

FUTURE SURFACE TEMPERATURE AND
PRECIPITATION PROJECTION IN A2 AND B2
EMISSION SCENARIO OVER MALAYSIA

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DECLARATION

I affirm that this dissertation is of my own effort, except for the material referred to as cited in reference section and acknowledged.

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UNJURAN SUHU PERMUKAAN DAN HUJAN BERPANDUKAN SCENARIO PERLEPASAN A2 DAN B2 DI MALAYSIA

ABSTRAK

Perubahan iklim adalah krisis alam sekitar yang berterusan seperti perubahan suhu, hujan dan pembolehubah iklim yang lain. Sejak tahun 1990, suhu iklim global didapati meningkat sebanyak 0.74 °C dan variasi hujan pula tidak consistent sepanjang rantau. Kajian ini adalah untuk mengetahui suhu permukaan dan hujan pada tahun masa depan di Malaysia. Pegesahan telah dibuat untuk periksa prestasi PRECIS. Kedua-dua pembolehubah iklim dalam tahun 2070-2100 dalam scenario A2 dan B2 telah diramalkan dengan PRECIS. Data iklim yang diramalkan dan mentah akan kemudian diproses dengan menggunakan CDAT. Pengesahan statistic telah dilakukan dengan perbandingan antara Baseline dengan ERA40 dan CRUdat. Dalam kajian ini, corak perubahan yang sama didapati dalam kedua-dua pembolehubah iklim. Suhu telah meningkat sebanyak 2.56 °C - 2.80 °C dalam scenario A2 dan 1.61 °C - 2.12 °C dalam scenario B2. Hujan didapati menurun sebanyak -0.68 mm/day - -1.45 mm/day dalam scenario A2 dan -1.01 mm/day ke -1.67 mm/day dalam scenario B2. Penemuan dalam kajian boleh diterima secara keseluruhan kerana perbezaan dalaman model tidak ketara. Selain itu, pengesahan model menunjukkan korelasi yang baik dalam ramalan suhu iklim dan hujan di Malaysia. PRECIS adalah lebih baik dan sesuai untuk meramal suhu iklim masa depan berbanding dengan hujan.

ABSTRACT

Climate change is a continuous environmental crisis which leads to changes in temperature, precipitation and other climate variables. Global climate temperature is increased 0.74 °C since 1900 and observed rainfall variation variability exist over the regions. This research was to project future surface temperature and precipitation for Malaysia. The PRECIS regional climate model was also examined to validate its simulating performance. Both of the climate variables in the year of 2070 to 2010 were projected under A2 and B2 emission scenarios by using PRECIS. Raw projected climate data was then post-processed using CDAT. Statistical validations were done by comparison of Baseline scenario to ERA40 and CRUdat. Generally, the findings showed similar patterns of projected changes for temperature and precipitation. The temperature was increased as much as 2.56 °C to 2.80 °C and B2 scenarios have recorded 1.61 °C to 2.12 °C. Reduction of precipitation flux was found. Precipitation decreased -0.68 mm/day to -1.45 mm/day in A2 scenario and -1.01 mm/day to -1.67 mm/day in B2 scenario. The projected future climate is acceptable as the internal model bias is not significant in overall. Strong statistical correlations further validated the model as correlation value of temperature (0.966) and precipitation (0.830). With comparison to CRUDAT, PRECIS performs better in simulation temperature of climate than precipitation.

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LIST OF SYMBOLS AND ABBREVIATIONS

°C	Celsius
mm/day	Millimetre per day
hPa	Hectopascal
GHG	Greenhouse gases
IPCC	Intergovernmental Panel on Climate Change
GCM	Global climate model
RCM	Regional climate model
PRECIS	Providing Regional Climate for Impacts Studies
ERA40	ECMWF re-analysis 40 years
CRUDAT	Climate Research Unit Data
JJA	June-July-August
DJF	December-January-February
MAM	March-April-May
SON	September-October-November
WCRP	World Climate Research Programme
ENSO	<i>El Nino</i> Southern Oscillation
SST	Sea Surface Temperature
MJO	Madden-Julian Oscillation
MMD	Malaysia Meteorology Department
AOGM	Atmosphere-Ocean General Model
SRES	Special Report on Emission Scenario
CDAT	Climate Data Analysis Tool

CHAPTER 1

INTRODUCTION

1.1 Overview

Climate change is an environmental crisis which begins to transform the life on earth. It refers shift in long-term average weather which leads to changes in temperature, precipitation or wind patterns on earth (Kaufmann & Cleveland, 2008). It is concerned as a major challenge of environmental issues. Consequences of climate change are such as global warming, melting of glaciers, and rising of sea levels, wildlife at risk, and increase risk of natural disaster, economic loss, health and safety, security and any other dimension. Temperature on earth's surface is dependent on four factors which are amount of solar radiation reflected and received, amount of heat trapped in atmosphere, and evaporation and transpiration of water vapour (Botkin & Keller, 2003). According to Environmental Protection Agency of United States, earth's temperature has increased by 0.7 °C over the past century. The small increase of earth's average temperature could make huge impacts and shifts climate and weather patterns. Climate change is result of both natural and anthropogenic causes. Natural processes do not make significant contribution on climate change but anthropogenic activities do. Rate of global warming is



changing every year as it depends on level GHG emission from human activities and natural variability such as solar intensity, volcanic activities, and *El Nino* cycle (Mayer, 2001).

The greenhouse gases (GHGs) are gases that trap heat and warm our atmosphere. It is a natural balancing act of temperature on earth (Botkin & Keller, 2003). It warms earth's nighttime and avoids dramatic temperature change in the course of a day. However, man-kind activities emitted abundance of GHG which contribute to greater and stronger greenhouse effect. As a result, the Earth is becoming warmer and warmer. There are several greenhouse gases such as carbon dioxide, methane, nitrous oxide, and fluorinated gases (Mayer, 2001). Contribution of the gases to climate change is determined by concentration, duration and effectiveness. Measure of warming effect on the climate is known as radiative forcing. Radiative forcing has risen as much as 30% from year 1990 to 2011 due to increase of greenhouse gases. Gases that able to stay in atmosphere for long period and absorb more energy will greatly impact the global temperature (Mayer, 2001).

Impacts of climate change should be recognized in order to facilitate adaptation. Dramatic change is observed in the Arctic as the sea ice extent is reduced 13.7 percent per decade. Melting glaciers and ice caps return the water back into the sea and alter the albedo feedback loop. As such a change of earth landscape, positive feedback to earth warming is observed. Albedo is the reflectivity of earth surface (Ahrens, 2008). In comparison to open water's albedo of 0.1, the albedo of sea ice is higher which ranged 0.9 in winter to 0.4-0.55 in summer (Wadhams, 1995). Greater amount of incoming shortwave radiation will be absorbed by ocean as area of reflective earth surface is decreased. As a result, the earth surface getting warmer along with such continuous positive feedback.



Particulate matter and aerosol in air could affect the intensity of sun radiation reaching or leaving the atmosphere by affecting the reflectivity of solar radiation. Emergence of black carbon is studied and it contributes to global warming greatly. Black carbon is estimated to cause more than 30% of recent warming in the Arctic (Shindell & Faluvegi, 2009). Black carbon or soot is primarily emitted from incomplete combustion of fossil fuels and biomass. Suspended black carbon will absorb solar energy and heat up to warms the air. Other than this, black carbon that deposited on snow or ice glacier will accelerate the melting process as it absorb sunlight and release the heat energy to surrounding (Zimmer, 2013).

Melting of ice and glacier have increase sea level globally. Its increasing rate over the past decade was 3.2mm annually. The sea levels will still rise if the global temperature does not reduce. Lately sea levels rise is projected to be 18 to 58 cm by 2100 (IPCC, 2013). Climate change influence the occurring possibilities of extreme events and studies are on-going to determine impacts of climate change on such events. Climate change could alter the habitat and lifestyle of species in ecosystems. It contributes to species extinction and 20-30% of flora and fauna species are evaluated to be under the risk of extinction (Fischlin *et al.*, 2007) Climate change has not only degraded air and water quality which essential to sustain our life; it is also challenged public health with increased flooding and extreme events. In another words, climate change alters the atmospheric circulation which drives our weather.

The general circulation creates an energy conversion and transportation system in Earth's climate (Reichler, 2009) and hence reduces the temperature gradient between low and high latitude. Atmospheric circulation promotes the water cycle which water is bringing from ocean to land surface via precipitation. It reduces the occurrence of extreme events such as droughts. As the ocean is driven by the atmospheric circulation, it facilitates the carbon to diffuse into ocean, nutrients deep under than ocean turn to the surface and redistribution of heat against spatial gradients. It is an essential



indicator as trends of climate change (Reichler, 2009). It is driven by earth rotation and solar radiation. Earth rotation is a natural and unchanging process. Therefore, incoming energy from sun contributes to greenhouse effect which induced climate change as mentioned earlier. The wind obtains energy from the sun and circulates above earth surface as warm air rises and colder air sinks. Variation of solar radiation causes differential of temperature and consequently air masses and pressure. Planetary-scale circulation is complex and it is featured by trade winds, subtropic highs, the westerlies, polar front, subpolar lows and polar easterlies (Moran & Morgan, 1995). It is essential as facilitator of development and displacement of most local or regional weather systems.

Monsoon circulation is one of local and regional circulation systems. It is related to seasonal shift in planetary scale circulation as it characterizes the north-south wind shifting at inter-tropical convergence zone (Moran & Morgan, 1995). Similar with other circulation system, it is influenced by land-sea temperature, topography and contrasts. A monsoon circulation provides region seasonal reversals in prevailing winds. It leads to occurrence of wet summers and relatively dry winters. In summer, horizontal air pressure gradient from sea to land is formed. The humid air flow onto the land and heated by intense solar radiation and followed by convection (Moran & Morgan, 1995). During dry winter monsoon, the continental cools rapidly due to radiation chilling effect. Air aloft over the warm sea surface and drifted landward. Monsoon winds prone to Coriolis effect as it occurs for a relatively long period and trajectories. During January, monsoon circulations are deflected to the right in Northern Hemisphere. Meanwhile, the monsoon is drifted to the right in Southern Hemisphere on month of July. Monsoon rainfall is categorized into two phases which are monsoon active phase and dormant phase (Moran & Morgan, 1995).

Malaysia sits in the center of Southeast Asia. According to Malaysian Meteorological Department, weather in Malaysia is dominated by monsoon and result in a humid tropical climate with temperature ranging from 21°C to 32°C. The climate is hot and humid with 80 to 90% of relative humidity. The weather is featured by two monsoon regimes which are Southwest Monsoon and Northeast Monsoon. The



Southwest monsoon is also known as summer monsoon which circulates during the period of late May to September. It leads to drier weather as most states experience least monthly rainfall; high temperature and high Mean Sea Level (MSL) pressure (Yahya *et al.*, 2009) except the Sabah in East Malaysia. The monthly rainfall is typically as low as 100 to 150mm for Sabah is experienced wetter weather than other states with more than 200mm monthly precipitation. The Northeast monsoon or winter monsoon is happening from November to March. Due to the winter monsoon, east coast states of West Malaysia and western Sarawak is facing intense precipitation and high amount of relative humidity.

1.2 Research question

Climate change is an inevitable global environmental issue. In Africa and Asia, climate is mainly driven by monsoon (Moran & Morgan, 1995). As mentioned earlier, weather in Malaysia is dominated by two monsoon systems which are Southwest Monsoon and Northeast Monsoon. Climate change will shift the monsoon circulation and leads to changing of other climate variables. Projection of atmospheric circulation can be done with various types of climate models. Two of the major indicators of climate change are surface temperature and precipitation. Climate models utilize past and present climate data to address future climate scenarios (Hudson & Jones, 2002). By using climate models, we can predict the future surface temperature and rainfall rate variation globally. There are several questions addressed in this thesis. Firstly, what is the future temperature and precipitation for Malaysia based on A2 and B2 scenarios? Are there significant differences in future climate condition? Projected climate is just a prediction with mathematical expressions. Hence, is the climate model and future climate scenarios validated for prediction purpose? In other words, how is the simulation performance of regional climate model?

1.3 Objective of Study

In accordance to the uncertainties that addressed in the research question, this study is designed to achieve the purposes as following: 1) To develop future climate scenarios for Malaysia based on A2 and B2 emission scenario of the IPCC. 2) To project the land-sea surface temperature and precipitation in Malaysia. 3) To identify future changes of temperature and precipitation and its significance. 4) To validate the findings of PRECIS-regional climate model in Malaysia.

1.3 Scope of Study

This study is focused in Malaysia with latitude 4.000° N and longitude 102.5000° E. Regional climate model to be used is Providing Regional Climates for Impact Studies (PRECIS) is applied in this study. Baseline scenario of year 1960 to 1990 is input to stimulate future scenarios and 2070 to 2100 boundary conditions under the A2 and B2 emission scenarios. Parameters to be analysed are temperature and precipitation. Performance of PRECIS regional climate model will be evaluated.

CHAPTER 2

LITERATURE REVIEW

2.1 Climate Change

Climate observation showed the global temperature as risen as much as 0.74 °C since beginning of 20th century (Hansen *et al.*, 2006) as an overriding crisis. Figure 2.1 denotes the annual average temperature with combination of surface air temperature and sea surface temperature. Since 1895, no single year with temperature below the average mean is observed. The previous decade, 2001 to 2010 was the warmest decade with estimated 0.47°C above 1961 to 1990 average mean of 14°C. The warmest year recorded is year 2010 with temperature of +0.56°C ±0.09°C while the second and third warmest year is 2005 and 1998 respectively.

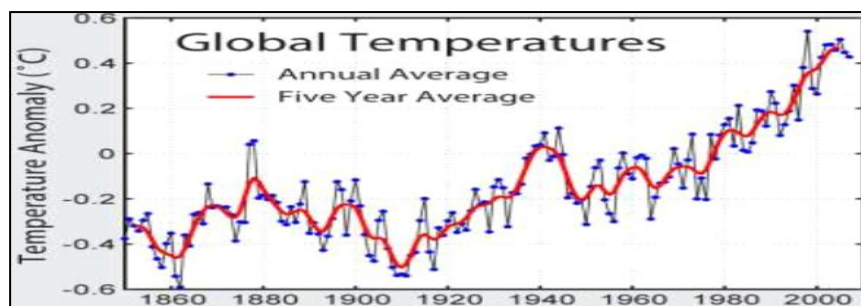


Figure 2.1 Global average surface temperature (Source: IPCC, 2007).

Acceleration of climate change due to man-made GHGs is still questioned (Baum *et al.*, 2012). There are various uncertainties in the complex climate system. Climate model should be able to distinguish among natural fluctuations and human-induced climate change, and incorporates both in modelling (Frolov *et al.*, 2009). Anthropogenic causes are claimed to be responsible for the risen global mean surface temperature from 1951 to 2010 (IPCC, 2013). Figure 2.2 illustrates the fingerprint assessment of global surface temperature change in 1860-2000. Human activities have induced changes in greenhouse gases and aerosols. The thick blue and yellow lines indicate the ensemble average temperature from climate model. Comparison of simulated fingerprint patterns with observed climate change showed the changes of temperature cannot merely explained by the fingerprints of natural forcing or internal variability.

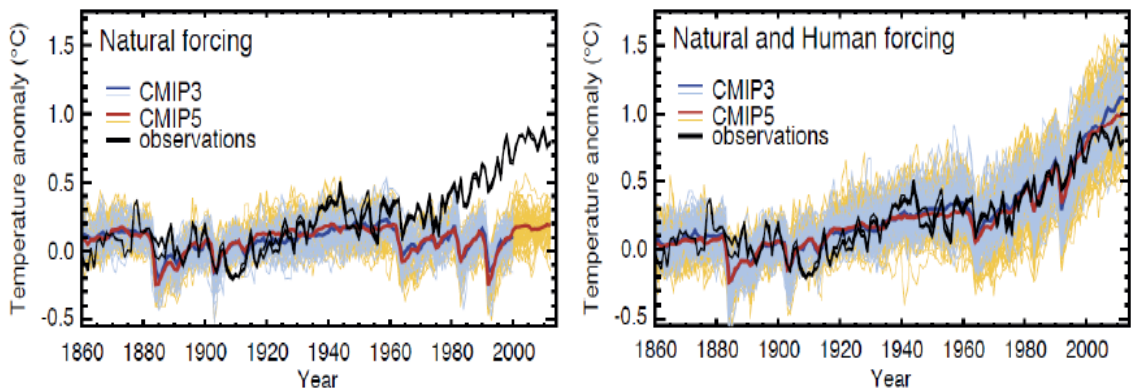


Figure 2.2 Time series of global and annual-averaged surface temperature change from 1860 to 2010. The left panel shows result from two ensemble of climate models driven with just natural forcing, and the right panel is driven by natural and human forcing. (Source: IPCC, 2013)

However, anthropogenic causes to climate change are studied and justified by Solomon *et al.* (2007). Future global average temperature will be risen up to 6.4 °C by year 2100 due to significant increase in GHG emissions (IPCC, 2007). From 1950 to 1999, the trend of global warming is proportional to the concentration of atmospheric GHGs

(IPCC, 2007). Its amount has reached 390.9 parts per million in 2011. Methane is a long-lived GHG. Atmospheric concentration of methane in 2011 is 259% of the pre-industrial level due to increased emission from production and transport of coal, oil and natural gas. Nitrous oxide is emitted from natural processes and man-kind sources such as industrial processes and fertilizer uses. Its concentration in atmosphere in 2011 was about 324.2 ppb. It was 120% above of the pre-industrial level.

Climate change will primarily lead to changes of physical nature such as temperature, precipitation, sea levels and occurrence of extreme weather and as a result it impacts the social, economic and ecological system (Anja & Salik, 2009). As a result of extreme event's analysis for past century, climate system is observed with reduce diurnal temperature range, increase in heat index, more intense rainfall, drought and increased tropical storm intensity (Maracchi & Baldi, 2006). Rising of global average temperature enhance the rate of evaporation and leads to more precipitation. Atmospheric energy potential is elevated to hold more water vapors from evaporation (Wang, 2006). Climate change affects the carbon cycle including the freshwater carbon budgets. Dissolved inorganic carbon in freshwater is noticed to be risen along with increases of temperature. Study indicated the carbon dioxide is emitted in abundance as climate changes (Oni *et al.*, 2012). Increase temperature causes longer and more intense heat waves. Greater the duration of heat waves will implies higher temperature (WHO, 2005). Sea level is rising due to melting of glacier and ice. Consequently, storm events are increased and lead to more intense storm surges (Woth, 2006). Climate change alters our ecosystem especially the loss of species and biodiversity. Variation of precipitation and temperature as well as seasonal variation are altering and degrading the habitat quality (Rannow *et al.*, 2010).

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