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Indonesian Climate under 2°C and 4°C Global Warming: Precipitation Extremes

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Indonesian Climate under 2ºC and 4ºC Global Warming: Precipitation Extremes

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Abstract. The Paris Agreement, signed in 2015, is intended to limit global warming well below 2°C. This paper is aimed to assess the potential key impact of 2°C and 4°C global warming on the characteristics of precipitation extremes over Indonesia. For this purpose, the CSIRO-Mk3.6.0 global projections forced by the representative concentration pathway (RCP8.5) scenario is dynamically downscaled using the RegCM modelling system. The results show that under these two global warming level, total annual precipitation (PRCPTOT) will decrease in most regions. Consistently, the dry spell duration (CDD, consecutive dry days) is projected to increase. On the other hand, the frequency and the intensity of precipitation extremes (R50mm and RX1day) are projected with mix increase and decrease tendency. Seasonally, the contrast changing of PRCPTOT is projected. PRCPTOT tends to decrease during dry season (June-July-August, JJA) and tends to increase during wet season (December-January-February, DJF). The similar pattern is found for other indices e.g. CDD, R50mm and RX1day. In general, changes at 4°C global warming are statistically more significant and more intensified compared to that at 2°C. Our findings suggest the benefit of limiting global warming at a lower level.

Keywords : RCP8.5, dry spell duration, total annual precipitation, global warming.

1. Introduction

The Paris Agreement which was signed in December 2015 by world leaders bounds the participated countries to limit global warming well below 2.0°C and to pursue efforts to limit the warming even further to 1.5ºC above the pre-industrial level [1]. A global warming level (GWL) of 2.0°C (above the pre-industrial level) has been considered as a threshold where society has to try to keep, in order to limit the unanticipated effects of anthropogenic climate change. This global ambition is partly pursued by all parties by reducing their national greenhouse emissions where the result should be reported regularly.

In line with the global response to the Paris Agreement, in the last recent years, scientists reported their studies on the potential consequences of different global warming levels at regional and local scale [2–6]. While there are many studies on the topic of global warming level in the literature, this is not a case for Indonesia, a country with highly vulnerable to the climate change impact. Moreover, for the research quantifying differences in precipitation extremes between the 1.5◦C and 2.0◦C global warming levels. Thus, it is an urgent need for more studies on the potential impacts of a 2 ◦C warmer world.

Hence, this paper aims to examine the potential key impacts of climate change on precipitation extremes over Indonesia under 2.0◦C global warming levels. As a comparison, a GWL of 4.0◦C is also investigated to give insight on the response of precipitation extremes if the warming continues with double magnitude. By doing so, we hope to provide a quantitative evaluation of what may occur when the global surface temperature warms reaching 2.0◦C and 4.0◦C which is relevant for policymakers.

2. Data and Methods

In this study, we analysed the downscaling product involving a single global climate model (GCM) and a single regional climate model (RCM) run by the centre for research and development, BMKG. This experiment is intended to participate in the CORDEX-SEA project (Coordinated Downscaling Experiment – Southeast Asia) [7]. In this collaborative experiment, BMKG contributes to the project by downscaling the CSIRO-Mk3.6.0 global model using a regional model of RegCM4. The control simulations driven by observed natural forcing and observed GHG (greenhouse gases) were run for period of 1950–2005 while climate projections forced by two RCPs (Representative Concentration Pathways [8] were run for period of 2006-2100. Even though RCP4.5 is also available, the RCP8.5 is selected in this paper because the projection under RCP4.5 never reaches global warming level of 4°C. Also, RCP8.5 is considered as a realistic business-as-usual scenario referring to the current trajectory of greenhouse gases emissions. The satellite-based precipitation product i.e. TRMM 4B42v7 [9] is also used to validate the model.

To characterize the precipitation extremes, four indices of ETCCDI (Expert Team for Climate Change Detection and Indices) [10] were selected i.e. PRCPTOT (annual/seasonal total of wet days), CDD (consecutive dry days), R50mm (frequency of days with rainfall at least 50mm) and RX1day (annual/seasonal maxima of daily rainfall). For more detailed characterization of possible changes, the analysis was also performed based on sub-country level (Figure 1) partly based on Kang et al., [11], particularly over Sumatra and Java. This sub-country boundary is also an extension of regionalization in Amsari et al., [12] who used 8 sub-countries in their El Nino impact analysis.

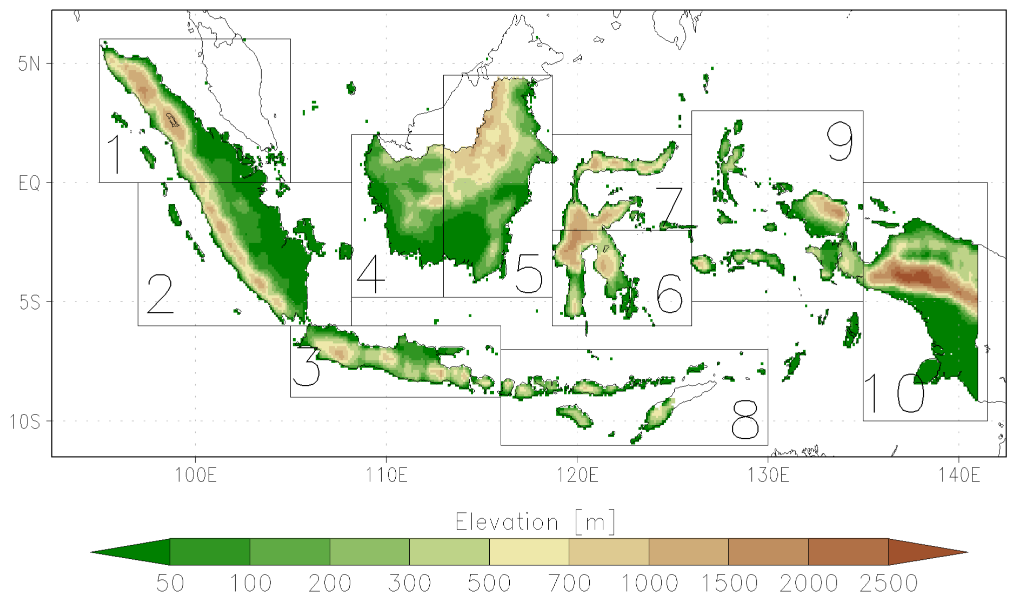

Figure 1. Indonesia and its topography. Boxes indicate the ten sub-countries level used for more detailed analysis. 1 for northern Sumatra, 2 for southern Sumatra, 3 for Java-Bali, 4 for western Kalimantan, 5 for eastern Kalimantan, 6 for southern Sulawesi, 7 for northern Sulawesi, 8 for Nusa Tenggara, 9 for Maluku and western Papua, 10 for eastern Papua.

The timing year of GWL (global warming level) of 2°C and 4°C was defined based on study by Karmalkar & Bradley [13]. They analysed 32 GCMs from CMIP5 and found that the ensemble mean of those GCMs is projected to cross the threshold of 2ºC and 4ºC by 2041 and 2083, respectively (Figure 2). However, it is reported also that there is large spread among ensemble member suggesting the uncertainty in the exact timing of thresholds. Hence, to reduce the uncertainty, the climate over 20-year period around the timing year is chosen for the analysis. To be more specific, for GWL 2ºC (and 4ºC), the changes are calculated by subtracting indices over the 2031–2050 (2073-2092) period with indices over reference period i.e. 1986-2005. Additionally, besides assessing the magnitude of possible changes, we also evaluate the significance of changes using Monte-Carlo test [14].

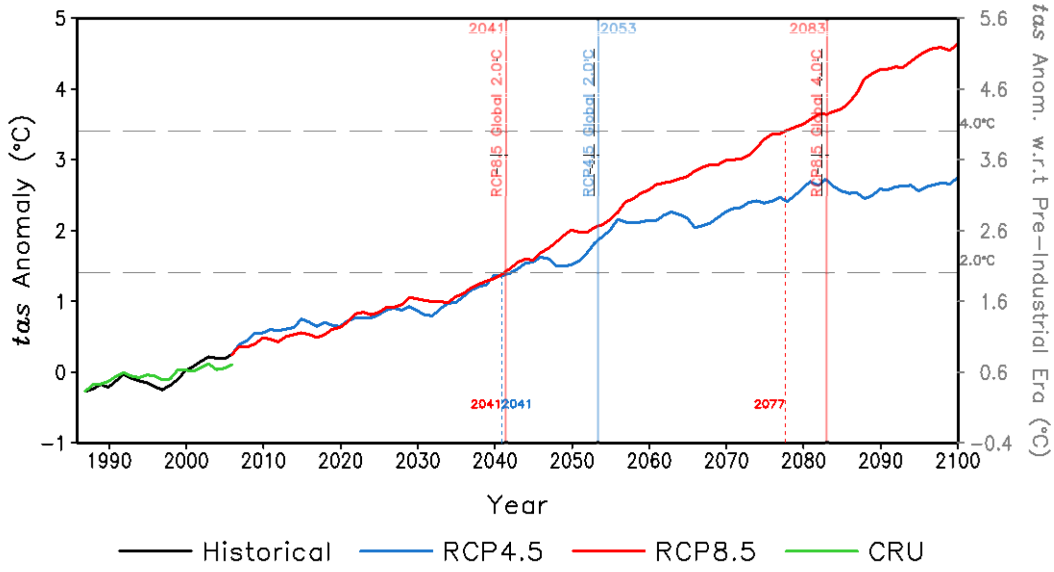

Figure 2. Annual mean of surface temperature anomalies in the CSIRO(RegCM) simulation relative to reference period of 1986–2005 (left Y-axis) and relative to Pre-industrial period (right Y-axis) under RCP4.5 (blue line) and RCP8.5 (red line) averaged over CORDEX-SEA domain. Also plotted in the figure is the timing of global warming level (GWL) based on GCMs analysed in Karmalkar & Bradley [13] (solid vertical line) and based on CSIRO(RegCM) (dashed vertical line).

3. Results and Discussion

3.1. Model Validation

Figure 3 presents the spatial pattern of four indices during 1998-2005, a common period for those two datasets i.e. TRMM and simulation data. The model simulates realistically the spatial pattern of observed PRCPTOT but with slightly higher magnitude indicating the wet bias of model. In TRMM data, PRCPTOT of more than 4000 mm is only found over mountainous area in Papua Island. On the other hand, it is observed over all islands in model data. The wet bias of model is also shown by CDD index even though its spatial feature in TRMM data is captured well in model data. The observed TRMM data estimates the largest CDD value (over Nusa Tenggara Islands) is more than 50 days while in the simulation data, it is around 30-50 days. Over Kalimantan and Sumatra, the difference in CDD between TRMM and model data is also clear where the shortest dry spell (lowest CDD) is around 5-10 days in TRMM and less than 5 days in model data. Similarly, the pattern of observed R50mm and RX1day are spatially replicate in model data with wet bias in magnitude. Overall, the model data is able to reproduce the spatial pattern of observed indices. However, the model tends to produce more rainfall (higher PRCPTOT), more rainy days (shorter CDD), more frequent heavy rainfall (higher R50mm) and more intensified extreme rainfall (higher RX1day). The wet bias in the output of RegCM downscaling of CORDEX-SEA is known related to the selection of parameterization [15].

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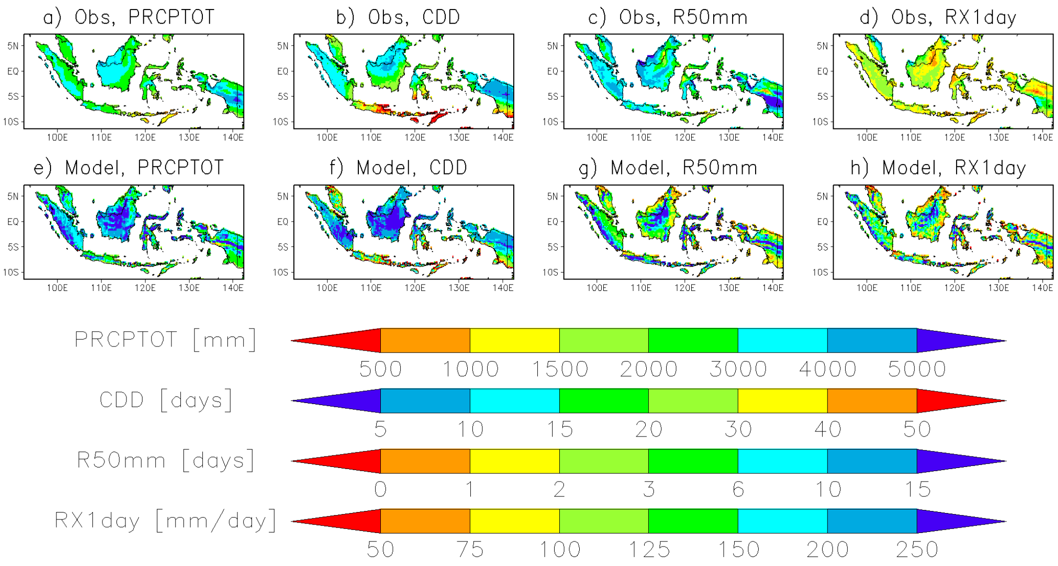

Figure 3. The spatial pattern of indices based on TRMM 4B32v7 (top row) and CSIRO(RegCM4) (bottom row) during 1998-2005.

3.2. Projection of Annual Indices

The future projection of PRCPTOT under GWL 2ºC and 4ºC is illustrated in Figure 4. Under 2ºC global warming, PRCPTOT over Indonesia is projected to decrease with magnitude up to -20%, particularly over south of equator line. In contrast, for the area north of equator line, PRCPTOT is projected to increase including northern Sumatra, western and eastern Kalimantan, northern Sulawesi and northern Papua. The decrease of PRCPTOT is significant over South Kalimantan, East Java, Bali, Nusa Tenggara and part of Papua. The increase in PRCPTOT over northern Kalimantan and northern Papua is also significant.

Under a warmer environment, GWL 4ºC, the decrease of PRCPTOT becomes more obvious covering wider area compared to that under GWL 2ºC, in particular over Kalimantan and Sulawesi. We found that the magnitude of decrease is also larger in this warmer temperature. Over Java, Bali and Nusa Tenggara the PRCPTOT may decrease up to -50% while over Sumatra, Kalimantan, Sulawesi and Papua the decrease in PRCPTOT may up to -30%. On the other hand, the increase of this index over northern Sumatra and northern Papua is found to have a larger magnitude as well. Besides, the negative change is statistically significant over almost all areas including a large part of Sumatra, Kalimantan, Sulawesi and Papua where the decrease is not significant in the GWL 2ºC. Overall, under GWL 2ºC, PRCPTOT decrease up to -20% and the decrease becomes more intensified and more significant when global temperature warming reaches 4ºC.

In figure 5, the projection of CDD when the global mean temperature reaches 2°C and 4°C above pre-industrial level is presented. Consistent with PRCPTOT, the CDD index shows a drying tendency both under GWL 2ºC and 4ºC. The CDD is projected to lengthen up to 20% over Java, Bali, Nusa Tenggara, southern Sumatra, Kalimantan, Sulawesi and southern Papua. Over certain spots such as South Sumatra and Central Kalimantan, even the increase of CDD reaches 30%. Also seen from the figure 5, the magnitude of increase of CDD under 4ºC is higher than that under 2ºC.

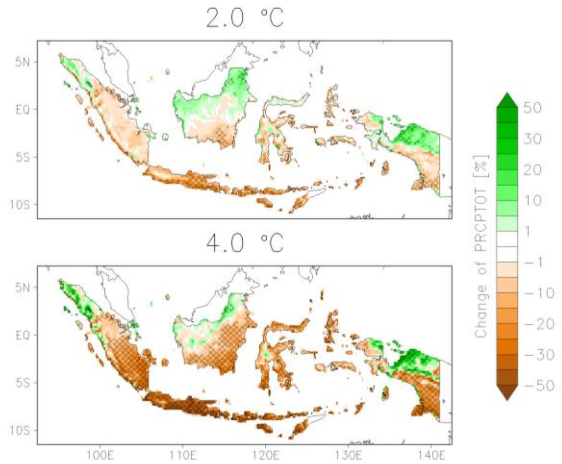

Figure 4. Projected changes of PRCPTOT under GWL 2ºC (top) and 4ºC (bottom). Areas with statistically significant changes are marked by hatching.

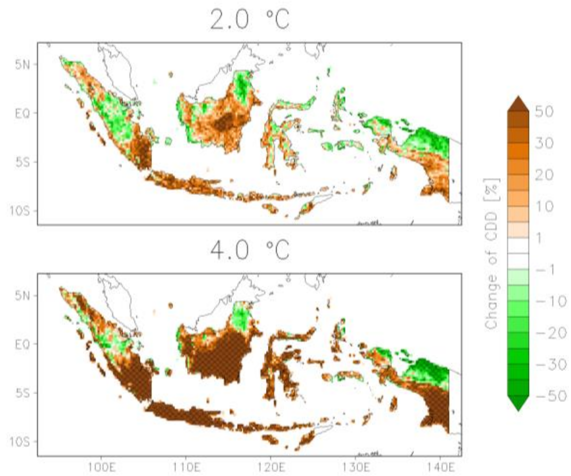

Figure 5. Projected changes of CDD under GWL 2ºC (top) and 4ºC (bottom). Areas with statistically significant changes are marked by hatching.

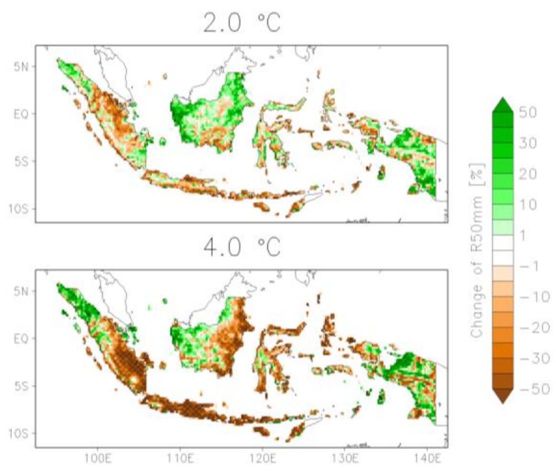

Figure 6. Projected changes of R50mm under GWL 2ºC (top) and 4ºC (bottom). Areas with statistically significant changes are marked by hatching.

Figure 6 displays the possible changes of R50mm under 2^{o}C and 4^{o}C global warming. Under 2^{o}C global warming, R50mmm is projected to increase over northern Sumatra, western and eastern Kalimantan and over Papua. In contrast, it may decrease over Central part of Sumatra, Java, Bali-Nusa Tenggara and most of Sulawesi. Under 4^{o}C global warming, while the other parts show similar characteristics with that under 2^{o}C, southern Sumatra and eastern Kalimantan depict contrast pattern. In the southern Sumatra and eastern Kalimantan where R50mm are projected to increase under 2^{o}C, it is projected to decrease under 4^{o}C global warming with high magnitude (> 30%) and are statistically significant. In general, the magnitude of both increase (e.g. over northern Sumatra) and decrease (e.g. over Java and Bali-Nusa Tenggara) is higher compared to that under 2^{o}C. Differently, the changes of RX1day is less spatially coherent (Figure not shown). Mixed positive and negative changes are projected over all islands, except Java, Bali and Nusa Tenggara Islands under 4^{o}C global warming that may indicate a more independent characteristic of extreme intensity. Also, we note that the changes of RX1day are not significant.

3.3. Projection of Seasonal Indices

To get more detailed characteristics, the seasonal changes are also assessed. As shown in Figure 7, PRCPTOT is projected to decrease almost over whole country during JJA under those two GWLs with magnitude of 5-50%. Under 4^{o}C global warming, the negative change is found to be significant everywhere. During DJF, the contrast tendency is found. The PRCPTOT is projected to increase during this season except over Java, Bali, Nusa Tenggara, Maluku and small part of Papua. Over Kalimantan, the increase in PRCPTOT is significant under both 2^{o}C and 4^{o}C global warming.

For CDD, the changes during JJA is consistent with that for PRCPTOT (Figure 7). The lengthening of CDD (an indication of drying tendency) is projected by 10-50% particularly over Sumatra, Kalimantan, Java, Bali and Nusa Tenggara under 2^{o}C and including Sulawesi, Maluku and Papua under 4^{o}C global warming. Moreover, the drying tendency is statistically significant for almost all areas under 4^{o}C global warming. During DJF, the CDD shows a wetting tendency particularly over Sumatera, Kalimantan and Papua. Over southern part of the country (e.g. Java, Bali, Nusa Tenggara) the drying tendency is found, similar to that during JJA. The significant changes are seen only under 4^{o}C global warming, in particular over Java (significant drying) and over Papua (significant wetting).

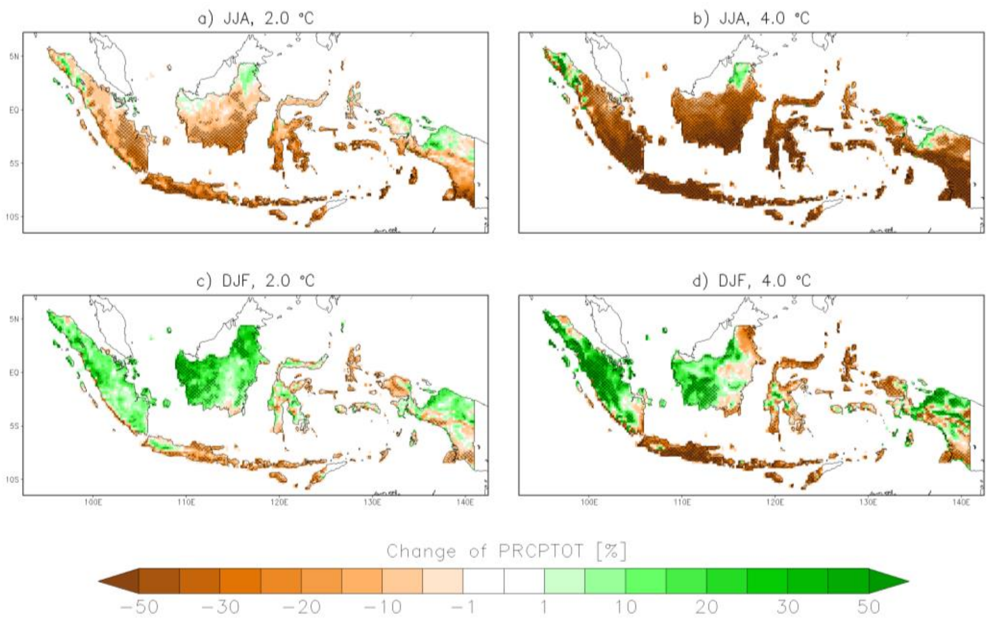

Figure 7. Projected changes of PRCPTOT under GWL 2^{o}C (left) and 4^{o}C (right) for JJA (top) and DJF (bottom). Areas with statistically significant changes are marked by hatching.

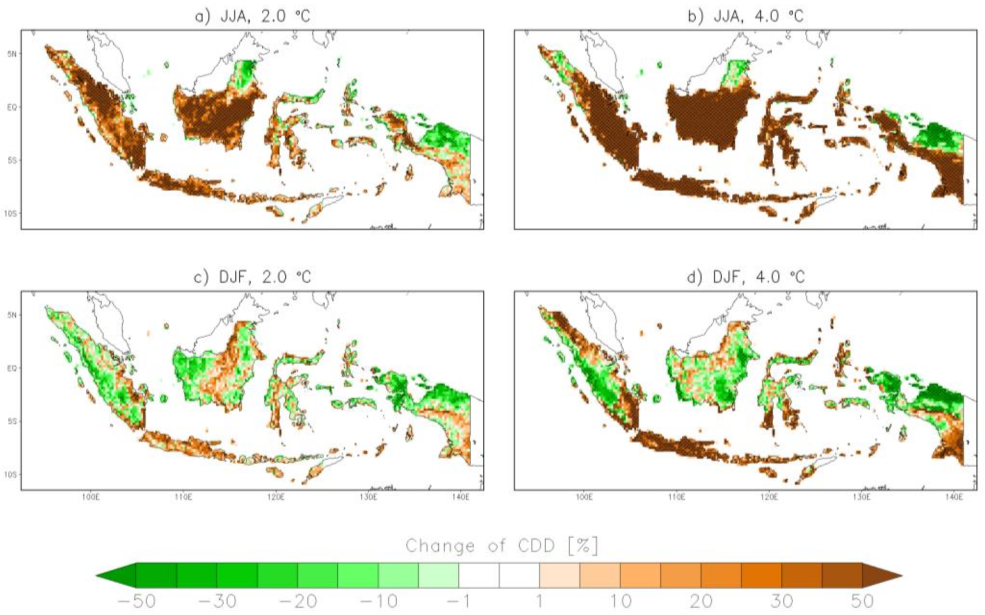

Figure 8. Projected changes of CDD under GWL 2°C (left) and 4°C (right) for JJA (top) and DJF (bottom). Areas with statistically significant changes are marked by hatching.

A similar drying tendency is also projected for R50mm and RX1day during JJA both under those two GWLs. For R50mm, the changes are generally less spatially coherent (Figure not shown) while for RX1day, the drying tendency is clearly observed over most of the country. The changes of R50mm and RX1day are generally not significant under GWL 2°C and 4°C except for RX1day where the drying tendency is significant and in high magnitude under 4°C GWL (Figure not shown). During DJF, those two indices show a wetting tendency over Sumatera, Kalimantan and small part of Papua and a drying tendency over eastern Java, Bali, Nusa Tenggara and Maluku. The wetting tendency over Sumatera and drying tendency over Java during this wet season are significant under 4°C global warming both for those two indices.

3.4. Sub-Country Analysis

Figure 9 presents the projected changes of all studied indices for each sub-country. In general, the changes of indices under 4°C global warming is in similar direction but with higher magnitude compared to that under 2°C global warming. The changes of all indices under 2°C global warming are less than 30 % for all sub-country while those under 4°C global warming may reach more than 100% (e.g. CDD over Java-Bali, sub-country 3). From this sub-country analysis, some remarkable findings are found. First, we note that Java-Bali (sub-country 3), northern Sulawesi (sub-country 7) and Nusa Tenggara (sub-country 8) show a consistent drying tendency in all indices. Over those regions, the decrease in PRCPTOT (decrease in annual rainfall) is followed by increase in CDD (longer dry spell), decrease in R50mm (lower frequency of very heavy rainfall) and decrease in RX1day (lower magnitude of annual maxima of daily rainfall). This consistent drying tendency is in agreement with seasonal analysis showing a negative changes both during dry season (JJA) and wet season (DJF). Second, there are also regions (e.g. sub-country 4, western Kalimantan) where, under 2°C global warming, the increase in CDD is accompanied by increase in RX1day. CDD, in general, represents a condition of dry season while RX1day represents a condition of wet season. Thus, this combination of changes indicates a drier dry season followed by a wetter wet season.

Overall, we found that the country may experience drying tendency in particular over southern part when global warming reaches 2°C, relative to pre-industrial level. This drying tendency may occur with higher magnitude and cover wider area when the global surface temperature warms with double magnitude. With different emphasize, study by Kang et al., [11] found a similar drying tendency in the future climate of western Maritime Continent (WMC). They proposed that the main mechanism behind the simulated decrease in rainfall over the WMC is the enhancement and expansion of sinking motion of Hadley circulation under global climate change, particularly in RCP8.5 scenario. Their explanation is in agreement with that stated by Fu [16].

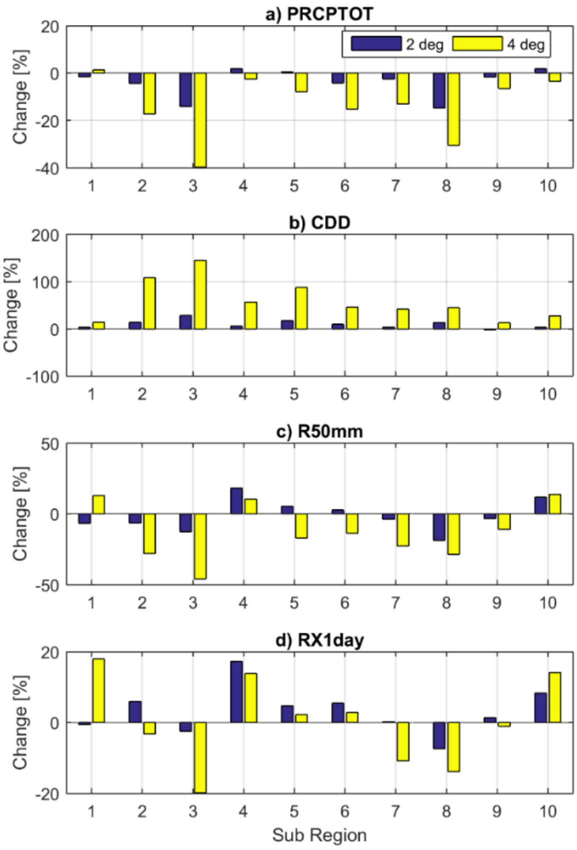

Figure 9. Projected changes (in %) in annual indices under GWL 2°C (blue) and 4°C (yellow) relative to the reference period (1986–2005) for RCP8.5. The changes are shown in term of areal mean for each of the 10 sub-country (Figure 1).

4. Conclusion

The possible changes of annual and seasonal precipitation extremes over Indonesia are assessed in this study for the case of global mean temperature reaching 2°C and 4°C above pre-industrial level under RCP8.5 as the unmitigated climate change scenario. The assessment is based on the downscaling product involving the CSIRO-Mk3.6.0 as GCM (global climate model) and RegCM as the regional modelling system. We find that the decrease in PRCPTOT and the increase in CDD over most of the country is the most notable changes under those two global warming levels. On the other, mixed negative and positive changes are found for R50mm and RX1day. Seasonally, the southern part of the country may experience consistent drying tendency both during dry and wet season. These findings suggest that there will be some implications for water resources and food security if we are not able to mitigate well the global warming so that it continues above 2°C.

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