The Relevance of CORDEX Southeast Asia Regional Climate Projection: Malaysia's Perspectives

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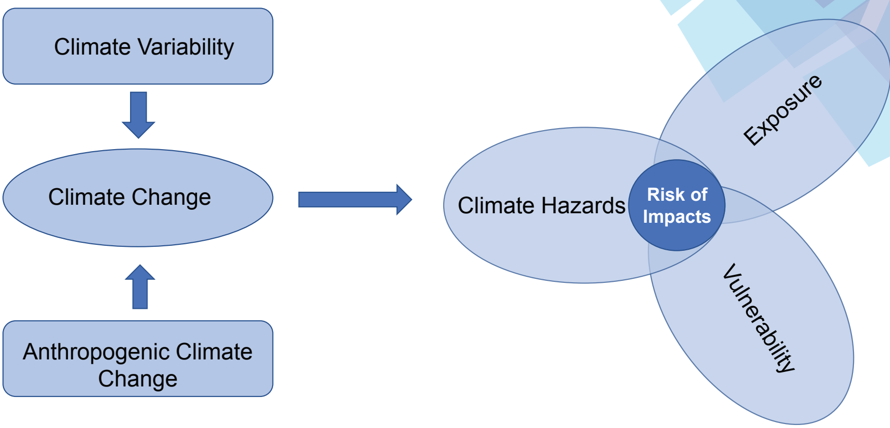
Introduction

Mounting scientific evidence unequivocally points to the fact that climate change is real, worsening and will pose a major threat to human as well as natural systems in the coming decades if substantial action is not taken to mitigate and adapt its impacts (IPCC, 2014; IPCC, 2018). As the current global mean temperature has already exceeded 1.16°C above the pre-industrial level and the atmospheric carbon dioxide (CO_2) has reached 417 ppm, the Intergovernmental Panel on Climate Change (IPCC) Special Report of 1.5°C indicated that the 1.5°C threshold is likely to be reached between 2030 and 2052 if global warming continues at its current rate (IPCC, 2018). The report had also indicated that climate-related risks in critical sectors including health, livelihoods, food security, water supply, human security and economic growth are projected to increase with global warming of 1.5°C, and elevate further with 2°C and beyond.

Furthermore, the nationally pledged mitigation ambitions submitted under the Paris Agreement would unlikely be able to limit the warming below 1.5°C (IPCC, 2018). In fact, the likelihoods for the world to successfully cap the warming at 1.5°C and 2.0°C have been estimated to be at a mere 1 percent and 5 percent respectively (eg. Raftery et al., 2017). This reflects the great challenges in achieving the target as ambitioned in the Paris Agreement. Therefore, while mitigation needs to be continually pursued and intensified, countries in the world, especially those least developed and developing ones, would need to strategise and adapt to the impacts of climate change for climate resilience.

According to the IPCC, climate change adaptation is defined as a practice of identifying options to adapt to climate change and evaluating them in terms of criteria such as availability, benefits, costs, effectiveness, efficiency, and feasibility (IPCC, 2012a). This implies a broad and wide range of criteria to be considered, and by no means to be a simple exercise. The evaluation process of an option incorporates various disciplines and sciences. However, this action is only necessary if it is robustly determined that the level of risk of climate change impact increases as global warming intensifies. A risk of climate change impact, on the other hand, is determined by the level of vulnerability and exposure to a climate hazard (Figure 1; IPCC, 2012b). The exposure is defined, according to the IPCC, as the presence of people, livelihoods, environmental services and resources, infrastructure, socio-economic or cultural assets in places that could be adversely affected by a climate hazard (IPCC, 2012b). The vulnerability, on the other hand, is defined as a propensity or predisposition to be adversely affected by a climate hazard (IPCC, 2012b). However, the determination of how climate hazards would change in future periods must precede the evaluation of exposure and vulnerability (Figure 1). This emphasises the importance of generating robust future climate information and evaluating changes of mean climate and extremes in future periods.

FIGURE 1. Illustration of the level of risk of climate change impacts as a function of climate hazards, exposure and vulnerability (modified from IPCC 2012b)



Since the assessment of risk of climate change impacts is usually done at a local scale, future climate information for this purpose must be tailored for such a locality. Incorrect information could lead to failed adaptation strategy or even maladaptation (Barnett and O'Neill, 2010; Magnan et al., 2016; McMullen et al., 2019). This is where the initial challenge lies for most countries, especially those least developed and developing ones including Malaysia. The common issue at hand is the lack of detailed future climate projection that can be reliably used for the assessment of risk and a basis for devising adaptation measures. Such detailed information may not be sourced from the IPCC reports but need to be independently generated. However, the process of generating robust future climate change information at a local scale is highly technical, requires huge computing resources and is time consuming. While most least developed and developing countries do not have the capacity to generate detailed future climate information, the recent progress of the Coordinated Regional Climate Downscaling Experiment (CORDEX) (Giorgi et al., 2009), a top-down initiative by the World Climate Research Programme (WCRP) of the World Meteorological Organisation, can be leveraged.

This article discusses this initiative and the progress made in Southeast Asia under the CORDEX Southeast Asia (CORDEX-SEA), and how countries in the region can benefit from such a well and globally coordinated programme. This article also demonstrates the application of CORDEX-SEA[1] climate projection data in highlighting some key findings of projected climate change in Malaysia.

[1] CORDEX Southeast Asia is funded by the Asia-Pacific Network for Global Change Research (APN) (ARCP2013-17NMY-Tangang, ARCP2014-07CMY-Tangang, ARCP2015-04CMY-Tangang) with additional support from Universiti Kebangsaan Malaysia (ICONIC-2013-001), Malaysian MOHE FRGS/1/2017/WAB05/UKM/01/2.

Regional climate downscaling and CORDEX framework

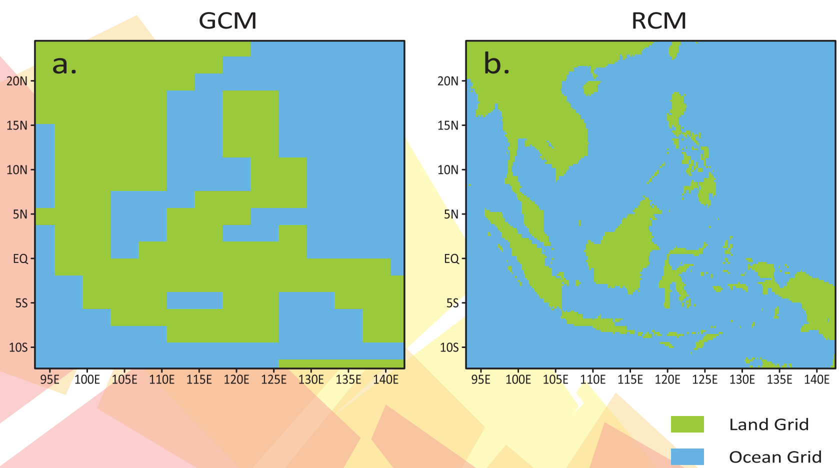
Projecting future climate requires a global climate model (GCM) (eg. Flato et al., 2013), a tool that allows evaluation of responses of the climate system to various forces. In the case of global warming, GCMs have been the main tool for scientists in evaluating future climate in response to various greenhouse gas emission scenarios. In conjunction with the IPCC, GCM simulations by modelling centres around the world have been coordinated under a common experimental protocol of the Coupled Model Intercomparison Project (CMIP) (Meehl et al., 2000; Eyring et al., 2016). GCM simulations under CMIP became the basis of IPCC key findings of climate change in future periods (IPCC, 2013). There have been a number of CMIPs implemented, with the CMIP6 being the latest one to feed into the on-going IPCC Sixth Assessment Report (AR6).

The limitation of GCMs, however, is their coarse resolution. With typical horizontal resolutions of 100-300 km, GCM is not able to resolve local features such as topography, coastlines and land use, which are important in characterising climate processes at the local scales. Furthermore, impact models such as hydrology models or crop models, which are used to evaluate impacts of future climate change, usually require localised outputs of climate models as inputs.

In Southeast Asia – where topography, coastlines and landmass distribution are significantly complex – GCM simulations may not be adequate in resolving local climate. Figure 2 shows the landmasses and coastlines of the IPSL-CM5A-LR model (Dufresne et al., 2013) that comes with a spatial resolution grid resolution of 1.9o × 3.75o, ie. ~ 200 km × 375 km. Such a coarse grid could hardly capture local climate complexity, although regional climate phenomena (such as a monsoon) can still be reasonably well simulated.

Increasing the resolution to better capture the regional and local processes comes with great challenges, such as huge computing resources. It is only recently that the modelling community had attempted to carry out the high-resolution climate simulation of 50 km under the High Resolution Model Intercomparison Project (HighResMIP v1.0) for CMIP6 (Haarsma et al., 2016). It may take some years for such a high-resolution GCM simulation to become a standard run in CMIP.

FIGURE 2. The model's representation of Southeast Asia landmasses in the IPSL-CM5A-LR GCM (a) and RegCM4 RCM (b) of ~ 200 km × 375 km and 25 km × 25 km resolution, respectively



The needs for climate change information at the regional to local scale have long been recognised in order to assess the impacts of climate change on the human and natural system. However, due to the coarser resolution of the GCMs, such needs were unmet. For bridging the spatial scale gap, scientific communities have developed various "downscaling" techniques to refine the climate information derived from the GCMs. These "downscaling" techniques fall into two categories – statistical and dynamical. The statistical downscaling technique relies on the relationship between the large-scale predictors and regional-to-local-scale predictands, which are then applied to the output of GCM simulations for future projection (Hewitson and Crane, 1996). The reliability of this approach is dependent upon long and reliable observation data to build a robust statistical model. However, in places where observational record is short and not reliable, statistical downscaling techniques may not be the appropriate choice. The dynamical downscaling technique, on the other hand, requires a Regional Climate Model (RCM) to be nested within and constrained at the boundary by the GCM outputs. The resolution of the RCM can be set to a scale that can resolve regional and local climate complexities. Figure 2 demonstrates how a 25 km resolution of the RegCM4 model resolves the coastlines and topography in Southeast Asia much better than the IPSL-CM5A-LR GCM.

Recognising the need for a framework for a better coordination in downscaling activities, the World Climate Research Programme (WCRP) of the World Meteorological Organisation (WMO) has established in 2009 the Coordinated Regional Climate Downscaling Experiment (CORDEX) (Giorgi et al., 2009). Much like CMIP for GCMs, CORDEX provides a framework for RCM model evaluation and regional climate projection. For more than a decade after its establishment, CORDEX regional climate downscaling activities have been well recognised with its 14 regional domains covering almost the entire globe[2] and publications of hundreds of scientific articles (Giorgi, 2019). In fact, the generated downscaled data at 50 and 25 km resolutions (12.5 km for EURO-CORDEX) have been made available to user communities through the Earth System Grid Federation (ESGF) data portal.

CORDEX has also created the so-called "Flagship Pilot Project", a framework that allows coordination of projects addressing specific scientific questions within CORDEX domains. The use of CORDEX data for climate change impact assessment at regional to local scales serves to provide a scientific basis for decision-making processes and formulation of adaptation measures. The generated data are also currently being used to produce the Regional Atlas of the IPCC AR6 Report. The CORDEX framework also promotes collaboration in conducting the simulations among institutions. This has been a viable way to produce multi-model and multi-scenario simulations for robust projections that would have been difficult to achieve by a single institution or country. Adequate sampling of probable outcomes by employing a multi-model and multi-scenario approach is necessary for uncertainty estimation in the projection (eg. Valle et al., 2009). This is illustrated in Figure 3 of multi-model simulations where the best estimate of projected changes can come from the ensemble mean with the range as an estimate of uncertainty.

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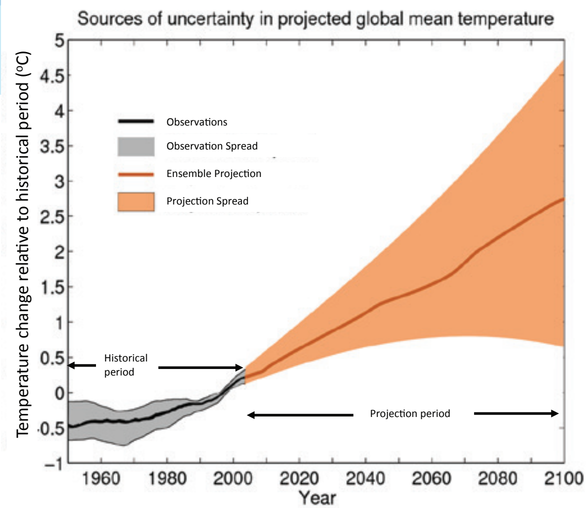
[2] www.cordex.org.

FIGURE 3. Illustration of projected temperature change best estimate of ensemble mean together with the projection spread (adapted from Kirtman et al., 2013)



The CORDEX Southeast Asia (CORDEX-SEA) is the 14th domain of CORDEX (Figure 3). This was initially the Southeast Asia Regional Climate Downscaling (SEACLID) project funded by the Asia Pacific Network for Global Change Research (APN), but later streamlined into CORDEX (eg. Tangang et al., 2018). In its first phase simulations, a total of 11 GCMs have been downscaled using seven RCMs at a resolution of 25 km (Tangang et al. 2020). The CORDEX-SEA simulations have been conducted by various institutions from within and outside the regions, and represent the most comprehensive set of simulations in Southeast Asia thus far (Tangang et al., 2020). A number of scientific articles have been published out of these CORDEX-SEA simulations, which contributed to enhanced understanding of how future climate and extremes would be changing in Southeast Asia (eg. Liew et al., 2016; Ngo-Duc et al., 2017; Cruz et al., 2017; Tangang et al., 2018; Tangang et al., 2020; Superi et al., 2020; Nguyen-Thi et al., 2020).

Also, as part of the SEACLID project, a data portal called the Southeast Asia Regional Climate Change Information System (SARCCIS) has been established for CORDEX-SEA data archiving and to facilitate data access to the user community (Tangang et al., 2020).[3] SARCCIS is linked to the Earth System Grid Federation (ESGF), a global climate data archiving system, for worldwide accessibility. With easy access to CORDEX-SEA downscaled climate data, users – especially from the vulnerability, impact and adaptation (VIA) community – would now be able to use the high-resolution climate projection data to assess the risk of impacts on critical sectors and formulate adaptation strategies. Subsequently, this would lead to narrowing down the knowledge gaps of climate change impacts in Southeast Asia as previously highlighted in the IPCC AR5 Report (Hijioka et al., 2014).

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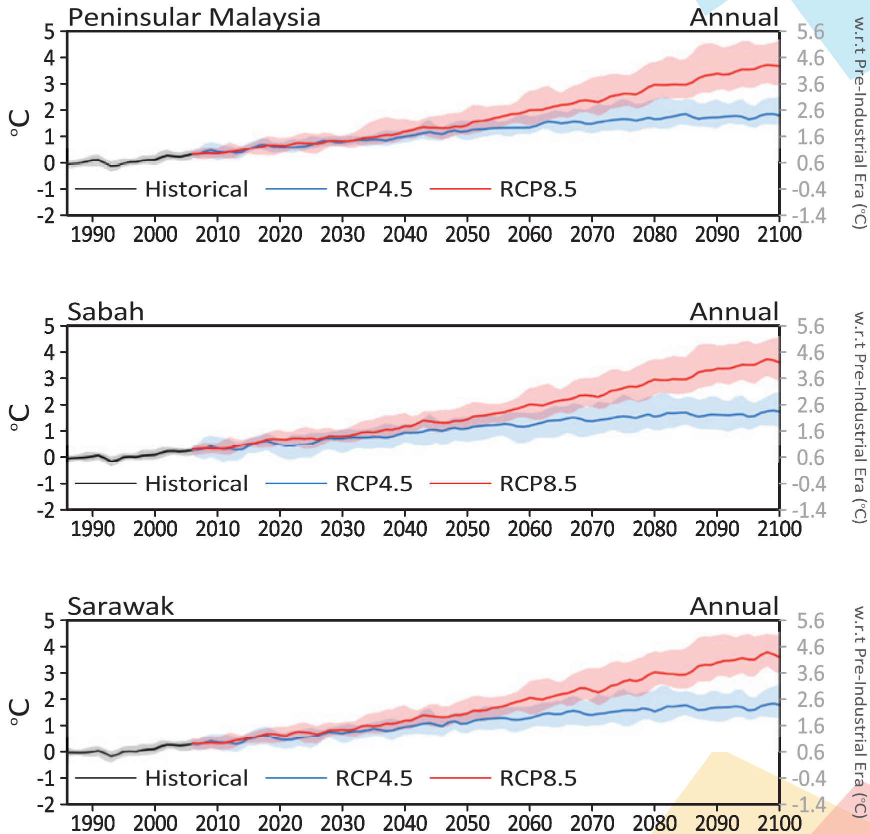
[3] http://www.rucore.ru.ac.th/SARCCIS.

[4] https://esgf.llnl.gov/.

FIGURE 4. The ensemble means of projected mean surface temperature changes relative to the baseline period (left axis) and pre-industrial global mean temperature (right axis) under RCP4.5 and 8.5 emission scenarios, plotted together with plausible ranges. Also shown are the ensemble means during the historical period



Leveraging CORDEX Southeast Asia: Projected future climate change in Malaysia

Countries in Southeast Asia can leverage on the availability of CORDEX-SEA simulations for climate change VIA studies and national assessment. In countries where climate projection data is not available or limited, CORDEX-SEA climate projections can certainly fulfil some data requirements. For example, CORDEX-SEA data has been used in providing detailed analysis of future climate in Thailand (Tangang et al., 2019). In the Philippines, Indonesia and Vietnam, CORDEX-SEA data has been used for climate change assessment at the national level.

Likewise, CORDEX-SEA can fulfil the data needs in Malaysia. Malaysia has conducted its own regional climate downscaling, albeit with a limited number of GCMs and RCMs as indicated in its third national communication (NC3). Furthermore, the climate projection data used in NC3 were that of the CMIP3 GCMs. Hence, Malaysia can leverage on the availability of CORDEX-SEA climate projection data, which are based on CMIP5 GCMs. In this section, we highlight key findings of the CORDEX-SEA climate projection for Malaysia. Detailed information of ensemble members of CORDEX-SEA simulations and models' performances during the baseline period can be found in Tangang et al. (2020).

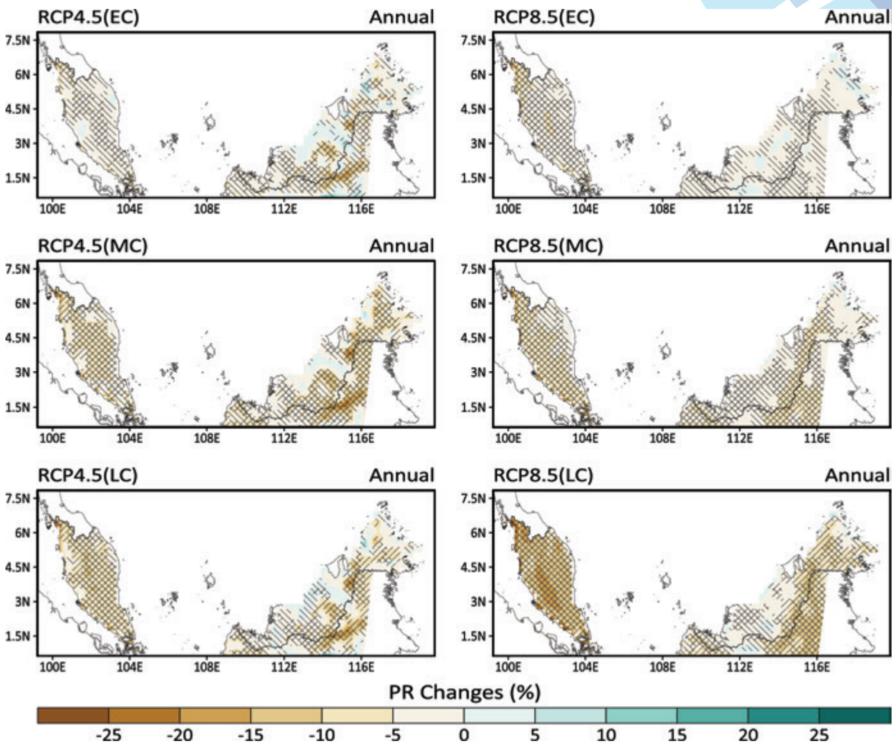
Figure 4 shows the times series of projected ensemble means of surface air temperature changes for Peninsular Malaysia, Sarawak and Sabah, relative to the mean temperature of 1976-2005 baseline period (left axis) and pre-industrial global mean temperature (right axis). Unlike rainfall, the projected changes of mean temperature are roughly spatially uniform throughout the country. Under the worst-case emission scenario of RCP8.5 (van Vuuren et al., 2011), the temperature in Malaysia is projected to monotonic increase to about 4.0-5.0°C relative to the global mean temperature during the pre-industrial era by 2100.

Table 1 provides further details of the projected changes of surface air temperature ensemble mean and respective ranges for early (2011-2040), middle (2041-2070) and late century (2071-2100). These values represent the climatological mean of annual changes of the 30-year periods, relative to the baseline period of 1976-2005. All values are significant and robust where significance is measured at 90 percent level above random noise while robustness signifies at least half of the ensemble members agreed with the sign of changes in the ensemble mean.

TABLE 1. The projected changes of mean surface temperature together with plausible ranges, averaged over Peninsular Malaysia (PM), Sabah (SB) and Sarawak (SR) for Early Century (2011-2040), Middle Century (2041-2070) and Late Century (2071-2100) relative to baseline period (1976-2005). Unit is °C.

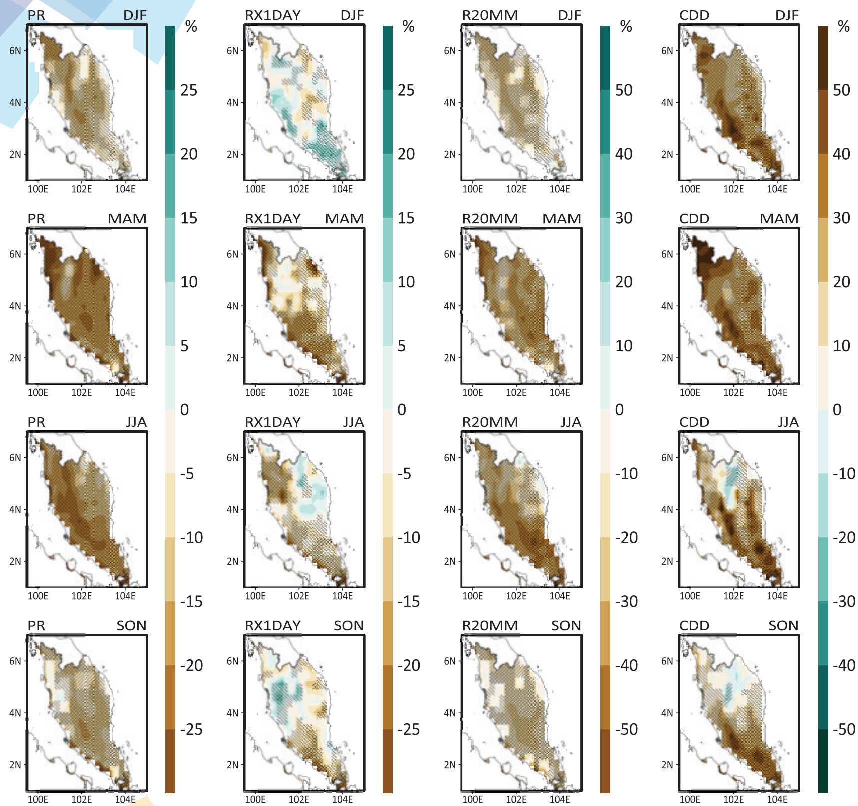
	Early Century			**Middle Century**			**Late Century**		
Scenario	PM	SB	SR	PM	SB	SR	PM	SB	SR
RCP4.5	0.75 [0.65, 0.94]	0.65 [0.21, 0.94]	0.67 [0.37, 0.93]	1.36 [1.19, 1.75]	1.26 [0.72, 1.69]	1.31 [0.92, 1.73]	1.74 [1.46, 2.39]	1.64 [1.12, 2.29]	1.69 [1.34, 2.32]
RCP8.5	0.81 [0.62, 1.14]	0.8 [0.60, 1.11]	0.82 [0.64, 1.11]	1.82 [1.45, 2.41]	1.81 [1.44, 2.32]	1.84 [1.52, 2.36]	3.15 [2.57, 4.11]	3.14 [2.58, 3.97]	3.17 [2.7, 4.06]

FIGURE 5. The projected percentage changes of mean annual rainfall (PR) of early century (EC), middle century (MC) and late century (LC) relative to baseline period. The forward slash indicates significance at 90 percent level whereas backward slash represents robustness, ie. more than half of the ensemble members agreed in the direction of change to that of the ensemble mean.



The projected changes in mean annual rainfall (PR) is shown in Figure 5. Generally, the annual mean precipitation in Malaysia is projected to continually decrease, especially in Peninsular Malaysia during the middle and late century periods, with a magnitude of projected reduction of approximately 15 percent relative to the baseline period. However, by the end of the 21st century under RCP8.5, the magnitude of projected rainfall decrease in Peninsular Malaysia increases to 15-20 percent and can be approximately 25 percent in some areas, especially in the northwest and interior regions. It is interesting to note that even in the early period of the 21st century under RCP4.5, signs of drying trend in the northwest region of Peninsular Malaysia already prevailed. The projected rainfall decreases over this area relative to the baseline period is even larger under RCP8.5. Unlike Peninsular Malaysia, the projected drying trend in Sabah and Sarawak does not dominate the entire region. There is a tendency for a drying trend in the interior parts while wetting trends in the coastal areas. There are also seasonal differences in the magnitude of rainfall reduction with largest in the months of June-July-August and March-April-May under RCP8.5 by the end of the 21st century (not shown).

FIGURE 6. The projected changes of seasonal rainfall (PR), extreme rainfall indices (RX1DAY, R20MM and CDD) for December-January-February (DJF), March-April-May (MAM), June-July-August (JJA) and September-October-November (SON) over Peninsular Malaysia during end of the 21st century and under RCP8.5 scenario



The changes of mean rainfall throughout the year is basically contributed by the changes in the rainfall frequency, duration and intensity. Figure 6 shows the projected seasonal changes of mean rainfall in Peninsular Malaysia during the end of the 21st century under RCP8.5, plotted together with three indices of extreme rainfall (Zhang et al., 2011). The RX1Day is the monthly maximum 1-day rainfall which measures the rainfall intensity. The R20mm is the number of days that the daily accumulated rainfall exceeds 20 mm, a threshold of heavy rainfall (Tan et al., 2019). R20mm measures the frequency of extreme rainfall. The CDD is the number of consecutive days without rainfall measuring the duration of dry spells. The projected changes of mean rainfall vary seasonally with largest reductions during MAM and JJA (Figure 6). It is interesting to note that the reductions in mean rainfall appear to be contributed by the decrease of rainfall intensity, frequency and increase in dry spells. However, during DJF, JJA and SON seasons, in some areas the rainfall intensity is projected to increase compensating the effects of reduction in the frequency of heavy rainfall and increase in dry spells. Interestingly, for extremely heavy rainfall (R50mm), significant increases have been projected in some areas (not shown).

This implies that climate change is projected to intensify dry spells as well as extremely heavy rainfall that can cause flooding. In addition, the projected increase of CDD in Sumatra and Kalimantan, Indonesia during JJA and SON in future warmer periods implies elevated risks of annual forest fires and haze episodes instead of inter-annually, following the El Niño periodicity of once in 3-5 years (Supari et al., 2018; Supari et al., 2020; Tangang et al., 2020). However, much worse droughts could likely happen in these regions taking into consideration the compounding effects of climate change and El Niño in future warmer periods. This represents a major risk factor in terms of transboundary haze episodes and air quality for Indonesia and surrounding countries including Malaysia and Singapore.

Compounding effects of anthropogenic climate change and climate variability

The projected changes indicated in the previous section mainly represent the anthropogenic or human-induced component due to increased greenhouse gases emission and dwindling carbon sink. In the real world however, observed climate fluctuation can be due to both the anthropogenic component and the natural climate variability (Figure 1). In the Southeast Asia region, natural climate phenomena such as the El Niño-Southern Oscillation (ENSO), Indian Ocean Dipole (IOD) and Madden-Julian Oscillation (MJO) can induce significant anomalous climatic conditions even in the current climate. Occurrences of flood and droughts in the current climate are largely attributed to these phenomena. In the inter-annual time scale, ENSO and IOD have been shown to influence mean and extreme rainfall in the region, including Malaysia and Indonesia (Tangang and Liew, 2004; Liew and Tangang, 2005; Tangang et al., 2017; Supari et al., 2018; Amirudin et al., 2020). Similarly, in the intra-seasonal time scales, MJO has been shown to affect mean climate and rainfall extremes in the region, especially Malaysia and Indonesia (Tangang et al., 2008; Xavier et al., 2020).

However, in future warmer periods, the characteristics of these natural climate variability phenomena can also be influenced by global warming. For example, the extreme El Niño equivalent to those of years 1982/1983, 1997/1998 and 2015/2016 is projected to be twice more frequent in a warmer world by the end of the 21st century (Cai et al., 2014a). The characteristics of La Nina (Cai et al., 2015), Indian Ocean Dipole (Cai et al., 2014b) and Madden-Julian Oscillation (Maloney et al., 2018) are also projected to change in future periods of warmer world. Hence, in a future warmer world, anomalous climate conditions may not be entirely due to anthropogenic climate change but a compounding effect of both anthropogenic climate change and climate variability. However, the projected changes highlighted in the previous section mainly represented the effects of anthropogenic climate change. In such analyses, the effects of natural variability are basically not included. This is because averaging analysis of ensemble members in a duration of 30 years would eventually eliminate the natural variability. Besides, the ability of CMIP5 GCMs in simulating the major modes of climate variability was modest (IPCC, 2013). For complete information of future climate hazards, both effects of climate variability and anthropogenic climate change must be considered (Figure 1).

Policy implications in climate change adaptation, disaster risk reduction and sustainable development

A country would need to have a national climate adaptation plan or policy to ensure climate resilience and minimisation of climate change impacts. However, any plan or policy towards climate resilience must be evidence-based to avoid unintended consequences or maladaptation. In the previous section, we have demonstrated the usefulness of CORDEX-SEA multi-model and high-resolution climate projection data for Southeast Asian countries. While such information of future climate is crucial to determine future hazards, it is equally critical to evaluate the levels of exposure and vulnerability of these sectors, communities or areas to these sectors, communities or areas to these climate hazards (Figure 1). However, the details of vulnerability and exposure assessments are sector, community and area specific and beyond the scope of this paper. However, it has been highlighted that knowledge gaps in how climate change would be affecting critical sectors in Southeast Asia remains large (Hijioka et al., 2014). There is a need for more studies in assessing the risk of climate change impacts by researchers from the VIA community. While in the past, lack of access to high-resolution climate projection data hindered such studies, the availability of CORDEX-SEA climate projection data should facilitate and expedite these studies. In fact, in some countries a number of studies have already been implemented or ongoing. For example, Tan et al. (2019; 2020) have utilised CORDEX-SEA climate projection data in their studies in assessing the impacts of climate change on water balance in Johor and Kelantan river basins. Subsequently, the number of risk and impact assessment studies would increase, and the findings would become important inputs to the formulation of adaptation plans or policy for climate resilience.

Addressing the impacts of climate change and increasing climate resilience must not be seen as a separate agenda from those of the United Nations' disaster risk reduction (DRR) and Sustainable Development Goals (SDGs). The Sendai Framework Disaster Risk Reduction (SFDRR) (2015-2030) identifies four priority actions including understanding disaster risk, strengthening disaster risk governance, investing in disaster risk reduction for resilience and enhancing disaster preparedness for effective response (UNISDR, 2015). According to the recently released United Nations Disasters Risk Reduction (UNDRR) report on 13 October 2020, in conjunction with the International Day for Disaster Risk Reduction, in the period of 2000-2019 a total of 7348 disasters events have been recorded worldwide, with 6681 events or 91 percent are climate related (UNDDR, 2020).

Hence, addressing the risk of climate change impacts through adaptation and mitigation efforts would commensurate well with the priority actions in SFDRR. In addition, climate change and disaster risk pose fundamental threats to sustainable development goals (SDGs). The negative impacts of climate related disasters could slow down or even roll back decades of development progress. Hence, addressing climate change through adaptation and mitigation efforts would also be in synergy with SDGs. This reiterates the relevance of generating robust climate information at finer scales in addressing climate change risk, DRR and SDGs.

Conclusion

For climate resilience, countries in Southeast Asia need to have evidence-based adaptation plans or policy. "What to do" and "how to do" in adaptation plans would require information on the levels of risk of impacts of future climate change, which are dependent on the detailed information of future climate hazards, the exposure and vulnerability of sectors, communities or areas. Robust climate projections at local scales are needed to evaluate future climate hazards. In the past, the scale-gap between the GCM outputs and data needed for local impact assessment hindered research in VIA. The establishment of CORDEX has been successful in bridging this scale-gap. In particular, the availability of CORDEX-SEA multi-model and high-resolution (25 km x 25 km) would facilitate such studies in the region. The on-going further initiative in downscaling at 5 km x 5 km resolution over several sub-domains in Southeast Asia under CORDEX-SEA Phase II would be even more relevant, especially for basin-scale studies.[5] Eventually, the findings would help the countries in formulating adaptation plans for climate resilience. In fact, CORDEX-SEA projection data has been or currently being used for climate change assessment at the national level in the Philippines, Vietnam and Indonesia. Detailed climate projection information may not just relevant for assessing the risk of climate change impacts but also DDR and SDGs.

In this paper we have demonstrated the use of CORDEX-SEA climate projections for Malaysia. Based on this analysis, Malaysia is projected to experience drier conditions relative to the baseline period (1976-2005), especially during the middle and end of the 21st century. This drying trend represents a potential risk to critical sectors such as agriculture and water resources. In addition, the compounding effects of climate variability, including ENSO, IOD and MJO and climate change, may exacerbate the risks in future warmer periods.

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[5] https://www.apn-gcr.org/resources/items/show/2048.

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