Vulnerability Assessment in Vietnam

Laure Collet, Caitlin Corner-Dolloff, Rod Lefroy

Decision and Policy Analysis Research Area
Centro Internacional de Agricultura Tropical (CIAT)

For submission to the Sumernet Secretariat
February 20123

International Center for Tropical Agriculture
Since 1967 / Science to cultivate change

Climate & Development Knowledge Network

Table of Contents

Abbreviations

ADW	Angular distance–weighted
CIAT	International Center for Tropical Agriculture (Centro Internacional de Agricultura Tropical)
CIP	International Potato Center (Centro Internacional de la Papa)
CRU	Climatic Research Unit
DAPA	Decision and Policy Analysis
GCM	Global Climate Models
GDP	Gross Domestic Product
GMS	Great Mekong Sub-Region
PSROI	Participatory Social Return on Investment
RCM	Regional Climate Model
SPS	Silvo-Pastoral Systems
SRES	Special Report on Emission Scenarios

List of figures

List of tables

Preface

This assessment, funded by CDKN and SUMERNET, makes up the first part of an on-going study on the vulnerability of crops in Vietnam to climate change that will be conducted by CIAT. The crops in this assessment pertained to Vietnamese study sites for the SUMERNET funded Participatory Social Return on Investment (PSROI): Greater Mekong Sub-region Climate Change Adaptation Planning and Costing Project. This study complements a similar assessment conducted by CIAT, with the support of GIZ, on crop suitability and land use in Lao PDR in 2010. Both products aimed as assisting with climate change adaptation decision-making. This assessment is being submitted as a project output to the SUMERNET secretariat, and is intended for publication along with the forthcoming assessment of all priority crops in Vietnam.

1. Introduction

1.1 Background

During the last 20 years, scientific advances and growing public awareness of climate change have generated an ever-widening body of literature on the issue, its causes and its potential effects. Many specialized institutions and organizations have been established at the international and national levels to research climate change, predict likely changes, assess likely impacts, and propose responses in terms of adaptation and emission mitigation. Research has tackled the subject from a variety of angles scientific, economic, social, and political.

The agriculture sector plays an important role in the economy and society of Vietnam. It is still widely regarded as the backbone of the economy. Despite the gradual reduction in its contribution to the country's total economic output, 21% of Gross Domestic Product (GDP) in 2009 (World Bank, 2012), the agriculture sector continues to provide the basis for an agro-based manufacturing sector. It also remains an important source of labour, with 60% of the labour force and represents 30% of exports (World Bank, 2012). In the last 15 years, there has been strong progress in the agricultural sector. Quality and quantity of rice production increased, better ensuring national food security and increasing exports, resulting in Vietnam being the 2nd biggest rice exporter after Thailand. Other crops such as maize, rubber, coffee, sugarcane and fruit trees also benefit from diversification policies and have become important exported crops and sources of income.

However, since climate is a major factor in agriculture production, a direct consequence of climate change will be an increase in the uncertainty of farmers' income sources and the concomitant impacts on livelihoods. Vietnam has been declared as one of the countries that may be the most affected by climate change (Dasgupta, 2007). Because of its long coastlines, high concentration of population and economic activity in coastal areas and heavy reliance on agriculture, natural resources and forestry, projected higher temperatures, climate variability, floods, droughts, severe storms and sea level rise may result in significant challenges for Vietnam. Potential damage to agriculture and aquaculture may have enormous economic, cultural and environmental impacts. Climate change also threatens food security through potential crop losses and yield declines. The exact nature and the extent of these changes though, and their likely impacts on agriculture and the environment, are not well understood at the national level, let alone at the level of the farmer.

1.2 Objectives of this study

The vulnerability assessment was designed to evaluate the exposure of agriculture to climate change as a background before applying the PSROI methodology. Specific objectives are:

1. Identify past changes in climate over the 20th century.
2. Assess potential future climate change in the medium-term horizon (2050), based on the IPCC A2 emission scenario.
3. Evaluate crop suitability for the 15 most important crops according to current climate conditions
4. Predict potential impacts of climate change on crop suitability on a country-wide scale for 2050, based on the IPCC A2 emission scenario.

2. Past and future climate of Vietnam

2.1 Introduction

As agriculture remains a major component of Vietnamese society and the major activity of Vietnamese people, climate is an important driver of the economy and individual livelihoods, especially the vulnerable rural poor. The potential for agricultural production is determined by many biophysical factors including climate, soil quality, topography, latitude and altitude; the main factor affecting annual yields is climate, in particular the amount and distribution of rainfall.

Projecting the likely impacts of climate change on agriculture in the next few decades requires first assessing how much climate has historically changed as well as how much climate is likely to change, and then relate these climate predictions to agricultural production. The natural variation in climate, both cyclical and non-cyclical, on an intra-annual, inter-annual, and on a longer-term basis, means that variations in climate need to be assessed over an extended period for there to be any confidence that the changes are not just a component of natural variation. This requires extensive records (Lefroy et al., 2010).

The IPCC has coordinated and assessed the results of climate change research and produced regular reports. The IPCC Third Assessment Report (IPCC, 2001) indicated that globally, the average diurnal temperature increased by 0.6ºC in the 20th century. This overall trend breaks down as a significant increase from 1910 to 1945, a slight decrease from 1945 to 1965, and a marked increase from 1976 to 2000. There was a general reduction in low temperature extreme events and an increase in high temperature extreme events. For rainfall, there were geographically differentiated increases and decreases in precipitation of at least 1% per decade. There was an increase in the frequency and the intensity of heavy rainfall events and an increase in cloud cover. A consequence of these various changes was an increase in sea level of between 0.1 and 0.2 meters.

While the potential for anthropogenic global warming was proposed more than a century ago, it is only in the last decade or so that the evidence has become very strong, and only in the IPCC's Fourth Assessment Report in 2007 did the organization of scientists conclude: "Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations."

2.2 Methodologies for assessing climate and climate change

2.2.1 Method for analysing past climate trends

The dataset and methodology of New et al. (2000) were used to reconstruct the Vietnamese climate from 1901 to recent times. This reconstructed climate was then analysed for spatial and temporal changes in a range of climate parameters.

The CRU TS2.1 Climate Dataset was produced by the Climatic Research Unit (CRU) of the University of East Anglia, and reformatted by Antonio Trabucco at the International Water Management Institute (IWMI) for the CGIAR-CSI into ArcInfo Grid format, to provide easy access (http://csi.cgiar.org/cru/) and use for geospatial analysis using common GIS software. The creator of this dataset and CRU retain full ownership rights (Mitchell and Jones, 2005).

The CRU TS 2.1 Global Climate dataset is comprised of 1224 monthly time-series of climate variables, for the period 1901 to 2002, covering the global land surface, excluding Antarctica, at 0.5 degrees resolution. Database was reconstructed by angular distance–weighted (ADW) interpolation, from stations dataset across the globe. The eight nearest stations, weighted by distance, were used for interpolation of each data point. For this study, the data from 166 data points, each one representing 0.5° by 0.5°, were required to cover the full extent of the Republic of Vietnam (figure 2.1), a total area of 331,698 km^2. The 0.5° by 0.5° data points represent rectangle areas of approximately 55.5 km from east to west and 51.3 to 55.8 km from north to south, depending on the latitudinal point (approximately 8.5° to 23° N). Thus each data area represents between 2,850 and 3,100 km^2. It is a large extent where climate can vary a lot, but this doesn't affect seriously the interpretation of results, as we are only using this size of resolution for identifying general trends of climate evolution at regional and national scale.

The nine climate variables available through the CRU dataset are daily mean, minimum and maximum temperature; precipitation; wet day frequency; diurnal temperature range; frost day frequency; vapour pressure and cloud cover. In this study the analysis was carried out on the annual mean, minimum, and maximum temperature; and the annual total rainfall.

The annual temporal variation in climate parameters is large, especially for variables such as rainfall. For this reason, analysis and more particularly depiction of such time series data must first be smoothed to make the trends more easily observable (figure 2.2). The most common technique is moving average smoothing, in which the non-systematic variations are cancelled by replacing each data point of the series by an average of the point and a number of surrounding points preceding and following it (Box and Jenkins, 1976; Velleman and Hoaglin, 1981). In this study, the CRU data for 1901 to 2005 was smoothed using a 10 year moving average to depict of the data and trends in graphs. For the statistical analysis, however, the unsmoothed data was used because using the smoothed data would have reduced the effective period of analysis is to 1905 to 2000, which could have affected, albeit slightly, the analysis of trends.

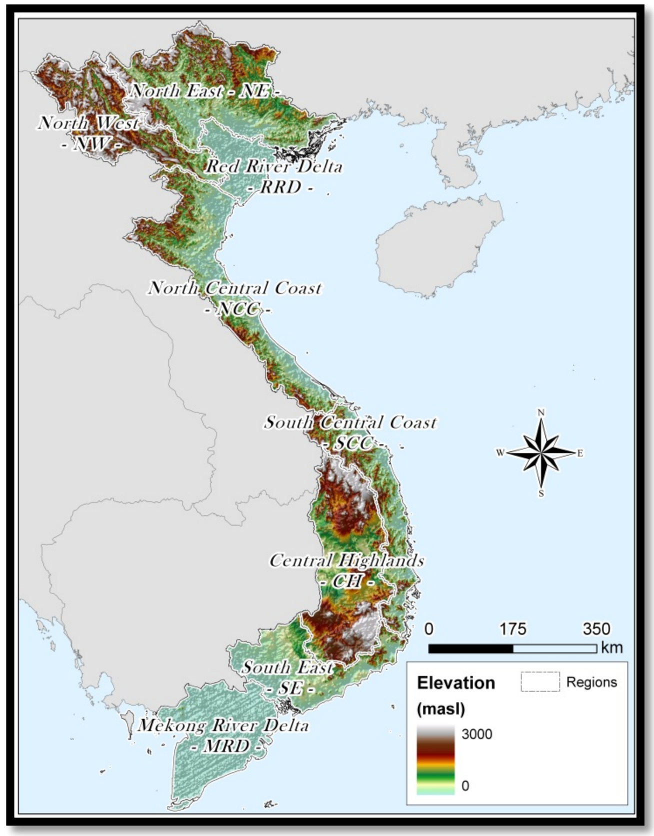


Figure 2.1 General map of Vietnam

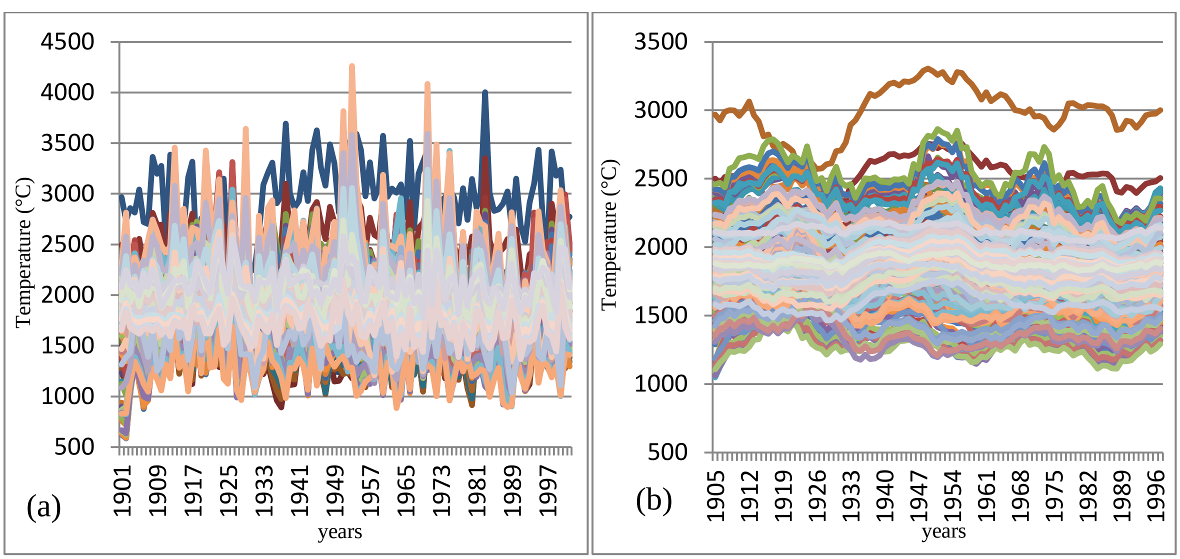


Figure 2.2 Real (a) and smoothed (b) temperatures values for the 166 data points covering Vietnam territory.

2.2.2 Methods for projecting the Vietnamese climate to future

Assessing to what degree the climate is likely to change involves the projection of data from climate models. The data used in this study are based on the mean of the nineteen Global Climate Models (GCM) used in the IPCC 4th Assessment Report (IPCC, 2007) for the medium time horizon of 2050.

The datasets used are part of the International Center for Tropical Agriculture (CIAT) climate change downscaled data, developed in the Decision and Policy Analysis (DAPA) program of CIAT. The data were downloaded originally from the IPCC data portal and re-processed using a spline interpolation algorithm of the anomalies and the current distribution of climates from the WorldClim database developed by Hijmans *et al.* (2005a). It is assumed that the geographies of changes in climate variables do not vary too much at regional scales and that the relationships between the different variables will remain basically the same in the future. The data surfaces used were generated using an empirical downscaling approach, which is the method preferred by CIAT and many others, rather than re-modelling the climate patterns using an RCM (Regional Climate Model) (Lefroy et al., 2010).

The downscaling process includes the following: (i) calculation of anomalies (if they are not provided directly by IPCC) by simply subtracting the future value of each variable with the baseline, (ii) interpolation of anomalies to a 30 arc-seconds resolution (approx. 1km) and (iii) addition of the interpolated anomalies to the current distribution of climates in WorldClim (www.worldclim.org). For temperature an absolute sum is used, but for precipitation the relative differences are used, as there are differences between the GCM baseline and the WorldClim baseline.

The IPCC Special Report on Emission Scenarios (SRES) (2000) included scenarios grouped into four families of scenarios, namely, A1, A2, B1, and B2, with a total of 40 scenarios developed under these four families. The different scenarios produce large differences in the patterns of GHG-emissions during the 21st century (figure 2.3).

The A1 scenario family describes a future world of very rapid economic growth, global population that peaks around the middle of the 21st century and then declines, and the rapid introduction of new and more efficient technologies. This scenario assumes a substantial reduction in regional differences in per capita income, based on increased cultural and social interaction between and within nations. The A1 scenario family includes three sub-groups that describe alternatives in terms of energy systems. A1FI takes a fossil intensive pathway, A1T relies more on non-fossil energy sources, while A1B involves a balance between fossil and non-fossil fuel sources. The A2 scenario group describes a very heterogeneous world that maintains regional differences in population growth and economic development, and thus large regional differences are maintained in per capita income and in technological change. The B1 scenario follows a similar line to the A1 scenario in population growth, but with a rapid change in economic structures toward more service and information oriented economies and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity. Finally, the B2 scenario group describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. Global population increases at a rate lower than the A2 scenario, with intermediate levels of economic development, and slower and more diverse technological change than in the B1 and A1 scenarios.

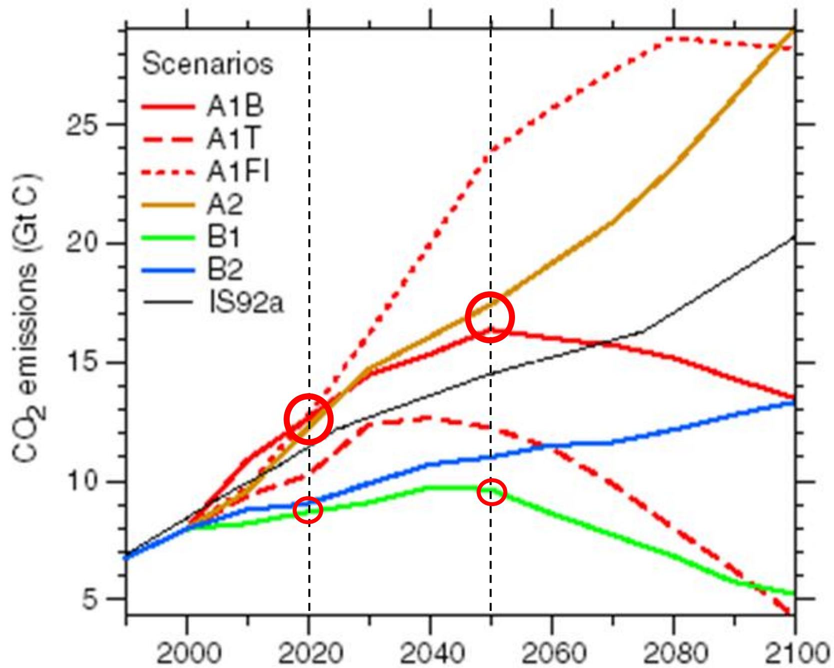


Figure 2.3 Six of the IPCC SRES emission scenarios from 2000 compared to the earlier, 1992, IPCC IS92a "business-as-usual" scenario

The majority of climate change research groups have focused on three emission scenarios, namely A1B, A2, and B1, and these are the three for which large datasets exist. Of these three scenarios, B1 already looks much too optimistic, considering the trends in global GHG emissions, which have continued to resemble a business-as-usual scenario since 2000. While

A1B and A2 have very different outcomes in terms of expected GHG emissions, and thus impacts on climate change, most of these differences do not occur until after 2050.

Consequently, the projected climate of Vietnam is presented for 2050, under the A2 scenario. We first present general evolution of changes from present to 2050 and then, detail the alteration for 2050 climate prediction. As for past climate data, we used smoothed data to focus on long-term variation instead of inter-annual changes but thanks to GCMs resolutions we present it with a 1km resolution instead of 55km for past climate trends.

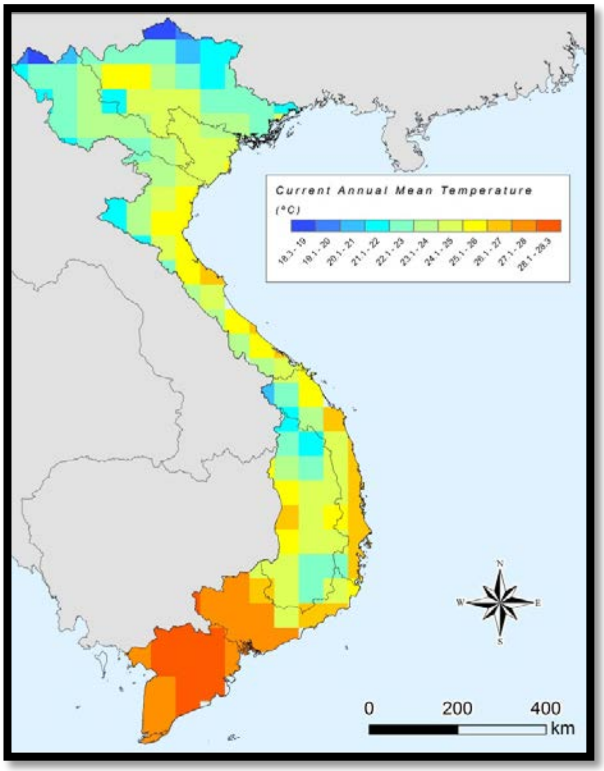
2.3 Reconstruction of Vietnam's 20th century climate

Vietnam's climate in the 20th century, from 1901 to 2005, was reconstructed according to the methods outlined in section 2.2.1 for four climate variables, namely annual mean, minimum, and maximum temperature, and annual precipitation. To visualize changes in climate, 2 types of figures are presented for each variable: First current climate variable values are presented on map. Current conditions are estimated by the average over 20 years from 1982 to 2002. Second, graph presents the evolution from 1901 to 2005 (for smoothed data) for the 8 regions of Vietnam.

2.3.1 Evolution of annual mean temperature in the 20th century

The annual mean temperature for the 166 data cells that cover Vietnam presents a range across the country of about 10°C, from 18.3 to 28.3°C (figure 2.4). Coldest temperatures are located in the mountainous terrains in the North of the country while hottest areas are in the southern Mekong River Delta region. Globally, mean temperature follow an increasing gradient from North to South, this gradient is partly affected in the central regions by high plateaus with temperate climate.

Figure 2.5 shows evolution over time of temperature for the 8 regions of Vietnam. The solid line represents the smoothed average value for the region, and broken lines represent its linear regression. Regions can be clearly divided in 3 groups according to their mean temperature and latitude. Hotter regions are the South East and Mekong River Delta regions in the south with average temperature values from 26 to 28°C. Medium regions are the 4 central regions: Central Highlands, South Central Coast North Central Coast and Red River Delta with values from 23.5 to 25°C. As explained in previous paragraph coldest region are the 2 extreme North regions: North East and North West, with values from 21.5 to 22.5 °C. All regions show a slight increase in temperatures over the 20th century. Hot regions of the South present a regular increase since 1935. Central and Northern regions present strong variability in the first part of the century, and, after a stable period from 1950 to 1980, mean temperature is increasing in all these regions. For the 8 regions of Vietnam, the increasing tendency is strongest after 1990.



Temperature (°C)

Years

Figure 2.5 Smoothed Annual Mean Temperature from 1905-2000 for the 8 regions of Vietnam. Solid line represents the average smoothed value for the region and broken lines represent linear regression trendlines.

2.3.2 Evolution of annual minimum temperature in the 20th century

The minimum temperature can be an important factor in controlling which plant species grows where and how well. The incidence of frost is a well-recognized determinant of species suitability and even survival, but the general minimum temperature also has broad impacts on many other aspects of plant physiology, especially with regard to reproduction and product quality. In many cases, because of impacts on reproduction, the heat tolerance is as much defined by tolerance to higher minimum temperatures as it is by tolerance to higher maximum temperatures.

Figure 2.6 shows a similar repartition of minimum temperature than mean temperature with lowest values in the North and highest in the South. Total range of minimum temperatures over the country varies from 13.7 to 24.5°C. Figure 2.7 presenting the evolution of minimum temperature over the 20th century in the 8 regions of Vietnam, highlighting different behaviours according to the regions. Two regions from the Northern part of the country, North East and Red River Delta, present a global decrease in minimum temperature values over the 20th century, with negative slope values for the regression trend lines. The North West and North Central Coast regions seem to have stable values of minimum temperature from 1905 to 2000. And all Central to Southern regions, including South Central Coast, Central Highlands, South East and Mekong River Delta, show increasing minimum temperature values. However, all regions present a quite strong increase between 0.4 – 1.0°C in the last 30 years, even if the global tendency in the century is stable or negative. The slope of the increase is even more important for most of them after 1990.

2.3.3 Evolution of annual maximum temperature in the 20th century

The maximum temperature is another important determinant of species suitability, with major impacts on physiology, particularly on enzyme reactions and on water relations.

Figure 2.8 shows similar tendencies for maximum temperature than for mean and minimum temperature with a spatial distribution from lowest values in the North to highest values in the South. Figure 2.9 shows that the 3 Southern regions (Mekong River Delta, South East, Central Highlands) of the country are more affected by maximum temperature increase over the 20th century than the 5 other regions, which seem to remain globally stable from 1905 to 2000 (according to slope value for the regression trend line). However, graph shows that all regions present an increase in maximum temperature from the 1970's, the tendency of the increase getting higher after 1990.

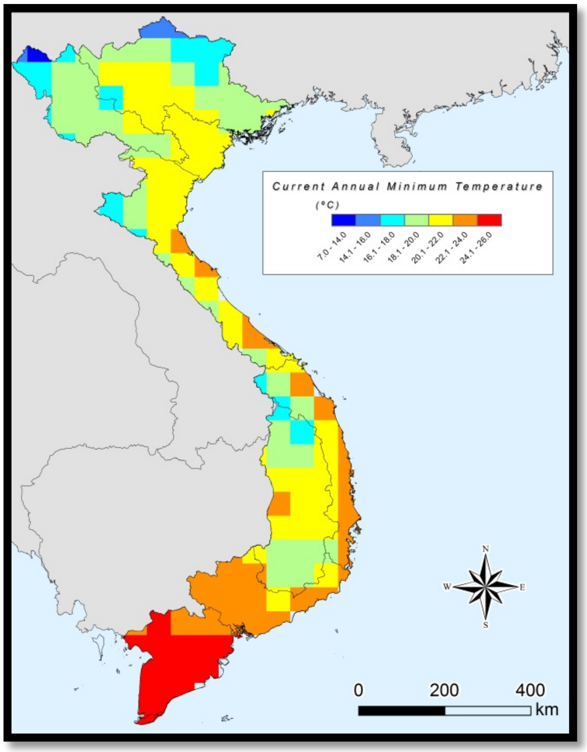


Figure 2.6 Average Annual Minimum Temperature for the current period (1982-2002)

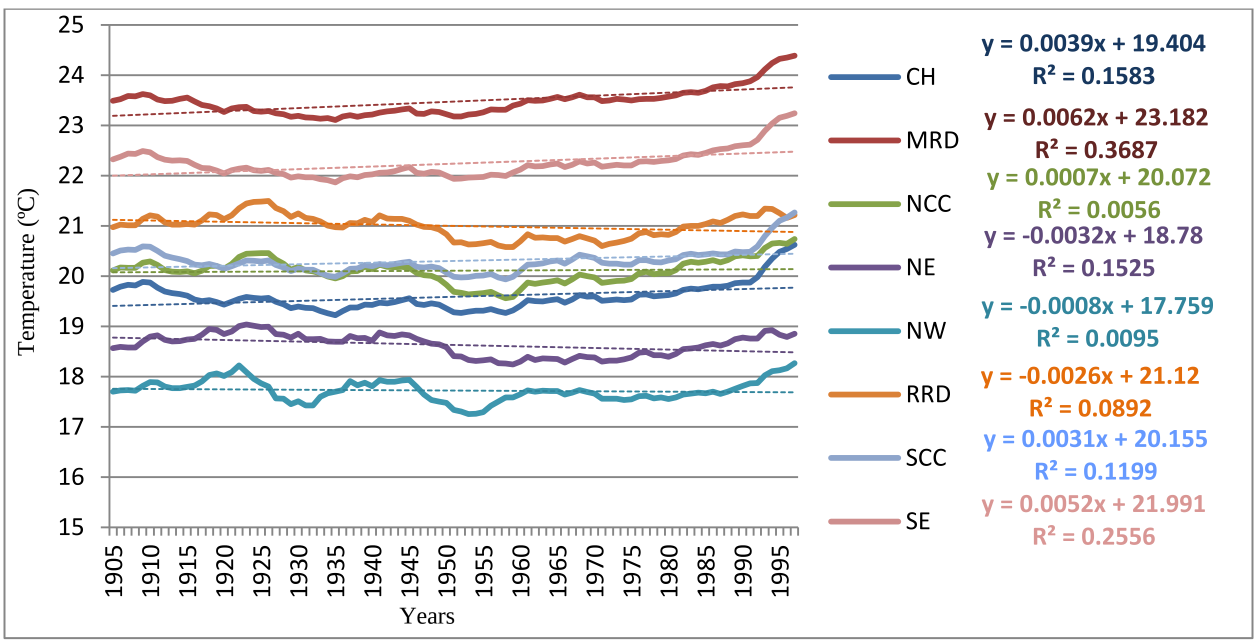


Figure 2.7 Smoothed Annual Minimum Temperature from 1905-2000 for the 8 regions of Vietnam. Solid line represents the average smoothed value for the region and broken lines represent linear regression trendlines.

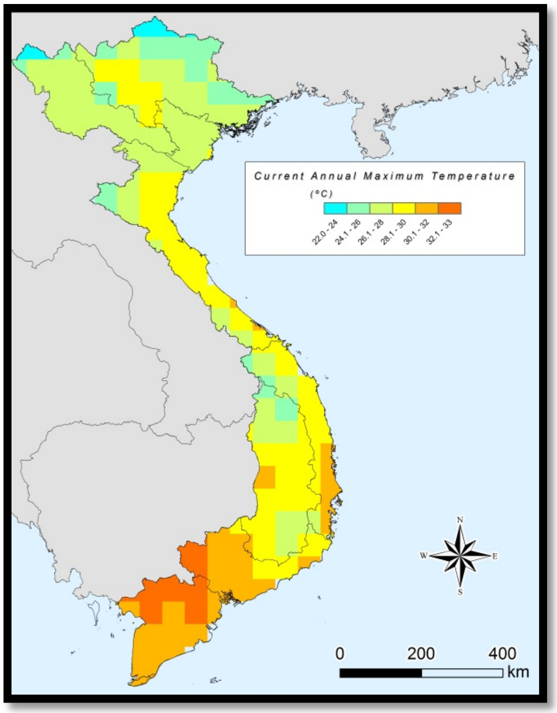


Figure 2.8 Average Annual Maximum Temperature for the current period (1982-2002)

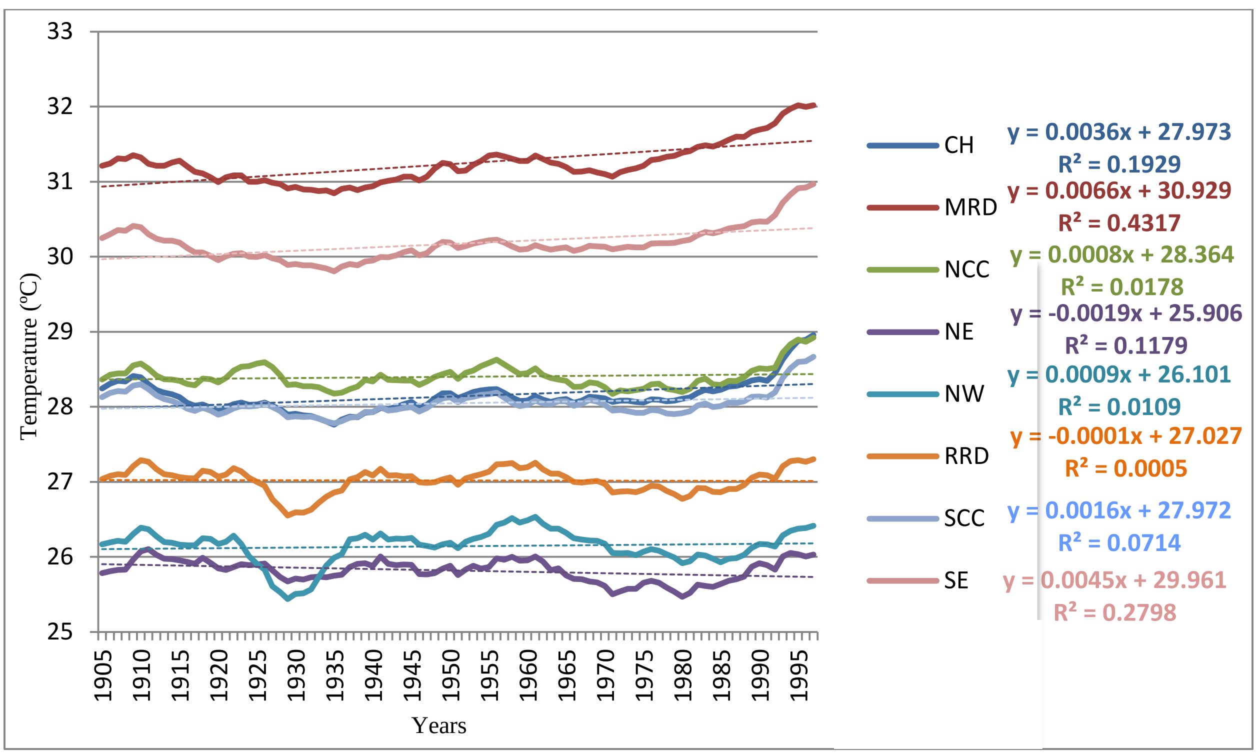


Figure 2.9 Smoothed Annual Maximum Temperature from 1905-2000 for the 8 regions of Vietnam. Solid line represents the average smoothed value for the region and broken lines represent linear regression trendlines.

2.3.4 Evolution of annual precipitation evolution in the 20th century

Currently, annual precipitation varies from 1200 to 2300 mm in Vietnam. The driest areas are located in the extreme North of the country, while the wettest area corresponds to the North Central Coast. The Mekong River Delta region is also in the wettest areas of the country with values from 1900 to 2100 mm (figure 2.10). Intermediate regions present values from 1600 to 2000mm per year.

The most apparent conclusion from the plots of annual precipitation over 1905 to 2000 is the enormous variability between the years (figure 2.11), which is much greater than for the temperature variables. This is something that every farmer knows and expects, so precipitation variation poses a major obstacle to developing sustainable and relatively risk-free livelihoods. The country seems to have known different period of high and low precipitations. However general tendency for annual precipitation, according to regression trend lines, seems to be from stable values in the South (Central Highlands, Mekong River Delta and South East regions) to decreases in Central and Northern part of the country. In the last 20 years, after reaching a temporal minimum in the late 80's annual precipitation values are increasing again across all the country.

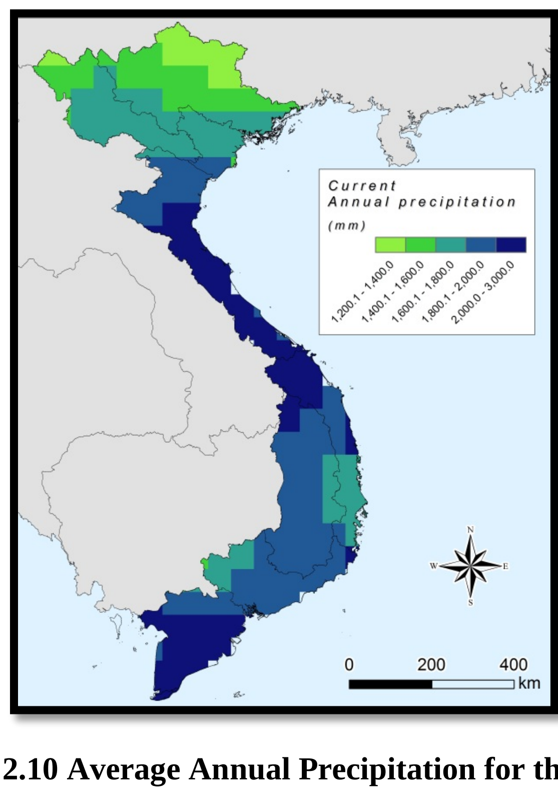


Figure 2.10 Average Annual Precipitation for the current period (1982-2002)

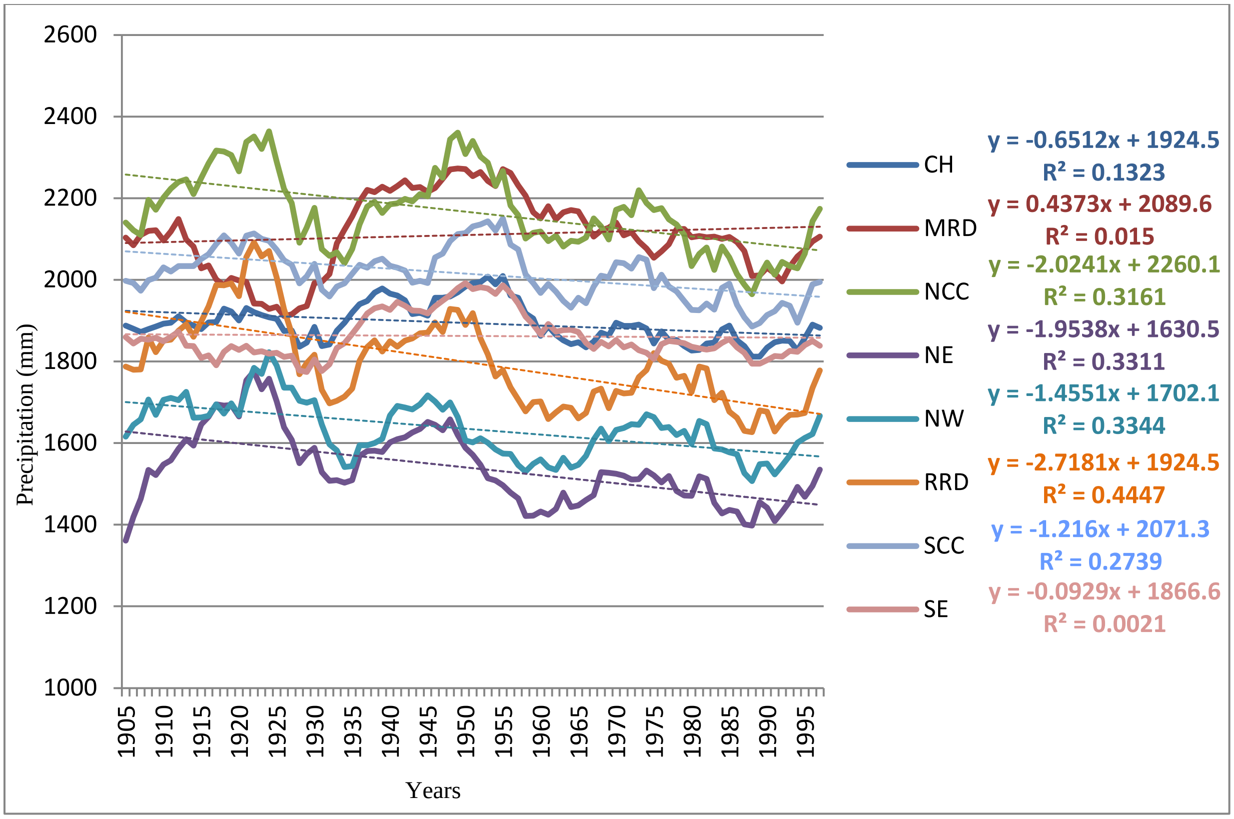


Figure 2.11 Smoothed Annual Precipitation from 1905-2000 for the 8 regions of Vietnam. Solid line represents the average smoothed value for the region and broken lines represent linear regression trendlines.

2.4 Projected changes in Vietnam's climate

The projections of the likely change in climate for Vietnam were based on the results of 19 GCMs and were projected and smoothed every 30 years from 2010 to 2050.

Of the three main scenarios in which modellers have been interested, SRES scenarios A1B, A2, and B1, it is clear that the B1 scenario is too optimistic and that, at least up until 2050, A1B and A2 are very similar. After 2050 the A2 scenario diverges onto a higher emission pathway. Due to this comparative lack of difference, only the A2 projections are presented. Some researchers suggest that even the A1B scenario is too optimistic, considering how much GHG emissions have continued to rise, and that the A1FI scenario may be more appropriate, but we hold that A1FI is on the pessimistic end.

To have global view of change in Vietnam's climate, results are presented in 2 steps for each of the 4 considered variables. First, evolution from 2010 to 2050 is observed through two visualisations. We observed graphical evolution of each variable at regional scale from current to 2050, with a 10 years step and mapped smoothed values comparing current, 2020 and 2050 predictions. Current values for comparison are extracted for the WorldClim database. Second, the predictions for 2050 are detailed and presented in the following format: Maps (a) and (b) present respectively minimum and maximum values of the variable across the 19 models. Map (c) presents the average value of the variables between the 19 models, and map (d) shows the difference between the average projections for 2050 and current values. To enable comparisons with the current climate, we use the same colour ranges for maps (a), (b) and (c) as in the maps presented in section 2.3.

2.4.1 Projected changes in temperature

Evolution from current to 2050

Figures 2.12 to 2.14 present evolution from 2010 to 2050 for annual mean, minimum and maximum temperature through graphical and maps representation. They show for the three variables a regular increase of temperatures. Broken lines connect GCMs projections to current values modelled by WorldClim. Interpretation on this part has to be careful, graphs show that GCMs tend to overestimate values comparing with WorldClim dataset (or WorldClim underestimate comparing with GCMs), but without climate data from local stations it is difficult to evaluate which of the model is biased. Mean temperature in all regions seems to increase by 0.9°C to 2020 on average for the entire country. Global increase to 2050 is expected to be by 2.00°C across the country but change is higher in the Northern than in the Southern region.

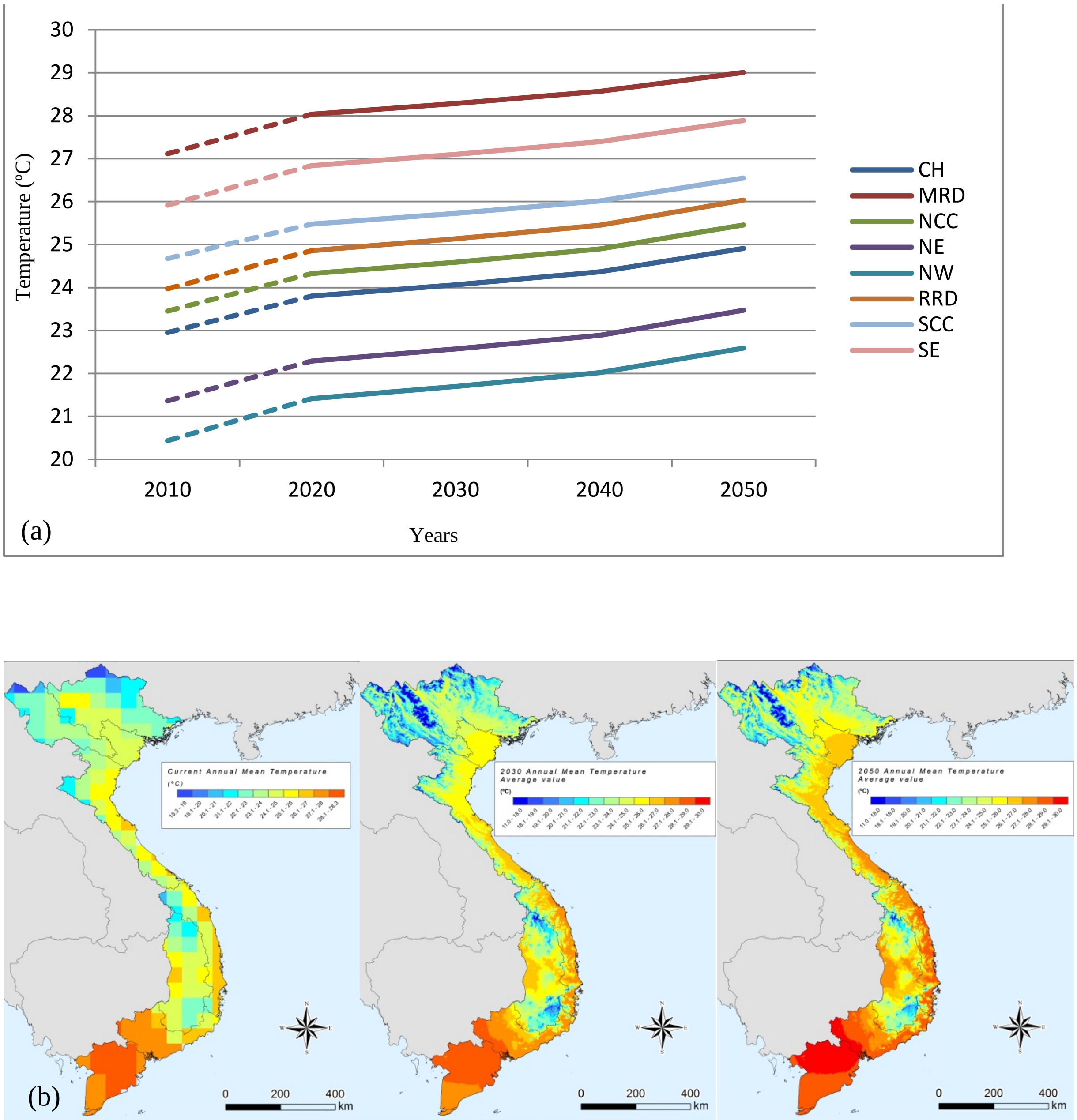


Figure 2.12 Annual mean temperature (a) evolution from 2010 to 2050 for the 8 regions (Solid lines represent the average value for the region for the 19 models and broken lines the connection of these average values to WorldClim current modelled data) (b) Maps for current, 2030 and 2050 climate. These results are the average value of prediction from 19 models wtih A2 scenario.

Minimum temperature is expected to rise by 0.6°C in the Northwest region to 1.1°C in the South Central Coast in 2020. Global increase for minimum temperature to 2050 is expected to be by 1.87°C across the country ranging from 1.7°C in Mekong River Delta to 1.9 in South East region.

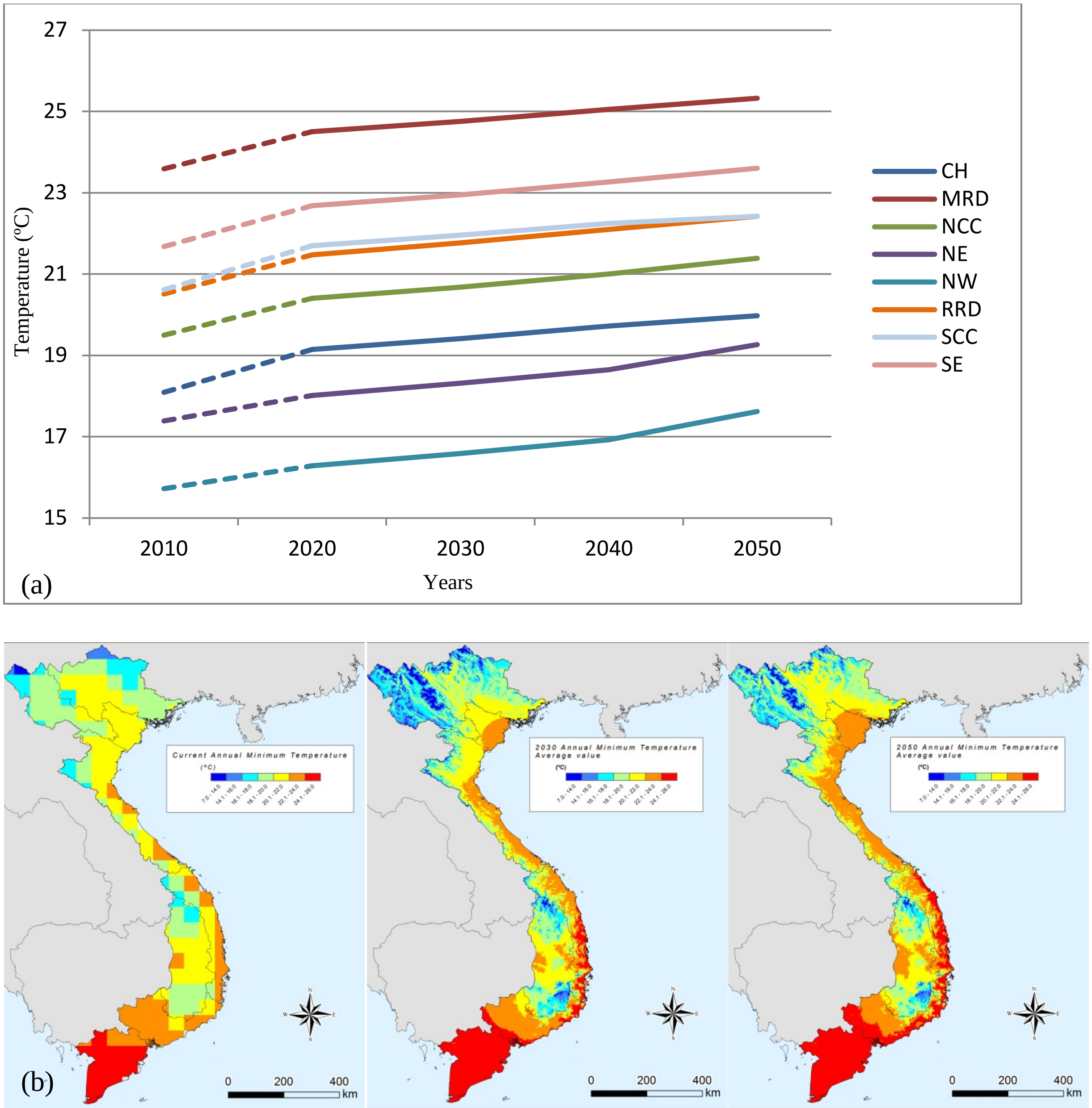
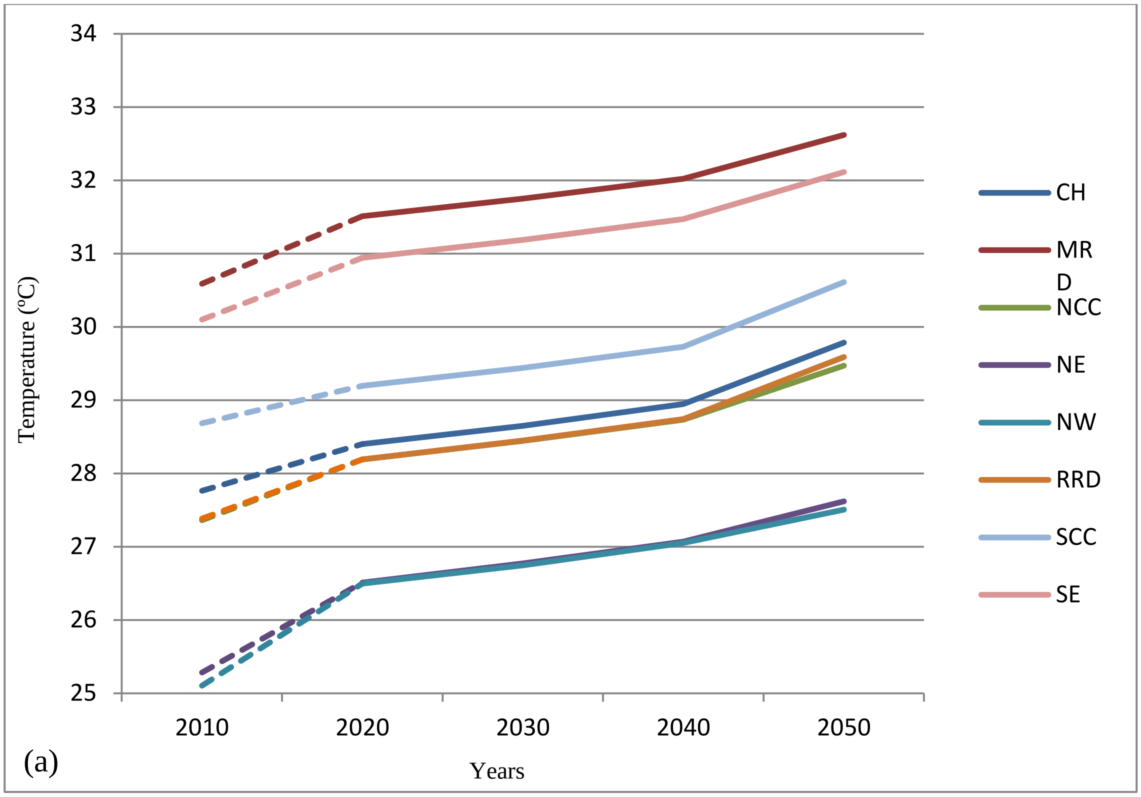


Figure 2.13 Annual minimum temperature (a) evolution from 2010 to 2050 for the 8 regions (Solid lines represent the average value for the region for the 19 models and broken lines the connection of these average values to WorldClim current modelled data) (b) Maps for current, 2030 and 2050 climate. These results are the average value of prediction from 19 models wtih A2 scenario.

Maximum temperatures seem to be the most affected by climate change. Change to 2020, range from 0.5°C in the South Central Coast region to 1.4°C in North West region. By 2050, maximum temperature is predicted to increase by 2.1°C across the country, from 1.9°C in the South Central Coast region to 2.4°C in the North West.



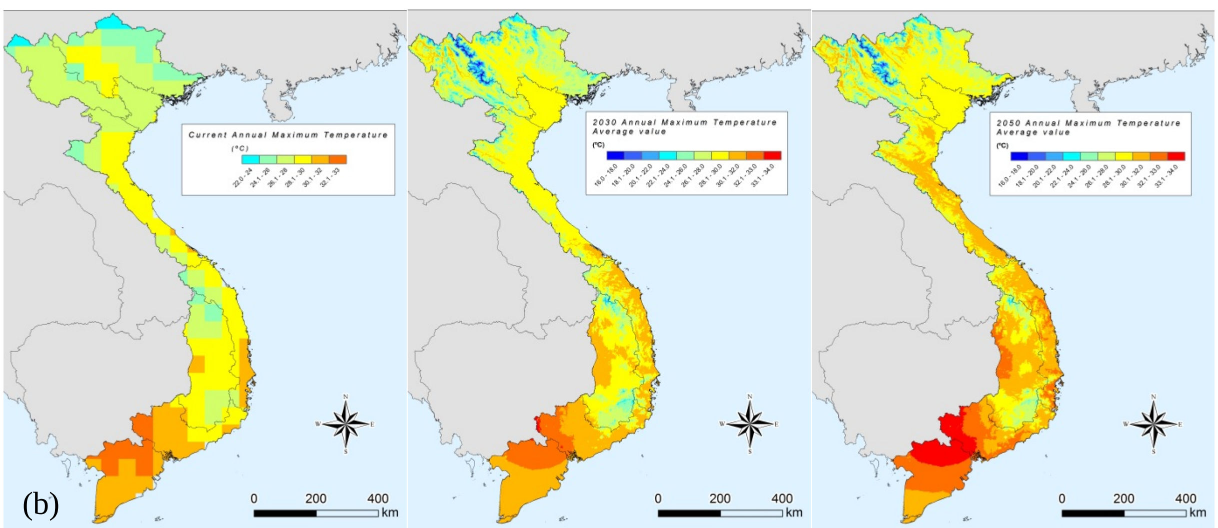


Figure 2.14 Annual maximum temperature (a) evolution from 2010 to 2050 for the 8 regions (Solid lines represent the average value for the region for the 19 models and broken lines the connection of these average values to WorldClim current modelled data) (b) Maps for current, 2030 and 2050 climate. These results are the average value of prediction from 19 models wtih A2 scenario.

Describing temperatures in 2050

Accordance between the 19 GCMs predictions for annual mean temperature in 2050 vary according to areas (figure 2.15). Model predictions present less difference in the Southern that in the Northern part of the country. The reconstructed data for the 20th century indicates that temperatures slowly increased during the 20th century, the rise getting even stronger after 1990. The projections to 2050 indicate that temperatures will continue to increase, with the mean temperatures reaching levels never seen before in the 20th century. The mean temperatures in 2050, on average, will likely be 1.1°C higher than the values in 2010. Across the country, the projected increase in mean temperature ranges from 0.5 to 1.3°C, with the highest values in the North East and Red River Delta regions. The entire country is getting hotter, respecting the current distribution of temperatures. However, change will be higher in cold regions than in hot ones, where the comparative increase will be less important.

The 19 GCM models differ less in their predictions of minimum temperature. On the contrary to mean temperature, models differences for minimum temperature are less important in the North than in the South. They predict that in 2050, a large area of the country will have minimum temperatures above 22°C, and even higher than 24°C in the Mekong River Delta region (figure 2.16). Although the current and future general distribution of temperatures is the same, minimum temperature increases even more in the North and Northeast regions (2°C from 2020 to 2050) than in the South (0.5°C from 2020 to 2050).

The difference between models is greater for maximum temperature; models differ even more in the Northern part of the country (figure 2.17). Generally, the models predict, again, an increase in maximum temperature across the country. All regions from North Central Coast down to the South have most of their area with maximum temperature higher than 30°C according to the average of the predictions for 2050. Differences between 2050 and 2020 extend from 0.5 to 2.1°C. Eastern regions present higher differences that Western.

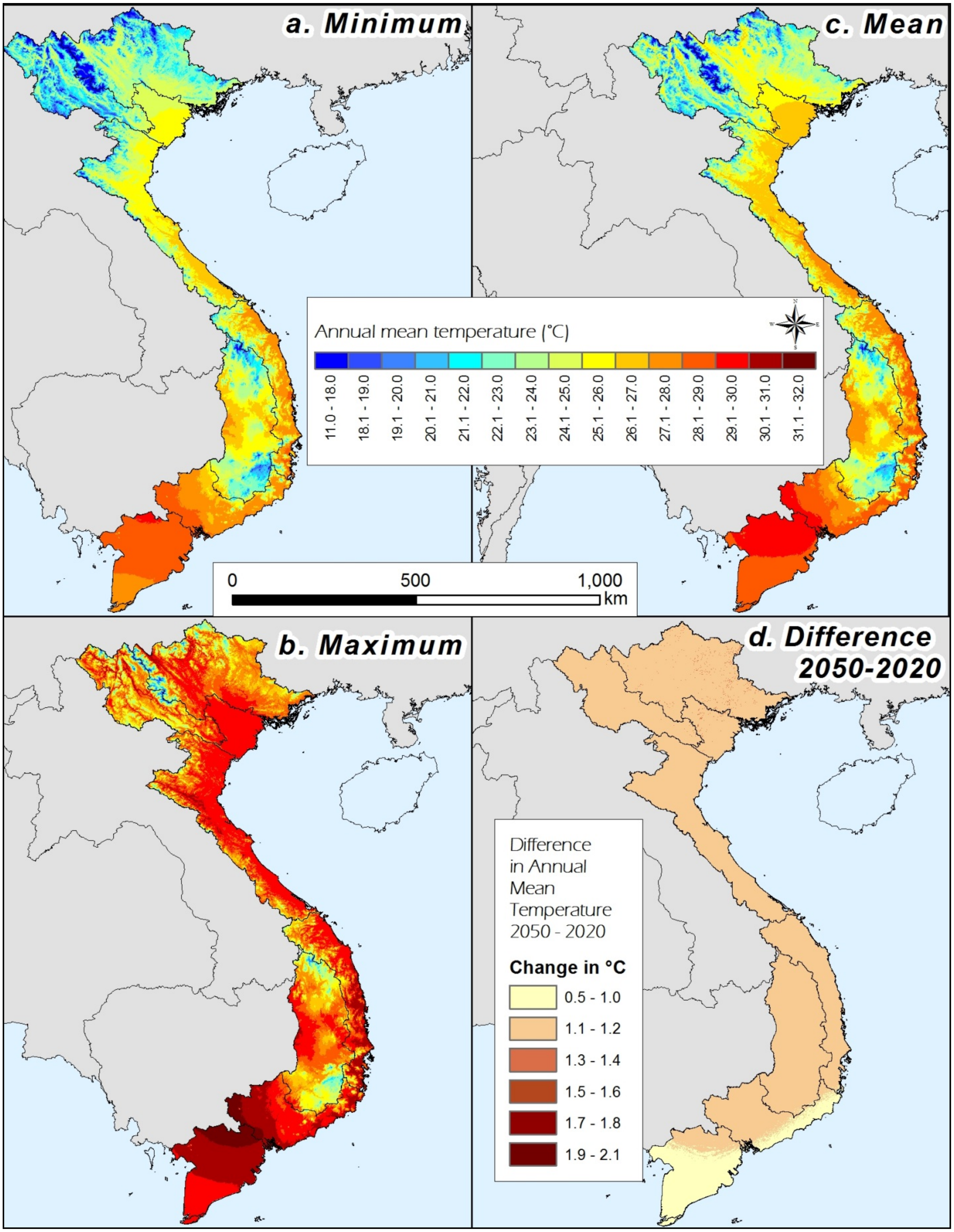


Figure 2.15 Projected changes in Annual Mean Temperature based on 19 GCMs and the A2 emission scenario: Minimum (a), Maximum (b), Mean (c) and change from 2020 to 2050 (d)

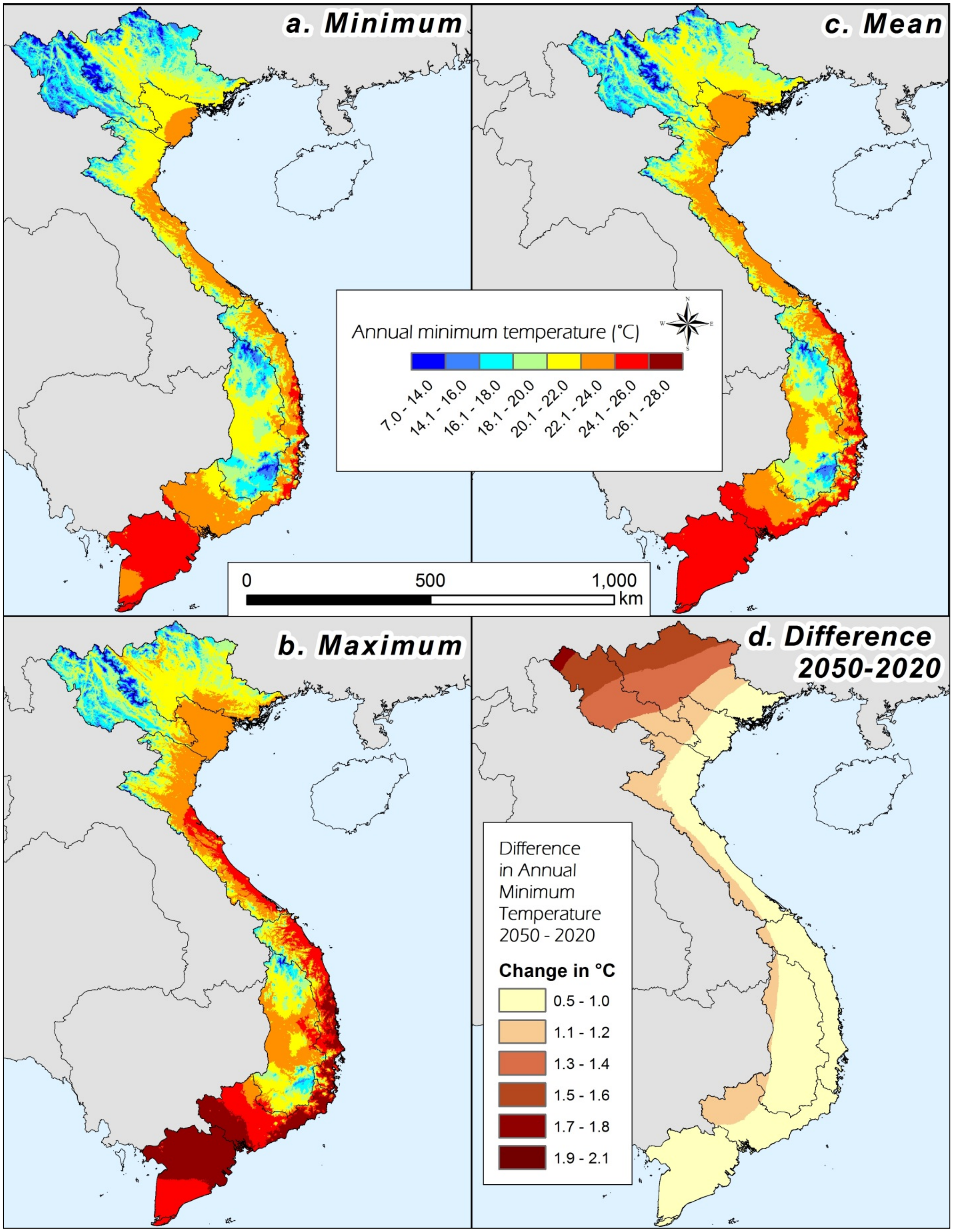


Figure 2.16 Projected changes in Annual Minimum Temperature based on 19 GCMs and the A2 emission scenario: Minimum (a), Maximum (b), Mean (c) and change from 2020 to 2050 (d)

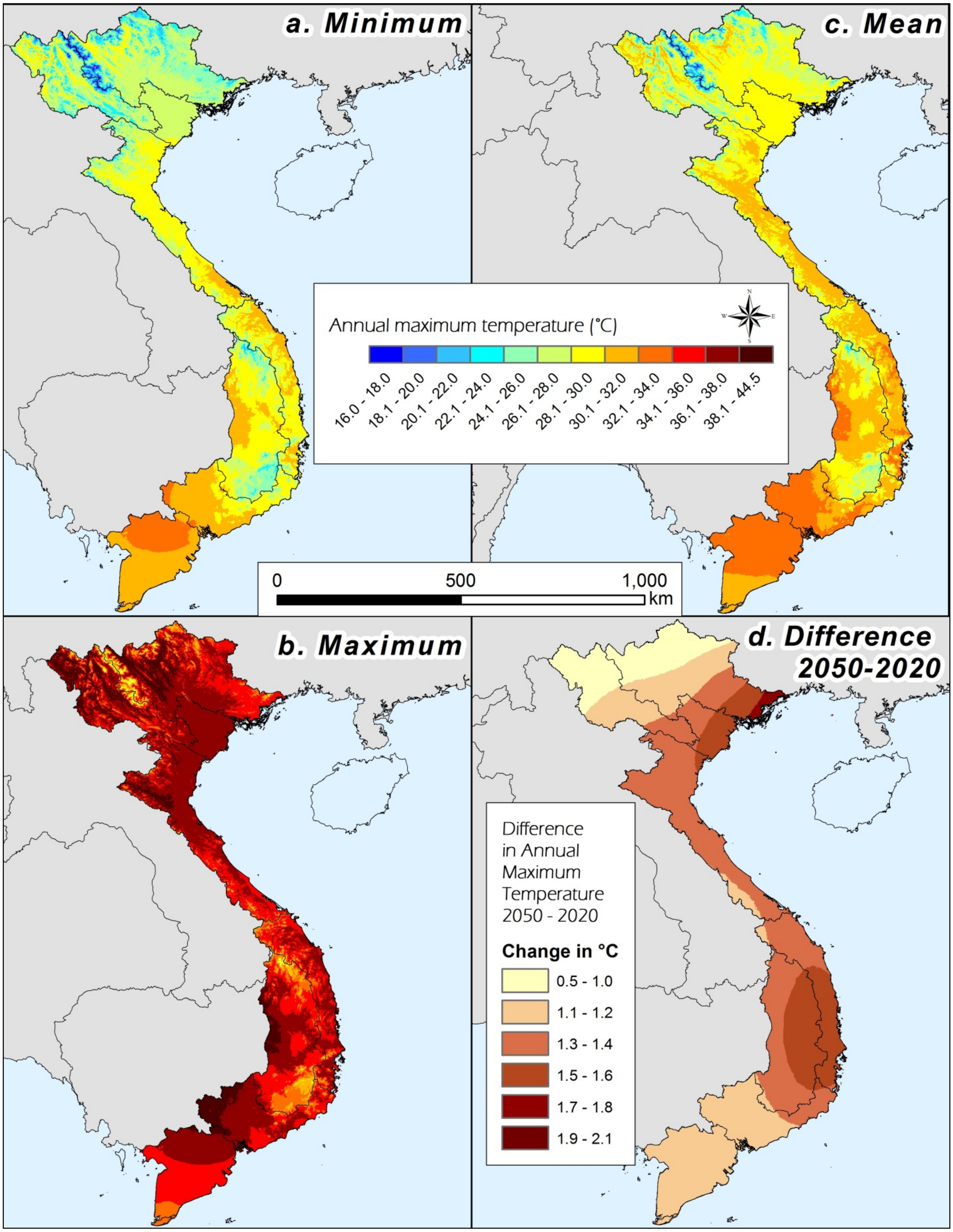


Figure 2.17 Projected changes in Annual Maximum Temperature based on 19 GCMs and the A2 emission scenario: Minimum (a), Maximum (b), Mean (c) and change from 2020 to 2050 (d)

2.4.2 Projected changes in rainfall

Evolution from current to 2050

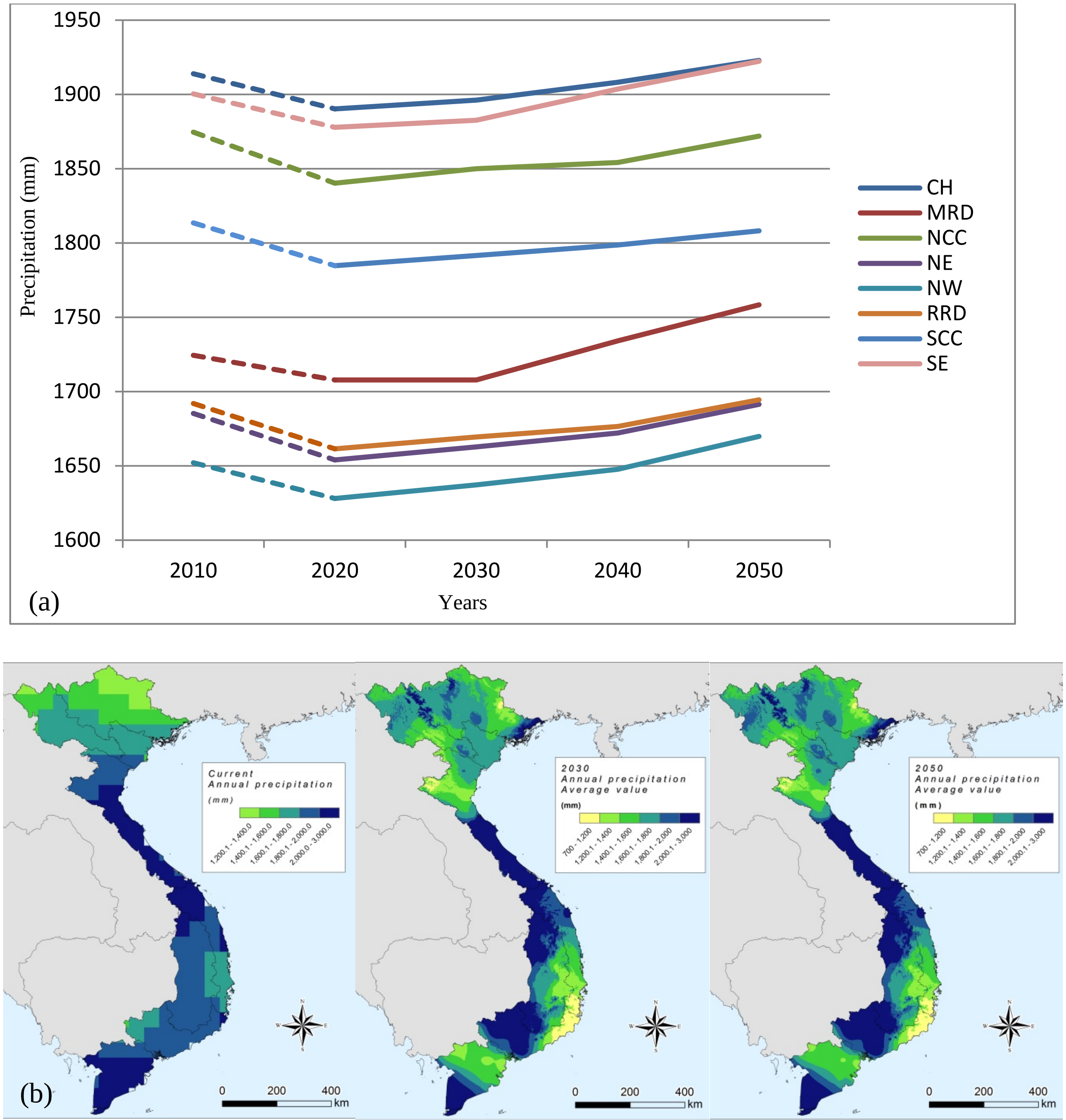


Figure 2.18 Annual precipitation (a) evolution from 2010 to 2050 for the 8 regions (Solid lines represent the average value for the region for the 19 models and broken lines the connection of these average values to WorldClim current modelled data) (b) Maps for current, 2030 and 2050 climate. These results are the average value of prediction from 19 models wtih A2 scenario.

Figure 2.18 presents evolution for annual precipitations from 2010 to 2050. Annual precipitation presented stabilization or decrease over the 20th century however figure 2.18 (a) shows that GCMs predict increase for all the regions to 2050. But these changes are not strong enough to be clearly seen on the map in figure 2.18 (b).

Precipitations in 2050

Within a pixel, differences between modelled values of annual rainfall range from 250 to 550 mm over the 7 models. Highest differences are located in the southern part of Central Highland region. Figures 2.18(a) and 2.19(b) shows that annual precipitation values tend to increase in the future but the difference between 2050 and 2020 values doesn't increase 100mm. Then predicted changes in rainfall are not clear as average tendency doesn't even exceed the difference between different models. We can conclude that annual precipitation seems to have an increasing tendency in the next years. However differences between the models being from the same range of values, this change can't be considered as significant.

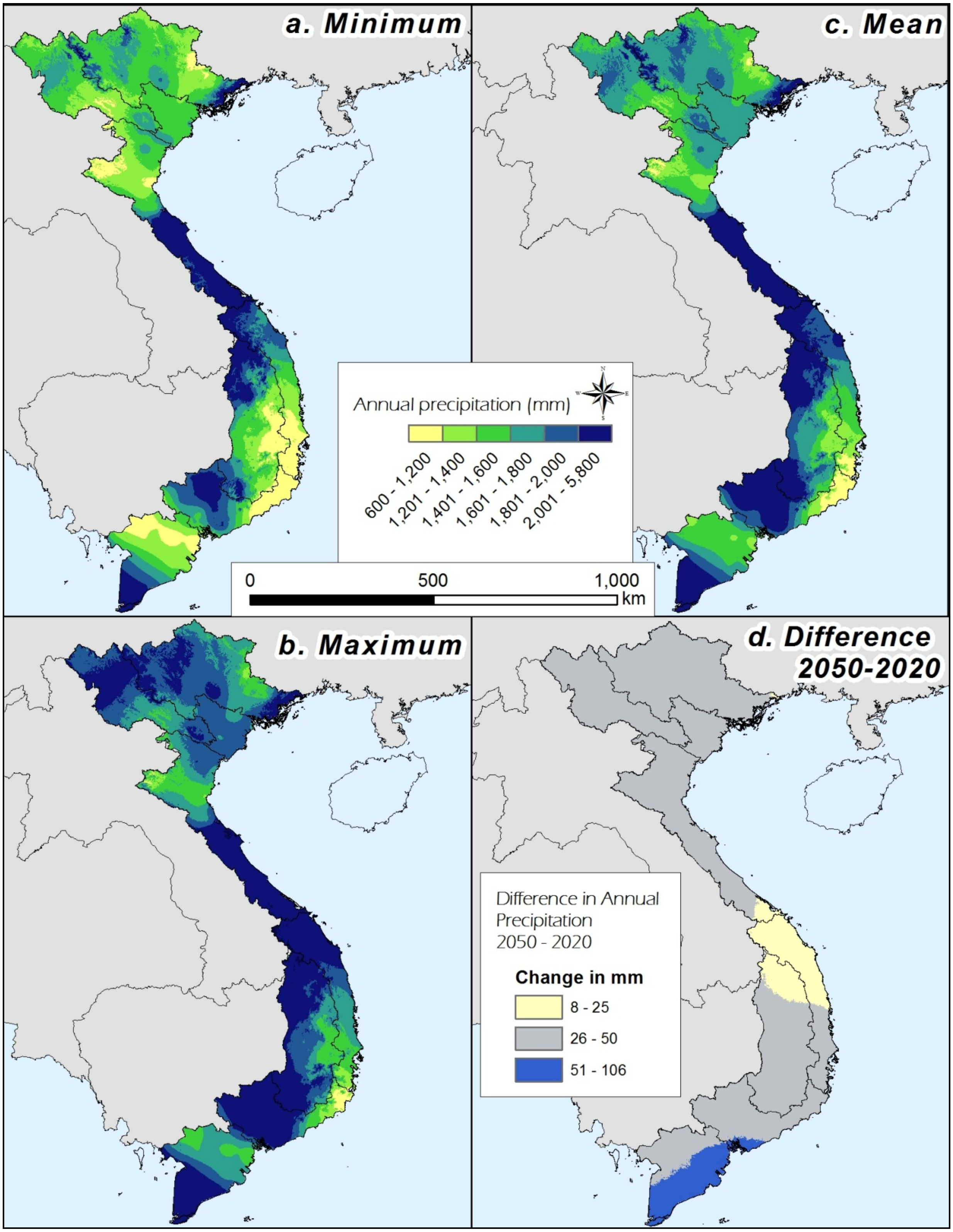


Figure 2.19 Projected changes in Annual Precipitation based on 19 GCMs and the A2 emission scenario: Minimum (a), Maximum (b), Mean (c) and change from 2020 to 2050 (d)

2.5 Principal results for past and future climate evaluation

Temperature

- ✓ *Current distribution:*
  - o Current distribution of temperatures (mean, minimum and maximum) follow a North-South gradient with coldest areas in the Northern mountains and hottest in the Mekong delta.

- ✓ *20th century evolution:*
  - o Mean temperature: all regions present a slight increase, stronger tendency after 1990.
  - o Minimum temperature: all regions increase in the last 30 years, stronger tendency after 1990. Variable global evolution according to the regions:
    - ▪ North East and Red River Delta region: global slight decrease
    - ▪ North West and North Central Coast: globally stable
    - ▪ All region in the South: increase
  - o Maximum temperature: all regions increase from the 1970's, stronger tendency after 1990. Variable global evolution according to the regions:
    - ▪ Mekong River Delta, South East, Central Highlands: increase over entire 20th century
    - ▪ North West and North Central Coast: globally stable
- ➢ Evolution over the century may be variable according to regions but tendency for the 3 temperature variables and all the regions is the same since 1990 with a net and strong increase in values.

- ✓ *Future prediction (evaluated from 19 GCMs)*
  - o Agreements between the 19 models vary according to variable and region. Models better agree in South part of the country for mean and maximum temperature, on the contrary minimum temperature results are more consistent in North of the country.
  - o Mean temperature seems to present a very low increase to 2050.
  - o Minimum temperature presents a stronger increase in Southern regions than in the North, on the contrary to maximum temperature which increases more in the North and East.

Rainfall

- ✓ *Current distribution:*
  - o Driest areas are all located in the extreme North of the country, wettest areas corresponds to the North Central Coast and Mekong River Delta regions.

- ✓ *20th century evolution:*
  - o High year to year variability
  - o Stable evolution in 20th century in Central Highlands, Mekong River Delta and South East regions.
  - o Small decrease in other regions.

- ✓ *Future prediction (evaluated from 19 GCMs):*
  - o No tendency as clear as for temperature
  - o Slight increase in annual precipitation, but to a very low extent (less than 100mm), even lower than year to year variations.

In addition to changes in mean values of weather variables, we must consider the extreme events, which often have the most serious impacts on farming systems and livelihoods (Easterling et al., 2007). There is very limited capacity for prediction of extreme events in the Global Climate Models, in terms of their frequency, spatial distribution, level or intensity. Furthermore, we worked in this study with smoothed data at intervals of 10 years to 30 years, to better evaluate general tendencies. Despite this weakness in the models, there is good evidence that the changes observed in mean values are driven, in part, by changes in the extreme values. In particular, where increases in temperatures have been observed, the trend has been for fewer cold nights and more hot nights, and to a lesser extent fewer cold days and more hot days, rather than a general increase in mean values (Lefroy et al., 2010). For rainfall, even where there has been limited change in total precipitation, the incidence of heavy rainfall appears to have increased. While the incidence of tropical storms and hurricanes is highly variable, influenced by such factors as the El Niño-Southern Oscillation, there is evidence that the number and intensity of storm events has increased significantly in the last few decades of the 20th century, and this trend appears likely to continue and increase in frequency and intensity.

In summary, the climate has become and is likely to continue to become hotter. The variations in rainfall are within the order of the normal year-to-year variations, so the climate change-induced variations in rainfall patterns are unlikely to be observed easily, at least for some time. The danger of this may be complacency. However, even if the methodology used in this study was not able to demonstrate increases in extreme events, other works show that the incidence of extreme events, such as hotter nights and days and heavy storms, is likely to increase. As a consequence, measures to increase farming system resilience to extreme events must be considered to limit negative effects of these events.

3. Climate and crop suitability

3.1 Background and methodologies

Changes in temperatures and in the amount and distribution of rainfall can be expected to affect the productivity of plants and thus agricultural crops and forests. The complex physiology of plants means that they have the ability to adapt to some level of change, but only up to a point. Estimating the likely responses to changes in temperature and rainfall patterns is complex, and there are several approaches that can be taken.

There are three basic ways to model the likely changes in plant productivity. The first is to develop full mechanistic models of plant and crop growth. These have to be complex; otherwise they cannot be expected to mimic the behaviour of the crop. While the quality of mechanistic models is improving, there remain several major drawbacks in using such an approach for estimating the impacts of climate change. First, though mechanistic models exist for the main staple crops, they do not exist for a very wide range of crops. Second, the degree of parameterization required to run these models effectively is very large, requiring large amounts of site-specific data that either does not exist or is too difficult to collect.

The second approach is to more empirical. This does not require detailed understanding of the mechanisms by which different plants respond to and adapt to changes in temperature and rainfall, but it does require a great deal of data on plant growth under a very wide range of conditions. In most cases this does not exist, especially when the aim is to predict how plants grow under conditions that they do not experience regularly.

The third method is a partially mechanistic approach based on understanding the specific bioclimatic niches in which a plant species grows and setting its limits and responses to different conditions.

CIAT, with support from Bioversity International and the International Potato Centre (CIP), developed a simple mechanistic model based on the FAO Ecocrop database of crop ecological requirements (http://ecocrop.fao.org/ecocrop/). Ecocrop is mechanistic in terms of the climatic niches to which a species is suited or less-well suited. The model, which uses the same name as the FAO database, Ecocrop, uses temperature and precipitation thresholds in order to evaluate the suitability of a certain place for a particular crop species. The model was developed to run from within the DIVA-GIS software (Hijmans et al., 2005b). The main use has been to predict the suitability of various crops under different climatic conditions, and thus at different locations. The aim is to assess suitability, rather than productivity or yield per se. In situations where there is a lot of information about yields under different conditions and locations, it is possible that the suitability assessment can be interpreted in terms more closely related to yield.

The model requires ten different parameters (figure 3.1):

- Tkill (the temperature at which the crop will die),
- Tmin (the minimum temperature at which the crop will grow),
- Topmin (the minimum temperature for optimal growth),
- Topmax (the maximum temperature for optimal growth),
- Tmax (the maximum temperature at which the crop will grow),
- Rmin (the minimum amount of rain required for the crop to grow),
- Ropmin (the minimum amount of rain required for optimal growth),
- Ropmax (the maximum amount of rain for optimal growth), Rmax (the maximum amount of rain below which the crop grows),
- Gmin (the minimum length of the growing season), and
- Gmax (the maximum length of the growing season),

with measurements of temperature, rainfall, and growing season being in °C, mm, and days, respectively. Using these parameters, the Ecocrop model computes separate suitability indices for temperature and rainfall, and then a combined suitability rating is computed by multiplying the two indices.

The Ecocrop model is a very convenient way to assess plant species suitability to a particular location or environment, although, like all such models, it needs to be interpreted carefully. The main limitations are that it is based purely on bioclimatic variables. Although these bioclimatic variables are extremely important for plant suitability and productivity, such a suitability rating ignores specific soil requirements, problems of pests and diseases, and their interactions with climate. Both soil requirements and the presence of pests and diseases can be considered as fairly simple modifiers of suitability, but both have important interactions with climatic factors. For instance, the upper and lower limits for rain are affected by the soil type via differences in soil water holding capacity when drought is a risk, and infiltration rates when waterlogging is a risk. Both of these are then further affected by topography and crop management. As far as crop management is concerned, relatively small differences in the maintenance of ground cover, the use of mulch, the degree of tillage, the use of raised beds, and of course the use of irrigation, can all affect the soil moisture regime of a soil, and in different ways under different rainfall regimes. Another issue is that the default parameters are inputs from the FAO dataset, and thus represent the mean values for major varieties, though there can be quite a range between the suitability of various crop varieties to specific environments. Careful selection of varieties can increase crop suitability, and inappropriate selection can reduce the crop suitability. Despite these limitations and the need to take care in interpreting Ecocrop, the model's results can provide a very useful starting point for assessing likely suitability and eventually productivity.

However, it is important to notice that climatic suitability can't be directly assimilated to current distribution as it doesn't include any socio-economic parameters, like costs of production, prices, infrastructures, policies, etc., which can largely influence planting politics or crop distributions at local and national scales.

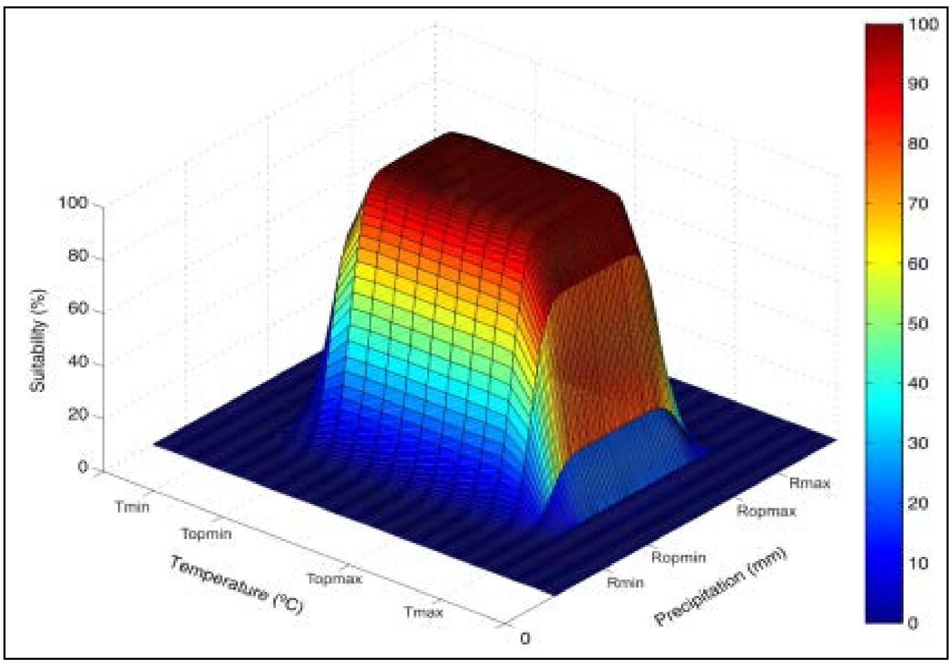


Figure 3.1 The use of climatic parameters to set the suitability of plant species to particular climates in the ecological niche-based Ecocrop model

In this study, Ecocrop was used to assess the suitability of a range of plant species to the current climate of Vietnam, by using the WorldClim database of world climate data (Hijmans et al., 2005a), and then to climate predicted by 19 GCMs for 2050 under the IPCC SRES A2 emission scenario. The plant species assessed were a range of staple crops, cash crops, and important tree species related to the study area in Vietnam for the Participatory Social Return on Investment (PSROI) Greater Mekong Sub-Region (GMS) Adaptation Planning and Costing project. The study took place in two villages in Yen Bai province, and the species selected for analysis were five species noted by study participants as being critical components of their livelihood: cassava, cinnamon, maize, rice, tea. Parameters used to run Ecocrop are presented in table 3.1. FAO Ecocrop database (http://ecocrop.fao.org/ecocrop/srv/en/home) was used to establish parameters to run Ecocrop for cinnamon, maize, tea. For cassava, and rice we used FAO parameters adapted to South East Asia in precedent study in Laos (Lefroy et al., 2010).

Table 3.1 Parameters used to run Ecocrop

	Gmin (days)	Gmax (days)	Tkill (°C)	Tmin (°C)	Top min (°C)	Top max (°C)	Tmax (°C)	Rmin (mm)	Rop min (mm)	Rop max (mm)	Rmax (mm)
Cassava	120	365	0	15	22	32	45	300	800	2200	2800
Cinnamon	330	365	0	17	20	30	34	1500	2500	3000	3500
Maize	65	365	0	10	18	33	47	400	600	1200	1800
Rice (paddy indica)	80	200	0	16	25	35	38	1000	1500	2000	4000
Tea	240	365	-5	8	20	30	35	1000	1400	2000	5000

3.2 Current suitability of crops

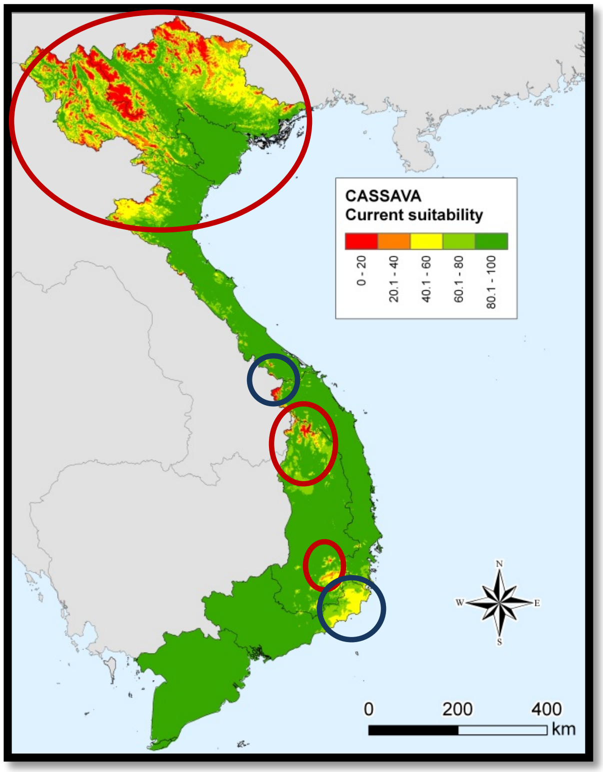
We analyse in this section current climate suitability of the 5 selected crops presented in table 3.1 evaluated through Ecocrop modelling. Crops have been classified in three groups according to the results of modelling, as either having good current suitability, bad current suitability, and variable current suitability. In this section crops will be displayed as they relate to the suitability groups in the order listed above.

Cassava:

Currently, cassava has a very high suitability when looking at Vietnam collectively. Cassava is climatically suitable in most of the country except in mountaineous areas where the PSROI study took place. Temperature is limiting factor in these low suitability zones. On the coast and in the extreme part of Quang Nam province, precipitation has also a limiting effect (figure 3.2). It is important to note that cassava is characterized by low requierements in water.

Rice:

Rice presents a generally low suitability across Vietnam. According to Ecocrop modelling rice is unsuitable in most of the country, due mainly to high requirement for water (figure 3.3). Good water management practices in the field may be applied to fend off this tendency and allow rice cultivation in areas that seem at first climatically unsuitable.



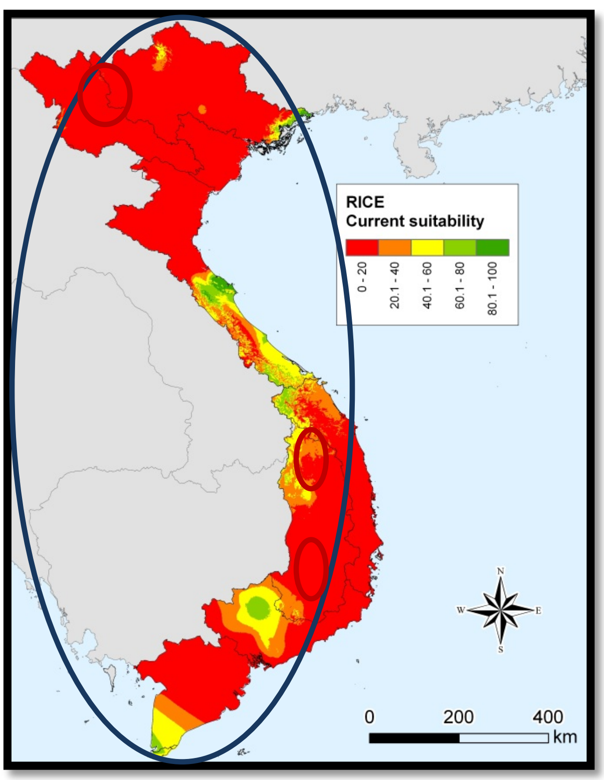


Figure 3.3 Suitability of rice in the current environment as assessed by Ecocrop. Circles highlight areas where temperature (red) or precipitation (blue) values are a limitative factor.

Tea, cinnamon and maize:

These three crops present variable suitability values across Vietnam *tea and cinnamon:*

Tea and cinnamon are unsuitable in all of the Northern part of the country (North West, North East, Red River Delta and North of North Central Coast regions). In this area, temperature is a globally limiting factor, precipitation also has a limiting effect in areas where it has the lowest values. In the rest of the country these 2 crops are mainly suitable (figures 3.4 and 3.5). Due to low precipitation two zones remain unsuitable because minimum precipitation for cinnamon and tea are higher than 1000mm (table 3.1).

Maize suitability is mainly driven by its low precipitation requirements. Only areas where precipitation remains low are suitable for maize (figure 3.6), such as all of the Mekong River Delta and South East regions as well as Dak Nong, Lam Dong, Khanh Hoa, Thanh Hoa, Land Son and Son La provinces.

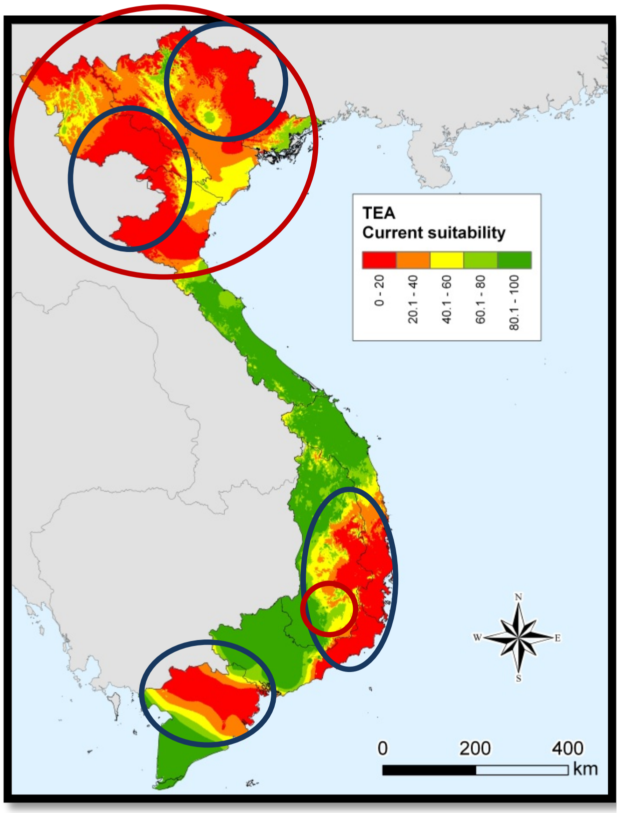


Figure 3.4 Suitability of tea in the current environment as assessed by Ecocrop. Circles highlight areas where temperature (red) or precipitation (blue) values are a limitative factor.

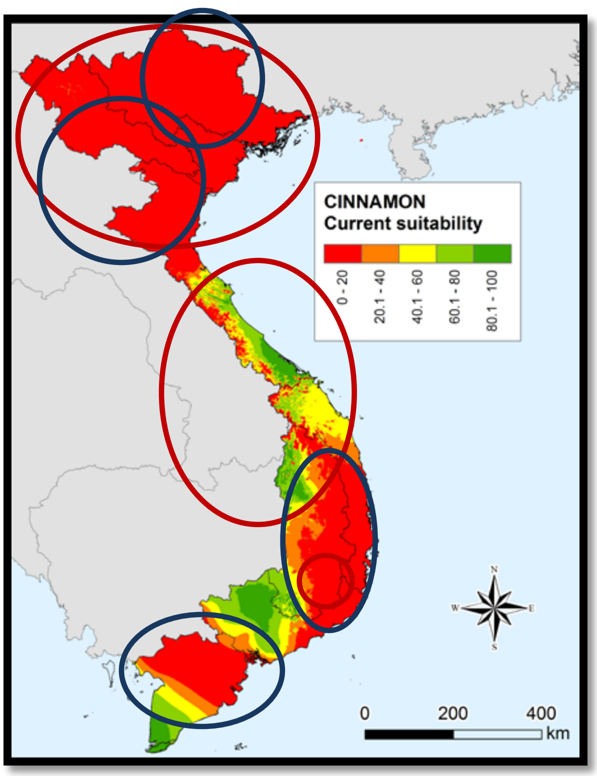


Figure 3.5 Suitability of cinnamon in the current environment as assessed by Ecocrop. Circles highlight areas where temperature (red) or precipitation (blue) values are a limitative factor.

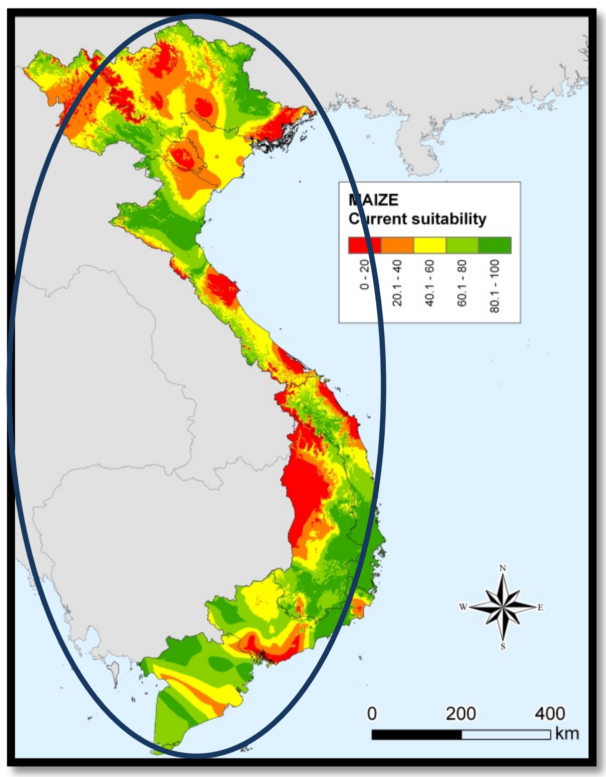


Figure 3.6 Suitability of maize in the current environment as assessed by Ecocrop. Circles highlight areas where temperature (red) or precipitation (blue) values are a limitative factor.

3.3 Future suitability of different crops

This section presents the expected climate suitability assessed by Ecocrop for considered crops for year 2050. For each crop, 19 different runs have been done according to the 19 different GCMs used in this study, using the A2 emission scenario. From the 19 runs we calculated average, minimum and maximum suitability.

3.3.1 Uncertainty and agreement between models

In this short section, we study differences between Ecocrop results according to the different climate models to estimate uncertainty of the prediction. We consider that uncertainty is high if the different models present high differences; on the contrary, uncertainty is low if results for all models are similar. The difference between maximum and minimum suitability values were calculated for all of Vietnam. For each crop, table 3.2 presents the percentage of area of Vietnamese territory with the calculated index of agreement higher than 50 (index goes from 0 to 100). Furthermore, figure 3.7 presents the geographical distribution of the agreement between the results of Ecocrop modelling in 2050 with the 19 different GCMs. From table 3.2 we can classify crops according to their level of uncertainty: with cassava having more than 80% of the territory with an index of agreement higher than 50, it is considered a crop with low uncertainty on its future climate suitability. Cinnamon, rice, maize, and tea are classified as crops with moderate uncertainty (with 50 to 79% of the area with high index of agreement). Level of uncertainty and spatial distribution of uncertain areas will be taking into account in the next section describing suitability change from current to 2050 conditions for all studied crops.

	Low uncertainty	***Moderate uncertainty***			
	Cassava	Cinnamon	Rice	Maize	Tea
Percentage of national territory with index of agreement higher than 50.	81%	74%	73%	70%	68%

Table 3.2 Differences in Ecocrop suitability between the 7 GCMs

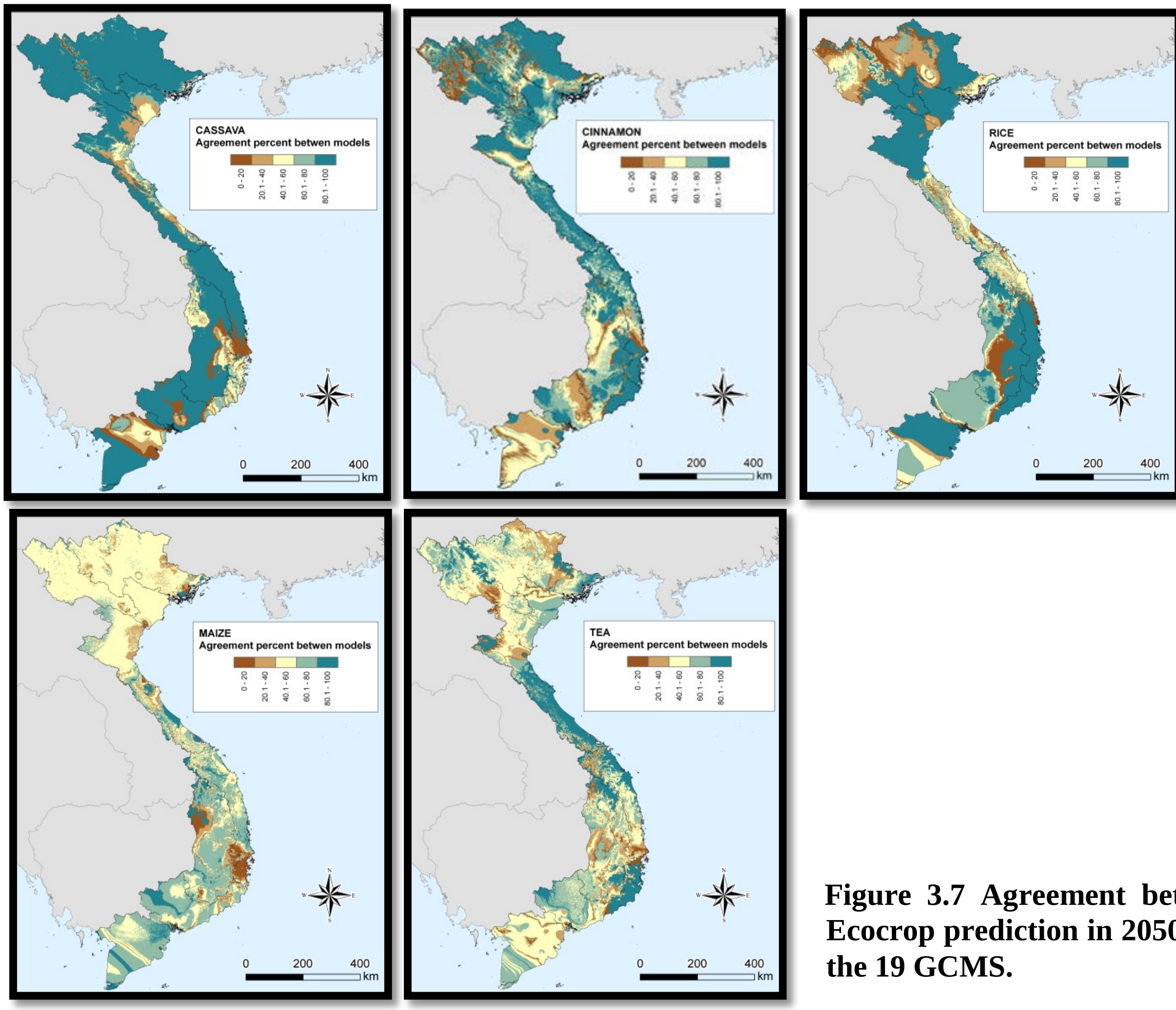


Figure 3.7 Agreement between Ecocrop prediction in 2050 with the 19 GCMS.

3.3.2 2050 suitability and changes from current

Crops with low uncertainty

For crops with low suitability we consider that, because all models agree on most of the territory, the examination of mean suitability for the 19 GCMs is the most appropriate for evaluating the change of suitability to the year 2050.

Figure 3.8 presents suitability in 2050 predicted through Ecocrop averaged for the 19 GCMs for cassava and the difference between suitability predicted according to 2050 and 2020. Suitability of cassava tends to improve from 2010 to 2050. All currently unsuitable areas in North West and North East regions are sharply reduced as well as unsuitable areas in Kon Tum, Dak Lak and Khan Hoa provinces.

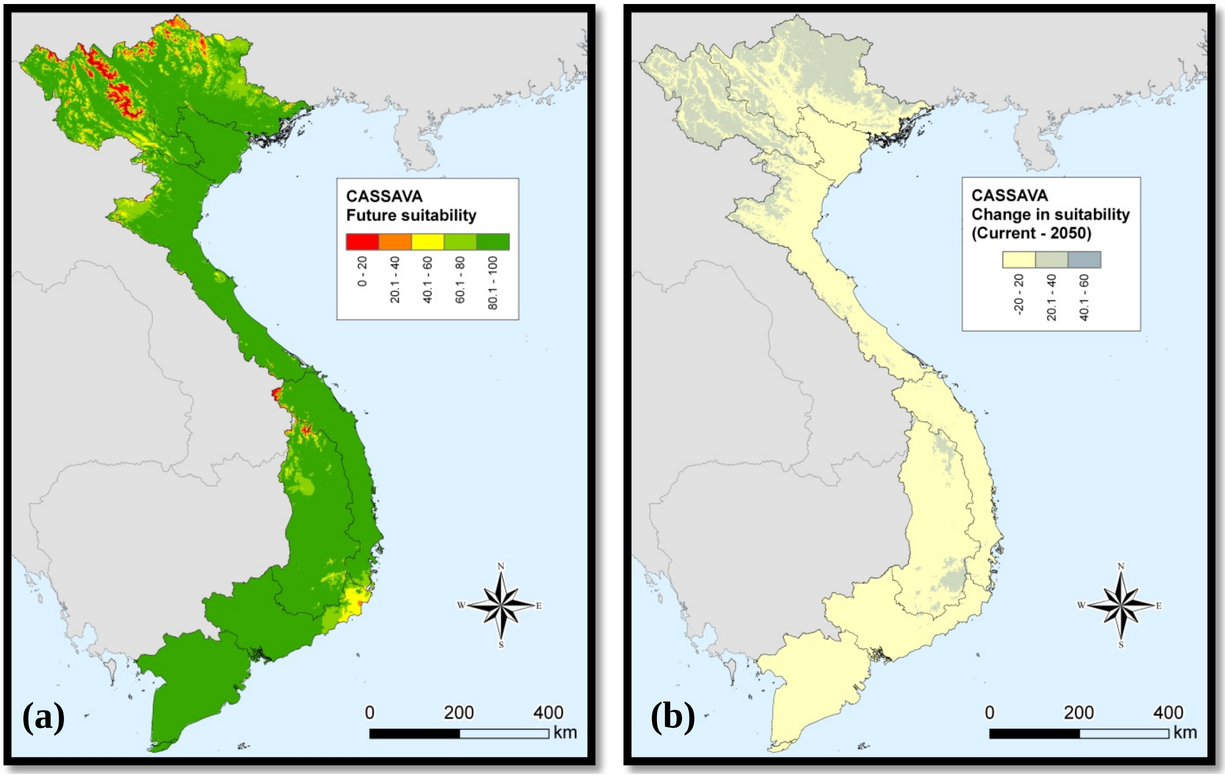


Figure 3.8 Projected changes for cassava suitability based on 19 GCMs and the A2 emission scenario: (a) Future mean suitability (b) Average change from 2010 to 2050

Crops with moderated to high uncertainty

Figures 3.9 to 3.12 present Ecocrop suitability predicted for 2050 with the 19 GCMs for cinnamon, rice, maize, and tea. As these crops have a moderate to high uncertainty, results are presented by four different maps for each crop. The first two maps show minimum and maximum values for suitability according to the 19 GCMs to be able to compare the extreme results for future suitability. The two other maps are the difference between average 2050 and current suitability to evaluate the trend of change and the agreement between models to localize the areas of major uncertainty. We classified crops in 3 classes according to their potential evolution to 2050 in terms of climate suitability.

Rice is expected to remain stable or presenting an increase in suitability. When considering minimum values of the prediction suitability remains globally stable, apart from unsuitable areas (in red), which tend to expand slightly. In the case of maximum suitability, according to the 19 run with GCMs, our results show that suitability may globally increase across Vietnam. For rice, to 2050, current suitable areas get extended mainly in the Southern part of Mekong River Delta, South East, North Central Coast, Northern part of Central Highlands regions according to maximum values (figure 3.9). Comparing average 2050 values with current suitability, maps of rice cannot show visible changes (maps (c) of figures 3.9).

Tea, cinnamon and maize present variable results in expected 2050 suitability. According to worst scenario (minimum value for the prediction), the three crops present a general decrease of suitability (figures 3.10 to 3.12) and highly unsuitable areas are more extended than in current conditions. On the contrary, considering best scenario (maximum value), highly suitable areas are much more expanded in than in current condition, in particular in the Northern regions for maize and tea, and in the Centre for cinnamon. Considering the change between current and future average suitability, maize seems to remain globally stable while cinnamon remains stable in most of the country, except in the central part where results largely differ according to the GCMs. Tea suitability decrease on the coast of North Central Coast and in the northern part of South Central Coast regions, areas where agreement between models is high.

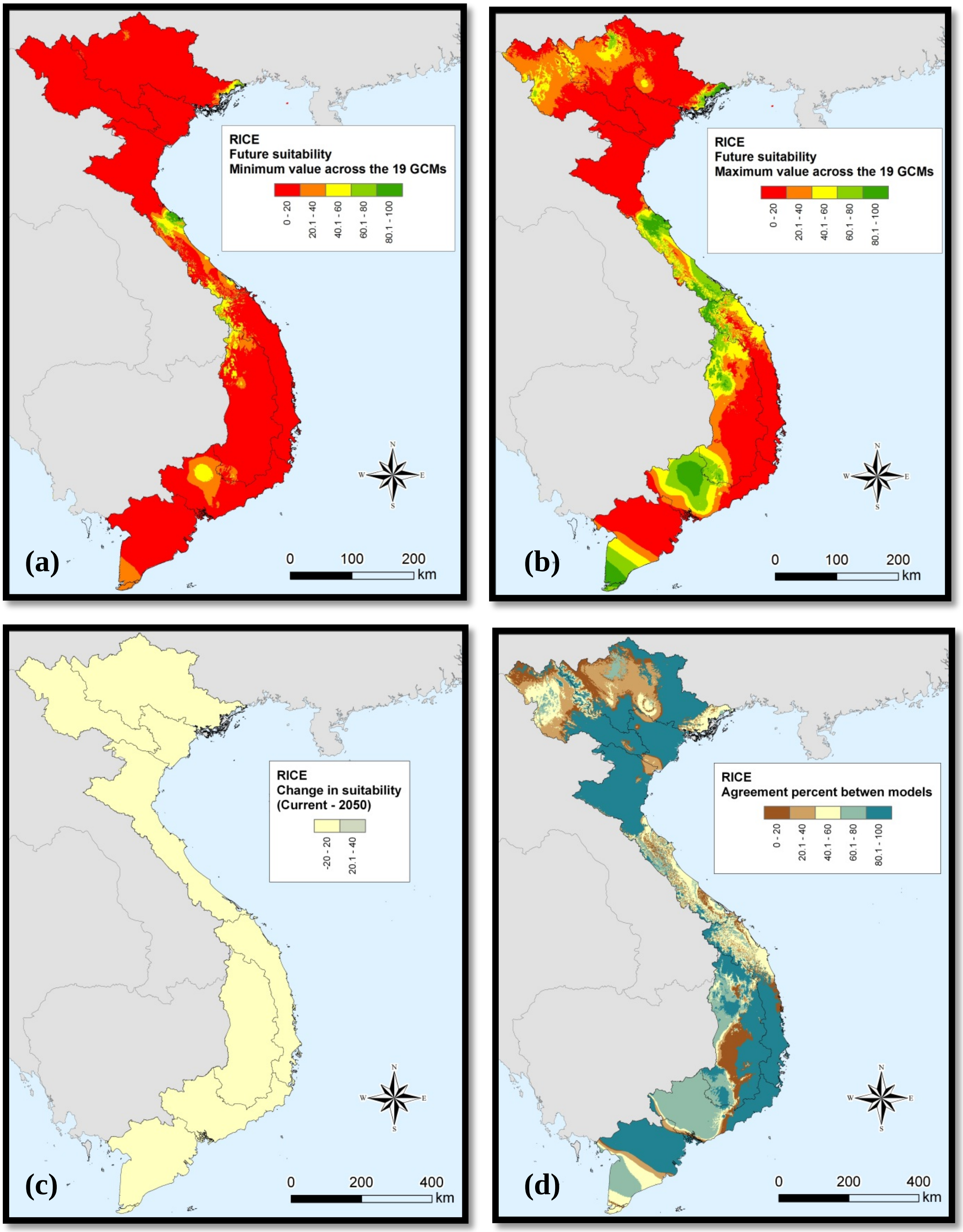


Figure 3.9 Projected changes for rice suitability based on 19 GCMs and the A2 emission scenario: (a) Future minimum suitability (b) Future maximum suitability (c) Average change from 2010 to 2050 (d) Agreement percent between models

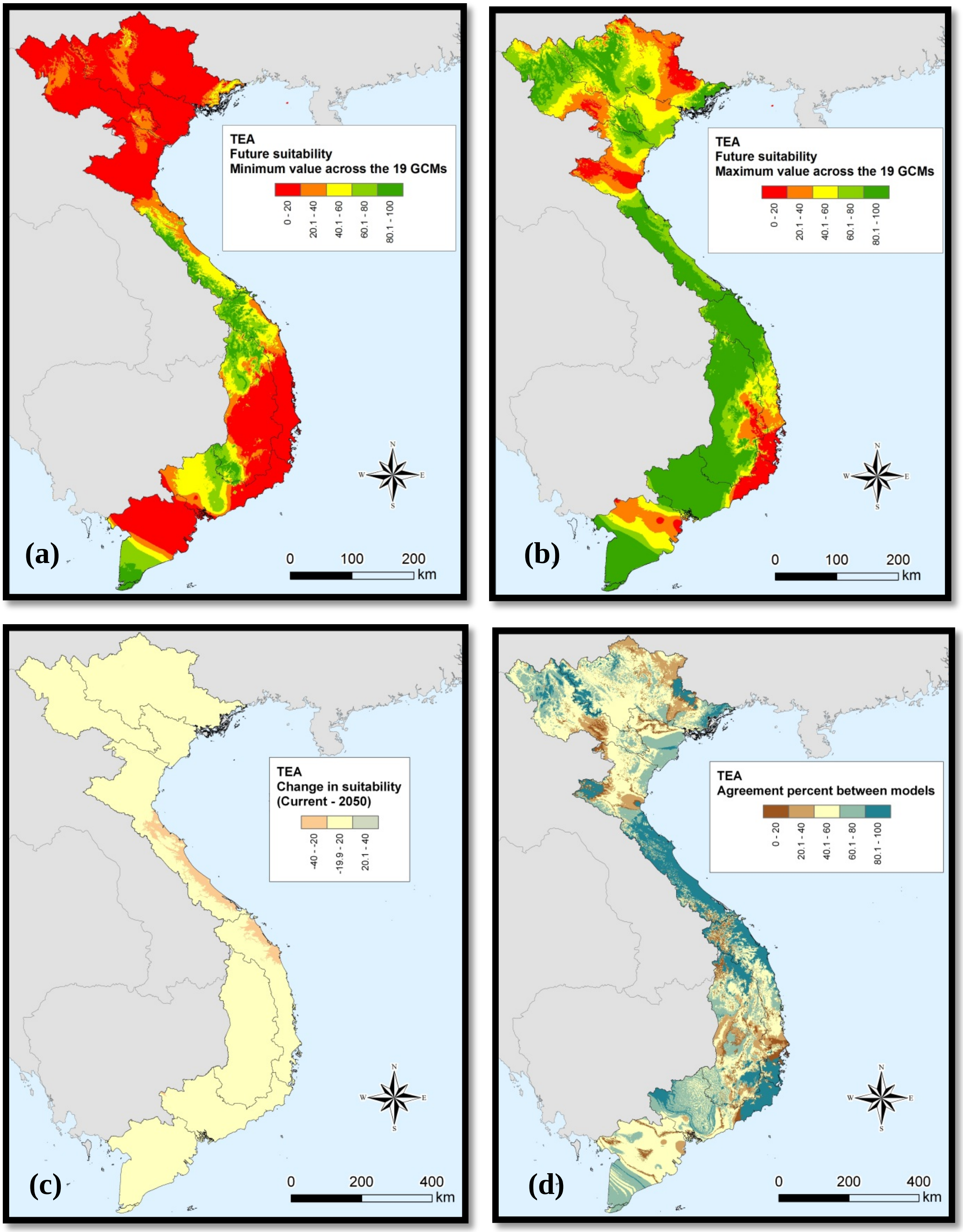


Figure 3.10 Projected changes for tea suitability based on 19 GCMs and the A2 emission scenario: (a) Future minimum suitability (b) Future maximum suitability (c) Average change from 2010 to 2050 (d) Agreement percent between models

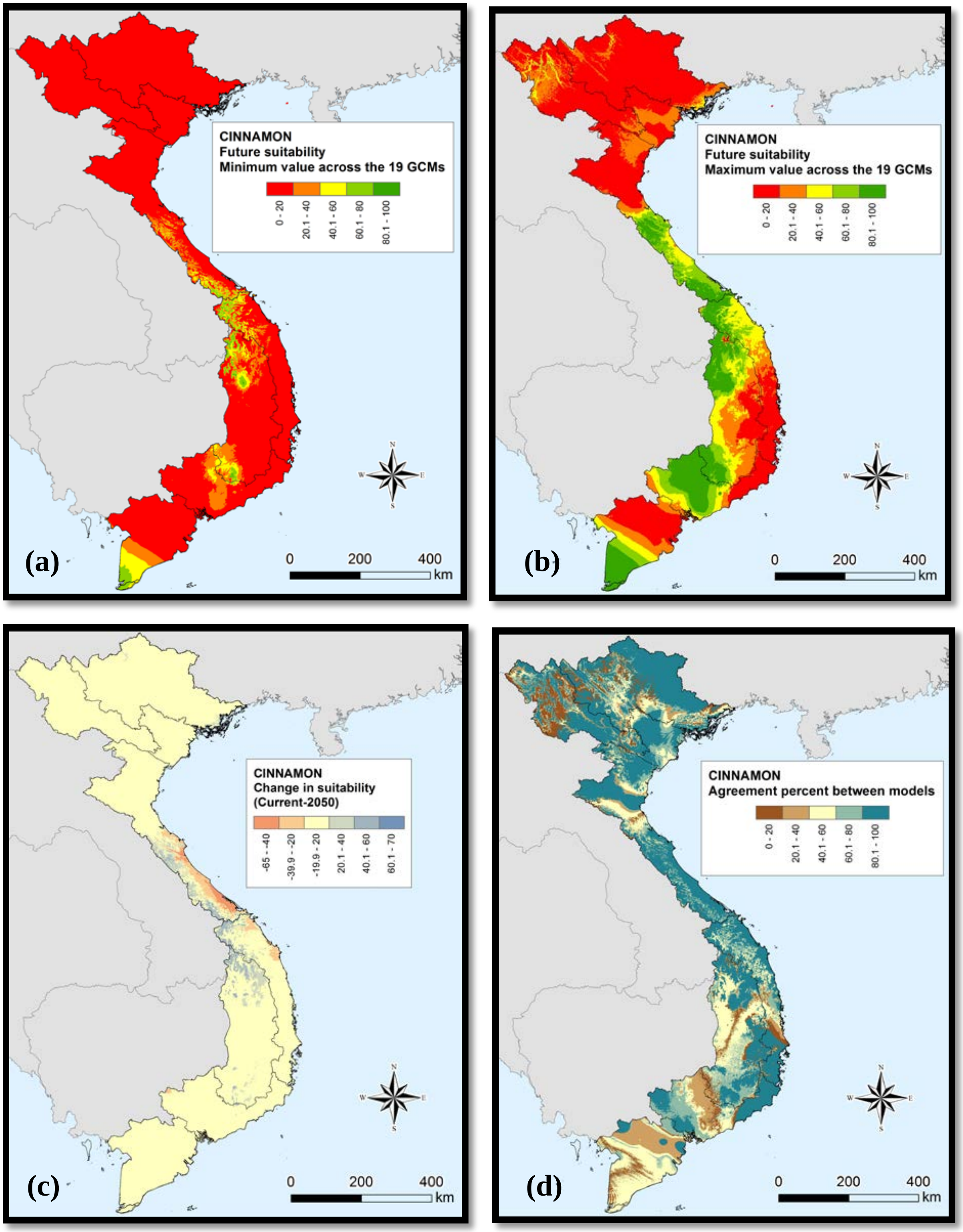


Figure 3.11 Projected changes for cinnamon suitability based on 19 GCMs and the A2 emission scenario: (a) Future minimum suitability (b) Future maximum suitability (c) Average change from 2010 to 2050 (d) Agreement percent between models

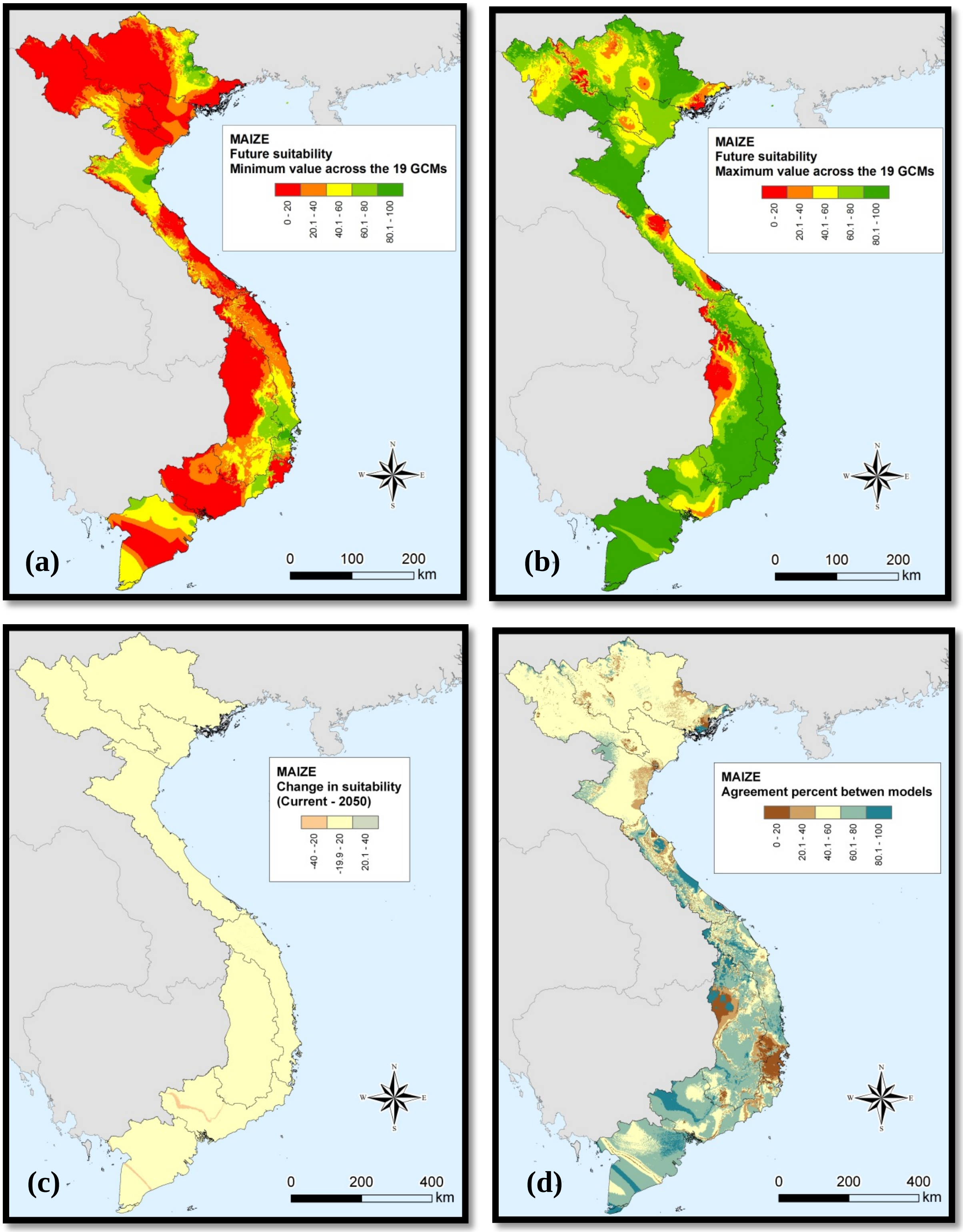


Figure 3.12 Projected changes for maize suitability based on 19 GCMs and the A2 emission scenario: (a) Future minimum suitability (b) Future maximum suitability (c) Average change from 2010 to 2050 (d) Agreement percent between models

3.4 Principal results on current and future crop suitability assessment

It is important to note that the methodology used for modelling crop suitability here only considers climate suitability including temperature and precipitation. No global conclusion, specifically with relation to soil and socioeconomic factors, can be drawn from these results, not only in terms of current distribution, but also considering future change.

Current suitability

Five crops have been analysed with Ecocrop bioclimatic suitability model. In current conditions they've been classified in 3 groups:

- Crops with global good current suitability in Vietnam: cassava.
- Crops with bad current suitability: rice.
- Crops with variable current suitability across the country: maize, cinnamon, and tea.

An interesting feature of crops with good current suitability in Vietnam, in this case cassava, is that it is characterized by low water requirement. Limitative factors are detailed in table 3.3 showing results by crop.

Future suitability:

For 2050 suitability, Ecocrop has been run with 19 GCM and uncertainty of the prediction has been evaluated according to maximum difference between results of the runs made with the different climate models. Results show that climate change seems to affect each crop differently at a 2050 horizon.

First, crops were classified according to their uncertainty level:

- Low uncertainty: cassava.
- Moderated uncertainty: cinnamon, rice, maize, and tea.

For analysing changes in suitability of cassava, given that it had low uncertainty we consider the mean suitability for the 19 GCMs:

- Cassava suitability tends to improve from 2010 to 2050.

For cinnamon, rice, maize and tea as crops with moderate to high uncertainty, instead of considering the average value for the 19 GCMs used for modelling, we prefer to evaluate the range of potential change from minimum to maximum value for expected suitability. Rice is expected to remain globally stable in the model outcomes where rice is shown to have lower suitability or present an increase in suitability in assessments demonstrating maximum value of suitability. Comparing average 2050 values with current suitability, maps of the change in rice do not show visible changes (maps (c) of figures 3.9). Tea, cinnamon and maize present variable results in 2050 expected suitability. Considering the change between current and future average suitability, maize seems to remain globally stable, as well as cinnamon (except in the central part of the country), while tea suitability decreases on the coast of North Central Coast and in the northern part of South Central Coast regions. Following table 3.3, the results for each crop are presented including the state of current suitability, the limitative factors according to unsuitable regions, the uncertainty of the results modelled for 2050, the state of suitability for 2050, and the change of suitability between 2010 and 2050.

Table 3.3 Summary of current and future suitability for study crops

	Current suitability distribution	Limitative factors[1]	Uncertainty	Future suitability	Change 2050-2010
Cassava	Good	Temp: NE, NW, LD, KT Prec: QN, BT, NT	Low	Good	Increase
Cinnamon	Variable	Temp: NE, NW, RRD, SCC, LD Prec: LS, SL, NA, SCC-SE border, MRD	Moderated	Variable	Stable to variable
Maize	Variable	Prec: all country	Moderated	Variable	Stable
Rice	Bad	Temp: NW-NE border, KT, DN Prec: all country	Moderated	Bad to variable	Stable to increase
Tea	Variable	Temp: NE, NW, RRD, LD Prec: LS, SL, NA, SCC-SE border, MRD	Moderated	Variable	Decrease

[1] Indicate which factor, from temperature (Temp) and precipitation (Prec), is limitative factor that reduce suitability. Abbreviation correspond to: Central Highlands Region (CH), Mekong River Delta Region (MRD), North East Region (NE), North West Region (NW), Mekong River Delta Region (MRD), South Central Coast Region (SCC), Red River Delta Region (RRD), An Giang Province (AG), Binh Thuan Province (BT), Dak Nong Province (DN), Gia Lai Province (GL), Khanh Hoa Province (KH), Kon Tum Province (KT), Lam Dong Province (LD), Land Son Province (LS), Nghe An Province (NA), Ninh Thuan Province (NT), Quang Binh Province (QB), Quang Nam Province (QN), Quang Ninh Province (QNi), Son La Province (SL)

This study on climate change, and its impact on agriculture, has involved two separate, but related, components: (i) analysing the changes in climate over the last 100 years and the likely change in climate up to 2050; (ii) assessing the climate suitability of crops in current climate conditions and how suitability will be affected by climate change. According to these results, some adaptation and mitigation measures seem to be more interesting and effective than others considering Vietnam's conditions.

The first objective for adaptation policies should be to improve resilience of production systems to changing climates. Improving varieties to have drought resisting characteristics, natural resource management, and advanced agrichemicals are proven effective ways of decreasing susceptibility to individual stresses, and should offer increasingly important solutions for adapting to progressive climate change. These adaptation options may be especially useful for enhancing resilience in areas where precipitation variability appears to be an important factor of uncertainty for future crops suitability. The areas of Vietnam to consider for these adaptation options vary for each crop. There are three results to consider in determining areas of uncertainty in future crop suitability due to precipitation. The first is that all crops studied have associated areas within Vietnam where precipitation is a limiting factor for suitability, with crops displaying a range in the area from small to the entire country for maize and rice. Secondly, precipitation is highly variable and therefore hard to model for the future across Vietnam, as well as globally. Third, modelling future suitability presents uncertainty for several crops. These results suggest that adaptation options and policies are needed that can address these issues of uncertainty.

Consideration of a wide range of possible measures is needed to decrease susceptibility of crops to individual stress from precipitation variability, especially where uncertainty in future suitability is high. Irrigation and good water management practices should be developed in these areas as they are necessary to improve current production of rice and maize, but also will be able to limit climate change effects on rainfed systems, such as rainfall variability and extreme events. Locally, diversifying crops can be a good way of limiting negative effects of climate change on yields and production, but the diversification process must be supervised and access to markets facilitated. Silvo-pastoral systems (SPS) are another high-potential adaptive strategy. Tea appears to be the crop most potentially affected by climate change. Development of new tea varieties is vital to limit the loss in yields and production. Important mitigation measures focusing on carbon sequestration, such as logging bans and forest cover targets, should be enforced. Sustainable development goals may also be tied more closely to climate change adaptation; in the future, adaptation could be mainstreamed as part of development and agricultural policy.

4. References

Box, G.E.P. and Jenkins, G.M. (1976). Time Series Analysis: Forecasting and Control (revised edition), Holden Day, San Francisco.

Dasgupta, S. et al. (2007): The Impact of Sea Level Rise on Developing Countries. A Comparative Analysis. World Bank Policy Research Working Paper 4136, February 2007.

Easterling, W. E.; Aggarwal, P. K.; Batima, P.; Brander, K. M.; Lin, E. D.; Howden, S. M.; Kirilenko, A. P.; Morton, J.; Soussana, J.; Schmidhuber, J.; Tubiello., F. (2007). Food, fibre and forest products. In M. Parry, O. F. Canziani, J. Palutikof, P. J. van der Linden, and C. E. Hanson, eds. Climate Change 2007: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press.

Hijmans, R.J.; Cameron, S.E.; Parra, J.L.; Jones, P.G.; Jarvis, A. (2005a) Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology 25: 1965-1978.

Hijmans, R.J.; Guarino, L.; Jarvis, A.; O'Brien, R.; Mathur, P.; Bussink, C.; Cruz, M.; Barrentes, I.; Rojas, E. (2005b). Diva-GIS version 5.2.

IPCC (2001). Climate Change 2001: Synthesis Report. A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA, 398 pp.

IPCC (2007). Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland, 104 pp.

Lefroy, R.D.B.; Collet, L.; Grovermann, C. (2010) "Study on Potential Impacts of Climate Change on Land Use in the Lao PDR" A report prepared for Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH.

Mitchell, T.D. and Jones, R.G. (2005). An improved method of constructing a database of monthly climate observations and associated high-resolution grids, International Journal of Climatology vol 25, 693 – 712

World Bank, (2012). World Development Indicators. Data retrieved September 28, 2012 from World Development Indicators Online (WDI) database.