

High Resolution Climate Change Projection under SRES A2 Scenario during Summer and Winter Monsoons over Southeast Asia using PRECIS Regional Climate Modeling System

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Abstract—Climate change is the significant change of weather pattern over long period of time and it is related to interaction of complex system. Climate change brings adverse impacts to Southeast Asia since most economics are relying on agriculture and natural sources. The aim of this paper is to investigate and project the future climate for Southeast Asia by the end of 21st century. The PRECIS-RCM (Providing Regional Climates for Impact Studies) is the latest version of Hadley Centre model and used to downscale global data from HadAMP-GCM to regional data by generating the A2 future climate change scenario. Under the A2 climate scenario, the surface temperature is projected to increase during DJF and JJA (3.0°C and 3.1°C). T-test shows that surface temperature changes of all seasons were statistically significant at 95% confidence level over the whole SEA area. In response to the warming across the region, there was a reduction in cloud fraction and increased in solar radiation. Meanwhile, the future changes in precipitation have shown a high degree of variability. These results suggest that significant changes particularly the surface temperature and precipitation could potentially increase the climate-related risks and vulnerability in the region.

Keywords—Climate Change; Cloud; Precipitation; PRECIS; Solar Radiation; Surface Temperature; Southeast Asia.

Abbreviations—Climate Research Unit (CRU); December-January-February (DJF); ECMWF Re-Analyses-40 (ERA-40); Global Circulation Model (GCM); Intergovernmental Panel on Climate Change (IPCC); June-July-August (JJA); March-April-May (MAM); Providing Regional Climates for Impact Studies (PRECIS); Regional Climate Model (RCM); September-October-November (SON).

I. INTRODUCTION

CLIMATE change is the significant change of weather pattern over long period of time and it is related to interaction of complex system. These changes are particularly critical, particularly in areas with population and economics are relying on agriculture and natural sources such as in Southeast Asia. Therefore, it is equally important to understand the climate change impacts for the purpose of adaptation and mitigation planning. Hence, projection long-term future climate trend is necessary to clearly capture future climate change [IPCC, 2007].

Southeast Asia (SEA) is a sub-region of Asia and is located to the east of India, south of China, west of New Guinea and north of Australia. It can be geographically divided into two sub regions; continental Southeast Asia and maritime Southeast Asia. Continental Southeast Asia includes Cambodia, Laos, Myanmar, Thailand, Vietnam and Peninsular Malaysia while maritime Southeast Asia includes Borneo island (East Malaysia, Brunei and Indonesia), the Philippines, Singapore and East Timor. Based on the IPCC Report (2007), SEA is one of the regions that are seriously affected by the adverse impacts of climate change due to the high economic reliance on agriculture and nature resources. Despite the recognition of uncertainties in regional climate

change simulations, understanding the impacts of climate change on various sections is crucial and important in the management of climate change vulnerability and risk. A recently developed RCM from the Hadley Centre, UK, and called PRECIS (Providing Regional Climates for Impact Studies) has been used in this study to investigate climate changes in SEA. The main objective of the investigation presented in this paper is to project and assess regional climate changes in terms of surface temperature, total precipitation, cloud and solar radiation under the SRES A2 scenario. It is expected that the improved understanding on these issues will be useful to the establishment of vulnerability and risk assessment methodology and to the development of technologies and adaptation on policy to reduce human risks and increase security.

II. RELATED WORKS

Global Circulation Model (GCM) can be used for future climate change research. However, GCM was conducted in low resolution and is not suitable for local scale assessment. Therefore, a Regional Climate Model (RCM) with high resolutions model that covers a limited area of the globe should be utilized. In the last 15 years, Regional Climate Models (RCMs) have been recognized as an excellent tool in a number of climate studies in smaller regions for topics such as those in paleoclimate studies [Hostetler et al., 1994], atmospheric chemistry studies [Stevenson et al., 2005; Sentian, 2009], climate impact studies [Huntingford et al., 2003], temperature extremes [Mearns, 2004], water resources [Stone et al., 2003], agriculture [Challinor et al., 2006], energy demand [Lalas et al., 2005], forest fires [Wotton et al., 1998] and biogenic emissions [Sentian et al., 2011]. RCMs have well-known drawbacks in terms of dependency on input from the GCM driving model, the lack of two-way nesting with its driving GCM, as well as computational cost. Nevertheless, RCMs are widely used in climate change investigations, where they provide higher spatial and temporal resolution information for a number of climatic variables while still providing better representation than the GCM for some weather extremes.

Several countries in Asia have used RCM system for the purpose of investigating future regional climate change. For example, Xu et al., (2006) had conducted an experiment by using PRECIS to investigate climate scenarios for the recent past (1961-1990), the SRES A2 (2071-2100) and the SRES B2 (2071-2100) of the IPCC emission scenarios in China. The results showed that under the SRES A2, the average surface air temperature would increase by about 3.89°C at the end of 21st century. In addition, the future changes of precipitation in China shows a similar pattern as the average surface temperature. The percentage of precipitation increased by 12.9% under the A2 scenario at the end of this century. Another similar investigation by Kumar et al., (2006) in India has found that surface air temperature and precipitation show similar patterns of future changes under both scenarios. However, the annual mean surface air

temperature increased in the range 3–5°C under the SRES A2. Meanwhile, the percentage of annual mean precipitation rose around 20% for the entire Indian region.

A recent study over SEA had been conducted by Chotamonsak et al., (2011) to project future climate change from 1990–1999 to 2045–2055 by using a Weather Research Forecast (WRF) RCM under the A1B emission scenario. According to the authors, the temperature rises in the range <0.1–3°C depending on the location and season. The precipitation increased in average, but decreased during the rainy season. An earlier study by Chinvarno (2009) in some parts of the Southeast Asia region, which applied PRECIS–RCM to downscale ECHAM4–GCM data during present day (1970-1999) and future projection (2010-2100), has found that the range of average maximum temperature and average minimum temperature in Thailand and SEA increasing between 2°C and 3°C during the middle of the century and the trend continued until the end of the century. The region of Thailand and some parts of SEA showed higher precipitation towards the end of the century. The percentage of high precipitation reaches 25% or even 50% in certain areas of Thailand. By utilizing downscaling technique, the World Bank Group (2011) indicated that mean annual temperature would increase in the range 0.7°–2.7°C by the 2060s and 1.4°C–4.3°C by the 2090s across the Cambodian region. The precipitation in the region was projected to increase during the monsoon season, though the variability of changes was unclear due to large model uncertainty.

III. METHODOLOGY

This study utilised the latest version of regional climate model (PRECIS) developed by Hadley Centre UK. PRECIS is a nested RCM, which utilised output from GCM simulation. It provided the boundary conditions and also the time-dependent lateral boundary condition (LBC). The model was developed in a one way nesting mode to ensure that RCM outputs are consistent with GCM outputs [Gordan et al., 2000]. The atmospheric component (HadAM3H) of HadCM3 is the basic component of PRECIS RCM. The detail description and concept of the model is largely discussed in Jones et al., (2004). HadAM3H is an improved or enhanced version of HadCM3 [Gordon et al., 2000]. The PRECIS is a regional climate model with atmospheric and land surface model of limited area and contain a high resolution of $0.44^\circ \times 0.44^\circ$ (2500 km^2) or $0.22^\circ \times 0.22^\circ$ (625 km^2) and timestep of 5 minutes [Jones et al., 2004]. The model is developed under HadAM3H with a spatial resolution of $1.875 \times 1.25^\circ$. Then, HadAM3H itself used sea surface boundary conditions from HadCM3, an AOGCM with spatial resolution of $3.75 \times 2.5^\circ$ [Arnell, 2003]. The PRECIS contains 19 levels in atmosphere (from the surface to 30km in the stratosphere), four levels in the soil and up to 0.5hPa. The same formulation occurs within GCM (HadAM3P) [Hudson & Jones, 2002].

In this paper, PRECIS RCM is used to downscale HadAM3H GCM data based on the IPCC A2 scenario with present-day (1961-1990) and future-day (2071-2100). The

data was downscale from $0.44^{\circ} \times 0.44^{\circ}$ to $0.22^{\circ} \times 0.22^{\circ}$. The coordinate of domain research is 30°N to 15°S and 90°E to 140°E in Southeast Asia.

IV. RESULT AND DISCUSSION

The results are presented in two parts: first, the evaluation of regional climate model results by comparing them with the dataset from CRU and ERA-40; secondly, the investigation of climate changes under the A2 climate scenario. In this paper, surface temperature, precipitation, cloud fraction and solar radiation change are discussed. In addition, discussion will be limited to the climate change during the winter season, which is denoted as DJF (Dec-Jan-Feb) and summer season, which is denoted as JJA (Jun-Jul-Aug). In this paper, intermediate periods are not discussed; these are denoted as MAM (Mar-Apr-May), and SON (Sep-Oct-Nov).

4.1. Regional Climate Model Evaluation

4.1.1. Evaluation between RCM and CRUDAT

The observed CRU data were regridded to the RCM grid, and only land points were used in the interpolation. The mean surface temperatures over the land were higher in the PRECIS-RCM compared to the CRU in all seasons with differences of about 0.82°C (3% overestimated) during DJF and 0.95°C (4% overestimated) during JJA. In terms of correlation between the simulated surface temperature by PRECIS-RCM and observed (CRU), high correlations of about 0.7 were observed during DJF and JJA. The calculated

Fractional Bias (FB) between the simulated (PRECIS-RCM) and observed (CRU) was less than zero and the FB values were relatively very small. Relatively, there was less systematic error for the simulation of surface temperature using PRECIS-RCM for SEA. The Normalised Mean Square Error (NMSE) of 0.004 during DJF and 0.003 during JJA indicated a relatively high efficiency of the PRECIS-RCM in simulating surface temperature. Generally, seasonal mean surface temperature simulated by PRECIS-RCM compared well with the observed CRU climatology in terms of the large scales spatial features.

For total precipitation, the mean differences were relatively small, from 0.42 mm/day (6% overestimated) during DJF and 0.42 mm/day (11% underestimated) during JJA. The correlations between the simulated precipitation (PRECIS-RCM) and observed (CRU) in all seasons were relatively high, between 0.6 and 0.8. The calculated values of Fractional Bias (FB) were also small, indicating a good performance of the PRECIS-RCM in simulating precipitation over the land in SEA. The relatively small NMSE values (between 0.009 and 0.033) also indicated a high efficiency of PRECIS-RCM in the regional simulation of total precipitation.

The performance of PRECIS-RCM in simulating total clouds was good, with small differences in the total cloud mean for all seasons and relatively very small values of FB and NMSE. Correlation between the simulated and observed total cloud during both DJF and JJA was high, but relatively small during other seasons (MAM and SON).

Table 1: Comparison of seasonal response statistics between the Baseline scenario and CRU datasets over land grid points. The area-averaged mean and spatial standard deviation of the response are shown, together with the Fractional Bias (FB), Normalised Mean Square Error (NMSE), and Correlations between the Baseline and CRU datasets

Variables		Baseline		CRU		Fractional Bias (FB) [%]	Normalised Mean Square Error (NMSE)	Correlation
		Mean	sd	Mean	sd			
Surface Temperature ($^{\circ}\text{C}$)	DJF	26.88	0.24	26.06	0.24	-3.1	0.0004	0.7
	MAM	27.12	0.21	26.06	0.20	-4.0	0.003	0.4
	JJA	26.59	0.15	25.61	0.16	-3.7	0.003	0.7
	SON	25.36	0.34	24.11	0.46	0.3	0.004	0.5
Precipitation (mm/day)	DJF	7.53	1.10	7.11	1.10	-5.8	0.025	0.7
	MAM	6.97	0.93	6.97	0.90	0.1	0.009	0.8
	JJA	5.73	0.94	6.46	0.87	11.9	0.033	0.7
	SON	6.16	1.24	6.45	0.64	3.7	0.037	0.6
Total Cloud (fraction)	DJF	0.62	0.04	0.61	0.01	-0.9	0.004	0.9
	MAM	0.72	0.03	0.70	0.01	-3.3	0.003	0.4
	JJA	0.67	0.04	0.65	0.01	-2.1	0.003	0.7
	SON	0.61	0.04	0.62	0.02	0.4	0.004	0.5

4.1.2. Comparison with ERA-40 Reanalysis

The PRECIS-RCM, driven by the GCM lateral boundary, was also compared to the RCM forced by ERA40-Reanalysis data in order to evaluate the internal model error of the PRECIS-RCM. Table 2 shows the comparison of seasonal response statistics between simulations from PRECIS-RCM and RCM-ERA40 for Baseline scenarios. In all seasons, the surface temperatures over the region simulated by PRECIS-RCM were well reproduced in RCM-ERA40. The seasonal

mean differences were relatively small, between 0.13°C and 0.15°C . The mean surface temperatures were underestimated by 0.6% and 0.5% during DJF and JJA respectively. In comparison with RCM-ERA40, most of the spatial features of the seasonal circulation of precipitation over SEA were well represented in PRECIS-RCM (F8). The total precipitation differences between PRECIS-RCM and RCM-ERA40 were in the range of -0.02 mm/day to 0.09 mm/day. During DJF, the mean precipitation was overestimated by

0.5% but underestimated by 3% underestimated during JJA (Table 2). Although highly correlated, large areas over the region showed significant differences (at 95% level) in simulated seasonal mean of total precipitation between

PRECIS-RCM and RCM-ERA40. The inherited circulation bias from the driving GCM through the lateral boundaries of the PRECIS-RCM domain could be an important factor to the precipitation bias over SEA.

Table 2: Comparison of seasonal response statistics between the Baseline scenario and ERA40. The area –averaged mean and spatial standard deviation of the response are shown, together with the Fractional Bias (FB), Normalised Mean Square Error (NMSE), and Correlations between the Baseline and ERA40

Variables		Baseline		ERA40		Fractional Bias (FB) (%)	Normalised Mean Square Error (NMSE)	Correlation
		Mean	sd	Mean	sd			
Surface Temperature (°C)	DJF	25.24	0.15	25.39	0.15	-0.6	0.001	0.92
	MAM	26.85	0.43	27.06	0.47	-0.8	0.001	0.90
	JJA	27.14	0.13	27.27	0.17	-0.5	0.001	0.91
	SON	26.57	0.36	26.72	0.30	-0.5	0.001	0.94
Precipitation (mm/day)	DJF	5.24	0.53	5.22	0.48	0.5	0.001	0.96
	MAM	5.46	1.29	5.33	1.08	-2.4	0.002	0.94
	JJA	8.37	0.07	8.61	0.02	-3.0	0.001	0.72
	SON	7.25	0.58	7.34	0.72	-1.3	0.001	0.89
Total Cloud (fraction)	DJF	0.61	0.03	0.60	0.01	1.2	0.001	0.96
	MAM	0.61	0.05	0.61	0.05	0.3	0.000	0.97
	JJA	0.72	0.01	0.73	0.01	-1.0	0.001	0.88
	SON	0.67	0.02	0.67	0.03	-0.8	0.001	0.97
Solar Radiation (Wm ⁻²)	DJF	214.69	11.91	215.99	11.34	-0.6	0.002	0.88
	MAM	239.24	9.83	241.14	9.83	-0.8	0.002	0.87
	JJA	213.54	3.11	212.15	3.15	0.7	0.003	0.90
	SON	220.30	5.45	220.47	5.37	-0.1	0.002	0.92

Seasonal means of total clouds across the region during the inter-monsoon periods (MAM and SON) were reproduced by PRECIS-RCM but were overestimated by 1.2% during DJF and underestimated by 1% during JJA (Table 2). Similarly with other climatic variables, the seasonal mean of solar radiation simulated by PRECIS-RCM reproduced most of the spatial features of the seasonal circulation from RCM-ERA. The mean solar radiation was underestimated by 0.6% during DJF and 0.1% during JJA. Statistically, mean differences were found to be significant at the 95% confidence level in some areas of the region.

4.2. Climate Changes in Southeast Asia

4.2.1. Surface Temperature

The simulated seasonal mean and seasonal cycle of average surface temperatures of the three member ensembles for the baseline scenario is shown in figure 1. The surface temperatures simulated in the A2 scenarios suggest a linear response to the emission forcing. The projected future mean surface temperatures over SEA were 28.2°C during DJF and 30°C during JJA. Relative to the baseline scenario, the A2 future scenario over SEA showed an average surface warming in the region of 3°C during DJF, and 3.1°C during JJA (Figure 2). Surface temperature changes in all seasons were statistically significant at 95% confidence level over the whole SEA domain (not shown). Comparatively, higher temperature changes were observed over the land than over the sea. The projected future mean surface temperatures under A2 scenario over SEA were found to be higher than those of the previous simulation by McGregor et al., (1998) using DARLAM, a fine resolution (44km) regional climate

model following the IS92a scenario from IPCC (1996). In the studies by Hori and Ueda (2006) using a composite of nine coupled atmosphere-ocean GCMs have revealed that SEA region will experience drier and warmer conditions during the northeast monsoon (DJF) and southwest monsoon (JJA) at the end of the 21st century (2081-2100) with projected temperature to increase between 2.2°C and 2.8°C.

4.2.2. Total Precipitation

In term of precipitation, the simulated total precipitation in the baseline scenario over SEA was markedly seasonal, with relatively lower precipitation over the continental region during DJF and higher over the sea (Andaman Sea/Bay of Bengal and South China Sea/Philippines Sea) during JJA (Figure 3). The results indicated a larger degree of variability between simulations. The projected future total precipitations in the A2 scenario were 4.8 mm/day during DJF and 8.6 mm/day during JJA. Relative to the Baseline scenario, the A2 future scenario over SEA showed a small reduction in total precipitation of about -0.4 mm/day during DJF but a small increment of about 0.2 mm/day during JJA (Figure 4). These changes accounted for the 8% reduction (DJF) and 3% increment (JJA) of total precipitation over the region. Future changes in total precipitation (with less than -1 mm/day) mostly over the sea (South China Sea, Celebes Sea and Andaman Sea) during DJF and over a larger area over the sea and insular region (southern Sumatra, southern Borneo, Mindanao, Java and Sulawesi) during JJA were found to be statistically significant at 95% confidence level (Figure 5). The largest changes were increases over the west Pacific Ocean and Bay of Bengal during JJA.

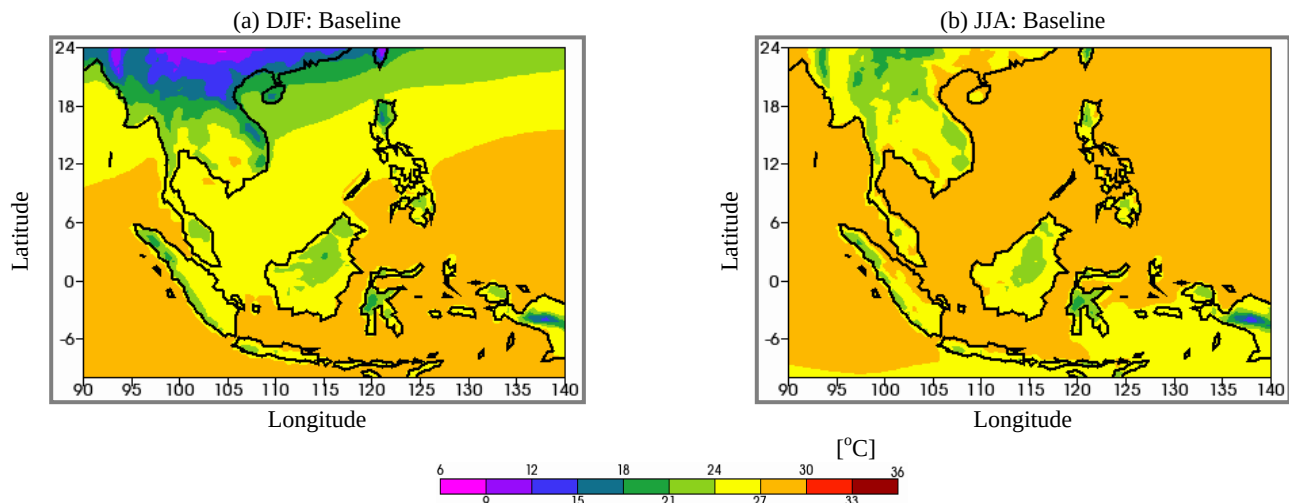


Figure 1: Baseline: Seasonal variability of surface temperature ($^{\circ}\text{C}$) over SEA for the Baseline (1961-1990) during (a) DJF (December to February) and (b) JJA (June to August)

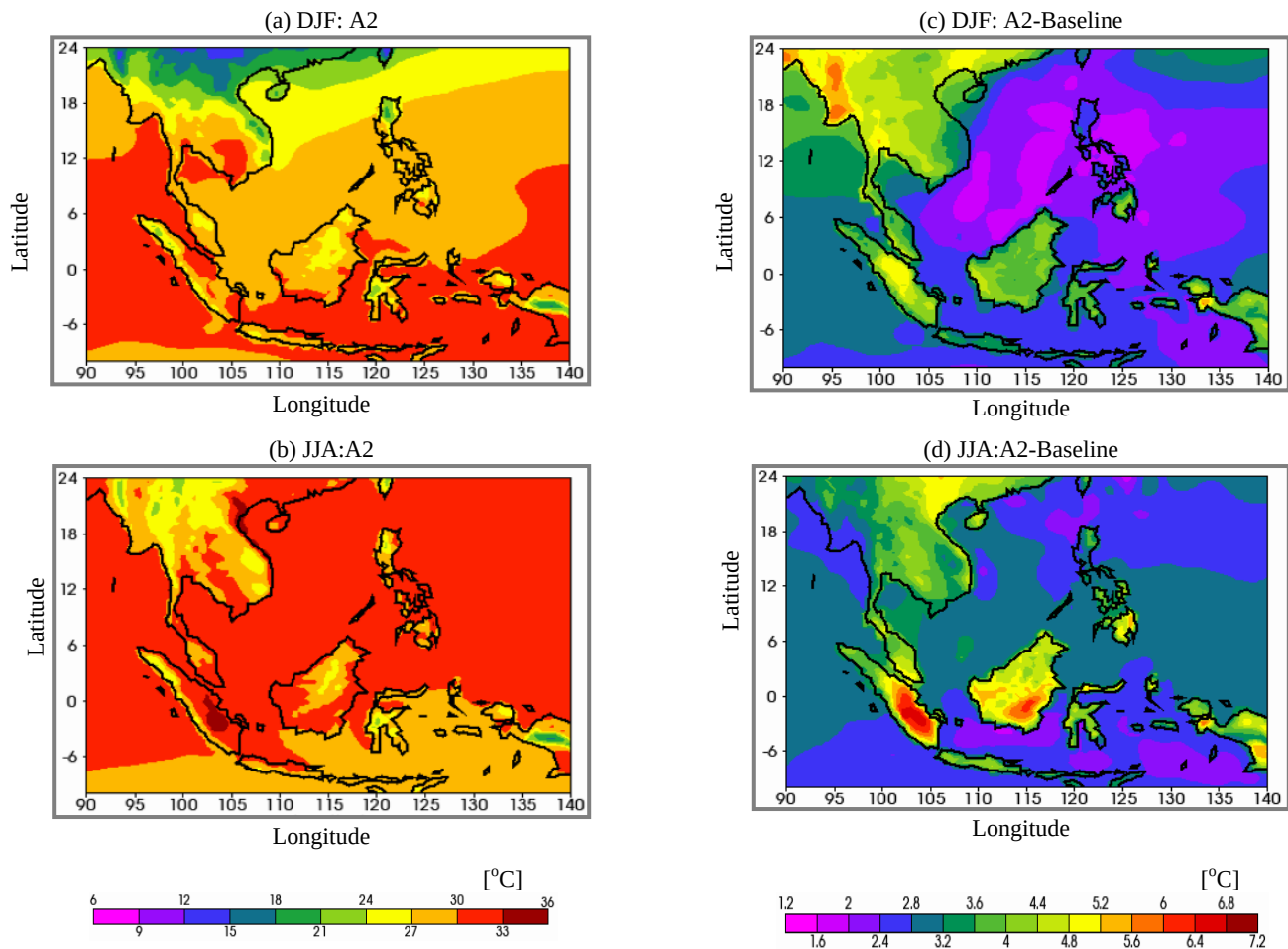


Figure 2: SRES A2: Atmospheric forcing effects on seasonal temperature in the SRES A2 scenario during (a) DJF (December to February) and (b) JJA (June to August). The temperature difference in comparison with the Baseline scenario (A2-Baseline) during (c) DJF (December to February) and (d) JJA (June to August)

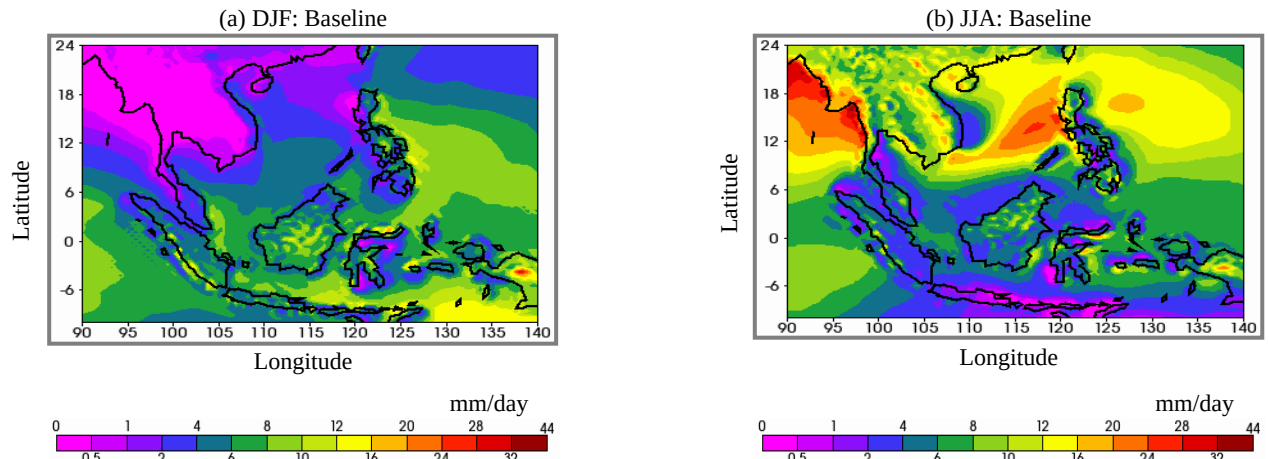


Figure 3: Baseline: Seasonal variability of total precipitation (mm/day) over SEA for the Baseline (1961-1990) during (a) DJF (December to February) and (b) JJA (June to August)

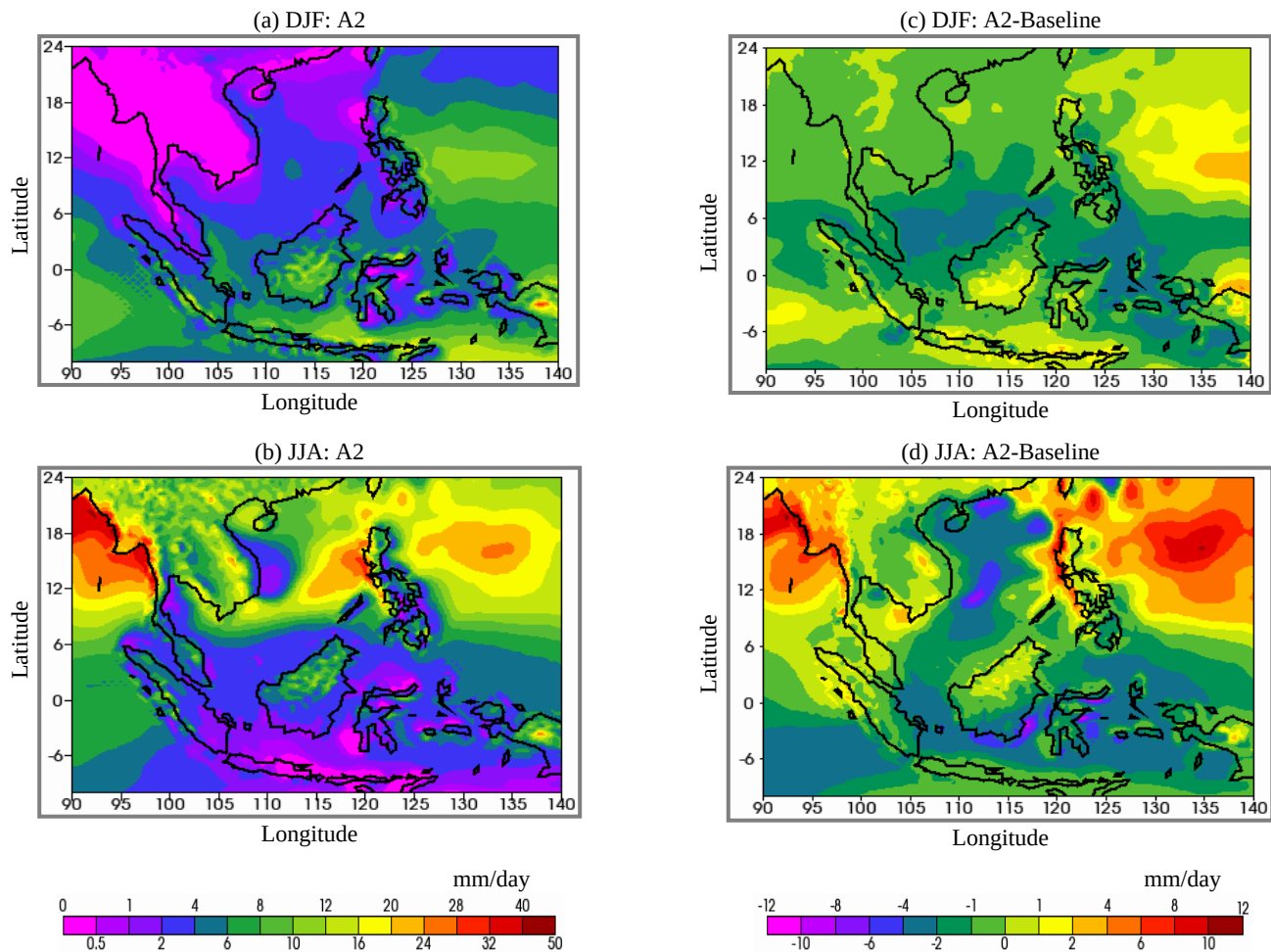


Figure 4: SRES A2: Atmospheric forcing effects on seasonal total precipitation in the SRES A2 scenario during (a) DJF (December to February) and (b) JJA (June to August). The total precipitation difference in comparison with the Baseline scenario (A2-Baseline) during (c) DJF (December to February) and (d) JJA (June to August)

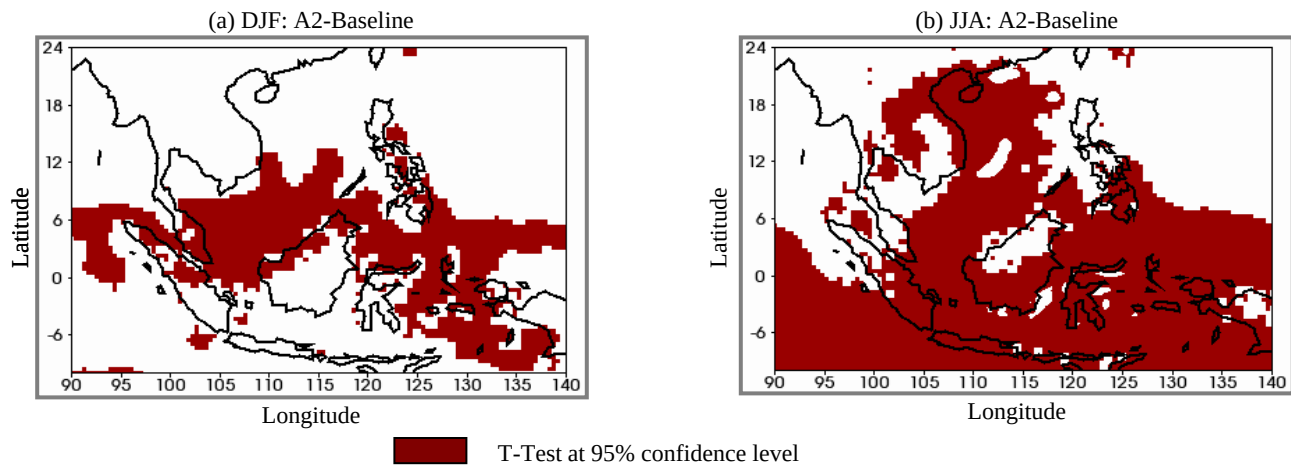


Figure 5: Significant t-test plots for the effect of atmospheric forcing alone on seasonal total precipitation for the A2 (A2-Baseline) during (a) DJF (December to February) and (b) JJA (June to August)

4.3. Total Cloud Fraction

The simulated total cloud fraction in the Baseline scenario over SEA was also markedly seasonal, with relatively less cloud over the continental region during DJF and higher over the sea (Andaman Sea/Bay of Bengal and South China Sea/Philippines Sea) during JJA (Figure 6). The projected future total cloud fractions in the A2 scenario were 0.5 during DJF and 0.7 during JJA (Figure 7). Relatively less cloud fraction was observed over the continent during DJF but increased during JJA. Relative to the Baseline scenario, the A2 future scenario over SEA showed a reduction in total cloud fractions of about -0.07 (12%) during DJF and -0.04 (6%) during JJA (Figure 7). Larger changes were observed over the west Pacific Ocean during DJF and extended to South China Sea and Indian Ocean between latitude 2°S and 12°N during JJA. Changes in total cloud fraction (roughly less than -0.04), mostly over the South China Sea, Indian Ocean and Celebes Sea during DJF and Indochina, the Philippines Sea, a large part of the South China Sea, and latitude between 10°S and 0° during JJA were found to be statistically significant at 95% confidence level (Figure 8).

4.4. Solar Radiation

The simulated solar radiation over SEA in the Baseline scenario was about 215 Wm^{-2} during DJF and slightly higher – about 220 Wm^{-2} – during JJA (Figure 9). Higher solar radiation over the continent (i.e. the Indochina region) was observed during DJF but it was lower during JJA. The projected future solar radiation in the A2 scenario was 221 Wm^{-2} during DJF and 218 Wm^{-2} during JJA (Figure 10). Relative to the Baseline scenario, the A2 future scenario over SEA showed a small increase in solar radiation of about 5.6 Wm^{-2} (3%) during DJF and 4.6 Wm^{-2} (2%) during JJA (Figure 10). The increase in solar radiation was also reflected in the increase of surface temperature and decreased cloud fraction over the region in the A2 scenario. Reduction of solar radiation was observed over the west Pacific Ocean during the both seasons with a larger magnitude of changes during JJA. Future changes in solar radiation were not statistically significant in most areas of the region during DJF. However, during JJA, it was observed that areas with negative changes (less than -5 Wm^{-2}) were found to be statistically significant at 95% confidence level (Figure 11), mostly over the sea (i.e. the west Pacific Ocean).

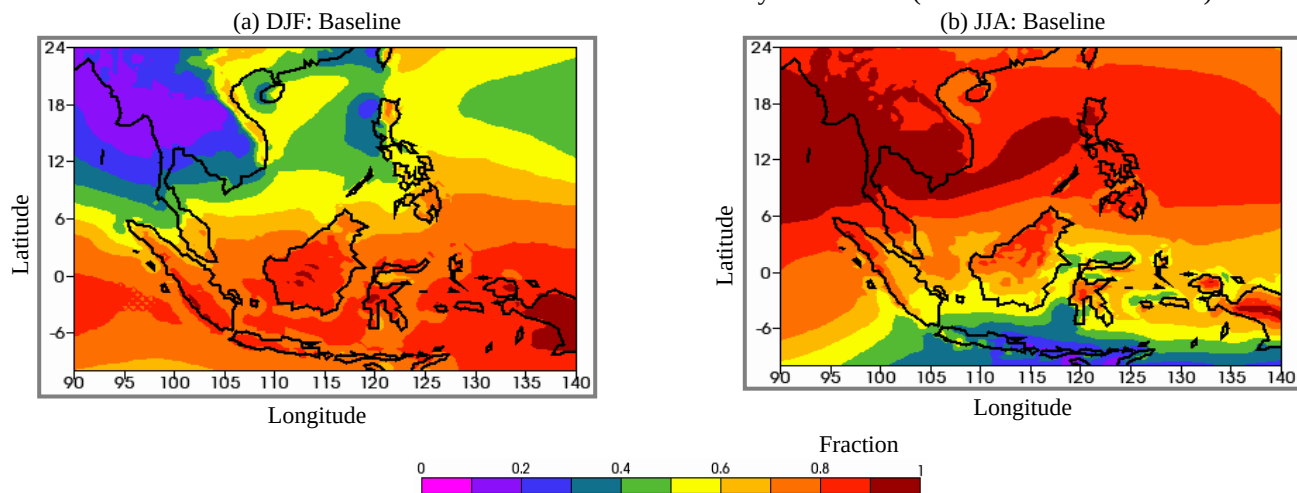


Figure 6: Baseline: Seasonal variability of total cloud fraction over SEA for the Baseline (1961-1990) during (a) DJF (December to February) and (b) JJA (June to August)

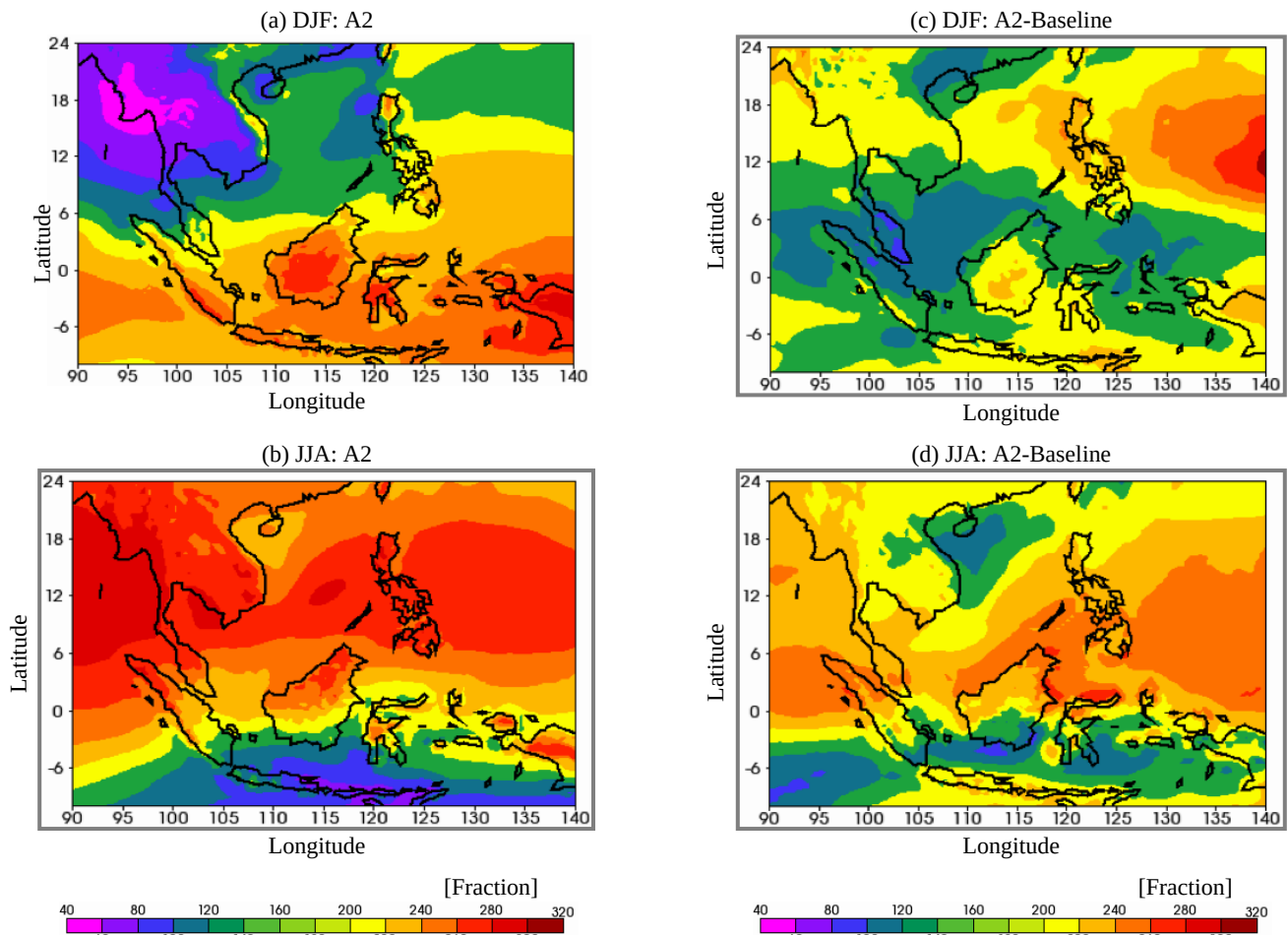


Figure 7: SRES A2: Atmospheric forcing effects on seasonal total cloud fraction in the SRES A2 scenario during (a) DJF (December to February) and (b) JJA (June to August). The total cloud fraction difference in comparison with the Baseline scenario (A2-Baseline) during (c) DJF (December to February) and (d) JJA (June to August)

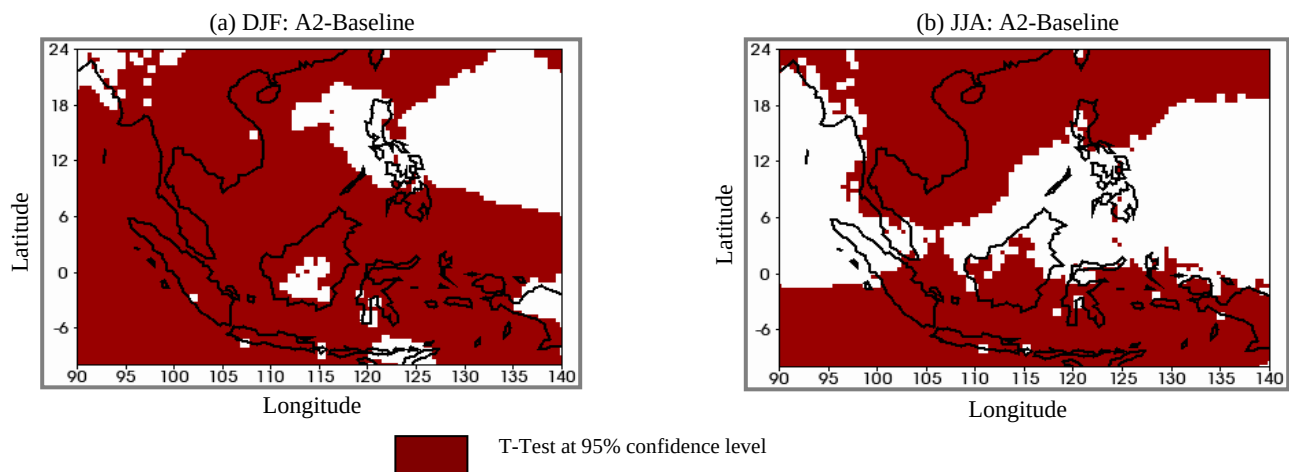


Figure 8: Significant t-test plots for the effect of atmospheric forcing alone on seasonal total cloud fraction for the A2 (A2-Baseline) during (a) DJF (December to February) and (b) JJA (June to August)

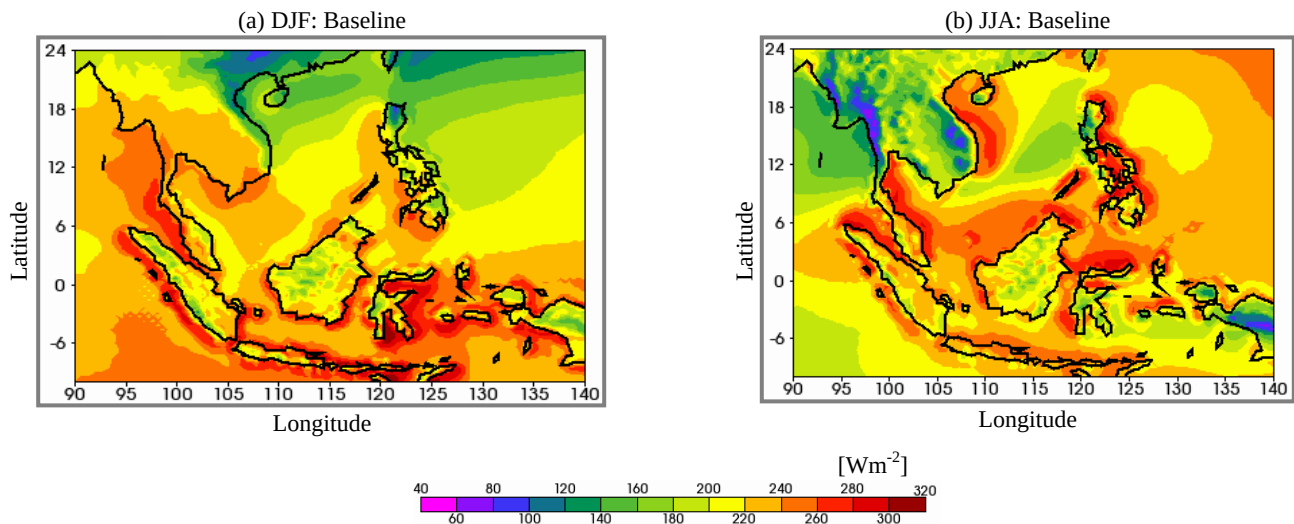


Figure 9: Baseline: Seasonal variability of solar radiation over SEA for the Baseline (1961-1990) during (a) DJF (December to February) and (b) JJA (June to August)

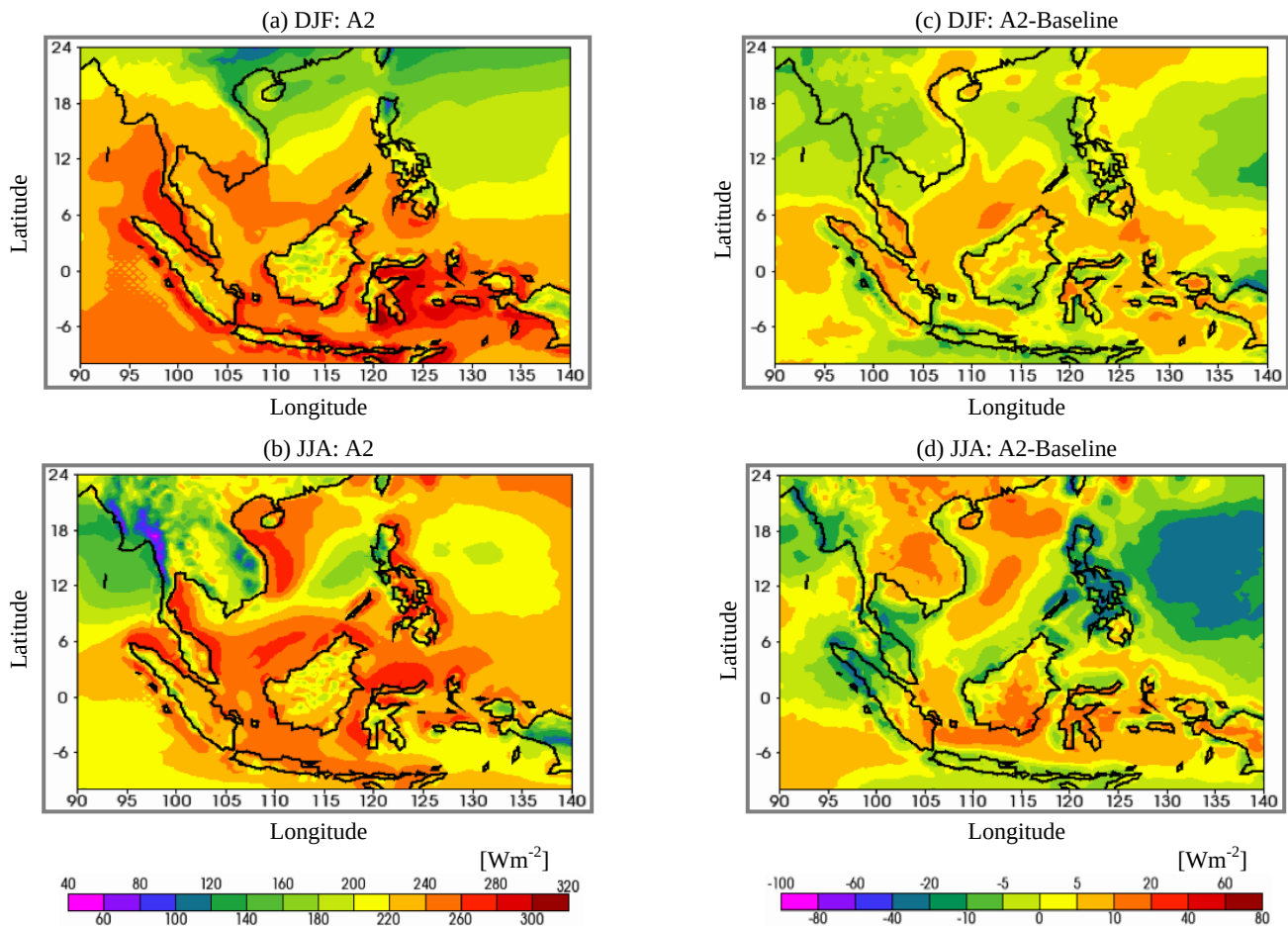


Figure 10: SRES A2: Atmospheric forcing effects on seasonal solar radiation in the SRES A2 scenario during (a) DJF (December to February) and (b) JJA (June to August). The solar radiation difference in comparison with the Baseline scenario (A2-Baseline) during (c) DJF (December to February) and (d) JJA (June to August)

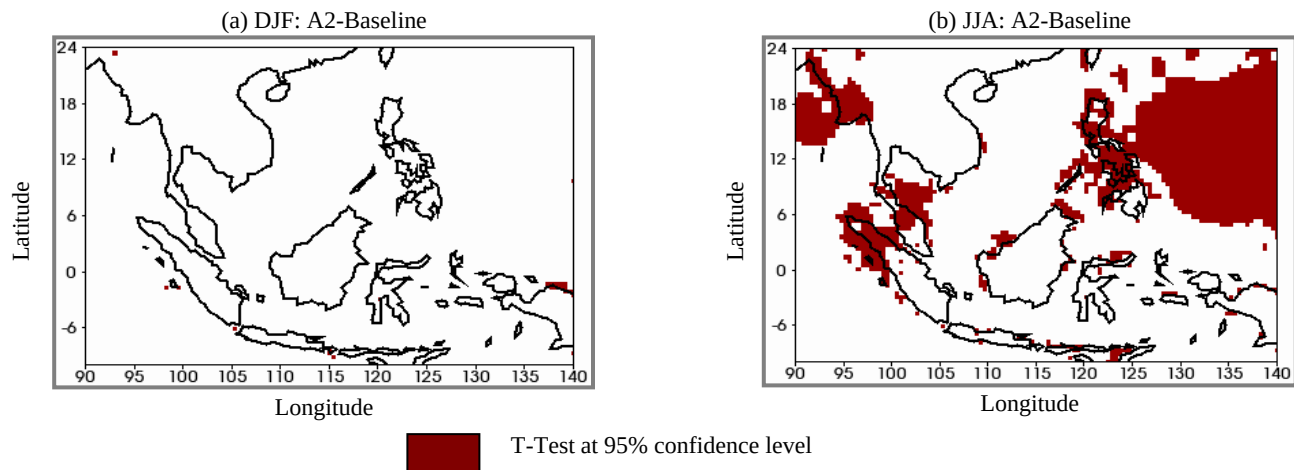


Figure 11: Significant t-test plots for the effect of atmospheric forcing alone on seasonal solar radiation for the A2 (A2-Baseline) during (a) DJF (December to February) and (b) JJA (June to August)

V. CONCLUSION

The present study has used a high resolution of PRECIS, a regional climate model developed by the Hadley Centre to examine present-day and future possible climates over SEA. The PRECIS-RCM captured the primary features of the observed data (CRU) and the patterns of seasonal change. In the next 100 years, there was a warming across the region, with the largest temperature increase over land during DJF and JJA. In the A2 scenario, there was an average surface warming of 3.0°C during DJF and 3.1°C during JJA. Surface temperature changes were statistically significant at 95% confidence level for all seasons for the whole modeled region-domain.

The total precipitation decreased during DJF by about -0.4 mm/day and slightly increased during JJA by about 0.2 mm/day. Precipitation changes of less than -1 mm/day, mostly over the sea during DJF and a larger area over the sea and insular region during JJA were found to be statistically significant. PRECIS-RCM projected that the increase in surface temperatures during DJF was consistent with lower precipitation, though similar trend was not observed during JJA. The slight increase in total precipitation during JJA, which is corresponding with the southwest monsoon, was lower than the earlier projection for Southeast Asia by Johns et al (2003). Increasing temperatures tend to increase evaporation, which leads to more precipitation [IPCC, 2007].

The total cloud fraction in the A2 scenario was projected to decrease slightly by -0.07 during DJF and -0.04 during JJA. Future changes in total cloud fraction in both seasons of roughly less than -0.04 in the A2 scenario was found to be statistically significant at 95% level. The projected solar radiation slightly increased by 5.6 Wm^{-2} during DJF and 4.6 Wm^{-2} during JJA.

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