise for the standard deviation of the average sea level in 14 tidal gauging stations (Cua Ong, Co To, Bai Chay, Hon Dau, Con Co, Son Tra, Quy Nhon, Phu Quy, Vung Tau, DK12, Con Dao, Tho Chu, and Phu Quoc) along the coast and islands of Vietnam, satellite data, and historical simulations of AOGCMs. It can be seen that for the period 1986-2013, computed trend of changing sea level in the Vietnam East Sea is in line with both observed data

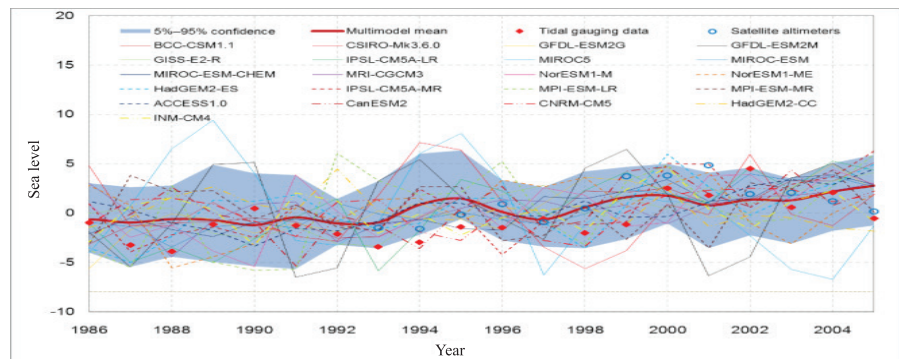


Fig. 3. Comparing the ensemble mean sea level with observed data for the period 1986-2005.

Level of uncertainty in the calculation of the total sea level rise was determined assuming that all contributions have a strong correlation with global air temperature and are correlated uncertainties; therefore can be added linearly as follows [1]:

$$\sigma_{tot}^2 = (\sigma_{steric/dynamic} + \sigma_{smb_a} + \sigma_{smb_g})^2 + \sigma_{glac}^2 + \sigma_{LW}^2 + \sigma_{dyn_a}^2 + \sigma_{dyn_g}^2$$

In which: σ_{tot} is the total uncertainty of sea level; $\sigma_{steric/dynamic}$, σ_{smb_a} , σ_{smb_g} , σ_{glac} , σ_{LW} , σ_{dyn_a} , σ_{dyn_g} are the uncertainties of the thermosteric, dynamic sea level, surface mass balance in Antarctica, surface mass balance in Greenland, glaciers, land water storage, dynamic

from the gauging stations and satellite. The rate of sea level change observed from the gauges is approximately 2.8 mm/year, slightly higher than computed results (approximately 2.4 mm/year). In general, for most of the analyzed period, average sea water level at the gauging stations as well as satellite data are within the 5-95% confidence levels of the modelled results.

The correlation coefficient of the average historical sea level data at the gauges and from the ensemble mean of the models (between 1986-2014) is 0.76; while the correlation coefficient of the satellite data and ensemble mean

of the models between 1993 and 2006 is 0.8 (Fig. 4A, 4B). The high level of agreement between simulation and observation data implies a high reliability level of the model in estimating sea level in the future for the Vietnam East Sea.

Estimating sea level rise for the Vietnam East Sea

Sea level rise in late 20th century is a result of global warming due to climate change [1]. Although the increasing trend of global air temperature in the beginning of the 21st century has slightly

diminished, the trend of sea level rise continues due to thermosteric and ice melting processes.

Figure 5A shows the estimated regional sea level rise for Vietnam East Sea. The estimated results imply that on both global and Vietnam East Sea regional scale, the rate of sea level rise in the 21st century is higher than the 20th century due to the increase in radiative forcing from increased greenhouse gas emissions. In the first decades of the 21st century, the rate of sea level rise

for the RCP 4.5 and RCP 8.5 scenarios are similar. However, this similarity no longer holds after 2040 with sea level for the two scenarios differing greatly. For the RCP 8.5 scenario, the regional sea level rise of Vietnam East Sea is 76 cm, with an upper estimate (95% quantile) of 106 cm and lower estimates (5% quantile) of 52 cm. For the RCP 4.5 scenario, at the end of the 21st century, the total sea level rise is 55 cm, with an upper estimate (95% quantile) of 81 cm and lower estimate (5% quantile) of 34 cm (Fig. 4A, Table 1).

In late 21st century, for the RCP 8.5 scenario, dynamic and thermosteric processes contributes most significantly to sea level rise, corresponding to a value of 33 cm, up to 44% of the total sea level rise. This is followed by sea level rise due to glaciers of 19 cm, up to 26% of the total. Similarly, ice melt in Greenland (both surface mass balance and dynamic ice sheet) accounts for 17 cm of sea level rise, equivalent to 23% of the total rise. Sea level rise due to ice in Antarctica contributes 5 cm, accounting for 6% of the total sea level rise. Surface land storage changes contribute an increase of 3 cm, approximately 4% of the total sea level rise. The total sea level rise in Vietnam

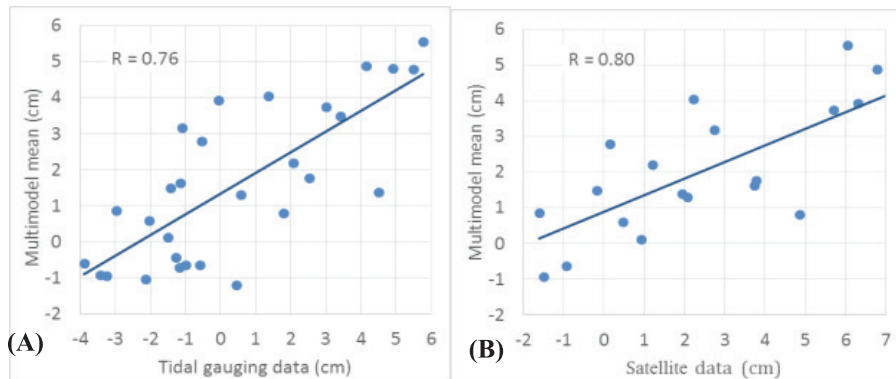


Fig. 4. Correlation between ensemble mean sea level of models and observed data from (A) tidal gauging stations in the Vietnam East Sea for the period of 1986-2014 and (B) satellite data for the period 1993-2006.

Note: Tidal gauging data (red diamond shaped), satellite altimeters (blue circle), historical simulations of AOGCMs (dotted lines), multimodel mean (red bold line), confidence interval 5-95% (grey shaded area).

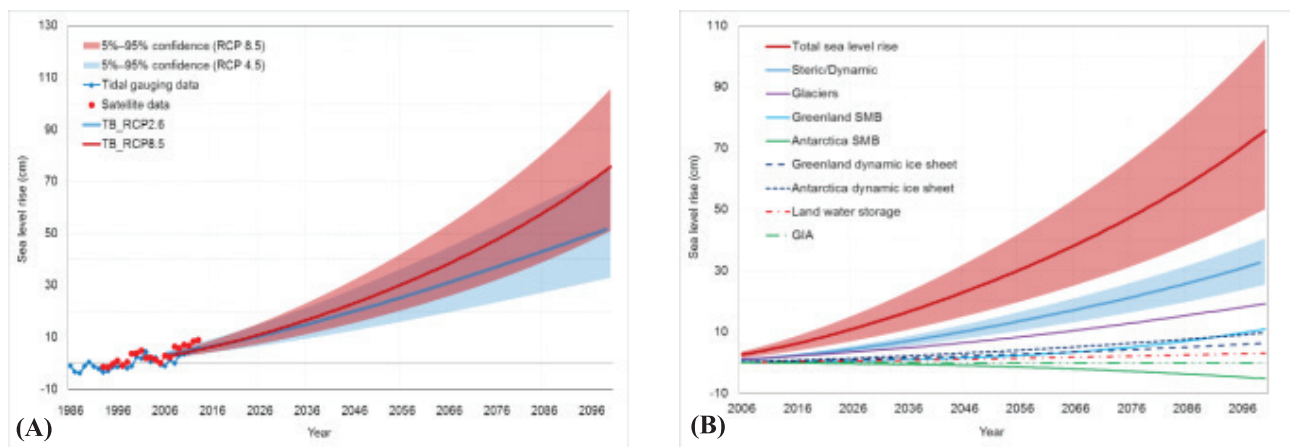


Fig. 5. Observed sea level data (red diamond shaped), estimated sea level rise under RCP 4.5 with likely range (blue) and RCP 8.5 with likely range (red) relative to the 1986-2005 period (A), and the contributions of sea level rise under RCP8.5 (B) in Vietnam East Sea.

Table 1. Estimated sea level rise and its contributions with likely ranges in the late 21st century with respect to a baseline period of 1986-2005 in Vietnam East Sea and globally (according to Table 13.5 from AR5, [1])

Component	RCP 4.5		RCP 8.5	
	Vietnam	Global	Vietnam	Global
Total sea level rise	52 [33÷75]	53 [36÷71]	76 [52÷106]	71 [52÷98]
Dynamic/ Thermosteric	21 [15÷34]	19 [14÷23]	33 [25 ÷ 40]	28 [21÷33]
Glaciers	14 [8÷20]	12 [6÷19]	19 [8÷25]	16 [9÷23]
Greenland Surface mass balance	5 [2÷10]	4 [1÷9]	11 [7÷20]	10 [3÷16]
Greenland Dynamic Ice sheet	5 [2÷7]	4 [1÷6]	7 [4÷10]	5 [2÷7]
Antarctic Surface mass balance	-3 [-4÷0]	-2 [-5÷-1]	-5 [-8÷-2]	-4 [-7÷-1]
Antarctic Ice sheet dynamic	10 [3÷18]	7 [-1÷16]	10 [3÷19]	8 [-1÷16]
Land water storage	3 [0÷8]	4 [-1÷9]	3 [0÷8]	4 [-1÷9]
GIA	-0.1	N/A	-0.2	N/A

East Sea and the separate contributions are similar in value yet slightly higher when compared to the global mean sea level rise. In particular, global mean sea level rise and its individual contributing component value of glaciers, ice melt in Greenland, ice melt in Antarctica and changes in land water storage are: 71 cm, 28 cm, 15 cm, 4 cm, and 4 cm respectively. Lastly, the glacial isostatic adjustment component contributes negatively to the increase in Vietnam East Sea (-0.2 cm) (Fig. 5B, Table 1).

The spatial distribution of sea level rise in late 21st century with respect to a baseline period of 1986-2005 for the RCP 4.5 and RCP 8.5 scenarios are depicted

in Fig. 5. Unsurprisingly, sea level rise for the RCP 8.5 scenario is higher than RCP 4.5 scenario. For both scenarios, in the central part of the Vietnam East Sea including Hoang Sa (Parcel) and Truong Sa (Spartly) islands, the sea level rise is significantly higher when compared to other areas. This is followed by the southern part of Vietnam East Sea. The area with lowest level of rise is the Northern Gulf (a.k.a. Gulf of Tonkin) and northern Vietnam East Sea. When only the coast of Vietnam is considered, increase in sea level in southern provinces from Da Nang southward is higher than that of the north. This result is compatible with the prognosis of sea level change based on the historical data

from gauging stations in this region [5].

Conclusions

Sea level rise in Vietnam was estimated in the 21st century for the RCP 4.5 and RCP 8.5 scenarios. The data and method used was based on data and method recommended by IPCC's AR5 [1]. Global sea level rise estimates were downscaled for Vietnam's coast through estimating the spatial distribution of the sea level rise contributions of ice melt and land water storage [5]. The changes in regional sea level due to dynamic and thermosteric processes were determined from 21 AOGCMs. Changes in sea level due to the glacial isostatic adjustment were determined based on ICE5G data (Peltier, 2004). The results showed:

- Estimated sea level rise in Vietnam by the late 21st century is slightly higher than global values determined in IPCC's AR5 (Fig. 6 A and Fig. 6B).

- In the first decades (up to 2040), there is no considerable difference between estimated sea level for the RCP 4.5 and RCP 8.5 scenarios. Therefore, up to this time period, the uncertainty of the estimated sea level rise does not depend on the greenhouse gas concentration scenario but only on the method of determining sea level rise.

- At the end of the century, there is a significant difference in estimated sea level rises for the RCP 4.5 and RCP 8.5 scenarios. Therefore, the uncertainty of the estimation depends both on the Representative Concentration Pathways and the method to determine sea level rise.

- The average sea level in the 21st century will consequently increase the extremities of sea level in Vietnam. This leads to an increased risk of natural disasters such as flooding due to storm surges, tidal activity.

- Sea level rise due to geological subsidence processes was not included in this study. Therefore, future research in determining regional sea level rise should also estimate this contribution.

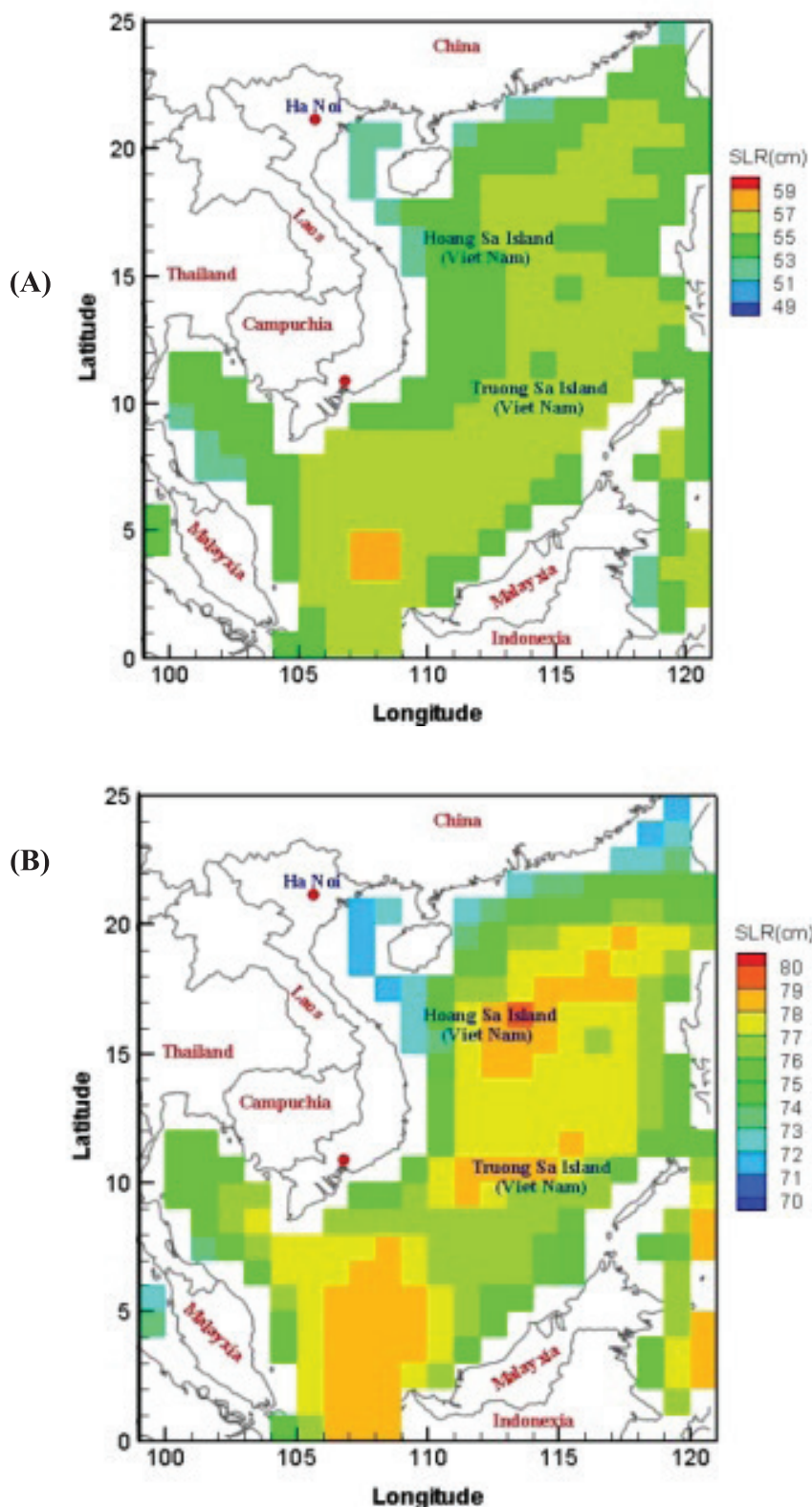


Fig. 6. Spatial distribution of sea level rise in the Vietnam East Sea in the late 21st century relative to the 1986-2005 period for the RCP 4.5 (A) and RCP 8.5 (B).

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