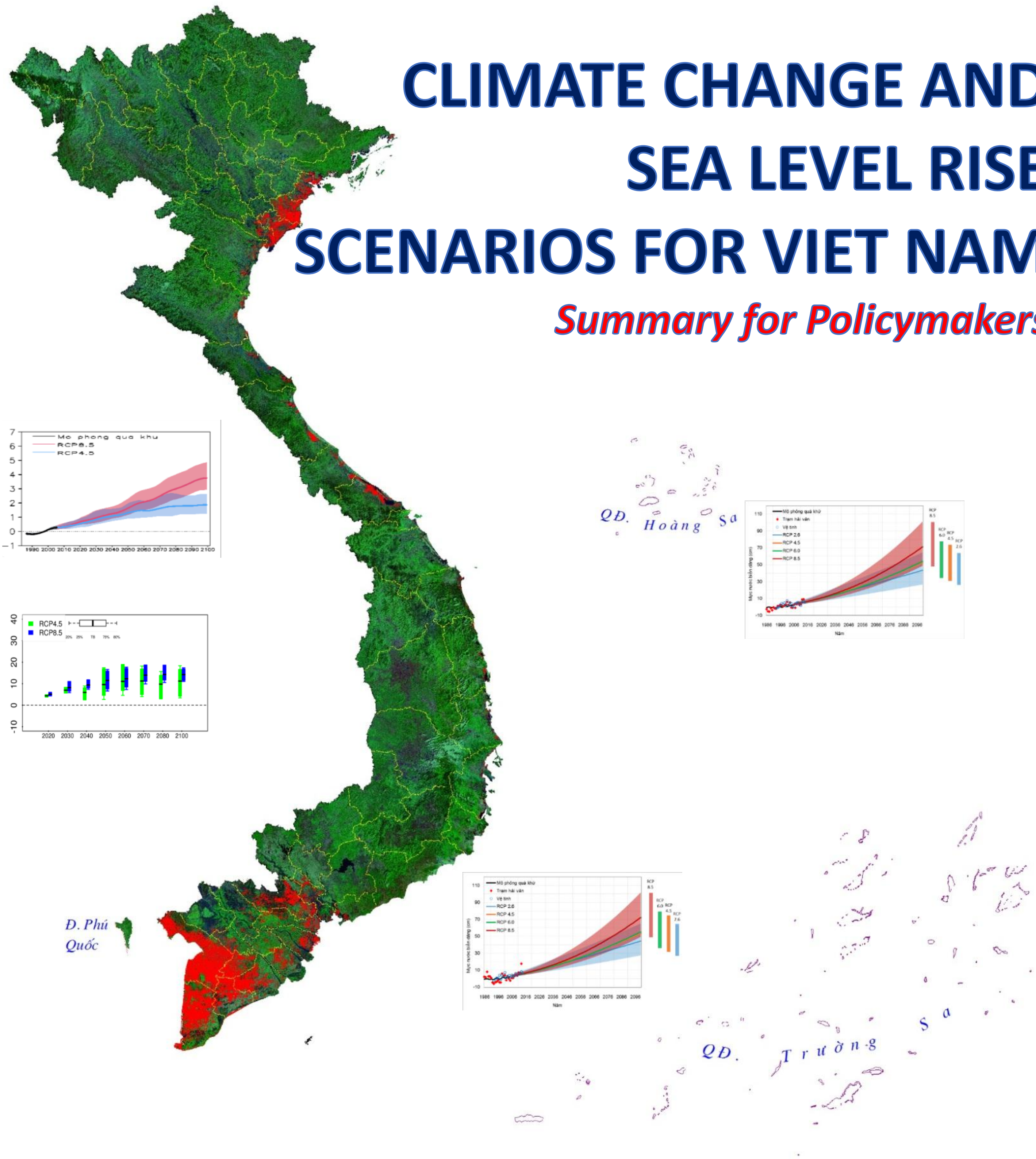
MINISTRY OF NATURAL RESOURCES AND ENVIRONMENT

CLIMATE CHANGE AND SEA LEVEL RISE SCENARIOS FOR VIET NAM

Summary for Policymakers



HÀ NỘI, 2016

CLIMATE CHANGE AND SEA LEVEL RISE SCENARIOS FOR VIET NAM

SPM **Summary for policymakers**

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I. Introduction

Climate change and sea level rise scenarios were released by the Ministry of Natural Resources and Environment for the first time in 2009 based on the synthesis of domestic and international researches in order to provide information to ministries, sectors and localities for climate change impact assessments, and contribute to the development of strategies and socio-economic development plans for the period 2010-2015. The boundaries of the scenarios were only for 7 climate regions and the coastal areas of Viet Nam.

In 2011, the National Strategy on Climate Change was issued, determining the priority targets for each period, the Ministry of Natural Resources and Environment has updated the climate change and sea level rise scenarios based on data sources, specific climatic conditions of Viet Nam and the results from climate models. The scenarios were for each decade of the 21st century, in which, the climate change scenarios were downscaled at provincial level, and the sea level rise scenarios were for coastal areas of Viet Nam.

Scenarios of climate change and sea level rise for Viet Nam are updated in 2016 following the roadmap defined in the National Strategy on Climate Change, providing the latest information on the trends of climate change and sea level rise in recent years, as well as climate change and sea level rise scenarios for Viet Nam in the 21st century.

The climate change and sea level rise scenarios are built upon the 5th assessment report (AR5) of the Intergovernmental Panel on Climate Change (IPCC); observed hydro-meteorological and sea level data till the year 2014, and digital national topographic maps updated till 2016; recent changing trend of climate and sea level in Viet Nam; global and regional climate models with high resolution for Viet Nam, and coupled atmosphere-ocean models; the studies derived from the Institute of Meteorology, Hydrology and Climate Change (IMHEN), the Viet Nam Panel on Climate Change (VPCC), and other research institutions of Viet Nam; research results in the framework of cooperation of IMHEN with the United Nations Development Programme through CBCC and CBICS projects; Commonwealth Scientific and Industrial Research Organisation (CSIRO); Climate Research Centre of Norway (Bjerknes); Meteorological Agency of the United Kingdom (UK MetOffice); and Meteorological Research Institute of Japan (MRI).

Climate change scenarios take into account the change of climate variables in the 21st century, namely, temperature (average annual temperature, seasonal temperature and temperature extremes), rainfall (annual rainfall, seasonal rainfall and rainfall extremes), summer monsoon and some extreme events (typhoons and tropical depressions, damaging cold days, the number of hot days and occurrence of droughts). Twenty-year average changes for the early 21st century (near term, 2016 - 2035), for the mid-21st century (mid-term, 2046 - 2065) and for the late 21st century (long term, 2081 - 2100) are given, relative to a reference period of 1986 - 2005.

Sea level rise scenarios take into account the trend of average sea levels due to climate change (thermal and dynamical expansion, thaw of glaciers, surface mass balance of Antarctic and Greenland ice sheets, dynamics of Antarctic and Greenland ice sheets, changes of water reserves on continents, and isostatic adjustments of ice sheets).

The inundation maps are based on the average sea level rise due to climate change. Other dynamical factors such as tectonic uplift and subsidence, topographical changes, land subsidence due to groundwater extraction, coastline change, influence of tides, storm surges, monsoon induced sea level rise, impact of hydropower cascade, and saline intrusion have not been considered in this scenarios. Transportation works and irrigation structures such as sea dykes and river dykes, embankments, roads, and others have not been considered when mapping inundation due to sea levels rise caused by climate change.

II. Changes in global and Viet Nam climate

2.1. Changes in global climate

1) Observed changes in global climate and sea level rise

The main manifestation of global climate change and sea level rise (IPCC, 2013):

Box 1. Observed changes in global climate

- Global average surface temperature increases by about 0.89°C (0.69÷1.08°C) in the period 1901-2012.
- The rate of global average sea level rise is of about 1.7mm/year in the period 1901-2010, about 3.2mm/year in the period 1993-2010.

- The globally averaged combined land and ocean surface temperature data as calculated by a linear trend show a warming of 0.89°C (0.69÷1.08°C) over the period 1901-2012.

- The global average temperature tends to increase more substantially in recent decades. The average rate is about 0.12°C/decade in the period of 1951-2012.

- Averaged over the mid-latitude land areas of the Northern Hemisphere, precipitation has increased since 1901.

- It is very likely that the number of cold days and nights has decreased and the number of warm days and nights has increased on the global scale since about 1950.

- Over the period from 1901 to 2010, the global mean sea level rose by 0.19m (0.17 ÷ 0.21). It is very likely that the global averaged sea level rise was 1.7mm/year (1.5 ÷ 1.9) between 1901 and 2010, and 3.2mm/year (2.8 ÷ 3.6) between 1993 and 2010.

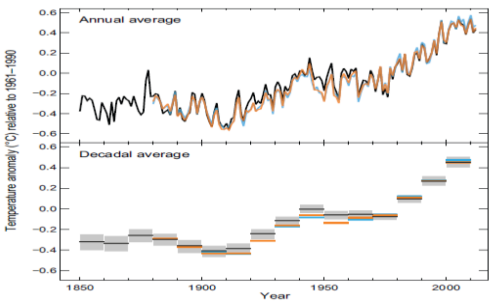


Figure 1. Temperature deviation (1850-2012) compared to the period 1961-1990
(IPCC, 2013)

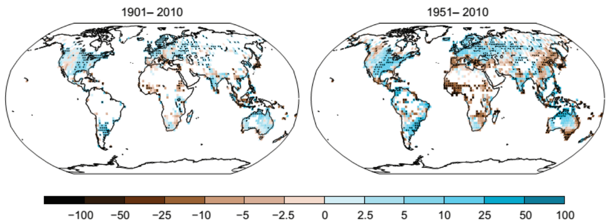


Figure 2. Change of annual rainfall
(IPCC, 2013)

2) Global climate change and sea level rise scenarios

Projected trends in global climate and sea level rise are as follows (IPCC, 2013):

- Temperature tends to increase on global scale with the highest increase at the poles. Increase of global mean surface temperatures for 2081-2100 relative to 1986-2005 is projected to be likely in the ranges derived from the concentration-driven CMIP5 model simulations, that is, 1.1÷2.6°C (RCP4.5), and 2.6÷4.8°C (RCP8.5). The rising temperatures in winter would likely be greater than in the summer. However, the summer temperatures in Viet Nam and the East Sea tends to rise more than the temperatures in winter.

- The high latitudes are likely to experience an increase in annual mean precipitation by the end of this century under the RCP8.5 scenarios. In many mid-latitude and subtropical dry regions, mean precipitation will likely decrease by the end of this century under the RCP8.5 scenarios. However, rainfall is expected to increase in winter and summer in many regions of Viet Nam (while AR4 (2007) showed a decrease in winter precipitation and an increase in summer).

Box 2. Global climate change and sea level rise scenarios

- Global average surface temperatures by the late 21st century will likely increase about 1.1÷2.6°C (RCP4.5), 2.6÷4.8°C (RCP8.5) compared to the period of 1986-2005.
- The high latitudes are likely to experience an increase in annual mean precipitation. In many mid-latitude and subtropical dry regions, mean precipitation will likely decrease.
- Global average sea level will likely rise to 36÷71 cm (RCP4.5), 52÷98 cm (RCP8.5) by 2100, compared to the period of 1986-2005.

- It is very likely that extreme temperatures will have an increasing trend. For the RCP8.5 scenarios, by late 21st century, temperatures of the coldest days will likely increase by about 5÷10°C; temperatures of the hottest days will likely increase by about 5÷7°C; number of frost days will likely decrease; the number of hot nights will increase markedly.

- Precipitation extremes would tend to increase: the annual maximum daily precipitation increases by 5.3%, corresponding to an increased surface temperature of 1°C.

- The amount of ice would have a decreasing trend. For the RCP8.5 scenarios, there would be little ice left at the North Pole by 2100.

- Globally, it is likely that the area encompassed by monsoon systems will increase over the 21st century. The summer monsoon onset dates are likely to become earlier and retreat dates will likely be delayed. Monsoon precipitation is likely to intensify due to the increase in atmospheric moisture.

- There would be no significant changes in intensity of ENSO. The influence of ENSO would tend to shift to the east of the North Pacific and North America.

- The number of weak and normal typhoons would decrease or be unchanged, while the number of strong typhoons would likely increase, resulting in heavy rainfall.

- The rate of sea level rise will likely exceed 2.0mm/year, mainly due to the thermal expansion of water and melting ice from glaciers and mountain peaks. By 2100, the global average sea level would rise 36÷71cm for the RCP4.5 scenarios, and of 52÷98cm for the RCP8.5 scenarios compared to the period of 1986-2005.

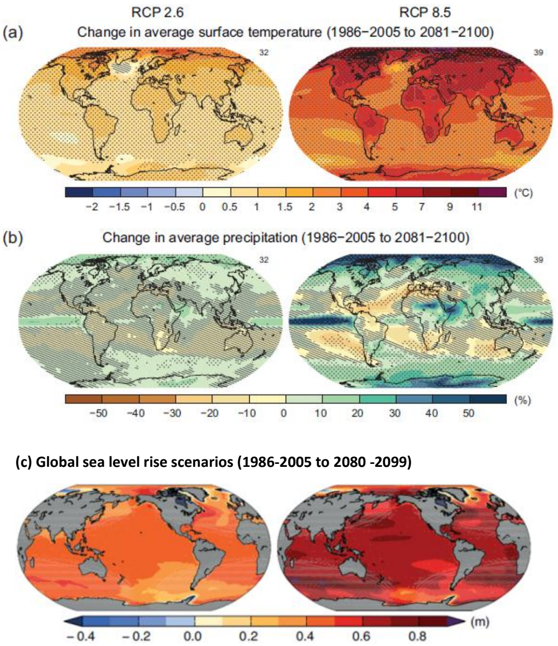


Figure 3. Global climate projection

(IPCC, 2013)

2.2. Observed changes in climate and sea level in Viet Nam

1) Observed changes in climate in Viet Nam

In the period of 1958-2014, temperatures show increasing trends in most observed stations. The annual average temperatures increased by about 0.62°C for the whole country, (about 0.10°C/decade). Annual rainfall had decreasing trends in the northern regions (from 5.8%÷12.5% over 57 years) and increasing trends in the southern region (from 6.9%÷19.8% over 57 years).

The number of typhoons and tropical depressions in the East Sea that directly affected or made landfall in Viet Nam show less change. However, the number of strong typhoons (maximum sustained winds from level 12 (33 m/s) to higher) had a slight upward trend in recent years, typhoon seasons ended later and there was an increased trend of typhoons making landfall in the South.

Daily maximum (Tx) and minimum (Tm) temperatures show increasing trends with the highest rate of up to 1°C/decade. Number of hot days (days with Tx ≥35°C) increased in most regions of the country, especially in the Northeast, the Northern Delta and the Central Highlands with an increase of about 2÷3 days/decade; while number of hot days decreased in some stations in the Northwest, South Central and the South. Number of droughts increased over the country, especially severe droughts. Number of extreme and damaging cold days had a decreasing trend, especially in the last two decades. However, there were some records of extreme and damaging cold days with relatively low temperatures. Extreme rainfall trends varied between climate zones, decreasing in most stations in the Northwest, Northeast, Northern Delta and increasing in a large number of stations in other climate zones.

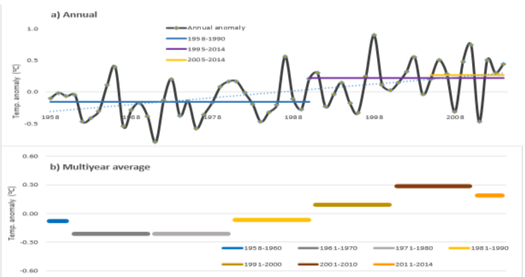


Figure 4. Annual temperature deviation (^{o}C) compared to long-term average

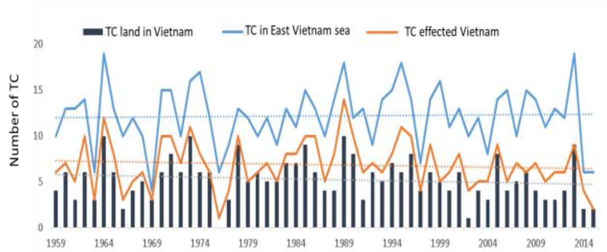
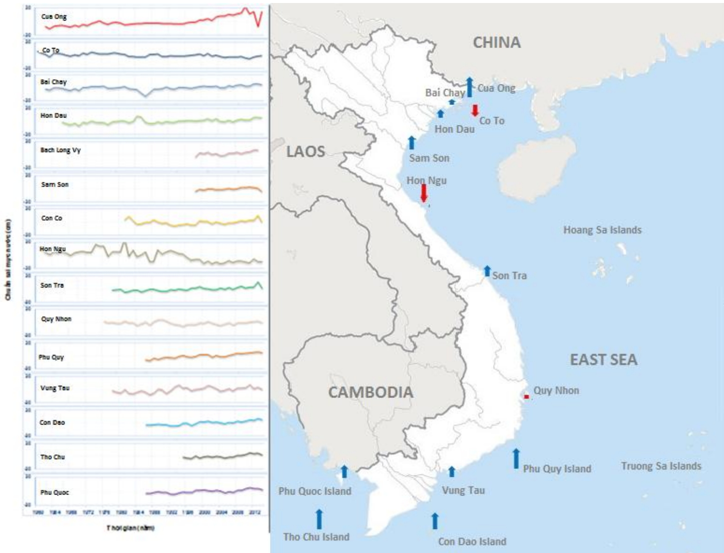


Figure 5. Evolution of typhoons and tropical depressions in the period 1959-2014

Box 3. Observed changes in climate in Viet Nam

- Average annual temperatures increased by 0.62^{o}C in the period 1958-2014, approximately 0.1^{o}C/decade. Temperatures increased by 0.38^{o}C in the last 20 years compared to the period 1981-1990.
- Annual rainfall decreased in the North, while it increased in the South.
- Extreme temperatures increased, but maximum temperatures decreased in some stations in the South.
- Droughts in the dry season occurred more frequently.
- Extreme rainfall decreased in the Northern Delta, increased considerably in South Central and Central Highlands.
- The number of strong typhoons had an increasing trend.
- The number of extreme and damaging cold days decreased, but there were some abnormally cold periods.
- El Nino and La Nina showed stronger impacts to weather and climate of Viet Nam.

2) Observed changes in sea level in Viet Nam



Box 4. Observed changes in sea level in Viet Nam

Sea level at coastal stations in Viet Nam:

+ Increased by about 2.45 mm/year in the period 1960-2014;
+ Increased by about 3.34 mm/year in the period 1993-2014;
+ According to satellite data, sea levels increase by 3.5±0.7 mm/year in the period 1993-2014.

Figure 6. Changes in sea level

Observed data derived from the water level gauging stations along the coast and islands of Viet Nam for the period 1960-2014 show that water levels at most stations had increased trends, the greatest increase was observed in Phu Quy station (5.6 mm/year). Water levels at Hon Ngu and Co To station had decreased trends (5.77 and 1.45 mm/year). Water levels at Con Co and Quy Nhon station had small changes. On average for all stations, sea water level increased about 2.45 mm/year. Water levels increased by about 3.34 mm/year for all stations in the period 1993-2014.

Data acquired from satellites over the period 1993-2014 show that the average sea level over the East Sea increased by 4.05±0.6 mm/year. The average water level over coastal areas in Viet Nam increased by 3.5±0.7 mm/year. The greatest increase in average water level was found along the coast of Central Viet Nam (4 mm/year), especially in the South Central (5.6 mm/year). The lowest increase in average water level was observed in the Northern Gulf coast (2.5 mm/year).

III. Data and methodology

3.1. Data

3.1.1. Climate data

1) Observed climate data

Observed data of 150 meteorological stations for which the time series are long enough (over 30 years) in the meteorological observation network of the National Hydro-Meteorology Service are used for assessing the changes in climate change and building climate change scenarios (Figure 7).

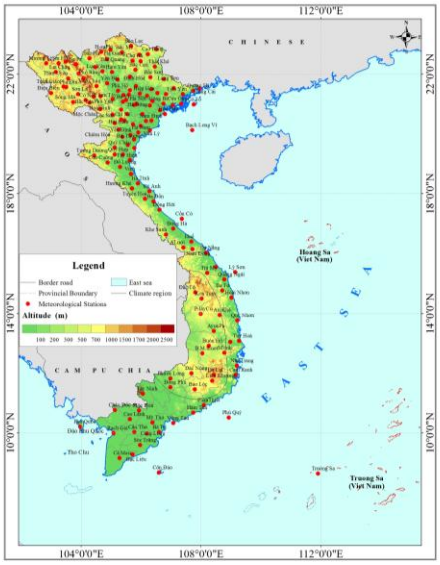


Figure 7. Meteorological stations

2) Results acquired from regional climate models

To assess the changes in climate extremes in the future, the results from numerical models were used including: (i) the AGCM/MRI model from Japan Meteorological Agency (JMA), (ii) the PRECIS model from the UK MetOffice, (iii) the CCAM model from CSIRO - Australia, (iv) the RegCM model from ICTP - Italy and the clWRF model from Santander Meteorology Group - Spain.

3.1.2. Sea water level data

Up to 2014, there are 17 sea water level gauging stations along the coast and islands of Viet Nam. The data series at Truong Sa station is relatively short (13 years) and water level data at the DK I-7 station are not stable because the measuring instruments are fixed on a floating rig (Table 1).

Table 1. Sea water level gauging stations

TT	Station	Time series	Location	TT	Station	Time series	Location
1	Cua Ong	1962-2014	Coast	10	Quy Nhon	1986-2014	Coast
2	Co To	1960-2014	Island	11	Phu Quy	1986-2014	Island
3	Bai Chay	1962-2014	Coast	12	Truong Sa	2002-2014	Island
4	Bach Long Vy	1998-2014	Island	13	Vung Tau	1978-2014	Island
5	Hon Dau	1960-2014	Island	14	Con Đao	1986-2014	Island
6	Sam Son	1998-2014	Coast	15	DK I-7	1992-2014	Floating rig
7	Hon Ngu	1961-2014	Island	16	Tho Chu	1995-2014	Island
8	Con Co	1981-2014	Island	17	Phu Quoc	1986-2014	Island
9	Son Tra	1978-2014	Coast				

Sea water level data measured by satellites from 1993 up to the present are also used for assessing sea water level changes in Viet Nam.

3.1.3. Topographic data

Topographic data includes:

+ Topographic map of scale 1:10,000 (2015) with the grid size 5m x 5m of 19 coastal provinces from Quang Ninh to Binh Thuan surveyed by the Department of Survey and Mapping of Viet Nam in 2012;

+ Digital elevation model for 13 Mekong Delta provinces with the grid size 2m x 2m produced by the National Remote Sensing Department in 2008;

+ Digital elevation model derived from map with scale 1:2,000 from project carried out by the Viet Nam Department of Survey and Mapping in 2015 using Lidar technology. The grid size is of 1m x 1m, the captured area is 26,765 km^2 with 21,535 pieces of the DEM map, including 8,500 km^2 (6,904 pieces) in the North, 4,765 km^2 (4,179 pieces) in the Central Coast and 13,500 km^2 (10,452 pieces) in the South;

+ Digital elevation model with grid size of 2m x 2m derived from map scale 1:2,000 for the Ho Chi Minh city conducted by the Viet Nam Department of Surveying and Mapping in 2010;

+ Topographic map scale 1:25,000 are used for areas outside the inundated area in the Red River Delta provinces and the Central Coast.

3.2. Methodology for developing climate change scenarios

3.2.1. Benchmark emissions scenarios

In the AR5, the IPCC has developed climate change scenarios based on a new approach on emission scenarios. The emissions scenarios are benchmark emissions scenarios or Representative Concentration Pathways - RCP. RCP scenarios focused on the greenhouse gas concentrations rather than the emission processes. In other words, RCP makes assumptions about the destination, enabling the world to have choices in the process of socio-economic development, technologies, population and etc. There are 4 RCP scenarios, namely, RCP2.6, RCP4.5, RCP6.0 and RCP8.5. (Figure 8 and Table 2).

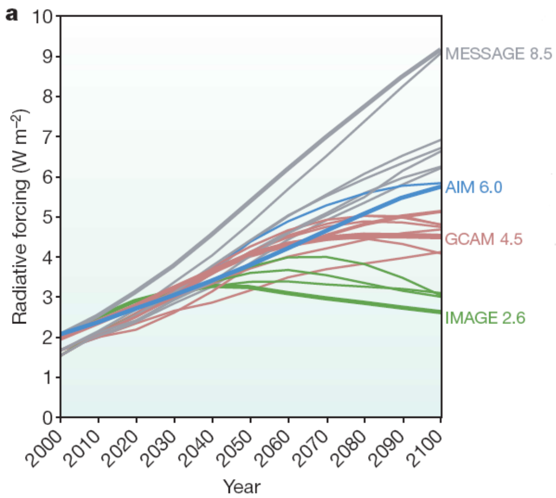


Figure 8. Changes in radiative forcing relative to pre-industrial conditions
(Moss et.al., 2010)

Table 2. Characteristics of the scenarios, temperature anomaly over pre-industrial levels and SRES comparisons

RCP	Radiative forcing in 2100	CO2 equiv. In 2100 (p.p.m.)	Global temperature anomaly over pre-industrial level in 2100 (°C)	Pathway till 2100	SRES temp anomaly equiv.
RCP8.5	8.5 W/m^2	1370	4.9	Rising	A1FI
RCP6.0	6.0 W/m^2	850	3.0	Stabilization without overshoot	B2
RCP4.5	4.5 W/m^2	650	2.4	Stabilization without overshoot	B1
RCP2.6	2.6 W/m^2	490	1.5	Peak at 3.0 W/m^2 and decline	None

3.2.2. Dynamical downscaling

Dynamical downscaling methods are applied to develop climate change scenarios for Viet Nam. Five global and regional climate models (Section 3.1.1) are applied in calculation. Different computational cases are conducted for each model based on the results from global models (IPCC, 2013) (Figure 9). Totally, there are 16 computational cases (Table 3).

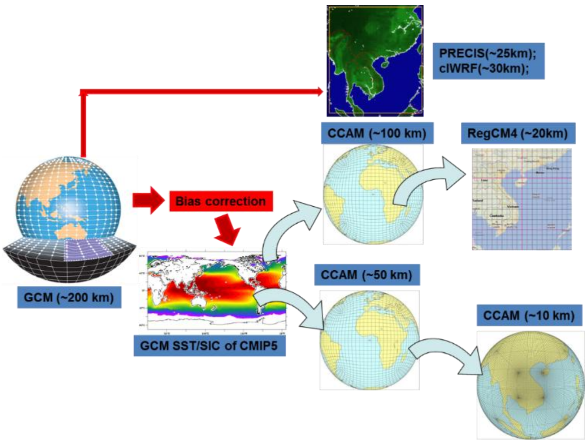


Figure 9. Climate projections using dynamical downscaling procedures

Table 3. Models used for developing climate change scenarios

No.	Model	Organization	Calculated scheme	Resolution, Domain	Vertical level
1	clWRF	NCAR, NCEP, FSL, AFWA, …	1) NorESM1-M	30 km, 3.5-27°N and 97.5-116°E	27
2	PRECIS	Hadley - UK	1) CNRM-CM5 2) GFDL-CM3 3) HadGEM2-ES	25 km, 6.5-25°N and 99.5-115°E	19
3	CCAM	CSIRO, Australia	1) ACCESS1-0 2) CCSM4 3) CNRM-CM5 4) GFDL-CM3 5) MPI-ESM-LR 6) NorESM1-M	10 km, 5-30°N and 98-115°E	27
4	RegCM	Abdus Salam International Centre for Theoretical Physics (ICTP), Italy	1) ACCESS1-0 2) NorESM1-M	20 km, 6.5-30°N and 99.5-119.5°E	18
5	AGCM/MRI	JMA, Japan	1) NCAR-SST 2) HadGEM2-SST 3) GFDL-SST 4) SST ensembles	20 km, globe	19

3.2.3. Statistical method for bias - correction of model outputs

As mentioned, dynamical downscaling has the advantage to simulate well the physical and chemical processes in the atmosphere and can provide many climatic variables. However, because of the limitation in resolution, this type of computation cannot capture accurately climate at a small local region, specifically in a complicated topographic region. Moreover, systematic errors always exist inside the model. Therefore, it is necessary to apply bias correction method using observed data at stations to minimize the bias from model results.

The bias correction procedures for daily temperature and rainfall are based on observed meteorological data. Quantile mapping method is applied to adjust daily rainfall from model. The quantile mapping method is also used for average, maximum and minimum temperatures.

3.2.4. Confidence level in climate change projections

In climate change scenarios, the state of climate in the future is addressed based on GHG scenarios. Different input of GHG concentrations for climate models generate different climate change scenarios. In addition, there are many uncertainties inside the model as well as from the outside. As a result, there is a range of projected future scenarios, both globally and regionally. Therefore, it is indispensable to consider several options and state of climate in the future under different GHG scenarios.

In this scenario, beside scenario is calculated from the models ensemble, a range of changes is also computed for different level of confidences. This allows the user to consider the full range of possible future.

3.3. Method for developing sea level rise scenarios

Sea level rise scenarios for Viet Nam are built on the basis of guidance from the IPCC AR5 report including the findings of Church et. al. (2013) and Slagen et. al. (2014). By using these methods, sea level rise scenarios have been developed for several developed countries such as Australia, the Netherlands and Singapore. Sea level rise scenarios are calculated from the components contributing to sea level in the region, consisting of 8 principal components, namely: 1) Thermal expansion; 2) Glaciers and ice caps; 3) Greenland ice sheet; 4) Greenland ice sheet dynamics; 5) Antarctic ice sheet; 6) Antarctic ice sheet dynamics; 7) Land water storage; 8) Glacial isostatic adjustment.

The uncertainties of the total sea level rise trends are estimated according to the methodology of the IPCC (Church et al (2013), AR5).

Table 4. Components contributing to sea level rise

No.	Component	Method	Data
1	Thermal expansion	Calculated by the contribution of change in sea level rise due to global thermal expansion (zostoga) in AOGCM. The component is adjusted before interpolating for the Viet Nam Sea region under the guidance of the IPCC.	Coupled atmosphere-ocean model - global climate model AOGCM.
2	Glaciers and ice caps	Interpolation for Viet Nam Sea regions using Slangen's method (2014), based on average global data.	From "*glaciers*" in the IPCC data.
3	Greenland ice sheet	Interpolation for Viet Nam Sea regions using Slangen's method (2014), based on average global data.	From "*greensmb*" in the IPCC data.
4	Antarctic ice sheet	Interpolation for Viet Nam Sea regions using Slangen's method (2014), based on average global data.	From "*antsmb*" in the IPCC data.
5	Greenland ice sheet dynamics	Interpolation for Viet Nam Sea regions using Slangen's method (2014), based on average global data.	From "*greendyn*" in the IPCC data.
6	Antarctic ice sheet dynamics	Interpolation for Viet Nam Sea regions using Slangen's method (2014), based on average global data.	From "*antdyn*" in the IPCC data.
7	Land water storage	Interpolation for Viet Nam Sea regions using Slangen's method (2014), based on average global data.	From "*landwater*" in the IPCC data.
8	Glacial isostatic adjustment	Using the results of ICE5G model, including components of rate changes in geoid, vertical shifting speed.	From the results of ICE5G model.

3.4. Methods for constructing inundation maps due to sea level rise

Inundation maps for 34 provinces/cities of coastal and delta regions are constructed in correspondence to sea level rise from 50 cm to 100 cm with the interval of 10 cm. For 10 island groups, inundation maps are constructed only for level of 100cm.

IV. Climate change and sea level rise scenarios for Viet Nam

4.1. Climate change scenarios

Box 5. Summary of climate change scenarios by late 21st century

- ***Temperature:*** For the RCP4.5 scenarios, surface temperatures would increase by 1.9÷2.4^{o}C in the North and 1.7÷1.9^{o}C in the South. For the RCP8.5 scenarios, temperature would increase by 3.3÷4.0^{o}C in the North and 3.0÷3.5^{o}C in the South. Extreme temperatures would have an upward trend.
- ***Rainfall:*** For the RCP4.5 scenarios, annual rainfall would generally increase in a range of 5÷15%. For the RCP8.5 scenarios, the greatest increase would increase by over 20% in most of the North, Central Coast, a part of the South and Central Highlands. Average maximum 1-day rainfall would increase all over Viet Nam (10÷70%) compared to the reference period.
- ***Monsoon and climate extremes:*** The number of strong and very strong typhoons has an upward trend. The time of the beginning of the summer monsoon would start earlier and end later. Monsoon rainfall would have an increased trend. The number of extreme cold and damage cold days would reduce in the provinces of the North, the Red River Delta, and the North Central. The number of hot days (Tx ≥ 35°C) would increase, the largest increase would be in the North Central Coast, South Central Coast and Southern Viet Nam. Droughts would become more severe due to rising temperatures and rainfall deficit in the dry season.

4.1.1. Average surface air temperature

Surface air temperatures, annual and seasonal temperatures (winter, spring, summer, autumn), show increasing trends for all regions of Viet Nam compared to the reference period; the increase depends on the RCP scenarios and climate zones.

For the RCP4.5 scenarios: Average temperatures by early 21st century would increases by 0.6÷0.8^{o}C throughout the country in general; increase by 1.3÷1.7^{o}C by mid-21st century; increase by 1.7÷2.4^{o}C by late 21st century. In general, temperatures in the North would be higher than in the South (**Figure 11**).

For the RCP8.5 scenarios: Average temperature by early 21st century would increase by 0.8÷1.1^{o}C throughout the country in general; increase by 2.0÷2.3^{o}C in the North and 1.8÷1.9^{o}C in the South by mid-21st century; increase by 3.3÷4.0^{o}C in the North and 3.0÷3.5^{o}C in the South by late 21st century (**Figure 12**).

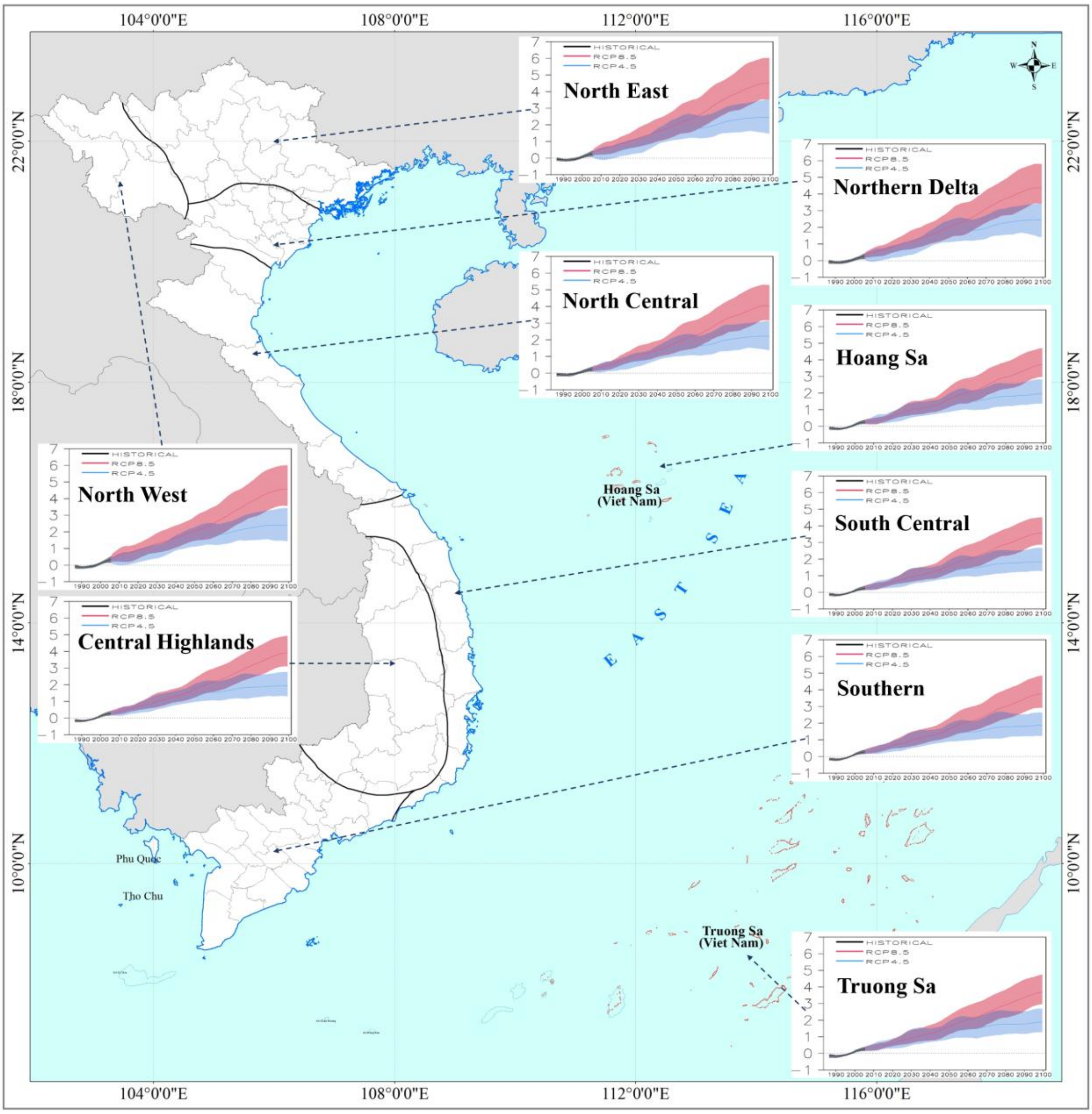
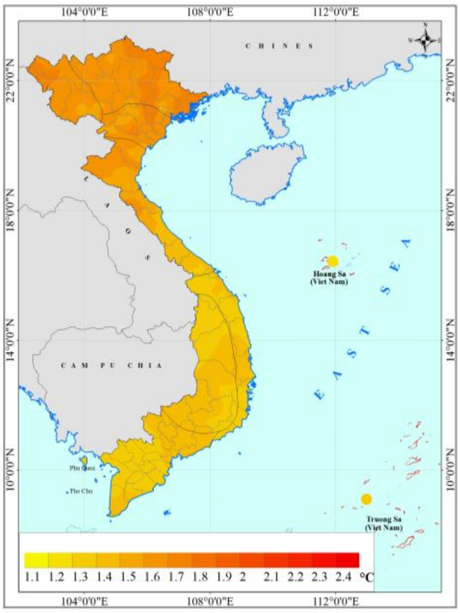
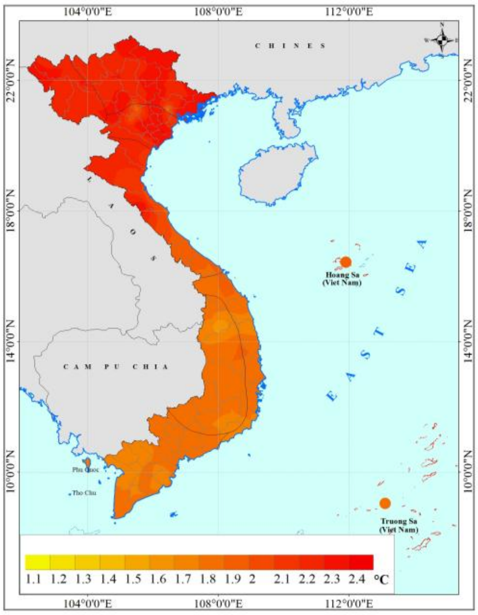


Figure 10. Changes in average annual temperature (°C) over 7 regions and islands of Viet Nam

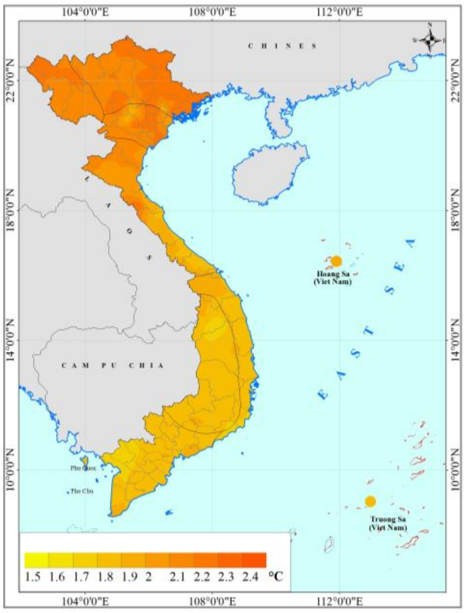


(a) mid-21st century

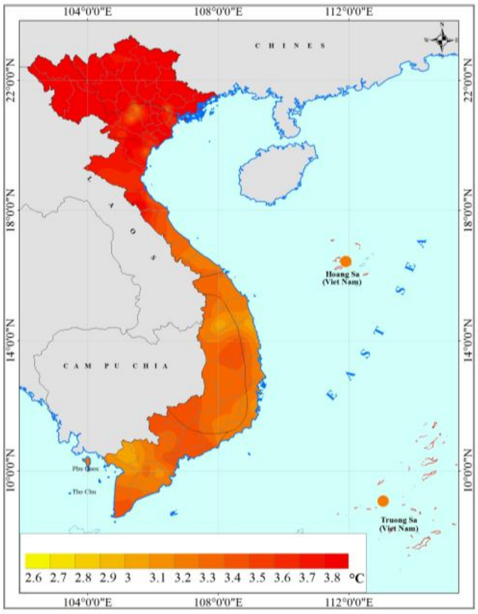


(b) late 21st century

Figure 11. Changes in average annual temperature (°C) based on RCP4.5 scenarios



a) mid-21st century



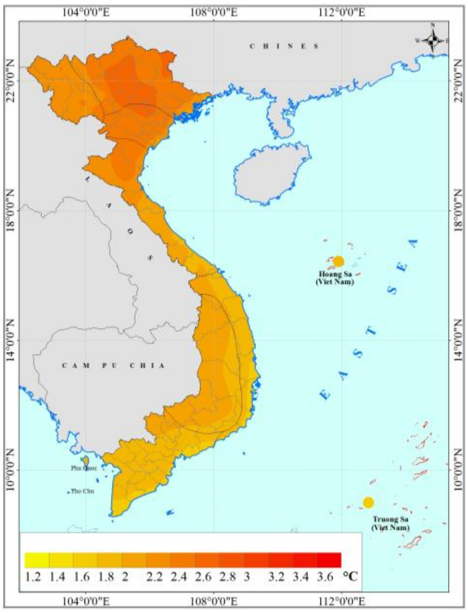
b) late 21st century

Figure 12. Changes in average annual temperature (°C) based on RCP8.5 scenarios

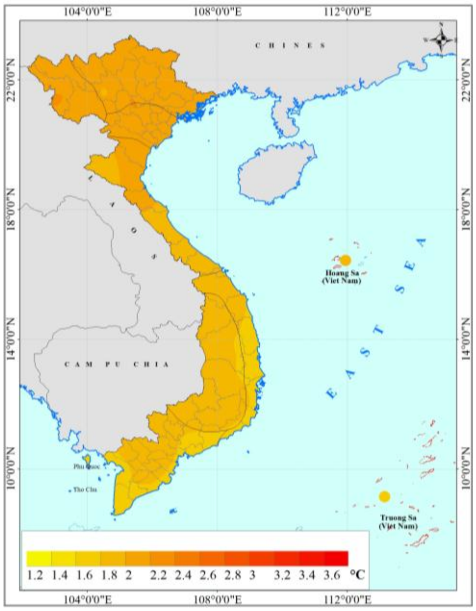
Changes in annual average temperatures at the early, mid- and late 21st century for 63 provinces, cities compared to the reference period are shown in **Table 5**. Values in parentheses are the 10% and 90% confident levels around the mean values. For example, average temperatures in Lai Chau by mid-21st century for the RCP4.5 scenarios would increase 1.2÷2.3°C with an average value of 1.7°C.

4.1.2. Extreme temperatures

Extreme temperatures tend to rise in all climate zones. By late 21st century, for the RCP4.5 scenarios, average annual maximum temperatures increase by 1.7÷2.7°C, the highest increase would be in the Northeast and the Red River Delta, the lowest increase would be in the South Central Coast and the South. The average annual minimum temperature would increase by 1.8÷2.2°C (**Figure 13**). For the RCP8.5 scenarios, the average annual maximum temperatures would increase by 3.0÷4.8°C, with the highest increase in the northern mountainous provinces, the lowest increase in the South Central Coast and Southeast. The average annual minimum temperature would increase by 3.0÷4.0°C, with some higher rates in the Northern provinces.



a) Average annual maximum temperature



b) Average annual minimum temperature

Figure 13. Changes in maximum and minimum temperatures (°C) by late 21st century based on RCP4.5 scenarios

Table 5. Changes in average annual temperature (°C) compared to the period 1986 - 2005

(Values in parentheses are the 10% and 90% confident levels around the mean values)

No.	Province, city	RCP4.5 scenarios			RCP8.5 scenarios		
		2016-2035	2046-2065	2080-2099	2016-2035	2046-2065	2080-2099
1	Lai Chau	0.7 (0.4÷1.1)	1.7 (1.2÷2.3)	2.3 (1.5÷3.3)	1.1 (0.6÷1.7)	2.2 (1.4÷3.1)	3.9 (3.1÷5.5)
2	Dien Bien	0.7 (0.4÷1.1)	1.7 (1.2÷2.3)	2.3 (1.5÷3.3)	1.1 (0.6÷1.7)	2.2 (1.4÷3.2)	3.9 (3.0÷5.6)
3	Son La	0.7 (0.3÷1.1)	1.6 (1.2÷2.3)	2.3 (1.6÷3.2)	1.1 (0.6÷1.6)	2.2 (1.5÷3.2)	3.9 (3.0÷5.6)
4	Hoa Binh	0.7 (0.3÷1.1)	1.6 (1.2÷2.3)	2.3 (1.6÷3.3)	1.0 (0.6÷1.5)	2.2 (1.4÷3.3)	3.8 (2.9÷5.5)
5	Lao Cai	0.7 (0.3÷1.1)	1.7 (1.2÷2.3)	2.3 (1.5÷3.3)	1.1 (0.6÷1.6)	2.2 (1.5÷3.2)	3.9 (3.1÷5.6)
6	Ha Giang	0.6 (0.1÷1.1)	1.7 (1.1÷2.5)	2.3 (1.5÷3.5)	1.1 (0.6÷1.6)	2.2 (1.5÷3.3)	3.9 (3.1÷5.8)
7	Yen Bai	0.6 (0.2÷1.1)	1.7 (1.2÷2.3)	2.3 (1.6÷3.3)	1.1 (0.6÷1.6)	2.2 (1.5÷3.2)	3.9 (3.1÷5.6)
8	Cao Bang	0.6 (0.2÷1.1)	1.7 (1.2÷2.6)	2.3 (1.6÷3.4)	1.1 (0.6÷1.6)	2.2 (1.5÷3.5)	4.0 (3.1÷5.7)
9	Tuyen Quang	0.6 (0.1÷1.1)	1.7 (1.2÷2.5)	2.4 (1.7÷3.5)	1.1 (0.5÷1.7)	2.3 (1.5÷3.4)	4.0 (3.0÷5.8)
10	Bac Kan	0.6 (0.2÷1.1)	1.7 (1.2÷2.6)	2.3 (1.6÷3.5)	1.1 (0.6÷1.6)	2.2 (1.5÷3.4)	4.0 (3.1÷5.7)
11	Lang Son	0.6 (0.2÷1.0)	1.7 (1.2÷2.6)	2.3 (1.6÷3.3)	1.0 (0.5÷1.6)	2.2 (1.4÷3.4)	4.0 (3.0÷5.6)
12	Thai Nguyen	0.6 (0.2÷1.1)	1.7 (1.2÷2.6)	2.4 (1.7÷3.4)	1.1 (0.6÷1.7)	2.3 (1.5÷3.4)	4.0 (3.0÷5.7)
13	Phu Tho	0.7 (0.2÷1.1)	1.8 (1.2÷2.5)	2.4 (1.7÷3.5)	1.1 (0.6÷1.7)	2.3 (1.4÷3.4)	4.0 (3.0÷5.8)
14	Vinh Phuc	0.7 (0.3÷1.1)	1.7 (1.2÷2.5)	2.4 (1.7÷3.5)	1.1 (0.6÷1.7)	2.3 (1.4÷3.4)	3.9 (2.9÷5.8)
15	Bac Giang	0.7 (0.3÷1.0)	1.7 (1.2÷2.5)	2.3 (1.6÷3.3)	1.0 (0.5÷1.6)	2.2 (1.4÷3.4)	3.9 (3.0÷5.5)
16	Bac Ninh	0.7 (0.3÷1.1)	1.7 (1.2÷2.5)	2.3 (1.6÷3.3)	1.0 (0.5÷1.5)	2.2 (1.4÷3.3)	3.9 (2.8÷5.6)
17	Quang Ninh	0.7 (0.4÷1.1)	1.6 (1.1÷2.3)	2.1 (1.5÷3.0)	0.9 (0.6÷1.4)	2.0 (1.5÷3.0)	3.6 (2.9÷4.8)
18	Hai Phong	0.7 (0.4÷1.1)	1.5 (1.0÷2.2)	2.0 (1.5÷2.9)	0.9 (0.6÷1.4)	2.0 (1.4÷2.8)	3.5 (2.8÷4.6)
19	Hai Duong	0.7 (0.3÷1.1)	1.7 (1.2÷2.5)	2.3 (1.6÷3.3)	1.0 (0.6÷1.6)	2.2 (1.4÷3.3)	3.8 (2.9÷5.5)
20	Hung Yen	0.7 (0.3÷1.1)	1.7 (1.2÷2.5)	2.3 (1.6÷3.4)	1.0 (0.6÷1.6)	2.2 (1.4÷3.3)	3.8 (2.9÷5.6)
21	Ha Noi	0.6 (0.2÷1.1)	1.7 (1.2÷2.5)	2.4 (1.6÷3.4)	1.1 (0.6÷1.6)	2.2 (1.4÷3.4)	3.9 (3.0÷5.7)
22	Ha Nam	0.7 (0.2÷1.1)	1.7 (1.2÷2.5)	2.4 (1.6÷3.4)	1.1 (0.6÷1.6)	2.2 (1.4÷3.4)	3.9 (2.9÷5.6)
23	Thai Binh	0.7 (0.3÷1.1)	1.6 (1.2÷2.4)	2.3 (1.6÷3.2)	1.0 (0.6÷1.5)	2.1 (1.5÷3.2)	3.7 (2.9÷5.2)
24	Nam Dinh	0.7 (0.4÷1.1)	1.6 (1.2÷2.2)	2.2 (1.5÷3.1)	0.9 (0.6÷1.4)	2.0 (1.4÷3.0)	3.6 (2.8÷4.9)
25	Ninh Binh	0.7 (0.2÷1.1)	1.6 (1.2÷2.3)	2.3 (1.6÷3.3)	1.0 (0.6÷1.5)	2.2 (1.4÷3.2)	3.8 (2.9÷5.4)
26	Thanh Hoa	0.7 (0.3÷1.1)	1.6 (1.1÷2.3)	2.2 (1.6÷3.2)	1.0 (0.6÷1.5)	2.1 (1.4÷3.2)	3.7 (2.9÷5.2)
27	Nghe An	0.7 (0.3÷1.1)	1.6 (1.1÷2.2)	2.2 (1.5÷3.1)	1.0 (0.6÷1.5)	2.0 (1.4÷3.1)	3.7 (2.9÷5.2)
28	Ha Tinh	0.6 (0.3÷1.0)	1.5 (1.0÷2.1)	2.0 (1.4÷2.9)	0.9 (0.6÷1.3)	1.9 (1.3÷2.8)	3.5 (2.8÷4.8)
29	Quang Binh	0.6 (0.3÷1.1)	1.5 (1.0÷2.1)	2.0 (1.5÷2.8)	0.9 (0.6÷1.2)	1.9 (1.3÷2.8)	3.3 (2.7÷4.7)
30	Quang Tri	0.6 (0.4÷1.2)	1.4 (1.0÷2.0)	1.9 (1.3÷2.8)	0.9 (0.6÷1.2)	1.9 (1.3÷2.7)	3.3 (2.6÷4.6)

No.	Province, city	RCP4.5 scenarios			RCP8.5 scenarios		
31	Thua Thien - Hue	0.7 (0.4÷1.1)	1.4 (0.9÷2.0)	1.9 (1.3÷2.7)	0.8 (0.6÷1.2)	1.9 (1.3÷2.6)	3.3 (2.6÷4.5)
32	Da Nang	0.7 (0.4÷1.2)	1.4 (1.0÷2.1)	1.9 (1.3÷2.7)	0.8 (0.6÷1.2)	1.9 (1.3÷2.6)	3.2 (2.6÷4.3)
33	Quang Nam	0.7 (0.4÷1.2)	1.4 (0.9÷2.0)	1.8 (1.3÷2.6)	0.8 (0.6÷1.2)	1.9 (1.3÷2.6)	3.2 (2.5÷4.2)
34	Quang Ngai	0.7 (0.4÷1.2)	1.4 (1.0÷2.1)	1.9 (1.3÷2.7)	0.8 (0.6÷1.2)	1.9 (1.3÷2.6)	3.2 (2.6÷4.3)
35	Binh Dinh	0.7 (0.4÷1.2)	1.4 (0.9÷2.0)	1.8 (1.3÷2.5)	0.8 (0.5÷1.2)	1.8 (1.3÷2.5)	3.2 (2.5÷4.1)
36	Phu Yen	0.7 (0.4÷1.2)	1.3 (0.9÷2.0)	1.8 (1.3÷2.5)	0.8 (0.6÷1.2)	1.8 (1.3÷2.5)	3.1 (2.5÷4.1)
37	Khanh Hoa	0.7 (0.4÷1.2)	1.4 (0.9÷2.0)	1.8 (1.2÷2.5)	0.8 (0.5÷1.2)	1.8 (1.2÷2.5)	3.2 (2.5÷4.1)
38	Ninh Thuan	0.7 (0.4÷1.1)	1.4 (1.0÷2.0)	1.8 (1.3÷2.5)	0.8 (0.5÷1.1)	1.8 (1.3÷2.5)	3.3 (2.6÷4.2)
39	Binh Thuan	0.7 (0.4÷1.2)	1.3 (0.9÷2.0)	1.7 (1.2÷2.4)	0.8 (0.5÷1.2)	1.8 (1.3÷2.5)	3.2 (2.6÷4.0)
40	Kon Tum	0.8 (0.4÷1.2)	1.5 (1.1÷2.2)	1.9 (1.4÷2.7)	0.9 (0.6÷1.3)	1.9 (1.5÷2.7)	3.5 (2.9÷4.6)
41	Gia Lai	0.7 (0.4÷1.1)	1.4 (0.9÷2.0)	1.8 (1.3÷2.6)	0.8 (0.6÷1.2)	1.8 (1.3÷2.6)	3.3 (2.7÷4.5)
42	Dak Lak	0.7 (0.4÷1.2)	1.4 (0.9÷2.0)	1.8 (1.2÷2.6)	0.9 (0.6÷1.2)	1.9 (1.3÷2.6)	3.3 (2.7÷4.4)
43	Dak Nong	0.7 (0.4÷1.2)	1.4 (1.0÷2.1)	1.9 (1.3÷2.6)	0.9 (0.6÷1.3)	1.9 (1.4÷2.7)	3.4 (2.8÷4.5)
44	Lam Dong	0.7 (0.4÷1.2)	1.5 (1.0÷2.1)	1.9 (1.4÷2.7)	0.9 (0.6÷1.3)	1.9 (1.4÷2.7)	3.5 (2.8÷4.5)
45	Binh Phuoc	0.7 (0.4÷1.2)	1.5 (1.0÷2.1)	1.9 (1.3÷2.7)	0.9 (0.6÷1.3)	1.9 (1.4÷2.7)	3.5 (2.8÷4.6)
46	Tay Ninh	0.7 (0.4÷1.2)	1.4 (0.9÷2.1)	1.9 (1.3÷2.7)	0.8 (0.6÷1.2)	1.9 (1.4÷2.7)	3.5 (2.7÷4.7)
47	Binh Duong	0.7 (0.4÷1.2)	1.5 (0.9÷2.2)	1.9 (1.2÷2.7)	0.9 (0.5÷1.3)	2.0 (1.4÷2.8)	3.6 (2.7÷4.8)
48	Dong Nai	0.7 (0.4÷1.2)	1.5 (0.9÷2.1)	1.9 (1.2÷2.7)	0.9 (0.5÷1.3)	2.0 (1.4÷2.8)	3.5 (2.7÷4.7)
49	Ho Chi Minh	0.7 (0.4÷1.2)	1.5 (1.0÷2.1)	1.9 (1.2÷2.7)	0.9 (0.5÷1.3)	2.0 (1.4÷2.8)	3.5 (2.8÷4.7)
50	Ba Ria - Vung Tau	0.7 (0.4÷1.2)	1.3 (0.9÷2.0)	1.7 (1.2÷2.3)	0.8 (0.5÷1.2)	1.8 (1.3÷2.5)	3.0 (2.5÷3.9)
51	Long An	0.7 (0.4÷1.2)	1.4 (0.9÷2.0)	1.9 (1.2÷2.7)	0.8 (0.5÷1.2)	1.9 (1.4÷2.7)	3.4 (2.7÷4.6)
52	Vinh Long	0.7 (0.4÷1.1)	1.4 (0.9÷2.1)	1.8 (1.2÷2.6)	0.8 (0.5÷1.2)	1.9 (1.4÷2.7)	3.5 (2.7÷4.6)
53	Hau Giang	0.7 (0.4÷1.2)	1.4 (0.9÷2.1)	1.8 (1.2÷2.6)	0.8 (0.6÷1.2)	1.9 (1.4÷2.7)	3.4 (2.6÷4.5)
54	Tien Giang	0.7 (0.4÷1.2)	1.4 (1.0÷2.1)	1.9 (1.3÷2.7)	0.9 (0.6÷1.3)	1.9 (1.4÷2.7)	3.4 (2.7÷4.6)
55	Dong Thap	0.7 (0.4÷1.2)	1.4 (0.9÷2.0)	1.8 (1.2÷2.6)	0.9 (0.6÷1.2)	1.8 (1.4÷2.6)	3.3 (2.7÷4.4)
56	Ben Tre	0.7 (0.4÷1.2)	1.4 (0.9÷2.0)	1.8 (1.2÷2.5)	0.8 (0.5÷1.2)	1.8 (1.4÷2.5)	3.3 (2.7÷4.2)
57	Tra Vinh	0.7 (0.4÷1.2)	1.4 (1.0÷2.0)	1.8 (1.2÷2.6)	0.8 (0.6÷1.2)	1.9 (1.4÷2.6)	3.4 (2.7÷4.5)
58	An Giang	0.7 (0.4÷1.2)	1.4 (1.0÷2.0)	1.9 (1.3÷2.7)	0.9 (0.6÷1.3)	1.9 (1.3÷2.7)	3.5 (2.6÷4.6)
59	Can Tho	0.7 (0.4÷1.2)	1.4 (0.9÷2.0)	1.8 (1.2÷2.6)	0.9 (0.6÷1.3)	1.9 (1.4÷2.6)	3.4 (2.7÷4.5)
60	Soc Trang	0.7 (0.4÷1.2)	1.4 (1.0÷2.0)	1.8 (1.2÷2.5)	0.8 (0.6÷1.2)	1.8 (1.4÷2.6)	3.3 (2.7÷4.3)
61	Kien Giang	0.7 (0.4÷1.2)	1.3 (0.9÷2.0)	1.8 (1.2÷2.5)	0.8 (0.5÷1.2)	1.8 (1.3÷2.5)	3.2 (2.6÷4.2)
62	Bac Lieu	0.7 (0.4÷1.3)	1.4 (1.0÷2.0)	1.8 (1.2÷2.5)	0.8 (0.6÷1.2)	1.8 (1.4÷2.5)	3.3 (2.7÷4.2)
63	Ca Mau	0.7 (0.4÷1.2)	1.4 (1.0÷2.0)	1.8 (1.2÷2.5)	0.9 (0.6÷1.3)	1.8 (1.3÷2.5)	3.3 (2.7÷4.3)

4.1.3. Rainfall

Annual rainfall would increase in all climate zones. In the dry season rainfall would decrease in some regions (e.g. spring in the South Central and the South, summer in the South Central, winter in the North). Extreme rainfall would increase (**Figure 14**).

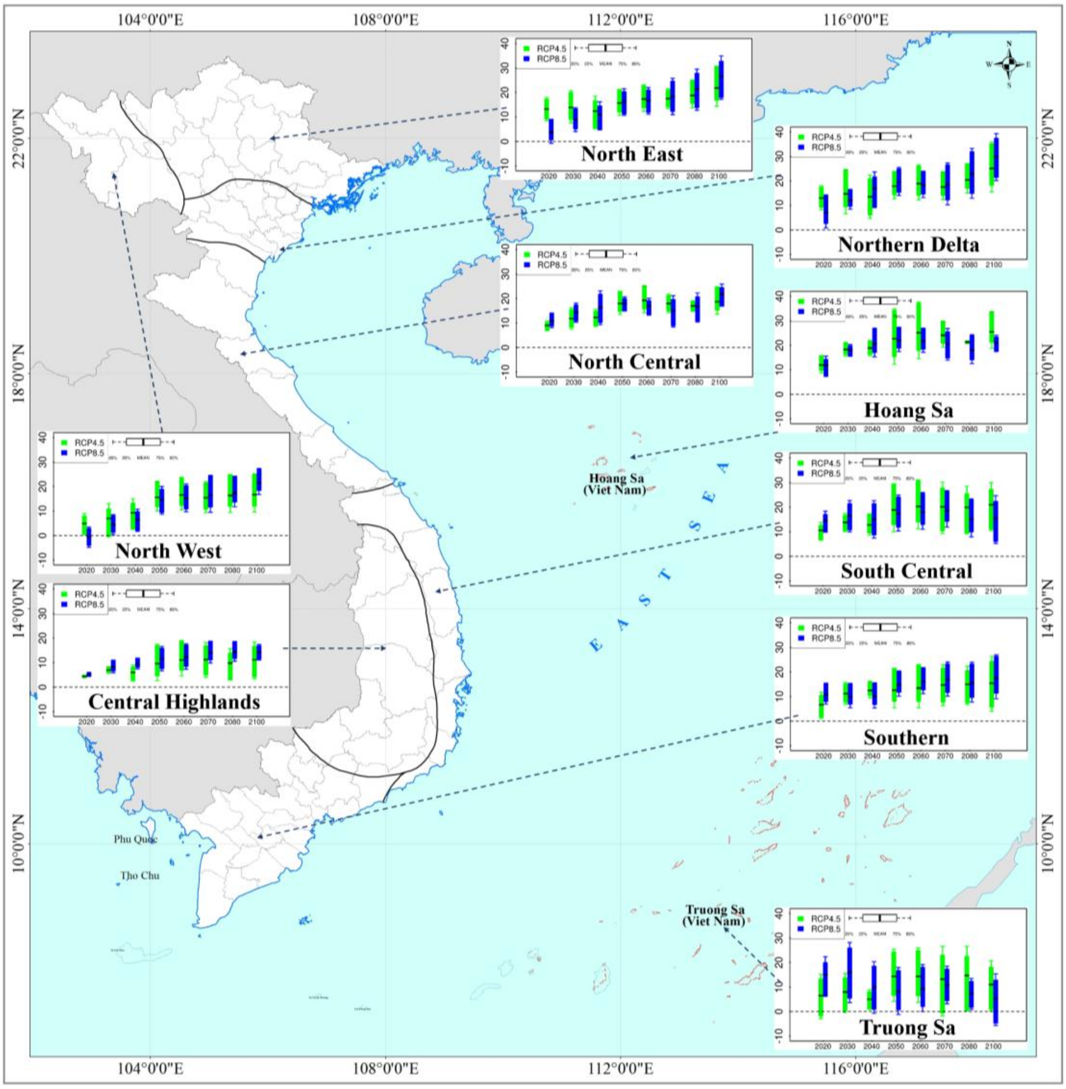
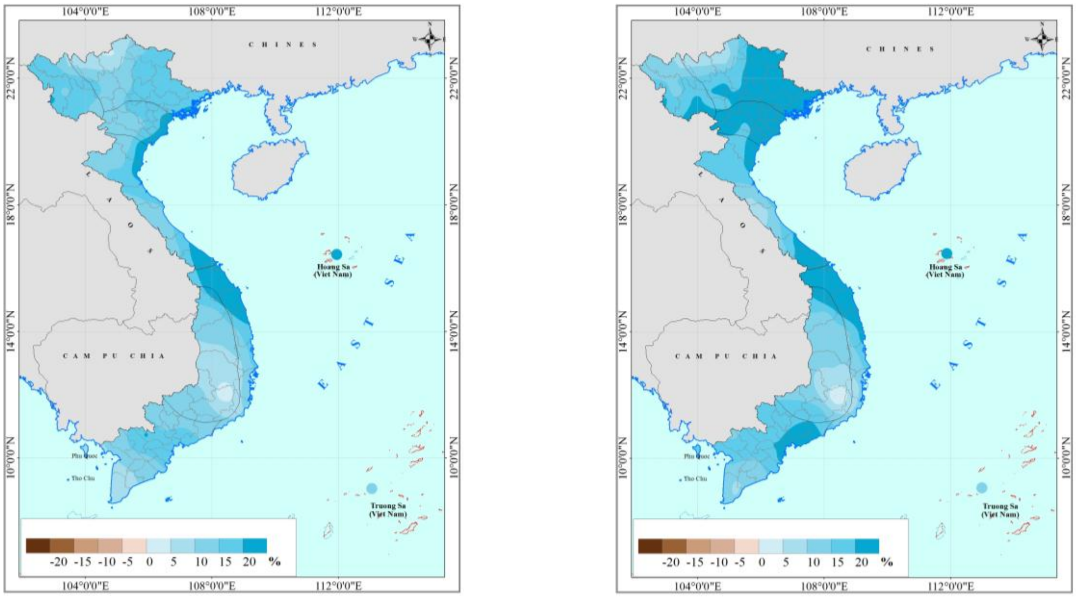


Figure 14. Changes in annual rainfall (%) over 7 regions and islands of Viet Nam

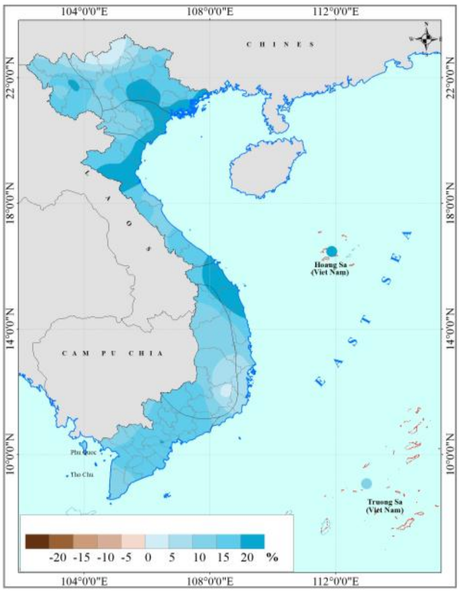


(a) mid-21st century *(b) late 21st century*

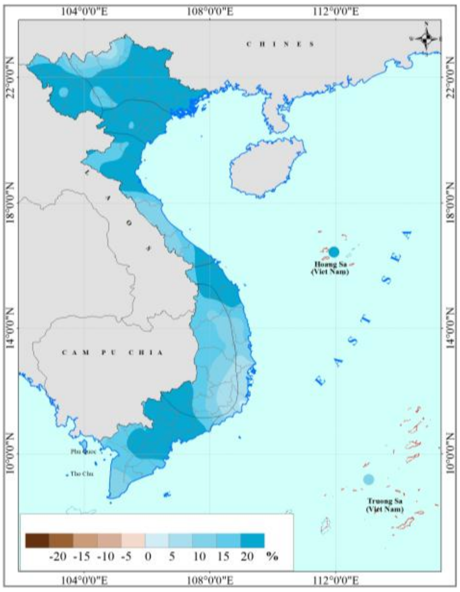
Figure 15. Changes in annual rainfall (%) based on RCP4.5 scenarios

For the RCP4.5 scenarios: Annual rainfall by early 21st century would increase by 5÷10% in general over most parts of the country; by mid- and late 21st century, annual rainfall would increase by 5÷15%, particularly in some coastal provinces in the Red River Delta, the North Central and a part of the South and Central Highlands annual rainfall would increase about 20% (**Figure 15**).

For the RCP8.5 scenarios: The increasing trend of annual rainfall would be similar to the RCP4.5 scenarios. It is noteworthy that the greatest increase of rainfall would potentially be over 20% in most parts of the North, Mid-Central and parts of the South and Central Highlands (**Figure 16**). **Table 6** shows changes in annual rainfall (%) for 63 provinces and cities by early, mid-, and late 21st century compared to the reference period.



(a) mid-21st century



(b) late 21st century

Figure 16. Changes in annual rainfall (%) based on RCP8.5 scenarios

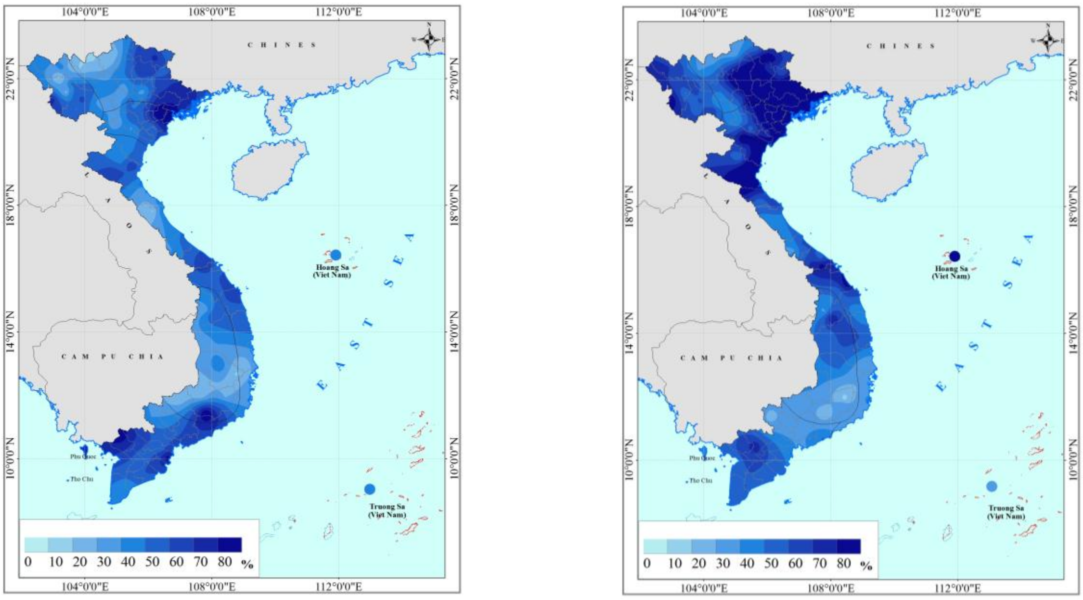
Table 6. Changes in annual rainfall (%) compared to the reference period

(Values in parentheses are the 10% and 90% confident levels around the mean values)

No.	Province, city	RCP4.5 scenarios			RCP8.5 scenarios		
		2016-2035	2046-2065	2080-2099	2016-2035	2046-2065	2080-2099
1	Lai Chau	3.3 (-3.3÷9.7)	13.5 (9.4÷17.9)	11.2 (4.6÷18.3)	-1.0 (-4.0÷2.1)	10.6 (4.4÷16.0)	18.4 (12.0÷25.3)
2	Dien Bien	5.9 (-2.2÷13.2)	16.5 (8.9÷24.3)	15.1 (6.6÷24.4)	2.7 (-1.7÷7.3)	15.2 (8.0÷21.7)	21.2 (14.8÷28.2)
3	Son La	7.0 (-0.5÷14.2)	15.5 (8.4÷23.4)	19.9 (10.3÷30.4)	5.1 (-1.3÷11.2)	15.3 (9.3÷21.3)	22.3 (15.7÷28.9)
4	Hoa Binh	7.5 (0.0÷15.4)	12.9 (8.1÷18.1)	20.2 (12.2÷29.1)	7.0 (1.4÷12.9)	12.8 (7.4÷18.2)	20.9 (12.4÷29.0)
5	Lao Cai	1.8 (-4.0÷7.1)	8.2 (3.0÷13.8)	9.3 (2.2÷17.0)	-2.9 (-8.0÷2.5)	5.9 (0.4÷10.9)	12.6 (5.2÷20.0)
6	Ha Giang	5.8 (2.7÷8.9)	7.8 (3.1÷12.6)	11.8 (5.0÷19.0)	-3.3 (-9.6÷3.3)	4.0 (-0.2÷8.1)	12.7 (6.6÷18.8)
7	Yen Bai	7.5 (0.2÷14.3)	14.8 (7.5÷23.0)	19.4 (7.8÷32.7)	5.9 (-0.7÷12.7)	15.6 (7.9÷23.3)	23.3 (9.4÷35.7)
8	Cao Bang	14.2 (8.2÷19.9)	16.0 (9.8÷21.8)	22.1 (13.1÷31.4)	3.8 (-4.2÷11.8)	12.8 (9.4÷16.1)	25.7 (17.0÷34.4)
9	Tuyen Quang	11.5 (6.2÷16.4)	12.5 (7.5÷17.7)	18.4 (10.2÷27.1)	5.8 (-0.1÷11.6)	16.7 (9.7÷23.5)	27.4 (15.0÷38.7)
10	Bac Kan	17.4 (11.3÷23.1)	18.3 (13.5÷22.7)	23.7 (16.9÷30.8)	6.6 (0.2÷13.1)	15.4 (10.4÷20.3)	28.0 (19.4÷36.1)
11	Lang Son	18.7 (7.0÷29.8)	18.7 (11.5÷25.5)	25.1 (16.5÷34.2)	10.5 (4.6÷17.0)	17.9 (12.4÷23.3)	27.8 (20.1÷35.1)
12	Thai Nguyen	15.9 (8.2÷23.3)	17.8 (11.1÷24.2)	22.5 (14.9÷31.0)	9.9 (4.9÷15.0)	22.0 (13.8÷30.2)	31.1 (21.8÷40.1)
13	Phu Tho	10.0 (0.3÷19.7)	15.0 (8.2÷22.6)	21.3 (10.7÷33.4)	8.5 (1.6÷15.6)	17.1 (7.5÷26.1)	25.4 (11.8÷37.4)
14	Vinh Phuc	14.8 (5.4÷24.6)	18.2 (10.6÷26.6)	22.4 (12.5÷34.1)	10.7 (4.7÷17.0)	22.2 (12.4÷32.1)	30.8 (18.5÷42.1)
15	Bac Giang	17.7 (5.4÷29.3)	18.8 (11.0÷26.9)	25.7 (16.6÷35.6)	10.9 (5.8÷16.7)	21.1 (15.4÷27.2)	32.7 (25.5÷39.5)
16	Bac Ninh	13.0 (4.1÷21.9)	13.9 (6.6÷22.2)	22.9 (14.2÷32.8)	4.8 (-0.9÷11.1)	15.4 (9.2÷22.0)	25.2 (15.4÷34.9)
17	Quang Ninh	20.4 (6.5÷33.4)	19.1 (11.7÷26.9)	29.8 (19.8÷40.9)	14.8 (6.4÷23.4)	24.0 (14.7÷33.0)	36.8 (25.9÷46.5)
18	Hai Phong	24.4 (10.1÷38.2)	26.4 (18.0÷35.5)	34.3 (19.3÷50.3)	17.9 (10.1÷26.0)	30.2 (21.4÷39.0)	44.1 (33.4÷54.5)
19	Hai Duong	17.4 (4.9÷30.0)	18.7 (9.6÷28.4)	27.8 (17.0÷39.6)	11.4 (4.0÷19.0)	23.0 (16.5÷30.2)	32.8 (24.0÷42.2)
20	Hung Yen	13.8 (4.3÷23.7)	16.3 (10.4÷22.9)	25.3 (15.4÷36.2)	8.2 (1.5÷15.3)	17.1 (11.1÷23.3)	28.5 (17.4÷39.8)
21	Ha Noi	12.6 (3.1÷22.9)	17.0 (10.8÷23.8)	24.0 (14.3÷35.3)	9.9 (2.7÷17.0)	17.8 (9.8÷25.9)	29.8 (18.0÷40.9)
22	Ha Nam	14.0 (3.8÷24.8)	17.6 (11.5÷24.4)	24.7 (14.8÷36.1)	10.5 (3.1÷17.9)	19.0 (10.8÷27.3)	30.1 (18.3÷41.3)
23	Thai Binh	19.8 (6.5÷32.5)	20.1 (14.2÷26.5)	27.6 (17.0÷39.1)	13.0 (4.9÷21.1)	23.9 (15.0÷33.0)	31.3 (19.4÷42.8)
24	Nam Dinh	16.0 (6.0÷26.0)	21.1 (14.8÷27.8)	27.5 (17.5÷38.1)	15.2 (8.6÷22.0)	21.9 (13.2÷30.5)	34.7 (24.8÷44.6)
25	Ninh Binh	11.2 (2.8÷19.5)	16.5 (10.6÷22.5)	22.0 (13.5÷30.7)	9.6 (4.8÷14.8)	17.7 (11.4÷24.2)	25.3 (18.4÷32.0)

No.	Province, city	RCP4.5 scenarios			RCP8.5 scenarios		
26	Thanh Hoa	10.1 (3.7÷16.8)	17.6 (11.5÷23.6)	21.3 (14.2÷29.0)	13.8 (8.5÷19.0)	18.6 (13.0÷24.5)	25.5 (19.9÷31.2)
27	Nghe An	10.2 (2.4÷17.7)	16.8 (10.6÷23.1)	18.1 (10.3÷26.3)	16.6 (7.7÷24.5)	21.6 (14.1÷28.5)	26.4 (18.8÷33.6)
28	Ha Tinh	11.3 (6.0÷16.6)	16.3 (8.5÷24.4)	13.0 (3.4÷22.6)	12.9 (6.8÷18.9)	14.1 (8.9÷19.0)	17.4 (10.6÷24.4)
29	Quang Binh	10.1 (3.5÷16.5)	12.6 (3.8÷22.0)	10.9 (0.0÷21.4)	10.8 (4.0÷17.4)	14.1 (8.2÷19.6)	12.1 (5.5÷19.0)
30	Quang Tri	11.4 (2.9÷20.0)	16.6 (7.5÷26.2)	20.1 (9.8÷31.3)	16.5 (9.9÷22.8)	16.8 (10.7÷22.6)	16.4 (8.2÷24.2)
31	Thua Thien - Hue	17.0 (10.4÷23.6)	22.5 (10.7÷34.3)	26.2 (15.4÷38.1)	16.5 (9.0÷23.3)	18.6 (12.9÷23.9)	21.2 (13.8÷28.2)
32	Da Nang	16.2 (11.7÷21.1)	22.7 (10.0÷36.1)	25.5 (14.4÷37.8)	16.4 (11.3÷21.3)	22.0 (15.9÷28.3)	20.8 (15.0÷26.8)
33	Quang Nam	18.2 (13.0÷23.7)	24.9 (14.3÷36.8)	29.9 (17.5÷42.9)	17.5 (12.2÷22.6)	25.9 (18.6÷33.5)	25.9 (13.0÷38.2)
34	Quang Ngai	18.0 (12.9÷23.2)	25.2 (14.0÷38.3)	29.5 (15.3÷42.9)	18.0 (12.2÷23.5)	25.1 (17.0÷33.5)	22.2 (7.2÷35.9)
35	Binh Dinh	14.9 (8.8÷21.2)	20.4 (10.9÷30.8)	23.0 (11.2÷34.3)	17.0 (10.1÷23.4)	19.0 (11.9÷26.2)	16.5 (5.8÷26.5)
36	Phu Yen	10.0 (3.2÷17.0)	13.4 (5.2÷22.8)	14.4 (0.9÷26.9)	12.4 (3.2÷21.9)	10.4 (2.7÷18.5)	10.1 (-1.0÷20.4)
37	Khanh Hoa	9.1 (-1.3÷19.2)	14.4 (3.9÷25.5)	11.0 (-0.2÷21.1)	16.1 (4.9÷27.2)	8.1 (-1.5÷18.0)	5.4 (-6.1÷15.6)
38	Ninh Thuan	5.0 (-0.9÷11.5)	6.2 (-0.8÷14.4)	8.1 (-2.9÷17.7)	14.0 (7.3÷20.2)	5.6 (-1.5÷12.5)	1.6 (-8.5÷11.6)
39	Binh Thuan	14.1 (5.9÷22.0)	13.6 (3.9÷24.2)	17.7 (9.4÷25.3)	12.5 (5.9÷19.8)	15.0 (7.8÷22.0)	14.9 (8.1÷21.6)
40	Kon Tum	7.2 (4.5÷9.9)	12.0 (2.4÷22.0)	14.1 (5.2÷23.3)	8.1 (5.0÷11.4)	12.5 (6.6÷18.4)	16.2 (12.0÷20.6)
41	Gia Lai	8.3 (3.4÷12.5)	11.0 (3.2÷19.5)	12.1 (4.2÷19.9)	10.0 (5.2÷15.1)	11.8 (4.7÷19.1)	14.6 (10.6÷18.5)
42	Dak Lak	6.5 (2.2÷10.9)	7.6 (0.8÷15.7)	10.1 (-1.0÷20.3)	5.3 (-1.0÷11.6)	8.7 (1.8÷16.2)	11.4 (2.4÷19.5)
43	Dak Nong	6.5 (3.7÷9.3)	11.3 (3.3÷20.7)	11.5 (4.0÷19.4)	5.0 (1.4÷8.6)	17.2 (13.6÷21.1)	18.6 (14.7÷22.7)
44	Lam Dong	3.9 (1.0÷6.8)	6.5 (0.3÷12.9)	7.8 (-0.6÷15.6)	4.7 (0.6÷8.9)	9.0 (4.8÷13.5)	10.1 (6.6÷13.6)
45	Binh Phuoc	8.7 (5.3÷12.4)	12.1 (4.3÷21.2)	15.1 (5.3÷24.1)	9.0 (2.8÷15.4)	16.0 (10.2÷21.6)	23.3 (17.8÷28.6)
46	Tay Ninh	9.4 (4.5÷14.3)	14.1 (5.2÷23.3)	16.0 (4.9÷26.1)	10.3 (4.2÷16.3)	15.0 (8.7÷21.9)	20.7 (13.6÷28.2)
47	Binh Duong	7.2 (1.8÷12.6)	10.4 (3.3÷18.4)	13.8 (2.6÷24.1)	7.5 (3.1÷12.1)	12.8 (6.9÷19.4)	16.8 (8.4÷25.9)
48	Dong Nai	8.3 (3.1÷13.0)	11.1 (3.8÷19.8)	15.0 (1.2÷28.0)	7.8 (3.7÷12.1)	13.3 (6.8÷20.4)	16.1 (5.9÷26.8)
49	Ho Chi Minh	9.7 (4.2÷14.9)	12.7 (5.1÷21.7)	16.9 (1.7÷31.1)	9.3 (4.6÷14.1)	13.5 (7.3÷20.2)	16.8 (6.4÷27.8)
50	Ba Ria - Vung Tau	17.5 (9.6÷25.0)	14.5 (4.6÷25.2)	17.5 (8.1÷27.0)	13.5 (7.3÷20.0)	16.4 (9.4÷23.6)	15.6 (7.7÷24.1)
51	Long An	11.7 (4.0÷18.5)	20.6 (7.8÷33.8)	16.7 (2.9÷29.0)	12.8 (5.9÷19.1)	16.1 (9.2÷23.4)	19.9 (11.6÷28.2)
52	Vinh Long	6.2 (2.5÷10.1)	9.1 (1.2÷17.9)	11.1 (0.6÷21.8)	7.6 (2.7÷13.2)	11.8 (7.0÷17.0)	13.4 (4.5÷23.7)
53	Hau Giang	4.9 (2.1÷7.8)	4.5 (-2.3÷11.7)	7.4 (-1.8÷17.0)	3.8 (0.2÷7.9)	8.6 (4.4÷13.4)	9.8 (0.5÷21.0)
54	Tien Giang	13.7 (8.6÷18.9)	17.1 (7.3÷28.3)	16.1 (2.7÷28.8)	12.7 (6.3÷18.9)	18.0 (10.6÷25.8)	20.9 (10.5÷32.3)
55	Dong Thap	10.0 (4.8÷15.1)	17.9 (8.9÷28.0)	17.2 (5.3÷28.4)	11.0 (4.4÷17.4)	16.2 (10.7÷22.2)	23.7 (15.6÷32.0)
56	Ben Tre	17.0 (10.1÷23.2)	18.2 (7.6÷30.4)	21.2 (7.7÷33.6)	14.7 (9.7÷19.8)	18.1 (11.3÷25.6)	21.8 (11.3÷33.0)
57	Tra Vinh	10.9 (4.9÷16.3)	15.7 (5.7÷26.8)	17.7 (4.1÷30.0)	11.4 (5.6÷17.5)	14.6 (8.4÷21.5)	18.2 (9.0÷28.2)
58	An Giang	4.7 (-0.3÷9.4)	13.1 (3.8÷23.3)	14.1 (0.5÷26.4)	8.2 (1.5÷15.1)	11.1 (5.4÷17.3)	14.7 (6.7÷23.4)
59	Can Tho	10.5 (6.6÷14.4)	13.7 (4.5÷23.6)	15.1 (2.8÷26.6)	10.7 (4.0÷18.0)	18.3 (13.5÷23.6)	21.2 (12.3÷30.7)
60	Soc Trang	11.1 (7.2÷15.0)	10.6 (2.2÷19.5)	14.0 (4.0÷23.7)	10.6 (5.1÷16.7)	15.4 (10.4÷20.6)	18.4 (9.8÷28.3)
61	Kien Giang	4.9 (0.0÷10.3)	9.2 (0.8÷18.4)	17.0 (2.3÷31.8)	6.5 (-1.2÷14.6)	14.4 (7.3÷21.9)	15.4 (4.4÷28.0)
62	Bac Lieu	9.6 (5.0÷13.9)	11.0 (2.3÷20.5)	13.6 (4.3÷22.8)	11.8 (6.4÷18.0)	16.5 (10.1÷23.3)	18.0 (8.5÷29.0)
63	Ca Mau	8.4 (2.1÷14.0)	5.8 (-2.4÷14.7)	9.6 (-0.3÷19.5)	6.7 (2.2÷11.7)	10.8 (6.0÷16.2)	12.6 (3.7÷22.9)

4.1.4. Extreme rainfall



a) Based on RCP4.5 scenarios *b) Based on RCP8.5 scenarios*

Figure 17. Changes in average maximum 1-day rainfall by late 21st century

For the RCP4.5 scenarios, average maximum 1-day rainfall would increase by 10÷70% throughout Viet Nam by late 21st century; greatest increase would be in the Northeast, Central (from Thua Thien - Hue to Quang Nam) and the Southeast (**Figure 17**).

For the RCP8.5 scenarios, by late 21st century, the average maximum 1-day rainfall would increase over the whole country with increases of 10÷70% in general, in which the great increases would be in the Northeast, south of Central Highlands and the South (**Figure 17**).

4.1.5. Monsoon and other climate extremes

Climate change may alter in frequency, intensity and activity of extreme climate phenomena. Some projected results can be summarized as follows:

- Typhoons and tropical depressions have no significant changes in number, but occur more on the end of the typhoon season, which is the period of typhoon activity mainly in the South. Strong to very strong typhoons would increase.

- Summer monsoon may start earlier and end later. Rainfall in monsoon would increase due to the increase of moisture in the atmosphere.

- Number of extreme cold and damaging cold days would decrease in the Northern mountainous provinces, the Red River Delta, and the North Central.

- Number of hot days (Tx ≥ 35°C) would increase in most parts of the country, highest would be in the North Central, South Central and the South. Droughts would be more severe in some regions due to increased temperatures and less rainfall in the dry season (e.g. spring and summer in the South Central, spring in the South and winter in the North).

4.2. Sea level rise scenarios

Sea level rise scenarios only consider changes in average sea water level caused by climate change. The scenarios do not take in to account the effects of other factors on sea water level, such as storm surge, monsoon induced water level rise, tide, tectonic uplift and subsidence, etc.

4.2.1. Sea water level of the East Sea

Projected changes in sea water level in the East Sea by late 21st century are summarized as follows:

- For the RCP4.5 scenarios, sea water level would rise about 55 cm (from 33÷75 cm);
- For the RCP8.5 scenarios, sea water level would rise about 77cm (from 51÷106 cm).

Box 6. Summary of sea level rise by late 21st century

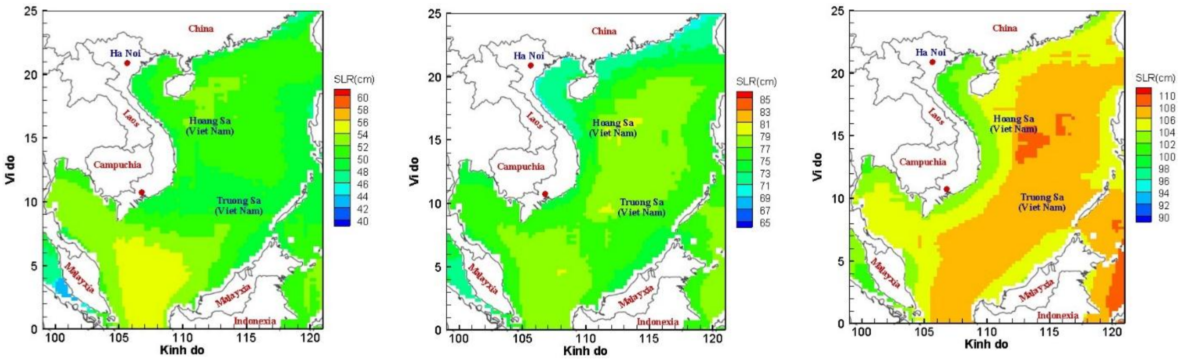
- Sea level rise in the Southern coastline would be higher than in the Northern coastline.
- For the RCP4.5 scenarios: The highest sea level rise would be at the regions of Hoang Sa and Truong Sa archipelago, with rising values of about 58 cm (36÷80 cm) and 57 cm (33÷83 cm) respectively; sea water level would rise about 55 cm at Ca Mau - Kien Giang regions; about 53 cm at Mong Cai - Hon Dau and Hon Dau - Deo Ngang regions.
- For the RCP8.5 scenarios: The Hoang Sa and Truong Sa archipelago would have the highest sea level rise, with rising value of about 78cm (52÷107 cm) and 77cm (50÷107 cm), respectively; sea water level would rise about 75 cm (52÷106 cm) at the Ca Mau - Kien Giang region; about 72 cm (49÷101 cm) at the Mong Cai - Hon Dau and Hon Dau - Deo Ngang regions.

The temporal and spatial distributions of sea level rise in the East Sea region by late

21st century compared to the period 1986-2005 based on the RCP8.5 are presented in **Figure 18**.

Table 7. Sea level rise scenarios for East Sea region (cm)

RCP scenarios	The timeline of the 21st century							
	2030	2040	2050	2060	2070	2080	2090	2100
RCP4.5	13(8÷19)	18(11÷26)	23(14÷34)	29(18÷43)	36(22÷53)	42(26÷62)	49(30÷72)	55(34÷81)
RCP8.5	13(9÷18)	19(13÷27)	26(17÷36)	34(23÷47)	43(28÷59)	52(35÷72)	64(42÷88)	77(51÷106)



(a) lower bound (5%) (b) median (50%) (c) upper bound (95%)

Figure 18. Distribution of sea level rise by late 21st century based on the RCP8.5 scenarios

Sea level rise in the central and south of the East Sea will be considerably higher than in other regions. The lowest sea level rise would be the Northern Gulf and north of the East Sea. Sea level rise in coastal areas from Da Nang to Kien Giang would be higher than in the Northern coast. This results are in line with the trends of changes in sea level rise from observed data.

4.2.2. Sea level rise for Viet Nam

By early 21st century, there is no significant difference in sea level rise for all RCP scenarios. By 2030, the average sea level rise for Viet Nam coast would be about 13 cm (8÷18 cm) for the RCP2.6, RCP4.5 and RCP6.0 scenarios, and 13 cm (9÷18 cm) for the RCP8.5 scenarios.

By mid-21st century, there is a difference in trend of sea level rise. By 2050, average sea level rise for the coastal areas of Viet Nam are about 21 cm (13÷32 cm) for the RCP2.6 scenarios, about 22 cm (14÷32 cm) for the RCP4.5 scenarios, about 22 cm (14÷32 cm) for the RCP6.0 scenarios, and about 25 cm (17÷35 cm) for the RCP8.5 scenarios.

By late 21st century, differences in trend of sea level rise for different RCP scenarios are clear. By 2100, average sea level rise for the coastal areas of Viet Nam would be about 44 cm (27÷66 cm) for the RCP2.6 scenarios, about 53 cm (32÷76 cm) for the RCP4.5 scenarios, about 56 cm (37÷81 cm) for the RCP6.0 scenarios, and about 73 cm (49÷103 cm) for the RCP8.5 scenarios.

Table 8. Sea level rise scenarios for the coastal areas of Viet Nam (cm)

Scenarios	The timeline of the 21st century							
	2030	2040	2050	2060	2070	2080	2090	2100
RCP2.6	13(8÷19)	17(10÷25)	21(13÷ 32)	26(16÷39)	30(18÷45)	35(21÷52)	40(24÷59)	44(27÷66)
RCP4.5	13(8÷18)	17(10÷25)	22(14÷32)	28(17÷40)	34(20÷48)	40(24÷57)	46(28÷66)	53(32÷76)
RCP6.0	13(8÷17)	17(11÷24)	22(14÷32)	27(18÷39)	34(22÷48)	41(27÷58)	48(32÷69)	56(37÷81)
RCP8.5	13(9÷18)	18(12÷26)	25(17÷35)	32(22÷46)	41(28÷58)	51(34÷72)	61(42÷87)	73(49÷103)

The sea level rise scenarios are built for coastal provinces and 9 regions, namely: (I) from Mong Cai to Hon Dau; (II) from Hon Dau to Deo Ngang; (III) from Deo Ngang to Deo Hai Van; (IV) from Deo Hai Van to Mui Dai Lanh; (V) from Mui Dai Lanh to Mui Ke Ga; (VI) from Mui Ke Ga to Mui Ca Mau; (VII) from Mui Ca Mau to Kien Giang; (VIII) Hoang Sa archipelago; and (IX) Truong Sa archipelago.

For the RCP4.5 scenarios: By late 21st century, the highest sea level rise would be in the regions of Hoang Sa and Truong Sa archipelagos with the sea level rise of about 58 cm (36÷80 cm) and 57 cm (33÷83 cm), respectively; Sea level rise would be about 55 cm (33÷78 cm) from Ca Mau to Kien Giang; the lowest sea level rise would be about 53 cm (32÷75 cm) in the regions of Mong Cai - Hon Dau and Hon Dau - Deo Ngang.

Table 9. Sea level rise scenarios based on the RCP4.5 scenarios (cm)

Region	The timeline of the 21st century							
	2030	2040	2050	2060	2070	2080	2090	2100
Mong Cai-Hon Dau	13 (8÷18)	17(10÷24)	22(13÷31)	27(17÷39)	33(20÷47)	39(24÷56)	46(28÷65)	53(32÷75)
Hon Dau-Đeo Ngang	13(8÷18)	17(10÷24)	22(13÷31)	27(16÷39)	33(20÷47)	39(24÷56)	46(28÷65)	53(32÷75)
Đeo Ngang-Đeo Hai Van	13 (8÷18)	17(11÷24)	22(14÷32)	28(17÷39)	34(20÷47)	40(24÷56)	46(28÷65)	53(32÷75)
Đeo Hai Van-Mai Đai Lanh	13 (8÷18)	17(11÷25)	23(14÷32)	28(17÷40)	34(21÷48)	40(25÷57)	47(29÷66)	54(33÷76)
Mui Đai Lanh-Mui Ke Ga	12 (8÷18)	17(11÷25)	23(14÷33)	28(17÷41)	34(21÷50)	40(24÷59)	47(28÷68)	54(33÷78)
Mui Ke Ga-Mui Ca Mau	12 (7÷18)	17(10÷25)	22(13÷32)	28(17÷40)	33(20÷49)	40(24÷58)	46(28÷67)	53(32÷77)
Mui Ca Mau-Kien Giang	12 (7÷18)	17(10÷25)	23(14÷32)	28(17÷40)	34(21÷49)	41(25÷58)	48(29÷68)	55(33÷78)
Hoang Sa archipelago	13 (8÷18)	18(12÷26)	24(15÷34)	30(19÷42)	37(23÷51)	43(27÷61)	50(31÷70)	58(36÷80)
Truong Sa archipelago	14 (8÷20)	19(11÷27)	24(14÷35)	30(17÷44)	36(21÷53)	43(25÷62)	50(29÷72)	57(33÷83)

For the RCP8.5 scenarios: By late 21st century, the highest sea level rise would be in the regions of Hoang Sa and Truong Sa archipelagos with the sea level rise of about 78 cm (52÷107 cm) and 77 cm (50÷107 cm), respectively; Sea level rise would be about 75 cm (52÷106 cm) from Ca Mau to Kien Giang; the lowest sea level rise would be about 72 cm (49÷101 cm) in the regions of Mong Cai - Hon Dau and Hon Dau - Deo Ngang.

Table 10. Sea level rise scenarios based on the RCP8.5 scenarios (cm)

Region	The timeline of the 21st century							
	2030	2040	2050	2060	2070	2080	2090	2100
Mong Cai-Hon Dau	13(9÷18)	18(13÷26)	25(17÷35)	32(22÷45)	41(28÷57)	50(34÷70)	60(41÷85)	72(49÷101)
Hon Dau-Đeo Ngang	13 (9÷18)	18(12÷26)	25(17÷35)	32(22÷45)	40(28÷57)	50(34÷71)	60(41÷85)	72(49÷101)
Đeo Ngang-Đeo Hai Van	13(9÷18)	19(13÷26)	25(17÷35)	33(22÷46)	41(28÷58)	50(34÷71)	61(42÷86)	72(49÷102)
Đeo Hai Van-Mai Đai Lanh	13 (9÷18)	18(13÷26)	25(17÷35)	33(22÷46)	41(28÷58)	51(35÷71)	62(42÷86)	73(50÷103)
Mui Đai Lanh-Mui Ke Ga	12 (8÷18)	18(12÷26)	25(16÷35)	33(21÷46)	41(27÷59)	51(34÷73)	62(41÷89)	74(49÷105)
Mui Ke Ga-Mui Ca Mau	12 (8÷17)	18(12÷26)	25(16÷35)	32(21÷46)	41(27÷59)	51(33÷73)	61(41÷88)	73(48÷105)
Mui Ca Mau-Kien Giang	12 (9÷17)	18(13÷26)	25(17÷35)	33(23÷47)	42(29÷59)	52(36÷73)	63(44÷89)	75(52÷106)
Hoang Sa archipelago	13 (9÷18)	19(13÷26)	26(17÷36)	34(23÷47)	44(29÷60)	54(36÷74)	65(43÷90)	78(52÷107)
Truong Sa archipelago	14 (9÷19)	20(13÷28)	27(18÷37)	35(23÷49)	44(29÷61)	54(36÷75)	65(42÷90)	77(50÷107)

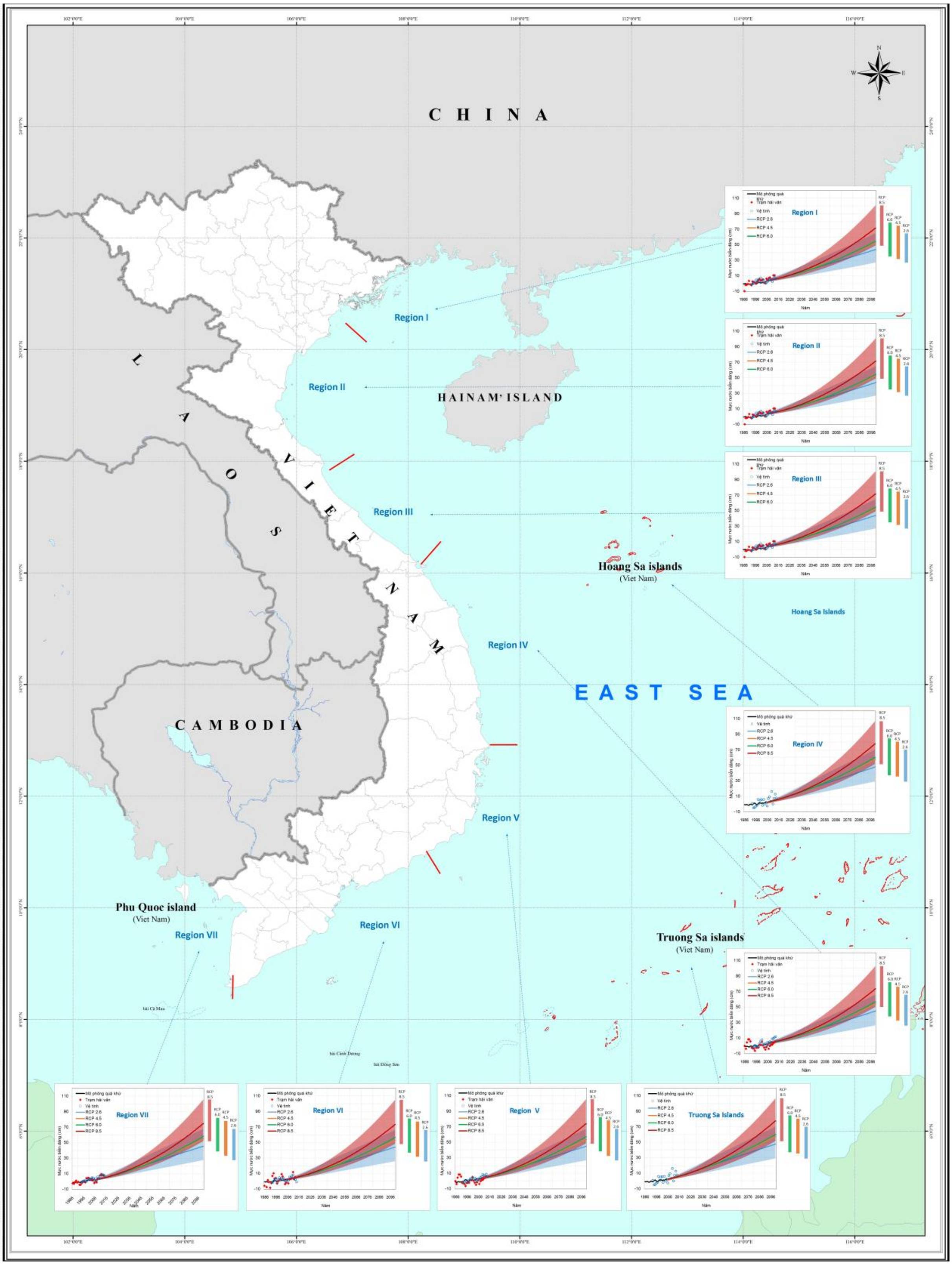


Figure 19. Sea level rise scenarios for coastal areas and islands of Viet Nam

Note: The observed water level at gauging stations (lozenges), data from satellites (circle); Water levels computed from models for the reference period (black line); Sea level rise scenarios of the RCP2.6 scenarios compared to the reference period (blue), RCP4.5 (orange), RCP6.0 (green), and RCP8.5 (red), levels of confidence of 5% - 95% (shading) of the two scenarios RCP2.6 and RCP8.5. The values of the right column indicate the levels of confidence of 5% - 95% by 2100.

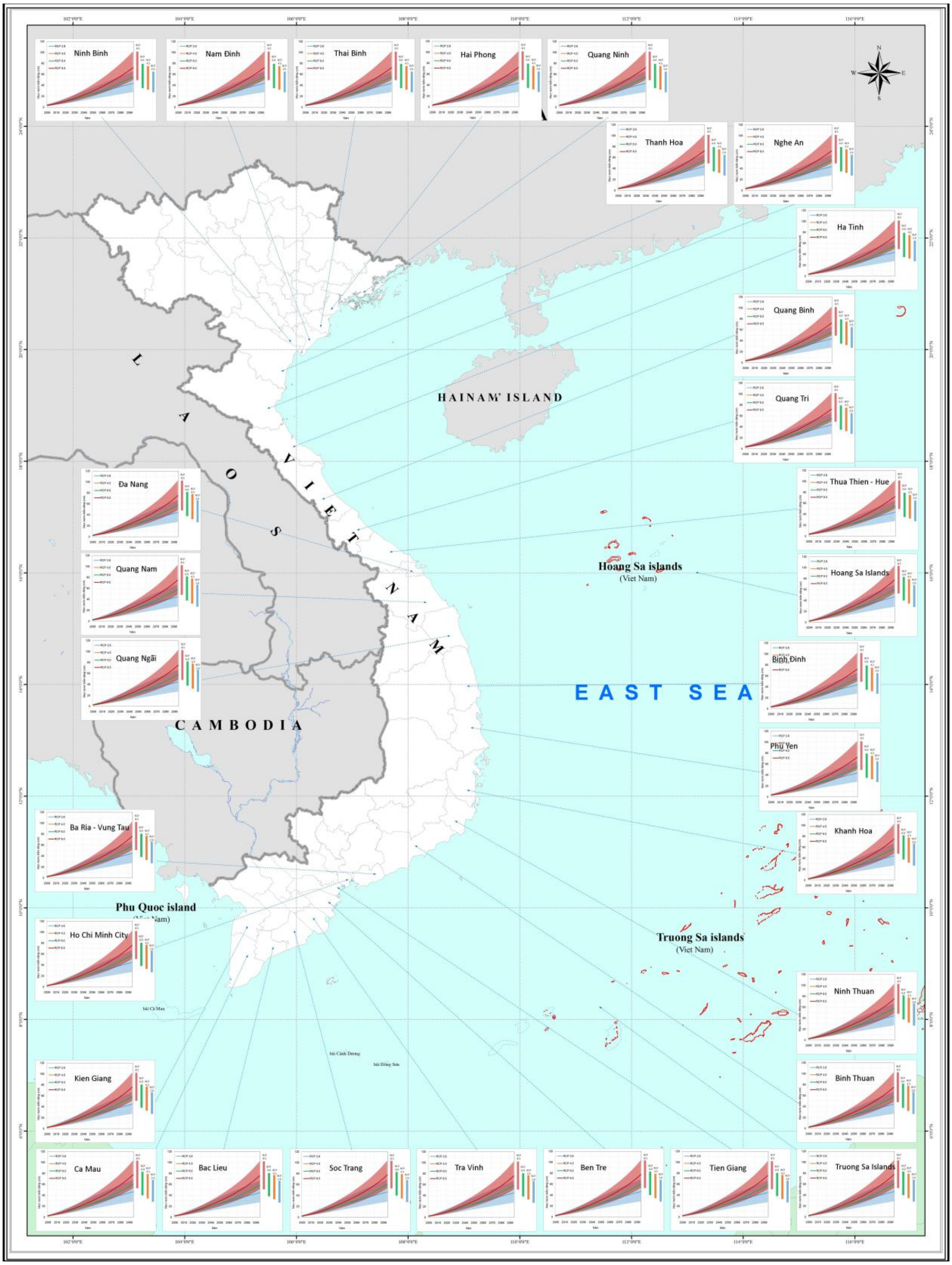


Figure 19. Sea level rise scenarios for coastal areas and islands of Viet Nam

Note: Sea level rise scenarios compared to the reference period, for RCP2.6 (blue), RCP4.5 (orange), RCP6.0 (green), and RCP8.5 (red), levels of confidence of 5% - 95% (shading) of the two scenarios RCP2.6 and RCP8.5. The values of the right column indicate the levels of confidence of 5% - 95% by 2100.

4.3. Evaluation of sea water level extremes

In assessing the impacts of sea level rise due to climate change for the deltas and coastal areas, it is necessary to consider the extreme sea water levels caused by other factors, such as storm surges, tide, storm surge in combination with high tides, etc.

4.3.1. Storm surge

Storm surge is a rise in sea level due to the direct impact of a typhoon. Although the frequency is not high, storm surges can be very dangerous due to sudden water level rise causing inundation for the coastal areas. Storm surge characteristics are different for different areas of the coastal areas of Viet Nam, the variation can be summarized in the Table 11.

Table 11. Storm surge for the coastal areas of Viet Nam

Coastal area	The observed highest storm surge (cm)	The highest storm surge that may occur (cm)
Quang Ninh - Thanh Hoa	350	400
Nghe An - Ha Tinh	400	450
Quang Binh - Thua Thien - Hue	300	350
Đa Nang - Binh Đinh	150	200
Phu Yen - Khanh Hoa	150	200
Ninh Thuan - Binh Thuan	150	200
Binh Thuan - Ca Mau	200	250

4.3.2. Tidal regime along the coastline of Viet Nam

There are 4 main types of tidal regimes along the coastline of Viet Nam, namely, diurnal, semidiurnal, irregular diurnal, and irregular semidiurnal tide. The diurnal tide are observed along the coastline of Quang Ninh to a half of the northern Thanh Hoa and part of the southern Ca Mau. The irregular diurnal tide are found from the southern Thanh Hoa to Nghe An, Da Nang to Quang Nam, the northern Binh Thuan, Soc Trang, Bac Lieu, and from Kien Giang to Phu Quoc. The irregular semidiurnal tide occurs along the coastline of Quang Binh, Thua Thien - Hue and southern Binh Thuan, and from Vung Tau to Tra Vinh. Semidiurnal tide is only found along the coastline of Quang Tri. The tidal amplitudes vary from region to region in Viet Nam, the highest tidal amplitude is observed along the coastline of Quang Ninh and Soc Trang (180÷220 cm). The lowest amplitude is found along the coastline of Thua Thien - Hue (40÷50 cm). Highest tide usually occurs from October to January of the following year.

4.3.3. Storm surge in combination with tides

Typhoon surges with strong waves may cause serious damages to sea dykes and coastal constructions, especially dangerous if it occurs during high tides. In the areas with high tidal amplitudes, such as Quang Ninh - Hai Phong and Vung Tau - Ca Mau, if typhoon hit the area during high tide period, then only a small storm surges can cause flooding of the coastal areas.

The total sea water level caused by storm surge in combination with high tide of 200-year return period along the coastline of Quang Ninh to Nghe An may reach value of 450÷500 cm, along the coastline of Quang Binh to Quang Nam has a value of 150÷200 cm. If wave induced water level is also considered, the total water level of a 100-year return period of for the Ha Phong region could reach a value of above 500 cm. Therefore, in this case, if the sea level rise due to climate change (100 cm) is considered, a total sea water level of a

100-year return period in Hai Phong could be over 600 cm.

4.4. Inundation due to sea level rise caused by climate change

Maps of inundation due to sea level rise caused by climate change are constructed for the regions of the Red River Delta and Quang Ninh province, the Central coastal provinces from Thanh Hoa to Binh Thuan, Ba Ria - Vung Tau, Ho Chi Minh City and the Mekong delta. Inundation maps are also constructed for islands, Hoang Sa and Truong Sa archipelagos of Viet Nam.

Box 7. Inundation due to sea level rise of 100 cm

- About 16.8% area of Red River delta, 1.47% area of the Central coastal provinces from Thanh Hoa to Binh Thuan, 17.8% area of Ho Chi Minh City, 38.9% area of the Mekong Delta would be at risk of inundation;
- Van Don Island group, Con Dao and Phu Quoc Island have high inundation risk. There is a low inundation risk for Truong Sa archipelago. Hoang Sa archipelago has higher inundation risk, especially the Luoi Liem Island group and Tri Ton Island.

The inundation maps are based on the average sea level rise due to climate change. Other dynamical factors such as tectonic uplift and subsidence, topographical changes, land subsidence due to groundwater extraction, coastline change, influence of tides, storm surges, monsoon induced sea level rise, impact of hydropower cascade, and saline intrusion have not been considered in this scenarios. Transportation works and irrigation structures such as sea dykes and river dykes, embankments, roads, and others have not been considered when mapping inundation due to sea level rise caused to climate change.

4.4.1. Inundation maps for delta and coastal provinces

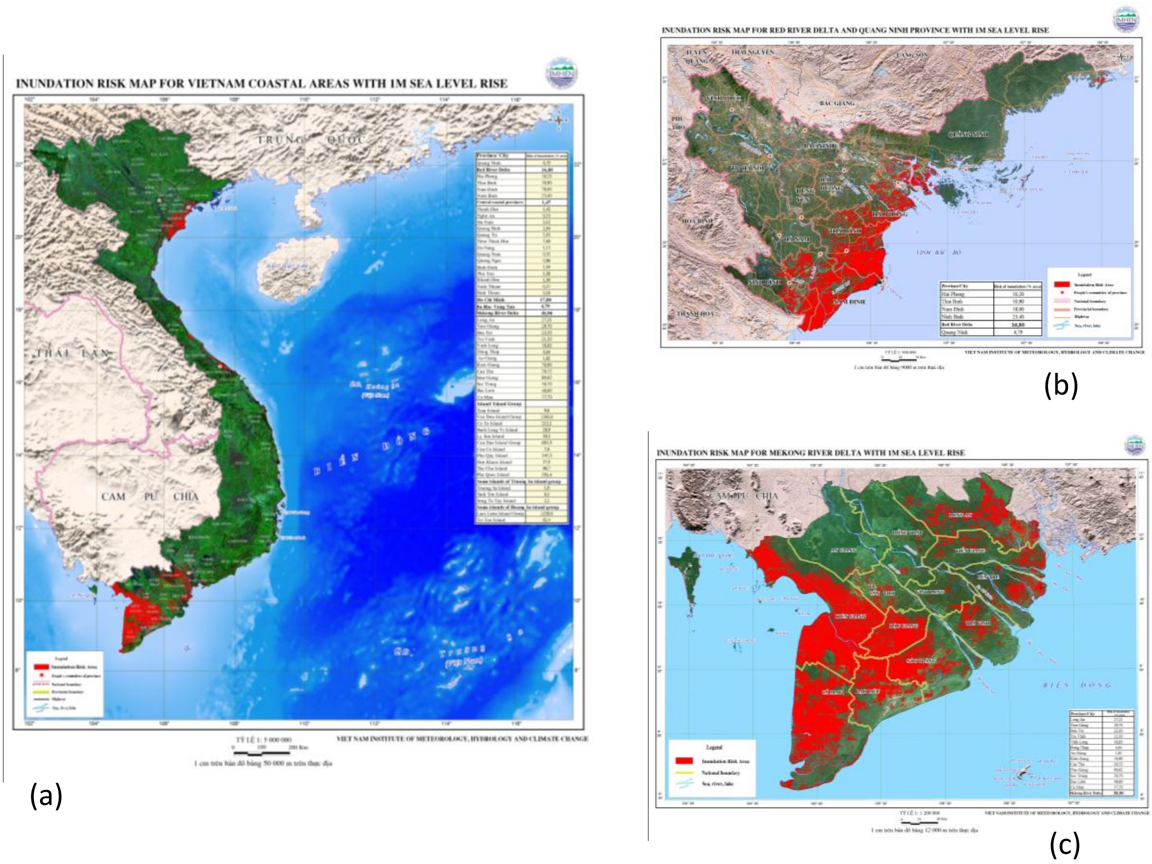


Figure 20. Inundation maps with a sea level rise of 100 cm

(a) Coastal areas of Viet Nam; (b) Red River Delta and Quang Ninh; (c) Mekong Delta

Table 12. Inundations due to sea level rise caused by climate change

Province/City	Area (ha)	Percentage of inundation (% area) corresponding sea level rise					
		50 cm	60 cm	70 cm	80 cm	90 cm	100 cm
Quang Ninh	967655	3.33	3.62	3.88	4.10	4.40	4.79
Red River Delta							
Hai Phong	154052	5.14	7.61	11.7	17.4	24.0	30.2
Thai Binh	158131	27.0	31.2	35.4	39.9	45.1	50.9
Nam Đinh	159394	26.0	32.5	39.1	45.8	52.3	58.0
Ninh Binh	134700	8.29	11.0	14.0	17.1	20.5	23.4
Red River Delta in total	***1492739***	***6.93***	***8.55***	***10.4***	***12.5***	***14.7***	***16.8***
From Thanh Hoa to Bìnth Thuan							
Thanh Hoa	1111000	0.51	0.65	0.8	0.98	1.2	1.43
Nghe An	1656000	0.13	0.17	0.22	0.27	0.32	0.51
Ha Tinh	599304	0.86	1.00	1.2	1.39	1.81	2.12
Quang Binh	801200	1.73	1.87	2.01	2.24	2.27	2.64
Quang Tri	463500	0.71	0.97	1.22	1.49	1.91	2.61
Thua Thien - Hue	503923	0.93	1.67	2.59	3.46	4.31	7.69
Đa Nang	97778	0.70	0.78	0.87	0.96	1.04	1.13
Quang Nam	1043220	0.18	0.20	0.23	0.26	0.28	0.32
Quang Ngai	514080	0.43	0.51	0.59	0.66	0.75	0.86
Binh Đinh	609340	0.55	0.64	0.74	0.84	0.93	1.04
Phu Yen	503690	0.55	0.63	0.74	0.86	0.97	1.08
Khanh Hoa	519320	0.72	0.89	1.04	1.19	1.38	1.49
Ninh Thuan	335630	0.20	0.24	0.28	0.30	0.33	0.37
Binh Thuan	796833	0.10	0.12	0.13	0.15	0.17	0.17
Total	***9554819***	***0.53***	***0.66***	***0.80***	***0.95***	***1.11***	***1.47***
Ho Chi Minh city	209962	11.4	12.6	13.9	15.2	16.5	17.8
Ba Ria - Vung Tau	190223	2.13	2.53	3.01	3.52	4.16	4.79
Mekong Delta							
Long An	449100	0.61	1.36	2.85	7.12	12.89	27.21
Tien Giang	239470	1.56	2.92	4.54	7.08	12.0	29.7
Ben Tre	235950	6.21	7.58	9.87	12.8	17.0	22.2
Tra Vinh	234120	0.80	1.02	1.33	2.38	4.93	21.3
Vinh Long	152020	6.55	7.49	8.23	8.97	11.27	18.83
Dong Thap	337860	0.36	0.69	0.96	1.28	1.94	4.64
An Giang	342400	0.08	0.16	0.29	0.49	0.90	1.82
Kien Giang	573690	7.77	19.8	36.3	50.8	65.9	76.9
Can Tho	140900	1.44	1.59	1.90	2.77	6.54	20.52
Hau Giang	160240	3.41	10.27	20.55	32.05	42.66	80.62
Soc Trang	322330	2.46	5.88	10.8	16.7	25.8	50.7
Bac Lieu	252600	3.65	7.65	14.5	23.4	33.8	48.6
Ca Mau	528870	8.47	13.7	21.9	30.3	40.9	57.7
Mekong Delta in total	***3969550***	***4.48***	***8.58***	***14.7***	***21.0***	***28.2***	***38.9***

The results show that with a 100 cm sea level rise, the inundations for provinces would be as follows:

- Hau Giang province has the highest percentage area of inundation (80%), Binh Thuan province has the lowest (0.18%);

- Inundation of the Red River Delta and Quang Ninh province are about 16.8% and 4.89% area, respectively;

- About 1.47% area of the Central from Thanh Hoa to Binh Thuan would be inundated, highest is in Thua Thien Hue province (7.69%);

- About 17.8% area of the Ho Chi Minh city and about 4.79% area of Ba Ria - Vung Tau would be inundated;

- The highest percentage area of inundation is in the Mekong Delta (38.9%).

4.4.2. Inundation maps for islands and archipelagos of Viet Nam

Van Don Island group, Con Dao and Phu Quoc Island have high percentage areas of inundation. There is a low inundation area for Truong Sa Archipelago. Hoang Sa Archipelago has higher inundation area, especially the Luoi Liem and Tri Ton Island group.

4.5. Remarks on other factors that may affect inundation

As mentioned above, inundation due to sea level rise caused by climate change is defined based on sea level rise scenarios. Other dynamical factors such as tectonic uplift and subsidence, land subsidence due to groundwater extraction are not considered. This session provides some general information on tectonic uplift and subsidence, and subsidence due to groundwater extraction basing on available results from researches and assessments.

4.5.1. Tectonic uplift and subsidence

Tectonic uplift and subsidence may decrease or increase the levels of inundation due to sea level rise under climate change, representing in three groups: (i) Tectonic subsidence would lower surface topography, therefore, the level of inundation due to sea level rise caused by climate change would be exacerbated; (Ii) The level of flooding in the regions of stable tectonics would be the same as that due to sea level rise under climate change; (iii) Tectonic uplift would raise the tectonic terrain surface, and thereby reducing the level of inundation due to sea level rise under climate change.

Mekong Delta: The General Department of Geology and Minerals of Viet Nam (2015) analysed the geological causes of lifting, such as: slow tectonic movements in pre-Holocen bed rock exposing regions; new compressive sediment; groundwater extraction; human activities, and magnetic-variability of rock. The results can be summarized as follows:

- The trend of tectonic uplift and subsidence had a difference in the blocks structure and geodynamics with the minimum average absolute subsiding speed of 2.3÷2.7 mm ±1 mm/year, the maximum of 19.9±3 mm/year, **on the average of 6±3 mm/year**, accounting for about 67% of the study area, which developed on the terrain formed by Holocene sediments of the blocks in Ca Mau - Phung Hiep and in Vinh Long - Tan An.

- The minimum rate of uplift was 0.8 mm/year, the maximum was 20.6±3 mm/year, the minimum average rate of uplift was 2.7 mm/year and the maximum average rate of uplift was 7.1±3 mm/year, the geodynamics blocks had average uplift trend of 5.9±3 mm/year, accounting for about 33% of study area, which developed on exposing Kainozoi sediments of the blocks in Dat Mui - Chau Doc and Dong Nai - Vung Tau.

- Vertical shifting at 5 stable and reliable geodynamic landmarks (A001, A007, A011, A013, A016) in the Mekong Delta showed that subsiding speed was 19.9 mm/year (A014 milestone in Can Gio), the largest speed of uplift 20.6 mm/year (A005 milestone in Hon Dat).

- The shifting of tectonic uplift and subsidence between geodynamic blocks in international reference system IGb08: geodynamic building blocks of Ha Tien - Kien Hai had the signals of absolute subsidence of 8.9 mm/year, Dat Mui - Ca Mau block has an absolute uplift of 11.3 mm/year, Ca Mau - Phung Hiep block had an absolute subsidence of 7.4 mm/year and Vinh Long - Tan An block had an absolute subsidence of 11.8 mm/year.

- Results acquired from geodynamic model: the amplitude of lifting and subsiding due to the cohesion by Holocene sediments was 0÷4 mm/year; Groundwater extraction led to subside about 0÷3.5 mm/year, the amplitude due to tectonic activities was 0÷1.5 mm/year shifting time. The total amplitude of the subsidence in the structural unit geodynamic changes was 0÷4.3 mm/year in developing regions of Holocene sediments. Total magnitude of uplift was 0÷6.7 mm/year in the area revealed sediments before Cenozoic. According to the GPS data, the greatest magnitude of uplift was nearly 5 times larger than the greatest magnitude of subsidence and nearly 6 times larger than the largest magnitude identified from dynamical models. However, on average, the rate of subsidence from 5 stable and reliable landmarks was just about 2.7 mm/year, almost equal to the amplitude identified from geodynamic models.

Central Coast:

According to the results of national projects BDKH-42, the amplitude of modern tectonic lifting for some areas along the coastal strip of the coast area of the Central can be summarized as follows: some areas have obviously expressed the tectonic subsiding due to the tectonic collapse by the operation of the fault as the tub pulled apart at a rate of 0.13 cm/year lower loss (Ho Hao Son, Phu Yen) to 1 cm (the Quy Nhon) and more than 2 cm/year (Cua Dai, Quang Nam). Many areas in the region have increased the speed of tectonic from under 1 to several mm/year and lifting tectonic levels in different regions is uneven, ranging from a few mm/year to less than 1 cm/year. Phu Yen area is generally located in the tectonic uplift is mainly but increased the uneven pace, from 0.16 cm/year in Ganh Ba, 0.27 cm/year at Hon Yen, 0.48 cm/year in Phong Nien, and 0.07 cm/year in Ban Thach. Similarly, tectonic uplifts are common in Ninh Thuan region but at different lifting speeds, highest in the north 0.40 cm/year (in Nui Chua), 0.21 cm/year in Ca Na, and 0.16 cm/year in Nha Ho. High uplift speed is found in Cam Ranh (Khanh Hoa), up to a value of 0.50 cm/year. Areas with high tectonic subsidence are most vulnerable to inundation due to sea level rise caused by climate change.

In 2014, the Government assigned the Ministry of Natural Resources and Environment to develop and implement a project to check the stability of the national topographic land level marks for the provinces as Tien Giang, Dong Thap, Vinh Long, Tra Vinh, Hau Giang, Soc Trang, Ben Tre, An Giang, Kien Giang, Bac Lieu, Ca Mau, Ho Chi Minh City and Can Tho City. The results of the project will enable the assessment of tectonic uplift and subsidence..

4.5.2. Land subsidence due to groundwater extraction

Changes in land surface elevation due to geological factors is a continuous process that occurs in deltas. Some processes may rise or subside the land surface elevation like sedimentation, sediment compaction, dehydration, erosion and organic deposition. The changes in elevation of the land surface can occur due to the lifting of the tectonic activities or the deposition of silt in delta regions. In fact, many deltas were subsided instead of rising up by silt. The reason is that the source of sediment in the delta region is deficient because of upstream dams and reservoirs, the constructions of flood control. Natural subsidence due to the compaction of sediment can reach to 10 mm/year.

Excessive groundwater extraction is also a cause of geological subsidence. There has been no formal evaluation of geological subsidence rate due to groundwater extraction in the country.

According to preliminary results of the research carried out by the cooperation between Viet Nam and the Geotechnical Institute of Norway for the Ca Mau province, the pace of geological subsidence due to groundwater extraction in Ca Mau is in a range of 1.9 to 2.8 cm/year. However, this estimation is only based on the level of groundwater extraction in the province, no actual measurements, thereby reference only.

The Prime Minister has approved a project "Investigation and assessment of the exploitation and use of underground water affecting the land surface subsidence for Ha Noi City, Ho Chi Minh City and the Mekong Delta, orienting the management, exploitation and sustainable use of groundwater resources". The project will be implemented from 2016 to 2020. One of the key objectives of the project is "... to assess the current status and changes in land surface subsidence in the areas of groundwater extraction and low groundwater level; and determine the impact of the exploitation of underground water induced the land surface subsidence ...". The results of the project will be updated in the next versions of climate change and sea level rise scenarios.

V. Conclusions and Recommendations

5.1. Conclusions

The 2016 version of the climate change and sea level rise scenarios were developed based on the knowledge gained from the previously released scenarios. The meteorological, sea water level and terrain data of Viet Nam were updated. The latest methods used in the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, the global and regional climate models, as well as statistical methods have been applied for regionally detailed computation for Viet Nam.

Comments and suggestions from line ministries, sectors and provinces on exploiting and applying the climate change and sea level rise scenarios for Viet Nam were taken in to account in the developing process of the scenarios.

Climate change, sea level rise scenarios can be summarized as follows:

- ***Temperatures*** show an increasing trend in all regions of Viet Nam compared to the reference period, with highest increase in the North. ***For the RCP4.5 scenarios***, by early 21st century, average annual temperatures would increase by 0.6÷0.8^{o}C across the country. By mid-21st century temperatures would increase 1.3÷1.7^{o}C in general, in which increase 1.6÷1.7^{o}C in the northern regions (Northwest, Northeast, North Delta), 1.5÷1.6^{o}C in the North Central Coast, 1.3÷1.4^{o}C in the South Central Coast, Central Highlands and South. By late 21st century, temperature would increase 1.9÷2.4^{o}C in the North, and 1.7÷1.9^{o}C in the South. ***For the RCP8.5 scenarios***, by early 21st century, average annual temperatures would increase 0.8÷1.1^{o}C. By mid-21st century, temperatures would increase 1.8÷2.3^{o}C, in which increase 2.0÷2.3^{o}C in the North, and 1.8÷1.9^{o}C in the South. By late 21st century, temperatures would increase 3.3÷4.0^{o}C in the North, and 3.0÷3.5^{o}C in the South. The average maximum and minimum temperature changes are expected to be “considerably higher” than mean temperature for both scenarios.

- ***Rainfall*** tend to increase over the whole country. ***For the RCP4.5 scenarios***, by early 21st century annual rainfall would increase in most regions of the country with general values of 5÷10%. By mid-21st century, rainfall would increase 5÷15% in general, while some coastal provinces in the North Delta, the North Central and the Mid-Central the increase would up to 20%. By late 21st century, the rainfall patterns are similar to that of mid-21st century, however, the areas with an increase of over 20% would expand. ***For the RCP8.5 scenarios***, annual rainfall would increase in the same trend of the RCP4.5 scenarios. However, the highest increase would be over 20% in most of the North, the Central Coast, part of the Central Highlands and the South by late 21st century. Changes in short term rainfall events will be higher than annual changes. The average 1-day and 5-day maximum rainfalls would increase by 10÷70% compared to the reference period in the western parts of the Northwest, the Northeast, the Red River Delta, the North Central Coast, Thua Thien - Hue to Quang Nam, the eastern South, the southern Central Highlands, and 10÷30% for other regions.

- ***Monsoon and other climate extremes: The number of typhoons and tropical depressions*** may decrease, occurrence would be more concentrated to the end of the typhoon season which is the main period of typhoon activity in the South. Strong to very strong typhoons would increase. ***The summer monsoon*** would start earlier and end later. Rainfall during monsoon activity would increase. ***The number of extreme cold and damaging cold days*** would decrease in the northern mountainous provinces, the Red River Delta and the North Central. ***The number of hot days*** (Tx ≥ 35^{o}C) has increasing trends in most parts of the country, the largest number wold be in the North Central, the South Central and the South. ***Droughts*** would become more severe in some regions because of increased temperatures and rainfall deficits in the dry season (e.g. spring and summer in the South Central, spring in the South and winter in the North).

- Sea level rise scenarios: Sea level rise in the coastal areas of Viet Nam would be higher than the average global sea level rise. The sea level rise at the central and south of the East Sea would considerably be higher than other regions. Sea level rise along the southern coast would be higher than along the northern coast. ***For the RCP4.5 scenarios***, the average sea level rises for coastal areas throughout Viet Nam would be about 22 cm by 2050 (14÷32 cm), and about 53 cm (32÷76 cm) by 2100, in which the lowest sea level rise would be about 53 cm (32÷75 cm) in the regions of Mong Cai - Hon Dau and Hon Dau - Deo Ngang. Sea level rise would be about 55 cm (33÷78 cm) from Ca Mau to Kien Giang. Highest sea level rise would be in the regions of Hoang Sa and Truong Sa archipelagos, with values of 58 cm (36÷80 cm) and 57 cm (33÷83 cm), respectively. ***For the RCP8.5 scenarios***, the average sea level rises for coastal areas throughout Viet Nam would be 25 cm by 2050 (17÷35 cm), and 73 cm (49÷103 cm) by 2100, in which the lowest sea level rise would be 72 cm (49÷101 cm) in the regions of Mong Cai - Hon Dau and Hon Dau - Deo Ngang. Sea level rise would be 75 cm (52÷106 cm) from Ca Mau to Kien Giang. Highest sea level rise would be in the regions of Hoang Sa and Truong Sa archipelagos, with values of 78 cm (52÷107 cm) and 77 cm (50÷107 cm), respectively.

- Inundation due to sea level rise caused by climate change: If sea level would rise to 100cm and there would be no adaptation measures, an area of about 16.8% of the Red River Delta, 1.5% of the Central Coast from Thanh Hoa to Binh Thuan, 17.8% of Ho Chi Minh City and 38.9% of the Mekong Delta would be in high risk of inundation. Van Don Island group, Con Dao Island and Phu Quoc Island have high inundation risk. There is a low inundation risk for Truong Sa archipelago. Hoang Sa archipelago has a higher inundation risk, especially in Luoi Liem and Tri Ton island group.

The new aspects in the 2016 climate change and sea level rise scenarios in comparison with the 2012 scenarios:

1) State of the art data were used, including: (i) Observed metrological data of 150 stations on land and island from the meteorological observation network of the National

Hydro-Meteorology Service up to 2014; (ii) Observed sea water level data of 17 gauging stations along the coast and islands of Viet Nam up to 2014; (iii) Sea water level data measured by satellites till 2014; (iv) Topographic maps with scales 1:2,000, 1:5,000 and 1:10,000 measured by the projects under the National Target Program to Response to Climate Change updated till 2016.

2) State of the art results of global climate models (under CMIP5 project) were used, namely: NorESM1-M, CNRM-CM5, GFDL-CM3, HadGEM2-ES, ACCESS1-0, MPI-ESM-LR, NCAR-SST, HadGEM2-SST and GFDL-SST.

3) Dynamical downscaling were applied basing on 5 high-resolution regional climate models, namely: AGCM/MRI, PRECIS, CCAM, RegCM and clWRF. There are 16 computational cases in total.

4) Statistical methods were applied for bias correction of the model output based on the observed data to minimize the bias of model results.

5) Climate change scenarios and climate extremes were provided in detail for 63 provinces/cities, the Hoang Sa and Truong Sa archipelagos of Viet Nam and 150 meteorological stations (the detail is at district level).

6) Sea level rise scenarios were developed in detail for 28 coastal provinces, as well as Hoang Sa and Truong Sa archipelagos of Viet Nam.

7) Certainty levels in terms of percentile were estimated for climate change and sea level rise projections for the future.

8) Inundations due to sea level rise caused by climate change for the delta, coastal areas, islands and archipelagos of Viet Nam were estimated. For areas, where topographic maps scale 1:2000 is available, the level of detail of the inundation maps were at commune level.

9) Extreme water levels were assessed, including due to storm surges, tides, and storm surges in combination with tides of Viet Nam. This can help the users to understand the double impact of sea level rise due to climate change and extreme sea level due to natural factors such as storm surges and high tides.

10) Remarks on some factors that influence the inundation due to sea level rise caused by climate change are drawn, including the geological uplift and land subsidence as a result of groundwater extraction in the Mekong Delta and the Central coastal areas.

5.2. Recommendations

1) In using climate change and sea level rise scenarios for assessing impacts and developing response measures as well as the integration into the strategy, planning and socio-economic development plans, it is necessary to select scenarios suitable for specific sector and locality considering the following criteria: (i) characteristics (of sectors, local circumstance, etc); (ii) multi-purpose; (Iii) efficiency in many aspects (socio-economics, and environmental); (iv) sustainability; (V) feasibility, ability to integrate into strategies, policies and development plans.

2) When applying climate change and sea level rise scenarios for impacts and vulnerability assessments, and development of sectoral or provincial action plan, the following steps are recommended: (i) identification of critical climate parameters for the sectors or research objects; (ii) selection of climate change and sea level rise scenarios from the national scenarios; (iii) application of computational analysis tools to determine important information such as changes in flow regimes, floods, saltwater intrusion, typhoon surges, changes in shoreline, etc.

3) The development and implementation of response measures for climate change are not necessarily carried out on large and century scale. It should be with specific phases. Priorities need to be identified based on practical needs and available resources in each phase in order to select the most appropriate scenario.

4) Under the Paris Agreement on climate change, all countries must take action to keep the global temperature rise well below 2°C by the end of the century compared to the pre-industrial era. This means the RCP4.5 scenarios is more likely to happen than the other RCP scenarios.

5) The RCP4.5 scenarios can be applied to design standards for non-long-term projects and short-terms plans.

6) The RCP8.5 scenarios should be applied to the permanent projects and long-term plans.

7) Climate change and sea level rise scenarios always have uncertainties, which depend on the identification of GHG scenarios (socio-economic development in global scales, population growth and the level of world consumption level, standards of life and lifestyle, energy consumption and global energy resources, technology transfer from developed to developing countries, land use change, etc.), the limited understanding of the global climate system and regions, ice melting dynamics, methods and mathematical models for developing scenarios and more. Therefore, when applying climate change and sea level rise scenarios for impact assessments, it is necessary to consider and analyse carefully all the possible occurrences of a future climate. Users should consult appropriate experts in determining these values as well as the most relevant changes in the planning process.

8) Climate models are being further developed to enhance the reliability of climate change and sea level rise scenarios. Climate change and sea level rise scenarios will be continuously updated according to the schedule of the IPCC. Thus the impact and vulnerability assessments should be reviewed and updated when new scenarios are published. The Global Conference on Climate Change in 2015 requested the IPCC to publish in 2018 a special report on scenarios of greenhouse gas concentrations and its effects when the global temperature increases by 1.5°C compared to pre-industrial era. Based on that, up-to-date information will be supplemented to the climate change and sea level rise scenarios for Viet Nam.

9) It is noted that the inundation maps are based on the average sea level rise due to climate change. Other dynamical factors such as tectonic uplift and subsidence, topographical changes, land subsidence due to groundwater extraction, coastline change, influence of tides, storm surges, monsoon induced sea level rise, impact of hydropower cascade, and saline intrusion have not been considered in this scenarios. Transportation works and irrigation structures such as sea dykes and river dykes, embankments, roads, and others have not been considered when mapping inundation due to sea levels rise caused by climate change.

Therefore, when using the climate change and sea level rise scenarios for assessing impacts of climate change in more detail, the dynamical factors, and relevant infrastructures mentioned above, should be considered in the calculation, along with climate change induced sea level rise.

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