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Climate Change and Variability over Malaysia: Gaps in Science and Research Information

(Perubahan dan Keragaman Iklim di Malaysia: Jurang dalam Maklumat Sains dan Penyelidikan)

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ABSTRACT

This paper provides an overview of the current available scientific knowledge pertaining to climate change and climate variability over Malaysia. Malaysia is situated in the western part of the Maritime Continent of the Southeast Asian region. Hence, regional climate change and climate variability over this region are of central importance to the understanding of climate change in Malaysia. The latest regional climate downscaling study indicates that, depending on the emission scenario, the mean surface temperature over Malaysia would increase by 3-5°C by the end of the 21st century. The mean precipitation is projected to decrease (increase) during Northern Hemisphere winter (summer). However, future variabilities associated with regional phenomena such as the monsoon, El Nino-Southern Oscillation (ENSO), Indian Ocean Dipole (IOD) and Madden-Julian Oscillation (MJO) are largely unknown. Current knowledge on the intensity and frequency of future extreme events (drought and flood) is limited. This is also the case for regional sea level rise and long-term changes in regional seas, especially in the southern region of the South China Sea. We conclude that knowledge gap in the science of climate change over Malaysia and the surrounding region remains wide.

Keywords: Climate change; climate variability; Maritime Continent; projection; Southeast Asia

ABSTRAK

Kertas ini merupakan ulasan mengenai status terkini pengetahuan saintifik mengenai perubahan dan keragaman iklim di Malaysia. Malaysia terletak di bahagian barat Benua Maritim, Asia Tenggara. Maka perubahan dan ragam iklim rantauan adalah penting dalam memahami perubahan iklim di Malaysia. Kajian penurunskalaan iklim rantauan bergantung kepada senario pembebasan gas-gas rumah hijau dan purata suhu udara di Malaysia pada penghujung abad ke-21 diunjurkan meningkat 3-5°C. Purata kerpasan dijangka menurun (meningkat) pada musim (panas) sejuk hemisfera utara. Bagaimanapun keragaman berkaitan dengan fenomena rantauan seperti monsun, El Nino-Southern Oscillation (ENSO), Indian Ocean Dipole (IOD) dan juga Madden-Julian Oscilation (MJO) sebahagian besarnya tidak diketahui. Pengetahuan terkini mengenai keamatan dan kekerapan fenomena ekstrim (kemarau dan banjir) adalah terhad. Keadaan juga adalah sama bagi kes peningkatan aras laut dan juga perubahan jangka panjang laut-laut sekitar, terutama di bahagian selatan Laut Cina Selatan. Disimpulkan bahawa jurang pengetahuan dalam sains perubahan iklim di Malaysia dan rantau ini masih besar.

Kata kunci: Asia Tenggara; Benua Maritim; keragaman iklim; perubahan iklim; unjuran

INTRODUCTION

Climate change has been recognized as the most pressing environmental problems that the world will face in the 21st century. In its Fourth Assessment Report (AR4), the Intergovernmental Panel on Climate Change (IPCC) concluded that the warming of the climate system is unequivocal (IPCC 2007a). Observed data showed increase in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level during the 20th century. The 100-year linear increase of surface temperature (1905-2005) is 0.74°C, while the global average sea level has risen since 1961 at a rate of 1.8 mm/yr. The IPCC has also concluded that most of the observed increase in global average temperatures since the mid-20th century is very likely caused by the increase in anthropogenic greenhouse gas (GHG) concentrations. Global atmospheric concentrations of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) have increased markedly due to human activities since 1750 and the current levels of these gases have far-exceeded pre-industrial values determined from ice cores spanning several thousands of years (IPCC 2007a). The warming has been shown to affect many natural systems based on observational evidence from all continents and most oceans. These include notable changes in snow, ice and frozen ground, increased runoff and changes in both terrestrial and marine ecosystems. In terrestrial ecosystems, poleward and upward shifts in plants and animal ranges have been attributed to recent warming. Similarly, notable changes in marine and freshwater ecosystems such as shifts in ranges and an abundance of algae, plankton and fish have been linked to changes in temperature (IPCC 2007b).

While the global average temperature increase experienced thus far (less than 1°C) has already caused significant changes in many natural systems, the impending impacts of much higher projected temperature increases by the end of the 21st century can be very alarming. The IPCC projected global average temperature for the SRES A1FI (the worst-case scenario) by 2100 relative to 1980-1999 is 4.0°C with an upper range of 6.4°C. The corresponding projected sea level rise (SLR) range by 2100, also relative to 1980-1999, is 0.28 – 0.59 m (IPCC 2007a). Such multi-fold increase of temperature and sea level can have disastrous impacts on various sectors. Malaysia will very likely be affected as well.

While the IPCC AR4 provides a comprehensive assessment of the climatic changes at the global scale, knowledge gaps remain at the regional and local levels. For example no specific assessment of climate change over Malaysia can be found in the IPCC AR4 report. In fact, the IPCC Assessment Report is not intended to provide an assessment of climate change of any particular country. The coverage of regional climate change in the report is limited especially for the Southeast Asian region. This could be due to a lack of published materials related to climate change in this region. The IPCC Assessment Report was written based on published materials, particularly from reputable journals. Without scientific publications, the authors of the report are unable to assess the current understanding of climatic changes in the region. Moreover, the lack of coverage for the Southeast Asian region is not only confined to the physical basis of climate change but is also limited in its assessment of impacts. The IPCC AR4 WGII reported that 89% of 29,000 observational data series from 75 studies showed significant changes in many physical and biological systems that are consistent with the influence of global warming. However, none of these 75 studies came from within the Southeast Asian region (IPCC 2007b).

Due to inertia in the system and long residence time of GHG in the atmosphere, the climate will continue to warm in the next few decades even if there is an immediate reduction in global GHG emissions. However, since the prospects of future GHG emission reductions remains unclear (Fox & Chapman 2011; Grassl 2011), the best option to minimize the impacts of climate change is adaptation. However, the planning and implementation of adaptation measures must be based on scientific assessments of climatic changes at the regional and local scales. Hence, it is vital that we assess the level of current understanding of the science of climate change in Malaysia.

This paper provides an assessment of the current understanding of the scientific basis of climate change over Malaysia. This assessment is based on published literature from local and international journals. Grey literatures (government reports) are mostly excluded from this review. We organize the paper as follows: the next section provides an overview of the climate system over Malaysia. The current level of understanding of climate change and variability over Malaysia and existing gaps are presented in the section that follows. Thereafter we present our comments on research directions and focuses.

OVERVIEW OF THE CLIMATE SYSTEM OVER MALAYSIA

An understanding of key processes within the climate system over a particular region is of central importance for assessment of climate change and variability. Situated in the western part of the Maritime Continent, the Malaysian climate is strongly dominated by the Southeast Asia Maritime Continent monsoon – an important component of the larger Asia-Australia monsoon system. Regionally, surface climate is influenced by two monsoon regimes namely the southwest monsoon (summer) and the northeast monsoon (winter). The southwest monsoon, characterized by low level southwesterly winds, commences in May and usually lasts between 3-4 months up to August. On the other hand, the northeast monsoon is dominated by northeasterly winds that cross over the South China Sea. The season usually commences in November and ends in February the following year. Intermittently during this period, strong pulses of wind known as cold surge penetrates to the most southern region of the South China Sea (Chang et al. 2005). The region is usually wetter during the northeast monsoon when the Inter-tropical Convergence Zone (ITCZ) is located close to the equator. However, the annual cycle of precipitation shows spatial variations due to the complex distribution of land, sea and terrain in the region (Chang et al. 2005).

Malaysia is geographically located in between two large oceans i.e. the Pacific Ocean to the east and the Indian Ocean to the west and hence its climate is also strongly influenced by natural climate variability associated with these oceans. Knowledge of how these natural climate phenomena modulate climate variability over the region is of central importance to the understanding of climate change impacts in this region. On interannual time scales, the El Nino – Southern Oscillation (ENSO) largely influences the climate variability over Malaysia and the greater Southeast Asian region (Juneng & Tangang 2005; Tangang 2001; Tangang & Juneng 2004). However, El Nino itself has its own variations largely due to the different evolution and warming patterns of ocean surfaces in the Pacific Ocean. A conventional El Nino is signified by a maximum warming at the eastern equatorial Pacific Ocean, whereas in extreme El Nino events such as the 1997/98 event, a sea surface temperature (SST) anomaly could rise as high as 5°C above normal temperature (Tangang et al. 1997). There is a tendency for the coupled ocean-atmosphere system in the Pacific Ocean to evolve differently with maximum warming occurring at the central equatorial Pacific Ocean. This variant of El Nino event is known as El Nino Modoki (Ashok et al. 2007). Other terminologies used are central Pacific El Nino (Kao & Yu 2009) and warm pool El Nino (Kug et al. 2009). These different positions of heating in the Pacific Ocean exert different perturbations to the Walker Circulation and hence different patterns of climate anomalies are expected around the globe (Ashok et al. 2007). Over Malaysia and the Maritime Continent, these two different variants of El Nino exert different patterns of influence on local and regional climate variability (Feng et al. 2010; Juneng & Tangang 2005; Tangang & Juneng 2004). During a conventional El Nino, drought induced conditions evolve seasonally from the beginning to the end of the El Nino stages (Juneng & Tangang 2005). This regional evolution of an El Nino-induced climate anomaly is basically associated with the strengthening of ocean-atmosphere interactions, modulated by background seasonal changes in the Southeastern Indian Ocean (SIO) region during the September-October-November (SON) period of the El Nino year and in the western north Pacific (WNP) region during the December-January-February (DJF) period (Juneng & Tangang 2005). Due to this evolution, drier-than-normal conditions persist in Sumatra and the southern region of Borneo, often inducing large-scale and uncontrollable forest fires. With prevailing winds blowing northwestward during this period, prolonged and large-scale forest fires in Sumatra and Kalimantan are almost certain to cause serious haze episodes in Malaysia and the greater Southeast Asian region. Serious haze episodes can exert significant impacts with cumulative economic losses reaching billions of US dollars (Tangang et al. 2011). During the DJF period, the maximum impact of drought is felt over northern Borneo where the duration can last until April or May as experienced during the 1997/98 El Nino. The evolution of a regional climate anomaly associated with a La Nina event can be taken as the opposite to that during an El Nino event, although they are not symmetrical. During a La Nina event, wet conditions are seasonally modulated by monsoonal background winds and increasing the occurrence of floods in low-lying areas (Juneng & Tangang 2005). In addition to precipitation, El Nino also modulates surface temperature causing it to soar, resulting in higher electricity demands for thermal comfort (Tangang et al. 2007). In contrast to the conventional El Nino, El Nino Modoki exerts different patterns of regional climate anomalies over the Maritime Continent especially during the DJF period. During this period, the maximum impact of deficit precipitation or drought occurs over the northern region of Peninsular Malaysia instead of the northern region of Borneo (Feng et al. 2010). Overall the predictive skills of various variables associated with the El Nino evolution can be used to provide reliable forecasts for seasonal precipitation anomalies (Juneng et al. 2010; Juneng & Tangang 2008).

In addition to ENSO, Malaysian climate variability is also modulated by Indian Ocean modes of variability. Two different modes are identified, namely the basin mode or Indian Ocean Basin (IOB) Mode (Klein et al. 1999) and the Indian Ocean Dipole (IOD) (Saji et al. 1999). The IOB is a manifestation of ENSO influence in the Indian Ocean (Klein et al. 1999). The IOD is a manifestation of Bjerknes mechanism associated with the coupled atmosphere-ocean system of the Indian Ocean (Saji et al. 1999). It can occur in conjunction with El Nino or independently. A positive (negative) IOD is characterized by warm (cool) SST in the southern (western) tropical basin of Indian Ocean (Saji et al. 1999; Webster et al. 1999). While the evolution of an El Nino event usually takes about a year, an IOD only lasts for about 5 to 6 months, usually from July to November (Saji et al. 1999). The IOD affects rainfall over the maritime continent, the Indian subcontinent, Australia and eastern Africa. During a negative IOD, the Maritime Continent and Australia experience deficit rainfalls whereas India and east Africa experience surplus rainfall (Vinayachandran et al. 2009). However, the extent to which the Malaysian climate is affected by the IOD is largely still not understood.

Another phenomenon that occurs on the intra-seasonal time scale and can exert significant influence on regional climate over the Maritime Continent is the Madden-Julian Oscillation (MJO), which is the dominant mode of intraseasonal rainfall variability over the MC region (Madden & Julian 1972; Zhang 2005). This intraseasonal oscillation (ISO) can be categorized into three different patterns of propagation: i) eastward propagation along the equator; ii) eastward propagation along the equator before bifurcate poleward near Sumatra; and iii) east and northward propagation over the Indian Ocean with or without east and northward propagation over the west of northern Pacific Ocean (Annamalai & Sperber 2005; Lawrence & Webster 2002; Nitta 1987; Sikka & Gadgil 1980; Sperber & Annamalai 2008; Wang & Rui 1990). In general, the MC region is strongly influenced by the three categories of propagation. Recent work by Jamaluddin (2011) provides a detailed analysis of how seasonal anomalous precipitation over Malaysia and the Maritime Continent region is modulated by MJO. The MJO also modulates diurnal cycle of precipitation over the region (Rauniyar & Walsh 2011).

Understanding synoptic circulations over the region is also crucial, particularly during the northeast monsoon where extreme precipitation events occur resulting in major floods. Major floods in eastern Peninsular Malaysia during the northeast monsoon can be devastating. The flood that occurred in southern Peninsular Malaysia during mid-December 2006 to late January 2007 is a good example of such a devastating extreme event. The number of evacuated residents affected by the flood reached 200,000 with 16 reported deaths. Economic losses from the flood were reported to be around USD 500 million (Tangang et al. 2008). Two major synoptic circulations namely the cold surge and the Borneo Vortex, which interacted with large-scale circulation associated with MJO, are linked to this major extreme precipitation event (Tangang et al. 2008). The cold surges are pulses of strong cold and dry air outbreaks from the Siberian High which later spreads equatorward in the form of a northeasterly cold surge wind around the eastern edge of low-level anticyclones over eastern Asia (Chang et al. 2005). These winds propagate equatorward across the South China Sea and become extremely moistened once over the southern region of the South China Sea (Johnson & Houze 1987). The Borneo vortex on the other hand is a quasi-stationary cyclonic low-level circulation located over Borneo Island. These two systems often interact and modulate the convective activities over the western Maritime Continent. Without the presence of the Borneo vortex, strong convective activities are largely occurring over Peninsular Malaysia, especially in the southern region (Chang et al. 2005). However, when the Borneo vortex is active, excess moisture is channeled to western Borneo, causing strong convective activities over the western region of Borneo. In certain cases, interaction between these two systems could result in the strengthening of the Borneo vortex. This strengthened system often propagates westward and eventually causes heavy precipitation over the eastern coast of Peninsular Malaysia. Two well-documented episodes that fall in this category are the 9-14 December 2004 extreme precipitation event that caused severe floods in the northeastern coast of Peninsular Malaysia (Juneng et al. 2007a) and the rare typhoon Vamei that wracked the southern tip of Peninsular Malaysia on 27 December 2001 (Juneng et al. 2007b; Tangang et al. 2007).

At the sub-daily scales, convective activities over the Maritime Continent respond to diurnal forcing (Holland & Keenan 1980; Murukami 1983; Satomura 2000). On land, convection usually attains maximum intensity in the evening whilst over a marine area, maximum convective activities generally occur in the morning (Nitta & Sekine 1994). However this diurnal characteristic shows considerable seasonal and spatial variation (Oki & Musiake 1994; Varikoden et al. 2010). Diurnal variations are significant over most seasons especially during the inter-monsoon months of April and May except in the west coast regions of the Peninsular where the diurnal cycle of rainfall is generally weaker during the southwest monsoon (June-August) (Varikoden et al. 2010). The diurnally forced land-sea breeze can also interact with larger scale background wind to produce intensive convective activities that lead to extreme rainfall (Joseph et al. 2008; Sow et al. 2011). However, the relationship of diurnal characteristic and large-scale synoptic circulation is not clear. The modulations of the diurnal cycle by ENSO, IOB and IOD remain unknown. Their influences are crucial in understanding the storm development (Sow et al. 2011) and extreme weather events in the region.

REGIONAL CLIMATE CHANGE AND KNOWLEDGE GAPS

The IPCC AR4 provided a limited assessment of regional climate change, particularly for the Southeast Asian region due primarily to the lack of published materials relevant to this region. However, for the current assessment cycle of the Fifth Assessment Report (AR5), the IPCC is emphasising on the regional aspects of climate change (IPCC WG1 website). Its Chapter 14: '*Regional Climate Phenomena and Their Relevance to Future Regional Climate Change*' is expected to provide assessment on patterns of variability, monsoon systems, extremes and inter-connectivity among phenomena and their relevance to regional climate change. However, the extent of which the Southeast Asia region would be assessed depends largely on the availability of scientific materials relevant to this region.

CHANGES IN THE MONSOON SYSTEM OVER THE SOUTHEAST ASIAN

Monsoon systems around the globe have been assessed in the IPCC AR4 report but the extent was somewhat limited. Monsoon systems have been described in Sub-Section 3.7 of Chapter 3 as part of observed surface and atmospheric changes. However, there was no elaboration on changes in the Southeast Asian and Maritime Continent monsoon. Also, in the discussion of regional climate projection of Chapter 11 of AR4, there was no explanation provided on future behaviour of the Maritime Continent Monsoon. This lack of assessment could be due to the lack of published materials related to the Maritime Continent Monsoon. In contrast substantial works have been carried out on the South Asian Summer Monsoon and its future projections under the doubling of CO_2 scenario (Kripilani et al. 2006 and references therein). Kripilani et al. (2006), based on multi-model ensemble of climate models under the IPCC AR4, concluded a significant increased of mean precipitation of 8% and extension of monsoon period over south Asia. A recent work by Kajikawa et al. (2012) indicated changes in the onset of the Asian summer monsoon in recent decades.

The obstacle in examining future changes of monsoon in this region is the climate model's inability to simulate climate over this region. Tangang and Juneng (2011) examined the performance of nineteen IPCC General Circulation Models (GCM) used in AR4 in simulating seasonal cycles of average precipitation over the western Maritime Continent. This simple analysis seems to suggest that the majority of the models fail to simulate the seasonal cycle of precipitation over this region. Figure 1 shows the observed seasonal cycle of precipitation versus simulated results of two groups of GCMs. The first group represents the best-performing GCMs that comprise two United Kingdom Meteorological Office (UKMO) GCMs and the Institut Pierre Simon Laplace (IPSL) GCM. These models simulate the seasonal cycle rather well although with amplitude biases. The second group represents the worst-performing GCMs in which the models failed to simulate the precipitation seasonal cycle. Figure 2 shows the spatial distribution of observed and simulated rainfall of the Hadley Centre Circulation Model Version 3 (HadCM3) and ECHAM5 of the Max Planck Institute during December-January-February (DJF) and June-July-August (JJA). For the HadCM3 the distribution pattern closely resembles the observed. On the other hand, the ECHAM5 fails to simulate the observed spatial distribution pattern of precipitation in the region. Other models in second group also fail to simulate the observed pattern. The failure of these models in simulating the precipitation over this region may be attributed to their coarse resolutions. However, with improvement in the resolutions, the performances of the latest version of the GCMs for the forthcoming IPCC AR5 may be better.

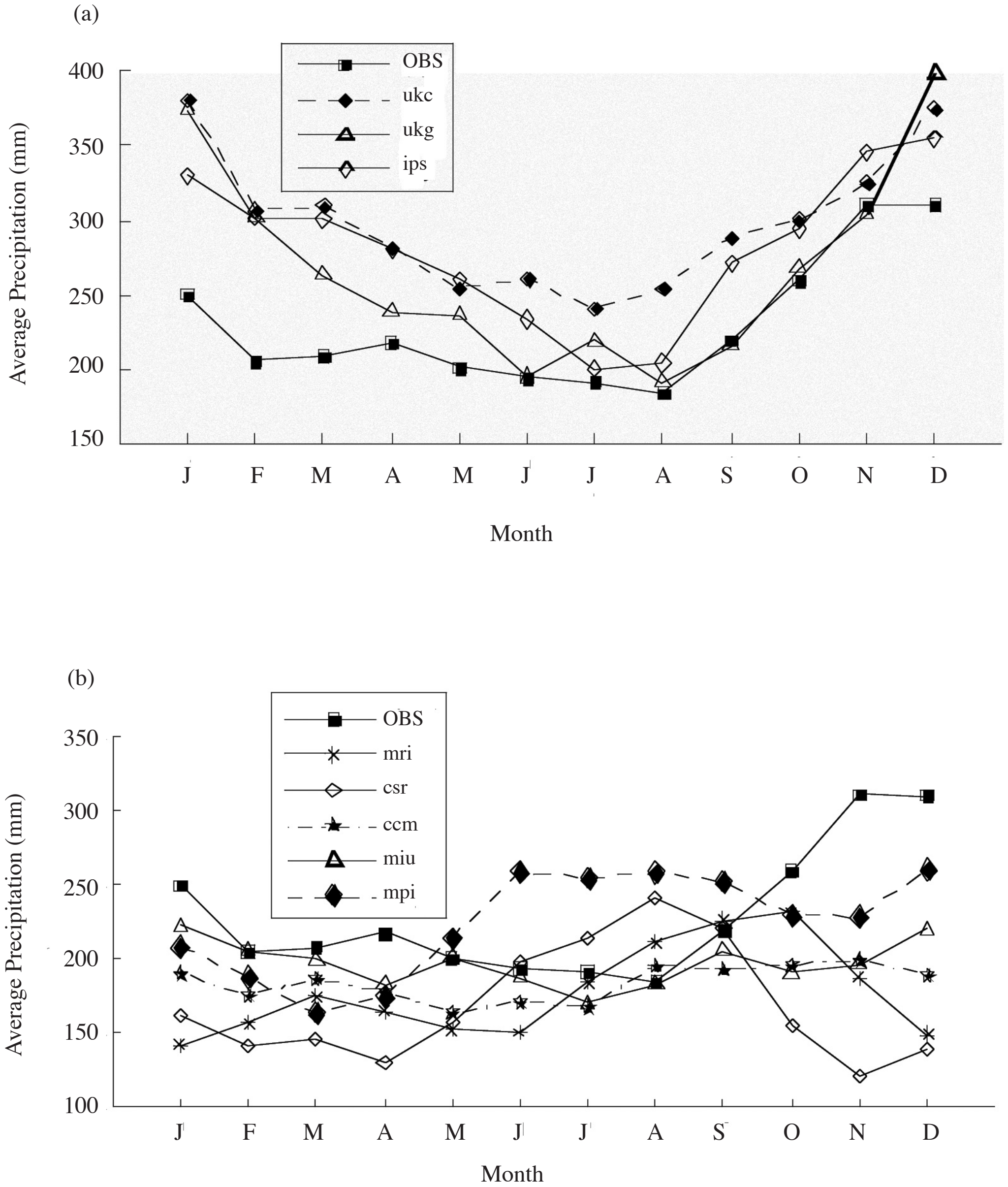

FIGURE 1. Observed (obs) vs simulated annual cycle of averaged precipitation for western Maritime Continent region (lat, lon). (a) The GCMs for Group 1 includes UKC= UKMO-HadCM3 (UK), UKG= UKMO-HadGEM1 (UK), IPS= IPSL-CM4 (France). (b)The GCMs for Group 2 comprises of MRI= MRI-CGCM2.3.2 (Japan), CSR= CSIRO-MK3.0 (Australia), CCM= CGCM3.1 (Canada), MIU=MIUB_ECHO (Germany), MPI= ECHAM5/MPI-OM (Germany)

CHANGES IN ENSO, IOB, IOD AND MJO AND THEIR RELEVANCE TO CLIMATE OVER MALAYSIA

The future behavior of these phenomena in a warmer environment is of critical importance to the understanding of climate change in the region. For example, changes in ENSO characteristics would alter how it impacts regional climate change. The assessment provided in the AR4 indicated that there is no consistent discernible change in the projected ENSO amplitude as well as frequency in the 21st century. However, recent works since AR4 suggested that the coupled atmosphere-ocean system in the tropical Pacific tends to prefer the El Nino Modoki mode after the 1980s due to changes of ocean sub-surface temperature distribution along the equatorial Pacific (Ashok et al. 2007; Kao & Yu 2009; Kug et al. 2009). Climate projections for the 21st century also showed a tendency for the Modoki type of El Nino than the conventional type (Ashok et al. 2007), indicating the probable influence of anthropogenic warming in the El Nino characteristic. Increasing number of Modoki types of El Nino in the 21st century would likely exert more droughts and heat waves over Peninsular Malaysia during the December – March period (Feng et al. 2010).

The mean SST of the tropical Indian Ocean has been rising steadily for much of the 20th century (IPCC 2007a). However, it is still not clear if such rises in background temperature will change modes of variability namely, the IOB and IOD modes. However, recent studies seem to

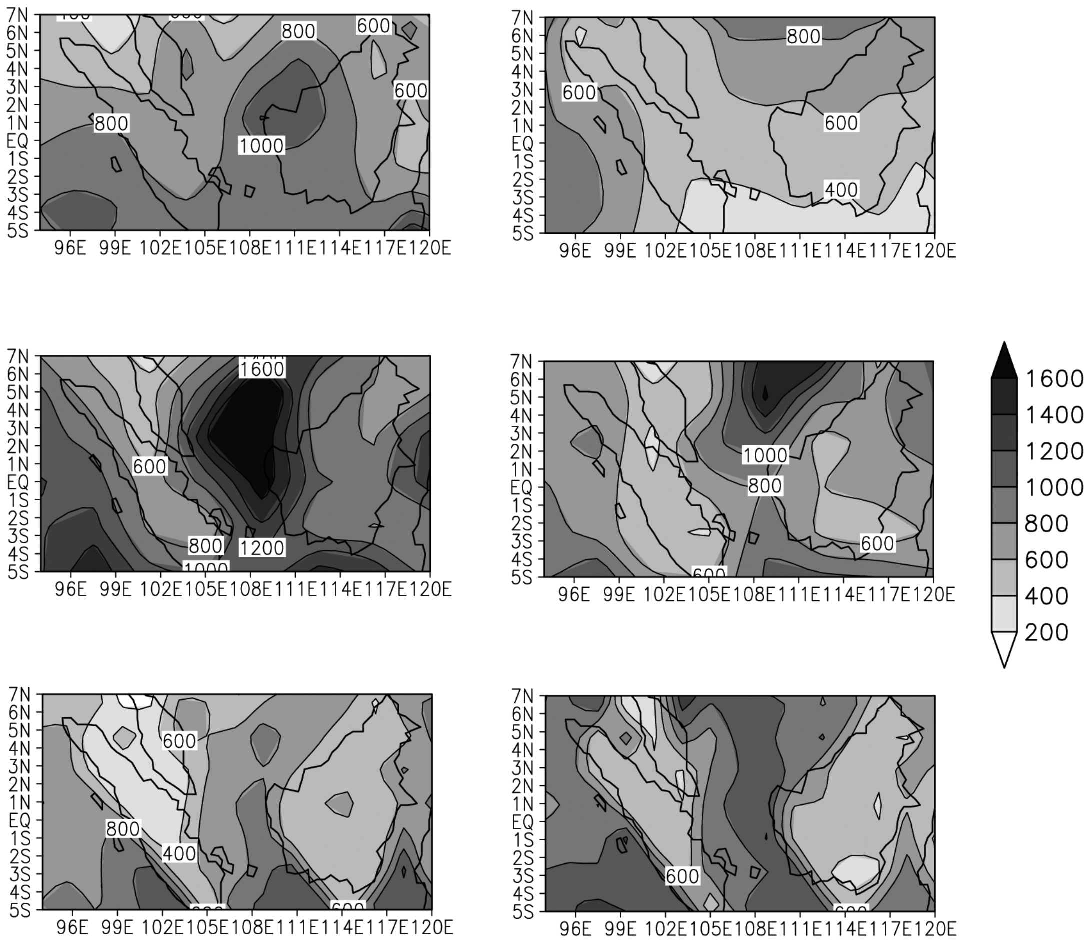

FIGURE 2. Precipitation spatial patterns for DJF (left column) and JJA (right colum). The top panel represents observed patterns based on the CMAP dataset the middle and bottom panels represent UKMO-HadCM3 and MPI-ECHAM5 simulated patterns, respectively. The unit is in mm

indicate a strengthening of IOB modes (Xie et al. 2010). Similarly, IOD variability has become more visible since the 1970s (Abram et al. 2008). However, global warming climate simulation results do not seem to indicate that the IOD is strengthening (Ihara et al. 2008). Nevertheless, the asymmetry of the IOD pattern that indicates a stronger cold structure on the eastern side and a weaker warm structure on the western side could be associated with anthropogenic warming (Zheng et al. 2010). Such dominant 'cold' patterns in the eastern side may have an impact on regional climate over the Maritime Continent. Generally, large knowledge gaps still exist in terms of how anthropogenic warming in the Indian Ocean would affect extreme events such as flood and droughts over the Maritime Continent.

There has been very limited work on how MJO would respond to global warming. Earlier work by Slingo et al. (1999), using GCM forced with SSTs, was able to reproduce positive trends of intra-seasonal variability since the mid-1970s. However, recently published work by Jones and Carvalho (2011) suggests a strong influence of anthropogenic warming on MJO frequencies. Using a non-homogenous stochastic model, they showed that under the SRES A1B, the number of MJO event per year is projected to increase from about 3.9 in 1948-2008 to about 5.7 for 2049-2099. The probability of very active years (5 or more events) is projected to significantly increase from 0.51 ± 0.01 (1990-2008) to 0.75 ± 0.01 (2010-2027) and 0.92 ± 0.01 (2094-2099). This study suggests that by the end of the 21st century, any year would almost certainly be classified as an 'MJO-active year' with 5 or more events in each year. The increasing number of MJO occurrences in the future would have major implications on rainfall variability over Malaysia and the Maritime Continent (Jamaluddin et al. 2011; Rauniyar & Walsh 2011) and possibly on extreme events (Tangang et al. 2008).

CHANGES IN SYNOPTIC CIRCULATIONS OVER THE MARITIME CONTINENT

There has been limited work done to understand long term changes of synoptic circulations over the Maritime Continent. Recent study by Juneng and Tangang (2010) highlighted long-term changes of synoptic circulations during winter monsoon over the maritime continent. The frequency of the Borneo vortex has increased over the

1962-2007 period. During this period, the centres of the vortex also shifted northwestward to be more over water rather than land, due to the strengthening of easterlies over the southern region of the South China Sea (Juneng & Tangang 2010). This location shift has important implication as the interaction between the vortex and the cold surge over warm waters could strengthen the system. The system that caused a major flood during 9-11 December 2004 (Juneng et al. 2007a) and the rare typhoon Vamei on 27 December 2001 (Juneng et al. 2007b) are examples of enhanced Borneo vortex due to its interaction with the cold surge over warm waters. However, it remains unclear if a correlation between the number of vortices and the flood events in the east coast of Peninsular Malaysia exists. There has been no previous work carried out on how Borneo vortex and cold surges would be affected by anthropogenic warming.

CHANGES IN CLIMATE AND WEATHER EXTREME EVENTS OVER MALAYSIA

The trend and future behaviour of extreme events (floods, droughts, heat waves) are central to understanding the impacts of climate change. According to the IPCC AR4, the frequency of heavy precipitation events is projected to increase for most regions during the 21st century, including the Southeast Asia region (IPCC 2007a). The latest IPCC Special Report on Managing the Risk of Extreme Events and Disasters to Advance Climate Change Adaptation (IPCC 2012) provided a similar conclusion. For 2046 to 2065 and 2081 and 2100 time horizons, the report indicated significant reductions of projected return periods of maximum daily temperature and daily precipitation event compared with the late 20th century.

In recent years there have been a number of studies on extreme precipitation events over Malaysia (Deni et al. 2010; Suhaila et al. 2010a, 2010b; Wan Zin et al. 2009; Wan Zin & Jemain 2010). Suhaila et al. (2010b) reported significant increase in the rainfall intensity and extreme occurrence over Peninsular Malaysia during the northeast monsoon. However, when considering the annual data, Wan Zin et al. (2010) argued decreasing trends of very wet events over the same region. However, earlier studies suggested that the proportion of annual rainfall from extreme events have increased over past decades (Manton et al. 2001). In addition to trends, process studies are important to better understand the mechanisms of these extreme events (Juneng et al. 2007a, 2007b; Loh et al. 2011; Salimun et al. 2010; Sow et al. 2011; Tangang et al. 2008).

The characteristics of droughts and heat waves will also be altered as anthropogenic warming continues. The IPCC AR4 indicated that it is virtually certain that there will be warmer and fewer cold days and nights over most land in the 21st century (IPCC 2007a). It is also virtually certain that there will be warmer and more frequent hot days and nights over most lands areas. Over the larger Southeast Asia regions, Manton et al. (2001) reported an observed increase of hot days and warm nights while the number of cool days and cold nights decreased. Anthropogenic warming is also very likely to increase the area affected by droughts (IPCC 2007a). Sheffield and Wood (2008) described projected changes in drought occurrence under future global warming based on multi-model, multi-scenario IPCC AR4 simulations. This study indicated that for future projections, the models show decreases in soil moisture globally for all scenarios with a corresponding doubling of the spatial extents of severe soil moisture deficits and twice the frequency of short-term (4-6 month duration) droughts from mid-20th century to the end of the 21st century. Long-term droughts (more than 12-month duration) became three times more common. However, these increases in trends of drought occurrences vary regionally. The Southeast Asia region appears to be less affected compared with regions such as Central America, Central North America, the Mediterranean and southern Africa.

CHANGES IN MEAN PRECIPITATION AND SURFACE TEMPERATURE

The IPCC AR4 reported that for the last 100 years, the temperature over Southeast Asia has been increasing at the rate of 0.15-0.25°C per decade. However, the warming rate has accelerated over the last 2-3 decades. Tangang et al. (2007) showed that for several locations in Malaysia, the rates of warming for the last 40 years were as high as 0.4°C per decade. In addition to long-term trend, surface temperature is also modulated by ENSO with anomalously warmer (cooler) temperatures during El Nino (La Nina). Depending on the emission scenario, the IPCC A4 future projections of temperature increase for the Southeast Asian region can reach up to 6°C by 2100 (IPCC 2007a). Recent regional climate downscaling work using the PRECIS regional climate model by Tangang and Juneng (2011) indicated mean surface temperature projections over Peninsular Malaysia and Sabah-Sarawak by 2070-2100 are 3-5°C warmer than the mean temperatures of the 1960-1990 period. Figure 3 shows the increasing trend of average mean surface temperatures over Peninsular Malaysia for the month of July. For the baseline period (1960-2000), simulated values (from PRECIS/HadCM3 and PRECIS/HadAM3P) appear to be consistent with the observed values of around 26°C. However, as shown by the PRECIS/HadCM3 projection, the mean surface temperature over Peninsular Malaysia continues to rise under the A1B scenario and by the end of the 21st century the mean surface temperatures over Peninsular Malaysia are projected to be around 29-30°C.

In contrast to global air temperature, the long-trend of global precipitation is difficult to establish. However, Zhang et al. (2007) was able to attribute zonal mean precipitation around the globe to anthropogenic climate change. For the tropical region (including the Southeast Asian region), precipitation from 1925 to 1999 appears to be decreasing. This is consistent with the time series of the

Palmer Drought Severe Index (PDSI) described in the IPCC Technical Paper VI on Climate Change and Water (Bates et al. 2008; Figure 3). This PDSI indicated that the Southeast Asia region experienced drier than average conditions for the last two decades.

There has been no previous work on the trend of precipitation over Malaysia. However, at the global scale a study by Zhang et al. (2007) indicated decreasing precipitation for latitudinal bands of 0-10°N during the 1925-1999 period. Based on the IPCC AR4, Peninsular Malaysia is projected to be drier during DJF under the A1B scenario. In contrast, the entire region is projected to be wetter during JJA. Recent regional climate downscaling by Tangang and Juneng (2011) appears to be consistent with the IPCC projection. However, there appears to be no clear long-term trend of precipitation changes over Peninsular Malaysia (Figure 4; Tangang & Juneng 2011).

CHANGES IN REGIONAL SEAS AND SEA LEVEL RISE (SLR)

Understanding and quantifying past and future sea level rise at the regional level is of critical importance for climate change adaptation in the coastal region. However, knowledge gaps remain large as reflected in the IPCC AR4 and also at the IPCC expert meeting on sea level rise held in Kuala Lumpur 21-24 June 2010 (IPCC 2010). In Malaysia, studies on SLR in the context of global climate change are limited. A projection of future SLR based on the IPCC AR4 global projection along the coast of Malaysia was conducted by NAHRIM (2011) using statistical techniques and very limited observational data. The results indicate that coastal areas along the northern part of the country are likely to experience higher SLR. The average sea level rise projected for Peninsular Malaysia toward the end of the 21st century is between 0.25 and 0.52 m. Higher rates are projected along the Sabah and Sarawak coasts with values ranging between 0.43 and 1.1 m by the end of the 21st century. However there is also uncertainty associated with the IPCC AR4 SLR projection. The AR4 GCM projection of SLR by 2100 represents a lower-bound estimate because it excludes sea-level changes caused by rapid dynamic changes in the flow of Greenland and Antarctic ice sheets (Overpeck & Weiss 2009) due to limited quantitative understanding of the dynamics internal to the Earth's ice sheets.

In addition to SLR, oceanographic conditions in regional seas are also expected to change. The southern region of the South China Sea is of particular importance to Malaysia. Rising sea surface temperature, changing currents and seawater acidification may have important repercussions on sectors such as fisheries. Together with SLR, changing wave characteristics due to changing winds may exacerbate coastal erosion. According to the Department of Irrigation and Drainage (DID), 29% of the Malaysian coast i.e. about 1380 km, is facing serious erosion (DID website). However, current understanding of the sea is limited and knowledge gaps remain large (Tangang et al. 2011).

RESEARCH DIRECTION AND FOCUSES

The physical basis and science of climate change at the regional level are of central importance for adaptation.

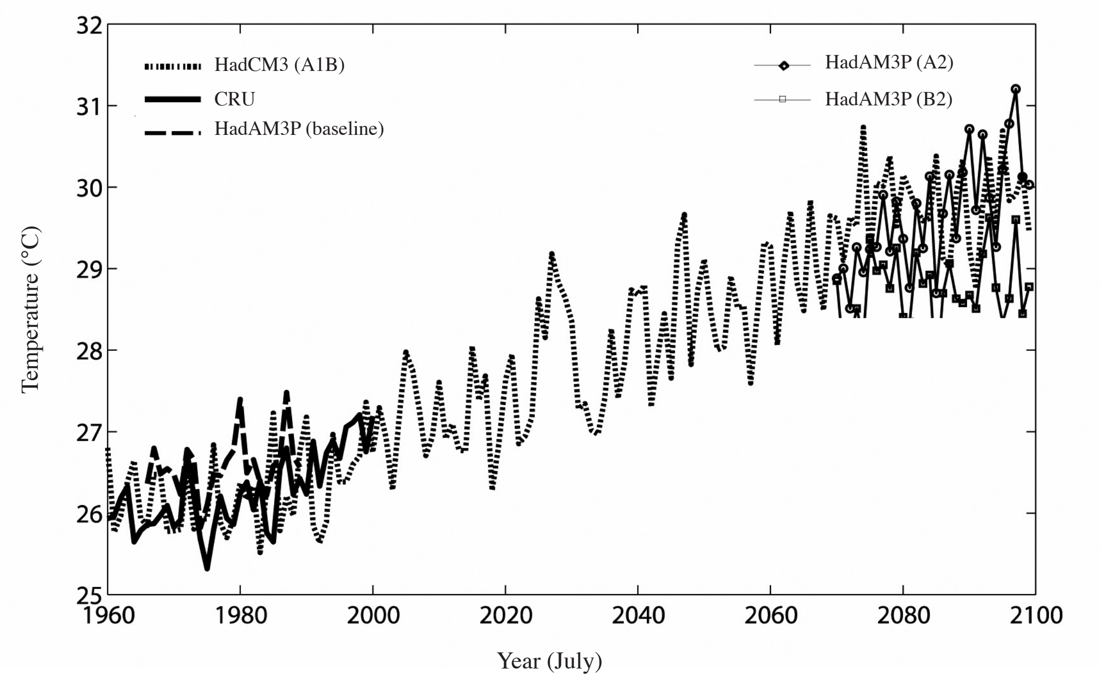

FIGURE 3. Observed (from CRU dataset) average surface temperature during July over Peninsular Malaysia vs simulated values of UKMO HadCM3 and HadAM3P for the baseline period (1960-2000). For the projection period the HadCM3 (A1B) spans a period from 2000-2100 while for the HadAM3P (A2 and B2) are available only for 2070-2100

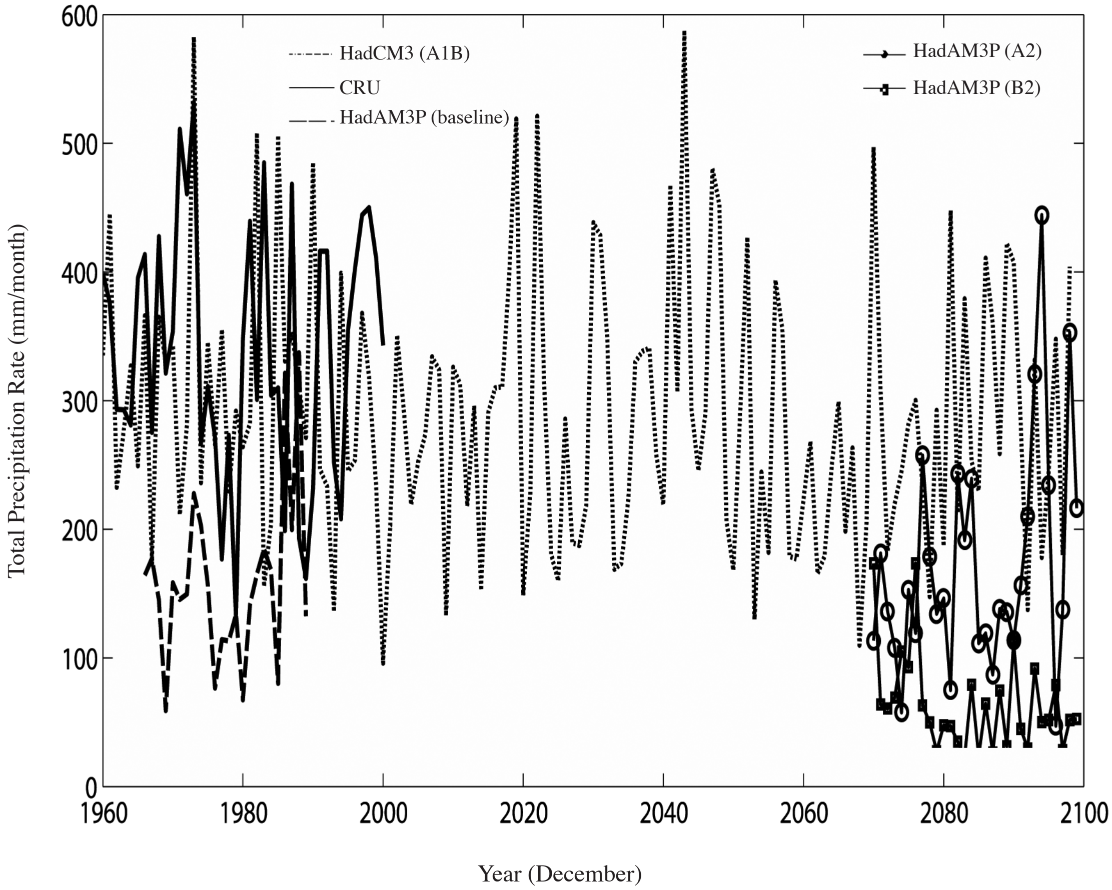

FIGURE 4. As in Figure 3, except for average precipitation over Peninsular Malaysia during the month of December

This has been recognized by the IPCC where a dedicated chapter on regional climate will be featured in the next IPCC AR5. The extent of coverage for the Southeast Asian and Maritime Continent region in this chapter depends on the amount of scientific literature available before the cut-off-date for publication inclusion into AR5. However, to date, the number of publications in the area is still low and knowledge gaps remain large. These re-emphasize the need for rigorous research programmes in this area. Research focuses can be in these six areas; projections of mean climate and its associated uncertainty using both statistical and dynamical downscaling tools; regional climate phenomena and how anthropogenic warming alters the way these phenomena affect the region; how anthropogenic warming influences extreme events; long-term changes in regional seas and SLR; inter-connectivity between higher latitudes and changes in the Maritime Continent.

CONCLUSION

This paper provides an overview of current knowledge in the physical basis and science of climate change over Malaysia and Southeast Asian / Maritime Continent region. Although some progress has been indicated, knowledge gaps remain large. Several important questions have yet to be adequately addressed. These include how monsoon and other regional phenomena (ENSO, IOD and MJO) are influenced by anthropogenic warming and how these in turn would affect the climate over this region. Large knowledge gaps remain with regards to extreme events such as flood and drought. We need to better understand the frequency and intensity of these events and whether they will increase in future. Our understanding of SLR and changes in regional seas, particularly the southern region of the South China Sea, is limited. In fact, our basic understanding of oceanographic dynamics in this region is minimal. Rigorous research needs to be carried out to better understand and quantify future changes in order to enhance scientific knowledge. Ultimately, these would reduce knowledge gaps, enhance scientific inputs to IPCC assessments of this region, formulate sound policies and provide the authority with facts and figures for scientifically sound adaptation measures.

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