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Projections of rising heat stress over the western Maritime Continent from dynamically downscaled climate simulations

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ABSTRACT

This study assesses the future changes in heat stress in response to different emission scenarios over the western Maritime Continent. To better resolve the region-specific changes and to enhance the performance in simulating extreme events, the MIT Regional Climate Model with a 12-km horizontal resolution is used for the dynamical downscaling of three carefully selected CMIP5 global projections forced by two Representative Concentration Pathway (RCP4.5 and RCP8.5) scenarios. Daily maximum wet-bulb temperature (TW_{max}), which includes the effect of humidity, is examined to describe heat stress as regulated by future changes in temperature and humidity. An ensemble of projections reveals robust pattern in which a large increase in temperature is accompanied by a reduction in relative humidity but a significant increase in wet-bulb temperature. This increase in TW_{max} is relatively smaller over flat and coastal regions than that over mountainous region. However, the flat and coastal regions characterized by warm and humid present-day climate will be at risk even under modest increase in TW_{max}. The regional extent exposed to higher TW_{max} and the number of days on which TW_{max} exceeds its threshold value are projected to be much higher in RCP8.5 scenario than those in RCP4.5 scenario, thus highlighting the importance of controlling greenhouse gas emissions to reduce the adverse impacts on human health and heat-related mortality.

1. Introduction

The deadly heat waves that have recently occurred worldwide have raised public awareness and concern about their destructive impacts on the heat-related morbidity and mortality as well as economic losses caused by crop failures and water and energy shortages (IPCC, 2007; Wilbanks et al., 2012; LeComte, 2014; Im et al., 2017a, 2017b). Given that the detection and attribution studies on recent climate change strongly support the anthropogenic influences on severe heat waves (Knutson and Ploshay, 2016; Lewis and Karoly, 2013; Fischer and Knutti, 2015), it is reasonable to expect that continuous increases in the concentration of greenhouse gases (GHGs) will further worsen heat stress in the future.

The Coupled Model Inter-comparison Project Phase 5 (CMIP5) multimodel projections forced by elevated GHG concentration show a robust pattern of temperature increase with well-established geographical patterns that are retained over time and across emission scenarios. It is very likely that the higher latitudes of the Northern Hemisphere will continue to experience substantial warming because of anthropogenic emission forcing (IPCC, 2012). In this regard, the tropics, particularly the Maritime Continent, where the magnitude of warming is smaller than the global mean temperature increase (Stocker et al., 2013; see Box TS.6, Fig. 1), have paid relatively less attention to climate change in terms of extreme hot temperature and related heat stress. However, less warming does not necessarily imply that the negative impacts of global warming are accordingly alleviated. Here, we describe three reasons for the tropics' high susceptibility to global warming.

First, in the tropics, the temperature increase expected from anthropogenic emission forcing is large relative to the model uncertainty and the natural variability (Hawkins and Sutton, 2009). Therefore, the signal-to-noise ratio for changes in surface temperature is the highest in the tropics, leading to the lowest uncertainty of temperature projections compared to that in other regions. This is because the background "noise" induced by internal variability is lower in the tropics than elsewhere around the world (Harrington et al., 2016). However, the high latitudes where the largest anthropogenic warming is expected are also characterized by large variability, which may delay the emergence

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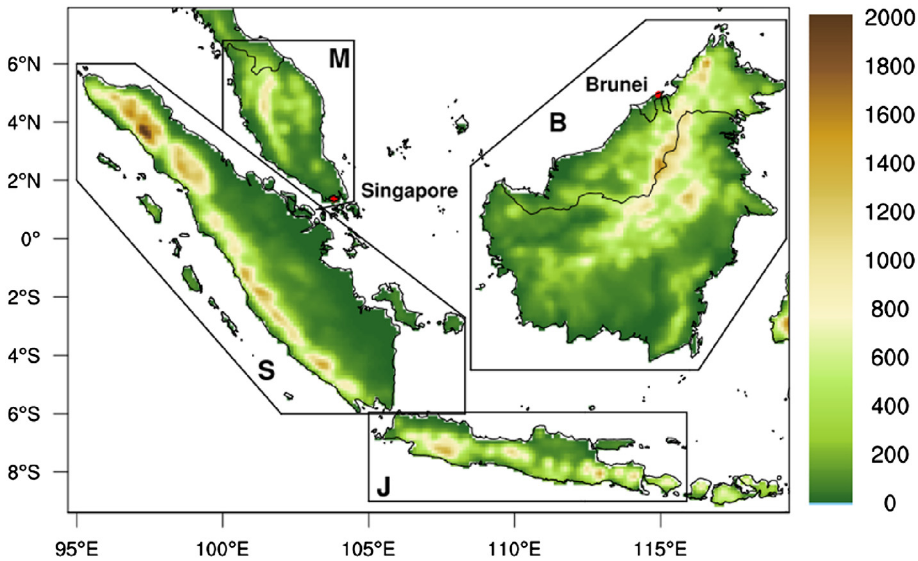

Fig. 1. Domain and topography (unit: m) used for the MRCM simulation. Land areas are divided into four subregions for detailed regional analysis (M: Malay, S: Sumatra, B: Borneo, and J: Java). Two red dots indicate the in situ observational locations within Singapore and Brunei that are used to validate the daily maximum temperature and the daily maximum wet-bulb temperature. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

of significant changes compared to internal climate variability. Furthermore, Hawkins and Sutton (2009) demonstrated that the model uncertainty measured by inter-model difference has a clear maximum at high latitudes. On contrary, the low-latitude countries around tropical areas exhibit the most imminent and robust emergence of hot temperature extremes (Diffenbaugh and Scherer, 2011; King et al., 2015; Mahlstein et al., 2011). This contrasts with the general consensus that high latitudes show the most accelerated warming in response to the increases in GHG concentration.

Second, the humid and hot tropical climate in the present day is particularly vulnerable to the increasing temperature because even modest warming may exceed the critical level of heat stress and become more dangerous and intolerable. In the absence of much seasonal temperature variation in the subequatorial zone, warm days can last almost all the year round. Although people living in these climatic conditions are relatively well acclimatizing to heat stress, there is a limit to acclimatization, which will place upper boundaries on human heat tolerance. Willett and Sherwood (2012) demonstrated that heat events may worsen more in humid tropical regions even if it warms less than the global average, due to greater absolute humidity increases. Therefore, the necessary heat acclimatization may exceed human tolerance, particularly in warm and humid tropical regions under global warming.

Finally, poor populations in areas of low socioeconomic status such as the majority of Indonesia and Malaysia rural areas will be more likely to be adversely affected by extreme heat events. The risk arising from heat stress is a function of both heat wave intensity and the vulnerability of populations influenced by socioeconomic factors (IPCC, 2012). The capacity to adopt and manage the risks of extreme heat is often limited in the tropics (IPCC, 2007). For example, limited access to air conditioning, underdeveloped infrastructure, and less-effective public health systems will greatly amplify the human vulnerability to heat stress.

Despite these foreseeable risks, few studies have comprehensively analyzed heat stress under global warming over the Maritime Continent. To the best of our knowledge, there is only minimal literature on the potential impact of climate changes on heat stress over the Maritime Continent, taking the humidity effect into consideration and using the high-resolution regional climate model (RCM) projections based on multiple global climate models (GCMs) and multiple emission forcings (e.g., RCP4.5 and RCP8.5). Recently, the unprecedented number of climate projections that have been produced within the framework of CMIP5 may provide the most reliable source of information in terms of anthropogenic climate change. However, GCM simulations suffer a significant disadvantage in simulating key climate features over the Maritime Continent (Im and Eltahir, 2017; Kang et al., 2018). Their coarse resolution is not appropriate to resolve the distinct geographical characteristics and to capture climate extremes at small spatial scales. In this regard, we produce fine-scale climate change projections focusing on the western Maritime Continent to investigate the impact of climate change in response to the different levels of emission forcing (RCP4.5 vs. RCP8.5). The three GCM projections participating in CMIP5 that are carefully selected are dynamically downscaled using the latest version of the Massachusetts Institute of Technology (MIT) regional climate model (MRCM). The MRCM simulations with greater regional details (horizontal resolution of 12 km) can increase the value of GCM projections with relatively coarse grids. While Kang et al. (2018) assessed rainfall changes using these high-resolution climate projections, in this study, we emphasize the detailed aspects of extreme hot temperature and resultant heat stress induced by anthropogenic GHG forcings.

2. Experimental design and analysis method

2.1. MRCM experimental design

To better resolve the region-specific changes in terms of geographical patterns and severity of heat stress over the Maritime Continent, the MRCM is used for the dynamical downscaling of global climate projections forced by two Representative Concentration Pathway (RCP4.5 and RCP8.5) scenarios. The MRCM is based on the Abdus Salam International Centre for Theoretical Physics Regional Climate Model Version 3 (RegCM3, Pal et al., 2007), but with several important improvements such as land surface scheme and convection scheme (Im et al., 2014). In particular, Im and Eltahir (2017) applied the MRCM to the western Maritime Continent (same domain as this study, see Fig. 1) and demonstrated that the MRCM with a 12-km horizontal resolution shows reasonable performance in reproducing the rainfall and low-level circulation that vary diurnally and regionally. Therefore, we adopt the same version of the MRCM used by them.

The initial and boundary conditions used to force the MRCM are taken from CMIP5 participant models. Because the RCM simulation strongly depends on the GCM performance, careful selection of the best GCMs is important in the case that a limited number of GCMs are used due to computational burden. In this study, three GCMs are selected based on the stepwise screening process, including the rigorous evaluation of the performance in simulating key climate variables for the historical period over the target domain. More specifically, we first