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INSTITUTE OF GEOGRAPHY AND GEOLOGY

CLIMATE CHANGE ASSESSMENT IN SOUTHEAST ASIA AND IMPLICATIONS FOR AGRICULTURAL PRODUCTION IN VIETNAM

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Phd. Thesis

CLIMATE CHANGE ASSESSMENT IN SOUTHEAST ASIA AND IMPLICATIONS FOR AGRICULTURAL PRODUCTION IN VIETNAM

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ABSTRACT

For many years, the study of climatic changes and variations has become the main objective of climatic research, as has been appreciated in the IPCC's reports and several publications regarding climatic evolution on different space-time scales. Since the 80's, many research groups have generated the extensive database from which the analysis of temperature, precipitation and other climatic parameters has been performed on a global scale (Jones et al., 1986; Hansen and Lebedeff, 1987, 1988; Vinnikov et al., 1987, 1990). The most important result of these research projects is the evidence of global warming during the 20th century, especially in the last two decades.

However, numerous challenges still exist about the structure and dimension of the climatic change on a considerable scale. Therefore, it is necessary to carry out studies on a local and regional scale that allow for a more precise evaluation of the global warming phenomenon. A statistical analysis approach was developed to identify systematic differences between large-scale climatic variable from the General Circulation Models (GCM), NCEP, CRU re-analysis data set and climatic parameters (temperature and precipitation data). Models are able to satisfactorily reproduce the spatial patterns of the regional temperature and precipitation field. The response of the climate system to various emission scenario simulated by the GCM was used to analyze and predict the local climate change.

The main objective of this study is to analysis the time evolution of the annual and seasonal temperature and precipitation during the 21st century and in order to contribute to our knowledge of temperature and precipitation trends over the century on a regional scale, not only in Southeast Asia but also in Vietnam; the study focuses to develop a dynamical – statistical model describing the relationship between the major climate variation and agricultural production in Vietnam. This study will be an important contribution to the present-day assessment of climate change impacts in the low latitudes. Regional scenarios of climate change, including both rainfall and mean temperature were then used to assess the impact of climate change on crop production in the region in order to evaluate the vulnerability of the system to global warming.

Climate change has adverse impacts on the socio - economic development of all nations. But the degree of the impact will vary across nations. It is expected that changes in the earth's climate will impact on developing countries like Vietnam, in particular, hardest because their economies are strongly dependent on crude forms of natural resources and their economic structure is less flexible to adjust to such drastic changes.

In Chapter 1: Introduction and background I describe in general terms climate, climate change, climate change model with benefits and problems. Chapter 2: methodology discusses the methods including interpolation, validation, clustering, correlation and regression which were applied in the study. Chapter 3 and chapter 4 describe the database and study area. The most important is chapter 5 Results. The last is chapter 6 Conclusion and outlook followed by the reference list and an appendix.

ZUSAMMENFASSUNG

Seit vielen Jahren ist die Erforschung von Klimawandel und -schwankungen das zentrale Thema der Klimatologie. Besonderes deutlich wird dies anhand der IPCC-Berichte, ebenso wie der zahlreichen Einzelstudien zur Entwicklung des Klimas auf unterschiedlichsten raum-zeitlichen Skalen. Insbesondere seit den 1980er Jahren befassen sich zahlreiche Forschungsgruppen weltweit mit der systematischen Sammlung, Aufbereitung und auch Auswertung von Klimadaten. Diese Datengrundlage erlaubt Analysen zur Entwicklung der globalen Lufttemperatur, des Niederschlags und anderer Klimaelemente (Jones et al., 1986; Hansen und Lebedeff, 1987; Vinnikov et al., 1987, 1990). Das wichtigste übergreifende Ergebnis dieser Untersuchungen ist die Feststellung einer globalen Erwärmung während des 20. Jahrhunderts, die sich in den beiden letzten Jahrzehnten besonders intensivierte.

Abschätzungen über die Art und Stärke des Klimawandels auf größeren, planungsrelevanten Massstäben sind jedoch nach wie vor mit großen Unsicherheiten verbunden.

Für eine detailliertere Erforschung der Auswirkungen der globalen Erwärmung auf regionaler oder gar lokaler Ebene besteht daher noch großer Forschungsbedarf. In dieser Dissertation wird zu diesem Zweck ein statistischer Ansatz verfolgt. Dieser erlaubt die Identifikation systematischer Unterschiede zwischen den Ausprägungen klimatologischer Feldgrößen (bodennahe Lufttemperatur und Niederschlag) wie sie von sogenannten General Circulation Models (GCMs) simuliert werden im Vergleich zu den betreffenden Parametern aus Beobachtungsdaten. Als Beobachtungsdaten werden die NCEP Reanalysen, die statistisch interpolierten Datensätze der CRU sowie Stationsdaten aus Vietnam verwendet. Hierbei zeigt sich, dass die aktuellen Klimamodelle die räumlichen Muster der betrachteten Variablen in befriedigender Weise reproduzieren. Die Analyse des regionalen Klimawandels in Südost-Asien erfolgt durch die Auswertung von Klimamodellrechnungen. Diese wurden von verschiedenen GCMs durchgeführt, wobei unterschiedliche Annahmen über die zukünftigen Treibhausgasemissionen berücksichtigt wurden.

Der Fokus dieser Dissertation ist die Analyse der projizierten zeitlichen Entwicklung von bodennaher Temperatur und Niederschlag im 21. Jahrhundert. Hierbei werden sowohl jährliche als auch saisonale Mittelwerte bzw. Summen berücksichtigt. Neben diesen rein physikalisch-klimatologischen Betrachtungen behandelt diese Dissertation auch einen angewandten Aspekt, nämlich den Impakt des Klimawandels auf die Landwirtschaft, exemplarisch untersucht am Beispiel Vietnams. Für die Abschätzung der Vulnerabilität dieses essentiellen Wirtschaftsbereiches wird ein statistisches Modell entwickelt in das an klimatischen Parametern die bodennahe temperatur sowie der Niederschlag einfliessen.

Diese Untersuchung leistet damit einen wichtigen Beitrag zum Wissenstand über die Auswirkungen des Klimawandels in den niederen Breiten.

Die sozio-ökonomische Entwicklung jedes Staates der Erde wird von den Folgen des Klimawandels beeinflusst, allerdings variiert der Grad der Beeinträchtigung erheblich. Vermutlich werden Entwicklungsländer wie Vietnam die Auswirkungen des Klimawandels besonders stark zu spüren bekommen. Die Ursachen für diese hohe Vulnerabilität liegen unter anderem in der Wirtschaftsstruktur: der allgemein hohe Stellenwert natürlicher Ressourcen und eine geringe Diversität verringern hier die Möglichkeiten zur Adaption an die beobachteten und projizierten Veränderungen.

Die vorliegende Dissertation gliedert sich wie folgt: In Kapitel 1 stellt eine allgemeine Einführung zur Thematik dar. Die Begriffe Klima und Klimawandel sowie einige übliche Modelle zum Klimawandel, verbunden mit einer Abwägung der spezifischen Vor- und Nachteile, werden erläutert. Kapitel 2 beschäftigt sich mit der Methodik. Hier werden die räumliche Interpolation sowie die angewendeten explorativen und inferentiellen statistischen Verfahren diskutiert. Die Kapitel 3 und 4 beschreiben die Datengrundlage und die betrachtete Region. Im Kapitel 5 werden die Untersuchungsergebnisse dargelegt. In Kapitel 6 erfolgt die Abschlussbetrachtung und ein Ausblick auf die Zukunft. Am Ende der Dissertation finden sich die verwendeten Quellen sowie ein Appendix mit landwirtschaftlichen Daten.

ABBREVIATION

Abbreviation	Meaning
ABI	Association British Insurance
AOGCM	Atmosphere – Ocean General Circulation Models
ASEAN	Association of Southeast Asian Nation
CRU	Climate Research Unit
EMICs	Earth System Models of Intermediate Complexity
GCM	General Circulation Models
GCOS	Global Climate Observation System.
GDP	Gross Domestic Product
GHCN	Global Historical Climatology Network
GHGs	Greenhouse gases
GIS	Geographical information system
GMT	Generic Mapping Tools
GTS	Global Telecommunication system
IPCC	Intergovernmental Panel on Climate Change
MJO	Madden – Julian Oscillation
NCAR	National Center for Atmospheric Research
NCEP	National Center for Environmental Prediction
NMSs	National Meteological Services
NNRP	NCEP/NCAR Reanalysis Project
Obs.	Observation
RMS	Root Mean Square
s.q	Square
SN	Signal to Noise Ratio
SRES	Special Report on Emission Scenarios
UEA	University of East Anglia
UNFCCC	United Nation Framework Convention on Climate Change
WMO	World Meteological Organisation’s

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CHAPTER 1 : INTRODUCTION AND BACKGROUND

1.1. Climate concept:

Climate is described by temperature, humidity, precipitation, atmospheric pressure, wind, phenomena occurring in the troposphere and other meteorological elements at a given time interval over the defined region. The climate of one region is depended on its geographical coordinate (latitude and longitude), relief, elevation, snow, ice, land surface, ocean and other bodies of water and life. The climate system is a complex, interactive system. It is necessary to distinguish clearly between climate and weather. Weather refers, generally, to day to day or near future temperature and precipitation activity. Climate is understood in term of the mean of temperature, precipitation and wind over a time period, which range from several months to years.

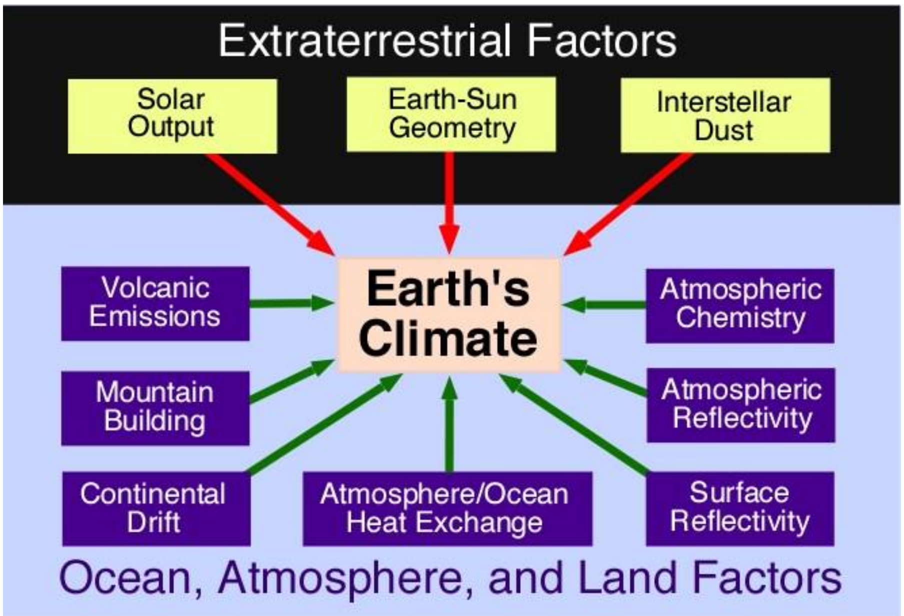
Climate is determined by basic mechanisms of heat, moisture exchange and atmospheric circulations:

+ The atmosphere absorbs some of the sun's rays through it and translates them into temperature changes.

+ In addition to heat fluxes, between the atmosphere and surface occur moisture fluxes. Water from the ocean surface and water storage areas, from soil moisture and plant evaporate into the atmosphere. This process of soil and top water layers provides a large amount of heat, resulting in clouds and precipitation. Due to the condensation, a large amount of latent heat is provided to the atmosphere.

+ The unequal distribution of heat in the atmosphere leads to unequal distribution of atmospheric pressure. The movement of air depends on the distribution of atmospheric pressure. The large-scale air flow system on the Earth is the common atmospheric circulation.

The climate system is under the influence of extraterrestrial and internal factors. Each factor has influence on other factors. The factors that influence on the Earth's climate are illustrated in figure 1.



Source: http://www.physicalgeography.net/fundamentals/7y.html

Figure 1: The factors influencing the Earth's climate

1.2. Climate change:

Climate change is understood in term of the change in the earth's climate system, including atmosphere, hydrosphere, biosphere, lithosphere present and future by natural causes and man-made. This different use of the Framework Convention of the United Nations on Climate Change (UNFCCC), where climate change refers to a change of climate which is directly or indirectly due to the operation of people change the composition of global atmosphere and which is outside the natural climate changes observed in the same period. "

Station data and observation show that there has been change in climate over time. The weather and climate are closely related but the difference between them is important. Weather is the state of meteorological factors (such as humidity, fog, rain, sun ...) took place at a certain time of year. Climate is the average meteorological conditions occur during long periods of time and bring stability. It is difficult to predict future climate changes based on current weather. Chaotic nature of weather makes it unpredictable beyond a few days. Climate change (ie, long-term average weather) due to changes in atmospheric composition or other factors is very different and many factors impact.

It is clear that climate has changed toward higher temperature recently. Over the period 1861 – 1999, average global surface temperature has warmed by about 0.6^{0}C. The warmest years of this record are in the 1990s with 1998 the warmest year. The warming has not occurred in a linear fashion, but in two phases, early 1920s to the mid-1940s and since the mid-1970s. Many regions exhibit local statistically significant warming, although 20-25 year period are too short to consider trends given the large inter decadal variability in some areas. (IPCC, 2007).

Climate changes have had visible impacts on the natural systems. Its impacts will be relevant to the hydrological cycle and heating the surface of the planet (warming of the Earth). Climate change is expected to aggravate current stresses from temperature and precipitation availability for population, urbanization and land-use. Wide spread mass losses from glaciers and reductions in snow cover over recent decades are projected to accelerate throughout the 21st century, reducing water availability, hydro-power potential, and changing seasonality of flows in regions supplied by melt water from mountain ranges (IPCC, 2007).

1.3. Climate change modelling:

In order to better understand the Earth's climate and the climate change, climate models have been developed, which base on the physical laws, governing climate, solving the resulting equation, and comparing the simulation with observations.

There are a lot of factors, which influence the Earth's climate and must be taken into account. Climate system is a complex system and it is very difficult to conduct a model, which simulates well the Earth's climate. There are two ways of climate modeling: First, it is to develop the simple models in which a high degree of parameterization of processes is used. The second, it is to develop the synthesis models, General Circulation Models (GCM), which incorporate three dimensional dynamics and all processes (such as radiative transfer, ice sea processes…) as explicitly as possible. Each model type has advantages and disadvantages, they can be used parallel and have been improved during the past several years.

A General Circulation Model (GCM) is a mathematical model in which all vertical and horizontal motions are included during the time. The Atmospheric and

Oceanic General Circulation Model (AGCM and OGCM) are two important components of Global Climate Models. GCM simulations are also useful for undertaking an analysis of the sensitivity of a particular region to climate change.

Today, the most important method for obtaining information on possible future climates is based on the use of atmospheric GCM simulations. The large-scale GCM results are regarded as prediction of future climates. For the predicted future changes in climatic variables at a smaller regional scale there are some considerable deficiencies in GCM models due to their coarse resolution and highly smoothed orography.

1.4. Benefits of climate change models:

The GCM are a useful tool to study current climate sensitivity. First, a GCM is established to model a simulation which relates to factors in the current climate. Second, an input parameter of the model is changed. The difference between the two model simulations is related to sensitivity of climate to this particular parameter that was changed.

Comparisons of observed and simulated climates from GCM point out that the GCM produce feasible, reasonable and high accuracy results at the global scale. GCM model assessment of Earth's climate and natural variability are quite similar to observations, the accuracy of GCM simulation is higher for some regions and periods.

Climate models have been improved with respect to resolution, computational methods, parameterizations and additional interactive processes.

With modeling other subsystems (model of land surface, sea ice, Atmosphere – Ocean General Circulation Model,…), simulation of extreme event of climate has been improved. These models are useful in addressing questions involving long time scales and large spatial scale, providing a large number of ensemble simulations or sensitivity experiments.

1.5. Problems of climate change models:

Although GCMs are general better at global scales, important large scale problems also remain. The reason of most errors is that many important small scale interactive processes cannot be considered explicitly in the models

The GCMs have not only limitations in computing resources, but also limitations in scientific understanding or in the availability of detailed observations of some physical processes, for instance in the deep ocean.

In general, all types of climate models sustain challenges from both conceptual and practical problems. The simple climate models apply for their solution on a small number of assumptions that are known to be violated by the observed climate system. Despite this, simple climate models are useful in helping to understand the results obtained from GCM. However, GCM are also based to an uncomfortable extent on assumptions about the behaviour on the unresolved scales, the parameterizations. There usually exist multiple parameterization schemes for each process and few compelling reasons for choosing between them.

1.6. Climate model development and potentials:

GCMs simulations play an important role in climate change research, which have been increasingly improved to meet the research objectives with a smaller scale, the forecast of severe weather anomalies. Capacity and speed of calculation will promote the increasing computational processes. The climate models input parameters will more accuracy.

However, climate models still exist significant limitations, such as simulating the formation and development of clouds in real-time and amplitude in a defined territory. Over several decades of model development, multi-model ensemble simulations generally provide more significant information than runs of any single model.

1.7. State of the art in term of climate change in Southeast Asia:

Climate change (CC) is a global danger and can become a disaster for humanity due to its impacts on the basic elements of human life worldwide. Hundreds of millions of people could fall into poverty, water shortages, floods and drought. All countries are affected by climate change, but the countries affected first and most powerful, are the developing countries, although they contribute least to cause climate change. Therefore, studying climate change is essential in the development country in general, and in Southeast Asia in particular. (Tran Thanh Lam, 2009.).

The climate changes in Southeast Asia and Vietnam show a similar trend to the changes worldwide and Asia. The results from TAR are the median responses of GCM simulations, which predicted that annual mean warming would be about 3°C in the middle of the 21st century and about 5°C in the late 21st century (Lal et al., 2001a). Climate change in the region is characterized by an increase in surface air temperature, more pronounced in winter than in summer. These observations suggest that the temperature rise from less than 1°C to 3°C per century (Savelieva et al, 2000;. Izrael et al, 2002a;. Climate change in Russia, in 2003; Gruza and Rankova, 2004 .). Prolonged heatwaves have been observed in many Asian countries, in accordance with a significant warming trend. (De and Mukhopadhyay, 1998; Kawahara and Yamazaki, 1999; Zhai et al., 1999; Lal, 2003; Zhai and Pan, 2003; Ryoo et al., 2004; Batima et al., 2005a; Cruz et al., 2006; Tran et al., 2005).

Overall, the increased frequency of occurrence of intense precipitation in Asia is obvious and causes flooding, landslides, flash floods and mudflows, but the total number of rainy days and actual precipitation during the year decreased (Zhai et al., 1999, Khan et al, 2000;. Shrestha et al, 2000;. Izrael and Anokhin, 2001; Mirza, in 2002, Kajiwara et 2003;. Lal, 2003; Min et al, 2003;. Ruosteenoja et al. 2003; Zhai and Pan, 2003; Gruza and Rankova, 2004; Zhai, 2004). However, some studies indicate that the frequency of extreme rainfall in some countries in the region tends to decrease (Manton et al, 2001; Kanai et al, 2004 ..).

The main causes of the phenomenon of drought increasing in intensity and spread over the territory in some parts of Asia are attributed mainly to increase temperature, especially during the summer months, even in term of ENSO (Webster et al., 1998; Duong, 2000; PAGASA, 2001; Lal, 2002, 2003; Batima, 2003; Gruza and Rankova, 2004; Natsagdorj et al., 2005).

The recent IPCC reports show that occurrence frequency and intensity of storms from the Pacific grew over decades (Fan and Li, 2005). In addition, storms originating from the Bay of Bengal and Arabian Sea have increased (Lal, 2001). In both cases, the adverse effects of cyclones affecting both people and infrastructure, especially in India, China, Philippines, Japan, Vietnam and Cambodia, Iran and Tibetan Plateau (PAGASA, 2001; ABI, 2005; GCOS, 2005a, b)

The temperature warming over the area will be the main reason for increased annually precipitation in winter, significantly reducing precipitation in the summer, but this is the main cause leading to desertification, or the extreme drought condition. The increase in rainfall intensity, particularly during summer, could increase in flood area. In South-East Asia, extreme weather events associated with El-Niño were reported to be more frequent and intense in the past 20 years (Trenberth and Hoar, 1997; Aldhous, 2004).

It is well known that temperature and precipitation are the most important climate parameters for crop yield. Scientific research from 1996 to 2000 shows that wheat, maize and rise production in Asia and southeast Asia in the last century has decreased because of increasing temperature, high frequency of occurrence of El-Niño, intensity of storms and typhoons and decreasing precipitation over many regions in Asia (Wijeratne, 1996; Aggarwal et al., 2000; Jin et al., 2001; Fischer et al., 2002; Tao et al., 2003a; Tao et al., 2004). The results research from Peng et al., 2004 show that when minimum temperature increases by 1°C during the growth period, the yield of rice was decreased by actually 10% (Peng et al., 2004). Fischer et al., 2002 supposed that the reduction of traditional agricultural land and land capable for agricultural cultivation has been confirmed. Climate change will make agricultural cultivation more difficult for other countries in Asia (Sirotenko Izrael, 2003); Climate change has adverse impacts on the socio - economic development of all nations. But the degree of the impact will vary across nations. It is expected that changes in the earth's climate will particularly impact on developing countries like Vietnam because their economies are strongly dependent on crude forms of their natural resources and their economic structure is less flexible to adjust to such drastic changes.

CHAPTER 2 : METHODOLOGY

The study process is illustrated in figure 2. In the upper section, the selection of GCM output data for different climate projection scenarios and the observational and reanalysis data is illustrated. In the middle section, the statistical approach for the interpolation of GCM data output, NCEP, CRU and observation station data is shown. The bottom section describes the statistical analysis and assessment of the climate data.

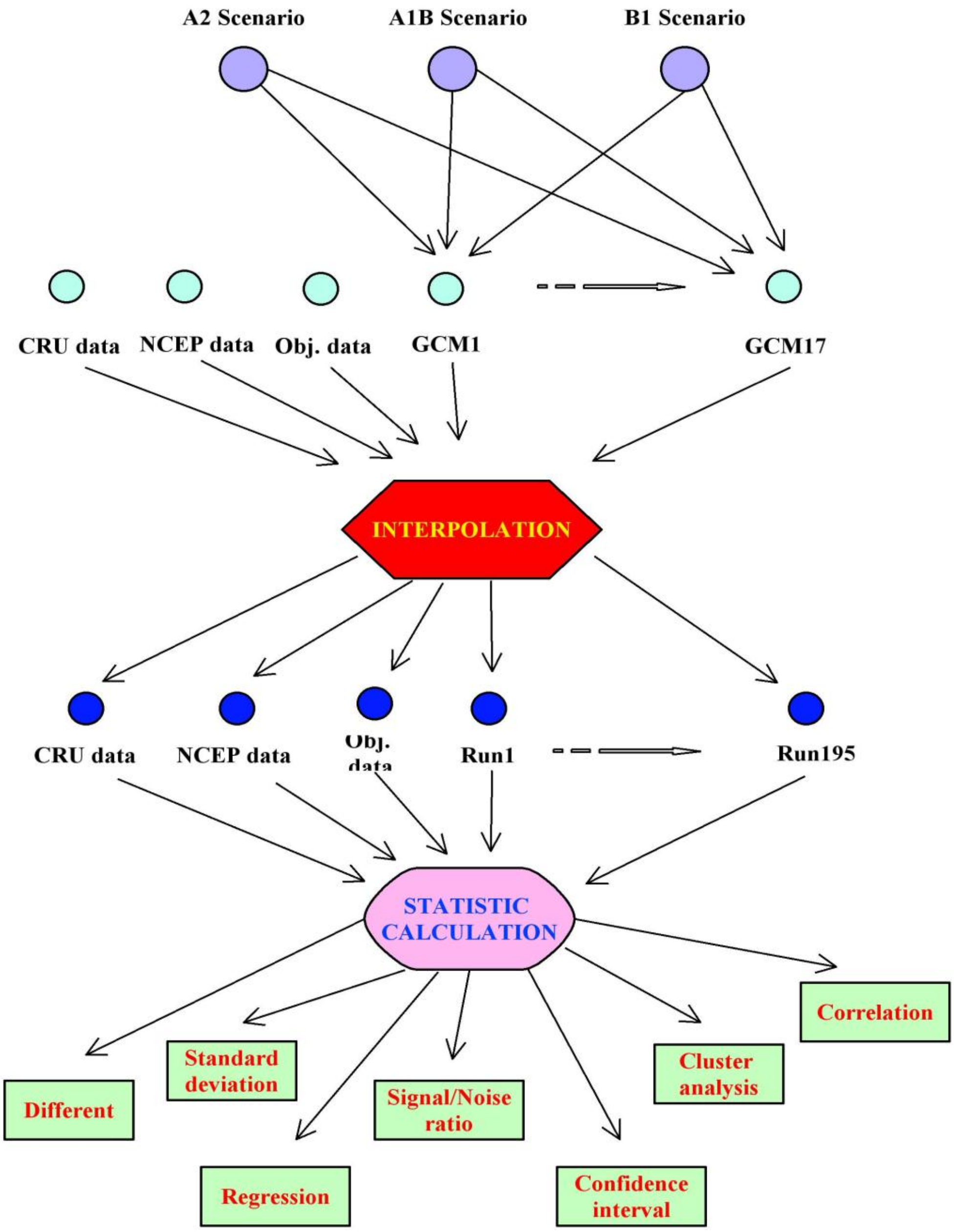


Figure 2 : Flowchart of the study process

2.1. Interpolation method:

At first, GCM have been recognized to be able to represent reasonably well the main features of the global distribution of basic climate parameters (Gates et al., 1999; Lambert and Boer, 2001), but these models so far could not reproduce well details of regional climate conditions at temporal and spatial scales of relevance to regional implications. In other words, GCM output data usually shows a resolution that is too coarse (generally greater than 2° for both latitude and longitude, i.e. greater than 200 km for middle latitudes) for many climate change impact study. At that scale, the regional and local detail of climate is lost. There are several problems associated with using climate change scenarios at the original GCM resolution:

1. sites in close proximity which fall in different grid boxes may have a very similar baseline climate but, after application of the coarse-scale model, there may be quite different climates.
2. a site on land may fall within the bounds of a GCM grid box defined as ocean (and vice versa). The climate response over ocean grid boxes is known to differ from that over land grid boxes.

For validation and comparison, it is necessary that all the fine resolution scenarios are interpolated to the same spatial grid, concerning GCMs, NCEP, CRU and station data. Each higher resolution data set contains monthly, seasonal and annual data. This spatial interpolation is a process by which simulated climate field are constructed showing the same resolution. After interpolation, all of the GCM data output, CRU, NCEP and observational data have the same resolution. This spatial interpolation can be described by the following figure 3.

a

4	4.7	5.5	6
4.7	4.3	6.2	6.8
3.7	2	7.2	8.3
5	4.5	7.5	9

b

4.4	4.4	6.1	6.1
4.4	4.4	6.1	6.1
3.8	3.8	8	8
3.8	3.8	8	8

c

4.4	6.1
3.8	8

Figure 3: The original grid-box values (c) is initially the same as in the second step in the grid-box approach (b), but contains the mean-values original grid-point (c) to interpolate into grid-box values (a).

Starting from the original higher resolution grid (a), spatial means new over grid boxes fitting into the new lower resolution grid box are computed (b), and assigned to the new resolution (a). In term of station data, all stations belonging to a grid box of the intended resolution are averaged.

In this study we interpolate GCM results to a 3° x 3° latitude/longitude grid for both monthly temperature and precipitation.

2.2. Validation method:

In order to determine how well GCM simulations capture the behaviour of the Earth's atmosphere and ocean, we compare these GCM simulations with data sets constructed from observations (not only the CRU, NCEP, but also station data in Vietnam were used in this study) (this is also referred to as "validation"). We compare simulations of different GCM in order to discover both the problems and successes common to various models, and to learn how their distinct modelling philosophies differ.

2.2.1 Computing Mean, variance and Standard deviation:

Definition of Mean or Average:

The Mean or Average is defined as the sum of all the given elements divided by the total number of elements[1].

Formula:

$$\bar{a} = \frac{\sum_{i=1}^{N} a_i}{N}$$

Where N = number of element

a_i = individual score

$\bar{a}$ = mean score

1. *Sourse : http://easycalculation.com/statistics/learn-mean.php*

Definition of Standard Deviation:

The Standard deviation is a statistical measure of spread or variability. The standard deviation is the root mean square (RMS) deviation of the values from their arithmetic mean[2].

$$S = \sqrt{\frac{\sum_{i=1}^{N}(a_i - \overline{a})^2}{N-1}}$$

where N = number of element
a_i = individual score
$\overline{a}$ = mean score
S = standard deviation

Definition of Variance:

The Variance is the square of the standard deviation. It is a measure of the degree of spread among a set of values; a measure of the tendency of individual values to vary from the mean value[3].

$$\text{Variance} = S^2$$

The mean temperature and precipitation of all GCM output data are calculated in the time from the 1980 – 1999 (reference period); 2011 – 2030; 2046 – 2065 and 2080 – 2099 period (future periods). The Variance and Standard deviation between all available GCM runs are calculated for the same periods.

2.2.2. Calculating the differences in mean-values:

The seasonal and the annual temperature and precipitation are calculated, next defining a summer (from the May to October) and a winter season (from November to April following year). Both annual and seasonal air temperature and precipitation were investigated by comparing multimodel mean differences between the reference and the future periods.

2. *Sourse : http://easycalculation.com/statistics/learn-standard-deviation.php*
3. *Sourse : http://easycalculation.com/statistics/learn-standard-deviation.php*

2.2.3. Calculating the signal/noise ratio:

The "Signal-to-noise ratio" (SN) is defined, the ratio of useful information or a desire signal to a false or signal noise. A ratio higher than 1 indicate more desired signal than noise and vice versa. The signal/noise ratio of climate projections can be computed with the following formula:

$$SN = \frac{\text{Difference between mean values (future – base period)}}{\text{Standard deviation (future period)}}$$

This is done for the differences of all future time period to the reference period.

2.2.4. Calculating the confidence interval:

The confidence interval is calculated to test whether the mean GCM output data agree with those of the CRU, NCEP and observation station data in Vietnam. The mean values are obtained from the GCM may be different from the mean values which would be obtained from CRU, NCEP and station data in Vietnam. The confidence interval is used to test if the true GCM mean falls within a particular probability range (90%, 95% or 99% in this study) around the CRU, NCEP or station mean data. The confidence interval can be computed with following formula:

$$\text{Cov\_interv al} = \text{MEAN} \pm Z * \left(\frac{S}{\sqrt{N}}\right)$$

Where:

MEAN = the mean over CRU, NCEP and station data in Vietnam.

S = the standard deviation between CRU, NCEP and station data.

Z = the particular quantile of the t-distribution given an error level of Z=90%, 95% and 99%).

N = 3 (sample consists of CRU, NCEP and station data variances).

2.3. Linear Regression:

Definition of Regression:

A regression is a statistical analysis assessing the relationship between two variables. In this study, we determine the relationship between the particular climatic parameters (temperature and precipitation) and the time. The regression allows us to determine the trend of the climatic parameters over the time[4].

Linear Regression Formula:

Linear Regression Equation (y) = a + b*x

$$b = \frac{(N * \sum_{i=1}^{N} (x_i * y_i) - \sum x_i * \sum y_i)}{N * \sum (x_i * x_i) - (\sum x_i)^2}$$

$$a = \frac{\sum_{i=1}^{N} y_i}{N} - b * \frac{\sum_{i=1}^{N} x_i}{N}$$

Where:

X and Y are the variables.

b = The slope of the regression line

a = The intercept point of the regression line on the y axis.

N = Number of values or elements

x = First score (time series)

y = Second score (a climatic element)

The trend (slope of regression) was calculated for the temperature and precipitation at stations in Vietnam and for the statistical transfer functions between climate parameters and agricultural yields in Vietnam.

4. *Sourse : http://easycalculation.com/statistics/learn-regression.php*

2.4. Multy Regression:

Definition of Multiple Linear Regression:

Multiple linear regression attempts to model the relationship between two or more explanatory variables and a response variable by fitting a linear equation to the data. Every value of the independent variable x is associated with a value of the dependent variable y.

The equation for multiple linear regression, given n observations, is

$$y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \dots \beta_p x_{ip} + \varepsilon_i \text{ for } i = 1,2, \dots n.$$

The population regression line for p explanatory variables $x_1, x_2, \dots, x_p$ is defined to be $\mu_y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_p x_p$. This line describes how the mean response μ_y changes with the explanatory variables. The observed values for y vary about their means μ_y and are assumed to have the same standard deviation σ. The fitted values b_0, b_1, ..., b_p estimate the parameters β_0, β_1, ..., β_p of the population regression line.

Since the observed values for y vary about their means μ_y, the multiple regression model includes a term for this variation. In words, the model is expressed as DATA = FIT + RESIDUAL, where the "FIT" term represents the expression $\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots \beta_p x_p$. The "RESIDUAL" term represents the deviations of the observed values y from their means μ_y, which are normal distributed with mean 0 and variance σ. The notation for the model deviations is ε.

In the least-square model, the best-fit line for the observed data is calculated by minimizing the sum of the squares of the vertical deviations from each data point to the line (if a point lies on the fitted line exactly, then its vertical deviation is 0). Because the deviations are first squared, then summed, there are no cancellations between positive and negative values. The least-square estimates b_0, b_1, ... b_p are computed by a FORTRAN program in this study. In this study, the x_i variables are temperature and precipitation; the y variable is the crop yield.

2.5. Correlation:

Correlation is a measure of the strength of the linear relationship between two variables. Correlation is normalized between -1.0 and +1.0. If the correlation is positive, the two variances develop in the similar direction. If it is negative, the relationship is opposed. The correlation between temperature, precipitation and the agricultural yields can be calculated with the following formula:

$$r = \frac{N * \sum_{i=1}^{N} x_i * y_i - \sum_{i=1}^{N} x_i * \sum_{i=1}^{N} y_i}{\sqrt{(N * \sum_{i=1}^{N} x_i^2 - (\sum_{i=1}^{N} x_i)^2) * (N * \sum_{i=1}^{N} y_i^2 - (\sum_{i=1}^{N} y_i)^2)}}$$

Where: r = Correlation

N = Number of values or elements

X =The temperature or precipitation (first score)

Y= The agricultural yield (second score)

This correlation is done for CRU and NCEP data with agricultural yield in Vietnam during 1995 – 2002.

2.6. Cluster Classification:

Classification is an important part of data analysis in general and of climate data analysis in particular. The classification becomes more complex when the data series increases. Clustering methods have been applied to solve classification problems. Several clustering-based classification techniques have been explored. In this study, we use a hierarchical cluster analysis combined with a k – mean algorithm to build cluster – based classification data performed by a FORTRAN program. This method is able to reduce wrong attributions in the cluster process and get high accuracy results. Each location in space is clustered independently into 10 classes. The resulting climate clusters presents the overview climate conditions of Vietnam.

The data used in this cluster classification are from 107 stations over Vietnam with 8 climatic parameters which are evaporation, precipitation, minimum – maximum - average temperature, wind speed, sunny hour and humidity.

CHAPTER 3 : DATABASE

The major climatic parameters used in this study are temperature and precipitation. The databases used in this work are from the GCM simulations, CRU, NCEP and observation station data in Vietnam.

3.1. GCM data:

Since 1996, the IPCC has developed a new set of scenarios of emissions of gases with greenhouse effect (the main reason for causing global warming and melting ice at the poles of the earth). The special report on emission scenarios (SRES), as depicted in the IPCC report, is the consensus of opinion among the scientific communities. Four scenario families were developed to describe the future development of mankind. The final result is a set of 40 scenarios (35 of which contain data about a range of gases needed to climate models). In this study, we used the data in scenarios A1B, A2 and B1.

A1 Scenario:

The A1 scenarios included three groups distinguished to describe the changing trend of technology in energy systems: energy sources from fossil products (non-renewable) (A1FI), non-fossil energy sources (A1T), or a combination of both (A1B) [5].

A2 Scenario:

The A2 scenario depicts a world very uneven. The global integration process occurs slowly, population growth is high, technological develop is low-speed and a high regional diversity occurs compared with other scenarios.

B1 scenario:

The B1 scenario describes a world of globalization, world population increases until the mid-21th century and then declined, as in the A1 scenario. World economy grows moderately is focused on service and information technology, reducing energy

5. *In one A1 scenario group the transition away from conventional oil and gas either leads to a massive development of unconventional oil and gas resources (A1G) or to a large-scale synfuel economy based on coal (A1C)*

utilization from fossil, implying development and application of clean technologies and a more effective utilization of resources. It aims at world-wide solutions to assure socio-economic sustained development and environmental protection.

Table 1: Overview of greenhouse gases (GHGs), ozone precursors, and sulfur emissions by the year 2100 for the SRES scenario groups.

	CO_2 (GtC)	CH_4 ($MtCH_4$)	N_2O (MtN)	HFC, PFC, SF_6 (MtC equiv.)	CO (Mt CO)	NMVOCs (Mt)	NO_x (MtN)	SO_x (MtS)
A1B	13.5 (13.5-17.9)	289 (289-640)	7.0 (5.8-17.2)	824 combined	1663 (1080-2532)	193 (133-552)	40.2 (40.2-77.0)	27.6 (27.6-71.2)
A1C	(25.9- 36.7)	(392- 693)	(6.1- 16.2)	same as in A1	(2298- 3766)	(167- 373)	(63.3 -151.4)	(26.9- 83.3)
A1G	(28.2- 30.8)	(289- 735)	(5.9- 16.6)	same as in A1	(3260- 3666)	(192- 484)	(39.9 -132.7)	(27.4- 40.5)
A1T	(4.3- 9.1)	(274- 291)	(4.8- 5.4)	same as in A1	(1520- 2077)	(114 -128)	(28.1- 39.9)	(20.2- 27.4)
A2	29.1 (19.6-34.5)	889 (549-1069)	16.5 (8.1-19.3)	1096 combined	2325 (776-2646)	342 (169-342)	109.2 (70.9-110.0)	60.3 (60.3-92.9)
B1	4.2 (2.7-10.4)	236 (236-579)	5.7 (5.3-20.2)	386 combined	363 (363-1871)	87 (58- 349)	18.7 (16.0-35.0)	24.9 (11.4-24.9)
B2	13.3 (10.8-21.8)	597 (465-613)	6.9 (6.9-18.1)	839 combined	2002 (661-2002)	170 (130-304)	61.2 (34.5-76.5)	47.9 (33.3-47.9)

Source: Climate Change 2007: Working Group I: The Physical Science Basis table 8.2

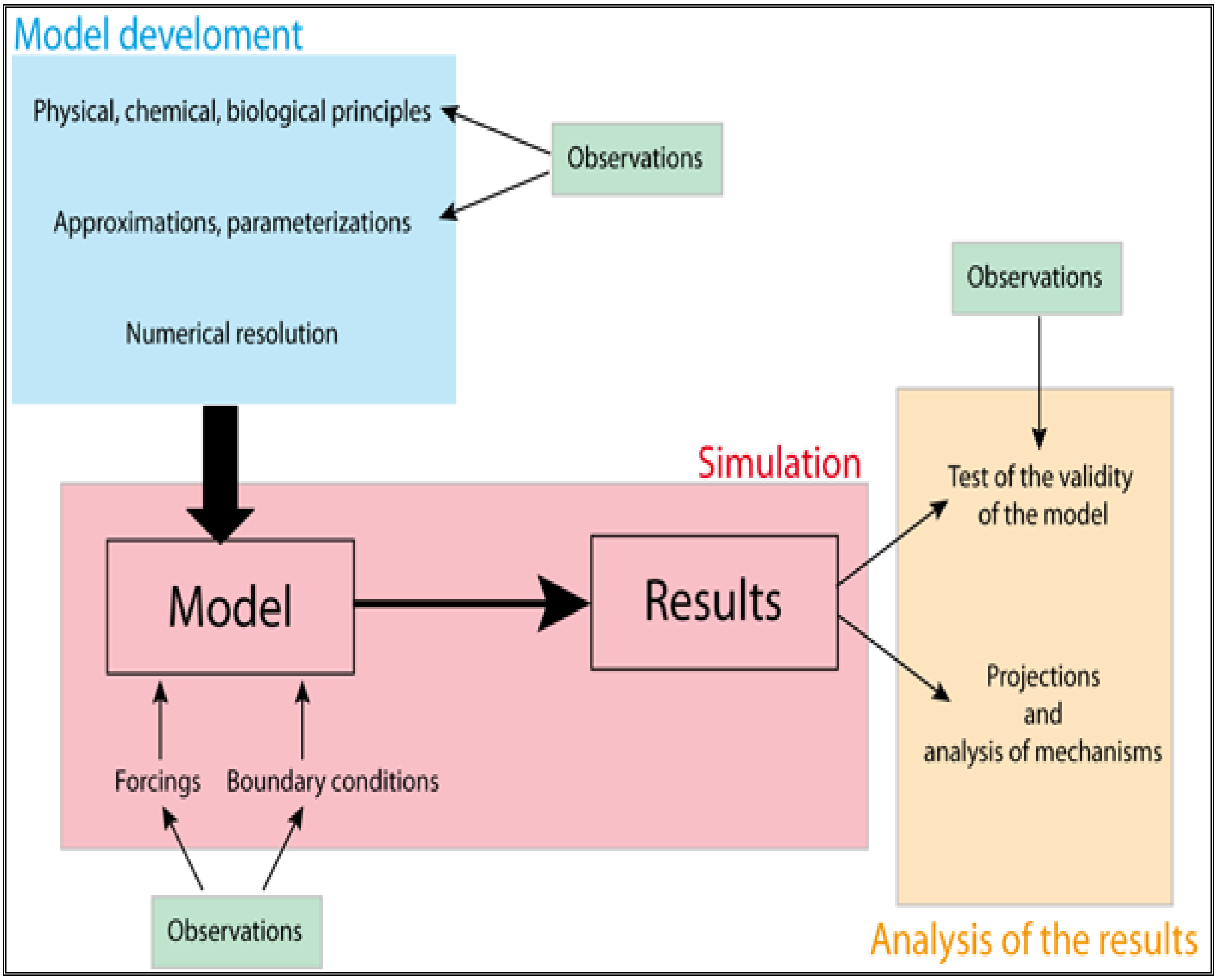
Regional scenarios of mean climate change in this study have been derived from the 17 GCM. The models considered are listed in the table 2. Scenarios of the change in temperature, precipitation are produced directly from the GCM grid-point output (run to run). The GCM models used have a spatial resolution of several hundreds of kilometer.

3.2. CRU data[6]:

The Climatic Research Unit (CRU) at the University of the East Anglia (UEA) has, since 1982, made available gridded datasets of surface temperature and precipitation data over land areas of Globe (New, M., Hulme, M. and Jones, P.D., 2000.). These datasets have been developed from data acquired from weather stations

6. Resource from Climatic Research Unit. http://www.cru.uea.ac.uk/

around the world. Almost all these weather stations are run by National Meteorological Services (NMSs) and they exchange these data over the CLIMAT network, which is part of the World Meteorological Organization's (WMO) Global Telecommunications System (GTS). Much of the original data in the early 1980s came from publications entitled 'World Weather Records'. They also make use of data available from the National Climatic Data Center in Asheville, North Carolina (their Global Historical Climatology Network, GHCN). Both the gridded datasets and the station data archived have evolved over the years.



Sourse : http://stratus.astr.ucl.ac.be/textbook/chapter3_node3.html

Figure 4: Schematic representation of the development and use of a climate model

Table 2 : Selected model features

Source: Climate Change 2007: Working Group I: The Physical Science Basis table 8.1

Model ID, Vintage	Sponsor(s), Country	Atmosphere Top Resolutiona References	Ocean Resolutionb Z Coord., Top BC References	Sea Ice Dynamics, Leads References	Coupling Flux Adjustments References	Land Soil, Plants, Routing References
(1)	(2)	(3)	(4)	(5)	(6)	(7)
BCC-CM1, 2005 (BCM)	Beijing Climate Center, China	top = 25 hPa T63 (1.9° x 1.9°) L16 Dong et al., 2000; CSMD, 2005; Xu et al., 2005	1.9° x 1.9° L30 depth, free surface Jin et al., 1999	no rheology or leads Xu et al., 2005	heat, momentum Yu and Zhang, 2000; CSMD, 2005	layers, canopy, routing CSMD, 2005
BCCR-BCM2.0, 2005 (BCR)	Bjerknes Center for Climate Research, Norway	top = 10 hPa T63 (1.9° x 1.9°) L31 Déqué et al., 1994	0.5°–1.5° x 1.5° L35 density, free surface Bleck et al., 1992	rheology, leads Hibler, 1979; Harder, 1996	no adjustments Furevik et al., 2003	Layers, canopy, routing Mahfouf et al., 1995; Douville et al., 1995; Oki and Sud, 1998
CCSM3, 2005 (NCC)	National Center for Atmospheric Research, USA	top = 2.2 hPa T85 (1.4° x 1.4°) L26 Collins et al., 2004	0.3°–1° x 1° L40 depth, free surface Smith and Gent, 2002	rheology, leads Briegleb et al., 2004	no adjustments Collins et al., 2006	layers, canopy, routing Oleson et al., 2004; Branstetter, 2001
CGCM3.1(T47), 2005 CGM	Canadian Center for Climate Modelling and Analysis, Canada	top = 1 hPa T47 (~2.8° x 2.8°) L31 McFarlane et al., 1992; Flato, 2005	1.9° x 1.9° L29 depth, rigid lid Pacanowski et al., 1993	rheology, leads Hibler, 1979; Flato and Hibler, 1992	heat, freshwater Flato, 2005	layers, canopy, routing Verseghy et al., 1993
CGCM3.1(T63), 2005 (CGM_t63)	Canadian Center for Climate Modelling and Analysis, Canada	top = 1 hPa T63 (~1.9° x 1.9°) L31 McFarlane et al., 1992; Flato 2005	0.9° x 1.4° L29 depth, rigid lid Flato and Boer, 2001; Kim et al., 2002	rheology, leads Hibler, 1979; Flato and Hibler, 1992	heat, freshwater Flato, 2005	layers, canopy, routing Verseghy et al., 1993
CNRM-CM3, 2004 (CNM)	Météo-France/Center National de Recherches Météorologiques, France	top = 0.05 hPa T63 (~1.9° x 1.9°) L45 Déqué et al., 1994	0.5°–2° x 2° L31 depth, rigid lid Madec et al., 1998	rheology, leads Hunke-Dukowicz, 1997; Salas-Mélia, 2002	no adjustments Terray et al., 1998	layers, canopy,routing Mahfouf et al., 1995; Douville et al., 1995; Oki and Sud, 1998
ECHAM5/MPI-OM, 2005 (MPE)	Max Planck Institute for Meteorology, Germany	top = 10 hPa T63 (~1.9° x 1.9°) L31 Roeckner et al., 2003	1.5° x 1.5° L40 depth, free surface Marsland et al., 2003	rheology, leads Hibler, 1979; Semtner, 1976	no adjustments Jungclaus et al., 2005	bucket, canopy, routing Hagemann, 2002; Hagemann and Dümenil-Gates, 2001
ECHO-G, 1999 (MEG)	Meteorological Institute of the University of Bonn, Meteorological Research Institute of the Korea Meteorological Administration (KMA), and Model and Data Group, Germany/Korea	top = 10 hPa T30 (~3.9° x 3.9°) L19 Roeckner et al., 1996	0.5°–2.8° x 2.8° L20 depth, free surface Wolff et al., 1997	rheology, leads Wolff et al., 1997	heat, freshwater Min et al., 2005	bucket, canopy, routing Roeckner et al., 1996; Dümenil and Todini, 1992

(1)	(2)	(3)	(4)	(5)	(6)	(7)
FGOALS -g1.0, 2004 (IFG)	National Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics (LASG)/Institute of Atmospheric Physics, China	top = 2.2 hPa T42 (~2.8° x 2.8°) L26 Wang et al., 2004	1.0° x 1.0° L16 eta, free surface Jin et al., 1999; Liu et al., 2004	rheology, leads Briegleb et al., 2004	no adjustments Yu et al., 2002, 2004	layers, canopy, routing Bonan et al., 2002
GFDL-CM2.0, 2005 (GCO)	U.S. Department of Commerce/ National Oceanic and Atmospheric Administration (NOAA)/Geophysical Fluid Dynamics Laboratory (GFDL), USA	top = 3 hPa 2.0° x 2.5° L24 GFDL GAMDT, 2004	0.3°–1.0° x 1.0° depth, free surface Gnanadesikan et al., 2004	rheology, leads Winton, 2000; Delworth et al., 2006	no adjustments Delworth et al., 2006	bucket, canopy, routing Milly and Shmakin, 2002; GFDL GAMDT, 2004
GFDL-CM2.1, 2005 (GC1)	U.S. Department of Commerce/ National Oceanic and Atmospheric Administration (NOAA)/Geophysical Fluid Dynamics Laboratory (GFDL), USA	top = 3 hPa 2.0° x 2.5° L24 GFDL GAMDT, 2004 with semi-Lagrangian transports	0.3°–1.0° x 1.0° depth, free surface Gnanadesikan et al., 2004	rheology, leads Winton, 2000; Delworth et al., 2006	no adjustments Delworth et al., 2006	bucket, canopy, routing Milly and Shmakin, 2002; GFDL GAMDT, 2004
GISS-AOM, 2004 (GSA)	National Aeronautics and Space Administration (NASA)/ Goddard Institute for Space Studies (GISS), USA	top = 10 hPa 3° x 4° L12 Russell et al., 1995; Russell, 2005	3° x 4° L16 mass/area, free surface Russell et al., 1995; Russell, 2005	rheology, leads Flato and Hibler, 1992; Russell, 2005	no adjustments Russell, 2005	layers, canopy, routing Abramopoulos et al., 1988; Miller et al., 1994
GISS-EH, 2004 (GSH)	National Aeronautics and Space Administration (NASA)/ Goddard Institute for Space Studies (GISS), USA	top = 0.1 hPa 4° x 5° L20 Schmidt et al., 2006	2° x 2° L16 density, free surface Bleck, 2002	rheology, leads Liu et al., 2003; Schmidt et al., 2004	no adjustments Schmidt et al., 2006	layers, canopy, routing Friend and Kiang, 2005
GISS-ER, 2004 (GSM)	NASA/GISS, USA	top = 0.1 hPa 4° x 5° L20 Schmidt et al., 2006	4° x 5° L13 mass/area, free surface Russell et al., 1995	rheology, leads Liu et al., 2003; Schmidt et al., 2004	no adjustments Schmidt et al., 2006	layers, canopy, routing Friend and Kiang, 2005
INM-CM3.0, 2004 (INM)	Institute for Numerical Mathematics, Russia	top = 10 hPa 4° x 5° L21 Alekseev et al., 1998; Galin et al., 2003	2° x 2.5° L33 sigma, rigid lid Diansky et al., 2002	no rheology or leads Diansky et al., 2002	regional freshwater Diansky and Volodin, 2002; Volodin and Diansky, 2004	layers, canopy, no routing Alekseev et al., 1998; Volodin and Lykosoff, 1998
IPSL-CM4, 2005 (IPL)	Institut Pierre Simon Laplace, France	top = 4 hPa 2.5° x 3.75° L19 Hourdin et al., 2006	2° x 2° L31 depth, free surface Madec et al., 1998	rheology, leads Fichefet and Morales Maqueda, 1997; Goosse and Fichefet, 1999	no adjustments Marti et al., 2005	layers, canopy, routing Krinner et al., 2005
MIROC3.2(hires), 2004 (M3H)	Center for Climate System Research (University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC), Japan	top = 40 km T106 (~1.1° x 1.1°) L56 K-1 Developers, 2004	0.2° x 0.3° L47 sigma/depth, free surface K-1 Developers, 2004	rheology, leads K-1 Developers, 2004	no adjustments K-1 Developers, 2004	layers, canopy, routing K-1 Developers, 2004; Oki and Sud, 1998

(1)	(2)	(3)	(4)	(5)	(6)	(7)
MIROC3.2(medres), 2004 (M3M)	Center for Climate System Research (University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC), Japan	top = 30 km T42 (~2.8° x 2.8°) L20 K-1 Developers, 2004	0.5°–1.4° x 1.4° L43 sigma/depth, free surface K-1 Developers, 2004	rheology, leads K-1 Developers, 2004	no adjustments K-1 Developers, 2004	layers, canopy, routing K-1 Developers, 2004; Oki and Sud, 1998
MRI-CGCM2.3.2, 2003 (MCG)	Meteorological Research Institute, Japan	top = 0.4 hPa T42 (~2.8° x 2.8°) L30 Shibata et al., 1999	0.5°–2.0° x 2.5° L23 depth, rigid lid Yukimoto et al., 2001	free drift, leads Mellor and Kantha, 1989	heat, freshwater, momentum (12°S–12°N) Yukimoto et al., 2001; Yukimoto Noda, 2003	layers, canopy, routing Sellers et al., 1986; Sato et al., 1989
PCM, 1998 (NCP)	National Center for Atmospheric Research, USA	top = 2.2 hPa T42 (~2.8° x 2.8°) L26 Kiehl et al., 1998	0.5°–0.7° x 1.1° L40 depth, free surface Maltrud et al., 1998	rheology, leads Hunke and Dukowicz 1997, 2003; Zhang et al., 1999	no adjustments Washington et al., 2000	layers, canopy, no routing Bonan, 1998
UKMO-HadCM3, 1997 (UH3)	Hadley Center for Climate Prediction and Research/Met Offi ce, UK	top = 5 hPa 2.5° x 3.75° L19 Pope et al., 2000	1.25° x 1.25° L20 depth, rigid lid Gordon et al., 2000	free drift, leads Cattle and Crossley, 1995	no adjustments Gordon et al., 2000	layers, canopy, routing Cox et al., 1999
UKMO-HadGEM1, 2004 (UHG)	Hadley Center for Climate Prediction and Research/Met Offi ce, UK	top = 39.2 km ~1.3° x 1.9° L38 Martin et al., 2004	0.3°–1.0° x 1.0° L40 depth, free surface Roberts, 2004	rheology, leads Hunke and Dukowicz, 1997; Semtner, 1976; Lipscomb, 2001	no adjustments Johns et al., 2006	layers, canopy, routing Essery et al., 2001; Oki and Sud, 1998

3.3. NCEP data[7]:

The National Centers for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR) have cooperated in a project (denoted “reanalysis”) to produce a retrospective record of more than 50 years of global analyses of atmospheric fields in support of the needs of the research and climate monitoring communities. This effort involved the recovery of land surface, aircraft, satellite, and other measurements. These data were then quality controlled and assimilated with a data as simulation system kept unchanged over the reanalysis period.

Products from NCEP/NCAR Reanalysis Project (NNRP or R1) are archived and available in the internet. There are over 80 different variables, (including temperature, relative humidity, U and V wind components, etc.) in several different coordinate systems on a 2.5° x 2.5° degree grid with 28 sigma levels. The temperature and

5. Resource from Earth System Research Laboratory. http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html precipitation datasets span over the period 1948 to 2002. The dataset continues to be updated regularly as new observational data become available.

3.4. Observation station data in Vietnam:

The available climatic data from Vietnam is still sparse and differ in term of the time length. The present network of weather station consists of 107 stations on Vietnam territory. The data (temperature and precipitation) from 107 weather stations were interpolated to the common grid mentioned above and cover the Vietnam region.

3.5. Agricultural database in Vietnam:

The Agricultural database in Vietnam is also quite spars. Annual crop yields were collected for the whole country and during the time 1995 to 2002, including several agricultural products: annual paddy, maize, cassava, sweet potato, sugar cane, annual industry crop (cotton, jute, rush and tobacco), permanent industry crop (tea, coffee, rubber, pepper, cashew nuts), peanut and soybean.

4.1. Large-scale perspective:

The region considered is Southeast Asia, consisting of the countries that are geographically south of China, east of India and north of Australia. The region lies on an intersection of tectonic plates, with heavy seismic and volcanic activity. Southeast Asia consists of two geographic regions: the Asian mainland (Indochina) and island arcs and archipelagoes to the east and southeast (Malayan Archipelago). The mainland section consists of Burma, Laos, Thailand, Vietnam and Malayan Peninsular while the maritime section consists of Brunei, East Malaysia, East Timor, Indonesia, Philippine and Singapore (Map 1). Indonesia is the largest county in region with 1,904,569 km^2; Singapore is a country with the smallest area in the region but has the highest GDP per capita reached $ 35,500 (2009) and claimed the title of fastest-growing economy in the world. Vietnam is approximately 331,688 km^2 in area and GDP per capital is 1,100$ ranked among the developing countries. The territory, population and level of development of countries are uneven; poor, backward countries often has large population, huge natural land; other countries have smaller area but the showing high growth in GDP. This will affect the role of individual countries in regional and response capabilities, sensitivity to different climate change.

Table 3: Countries in Southeast Asia

Country	Area (km^2)[10]	Population(2009)[1]	Density (/km^2)	GDP USD (2009)[11]	GDP per capita (2009)	Capital
Brunei	5,765	400,000	70	14,700,000,000	$36,700	Bandar Seri Begawan
Burma	676,578	50,020,000	74	26,820,000,000	$500	Naypyidaw
Cambodia	181,035	14,805,000	82	10,900,000,000	$800	Phnom Penh
Timor-Leste	14,874	1,134,000	76	599,000,000	$500	Dili
Indonesia	1,904,569	240,271,522	126	514,900,000,000	$2,200	Jakarta
Laos	236,800	6,320,000	27	5,721,000,000	$900	Vientiane
Malaysia	329,847	28,318,000	83	191,400,000,000	$14,900 [12]	Kuala Lumpur
Philippines	299,764	91,983,000	307	167,000,000,000	$1,750	Manila
Singapore	710.2	4,987,600[13]	7,023	177,100,000,000	$35,500	City of Singapore (Downtown Core)
Thailand	513,120	67,764,000	132	263,500,000,000	$3,900	Bangkok
Vietnam	331,210	88,069,000	265	97,120,000,000	$1,100	Hanoi

Source : http://en.wikipedia.org/wiki/Southeast_Asia

All of Southeast Asia falls within the warm, humid tropics, and its climate generally can be characterized as monsoonal. For South Asia, the monsoon anomalies appeared on the Indian Ocean region are composed the monsoon depressions and tropical cyclones. For East Asia, the extra-tropical cyclones in the lee of the Tibetan Plateau and the strong temperature gradient along the East Coast play an important role for the monsoon circulations. The influence of ENSO on the position and strength of the subtropical high in the North Pacific influences both typhoons and other damaging heavy rainfall events, and has been implicated in observed inter-decadal variations in typhoon tracks (Ho et al., 2004). The considered region is from -10° to 40° latitude and from 60° to 130° longitude, which covers from Arabian Sea in the west to Philippine Sea in the East and from Himalaya strip, Tibetan plateau in the North to the Indian Ocean in the South.

Map 1 : The countries and regions of South East Asia with borders, main cities and capitals

Source: http://www.nationsonline.org/oneworld/map_of_southeast_asia.htm

4.2. Small-scale perspective:

As a focus region within Southeast Asia, Vietnam located in the Southeastern extremity of the Indochinese peninsula and occupies about 331,688 square kilometers, of which about 25 percent was under cultivation in 1987. Vietnam borders the adjacent Gulf of Thailand in the south, Gulf of Tonkin and the South China Sea in the east, China in the north, Laos and Cambodia to the west. The S-shaped country has a north-to-south distance of 1,650 kilometers and is about 50 kilometers wide at the narrowest point. With a coastline of 3,260 kilometers, excluding islands, Vietnam claims 12 nautical miles as the limit of its territorial waters, an additional 12 nautical miles as a contiguous customs and security zone, and 200 nautical miles as an exclusive economic zone.

Topography includes lowlands, coastal strip and the mountains. The country is divided into the highlands and the Red River Delta in the north; and the Truong Son (Central mountain), the coastal lowlands, and the Mekong River Delta in the south.

Natural conditions and natural resources allow Vietnam to develop a tropical agriculture with a clear season ability. Terrain and soil conditions for planting adapted systems vary between regions.

Agriculture plays an important role and is an important economic sector of Vietnam. In 2009, the value of agricultural output reached 71.473 trillion vnd (Vietnam Dong) (compared to 1994 prices), increased by 1.32% compared with 2008 and accounted for 13.85% of the total domestic product. The proportion of agriculture in the economy decreased in recent years, while other economic sectors increased. The contribution of agriculture to create jobs is bigger than this sector's contribution to GDP (Gross Domestic Product). In 2005, approximately 60% of employees were working in agriculture, forestry and fisheries. Year 2005, agricultural product accounted for 30% of total Vietnam’s export. The liberalization of products, particularly rice, has helped Vietnam to become the world's second rice exporting nation.

Vietnamese agriculture has growth reasonability since the implementation of policy reforms in the late 1980s. Agricultural growth is dominated by a growth of rice productivity due to the rapid adoption of modern varieties, increased fertilizer use, and increased cropping intensity. The policy reforms created the right economic incentives for farmers to adopt to yield - increasing technologies. Rice production grew at more than 5 per cent per year during the early 1990s and Vietnam rapidly achieved the status of a major exporting country. Being an agricultural country, the relative attributions from agriculture, forestry and fisheries was 77%, 4% and 19%, respectively.

Vietnam economy is still classified as one of the developing countries in the World. Average GDP in 2005 was only 643 USD per capita. The yields of crops and animals depend on world market prices. The annual average birth-rate of 2.2% nationwide is still high, esp. in rural areas, causing a big difficulty in economic development.

4.3. Climate of Vietnam:

Vietnam has a humid tropical monsoon climate according to its geographical location. Atmospheric moisture is influenced by air mass as moving over the ocean and the South China Sea, effecting richness to diversity of the natural resources of Vietnam, with annual average humidity among 84%. The monsoon is related to the regime of trade winds and monsoons the large-scale Asian. The climate of Vietnam has distinct seasons: the winter or dry season, extending roughly from November to April, the monsoon winds usually blow from the northeast along the Chinese coast and across the Gulf of Tonkin, picking up considerable moisture; consequently the winter season in most parts of the country is dry only by comparison with the rainy or summer season. During the summer monsoon, occurring from May to October, the heated air of the Gobi Desert rises, far to the north, inducing moist air to flow inland from the sea and lead to heavy rainfall.

Annual rainfall is substantial in all regions and torrential in some, ranging from 1200 mm to 3000 mm. Nearly 90% of the precipitation occurs during the summer monsoon. The average annual temperature is generally higher in the plains than in the mountains and plateaus. Temperatures range from 5°C in December and January, the coolest months, to more than 37°C in April, the hottest month. Seasonal divisions are more clearly marked in the northern half than in the southern half of the country, where, except in some part of the highlands, seasonal temperatures vary only a few degrees, usually in the 21°C-28°C range.

Source: http://www.vietnamtravel.com.au/vietnam_map.html

Map 2: Vietnam's map with the main cities

According to the coordination between heat (Σ°C) and relative humidity – temperature (K), Vietnam has following types of climate: Dry sub-equator in Ninh Thuan, Dry sub-equator in upstream Da rang river – Khanh Hoa – Binh Thuan, Moisture sub-equator in Binh Dinh – Phu Yen – Southeast, Humidity sub-equator in Quang Nam – Quang Ngai – Song be – Minh Hai, Dry tropical in Muong Xen (Thanh Hoa), Dry tropical in Yen Chau – Song Ma, Moisture tropical in Northeast – Thanh Hoa – Nghe an, Humidity tropical in Ha Tinh – Thua Thien Hue; Moisture subtropical in the low mountain; Moisture subtropical in the mountains average and Humid and tempered climate in the high mountain. With a clear warming trend globally and regionally, the average annual temperature, minimum temperature increases are contrary to the trend of reducing evaporation, rainfall, hours of sunshine, wind speed decreased.(figure 5-9).

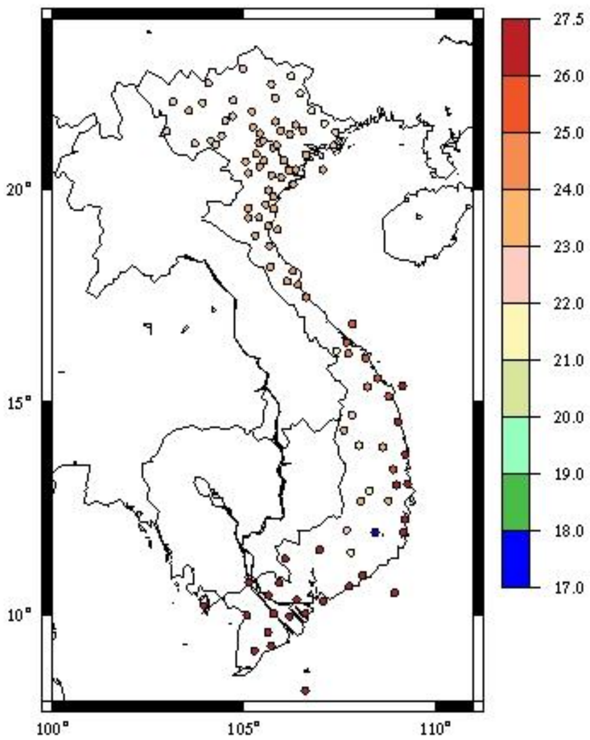


Figure 5: Annual mean temperature per station in Vietnam (°C)

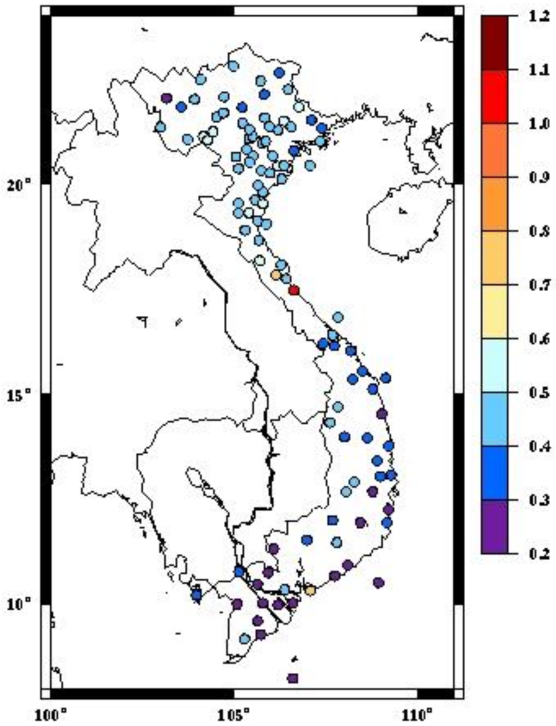


Figure 6: Standard deviation annual mean temperature per station in Vietnam (°C)

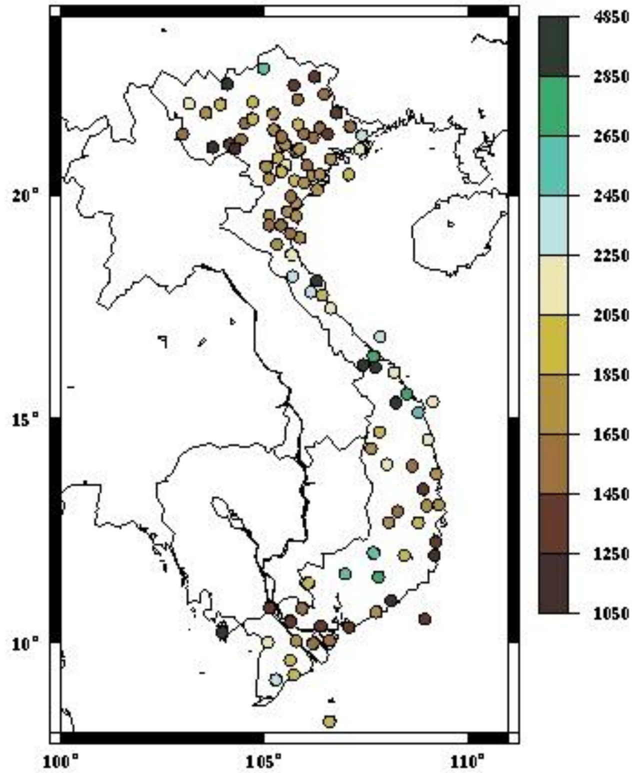


Figure 7: Annual mean precipitation per station in Vietnam (°C)

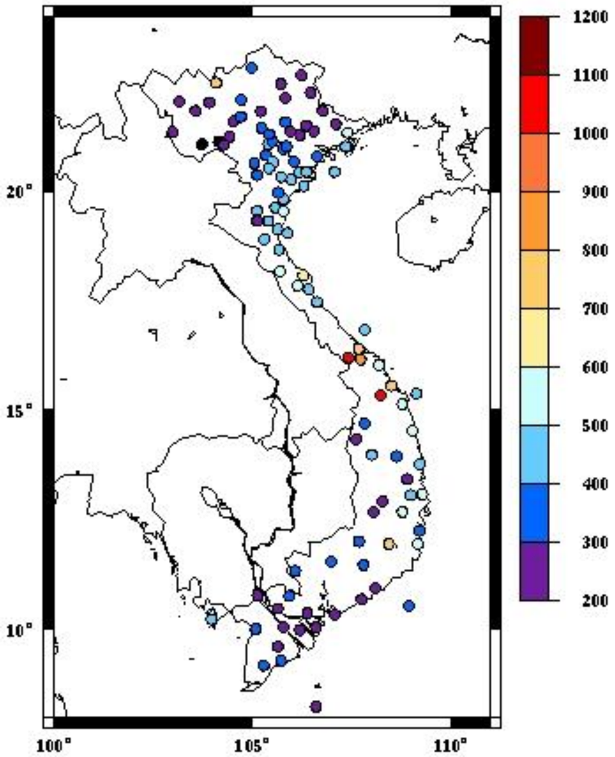


Figure 8: Standard deviation annual mean precipitation per station in Vietnam (°C)

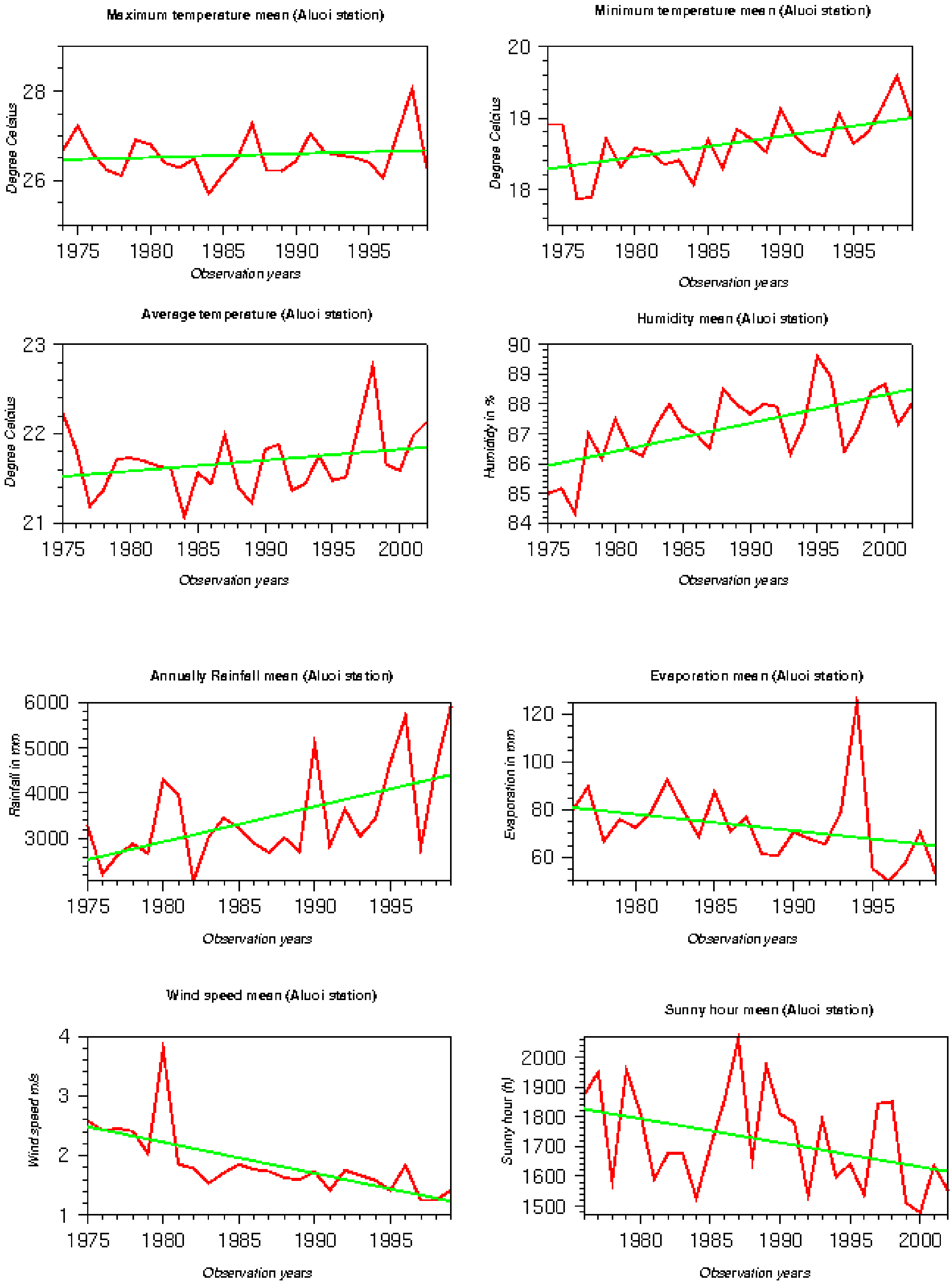


Figure 9: Regression of climatic parameters at a station in Vietnam

4.4. Cluster of climate in Vietnam:

A cluster analysis was carried out, based on 8 basis parameters of near surface climate over Vietnam: Annual evaporation, humidity, precipitation, mean temperature, maximum mean temperature, minimum mean temperature, sunny hour and wind-speed. We use a hierarchical cluster analysis combined with a k – mean algorithm (J. B. MacQueen. 1967) to build cluster – based classification data performed by a FORTRAN program. This method is able to reduce wrong attributions in the cluster process and get high accuracy results. The resulting climate clusters presents the overview climate conditions of Vietnam. The cluster of climate in Vietnam is illustrated in the figure 10. The results from each the particular climatic parameters were clustered independently into 10 classes. The values indicate the distinguishable of each cluster from the mean station of each climate parameter. The cluster is arranged from more humid climate to relatively dry climate.

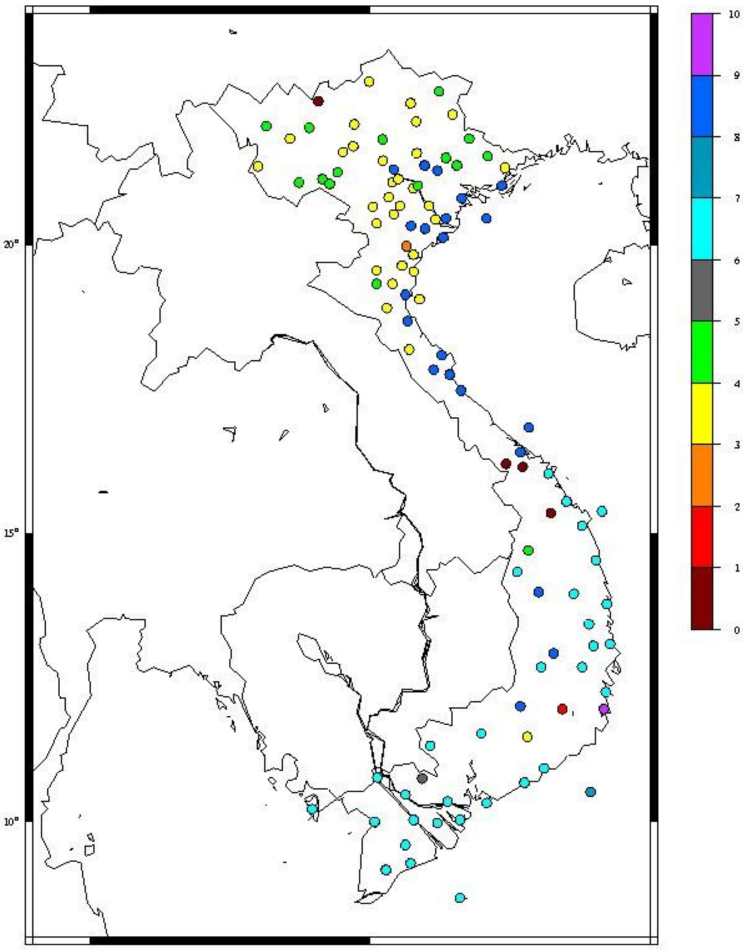
Table 4 : The cluster of climatic parameter observation station in Vietnam.

Number of Cluster	Evaporation (mm/month)	Humidity (%/month)	Precipitation (mm/year)	Sunny hour (hr/yr)	Average temperature (^oC/month)	Maximum temperature (^oC/month)	Minimum temperature (^oC/month)	Wind speed (m/s.mon.)
1	-1	1.43	3.64	-0.57	-0.35	-0.04	-0.38	-0.76
2	-0.57	0.96	0.06	0.68	-3.23	-2.95	-2.92	0.67
3	-0.54	1.31	-0.59	-0.6	-0.28	-0.62	-0.1	-0.81
4	-0.86	0.67	-0.1	-0.86	-0.52	-0.53	-0.43	-0.56
5	-0.13	-0.72	-0.62	-0.43	-0.94	-0.54	-1.04	-0.51
6	0.55	-1.38	-0.57	1.85	1.75	2.02	1.31	0.24
7	0.92	-0.68	-0.09	1.21	1.15	1.17	1.03	0.3
8	0.93	0.24	-1.05	1.82	1.69	0.67	1.88	4.88
9	-0.03	-0.01	0.35	0.18	-0.26	-0.58	-0.14	0.6
10	4.15	3.63	-3.27	-1.2	1.53	1.32	1.23	1.29
Value average	83.55	83.23	1904.4	1950.83	24.05	28.57	21.16	1.78

Table 5 : The standard deviation cluster of climatic parameter observation station in Vietnam.

Number of Cluster	Standard deviation evaporation	Standard deviation humidity	Standard deviation precipitation	Standard deviation	Standard deviation average temperature	Standard deviation maximum temperature	Standard deviation minimum temperature	Standard deviation wind speed
1	-0.55	-0.2	3.16	-0.48	-0.27	0.14	-0.26	-0.38
2	-0.69	0.25	2.14	-0.11	-1.32	-1.78	-1.41	0.53
3	0.38	-0.45	-0.08	6.52	0.28	-0.06	-0.05	1.8
4	-0.72	-0.44	-0.11	-0.31	0.36	0.42	0.41	-0.44
5	-0.36	0.53	-0.84	-0.43	0.39	0.94	0.77	-0.25
6	0.14	-0.73	-0.15	4.72	-1.67	-1.35	-1.34	-0.14
7	0.83	0.27	-0.11	0.3	-0.74	-0.93	-0.8	0.09
8	0.9	1.67	-0.32	-0.25	-1.23	-1.09	-1.48	3.73
9	-0.01	-0.15	0.19	-0.1	0.56	0.32	0.32	0.44
10	3.63	0.34	0.93	-0.24	-0.78	-1.35	-0.77	0.83
Value average	12.21	1.47	400.89	171.23	0.41	0.51	0.46	0.34

Figure 10: Cluster of near-surface climate in Vietnam



CHAPTER 5 : THE RESULTS

The regional projection of the future climate response to radiative forcing is a key component of any climate change impact assessment. The most credible tools currently available for projections under scenarios "of future climate change" are results from GCMs (Robinson, P.J., & Finkelstein, P.L., 1991). These numerical models largely agree on the expected global feature of climate change, but there are important uncertainties in regional projections. Some scientists do not believe that the components of climate models give an adequate description of circulation patterns which are believed to be important for regional climates change. Furthermore, the model topography has until now been crude, and some features have not been represented realistically in these models (Benestad *et al.* 1999).

Climate models are based on well-established physical principles and demonstrated to reproduce observed features of recent climate and past climate changes. There is considerable confidence that Atmosphere-Ocean General Circulation Models (AOGCM) provide credible quantitative estimates of future climate change, particularly at continental and larger scales.

GCMs try to simulate as much as possible about the climate system: the incoming and outgoing radiation, the way the air moves and precipitation falls, the way the ice sheets grow or shrink, etc. They are frequently (as in the models we use) coupled to an Ocean model. They may take into account how the vegetation on the Earth's surface changes. Critically, they try to calculate how all these different parts of the climate system interact with each other, and how the feedback processes work.

Since these projections are likely to be used for the assessment of impacts and for the development of mitigation strategies by policymakers there is concern about the accuracy of these model projections. Thus, a thorough validation of model results is required.

In order to determine how well the GCM simulation reproduces the behavior of the Earth's atmosphere and ocean, we compare these simulations with data sets constructed from observations. We compare results of different GCM in order to discover both failure and accuracy common to various models and to learn how the distinct modeling philosophies compare to each other in their application.

5.1. Validation data:

Within this study, we focus on comparing observations of daily surface temperature and precipitation (CRU, NCEP and station data in Vietnam) with the multimodel mean results for the Southeast Asia and Vietnam regions.

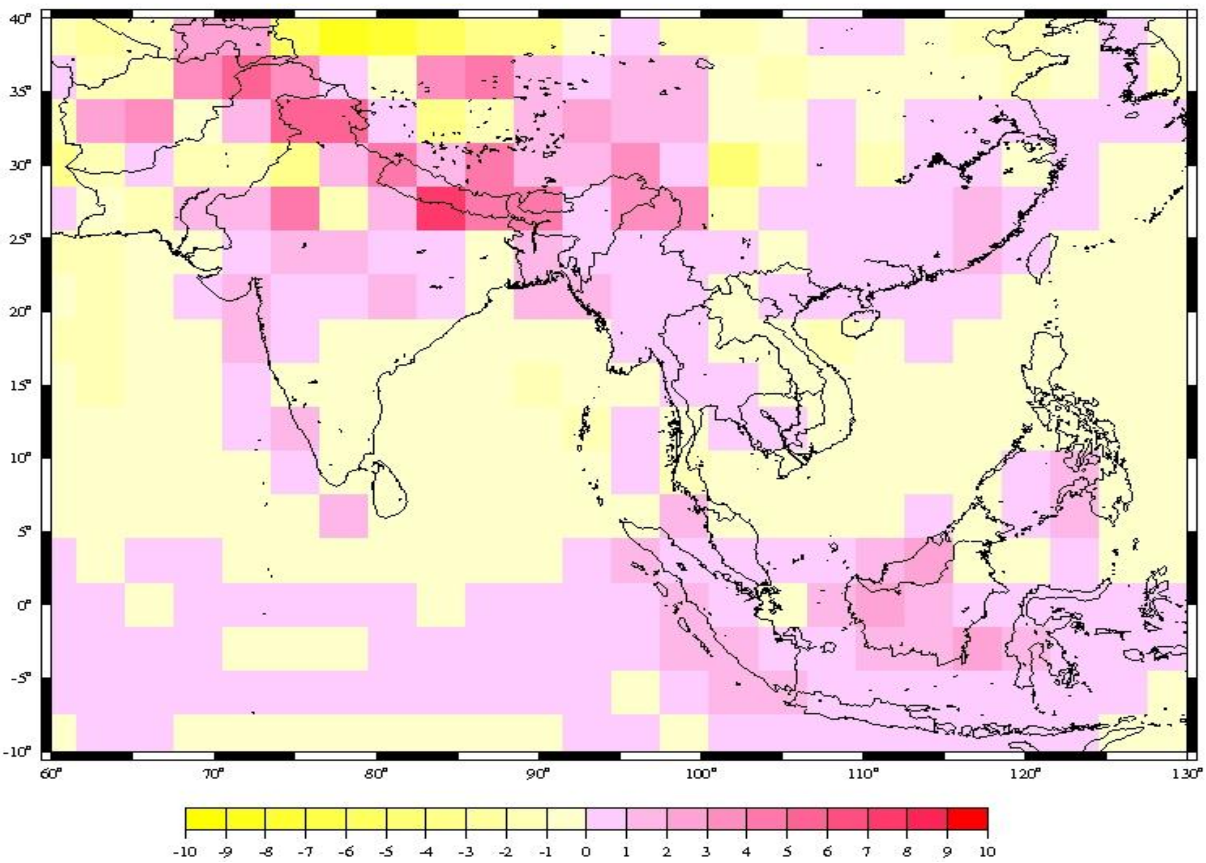
Both the observed and GCM-derived variables have been interpolated a 3^0 x 3^0 grid, calculated means for the 1948-2002 period.

5.1.1. Validating temperature data:

** Temperature differences between multi-model mean and NCEP data:*

The temperature differences between multi-model mean and NCEP data are illustrated in the figure 11 (in Southeast Asia region). In the multi-model mean present-day climate model appear to have a relatively low near-surface temperature bias in large part of the considered Southeast Asia region. Typically, the temperature bias is below ± 1°C. Along the equator, climate models tend to overestimate the observed temperature by partly about 2°C, probably due to deficiencies in cloud modeling and convection parameterization. However, the largest model bias is occurring over mountainous areas, especially along the Himalayan chain. Over the target region of Vietnam, observed temperature is quite well reproduced.

Figure 11: The temperature difference between multi-model mean and NCEP data in Southeast Asia over 1949 – 2002 (°C)

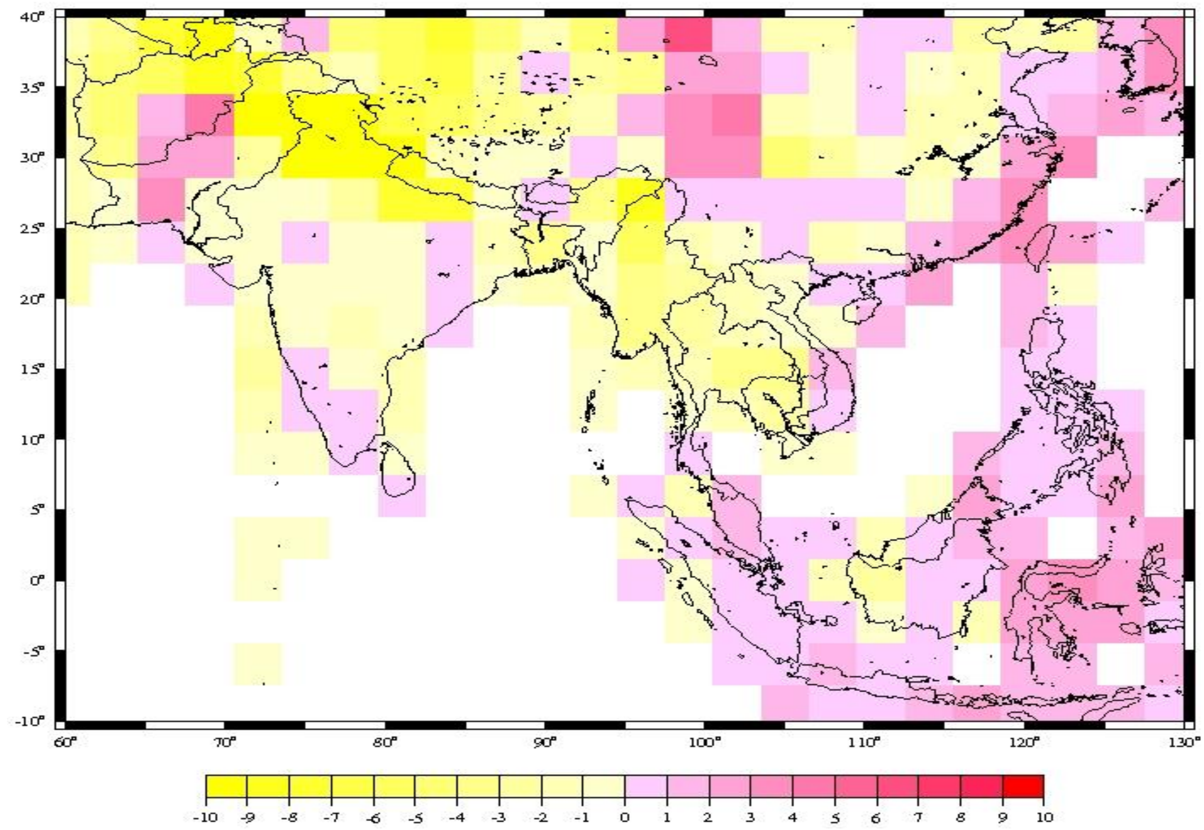


* T*emperature differences between multi-model mean and CRU data:*

The temperature differences between multi-model mean and CRU data is illustrated in the figure 12.

In general, the multi model mean result is lower than CRU over the whole land region. The differences are low in the coastal zone and high in the mountain area. Over the north part of Vietnam, the multi model mean result is lower than CRU by less than 1^0C, increasing to 2^0C - 3^0C in the central and southern part of Vietnam. It is striking that the pattern of temperature biases for NCEP and CRU look fairly different, reflection the high level of uncertainty in temperature observations.

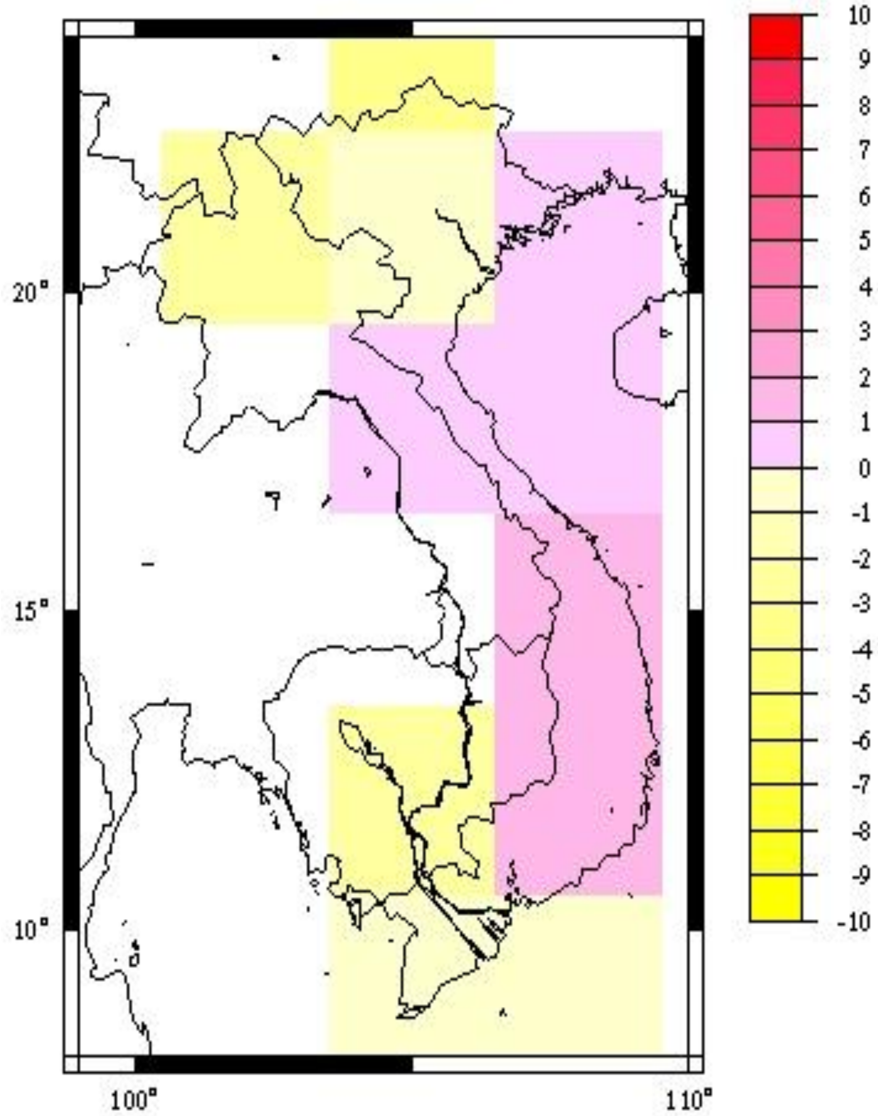
Figure 12: The temperature difference between multi-model mean and CRU data in Southeast Asia over 1949 – 2002 (°C)



* T*emperature differences between multimodel mean and observation station data:*

Temperature differences between multi-model mean and observation station data in Vietnam are illustrated in figure 13. The multi-model mean temperature is about 1°C lower in the north part of Vietnam; 1^0C higher in the center part of Vietnam and up to 2°C lower in the south part of Vietnam. Again, the bias largely differences from multi-model mean and station data.

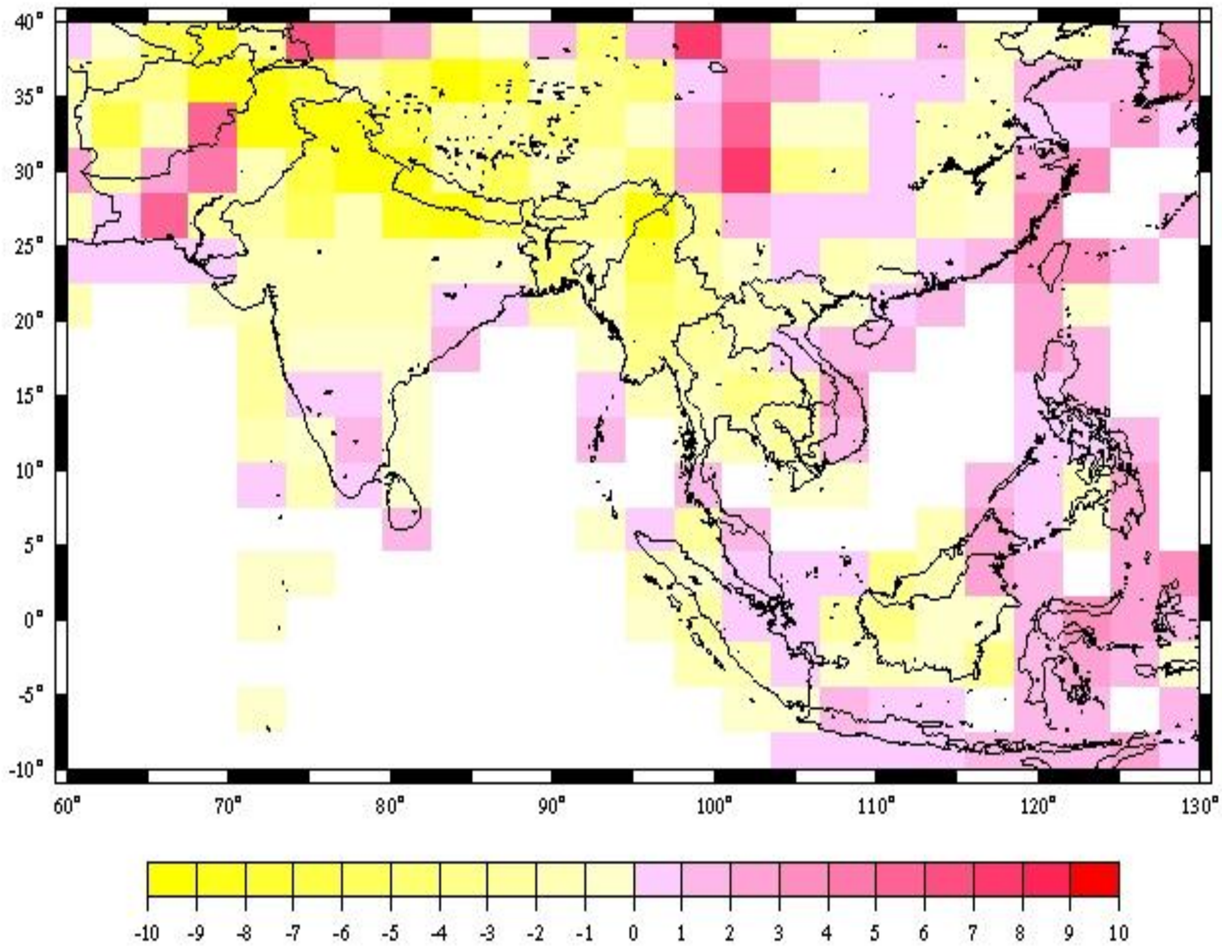
Figure 13: The temperature difference between multi-model mean and station data in Vietnam over 1949 – 2002 (°C)



* *Temperature differences between NCEP and CRU data:*

Temperature differences between NCEP and CRU data are illustrated in the figure 14 (in the Southeast Asia region). The temperature difference is about 1°C – 2°C along the coastal zone of China and over the islands of Indonesia. The land – sea temperature differences are probably due to the deficiencies in cloud modeling and convection parameters, which play a key role to bias differences from NCEP and CRU. The temperature difference is about -1°C in the center part of India, Laos, Thailand, probably due to the low – mountainous temperature differences.

Figure 14: The temperature difference between NCEP and CRU data in Southeast Asia over 1949 – 2002 (°C)



* T*emperature differences between NCEP and observation station data:*

Temperature differences between NCEP and station data are described in the figure 15. The NCEP temperature is about 0°C - 1°C higher than the observation temperature in the northern part of Vietnam and about 1°C – 2°C higher in the central and southern part of Vietnam. This can be explained as Northern Vietnam is influenced by the northeast monsoon usually blowing from the North - East along the Chinese coast and the Gulf of Tonkin, always following the river valley between the mountains in northeastern bow and carrying more moisture. The central and southern Vietnam is influenced by the southeast monsoon which develops further northern the Gobi desert development further north, causing moist air flowing from the sea to inland.

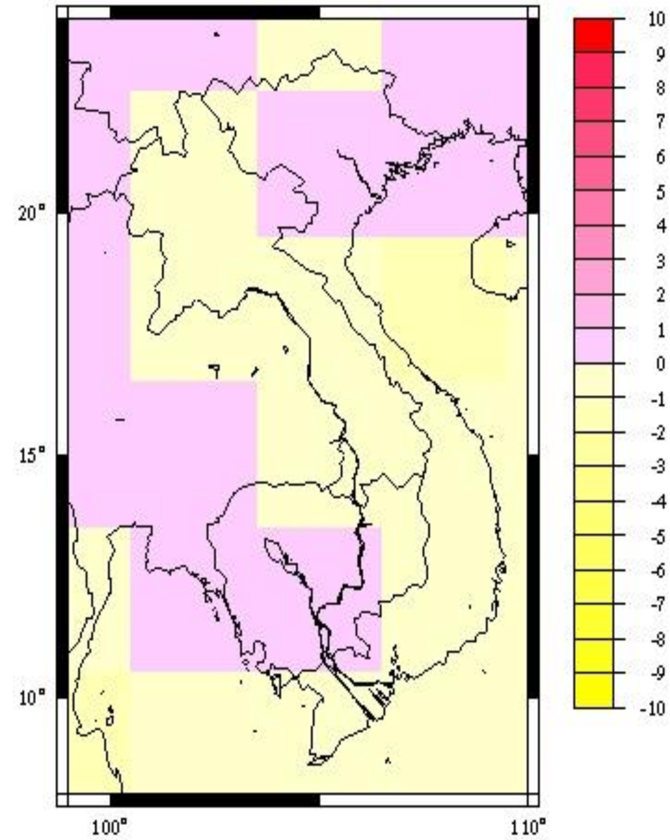


Figure 15: The temperature difference between NCEP data and station data in Vietnam over 1949 – 2002 (°C).

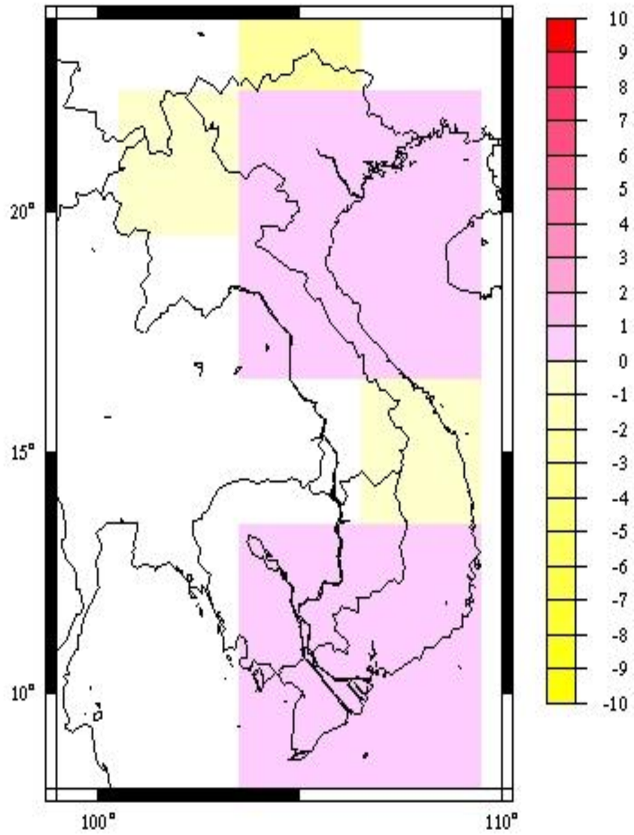


Figure 16: The temperature difference between CRU and station data in Vietnam over 1949 – 2002 (°C).

* *Temperature differences between CRU and observation station data:*

Temperature differences between CRU and observation station data in Vietnam is illustrated in the figure 16. The CRU data lies 1°C higher over the whole Vietnam region. Again, the land – sea temperature contrast and the low – mountains may cause temperature bias between CRU and station temperature.

In general, the land–sea temperature contrast, the low land and the mountain region differences are the basic forcing mechanism of the Southeast Asia region. In the multi-model mean, climate model appear higher over land and lower over the ocean. It can be explained by the attitude bias and density of station between stations and CRU, NCEP. Over Vietnam the NCEP data is smaller than CRU and station data. GCM reproduce higher temperatures in the central part of Vietnam and lower temperature over the northern and southern part of Vietnam than the stations.

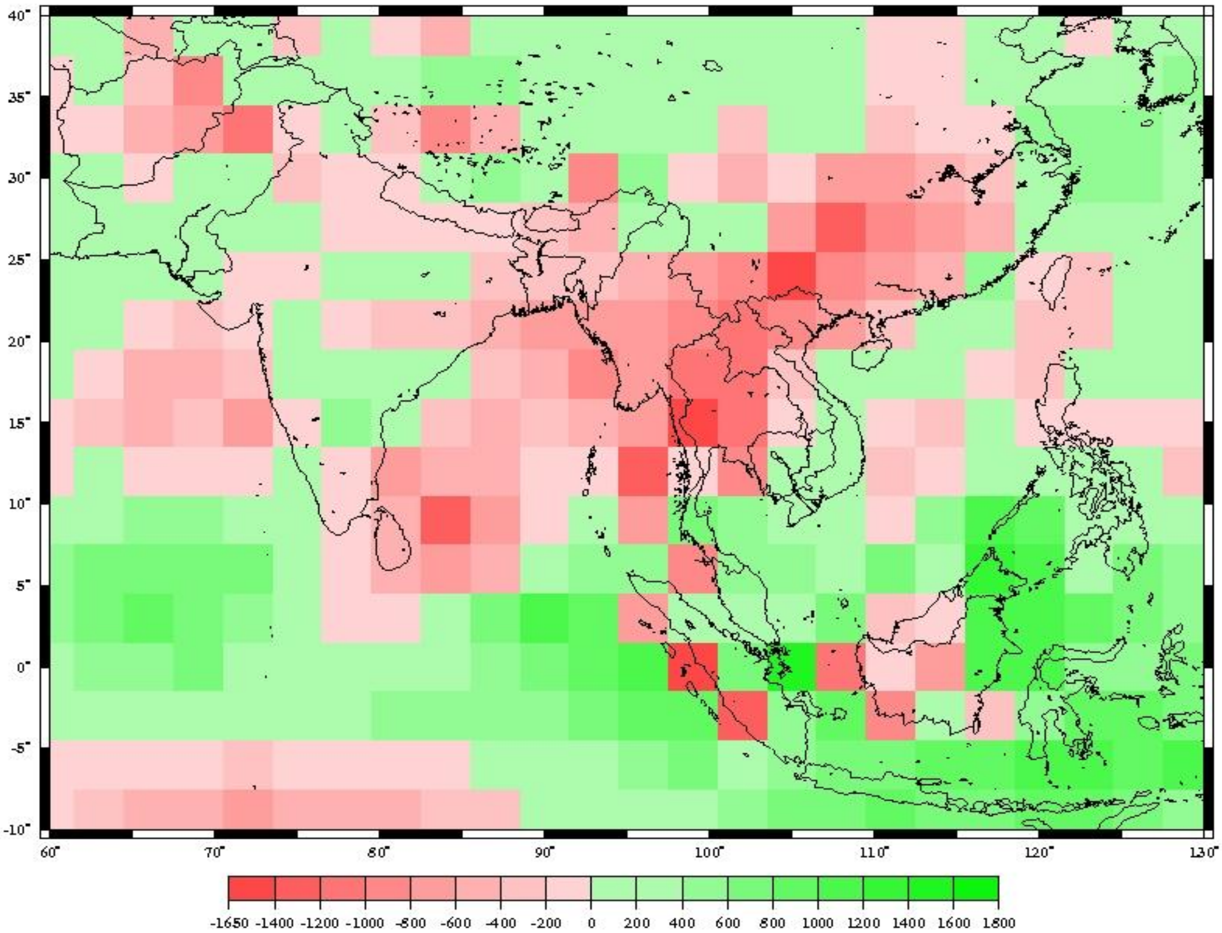
5.1.2. Validation of the precipitation data:

** Precipitation differences between multi-model mean and NCEP data:*

The precipitation differences between multi-model and NCEP data are shown in the figure 17 (in Southeast Asia region).

In south India, in the middle of East Sea and in the south of China simulated precipitation is about 200 – 400 mm lower than in NCEP, but with 200 - 400mm higher in the northern central part of Southeast Asia.

Figure 17: The precipitation difference between multi-model mean and NCEP data in Southeast Asia over 1949 – 2002 period in mm



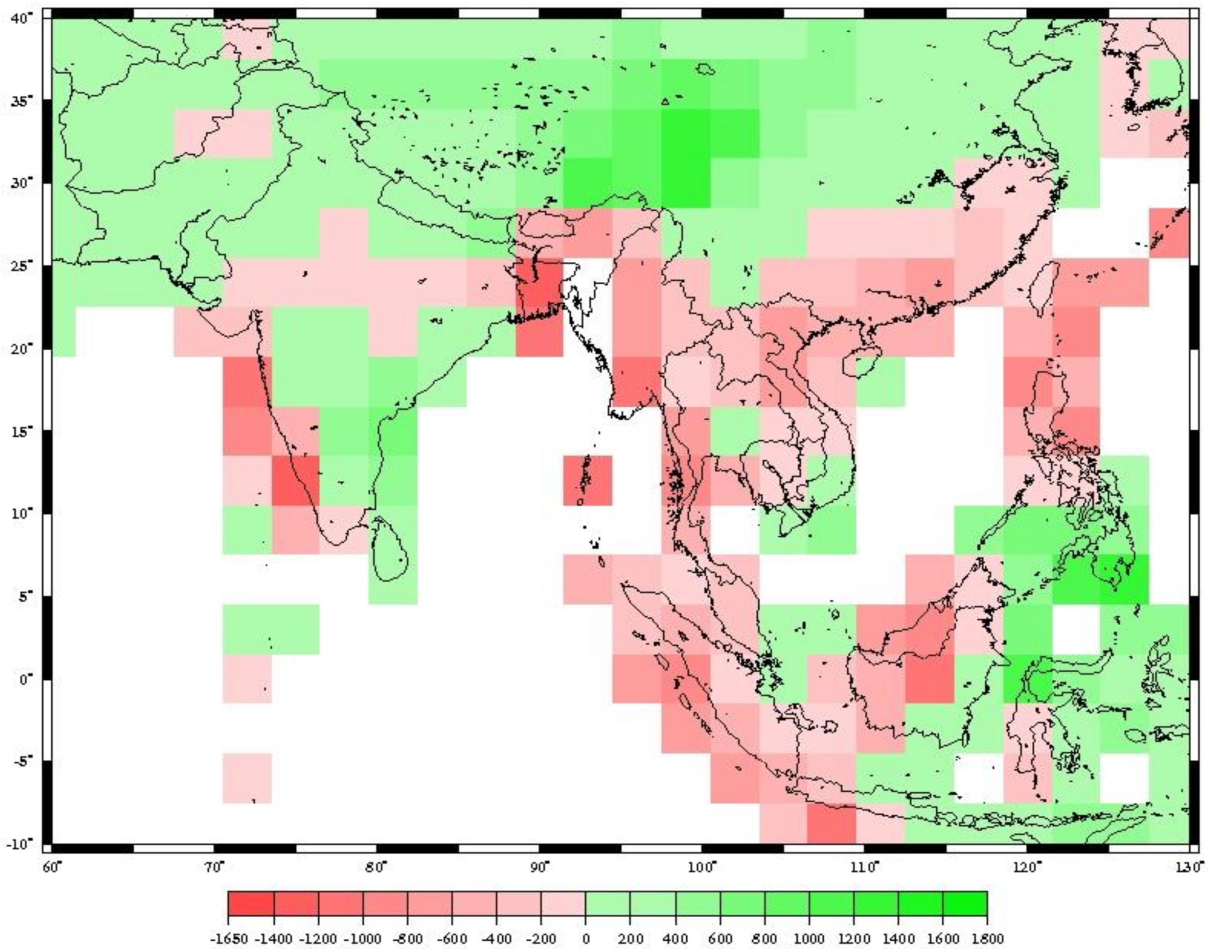
** Precipitation differences between multimodel mean and CRU data:*

The precipitation differences between multimodel and CRU data are illustrated in the figure 18 (in Southeast Asia region).

In general, the precipitation difference is about -200 – 400 mm compared with CRU data over the whole land region southward of 25°N. It lies with 600 – 800 mm above the CRU precipitation in the high latitudes over the land region and in the east of the Indonesian islands.

Comparing the model and NCEP (in figure 17) and model and CRU differences (in figure 18), it becomes clearly that the multi model mean precipitation is lower than NCEP and CRU over the southern part of India, China and central part of southeast Asia along the coastal zone. This can be explained as the land-sea temperature due to the water evaporation difference and due to the forcing of the model. In the mountain region and along the low attitude region, the multi model mean is higher than NCEP and CRU precipitation, which is maybe caused by the low and high relief and due to uncertain forcing in model, NCEP and CRU precipitation. Rainfall variability will be affected by changes in ENSO and its effect on monsoon variability and any change in tropical cyclone characteristics.

Figure 18: The precipitation difference between multi-model mean and CRU data in Southeast Asia over 1949 – 2002 period (in mm)

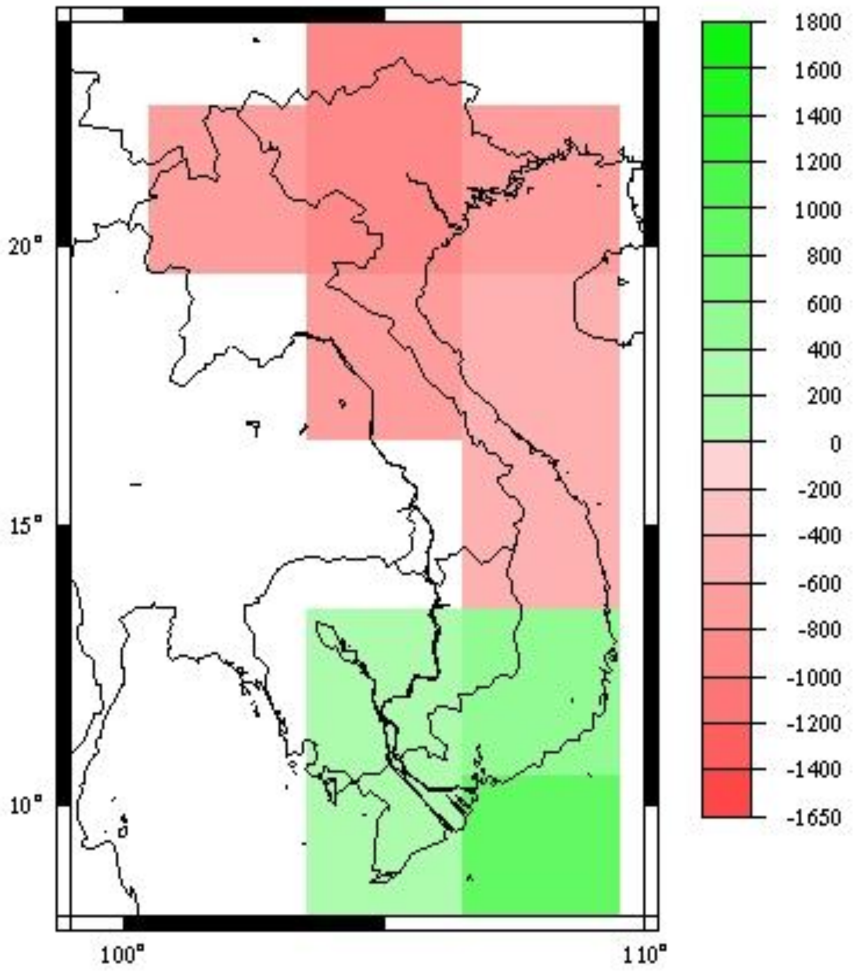


* *Precipitation differences between multimodel mean and station data:*

Precipitation differences between multimodel mean and station data in Vietnam are illustrated in the figure 19. The precipitation bias is about - 800 mm in the northern part of Vietnam, 400 – 800 mm in the central part of Vietnam and 200 – 600 mm in the south part of Vietnam.

In comparison, in northern part of Vietnam, the multimodel precipitation bias is lower than NCEP, CRU and station data and in the southern part of Vietnam multimodel mean precipitation bias is higher than NCEP, CRU and station precipitation. It is clear that the northern parts are mountainous areas and which have strong forcing in the model causing lower the precipitation vice versa the southern parts of Vietnam are lower region which have less forcing in the model causing higher precipitation.

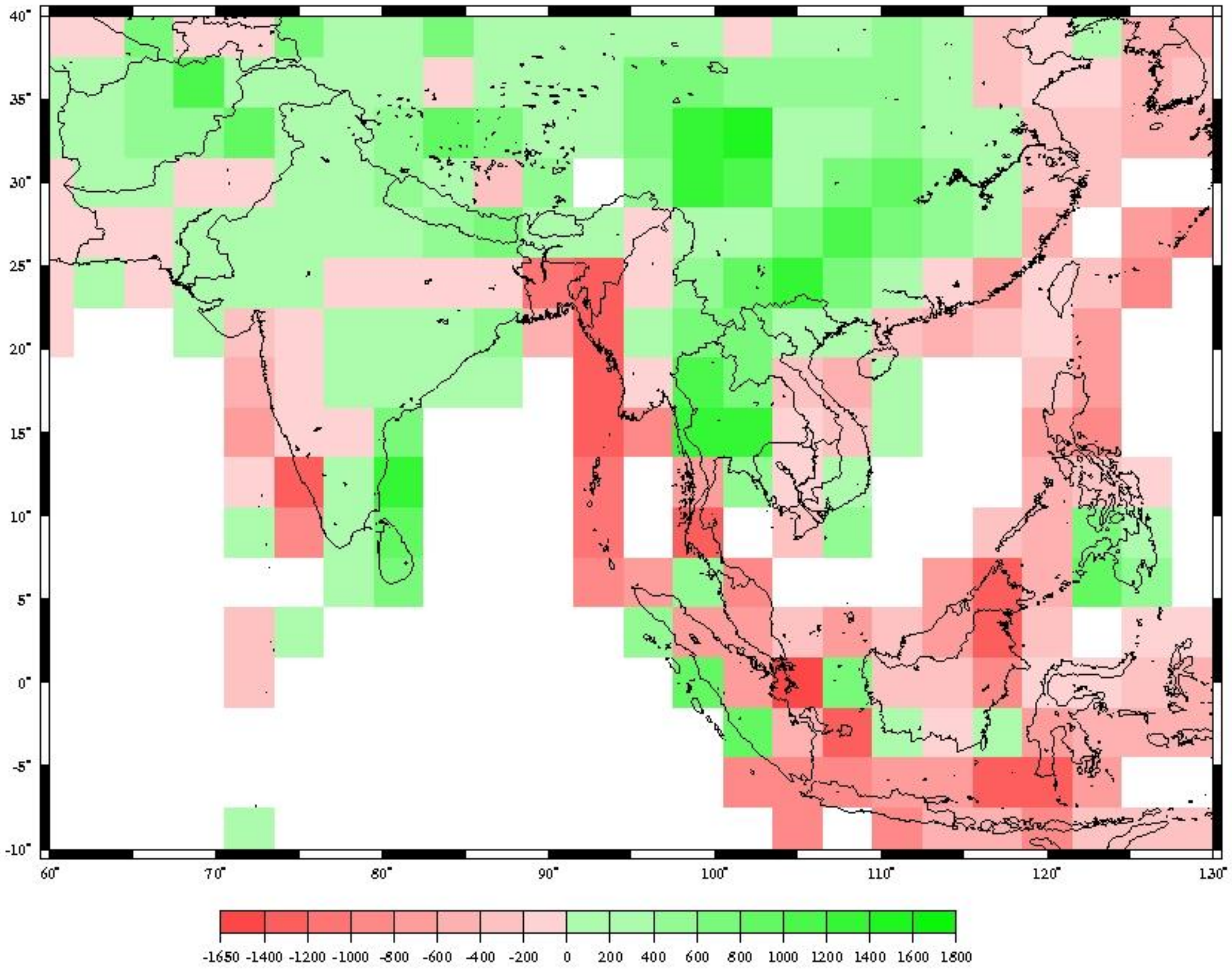
Figure 19: The precipitation difference between multi-model mean and station data in Vietnam over 1949 – 2002 period in mm



* *Precipitation differences between NCEP and CRU data:*

Precipitation differences between NCEP and CRU data are illustrated in the figure 20. In the central part of Southeast Asia, in Himalayan chain and south of China, precipitation bias is +200 – 400 mm CRU precipitation and -400 – 800 mm in the coastal zone and in the Indonesia's island. It can be explained by the altitude of the relief having stronger influence on the NCEP data than CRU data. In the low latitude area land-sea characteristic have strong influence on the CRU than NCEP data.

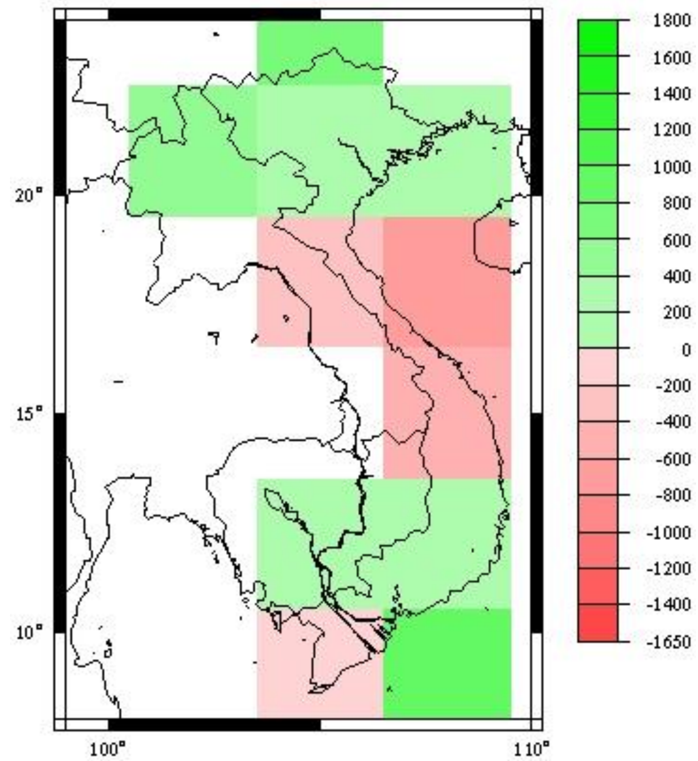
Figure 20: The precipitation difference mean between NCEP and CRU data in Southeast Asia over 1949 – 2002 period in mm.



* *Precipitation differences between NCEP and station data:*

Precipitation differences between NCEP and station data are described in the figure 21. The precipitation bias is + 200 – 400 mm station data over the northern part and southern part of Vietnam and -200 – 400 mm in the central part of Vietnam. The north part of Vietnam is the high mountain area having strong effect to the NCEP data, in southern part the humid air play a key role to increase precipitation on NCEP data. In central part of Vietnam, the land – sea temperature contrasts plays an important role to reduce the precipitation in NCEP data.

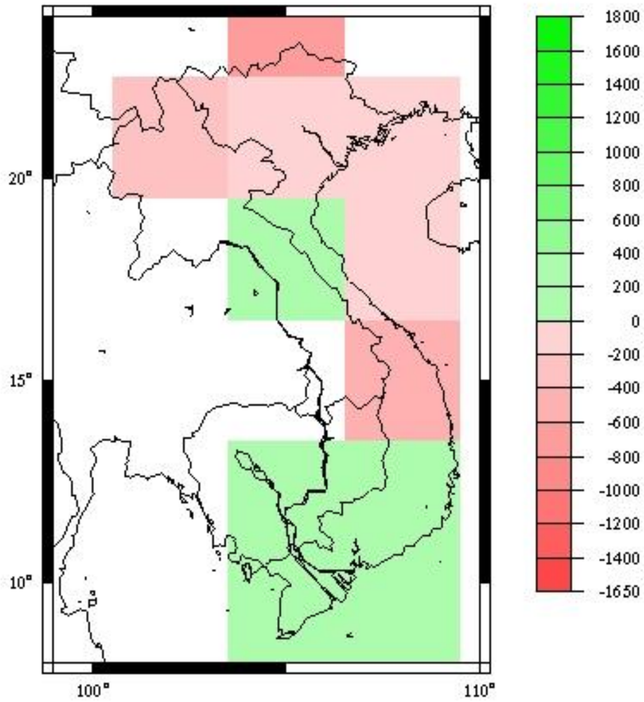
Figure 21: The precipitation difference mean between NCEP and station data in Vietnam over 1949 – 2002 period in mm.



* *Precipitation differences between CRU and station data:*

Precipitation differences between CRU and station data in Vietnam are shown in the figure 22. In northern and central part of Vietnam, precipitation bias is -200 – 400 mm from CRU and station data. The precipitation bias is 0 – 400 mm data over the south part of Vietnam. It shows that, the relief has strong influence on the CRU precipitation data in the northern part of Vietnam. Its precipitation is lower than the rainfall data from station. Probably, again in the southern part of Vietnam the humid air effect increases precipitation in CRU data.

Figure 22: The precipitation difference mean between CRU and station data in Vietnam over 1949 – 2002 period (in mm)



5.1.3. Confidence interval:

Given the considerable difference between observation and models data sets for temperature, precipitation in Southeast Asia, one may ask weather they belong to the same distribution. To assess this, multi model mean and individual model temperature and precipitation are compared with the confidence interval over the three considered observation data sets: NCEP, CRU and station data over Vietnam. For each comparison various error levels are taken into account. In terms of validation, the models are close to observation if they lie inside the 90% confidence interval, but do not fit to the real climate system, if they are outside the 90% confidence interval.

The confidence interval of observed temperature compared with multi model mean temperature is illustrated in the figure 23. We divide the Vietnam region into 11 grid boxes (size 3° x 3°). The confidence interval temperature reaches up to 90% in most of the grid boxes over Vietnam and in particular, over two boxes in the south and over one box in the northeast the value of the confidence interval is 99%. This can explain that, all of the multi model mean temperature lie on the side 90% confidence interval with low standard deviation compared to the mean temperature from observation data. At the multi-model mean results are close to the real temperature over

Vietnam, we can believe the future results from the multi model mean as an adequate progression.

Figure 23: The confidence interval temperature of Models data and station model in Vietnam.

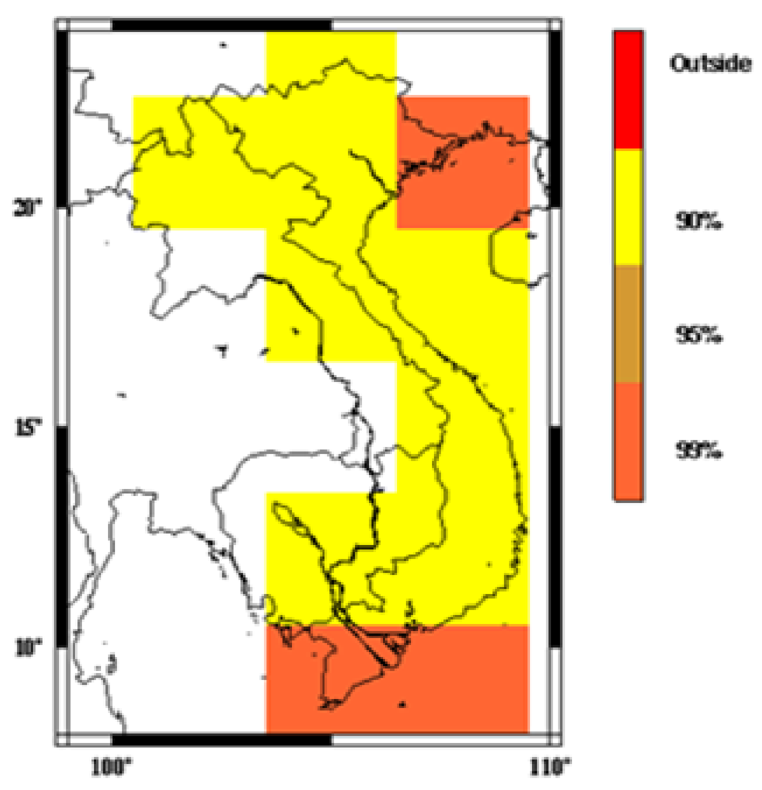


Table 6: The confidence interval temperature of models data and Observation data in Vietnam

Lon	Lat	NGM	CNM	GCO	GC1	GSA	IPL	IVE	M3H	MK3	MK5	UH3	IFG	M3M	MCG	MPE	NCC	NCP
105	9	3	4	4	4	1	4	3	3	4	4	4	1	4	4	3	3	4
108	9	4	4	4	4	1	4	1	3	4	4	4	1	1	4	3	3	4
105	12	2	4	3	2	3	3	2	2	2	3	2	3	3	2	3	3	2
108	12	3	3	3	3	3	3	1	2	3	1	4	3	3	3	3	3	3
108	15	3	3	3	3	3	3	1	2	3	1	4	3	3	3	1	3	3
105	18	4	4	2	1	4	1	4	1	4	4	3	4	1	3	1	1	4
108	18	3	1	1	3	3	2	3	3	4	3	4	1	3	3	1	3	4
102	21	4	4	2	3	3	1	3	3	4	2	3	4	1	3	3	4	4
105	21	4	3	3	3	4	4	4	4	4	3	4	4	4	3	4	1	4
108	21	4	1	3	3	2	4	4	4	4	4	4	4	3	4	4	3	4
105	24	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2

4 : Outside 3 90% 2 : 95% 1 : 99%

Figure 24: The confidence interval precipitation of Models data and station data in Vietnam.

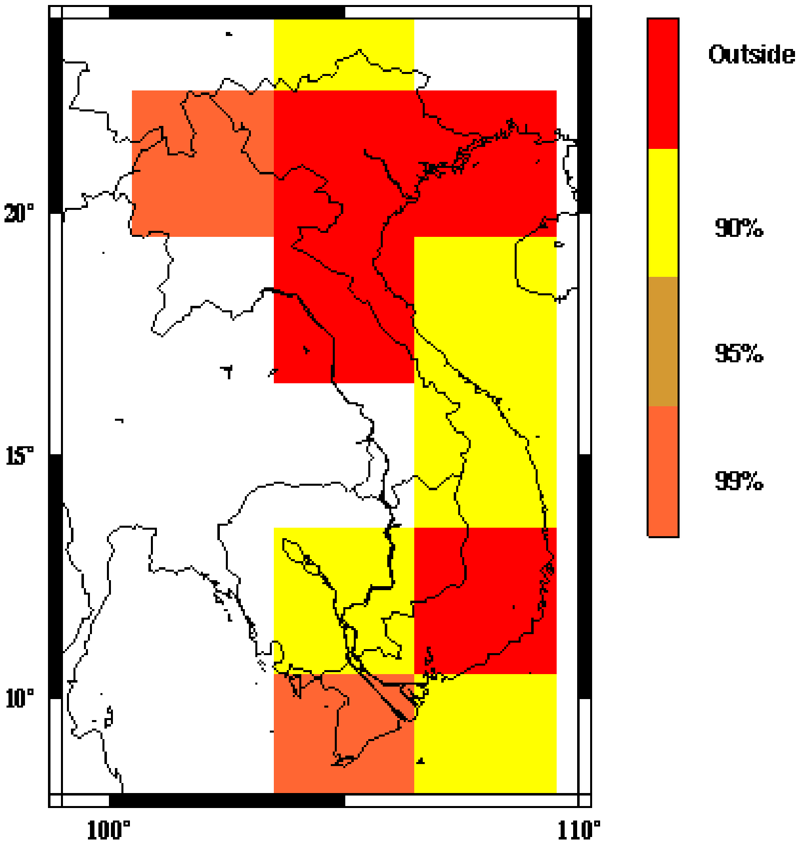


Table 7: The confidence interval precipitation of models data and Observation data in Vietnam

Lon	Lat	GC1	GSA	IPL	IVE	M3H	MK3	MK5	UH3	UHG	IFG	M3M	MCG	MPE	NCC	NCP
105	9	4	4	4	4	3	3	4	4	4	4	4	4	3	3	4
108	9	2	1	3	4	1	3	3	4	4	3	4	3	3	1	3
105	12	2	4	4	2	4	1	4	4	3	3	4		1	1	4
108	12	4	4	4	4	4	4	4	4	4	4	4		1	4	4
108	15	3	3	4	4	1	4	4	3	3	3	4	1	3	3	3
105	18	4	1	4	4	4	4	4	3	1	4	4	4	3	4	4
108	18	2	3	4	4	3	4	4	4	3	3	3	4	3	3	3
102	21	1	3	1	4	3	4	1	2	2	1	2	2	1	4	1
105	21	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
108	21	4	1	4	4	1	4	4	4	4	4	4	4	4	4	4
105	24	2	3	2	2	3	2	3	3	3	2	3	3	3	1	1

4 : Outside 3 90% 2 : 95% 1 : 99%

The confidence interval of precipitation of the multi model mean and the observation data is illustrated in the figure 24. The confidence interval of precipitation has 90% value in completely one grid in the central part of Vietnam (yellow color). It becomes obvious that, for precipitation, the multi model mean has low accuracy over Vietnam. Most of the precipitation result from multi model mean have a large standard deviation (confidence interval lies on side 95% and outside) compared to the real precipitation from observation data. This is necessary to remind that these should be caution when using multi-model mean precipitation result to evaluate precipitation over Vietnam. We also calculated the confidence interval for each model and the result is illustrated in the table 4 (temperature) and table 5 (precipitation).

In general, the multi model mean temperature results can be used in valuating climate in Vietnam with higher accuracy than precipitation results. In addition, using the multi model mean data set will gain more reliable results than using the individual model mean.

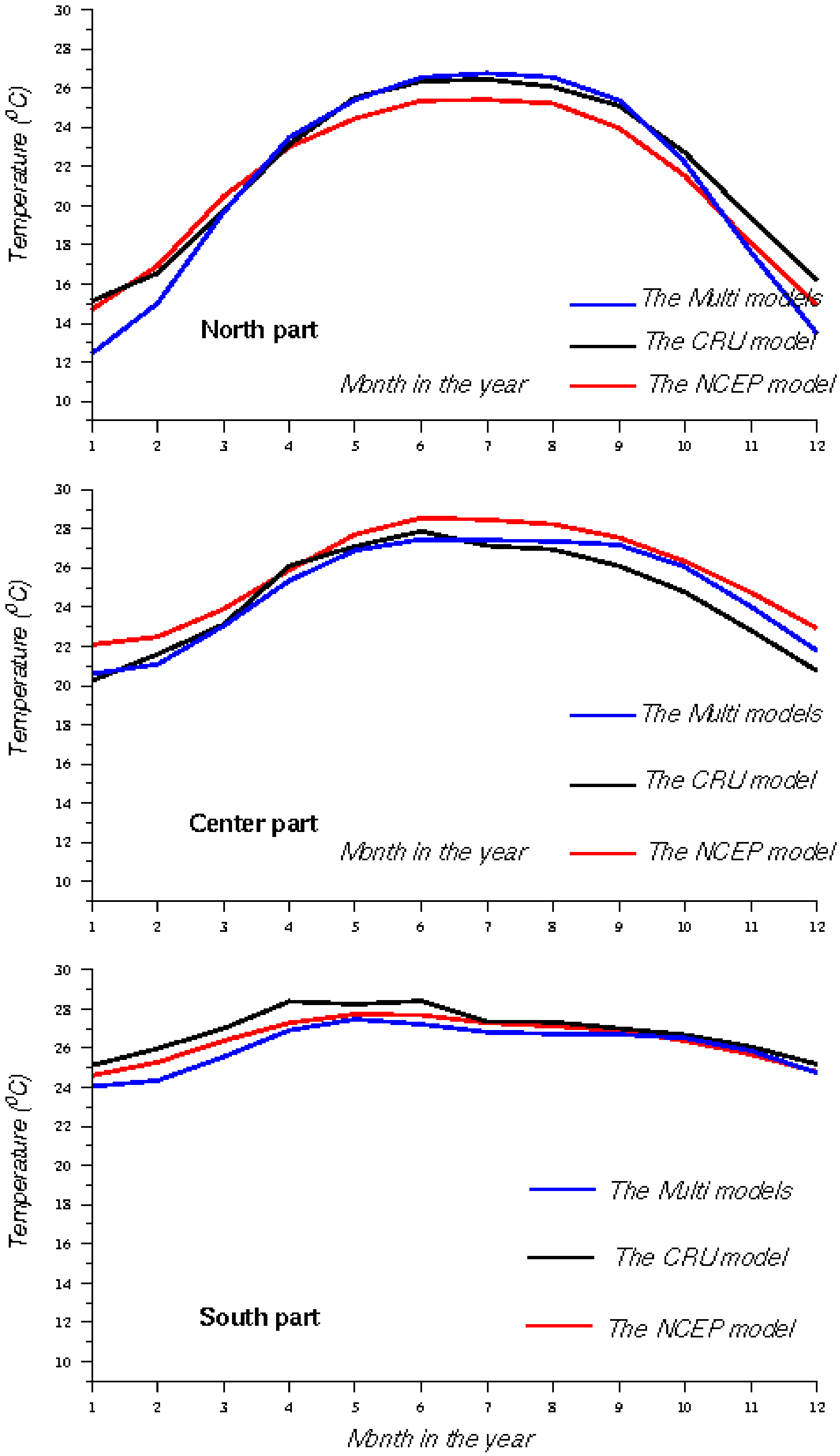
5.1.4. Validation of seasonal cycles:

The monthly means of temperature and precipitation were used to compare the seasonal cycle between the multi model mean, CRU and NCEP data. We divide the Vietnam region into 3 parts, the northern, the central and the southern part of Vietnam. The monthly mean was calculated during period from 1948 to 2002.

The seasonal cycle of the mean temperature is illustrated in the figure 25. The results of the multi model mean differ only slightly for the observation, which also differ slightly from each other. The different curves have a similar shape for each specific region of Vietnam. However, the multi model mean curve is slightly different during the winter (from the October to the April in the following year) over the north part of Vietnam.

The monthly cycle of the mean precipitation is illustrated in the figure 26. The results differ between the multi model values and the observations, in particular over the northern part of Vietnam and during the summer season (from the May to the October). However, NCEP and CRU also differ greatly from each other.

Figure 25: Monthly mean temperature circle in Vietnam (°C)



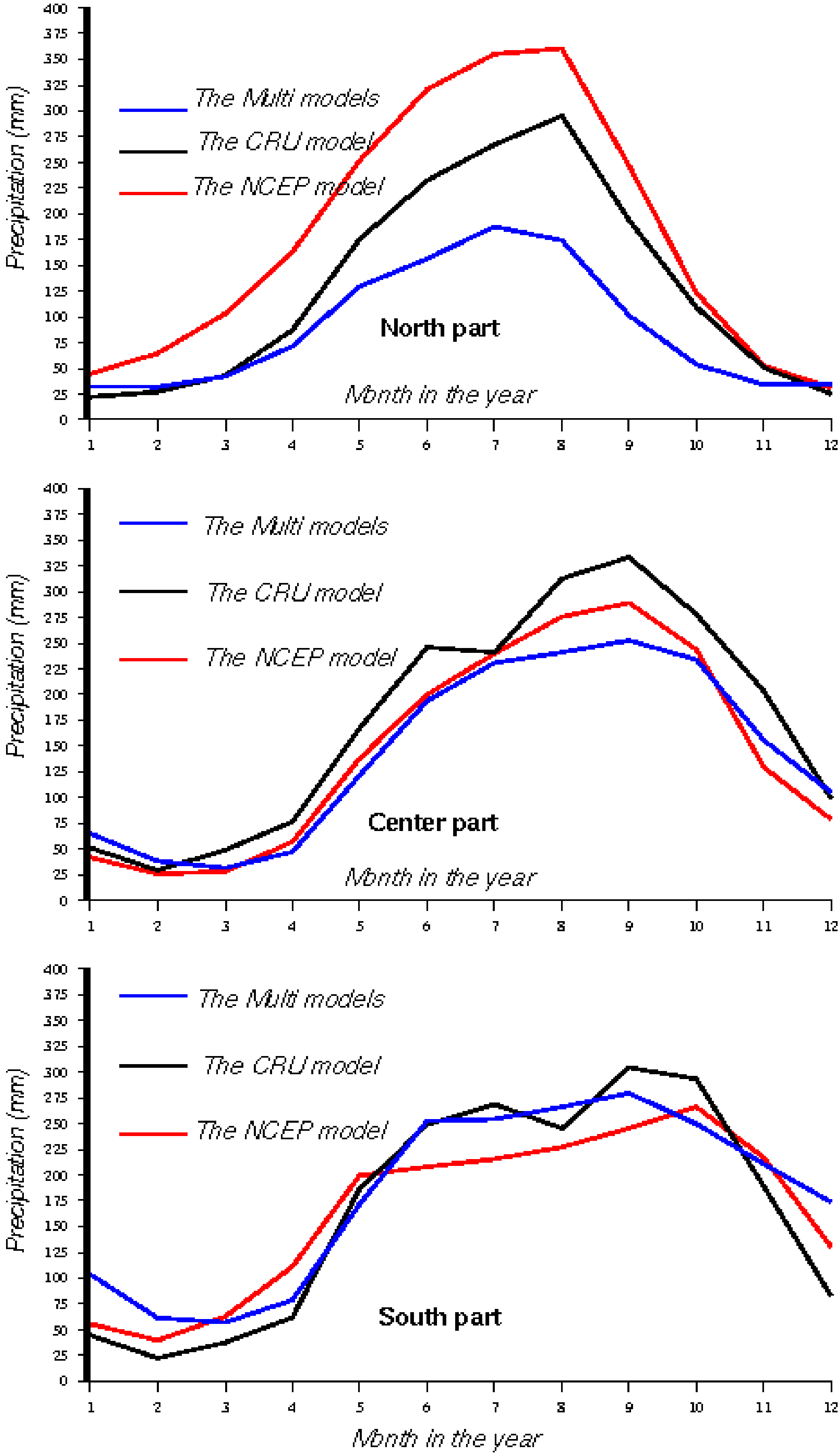


Figure 26: Monthly mean precipitation circle in Vietnam (°C)

5.2. Future climate projection:

The patterns of regional climate change in this study have been derived from the 17 GCM simulations. The multi model combination proposed in this study is motivated by the assumption that model uncertainties could be better reduced by combining the GCMs. The multi model projections are represented over the Southeast Asia for the A2, B1 and A1B scenarios. Both annual and seasonal values for temperature and precipitation were investigated by comparing means between the past period (1980 – 1999 period) and three future periods (2011 to 2030; 2046 to 2065 and 2080 to 2099).

In each figure, the multi model annual mean air temperature and precipitation difference with B1 scenario is shown in the upper panels, A1B scenario in the middle panels and A2 scenario at the bottom panels. The three future time slices are shown from left to right until the end of the 21st century.

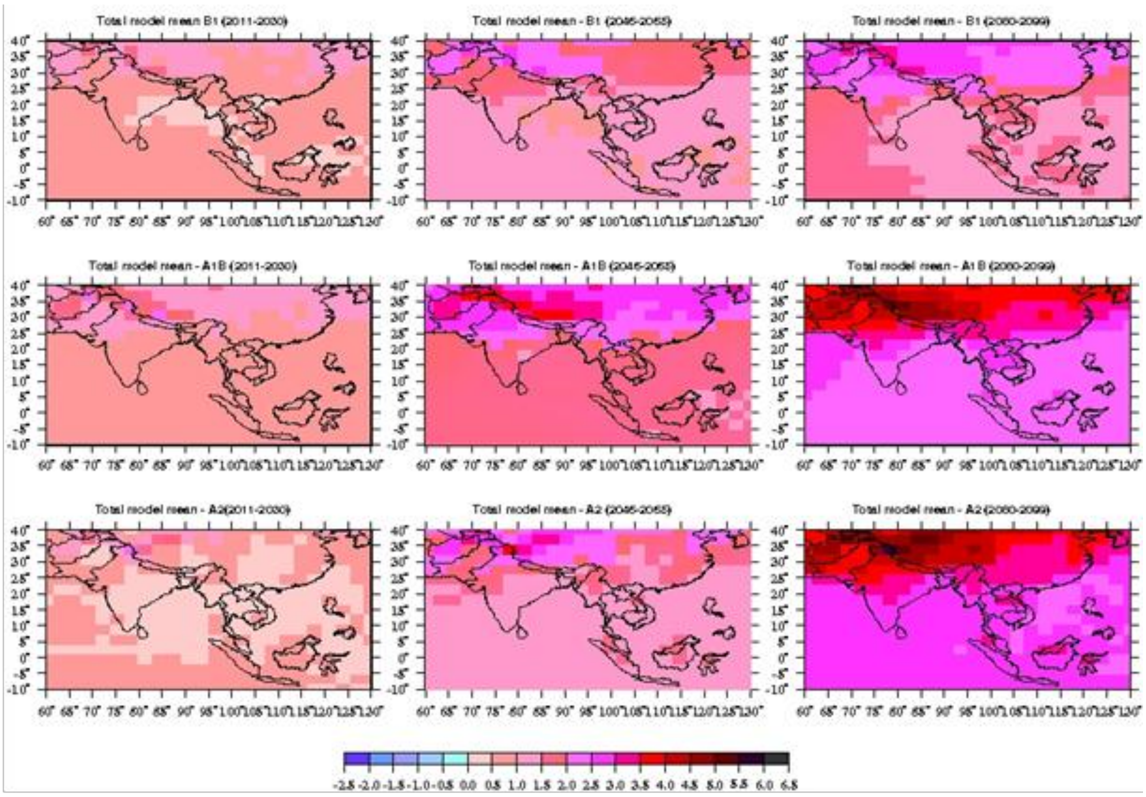
5.2.1. Temperature projection :

* *Annual temperature projection:*

The annual mean warming over the South Asia is illustrated in figure 27.

- With an increase in atmospheric concentration of GHGs under the A2 scenario, the annual mean warming over bay of Bengal, Southeast India, centre Southeast Asia, South China sea and one part of South china region of Southeast Asia is projected to increase by 0.0°C - 0.5°C in the 2020s; from -10° latitude to 25° latitude over the sea region is projected to 0,5°C – 1.0°C, over the mountain area is projected 2.0°C – 2.5°C and particular in the Himalaya, it reaches to 3.0°C in the 2050s; corresponding to the same region in the 2080s, the annual mean warming over the sea reachs to 2.5°C – 3.0°C and highest in the mountain area reach to 4.0°C - 4.5°C and higher.
- Under A1B scenario surface warming over the land region of Southeast Asia is projected to 0.5°C - 1.0°C (in the mountain area reach to 1.5°C - 2.0°C) in the 2020s; it reaches to 1.5°C - 2.0°C over the sea and 2.5°C – 3.0°C over the mountain are as in the 2050s, and 2.5°C - 3.0°C (in the mountain area it reaches to 4.5°C – 5°C in the 2080s.
- Under B1 scenario, the annual mean warming is projected to increase by 0.5°C - 1.0°C in the 2020s, 1.0°C - 1.5°C in the 2050s (over the mountain area it reaches about 2.0°C – 2.5°C), the annual mean warming enlarge in the mountain area and over Arabian sea reach to 1.5°C – 2.0°C and over the bay of Bengal, South of China sea reach to 1.0°C – 1.5°C in the 2050s.

Figure 27: Multi-model mean annual temperature change for different scenarios and time slices in °C.



In summary, the annual mean warming over South Asia is depended on the scenarios, with a higher warming in the A2 scenario. In the beginning of 21st century the warming is small and gradually increase to the end of 21st century. Over the sea and the low land the warming is relatively low and in the mountain area it is high.

* *Annual summer mean warming in Southeast Asia:*

The annual summer mean warming over South Asia is illustrated in the 28.

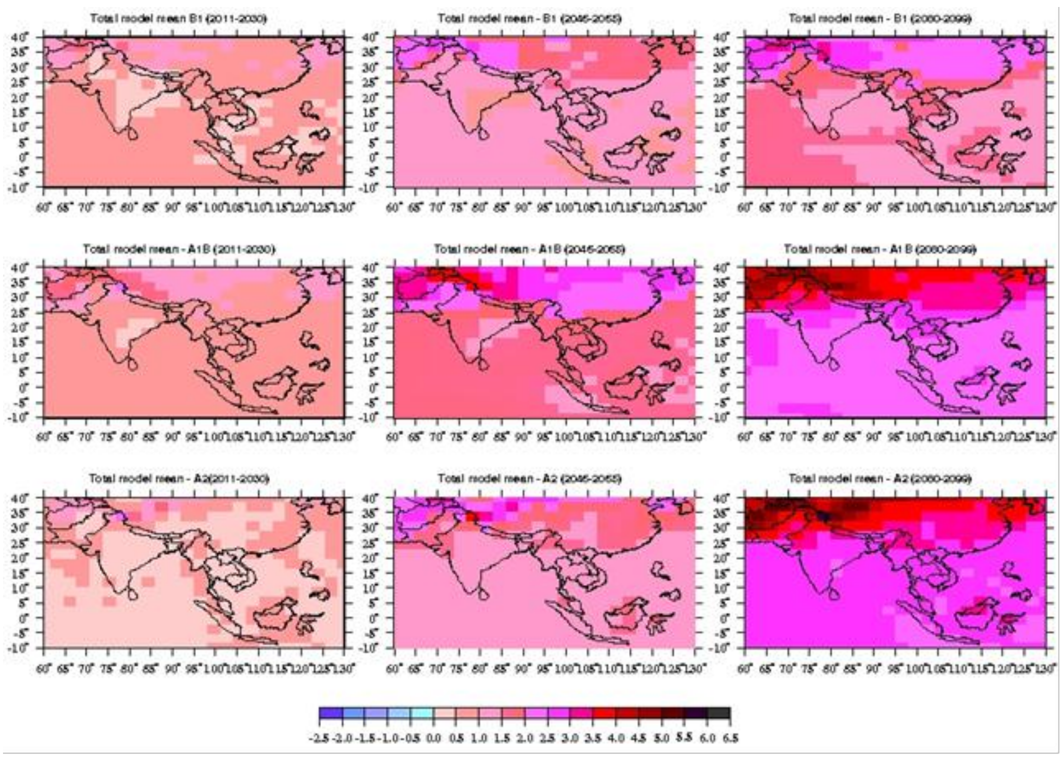
- Under the A2 scenario, the annual summer mean warming is projected to increase by 0.0°C - 1.0°C in the 2020s, 0.5°C -1.0°C from -10° latitude to 25° latitude, 1.5°C – 2.0°C in north part of India, centre Southeast Asia and south of China in the 2050s, and 2.5°C – 3.0°C over the Arabian sea, bay of Bengal, India Ocean and South China sea, in particularly, over the Himalaya mountain area the annual summer mean warming reaches to 5.0 – 6.0°C in the 2080s.
- Under A1B scenario, the increase of surface warming over Southeast Asia region. The annual summer warming is 0.5°C – 1.0°C over the sea region and centre Asia, south of India, over the Himalaya mountain area reach to 1.5°C – 2.0°C during the 2020s; gradually increasing temperatures corresponding to

the region in turn is 1.5°C - 2.0°C, 2.5°C - 3.0°C in the 2050s and 2.5°C - 3.0°C, 4.5°C - 5.0°C in the 2080s .

- Under B1 scenario, the annual summer mean warming is projected to 0.5°C - 1.0°C in the 2020s, a long strip from 30° latitude to 40° latitude warming is 1.0°C – 1.5°C and higher to 2.0°C – 2.5°C over the north part of India region in 2050s. At the end of 21st century, in the north part of the considered region warming is 2.0°C – 2.5°C, increasing to 3.0°C – 3.5°C over the Himalaya region, over Bay of Bengal, Indian Ocean and Philippine islands is low 1.0°C – 1.5°C and over the Arabian sea is 1.5°C – 2.0°C.

In general, during the summer period, the temperature warming is low in the beginning of 21st century and increase to the end of 21st century. The influence of topography on temperature change markedly in the high mountains, there is a temperature difference between ocean and continent is about 0.5 ° C - 1.0 ° C. This can be explained by the decrease in surface albedo associated with the melting of snow and ice in the region. (Giorgi et al., 1997).

Figure 28: Multi-model mean summer temperature change for different scenarios and time slices in °C.



** Annual winter mean warming in Southeast Asia:*

The annual winter mean warming over the South Asia is illustrated in the 29.

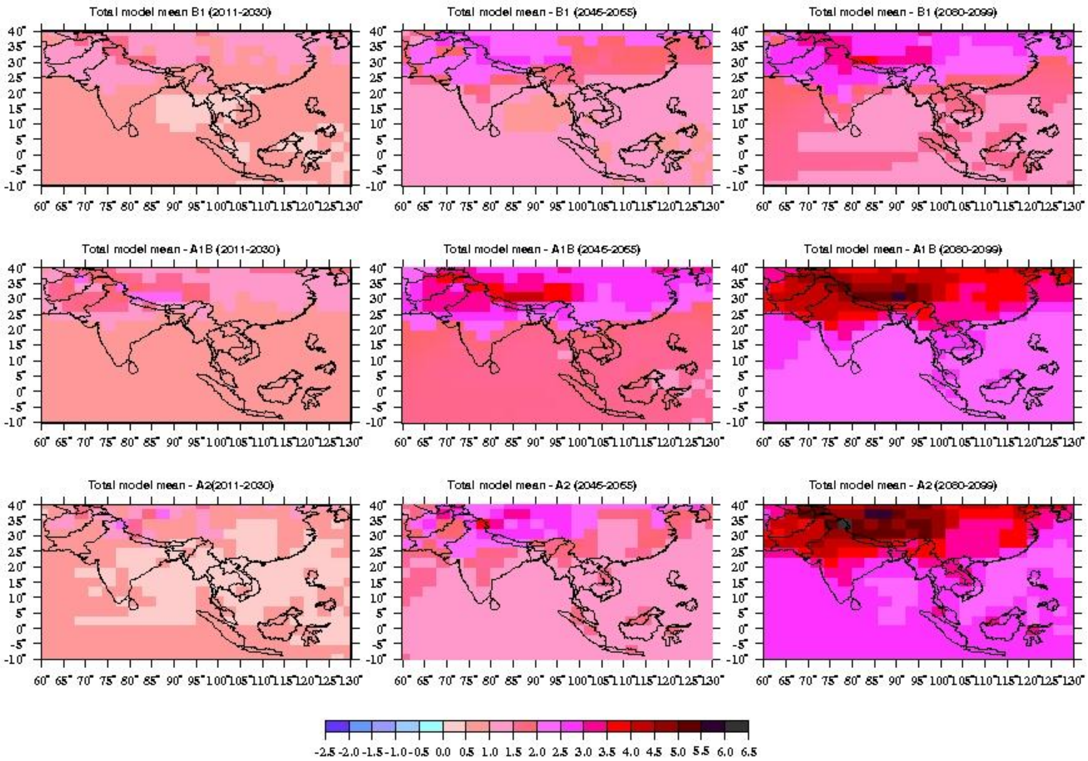
- With the A2 scenario, the annual winter mean warming over the Southeast Asia is projected to increase by 0.0°C – 0.5°C in Arabian Sea, Bay of Bengal, India Ocean and South China Sea and in the north part of Vietnam during 2020s period. (over land and mountain area region is projected to increase by 0.5°C – 1.0°C), 1.0°C – 1.5°C during the 2050s (2.0°C – 3.0°C over north of India, Himalaya and Centre of China), and 2.5°C – 3.0°C during 2080s (5.5°C – 6.0°C in the north part of the considered region).

- Under A1B scenario, the increase of surface warming over the whole land region of Southeast Asia is projected about 0.5°C - 1.0°C over the ocean region and reach to 2.5°C – 3.0°C over mountain and Himalaya in the 2020s; about 1.5°C - 2.0°C over tha same area (in the mountain area reach to 3.0°C) during the 2050s, at last reach to 4.5°C – 5.0°C over mountain area during the 2080s.

- For the Southeast Asian region, under B1 scenario, the annual winter mean warming is projected to 0.5°C - 1.0°C in the 2020s, 1.0°C – 1.5°C in the 2050s, and 3°C – 3.5°C in the 2080s.

The results show that in the Southeast Asia warming in the end of the 21st century and under A2 scenarios will be strongest and in winter the warming is stronger than warming in summer, particularly the tendency for warming to be significantly stronger over the interior of the landmasses than over the surrounding coastal regions. This is can be explained that the increased concentration of GHGs play an important role in climate warming; during the summer, the water vapor cloud cover over the equator and Tibet Plateau reaches its maximum (minimum in winter). The water vapor has a key role to impact the GCMs simulations.

Figure 29: Multi-model mean winter temperature change for different scenarios and time slices in °C.



5.2.2. Temperature Standard deviation:

Different models were taken into account and each model is characterized by a specific amplitude of climate change. It is useful to compute the standard deviation between model projections. It shows how much variation there is from the average projection. A low standard deviation indicates that the models tend to be very close to each other, whereas a high standard deviation indicates that the model spread is large.

The results of temperature standard deviation between the model to model in the Southeast Asia is illustrated in the figure 25a (annual), figure 25b (summer), figure 25c (winter).

** <u>Standard deviation of annual mean warning in Southeast Asia:</u>*

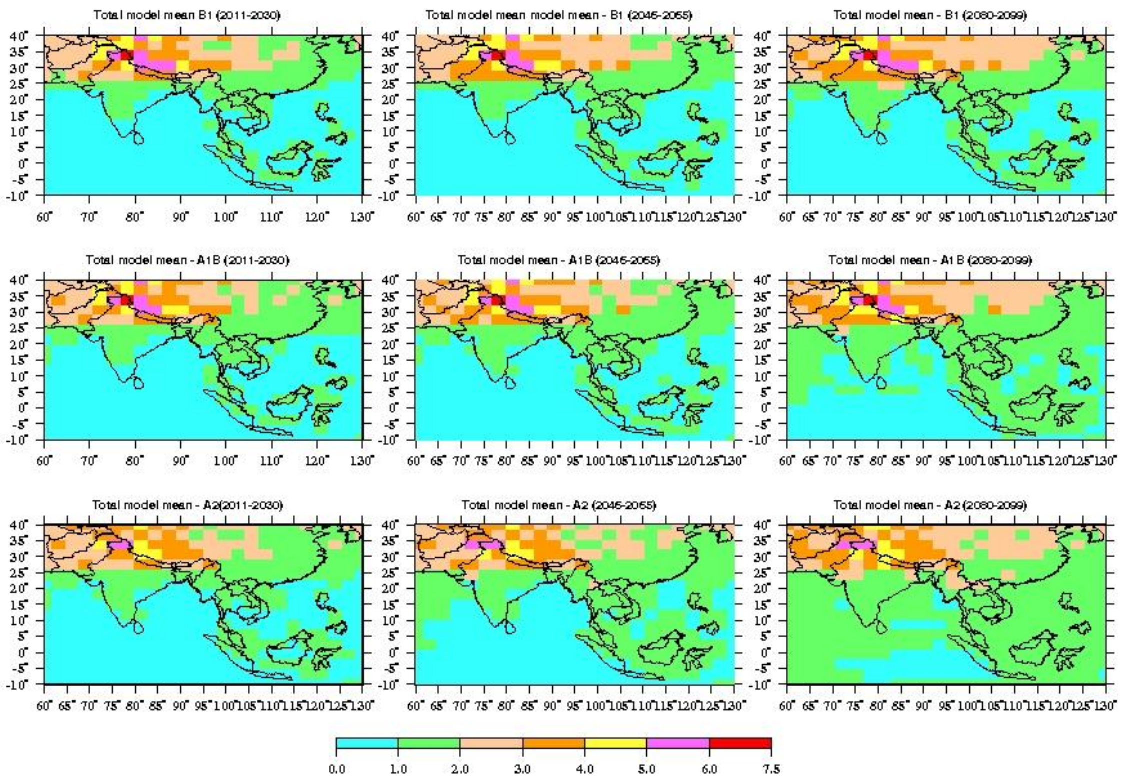
The run to run standard deviation of annual mean warning in the multi model ensemble is illustrated in figure 30.

- Under the A2 scenario, the annual standard deviation is below 1 in the early period over the whole ocean region of Southeast Asia; around 2 along south part of Asia landmasses and up to 3 over the mountain area in the North of the region. It is the same during the 2050s. But during the 2080s, the standard deviation reaches up to 2 over the ocean and up to 6 at high elevation sites.

- Under the A1B scenario, the annual standard deviation is projected about 0.0 - 1 in the 2020s over the Arabian sea, bay of Bengal, Indian Ocean and South China sea region, about 1 - 2 over coastal zone in south of India, south of China; over mountain area in north India, this index increase 5 – 6. It is slightly difference for the 2050s and 2080s.
- Under the B1 scenario, the annual standard deviation is about 0 - 1 in the 2020s over ocean region; increase 1 - 2 in coastal zone and projected about 7 in high elevation sites. The annual standard deviation slightly changes until the end of 21st century.

In general, the annual standard deviation temperature in Southeast Asia is small over the ocean and higher in mountain area. That mean, GMCs simulations have small uncertainty over the ocean and vice versa in the mountain area. The factors influence on the uncertainty GCMs simulation include scale and resolution (different climate processes operate on different scales in time and space), cloud (cloud is the key element of uncertain in GMCs simulation for future temperature increase over high elevation sites), aerosol and other natural variability.

Figure 30: Run to run standard deviation of annual mean warming in the multi-model ensemble in °C



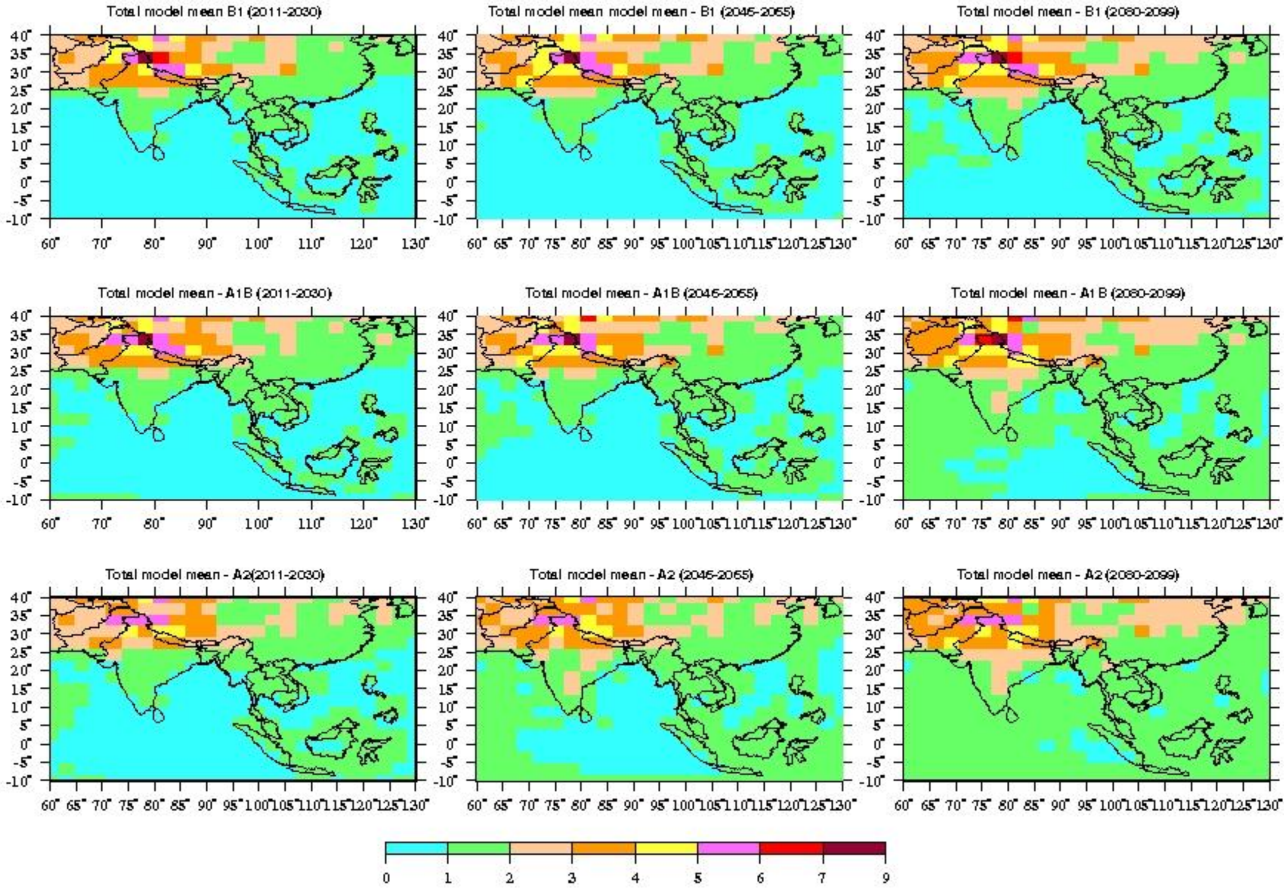
** Standard deviation of annual summer mean warning in Southeast Asia:*

The run to run standard deviation of summer mean warning in the multi model ensemble is illustrated in figure 31.

- Under the A2 scenario, the annual summer standard deviation warming is about 0 - 1 over ocean region; about 1 - 2 over coastal zone, Arabian sea, in the south of India, south of China and Indonesia's islands that is higher in the mountain area and about 5 - 6 over Himalaya. It is similar region during the 2050s. But during the 2080s, the standard deviation increase 1 - 2 in the ocean and coastal zone and this index rice over landmasses and over mountain site from 2 – 6 during the end of 21st century.
- Under A1B scenario, the annual summer standard deviation is computed about 0 - 1 in the 2020s over the e ocean region, reach to 2 in the South of India, Myanmar, Lao, Vietnam and south of China and reach to 6 in the mountain area. This index is slightly similar until middle of 21st century. During the end of 21st century, the standard deviation rise 1 – 2 over the ocean area this is can be explained that tropical monsoon character in the Southwest Africa and in Southeast Asia at the end of 21st century is strong.er than earlier of century.
- Under the B1 scenario, morphologically, the change of local standard deviation over region and time is a little different from the two above scenarios.

In general, during the summer time, uncertainty GCMs simulation is small over the ocean and high over landmasses and mountain area, increases from the early 21st century to the end of the century. It is clear that marine environment is more homogenous than land, which have small effect on the uncertainty GCMs simulation. However, Influence of West African monsoon, Indochinese monsoon maybe cause increasing uncertainty GCMs over ocean at the end of 21st century under A2 and A1B scenarios.

Figure 31: Run to run standard deviation of summer warming in the multi-model ensemble



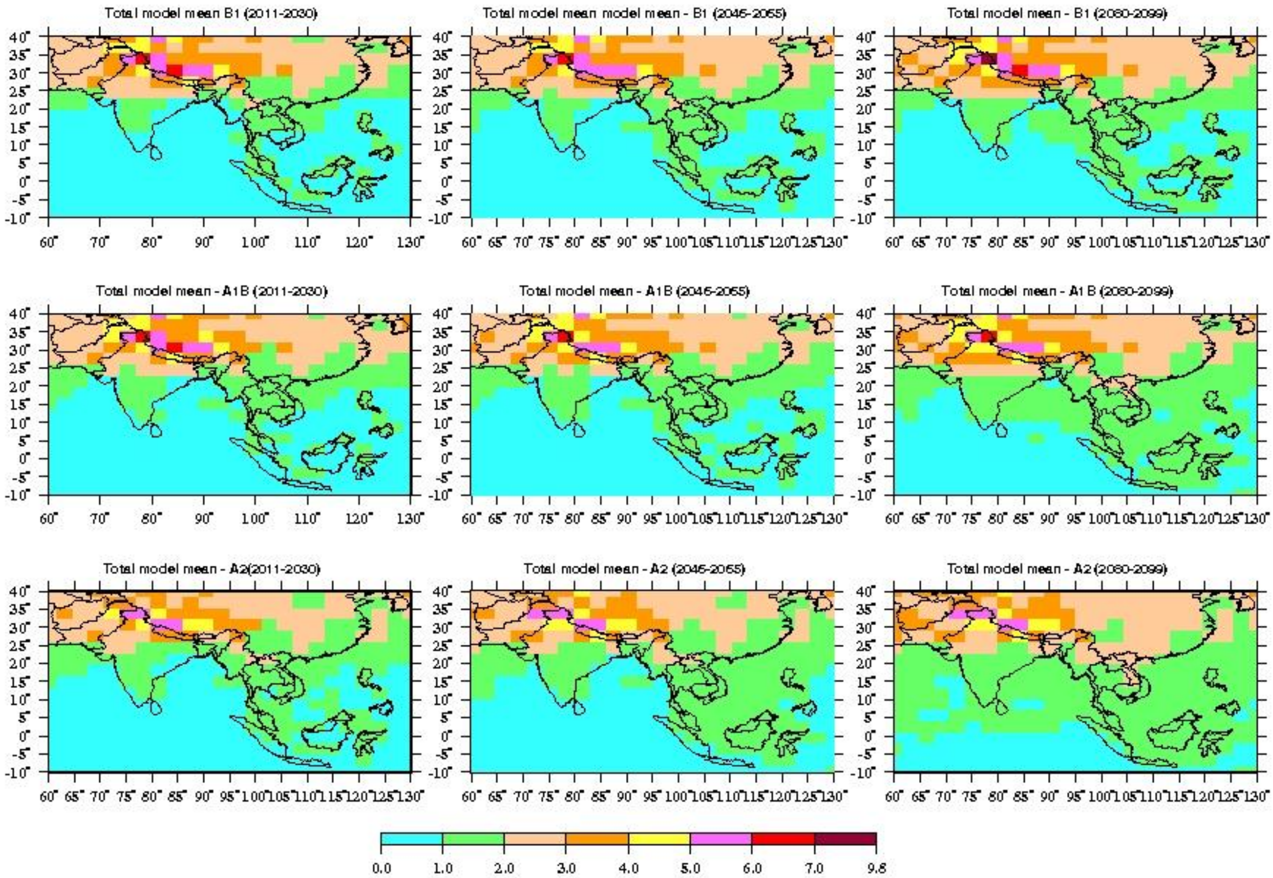
** Standard deviation of annual winter mean warning in Southeast Asia:*

The run to run standard deviation of winter mean warning in the multi model ensemble is illustrated in figure 32.

- Under the A2 scenario, the annual winter standard deviation is about 0 – 1 over ocean region; 1 - 2 over south of India, Philippine, Malaysia, Vietnam and coastal zone in south of China; this index is high over mountain in Pakistan, north of India and special over Himalaya. During the middle and the end of century standard deviation slightly changes over the ocean and high over the landmasses.
- Under the A1B and the B1 scenario, the annual winter standard deviation is about 0 - 1 over ocean region, rises up 1 - 2 over coastal zone and higher over mountain area.

In general, the standard deviation is a measure of model uncertainty. It is low over oceans and increasing toward mountain areas. This standard deviation warming in the winter is higher than one in summer over the mountain area. That mean during the winter, uncertainty GCMs simulation is higher than one during the summer over the mountain area. Under A2 scenario, this uncertainty is clearly defined during the middle and the end of 21st century. The factors that influence the uncertainty of GCMs simulation under A2 include the West African monsoon, Indochinese and monsoon maybe causes increasing uncertainty GCMs over ocean at the end of 21st century under A2 and A1B scenarios. It can be explained by that the difference in heating between continents and the sea, between the area and terrain to be divided makes local temperature and precipitation circulation, such as sea-land wind, wind mountain valley. Local terrain and distance from moisture sources plays a key role in the distribution of rainfall in a tropical: rainfall slope wind, slope wind dead with little rainfall.

Figure 32: Run to run standard deviation of winter warming in the multi-model ensemble



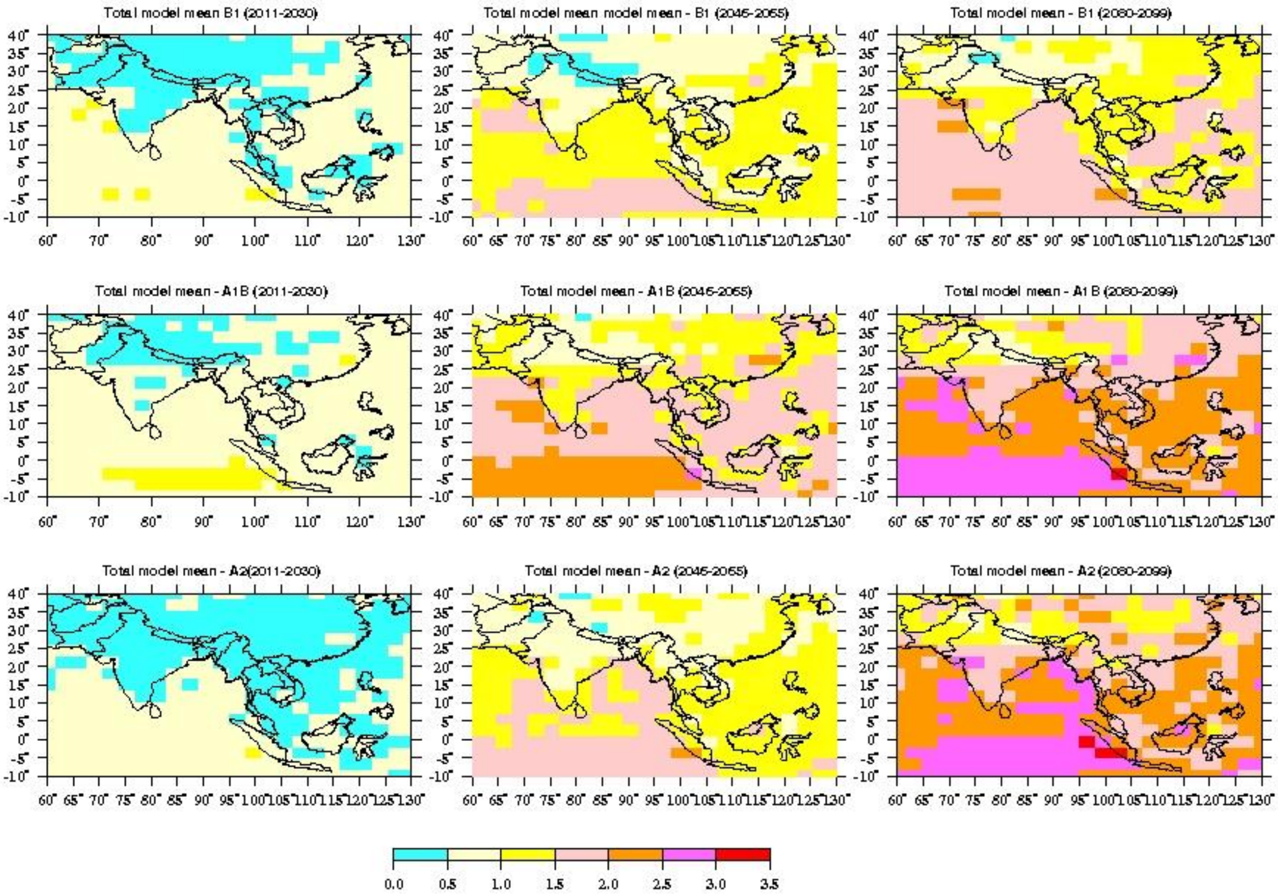
5.2.3. Temperature Signal/Noise ratio:

* <u>The Signal/Noise ratio of annual mean warning in Southeast Asia:</u>

- The three time slices under the A2 scenario are characterized by considerably different Signal/Noise ratio. This can easily be explained by the previous findings: while the standard deviation between model projections is rather constant over time, the amplitudes of climate change are increasing towards the end of 21st century. The spatial patterns are always the same: the Signal/Noise ratio is clearly higher over the ocean compared with the landmasses, reflecting enhanced model uncertainty in term of orographic effects and land-surface interaction.

- Under the A2 scenario, Signal/Noise of GCMs simulations seem to not change, but climate change increases by the end of the 21st century. Increasing uncertainty in the models over elevation sites is still available, reflecting the interaction of topography and surface coatings. The high, complex topography have stronger affect in GMSs than low and uniformity terrain.
- Under the B1 scenario, Signal/Noise ratio is smaller than above two scenarios. By the end of the 21st century, climate change tends to increase. Interactive terrain and surface coating still plays an important leakage effect on model uncertainty.

Figure 33: Signal/Noise ratio of annual mean warming in the multi-model ensemble



** The Signal/Noise ratio of annual summer mean warning in the multi model ensemble over Southeast Asia:*

The Signal/Noise ratio of annual summer mean warning in the multi model ensemble over the Southeast Asia is illustrated in the figure 34.

- Under the A2 scenario, the annual summer Signal/Noise ratio (SNR) are clearly higher over the Arabian Sea, Bay of Bengal, Indian Ocean and south China sea (0.5 – 1.0) than over the landmasses during 21st century. Spatial trends have not changed, the model uncertainty expressed in term of the influence of topography and interactions between them.
- Under A1B scenario, characteristics of topography and interactions between them has affected on integrity of the model. SNR values are higher over the landmasses and high latitude site than over ocean, which express strong effect on the model uncertainty.
- Under the B1 scenario, the SNR values are rather constant over time, the model uncertainty over the ocean is smaller than over than landmasses. It is clear that, properties of topographic lead to model uncertainty.

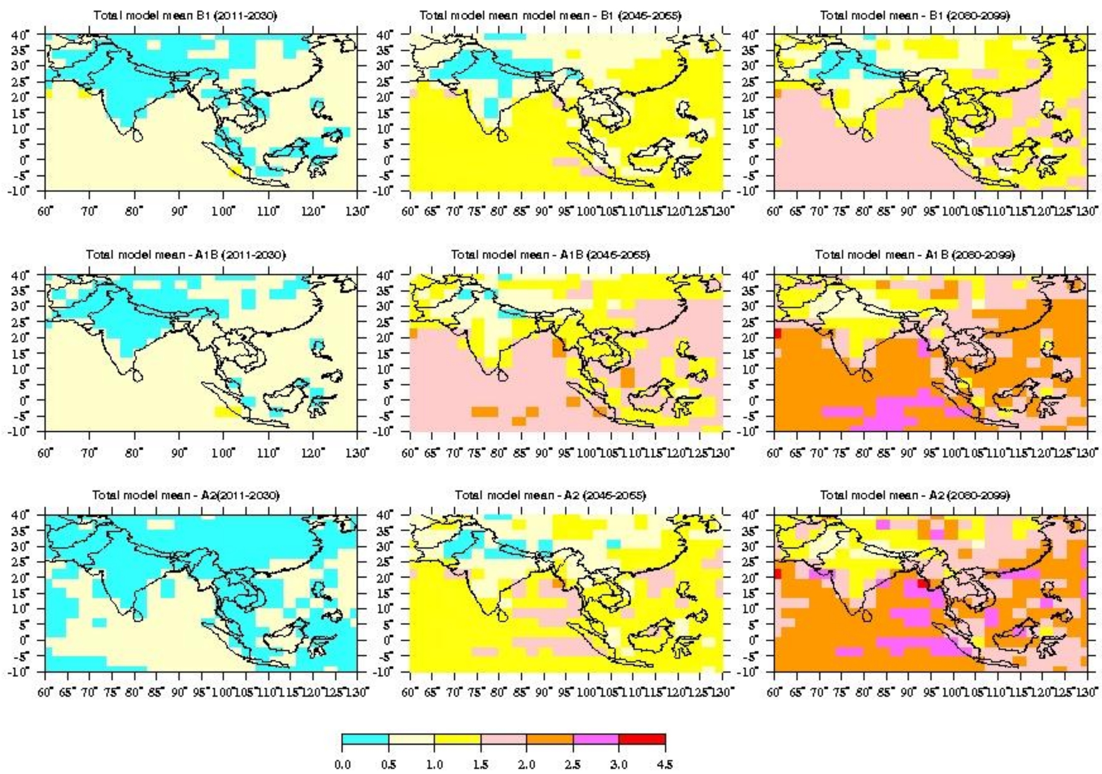
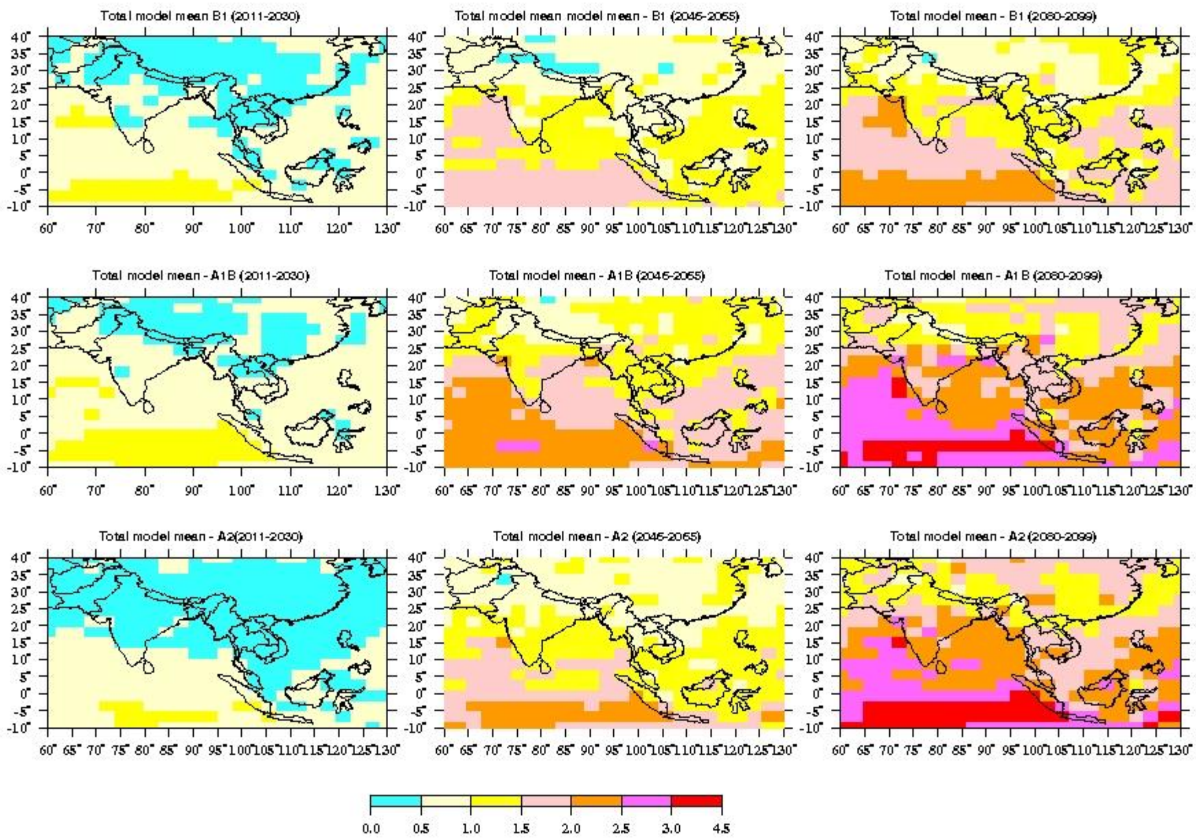


Figure 34: Signal/Noise ratio of summer mean warming in the multi-model ensemble

* *The Signal/Noise ratio of annual winter mean warning in the multi model ensemble over Southeast Asia:*

- The Signal/Noise ratio different is identified in three time slices under the A2 scenarios. The standard deviation between model projections is rather invariable during 21st century, climate change increasing toward the end of 21st century. The Signal/Noise ratio is rather higher in winter compared with in summer and over the ocean than landmasses, reflecting the enhanced model uncertainty in term of orographic effect and land-used interaction.
- Under A1B scenario, the annual winter SNR is projected rather high about 1.0 – 1.5 over Indian Ocean, the spatial pattern still the same, the SNR is higher over the ocean than over the landmasses and amplitude of climate change increasing toward the end of 21st century.
- Under the B1 scenario, once again the model uncertainty is greater over landmasses slices and high altitude than the ocean. Climate change is always increasing toward the end of 21st century.

Figure 35: Signal/Noise ratio of winter mean warming in the multi-model ensemble



In general, winter monsoon in Southeast Asia shows the penetration of air masses extreme cold to tropical low latitudes during winter in waves of about 5-7 days, mainly for the weather became cold and dry, little rainfall, except for coastal areas sea, where rainfall occurs in winter due to cold polar air variable properties over the ocean and become more humid. However, during winter the monsoon activity is relatively stable and predictable, because the penetration is usually associated with cold activity of cold continental high pressure. It is clearly that, during the winter, SNR is rather smaller than that during the summer. Monsoon factors also play an important role in affecting model uncertainty

5.2.4. Precipitation projection:

It is obviously, the changes in atmospheric water content, precipitation and land surface hydrology under greenhouse forcing could be more important than the increase in the land-sea thermal gradient for the future evolution of the monsoon precipitation. A significant spread in the summer monsoon precipitation anomalies despite a general weakening of the monsoon circulation. The weakening of the ENSO-monsoon correlation could be explained by a possible increase in precipitable water as a result of global warming, rather than by an increased land-sea thermal gradient. Both above mechanisms can play a role in monsoon changes in a greenhouse-gas warming scenario. Time-slice experiments with GCM indicate a general increase in the intensity of heavy rainfall events in the future, with large increases over the Arabian Sea and the tropical Indian Ocean, in northern Pakistan and northwest India, as well as in northeast India, Bangladesh and Myanmar.

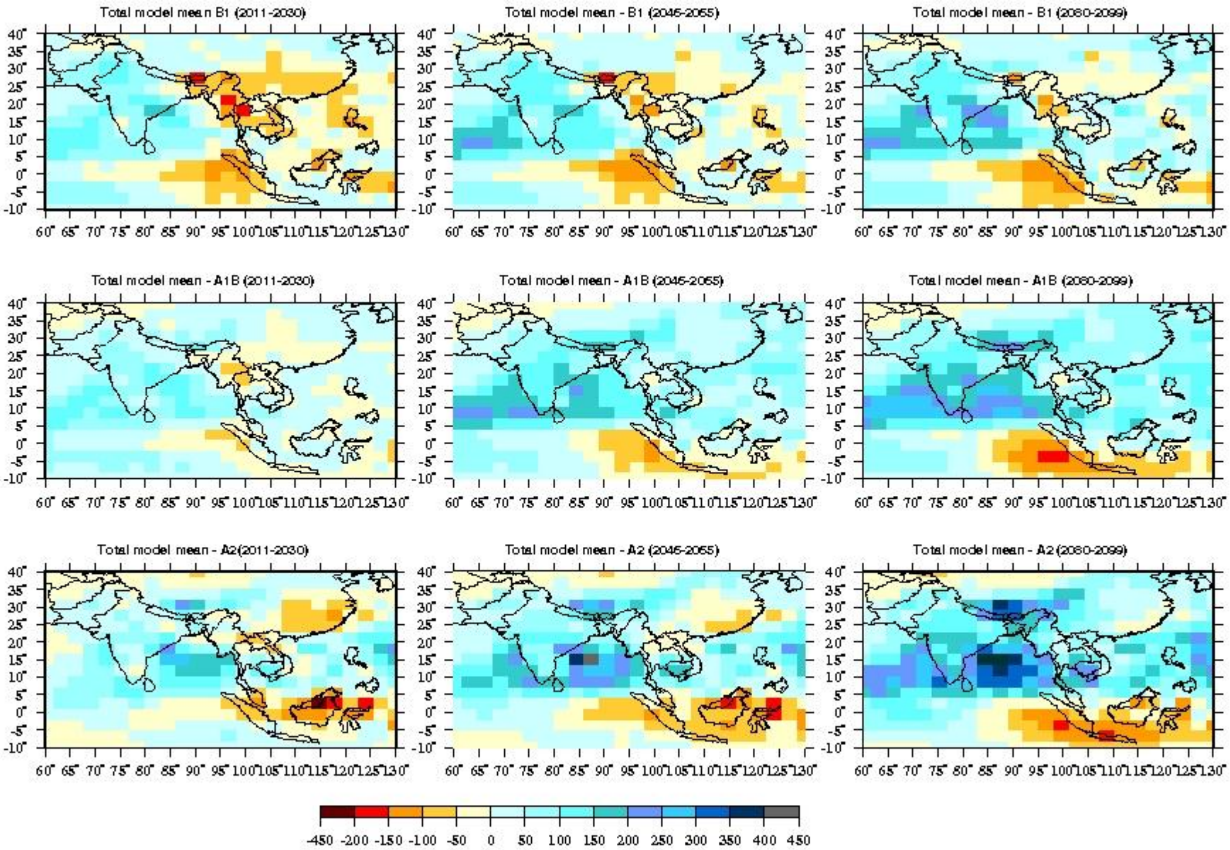
* *Annual precipitation projection:*

The multi-model mean annual precipitation changes for different scenarios and time slices in mm is illustrated in figure 36.

- Under the A2 scenario, precipitation over the Arabian sea, Bay of Bengal, India Ocean is projected to increase about 0 - 100 mm in the 2020s, about 100 - 200mm in the 2050s, and about 250 - 300mm in the 2080s. But over the mountain and over the Indonesia's islands (along the 5° latitude in north and south hemisphere) the precipitation is projected about (-50mm) – (-450mm) in the 2020s; and (-50mm) – 450mm) in the 2050 and (-100mm) –(-200mm) in the 2080s.

- Precipitation over the considered region increases in multi model A1B projections for annual toward the end of 21st century over the central India, Bangladesh, Bay of Bengal but decreases in South China, Vietnam, Lao, Thailand, Philippine's Islands.
- Under the B1 scenario, precipitation over the Indochinese countries. Philippine's island, Malaysia, Indonesia decrease but increase over the rest of Southeast Asia region toward the end of 21st century.

Figure 36: Multi-model mean annual precipitation changes for different scenarios and time slices in mm



** Summer precipitation projection:*

The multi-model mean summer precipitation changes for different scenarios and time slices in mm is illustrated in figure 37.

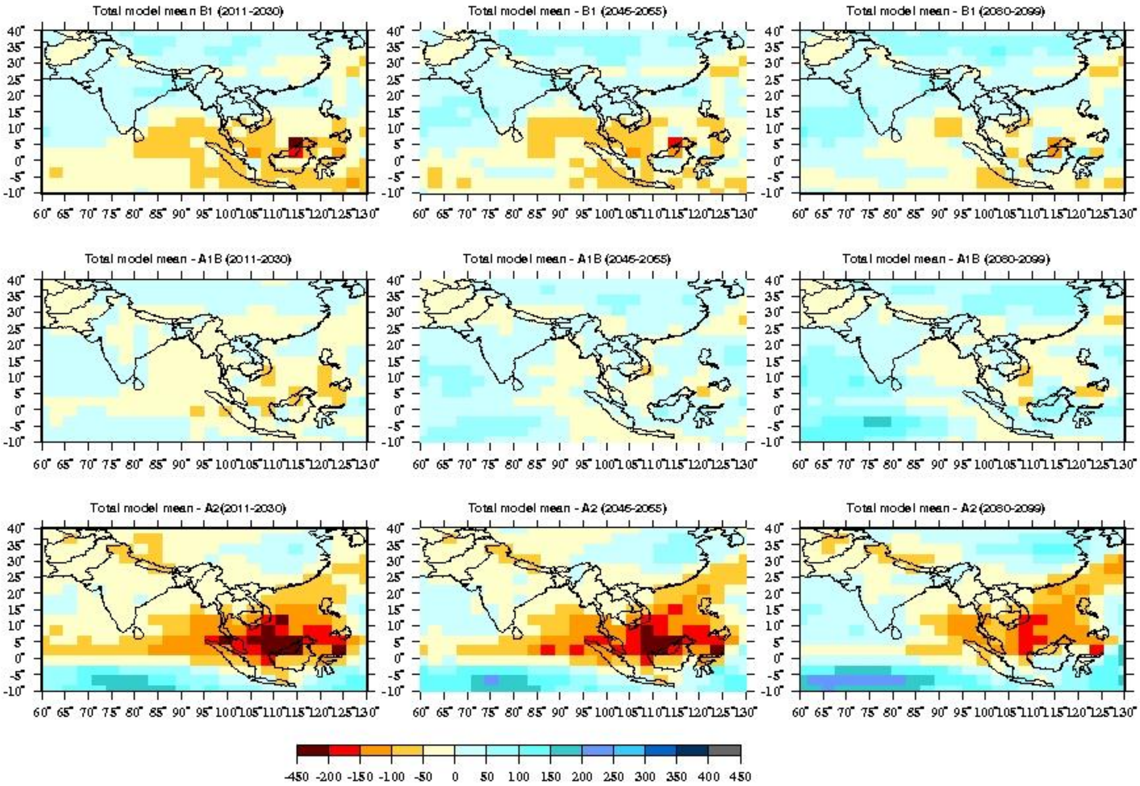
- Under the A 2 scenarios, precipitation increase across the Arabian Sea, Bay of Bengal, central of India, north of Philippine Sea and decrease over the southern Indonesian archipelago toward the end of 21st century.
    - Under the A1B, for Southeast Asia, the multi-model mean shows an increases in average summer precipitation over the west bank of India, Bay

of Bengal, while decrease precipitation over the Indian Ocean, Philippine sea, Philippine's islands and toward the end of 21st century.

- Under the B1 scenario, multi model simulation tends to project an average summer precipitation increase over South India, Bay of Bengal, while precipitation decreases over the Indian Ocean, Indochinese countries Indonesia, Philippine's islands and toward the end of 21st century.

The results show that, during summer precipitation increases over the west of the considered region but decrease over the east of the considered region. It can be explained by the characteristics of the monsoon over Southeast Asia. During summer, the Southwest monsoon blows from sea to land, carrying more water vapor. It creates warm and humid climate, accompanied with clouds and rain for areas near to the sea, the rain is more than in the inlands.

Figure 37: Multi-model mean summer precipitation changes for different scenarios and time slices in mm



* *<u>Winter precipitation projection:</u>*

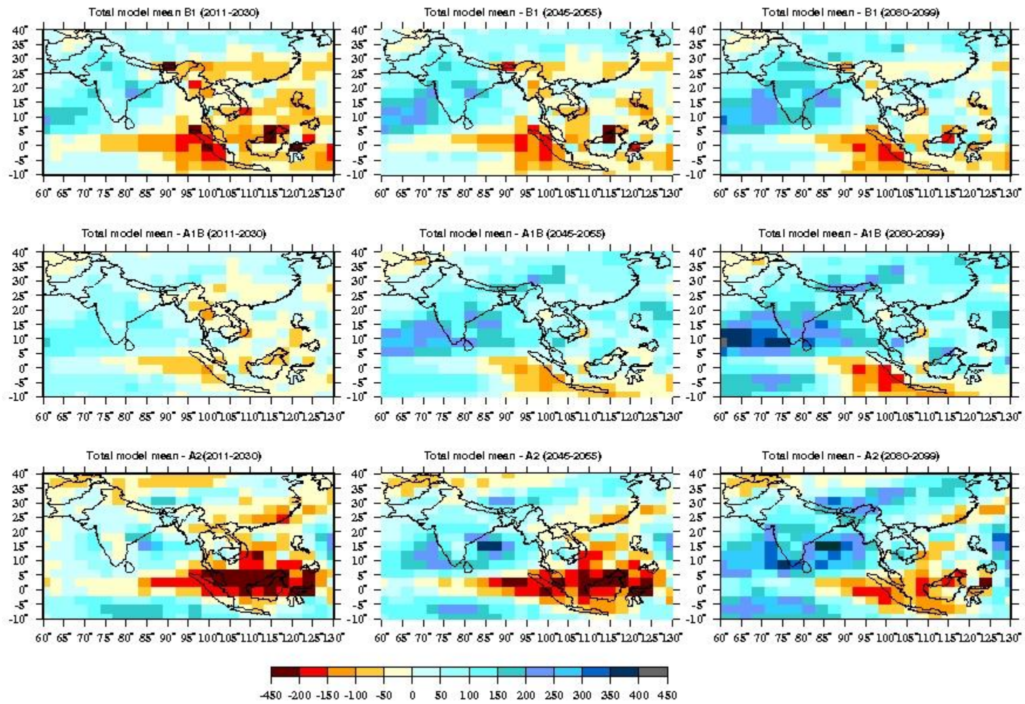
- Multi-model mean winter precipitation changes for different scenarios and time slices in mm are illustrated in figure 38.
- Under the A2 scenario: the spatial pattern of precipitation shows a decrease over the high altitude mountain Himalaya in the northern part of the

considered region over sea and islands, especially over Indonesia's islands, Philippine and south China sea. The end of century drought levels in the winter is somewhat lower than in the early years of the 21st century.

- Under the A1B scenario: precipitation decreases over west of India, Bay of Bengal, south of China, Philippine islands but increase over the Arabian sea, the northern part of considered region and some part of India sea. The precipitation increase toward the end of 21^{st} century.
- Under the B1 scenario, the precipitation pattern decrease over Bay of Bengal, India Sea, Philippine islands but increase over the rest of considered region and toward the end of 21^{st} century.

It is clear that, in winter, the monsoon blows from the Asian continent from northeast to southwest which brings dry and cold air, as close to the equator, the wind becomes warmer and wetter. Winter monsoon blows in waves, each of the wind, in areas near the tropics it gets colder in a few days, sometimes lasting for weeks. Besides, in the last decade of the twentieth century, regional weather had affected Southeast Asia strong ENSO phenomenon, which may effect on strong drought in beginning of 21^{st} century over considered region comparing with the end of 21^{st} century.

Figure 38: Multi-model mean winter precipitation changes for different scenarios and time slices in mm



In summary, climate models suggest that the climate in future period of Southeast Asia will be wetter in summer and drier in winter. The magnitudes are high in the A2 scenario over the Indonesia's islands; during the seasonal cycle, precipitation pattern changes are higher in winter than in summer, reflecting enhanced ENSO activities and monsoon properties over the considered region. It is clearly that, the changes in atmospheric water content, precipitation and land surface hydrology under greenhouse forcing could be more important than the increase in the land-sea thermal gradient for the future evolution of monsoon precipitation. A significant spread in the summer monsoon precipitation anomalies despite a general weakening of the monsoon circulation. The weakening of the ENSO-monsoon activities could be explained by a possible increase in precipitable water as a result of global warming, rather than by an increased land-sea thermal gradient. Both the above mechanisms can play a role in monsoon changes in a greenhouse-gas warming scenario. Time-slice experiments with GCM indicate a general increase in the precipitation over the Arabian Sea and the tropical Indian Ocean, in northern Pakistan and northwest India, as well as in northeast India, Bangladesh and Myanmar.

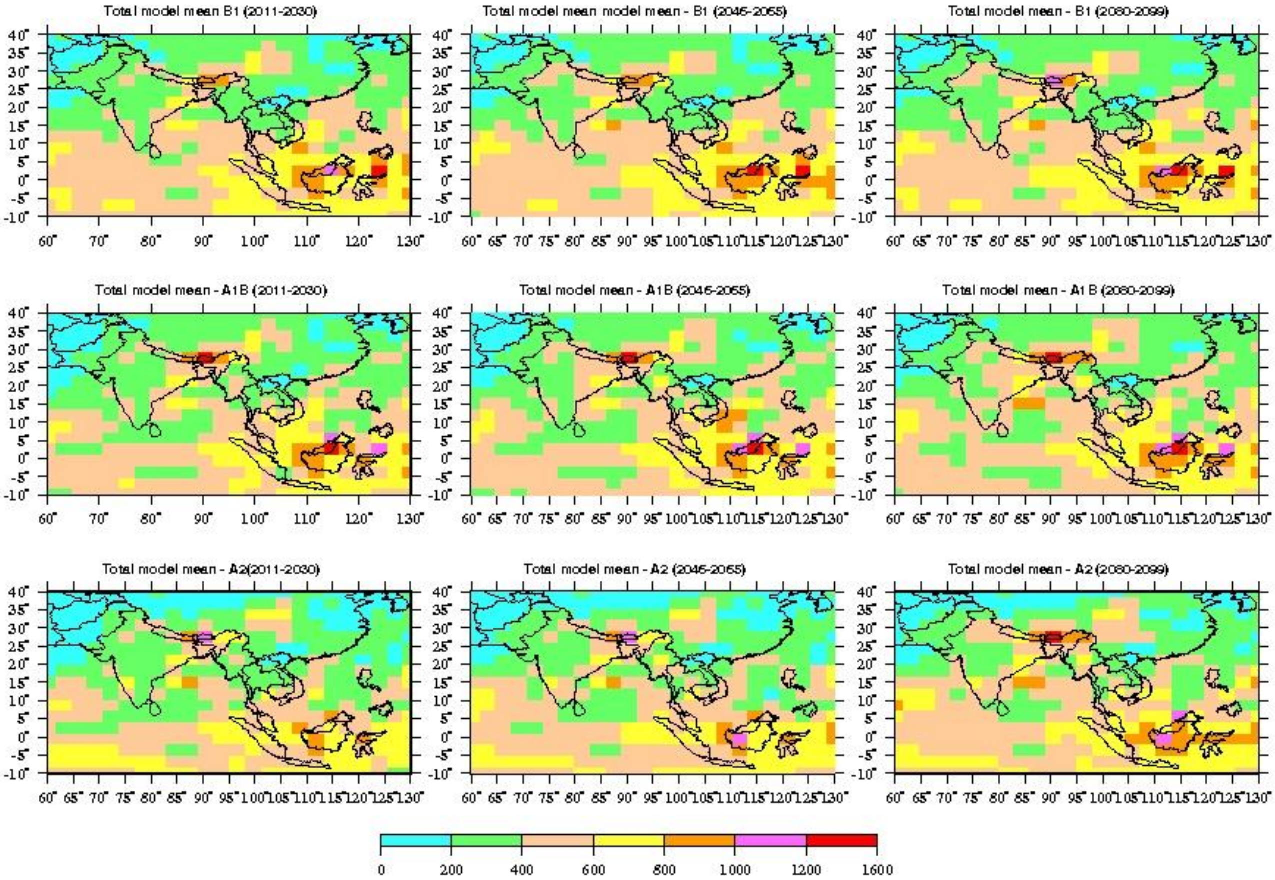
5.2.5. Precipitation Standard deviation:

** <u>Standard deviation of annual precipitation changes:</u>*

The run to run standard deviation of annual mean precipitation over the Southeast Asia is illustrated in figure 39.

- Under the A2 scenario, the annual standard deviation precipitation between model projections is rather constant over time. It is lower over the high altitude and higher over the ocean, reflecting enhanced model uncertainty in term not only of orographic effects and land–surface interaction but also relating to enhanced ENSO activities and monsoon properties over considered region
- Under the A1B scenario, the standard deviation shows the same pattern with above scenario over time, which is higher over the mountain area and lower over the ocean area. Characteristic of relief, the prevailing monsoon circulation and the strengthening of ENSO activity in the considered region play an important role effecting enhanced model uncertainty.
- Under the B1 scenarios, the standard deviation pattern is similar to two above scenarios. The closer to the equator, increasing standard deviation value, this can be explained by the interference region of the atmosphere is very complex over the low latitude region, very difficult to take into account correctly in GCM.

Figure 39: Run to run standard deviation of annual precipitation in the multi-model ensemble in mm



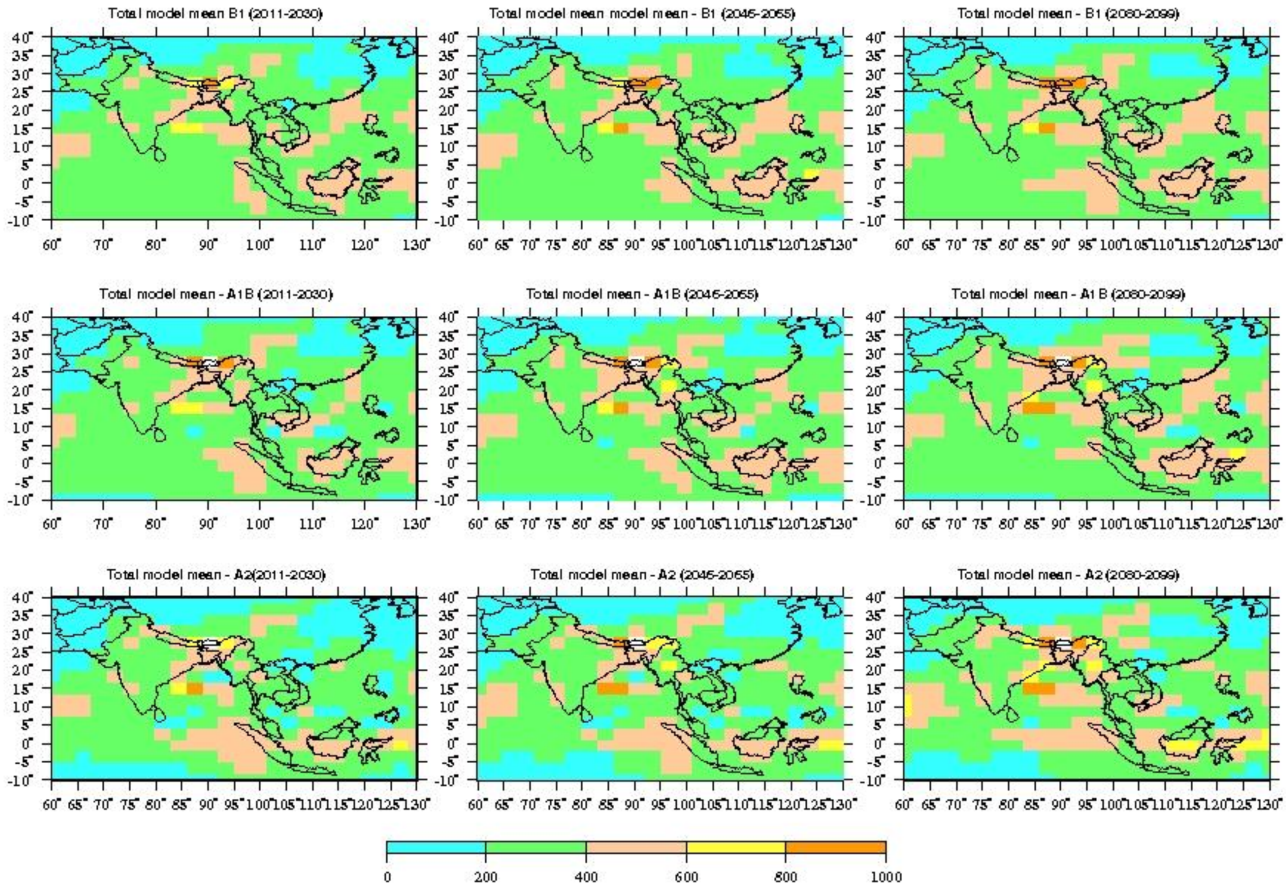
* <u>*Standard deviation of annual summer precipitation changes:*</u>

The run to run standard deviation of annual summer mean precipitation over the Southeast Asia is illustrated in the 40.

- Under the A2 scenario, the annual summer standard deviation precipitation pattern between model projections are lower (0 – 200) over the west north India, Tibet, east of China and Indian Ocean, but higher over the India sea, south of Arabian sea, bay of Bengal, Indochinese and south China sea. The spatial patterns are always the same toward the end of 21st century.
- Under the A1B scenario, the standard deviation pattern is lower over west of India, Tibet and east of China, but higher over the rest of considered region. It shows no changes over time toward the end of the 21st century. It is clear that over the low latitude and closer to equator, the model uncertainty is enhanced. Due to changes in atmospheric pressure in the summer monsoon blows from sea to land. This interaction between west Pacific, east pacific and Indian Ocean is an important source of model uncertainty.

- Under the B1 scenarios, as well as in the future above mentioned scenarios, the south-west monsoon nature, the interaction between ocean currents at low latitudes near the equator have strongly effects the model uncertainty. Therefore, it is higher in the low latitude than in the northern part of the considered region.

Figure 40: Run to run standard deviation of summer precipitation in the multi-model ensemble in mm



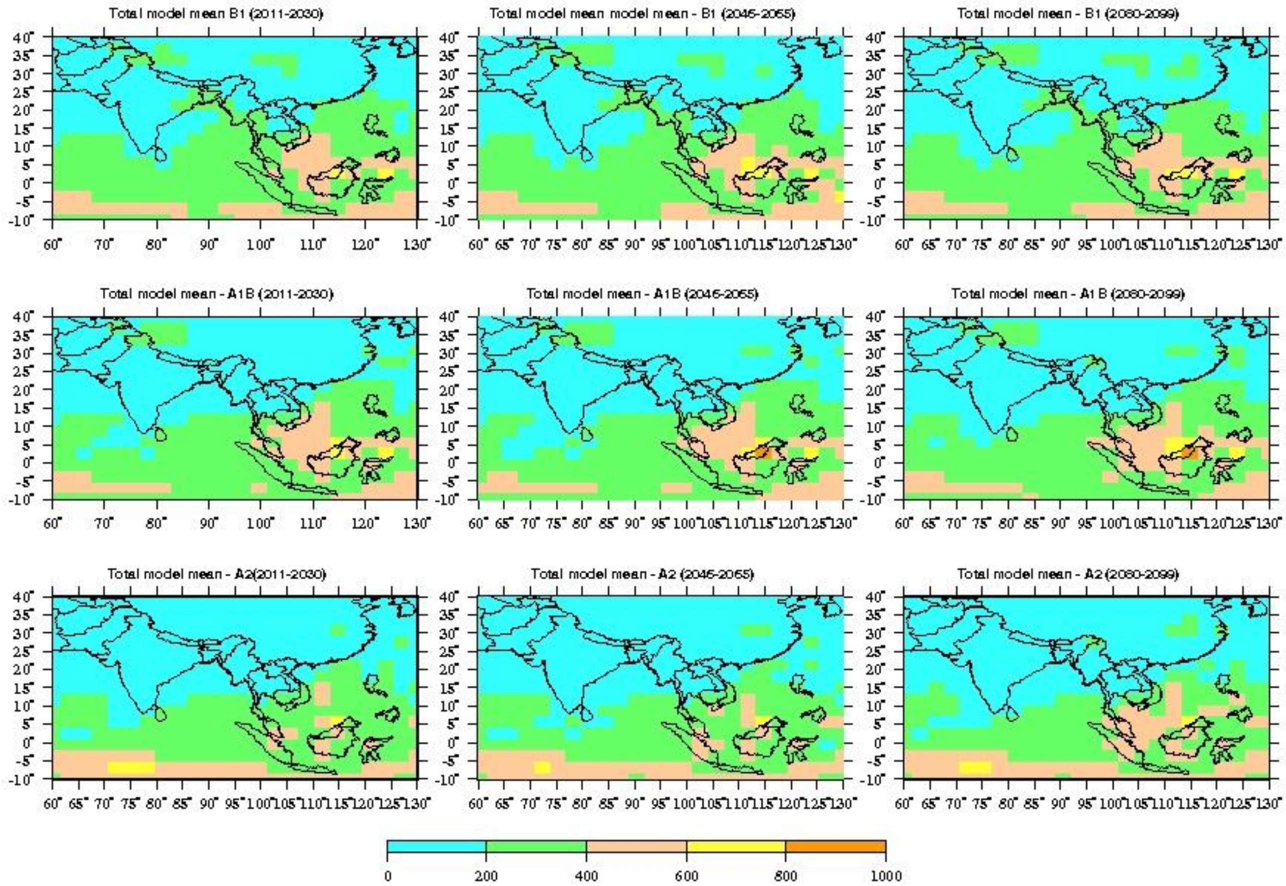
* *<u>Standard deviation of annual winter precipitation changes:</u>*

The run to run standard deviation of annual winter mean precipitation over the Southeast Asia is illustrated in the 41.

- Under the A2 scenario, the annual winter standard deviation precipitation pattern between model projections has its minimum values (0 – 200) from 20°N - 40°N latitude. Higher values are over south of the Arabian Sea, Bay of Bengal, and south of Chinese Sea and the 0°N - 10°S about (400 – 600) is rather constant over time. In winter, the monsoon blows from the Asian continent in the direction from northeast to southwest. Close to coastal and near the equator, the characteristic and composition of the wind has changed, affecting model uncertainty.

- Under A1B and B1 scenarios, the spatial patterns are similar. Compared to summer, over low latitude close to equator, influence the interaction between ocean currents, the lack of data records for climate models could have an impact model uncertainty.

Figure 41: Run to run standard deviation of winter precipitation in the multi-model ensemble in mm



5.2.6. The precipitation Signal/Noise ratio:

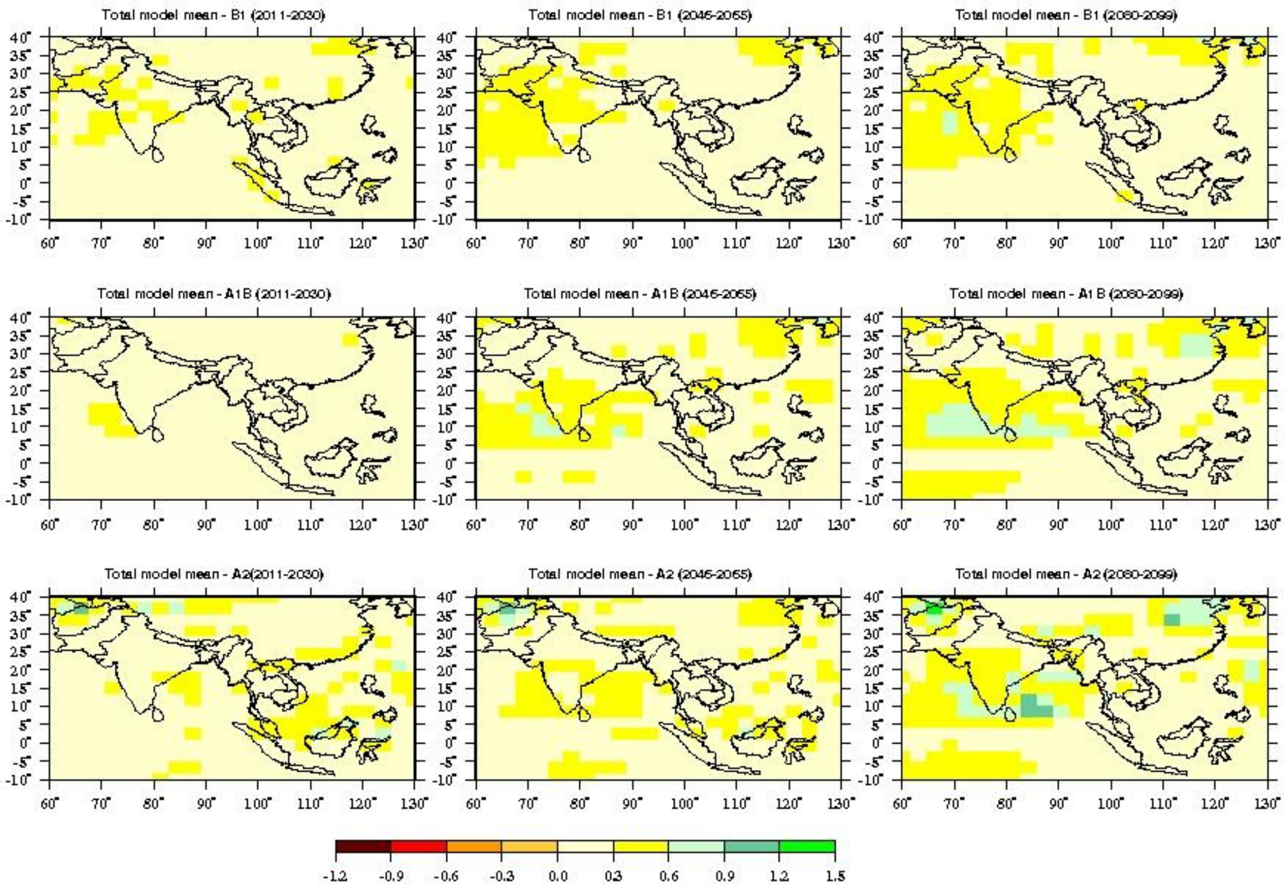
** <u>The Signal/Noise ratio of annual mean precipitation :</u>*

The Signal/Noise ratio of annual mean precipitation over the Southeast Asia region is illustrated in figure 42.

- Under the A2 scenario, the Signal/Noise ratio (SNR) of annual mean precipitation pattern increase over south west India, bay of Bengal and higher over mountain in northern part of India toward the end of 21st century. The spatial pattern are always the same, the Signal/Noise ratio is similar over the ocean compared with the landmasses, reflecting stable model uncertainty in term of orographic effects and land-surface interactions.

- Under A1B scenario, the spatial pattern of the annual Signal/Noise ratio is higher over southern Arabia, India and Bay of Bengal, the eastern of Chinese Sea and increasing toward the end of 21st century. It may be explained by mean temperature over this region is high cause low presses heat formed and air is sucked into the low pressure domain over the continent, reflecting high model uncertainty.
- Under B1 scenarios, the spatial pattern is rather constant over the time, amplitude of SNR is high over the Arabian Sea and southern India.

Figure 42: Signal/Noise ratio of annual mean precipitation in the multi-model ensemble

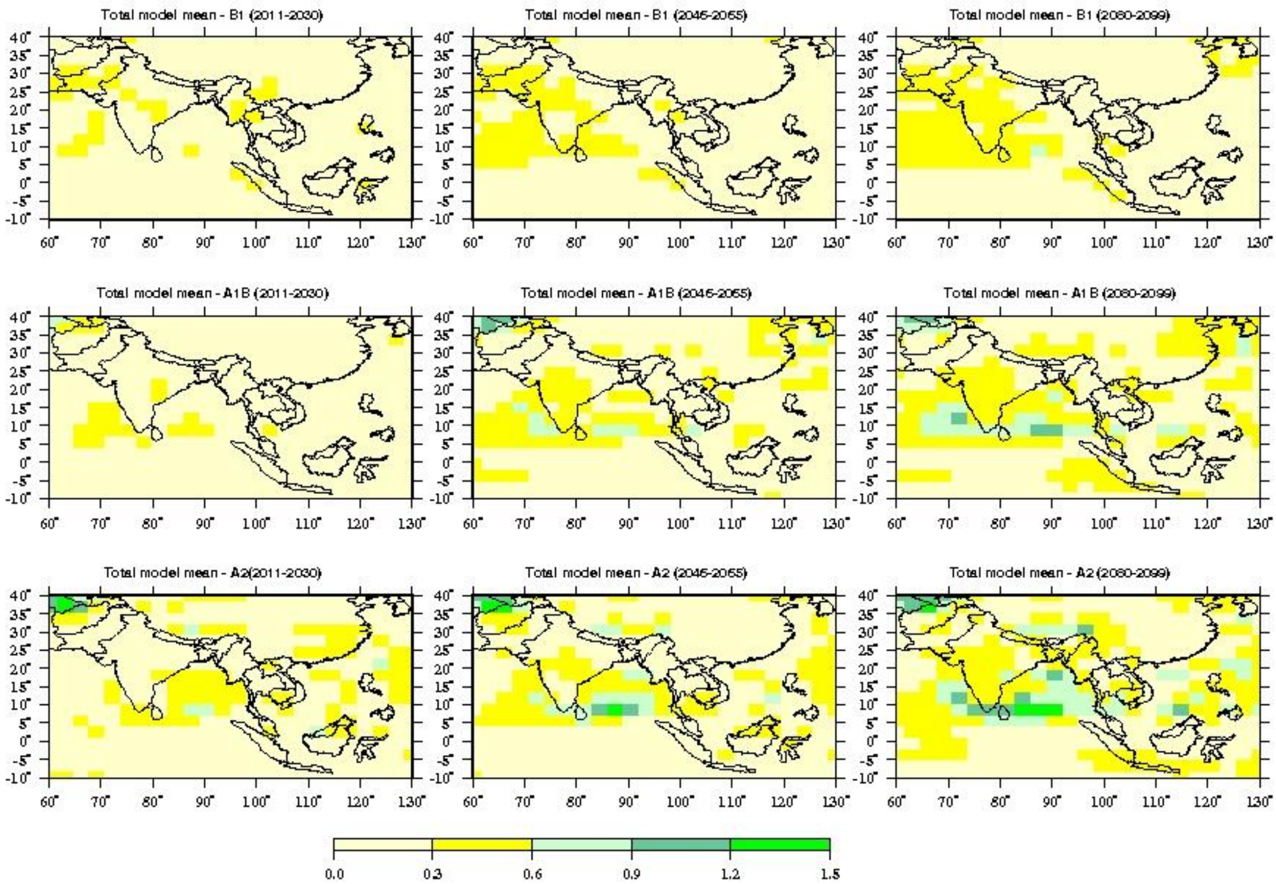


* <u>The Signal/Noise ratio of annual summer mean precipitation :</u>

The Signal/Noise ratio of annual summer mean precipitation over Southeast Asia is illustrated in figure 43.

- South Asian monsoon is the dominant factor in the Asian climate in general and Southeast Asia in particular. In summer, strong activity of the South Asia monsoon causes lower grooves formed in the Arabian Sea, Bay of Bengal. South Asian monsoon mechanism is a combination of motivation and terrain and causes high precipitation and high SNR. This is similar over the time under the A2 scenarios.
- Under A1B and B1 scenario, the annual summer SNR has similar patterns to A2 scenario with lower intensity over the time.

Figure 43: Signal/Noise ratio of summer mean precipitation in the multi-model ensemble

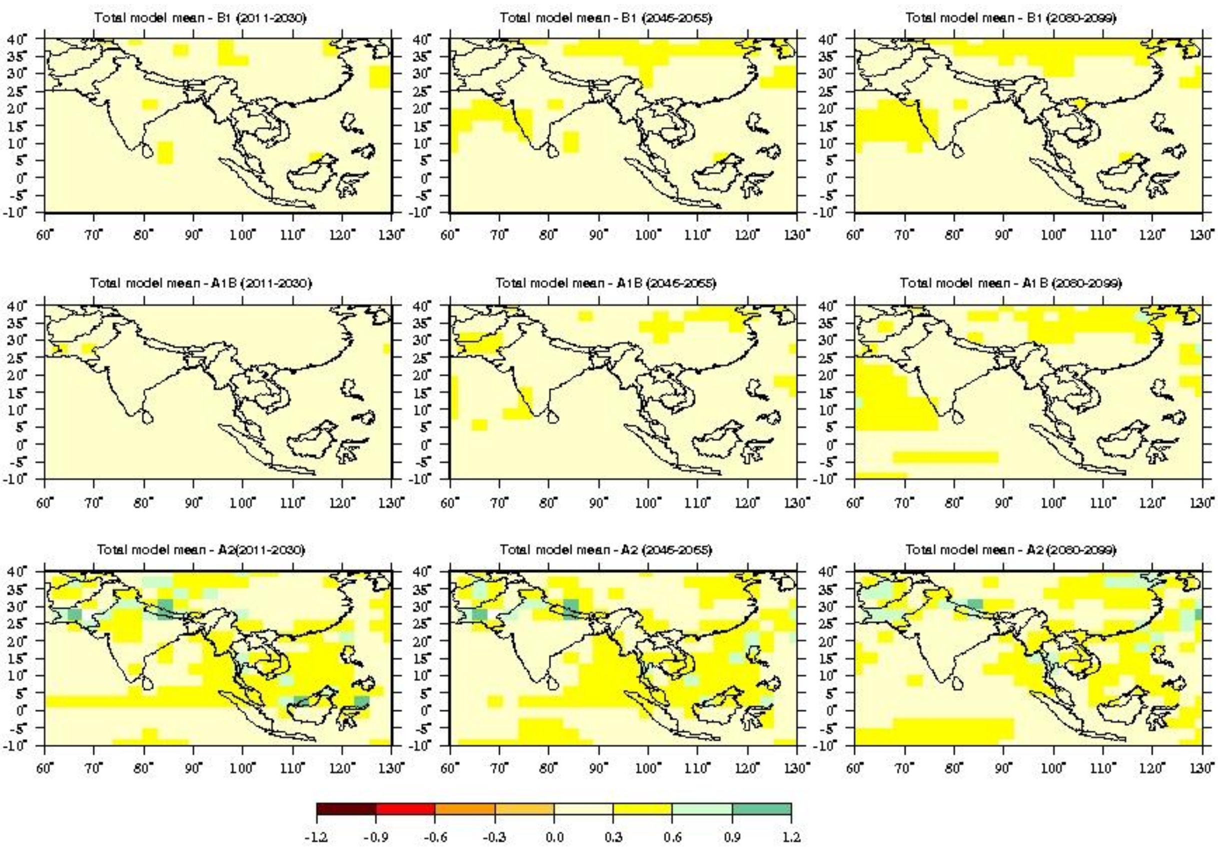


The Signal/Noise ratio of annual winter mean precipitation:

The Signal/Noise ratio of annual winter mean precipitation over Southeast Asia region is illustrated in figure 44.

- Under the A2 scenario, the annual winter Signal/Noise ratio (SNR) of annual mean precipitation is high over the north of India, Himalaya, east of Bengal, over south of Chinese Sea including Philippine and Indonesia' islands. And lower over the rest of the regions. In winter, the SNR high-value region corresponding to the center where the gas pressure and interaction between winter monsoon in the Northern Hemisphere with summer monsoon in the Southern hemisphere over low latitude regions.
- Under A1B and B1 scenario, the SNR pattern is rather constant over the time except some higher values over Arabian Sea and in the central of China in the end of 21^{st} century.

Figure 44: Signal/Noise ratio of winter mean precipitation in the multi-model ensemble



5.3. Climate projection over Vietnam:

5.3.1. Temperature projection over Vietnam:

In general, the changes in Vietnam's climate show a similar trend to the changes in the whole Southeast Asian region.

The annual air temperature in Vietnam will increase constantly into future, with a rate in a range about 0.1ºC/decade for the B1 scenario, 0.3ºC/decade for the A2 scenario, 0.3ºC/decade for the A1B scenario until the end of the 21st century. The climate warming reaches 2ºC for the B1 scenario and 3ºC for the A2 and A1B scenario. This rate of warming is quite uniform during the year for the whole region.

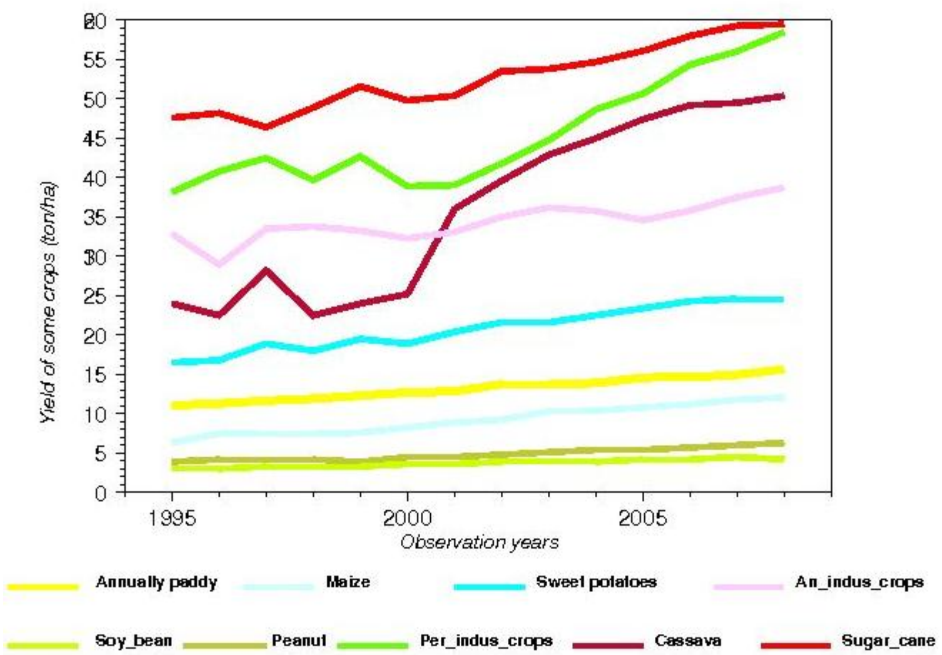
5.3.2. Precipitation projection over Vietnam:

The future annual precipitation change over Vietnam is expected to increase over most part of 21st century. During the 2020s, the future annual average precipitation is drier by about 50 mm, except for the southern part of Vietnam. But in the middle and at the end of 21st century precipitation increases over the whole country by about 50 – 100mm. This tendency of precipitation is quite uniform over all seasons and for the whole country.

5.4. Correlation between temperature, precipitation and crop yields:

The annual yields of some crops in Vietnam are illustrated in figure 45. It is obvious, agricultural productivity has increased during this period.

Figure 45: Agricultural yield of some crops time series



It is well known that temperature and precipitation are the most important climate parameters for crop yield. Hence, it is possible to examine the relationships between temperature, precipitation and crop yield. Temporal correlations (1995-2002) are computed between the observed climate data (CRU, NCEP and station data in Vietnam) and the crop yield amounts in table 8 (temperature).

Table 8: Correlation between Agricultural yields and temperature in Vietnam (1995 - 2002), statistical significance at the 90% level is indicated by an asterisk.

	Paddy (1)	Maize (2)	Sweet potatoes (3)	Cassava (4)	Peanut (5)	Soybean (6)	Sugar cane (7)	Annual industrial crop (8)	Permanent industrial crop (9)
Observations station data	0.44	0.35	0.47	0.29	0.35	0.51	0.30	0.73*	0.13
NCEP data	0.33	0.25	0.35	0.17	0.24	0.38	0.24	0.64*	0.06
CRU data	0.22	0.1	0.27	-0.08	0.06	0.3	0.09	0.6*	0.18

It appears that, the temperature has some influence on the agricultural yield. The correlation between them is positive. When temperature increases, crop yield increases too. This relationship is stronger between station data and crop yield and is weaker between CRU data and crop yield. The strongest relationship is the relationship between the annual industrial crop yield and the temperature and the lowest one is the one between permanent industrial crop yield and temperature. In general, all of the data set has the same tendency correlation with the crop yield but the actual values are difference from crop to crop. So the positive correlation seems stable. In a warmer climate, crop yield could be increased. Anyway, it is also conceivable that these temperature thresholds limit crop yield in the future.

However, a two side t-test (90%) shows that most of the correlation coefficient are not statically. This is partly due to the very small sample size spanning only 8 years (1995 – 2002).Anyway, the annual industrial crop yield has a correlation coefficient which is significantly different from 0 this means we can use the regression line to model the linear relationship between annual industrial crop and temperature.

REMOVE TREND

Table 9: Correlation between crop yields and temperature in Vietnam (1995 - 2002)

	Paddy (1)	Maize (2)	Sweet potatoes (3)	Cassava (4)	Peanut (5)	Soybean (6)	Sugar cane (7)	Annual industrial crop (8)	Permanent industrial crop (9)
Observations station data	-0.15	-0.30	0.09	-0.11	-0.04	0.22	-0.18	0.64	0.06
NCEP data	-0.27	-0.33	-0.01	-0.20	-0.11	0.08	-0.15	0.56	0.01
CRU data	-0.35	-0.49	0.01	-0.46	-0.27	0.10	-0.27	0.55	0.15

When removing the long-term trend from time series (table 9) only Soybean, annual and permanent industrial crop have positive correlation with temperature. This is not true for Paddy and Maize and other crops in table 9. This result is different to the result on table 8. Revealing that some of correlations in table 8 are simply related to the long-term trend in temperature and crop yield.

For the crop yield, the need of water is also very important including the total water amount and the distribution in time. It means that, crop yield is highly sensitive to wet and dry sequences during the crop growing season. Not only a gradual increasing of wet or dry day occurrences is important, but also the timing within the growing season when these wet or dry speech occurred, play a very important role. This is also true for Vietnam, where storms play an important role in the water balance. Vietnam's annual average of about 10 major storms mostly occurs in September annually. For Vietnam, storms are considered the leading type of natural hazard and damage largest for the person and property. Metrics storms were collected from storms statistical recorded which occurred over Southern China Sea and landed into Vietnam stage 1995 – 2002. The correlation between crop yield and storms in Vietnam are showed in table 10.

Table 10: Correlation between crop yield and storms in Vietnam (1995 - 2002), statistical significance at the 90% level is indicated by an asterisk.

	Paddy (1)	Maize (2)	Sweet potatoes (3)	Cassava (4)	Peanut (5)	Soybean (6)	Sugar cane (7)	Annual industrial crop (8)	Permanent industrial crop (9)
Storm	-0.63*	-0.39	-0.61*	-0.61*	-0.42	-0.70*	-0.47	-0.86*	0.2

This result shows that the number of the storms strongly influences the crop yield. The correlation between them is mostly negative, which means, that more storms reduces crop yield in Vietnam. The strongest relationship is the relationship between the annual industrial crop yield and the storm number and the lowest one is the one between maize crop yield and storms.

It appears that, the paddy, sweet potatoes, cassava, soy bean and annual industrial crops have a significant correlation with the number of storms. It is obvious, that storms play a more important role then temperature in Vietnam, in particular for crop in Vietnam. Global warming might bring more storms and hurricanes and also a rising of sea level, which further influence the development of agriculture in Vietnam.

Along with temperature, precipitation also has some effects on agricultural production in Vietnam (table 11).

Table 11 : Correlation between crop yields and precipitation in Vietnam (1995 - 2002), statistical significance at the 90% level is indicate by an asterisk.

	Paddy (1)	Maize (2)	Sweet potatoes (3)	Cassava (4)	Peanut (5)	Soybean (6)	Sugar cane (7)	Annual industrial crop (8)	Permanent industrial crop (9)
Observations station data	-0.81*	-0.74*	-0.71*	-0.77*	-0.84*	-0.9*	-0.52*	-0.61*	0.27
NCEP data	-0.46	-0.36	-0.23	-0.26	-0.42	-0.35	-0.63*	0.1	-0.02
CRU data	0.21	0.25	0.12	0.2	0.17	0.20	0.09	-0.17	-0.57*

It is obvious that most of the correlation with station data and NCEP data are negative. This relationship is stronger between station data and crop yield and is weaker between CRU data and crop yield. This can be explained by the relationship between annual precipitation and storms in territory of Vietnam. Precipitation during the storms is very large. Sometimes in a storm rainfall is about several hundred mm. Precipitation increases when the number of storms increases. As discussed above, the correlation between number of storm and crop yield is mostly negative lead to correlation between precipitation and crop yield is mostly negative, too.

The statistical significant tendency reveals that the correlation coefficient between crop yield and precipitation is "significant" for most crops but only for station data in Vietnam.

In summary, the used data set in this study are sample data over a very short time (only 8 year, from 1995 – 2002)

REMOVE TREND

Table 12 : Correlation between crop yields with precipitation in Vietnam (1995 - 2002)

	Paddy (1)	Maize (2)	Sweet potatoes (3)	Cassava (4)	Peanut (5)	Soybean (6)	Sugar cane (7)	Annual industrial crop (8)	Permanent industrial crop (9)
Observations station data	-0.33	0.01	0.12	-0.42	-0.56	-0.77	0.42	-0.37	0.64
NCEP data	-0.77	-0.15	0.24	-0.02	-0.27	-0.13	-0.67	0.34	0.03
CRU data	-0.36	-0.03	-0.4	-0.02	-0.09	-0.26	-0.26	-0.39	-0.64

Table 14 shows that removing the trend has a considerable effect on the correlation coefficients. This mean that's part of the relationship is related to the long-term trend.

5.5. Multiple regression:

In order to investigate the combined impact of temperature and precipitation from station data, NCEP and CRU on crop yield, multiple regressions is applied. The results are listed in the table below.

The first column is the crop type; the second one is the regression constant (A_0); the third one is the temperature regression coefficient (A_temp – influence of temperature factor), the fourth one is the precipitation regression coefficient (A_pre – influence of precipitation factor) and the last one is the squared multiple correlation, indicating the percentage of variability (change) in crop yield explained by temperature and precipitation variations.

Table 13: Multi regression observation data and crops yield

Crops	A_0	A_temp	A_pre	Percentage (%)
Paddy	3.26	0.07	-0.00057	66.82%
Maize	3.06	0.02	-0.00055	54.90%
Sweet potatoes	0.9	0.28	-0.00089	53.25%
Cassava	24.91	-0.35	-0.00426	58.77%
Peanut	1.96	-0.01	-0.00022	69.90%
Soybean	0.59	0.04	-0.00021	81.24%
Sugar cane	40.83	0.55	-0.00268	27.31%
Annual industrial crop	-9.19	0.86	-0.00052	63.12%
Permanent industrial crop	1.26	0.46	0.00058	14.55%

It above table, the correlation between precipitation from station data and the crop yield is negative. Both of temperature and precipitation influence on the crop yield and it change from the soybean, paddy (high impact with highest percentage values 81.24% and 66.82%) to Maize (54.90%) to permanent industrial (low impact with lowest percentage value, 14.55%). In Vietnam, the irrigation systems with dikes and reservoirs play an important role in agricultural cultivation, which help to an active role in water supply in time for the dry period and active drainage during floods as well as the initiative to provide potable water needs of plants in each period of their development.

In order to have a robust relationship between crop yield and climate parameters (temperature and precipitation), it is necessary to investigate trend removed correlations between them. This process eliminates the influence of futures on correlation such as technological progress and global warming. The results are listed in table 14 below.

Table 14. Multi regression remove trend observation data – crops yield results

Crops	A_0	A_temp	A_pre	Percentage (%)
Paddy	-0.000121	-0.03	-0.00804	13.92%
Maize	0	-0.09	-0.00105	8.91%
Sweet potatoes	0.000178	0.06	≈0	2.71%
Cassava	-0.003.80	-0.69	≈0	20.16%
Peanut	-0.000215	-0.02	≈0	30.66%
Soybean	-0.000139	0.02	-0.00926	61.10%
Sugar cane	0.00304	-0.44	≈0	18.57%
Annual industrial crop	-0.000851	0.88	≈0	49.47%
Permanent industrial crop	0.002.30	0.26	≈0	42.79%

When removing the trend in multiple regressions, most of temperature coefficient (A_temp) change to negative values (negative correlation) or lower values. Both temperature and precipitation have lower impact on crop yield, the percentage is lower than that in table 13. This mean both temperature and precipitation from station data have low impact on crop yield. The increased crop production is brought mainly from other factors such as cultivation techniques, plant varieties,.etc…

As NCEP and CRU were shown to be less related to crop yield in Vietnam, multiple regression is limited to station data as climate prediction.

5.6. Summary and discussion:

Based on the results of simulation of 17 GCM simulation and combined comparing with NCEP, CRU and station data in Vietnam, this study has demonstrated the ability to simulate a future climate change over Southeast Asia and Vietnam toward 21st century. The temperature and precipitation over each region compared with observation have shown a system bias, with lower temperature and stronger precipitation simulated than observations across the considered region, stronger in summer than winter. These multiple model simulation obvious have significant problems over high altitude, due to the difficulty in simulating the effects of the dramatic topographic relief, reflecting enhanced model uncertainty in term of orographic effects and land-surface interactions, as well as the distorted albedo feedbacks due to extensive snow cover. However, with only limited observations available, large errors in temperature and significant underestimates of precipitation are likely. Over South Asia, the summer is dominated by the southwest monsoon, which plays an important role to control the seasonal cycles of the climatic parameters. However, the simulations of the annual cycles in South Asian mean precipitation and surface air temperature are acceptable. The study indicates that the climate of Southeast Asia will mostly be warmer and wetter in all seasons towards the end of the 21st century.

The results show that, over the territory of Vietnam, temperature plays an important role for the growth of crop yield. In warmer climate, the crop yield shout be increased. It is significant in Vietnam, that global warming in the future maybe impact to develop agriculture in country. However, climate change can also increase the frequency and intensity of extreme weather hazards such as storms, floods, elements, cyclones, droughts (IPCC 2007).

With Southeast Asia in general and Vietnam in individual, it is necessary to improve GCM simulations to avoid model uncertainty. Correlation between GCM simulation and observed is often not high which shows that the relationship between them is not linear.

CHAPTER 6 : CONCLUSION AND OUTLOOK

Climate has a significant impact on life on Earth as well as on human activities. Temperature and precipitation strongly constrain the type of vegetation that could grow in a particular region. Because of the complexity of the climate system, many analyses devoted to a quantitative estimate of climate change or climate variability rely on the use of comprehensive three-dimensional numerical models (Goosse H). The objective of this study was to assess how climate models could be used to make quantitative estimates of climate change in Southeast Asia as well as to analyse the how relationship between climatic parameters and crop yield in Vietnam.

GCMs simulations provide a general view of the relationship between increasing greenhouse gas concentrations and the resulting climate changes. By simulating plausible climate scenarios, GCMs help identify climate outcomes consistent with physical laws and understood changes taking place in the atmospheric composition.

The resulting analysis in this study has two important purposes. First, GCM simulations play an important role to determine a climate change scenario in Southeast Asia and Vietnam, with detailed spatial and future climate information that can be used for impact research. The multi-model ensemble statistic approach allows us to identify what part is significant and what part is noise. Second, the study identifies a relationship between climatic parameters and crop yield and calculates the correlation between agricultural yield and station data in Vietnam. For these purposes, I collected 17 GCMs simulation, NCEP, CRU and station data during the period 1948 – 2002. Those data was interpolated and validated.

The study demonstrated that the simulated climate from 17 GCMs has a bias with respect to observed values. The difference is not large and is not statistically significant for temperature. However, the simulated precipitation shows large statistically significant systematic deviations from observations

GCMs can be considered to simulate reasonably well the global and continental-scale climate, but confidence is lacking in the regional detail. The analysis also shows that the seasonal cycle over the land regions of Southeast Asia also change, with warming in winter being higher than warming summer. These different magnitudes of seasonal warming are also expected to occur in Vietnam but with relatively lower magnitudes.

Climate predictions resulting from the GCM multiple-model ensemble show that the climate of Southeast Asia will mostly be warmer and wetter in all seasons relative to current conditions. However, the change in Southeast Asia will happen at a lower rate than in other regions of the World (IPCC report 2007).

Southeast Asia and Vietnam climate change and variability are embedded in global climate change. The climate change in this region will definitely affect agriculture. In Vietnam, the change and variability of climate elements in every agro – ecological regions is different.

- *Climate change scenarios over Vietnam:*

The air temperature in Vietnam will increase rather slowly in the future compared to the global average, with a rate in a range between about 0.1^0C/decade for B1 and 0.3^0C/decade for the A2 scenario. The Global average is in a range between 0.1^0C/decade for B1 and 0.4^0C/decade for A2 scenario. (IPCC report 2007). This rate of warming is quite uniform during the 21st century for entire Vietnam and comparable to the rate of observed temperature trends from 107 selected climate stations in Vietnam.

Future annual precipitation over Southeast Asia is expected to increase in most of Vietnam, except for the southern part, where negative changes prevail.

Currently, the Earth is warming trends and extreme phenomena frequently occur, GCM's simulation ability needs to be improved. So the problem prediction climate change for Asia in general and Southeast Asia still need more investment in future research. In particular, monsoon research for Southeast Asia is still a new field, much untapped. Studies on Southeast Asia are very few areas, such as the Philippines, Indonesia, Vietnam... and most involved only a small part of the research project about the Asian monsoon. Especially in Vietnam, with the most complex tropical monsoon in Asia, but is only accessible methods in climate modeling since ten years and there are no studies specific application.

As any other statistical study, this study still has limitation, which can be regarding as a starting point for future research. The available of data set and GCM simulation allowed me to carry out this research for the Southeast Asia and Vietnam. Unfortunately, I did not have the opportunity to obtain the agriculture data for Vietnam in order to define the correlation between crop yield and climatic parameters. The model can also be extended to test the relationship between precipitation and crop yield.

In practice, researchers should be aware that the GCM simulation does not reflect the current development of the climate system and requires strengthening the GCM models include resolution and uncertainty. In this context, the multi-model ensemble can be used in global and region climate change forecasting research. In fact, the results of the study can be used for Southeast Asia and Vietnam. I believe that local climate change is still a very young field of theoretical study and invite theoreticians and practitioners to continue the examination of this challenging and promising area of Southeast Asia and Vietnam. This research project was inspired by the statistical approach contributes new insights to this exciting and complex field of GCM simulation applied. I avoid the limitations of GCM simulation and deliver a comprehensive theoretical framework of the multi-model ensemble. Therefore, my research contributes to a better understanding of GCM simulation applied in region scale.

My research brings the scientific community a bit further in the understanding of climate change during 21st century over Southeast Asia and Vietnam., contributing to our knowledge of temperature and precipitation trends over the century on a regional scale, not only in Southeast Asia but also in Vietnam; the study focuses to develop a dynamical – statistical model describing the relationship between the major climate variation and agricultural production in Vietnam. This study will be an important contribution to the present-day assessment of climate change impacts in the low latitudes. Regional scenarios of climate change, including both rainfall and mean temperature were then used to assess the impact of climate change on crop production in the region in order to evaluate the vulnerability of the system to global warming. Using multi-model GCM ensemble is good regime for climate change research in Vietnam and Southeast Asia.

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APPENDIX

Tabe 15: Data for correlation between temperature, precipitation and some crops.

Year	Annual Temperature	Annual Precipitation	Yield ton/ha								
			Paddy	Maize	Sweet potato	Cassava	Soybean	Peanut	Suga cane	Annual industry crops	Permanent industry crops
1995	23.96	1848.38	3.69	2.11	5.5	8.0	1.3	1.0	47.6	10.95	12.72
1996	23.80	2269.33	3.77	2.50	5.6	7.5	1.4	1.0	48.2	9.65	13.6
1997	24.36	1824.51	3.88	2.49	6.3	9.4	1.4	1.1	46.4	11.16	14.17
1998	25.03	1752.75	3.96	2.48	6.0	7.5	1.4	1.1	48.9	11.26	13.24
1999	24.23	2101.42	4.10	2.53	6.5	8.0	1.3	1.1	51.6	11.09	14.23
2000	24.18	1307.85	4.24	2.75	6.3	8.4	1.5	1.2	49.8	10.77	12.96
2001	24.36	1326.70	4.29	2.96	6.8	12	1.5	1.2	50.4	11.04	13.02
2002	24.63	1125.98	4.59	3.08	7.2	13.2	1.6	1.3	53.5	11.66	13.94