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Original Article

Assessments of CMIP3 Climate Models and Projected Climate Changes of Precipitation and Temperature for Vietnam and the Southeast Asia

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Abstract: The main objective of this study is to assess the information of climate simulation and projection of temperature and precipitation based on the results of 23 models from the World Climate Research Programme's (WCRP) Coupled Model Inter-comparison Project phase three (CMIP3) for Southeast Asian Countries with a more focus on Vietnam. The research is divided into two parts: i) Validation of the simulation of the 1948-2002 period with observations (gridded NCEP and CRU data and Vietnam's surface station data) and ii) Assessments of projected climate changes for both precipitation and temperature variables. For the first part, depending on areas, main results showed a very systematic bias for the simulations of temperature and precipitation. CMIP3's simulations have significant issues regarding high altitude regions, which can be explained by coarse of model resolutions to represent the effects of the complex topography, land-surface interactions, and the distorted albedo feedbacks due to extensive snow cover. In the second part, regarding the climate projection for temperature, It is projected to get warmer from 3.5 to 6 degrees in 21st Century in all scenarios. For the details in 2030 and 2050, the average annual temperature will clearly increase in the whole Vietnam. The trend of annual precipitation conditions at multi-scenarios in Southeast Asia compared to the current climate condition is not as clear as that of the temperature. The remarkable issue for Vietnam is in the A2 scenario, which provides the most change for the whole country.

Keywords: Climate change, Vietnam, statistical model, regional scenario.

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1. Introduction

Since the 80's, many research groups have generated extensive databases from which the analysis of temperature, precipitation, and other climatic parameters has been performed on a global scale [1-3]. One of the most important results of these research projects is the evidence of global warming during the last two decades.

It is necessary to carry out studies on local and regional scales 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 variables from the General Circulation Models (GCM), NCEP, CRU re-analysis 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 scenarios simulated by the GCM was used to analyze and predict the local climate change [4].

Temperature, precipitation and other climatological elements may vary through a complex set of interactions, as a consequence of modifications in the Earth's radiative budget. The air temperature measurements, which have been performed for the last fifty years and in some areas for over hundred of years, show an increase in global average temperature from 0.3ºC – 0.6ºC over the past 80 – 100 years. Some years in the last decade were the century's hottest years [1]. Today, the most important method for obtaining information on possible future climates is based on the use of atmospheric General Circulation Models (GCMs) [4,5]. The large-scale GCM results can be accepted, with moderate confidence, as prediction of future climates. For the predicting future changes in climatic variables at a smaller regional scale, there are some considerable deficiencies in GCMs models due to their coarse resolution and highly smooth orthography.

The regional scenarios of future climate response to radiative forcing are a key component of any climate change impact assessment; their construction is one of the greatest challenges for national researchers [6]. The most credible tools currently available for developing the scenarios are resulted from General Circulation Models (GCM). The course spatial resolution of GCMs presents a serious limitation in their application, especially for a small country such as Vietnam. The Southeast Asia region including Vietnam, as well as any other countries, has a different position in the regular grids of different GCMs, occupying very unequal parts of several boxes [7].

Studies for the Southeast Asian region show that climate change could lower agricultural productivity by 15% — 26% in Thailand, 2%–15% in Vietnam, 12% – 23% in the Philippines and 6% – 18% in Indonesia. It is found that the Mekong River Delta and the coastal areas in the north of the central region are most vulnerable to the impact of global warming in Vietnam due to rising sea levels. The changing climate could be especially damaging for rice cultivation due to substantial modifications in land and water resources. Hydro-climatic disasters such as typhoons, floods, and droughts, which could become more severe and more frequent as the climate changes, would also affect rice production substantially in the country.

In this study, we aim to analyze the status of the annual and seasonal temperature and precipitation during the 21st century to better understand future trends over the 21 century on a regional scale, not only in Southeast Asia, but also in Vietnam. The study focuses on building a combined dynamical and statistical model that thoroughly explains the relationship between changes in climate condition and its impact on agricultural production in Vietnam. The outcome of this study will contribute to the contemporary assessment of climate change impacts in the low latitudes. Regional scenarios of climate change, including rainfall and mean temperature, were then used to assess the impact of climate change on crop production in the region to evaluate the vulnerability of the system to global warming. Climate change has negative impacts on the socio-economic development of all nations. But the degree of impact will vary across nations. It is expected that changes in the earth's climate will impact developing countries like Vietnam, particularly, 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.

The paper is divided into four sections: i) the introduction, ii) the overview of research areas, observational and model data and evaluation methodologies, iii) the validations of the simulation of the 1948 − 2002 period with observations (gridded NCEP and CRU data and Vietnam's surface station data) and iv) assessments of projected climate changes for both precipitation and temperature variables. Some remarked results are summarized in the final section.

2. Research Areas, Observational, Model data, Evaluation Methodologies

2.1. Research areas

This study focuses on Southeast Asia area including Vietnam. The terrain of Vietnam is characterized by a complicated topography. In general, there are 2 climatic types in the 2 parts of Vietnam being separated by the Hai Van Pass at 16°N. However, depending on the local characteristics, the climate of Vietnam can be divided into 7 sub-regions. From Hai Van Pass towards the North, the climate is tropical and monsoonal with a cold winter. From 16°N towards the South, the climate is tropical and monsoonal with only two seasons, a dry and a rainy. The coastal provinces of the country are hot all year-round and have a similar rainfall condition.

2.2. Observational and model data

2.2.1 Observational data

There are two types of observational data including grid data (NCEP, CRU) and Vietnam's station data using for validations. 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 on 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 precipitation datasets span over the period 1948 to 2002. 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. These datasets have been developed from data acquired from weather stations 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.

The available climatic data from Vietnam is still sparse and differs in terms of the time length. The present network of weather stations consists of 107 stations on Vietnam territory. The temperature and precipitation data from 107 weather stations were interpolated to the common grid mentioned above and covered the Vietnam region.

2.2.2 Model Data

Since the Third Assessment Report (TAR), the scientific community has undertaken the largest coordinated global coupled climate model experiment ever attempted in order to provide the most comprehensive multi-model perspective on climate change of any IPCC assessment, the World Climate Research Programme (WCRP) Coupled Model Inter-comparison Project phase three (CMIP3), also referred to generically throughout this report as the 'multi-model data set' (MMD) archived at the Program for Climate Model Diagnosis and Inter-comparison (PCMDI). Regional scenarios of mean climate change in the South- East Asia and Vietnam have been developed from the equilibrium response of 17 GCMs which were based on TAR by IPCC. The three commonly used climate scenarios worldwide provide the future projections including: The A2 scenario (low emissions); The A1B scenario emphasis on the balanced on all energy sources; The B1 scenario: an emphasis on global solutions to economic, social, and environmental stability.

It is necessary to interpolate the data into a same resolution (grid point). In this study we interpolate data into 3^o x 3^o latitude/longitude grid of the region established both annually and seasonal for multi-models and observation station data (NCEP and CRU data). Therefore, a second set of sub-grid scale scenarios (for temperature and precipitation) were deduced, based on the statistical relationship between large-scale climate data and small-scale climate observations from surface meteorological stations. For this construction study, the results from multi-model mean are synthesized to produce a single scenario for each climate variable (temperature and precipitation) [8]. The future conditions of the 21st century (2011-2099) are selected for the study.

2.3. Evaluation Methodologies

The large-scale GCMs results can be accepted, with some confidence, as predictions of future climates [7]. For predicting future changes in climatic variables at a smaller regional scale there are some considerable deficiencies in GCMs models due to their course resolution and highly method orthography. The resolution problem of GCMs is particularly important not only in South-East Asia but also in Vietnam territory where many of the characteristics features of climate are controlled by meteorological and geographical factors which are of a scale considerably smaller than the grid used in GCMs. Scenarios of the change in temperature and precipitation are produced directly from GCMs grid point output. The GCMs used have a different spatial resolution. Therefore, it is necessary to interpolate the GCMs data into the same spatial resolution. In this study, a set of sub-grid scale scenarios were produced, based on the statistical relationship between large-scale climate data and the small-scale climate observations from surface meteorological stations in Vietnam and the data from CRU and NCEP.

The Figure 1 illustrates the process of building a combined statistical and dynamical model used in this study. Firstly, the future projections for temperature and precipitation given at original resolution by GCMs were biases corrected with high resolution CRU and NCEP reanalysis. Secondly, the bias-corrected GCMs at coarse resolution were downscaled to finer resolution by interpolation.

In order to determine how well GCM simulations capture the behavior 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. Some main statistical scores are mean, variance and Standard deviation, the differences in mean-values, the signal/noise ratio and the confidence interval [8-10].

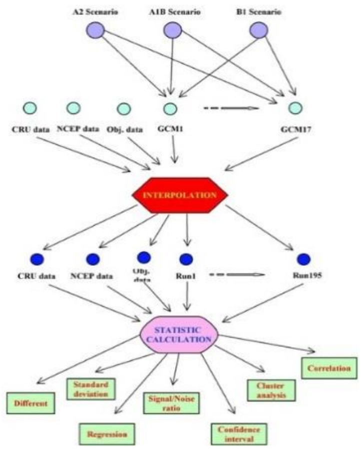
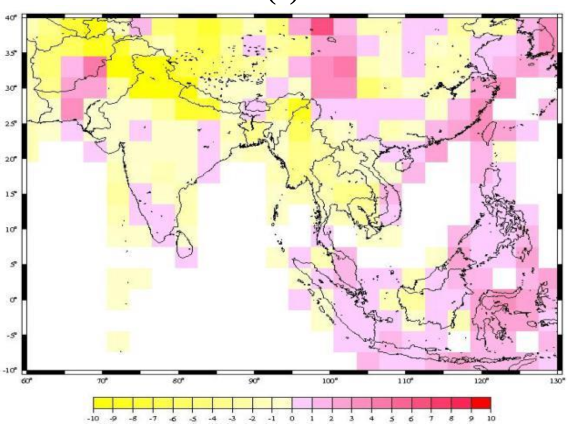


Fig.1. Mothod diagram and step taken in the study.

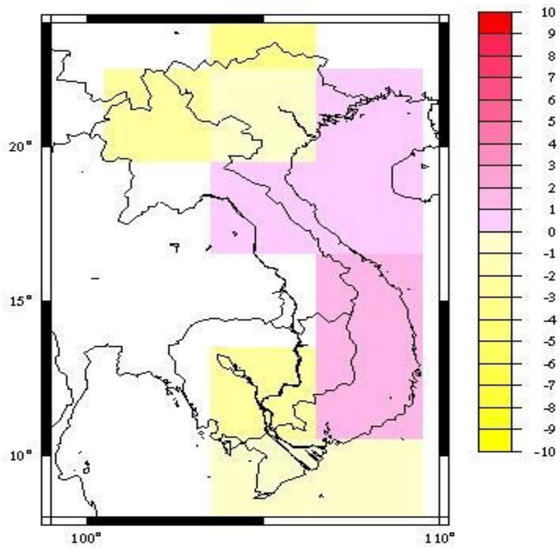
3. Validation of Model Simulations for the Period 1949 – 2002

The temperature differences between multi-model mean and CRU data is illustrated in the figure 2 (left, a). 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 (figure 3, left, b) and CRU look fairly different, reflecting the high level of uncertainty in temperature observations.

(a)



(b)



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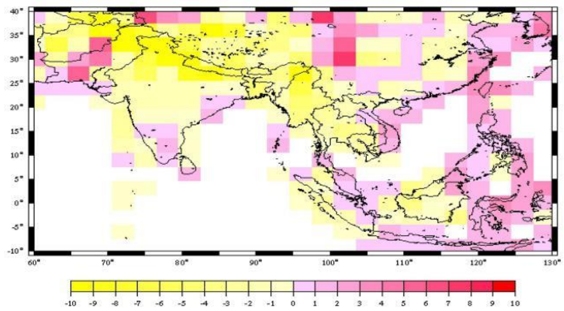

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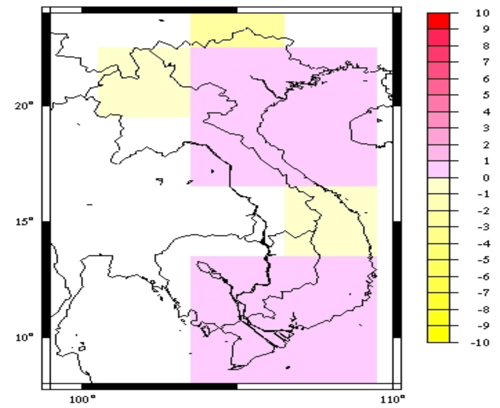
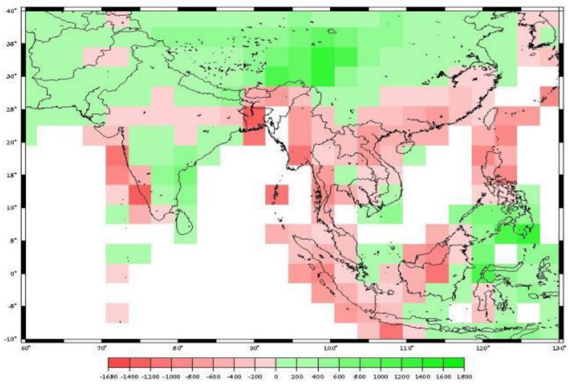


Fig. 2. The temperature difference between multi-model mean and CRU (a,b) and NCEP (c,d) data in Southeast Asia over 1949 – 2002 (left) and zooming for Vietnam. Unit is °C.

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

The precipitation differences between multi-model and CRU data are illustrated in the figure 3 (left, a) for 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 3, left, b) and model and CRU differences (in figure 3, a), it becomes clear 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.

(a)



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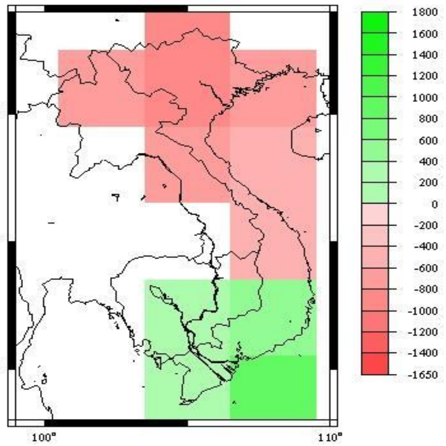

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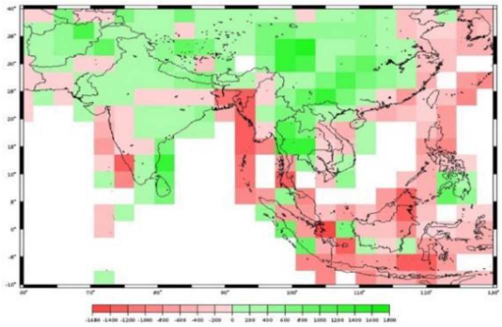

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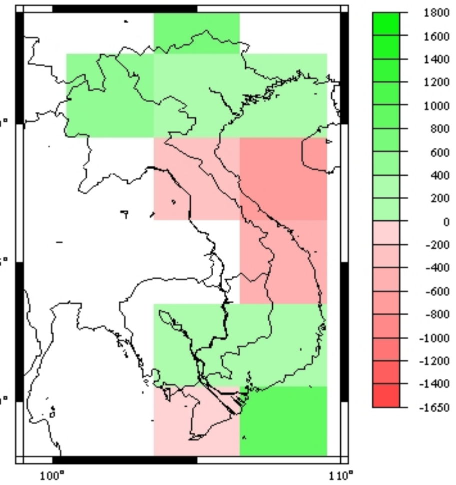

Fig 3. The precipitation difference between multi-model mean and CRU (a,b) and NCEP (c,d) data in Southeast Asia over 1949 – 2002 (left) and zooming for Vietnam (right). Unit is (in mm).

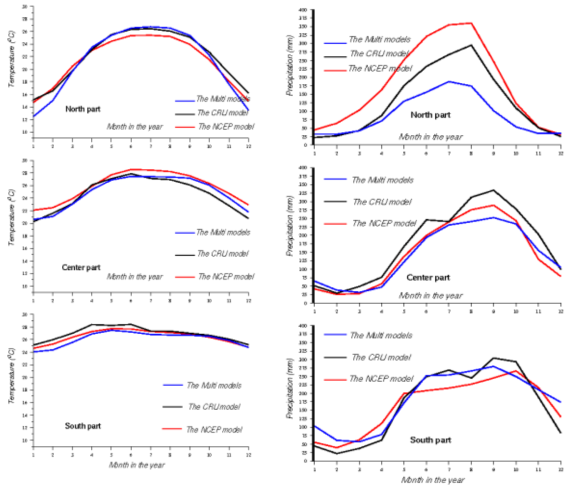

Fig 4. Monthly temperature (left, in °C) and precipitation (right, in mm) for Vietnam.

Precipitation differences between multi-model mean and station data in Vietnam are illustrated in the figure 3 (right). 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 the northern part of Vietnam, the multi-model precipitation bias is lower than NCEP, CRU and station data and in the southern part of Vietnam multi-model 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 precipitation vice versa the southern parts of Vietnam are lower region which have less forcing in the model causing higher precipitation.

Regarding to the 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 the 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 4. 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.

4. Projected Precipitation and Temperature Changes

Regarding to the spatial distribution of projected temperature, Figure 4 illustrates the Annual temperature difference in multi scenarios in Southeast Asia by subtracting the current climatology from the GCM projections. For the three climate change scenarios in 2030 and 2050, average annual temperature increases in all Vietnam regions. In general, temperature increases in 2050 are greater than those in 2030. And the future temperature tends to get warmer to the end of the 21st century when in all scenarios, the whole Southeast Asia region is projected 3.5 to 6 degree. In Vietnam, the hottest condition is found in the A2 scenario with the average increase of 2.5 to 3 degrees compared to the current climate condition. In the northern part of Southeast Asia, the temperature is projected much hotter than the southern region.

For the spatial distribution of projected precipitation, the annual precipitation in multi scenarios in Southeast Asia compared to the current climate condition is shown in Figure 5. Unlike the clear increasing trend in temperature, the tendency of precipitation is not clear and rainfall distribution is not equally distributed throughout the domain. For the southeastern corner of Southeast Asia, generally precipitation is projected to decrease, and for the rest of the domain, temperature seems to increase for about 50-100mm/year. The future trend in precipitation over the Vietnam domain is not clear. It seems to increase at the first half of the 21st century and tends to decrease at the latter half. In all three scenarios, the A2 scenario showed the most intense change in all regions when the variation intensity of both increase and decrease trend are significant.

Regarding to seasonal cycle information of temperature and precipitation, the regional models mean annual, seasonal temperature and precipitation during the 2011 – 2030; 2046 – 2065 and 2080 – 2099 periods are given an increase in temperature between 0.5ºC to 3ºC all over region by the end of next century (the different temperature and precipitation are the annual, seasonal temperature and precipitation mean between three periods above and the last two decades mean in the 20 century). In the North and in the mountain area the change is highest, and the change is low in the low part and in the ocean area. The temperature difference in the summer is the seemingly equal to winter and the annual. In the beginning of the 21st century (2011 – 2030 period) the temperature different is lowest different, about 0.5ºC to 1ºC, same in the B1, A1B and A2 scenarios; 1.5ºC to 2.5ºC higher in the middle of 21st century (2046 – 2065 period); 2.5ºC to 3ºC highest in the end of next century (2080 – 2099 period) (Figure 5).

It is the same for precipitation, the mean A1B scenario show that, during the beginning of 21st century (2011 – 2030), the precipitation mean decrease 50 mm in the most part of the ocean area and in the mountain area in the Northwest. During the next century the precipitation mean increase about 50 – 100mm. In the B1 scenario, the dry area, which correlate to the precipitation mean decreased area, is in the low latitude region and the volume is about -100 mm, the biggest volume is in the A2 scenario, which reach to -450mm in the beginning of 21st century and reduce gradually till the end of the 21st century. (Figure 6). The major tendency over the region is that temperature increases in both the Summer and Winter time, contrary to this tendency, the precipitation increases during the Summertime and decreases during the wintertime [8-10].

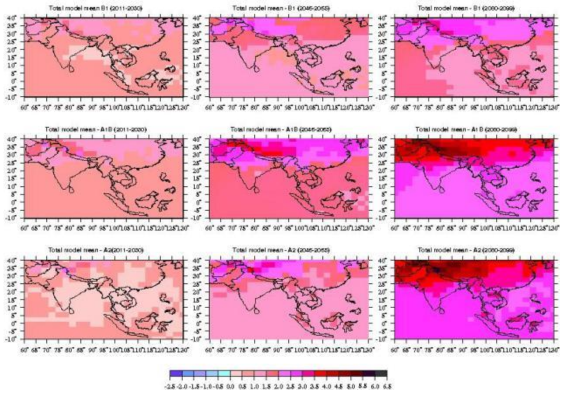

Fig 5. Annual temperature difference in multi scenarios (ºC in Southeast Asia).

5. Conclusion

A number experiments with this study of temperature and precipitation scenarios from the GCMs models scenario for the South-East Asia and Vietnam, indicate that the advantage of assessment of uncertainty by repeating the projection with different model setting (e.g., different data sets, predictor domain, record length and linear optimization method). The study gives an indication of how well the GCMs model data produces the observed climatic features and relies on the assumption that these features only change in strength of occurrence in the future [8,10].

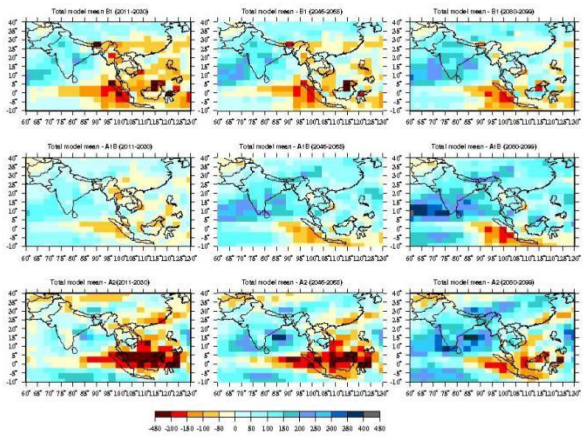

Fig 6. Annual precipitation in multi scenarios (mm in Southeast Asia).

The results from the study so far give roughly similar results to those from observed station data, but there are some differences and the major is in precipitation parameter. These differences may be interpreted as due to model uncertainties or deficiencies [8,10].

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