CLIMATE CHANGE SIMULATIONS IN TERMS OF SOLAR RADIATION AND CLOUD FRACTION BASED ON PRECIS OVER MALAYSIA REGION

Steven S.K. Kong & Justin Sentian

Climate Change Research Group,
Faculty of Science and Natural Resource,
University Malaysia Sabah, Jalan UMS, 88400, Kota Kinabalu, Sabah, Malaysia.
Email: kongksk@gmail.com

ABSTRACT. *Climate change is a significant change of weather patterns over a long period of time. Malaysia can be vulnerable to such impact, since economics of this region rely strongly on agriculture and natural sources. This paper simulated the solar radiation and total cloud fraction for Malaysia by the end of the 21st century based on the A2 and the B2 scenarios by utilizing the latest generation of the Hadley Centre regional climate modeling system, PRECIS (Providing Regional Climates for Impact Studies). Relative to the baseline scenario, the average increase in solar radiation was 5 – 12Wm^{-2} under the A2 scenario and 3 – 10Wm^{-2} under the B2 scenario. The changes were significant at 95% confidence level across most of the land area. The average total fraction over Malaysia was projected to reduce by 0.14 to 0.032 under the A2 scenario and 0.11 to 0.0057 under the B2 scenario compared to the baseline scenario. Significant changes were observed over the whole domain of investigation during December-January-February under both scenarios. Study results suggest that a significant change in climate variability may potentially increase climate-related risks such as air quality impact and vulnerability in the region.*

KEYWORDS. Climate Changes, Cloud Fraction, Malaysia, PRECIS, Solar Radiation

INTRODUCTION

Global Climate Model (GCM) is the main tool for global climate simulation and more specifically, for the projection of future climate over given regions around the globe. It is a mathematical representation of climate system. The construction of GCM is based on the physical properties of its components, interaction and feedback. GCM provides climate projections with a few hundred kilometers scale, and due to the course resolution, GCM is effective for terrain which is flat and uniform (IPCC, 2007). In other words, the low resolution GCM has difficulty simulating certain land areas such as coastline and mountainous areas (Met Office, 2002). The model has limitations in capturing regional or local detail that is necessary for impact assessments at national and regional levels such as extreme weather like heavy rainfall. To simulate climate change on a finer scale, regional climate model (RCM) with high resolution was developed. The RCM covers a limited area of the globe. The ocean is not included within RCM to reduce the complexity and cost. In addition, most of the impact assessment requires only surface and atmospheric data (Met Office, 2002).

Southeast Asia (SEA) is one of the most populated areas in the world with rapid urbanisation and industrialisation, and expansion of agricultural activities, but is still covered largely by tropical forest. Rapid changes to the general land cover of the region, coupled with an increase in anthropogenic emissions and naturally high levels of biogenic emissions have been important issues in recent years. Linked with these, another critically important issue is the climate change impact. SEA has been designated one of the most vulnerable regions; addressing the climate change issue in this region is relatively new and investigations related to climate impacts, at high-resolution, are scarce or even unavailable.

Surface temperature and precipitation are the main climatic variables discussed in a lot of climate change research. However, some of the meteorological parameters such as solar radiation and cloud fraction play an important role in the issues of climate change. A study by Sentian *et al*. (2009) and Sentian and Kong (2013) showed that solar radiation was projected to increase at the end of the 21st century over SEA. Under the A2 scenario, solar radiation was increased by 5.6Wm^{-2} during DJF (December-January-February) and 4.6Wm^{-2} during JJA (June-July-August) compared to the baseline scenario. Under the B2 scenario, the solar radiation increment was slightly lower at about 3.1 Wm^{-2} during DJF and 3.8 Wm^{-2} during JJA. Another meteorological parameter, the total cloud fraction, showed a reduction under the A2 scenario in the SEA region by 0.07 during DJF and 0.04 during JJA relative to the baseline scenario. In the B2 scenario, the total cloud fraction was found to decrease about 0.04 during DJF and 0.05 during JJA. An earlier study by McGregor *et al*. (1998) also showed that the total cloud fraction in SEA decreased 10% under IS92a scenario.

METHODOLOGY

Model description

PRECIS is a nested RCM, which utilises output from GCM simulation. It provides the boundary conditions and also the time-dependent lateral boundary conditions (LBC). PRECIS is the latest version of the Hadley Centre model based on the atmospheric components of HadCM3, coupled with AOGCM (coupled Atmosphere-Ocean General Circulation Models)(Gordon *et al*., 2000). The PRECIS-RCM (HadRM3P) is based on the atmospheric components of the HadCM3 climate model (Gordon *et al*., 2000). Several components such as atmospheric dynamics, physical parameterisations, and sulphur cycles are included within the model as described in detail by Jones *et al.* (2004) and Sentian (2009). It is an atmospheric and land surface model with a horizontal resolution of 0.44° x 0.44° (50km × 50 km) on its own rotated latitude–longitude grid and a timestep of 5 minutes. The HadCM3 or (AOGCM) contains simulations of 240 years from 1860 to 2100 and with lower-resolution 3.75° latitude x 2.5° longitude (~300 km) (Gordon *et al.,* 2000). The higher resolution global model (HadAM3H) with two time slices, 1961-1990 and 2071-2100, were selected from HadCM3. The HadAM3H is the atmospheric-only GCM with a resolution of 1.24° latitude × 1.88° longitude (~150km × 150 km) and a timestep of 15 minutes. Both GCM (HadAM3P) and PRECIS (HadRM3P) have 19 layers in the atmosphere, from the surface to 30 km in the stratosphere and four levels in the soil (Hudson and Jones 2002). In this study, a sulphur cycle was included within the model, since sulphur aerosols play an important role in radiation in the atmosphere (Ahrens, 2009; IPCC, 2007).

Experimental Design and Setup

A spin-up process is necessary to allow the atmospheric and land surface model to reach a mutual equilibrium state before starting the simulation of climate change over a 1year period (Jones *et al*., 2004). Boundary conditions were aggregated into the Malaysia region with coordinates 90°E – 130°E and 5°S – 15°N.

The PRECIS-RCM and the GCM driving model (GCM-HadAM3P) use emission scenarios developed by IPCC (2000), which were simulated by PRECIS-RCM and defined in terms of the source of the boundary data and the relevant emissions data. The time interval for the baseline scenario is 30 years from 1961 to1990. According to IPCC (2000), a period of 10 years and above is reasonable for climate change investigation. However, a simulation length of 30 years is preferable, as this long period is vital in analysing the variability of climate change (such as solar radiation and cloud fraction) and in capturing 75% of true signals.

In this study, the future climate assessment was carried out utilizing the emission projection from IPCC Special Report on Emission Scenarios (SRES). It is an assumption regarding demographic, socio-economic technology change and greenhouse gas emissions based on the global scale. The SRES provides alternative development pathways and inputs to climate change vulnerability and impact assessment (IPCC, 2007). The future scenarios that we selected for main investigation were the IPCC SRES A2 and the B2, which is the time slice between 2070 and 2100.The SRES A2 scenario is developed based on medium–high emissions(850 ppm of CO_2 concentration by 2100) and high population growth (15 billion people) for the 2071–2100 period (Giorgi &Bi, 2005). On the other hand, the B2 scenario is denoted as a lower-emission scenario (550 ppm by 2100) with reduced population growth (10.4 billion people).

Model Evaluation

Mearns *et al*. (2003) stressed that any RCM to be used for climate change studies should be capable of reproducing the present day climate of the region of interest; model errors should also be identifiable. Since signals of a GCM and an RCM are often different, either at the regional or at the sub-regional scale, RCM simulations should be validated and performance of the simulation verified to ensure that the model errors are identified, quantified and understood as these can help in the interpretation of the climate change simulations.

The evaluation of the ability of a RCM to simulate climate variability in Malaysia for the present-day period (1961-1990) was performed in this study. The model was evaluated by comparing statistically between the output data from the PRECIS-RCM driven by GCM and the European Centre for Medium Range Weather Forecasts (ECMWF) re-analysis from 1957 to 2001(ERA40) (Uppala *et al*., 2005). A horizontal spectral resolution of T159 and L60 height level was used within the ERA40. The model was constructed with a spatial resolution of 1.125°latitude × 1.125° longitude. Moreover, the dataset was built in 6-hourly intervals at four times (0:00, 6:00, 12:00, 18:00) (Uppala *et al*., 2005). ERA40 does not fully represent the state of the atmosphere since it is not a fully observed dataset, but it can fill the gaps in areas where observations are missing or sparse, such as in Malaysia. The weekly NCEP (National Centers and Environmental Protection) observed dataset and monthly HadISST (Hadley Centre Sea Ice and Sea Surface Temperature) were the main sources of the sea surface temperature (SSTs) and sea-ice fractions (Wilson *et al*., 2005).

A number of statistics were used in this study to evaluate the climate model results. Statistical analysis was performed by means of variables such as mean, standard deviation, fractional bias (FB), normalized mean square error (NMSE), factor of two (Fa2) and validation test (two tailed t-test)(Von Storch & Navarra, 1995; Ojha & Kumar, 2010). A systematic error in a given variable can be detected using the bias of a series of observations and their corresponding simulations. When the value of the bias is less than zero, the model is under the predicted mean. When the value of the bias is more than zero, the model is over the estimated mean. The fractional bias is normalized to make it non-dimensionless. The statistical analysis lies between +2 and -2 and has a value of zero for an ideal model. Mean Square Error (MSE) isused to estimate the typical difference between observations and model predictions. The value of zero gives a perfect forecast. MSE is sensitive for a few large differences between observations and predictions caused by squaring the difference. Root Mean Square Error is the variant of MSE. It means the expected error of simulations. Normalised Mean Square Error (NMSE) is another variance. It is used to compare the relative efficiency between observations and simulation. The Factor of Two (Fa2) is another method that presents in percentages and predictions with a factor of two of the observed values. A perfect simulation produces a value of one. Below are the formulations utilised for model evaluation:

Fractional Bias (FB) = $\frac{\overline{O}-\overline{P}}{0.5(\overline{O}+\overline{P})}$

Normalised Mean Square Error (NMSE) = $\frac{\sum_{i=1}^{n}(O_i-P_i)^2}{\sum_{i=1}^{n}(O_iP_i)}$

Factor of Two (Fa2) =Fraction of data $0.5 \leq \overline{P}/\overline{O} \leq +2.0$

A two sided t-test was also used to measure the statistical significant of the difference between the PRECIS-RCM and ERA40-reanalysis dataset for model evaluation. The test also allowed us to investigate whether the differences between the future and current climate are significant or not. In the present study, a p value of 0.95 was produced between averages of two series of datasets. In other words, the probability of the second dataset being higher than the first is 95%. A detailed explanation and the method of calculations can be referred to Met office (2014).

RESULT AND DISCUSSION

Results and discussion of this study are presented in two sections. The first section presents the evaluation of an RCM by comparing the results from RCM with ERA40. In this section only the recent period (1961-1990) was considered. The second section describes the investigation of climate change in terms of total cloud fraction and solar radiation under the A2 and the B2 scenarios.

Results are presented based on seasonal variables such as variations during DJF (December–January–February), MAM (March–April–May), JJA (Jun–July–August) and SON (September–October –November). However, the discussion is focused on DJF, which is denoted as the winter monsoon (northeast monsoon) and JJA which is denoted as summer monsoon (southeast monsoon)(Sentian *et al.*, 2009; Sentian and Kong, 2013). Results of intermediate periods (MAM and SON) are shown in the paper but will not be discussed in detail.

RCM Evaluation

This section evaluates the results of the baseline scenario or the present-day (30 years or n=30) simulated by PRECIS-RCM with the ERA40-Reanalysis datasets in order to investigate the performance of the PRECIS-RCM.

Table 1presents the statistical analysis of the PRECIS-simulated solar radiation, total cloud fraction and ERA40-reanalysis data. Results showed that the mean difference of total cloud fraction between simulated and ERA40 was small between –0.05 and 0.06. In terms of FB, the model results were over-predicted by 0.028 during DJF and under-predicted by 0.077 during JJA. In addition, NMSE was close to zero value at0.071 during DJF and 0.024 during JJA. The PRECIS-RCM performed well in simulating total cloud fraction as it produced Fa2 value of 0.93 and 1.08 during both seasons. Differences in total cloud fraction were found significant at 95% confidence level over south Peninsula, east Sabah and most parts of seas during DJF and around Peninsula with latitude above 3.5° and most parts of Sabah during JJA (figures not shown).

For solar radiation, the mean differences between both models were small at 3.16 Wm^{-2} during DJF and 2.57 Wm^{-2}during JJA. The mean solar radiation was under-predicted by 0.014 during DJF and 0.012 during JJA. Meanwhile, the small values of NMSE (0.0052 and 0.0019) showed high performance of PRECIS. The model recorded a high value of Fa2 at 1.01 during both seasons indicating PRECIS-RCM behaved as an ideal model. The differences between both models were significant at 95% confidence level over Sarawak in DJF and most parts of land and sea area in Sarawak in JJA (figure not shown).

Table 1. Comparison between RCM and ERA40

Variables		Baseline		ERA40		Fractional Bias (FB)	Normalized Mean Square Error (NMSE)	Factor of Two (Fa2)
		Mean	Sd	Mean	Sd			
Total Cloud Fraction	DJF	0.64	0.10	0.69	0.092	0.028	0.071	0.93
	MAM	0.67	0.090	0.60	0.070	–0.12	0.031	1.12
	JJA	0.76	0.062	0.70	0.097	–0.077	0.024	1.08
	SON	0.76	0.058	0.73	0.063	–0.044	0.012	1.05
Solar radiation (Wm^{-2})	DJF	222.86	19.15	219.70	21.99	–0.014	0.0052	1.01
	MAM	246.32	10.71	245.19	11.55	–0.0046	0.0016	1.00
	JJA	235.31	7.81	232.56	9.78	–0.012	0.0019	1.01
	SON	232.20	13.08	226.65	15.95	–0.024	0.0025	1.02

Climate change in Malaysia

The simulated solar radiation over Malaysia under the baseline scenario was about 223Wm^{-2} during DJF and 235Wm^{-2} during JJA (Figure 1). The mean seasonal cycle of solar radiation over Malaysia is shown in Figure2. Figures indicated that all of the scenarios have a similar trend of mean solar radiation. The season of JJA reached higher solar radiation than DJF.

Under the A2 scenario, the simulated mean solar radiation was 235 Wm^{-2} during DJF and 240 Wm^{-2} during JJA (Figure 3). Relative to the baseline scenario, the mean solar radiation increased by 12Wm^{-2} (5.4%) during DJF and 5Wm^{-2} (2.1%) during JJA under the A2 scenario. During DJF, larger changes (>1Wm^{-2}) were observed over most parts of Peninsular Malaysia, Sarawak, and South China Sea. In certain parts of Peninsular Malaysia and the entire Sabah area, the solar radiation could increase to more than 20Wm^{-2}. During JJA, the solar radiation in south Peninsular Malaysia experienced a large change with more than 20Wm^{-2}. The changes were significant at 95% confidence level for both DJF and JJA over most parts of Malaysia region (Figure 5).

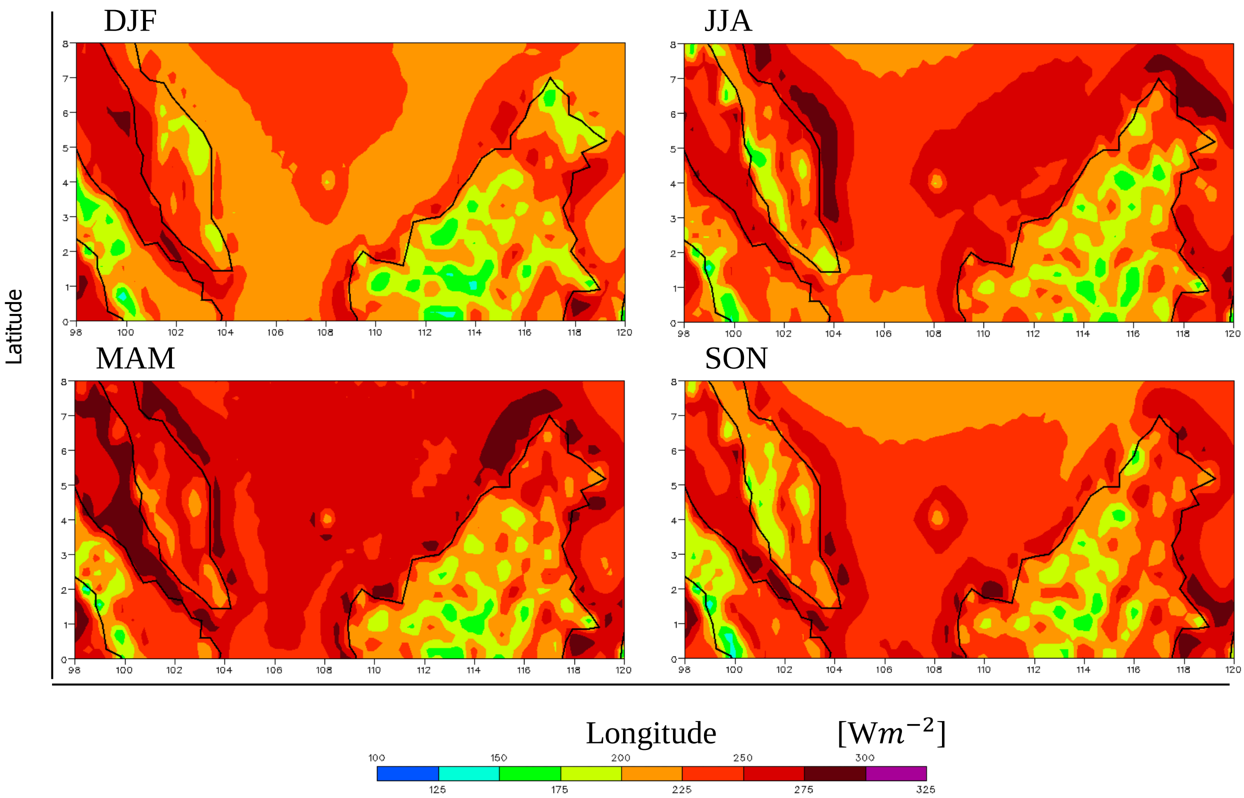

Figure 1. SRES Baseline: Seasonal mean variables of solar radiation during DJF (December to February), MAM (March to May), JJA (June to August) and SON (September to November).

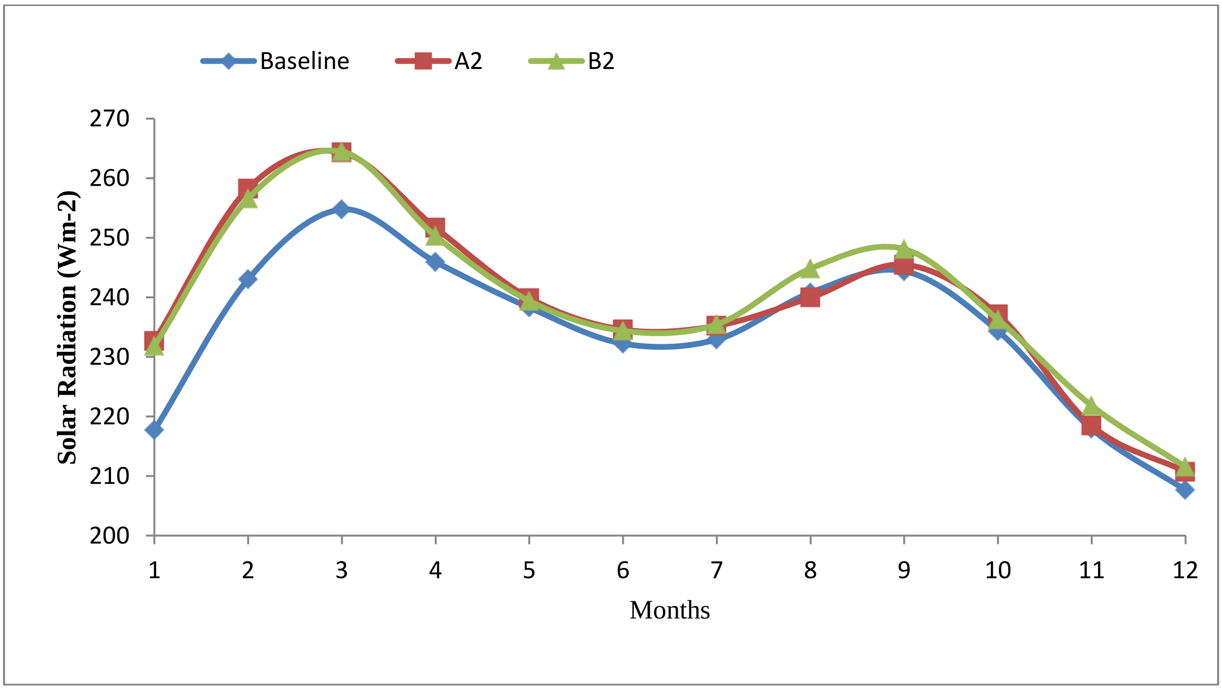

Figure 2.Seasonal cycle of solar radiation under SRES Baseline, SRES A2 and SRES B2.

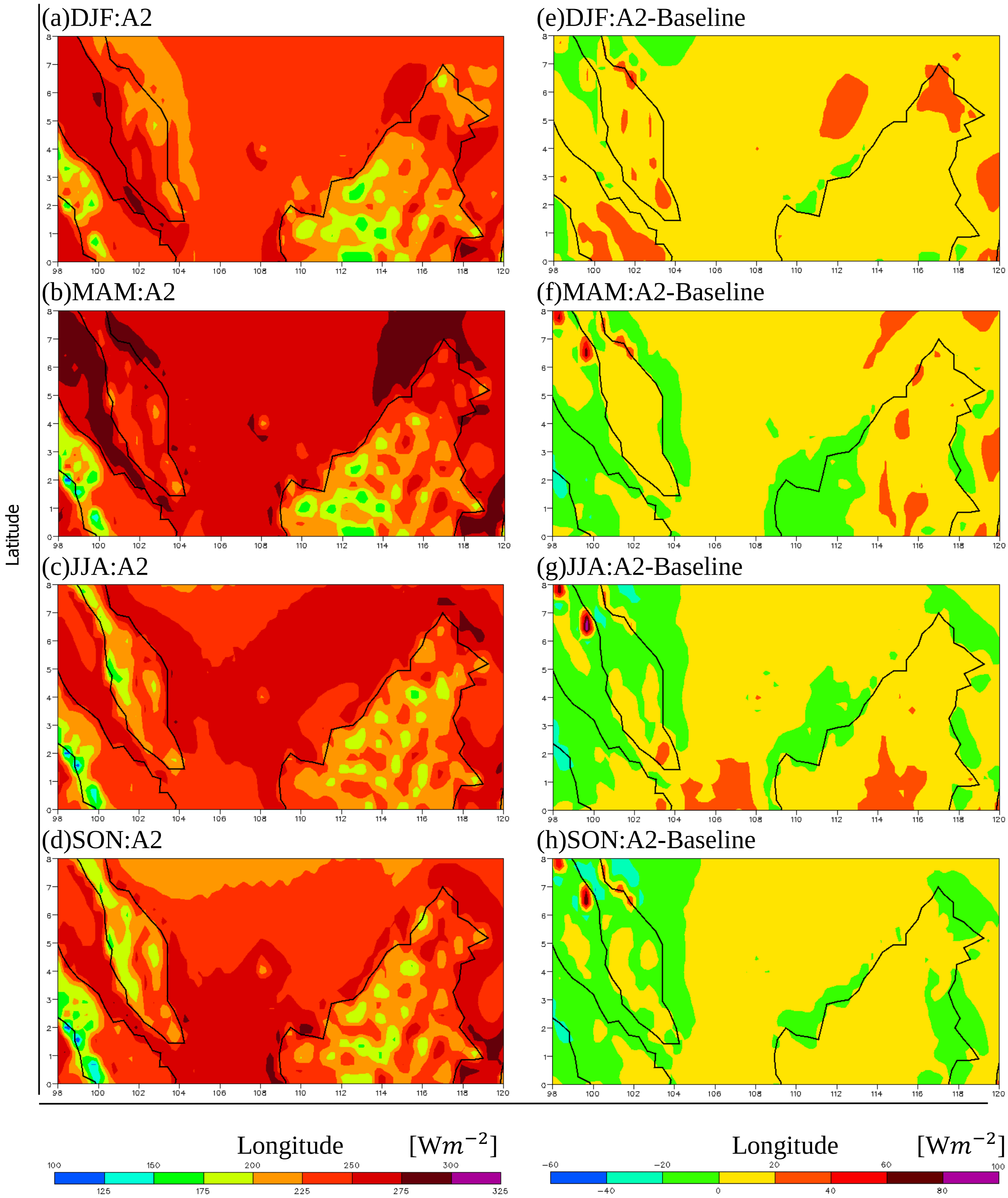

Figure 3. SRES A2: Seasonal mean variables of solar radiation during DJF (December to February), MAM (March to May), JJA (June to August) and SON (September to November), and the changes of precipitation compared to SRES Baseline (A2-Baseline).

The simulated mean solar radiation was 234 Wm^{-2} and 238 Wm^{-2} during DJF and JJA respectively under the B2 scenario, as shown in Figure 4. The seasonal mean of solar radiation was observed to increase by about 10Wm^{-2} (4.5%) during DJF and 3Wm^{-2} (1.3%) during JJA under the B2 scenario. During DJF, a large change of solar radiation was observed for the whole Malaysia region with more than $1\mathrm{W}m^{-2}$. The increase of solar radiation can reach more than $20\mathrm{W}m^{-2}$in certain areas such as north and south Peninsular Malaysia, and north Sabah. During JJA, most parts of the country underwent changes of solar radiation from 0–$20\mathrm{W}m^{-2}$. However, radiation decrease of about $20\mathrm{w}m^{-2}$was observed across northern and sea areas of Peninsular Malaysia and sea areas of East Malaysia. The solar radiation increments were significant during DJF over most parts of Peninsular Malaysia and north of East Malaysia. Meanwhile, during JJA, the changes were significant all over Malaysia with the exception of the central part of Peninsular Malaysia, south and east coasts of East Malaysia (Figure 5).

In general, the solar radiation increased across Malaysia in both the A2 and the B2 scenarios during DJF and JJA. The change of solar radiation was relatively lower than the Southeast Asia region (Sentian,2009). The solar radiation increment from the sun may be associated with surface temperature. The increases of solar radiation causes extra warming across the earth's surface and finally lead to surface temperature increments in the future. The change was also related to precipitation. Less precipitation indicates clearer days, when more solar radiation from the sun can reach the earth's surface (Klemen, 2006).

The simulated total cloud fractions were 0.68 during DJF and 0.76 during JJA as shown in Figure 6. The seasonal mean cycle of total cloud fraction over Malaysia for the Baseline, the A2 and the B2 (shown in Figure 7). It was observed that cloud fractions in the future projections of the A2 and the B2 scenarios contain less cloud relative to the baseline scenario, except during July to September for B2 scenario and August to September for A2 scenario. The total cloud fraction of JJA was higher than DJF for both scenarios.

The simulated total cloud fractions were 0.55 and 0.73 during DJF and JJA respectively under the A2 scenario (Figure 8). There was less cloud during DJF, but it increased during JJA. Relative to the baseline scenario, the changes of total fraction over Malaysia indicated a reduction by about 0.14 (20.5%) during DJF and 0.032 (4.2%) during JJA. Larger changes (<–0.12) were observed in Peninsular Malaysia and the northern part of East Malaysia (above 4.5°N) during DJF. The changes were statistically significant for the whole domain (Figure 10). Meanwhile, during JJA, large areas of Malaysia experienced decreased cloud fractions. The decrement of cloud fraction was significant at 95% confidence level around the coast of southwest Peninsular Malaysia and most of East Malaysia (Figure 10).

Similar patterns were also observed in the B2 scenario (Figure 9) where there was less cloud during DJF (0.57) and more cloud during JJA (0.75). Similarly under the A2 scenario, the total cloud fraction was observed to reduce by about 0.11 (16.2%) during DJF and 0.0057 (0.75%) during JJA. During DJF, the areas that experienced large changes (less than 0.12) were Peninsular Malaysia, Straits of Malacca and most parts of South China Sea. However, East Malaysia showed changes between –0.04 and –0.12. The changes were significant at 95% confidence level over the whole Malaysia region (Figure 10). During JJA, peninsular latitudes approximately above 5.5°N and below 3°N, Sarawak and small parts of Sabah underwent increased cloud fractions. The cloud fraction increment was significant at 95% confidence level around sea areas of East Malaysia. Areas around the southern part of Peninsular Malaysia also showed significant reduction of cloud fractions during JJA (Figure 10).

A previous study by McGregor *et al*. (1998) stated that total cloud fraction in Southeast Asia decreased 10% under IS92a scenario which indicated a similarity with this study. However, the decrement of total cloud fraction was larger during DJF and lower during JJA as compared to Sentian *et al.* (2009). The reduction of cloud fraction is associated with decrease of precipitation (Marengo *et al*., 2009; Hudson & Jones, 2002).

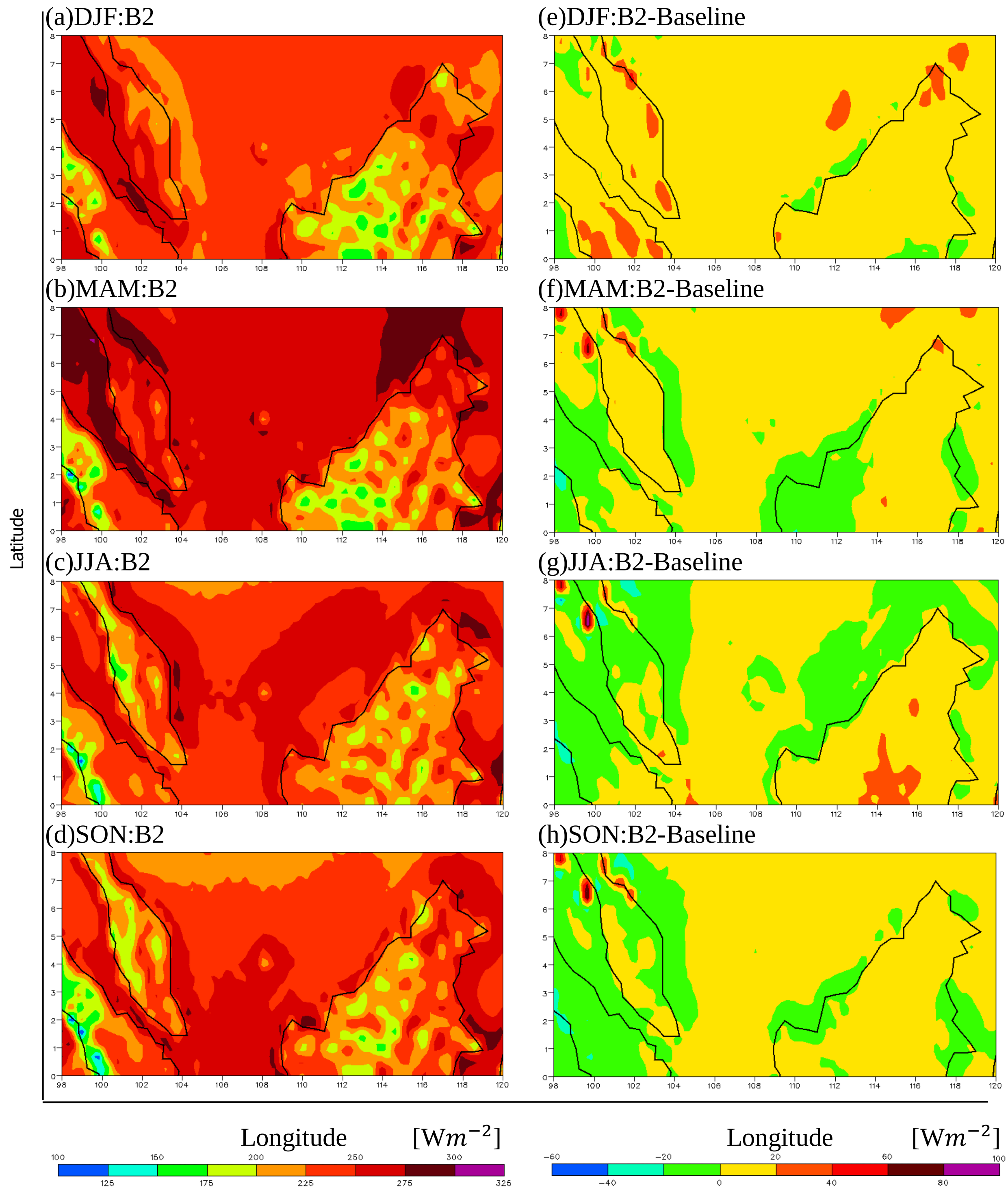

Figure 4. SRES B2: Seasonal mean variables of solar radiation during DJF (December to February), MAM (March to May), JJA (June to August) and SON (September to November), and the changes of precipitation compared to SRES Baseline (B2-Baseline).

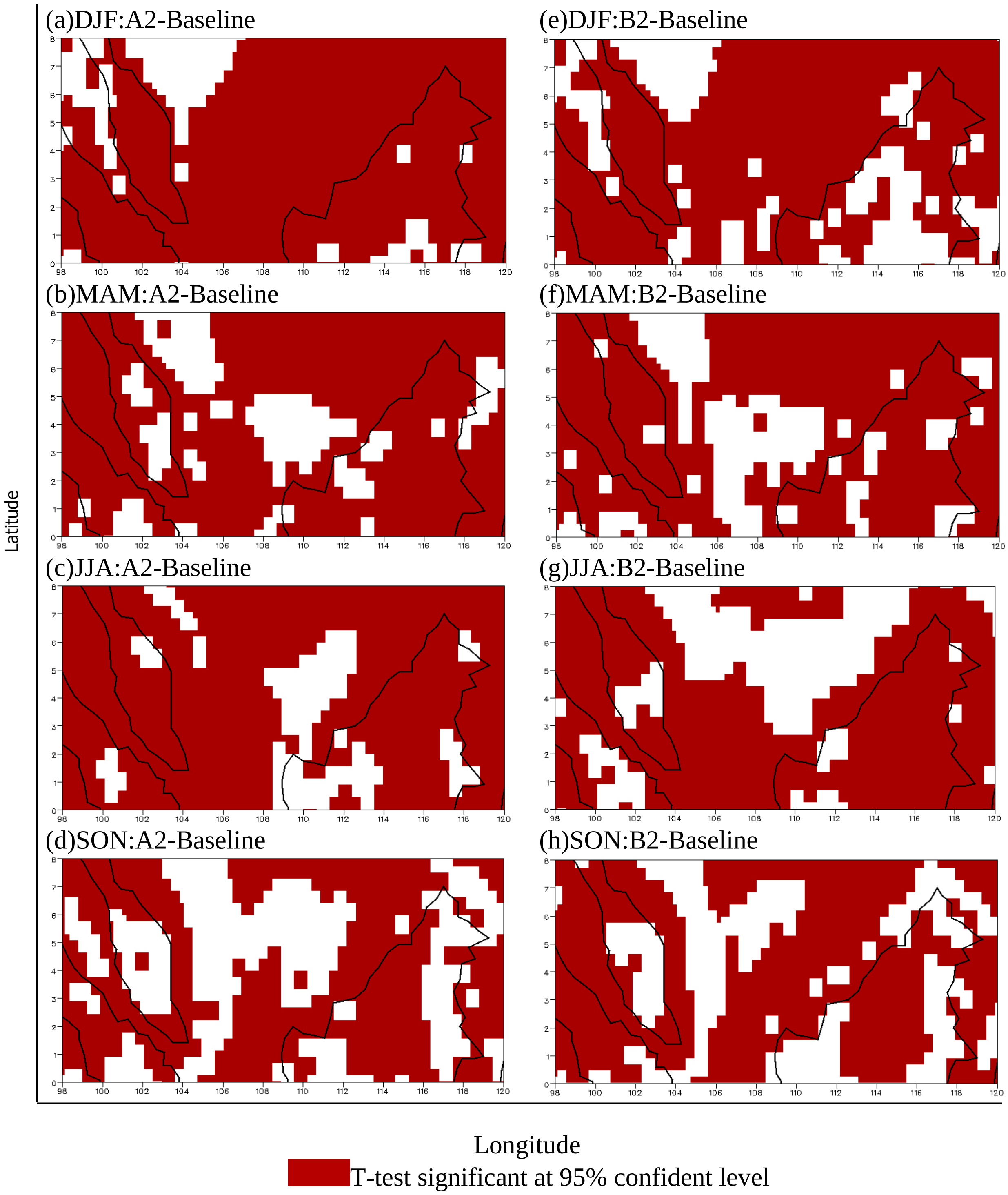

Figure 5.Significant t-test plots for seasonal total solar radiation for the A2 (A2-Baseline) (left panel) and B2 (B2-Baseline) (right panel) climate scenarios relative to the Baseline scenario.

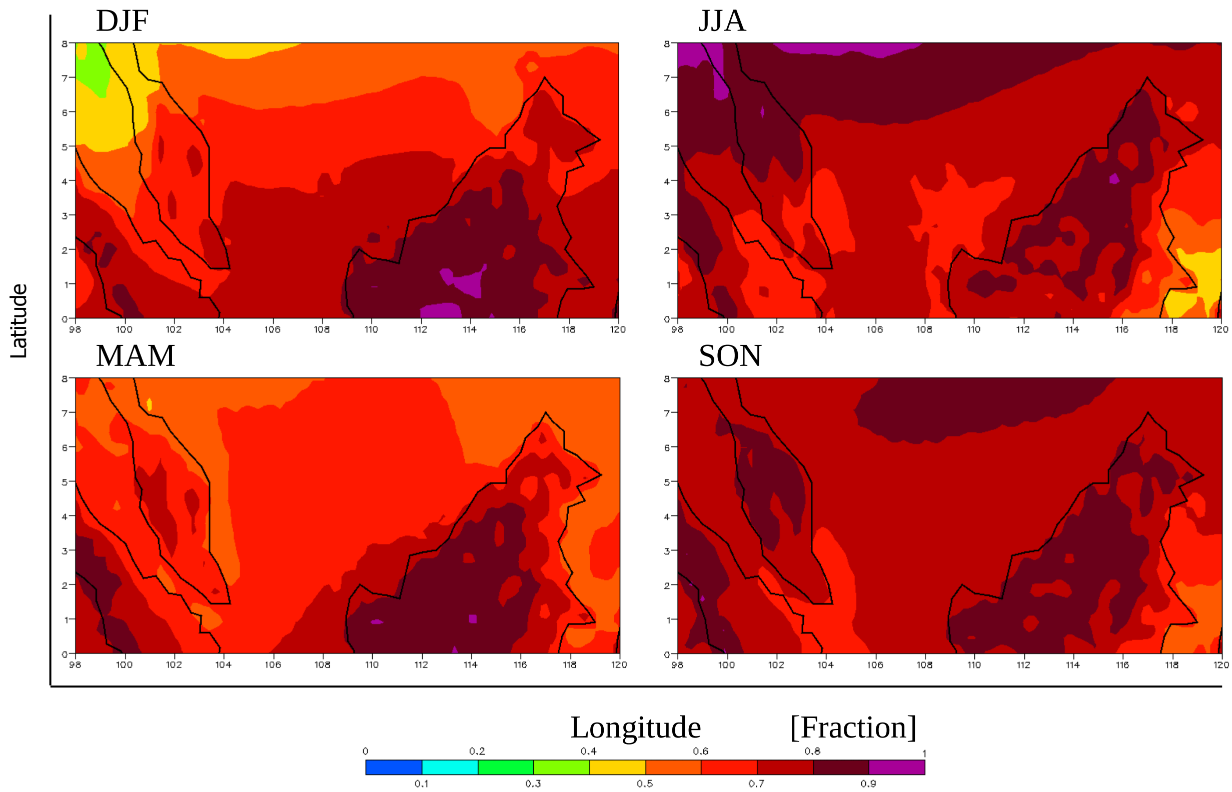

Figure 6. SRES Baseline: Seasonal mean variables of cloud fraction during DJF (December to February), MAM (March to May), JJA (June to August) and SON (September to November).

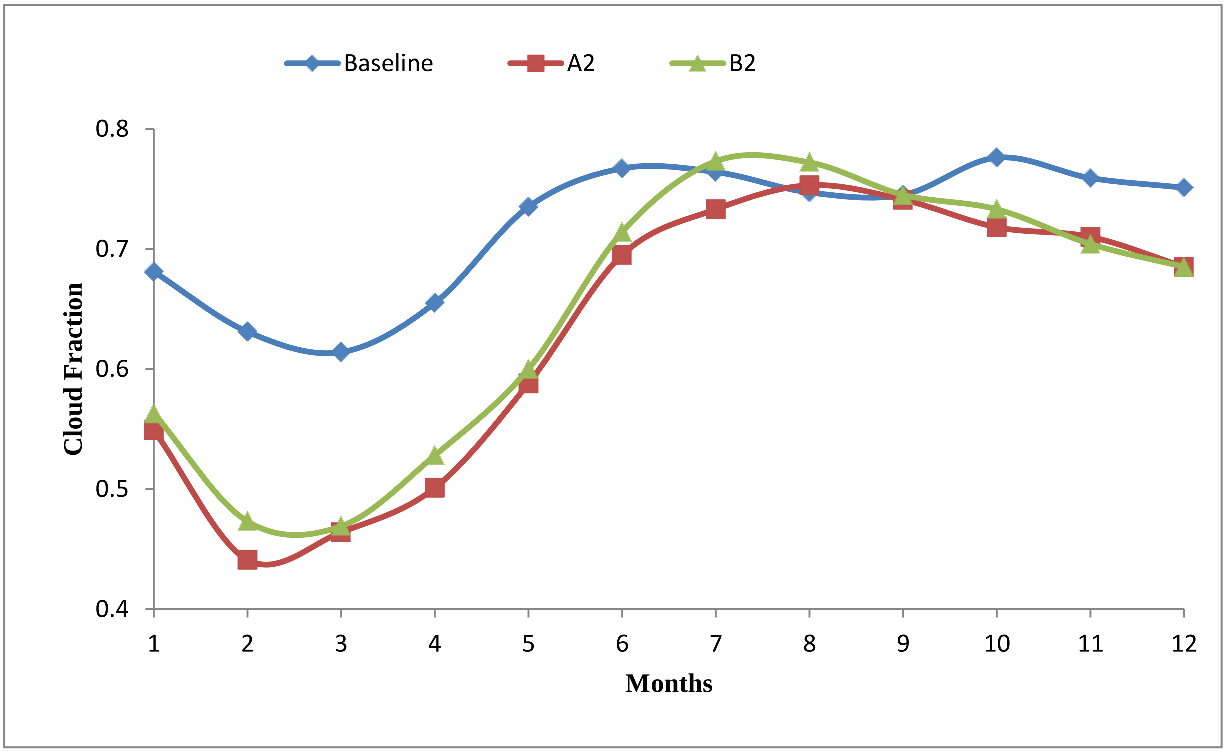

Figure 7.Seasonal cycle of cloud fraction under SRES Baseline, SRES A2 and SRES B2.

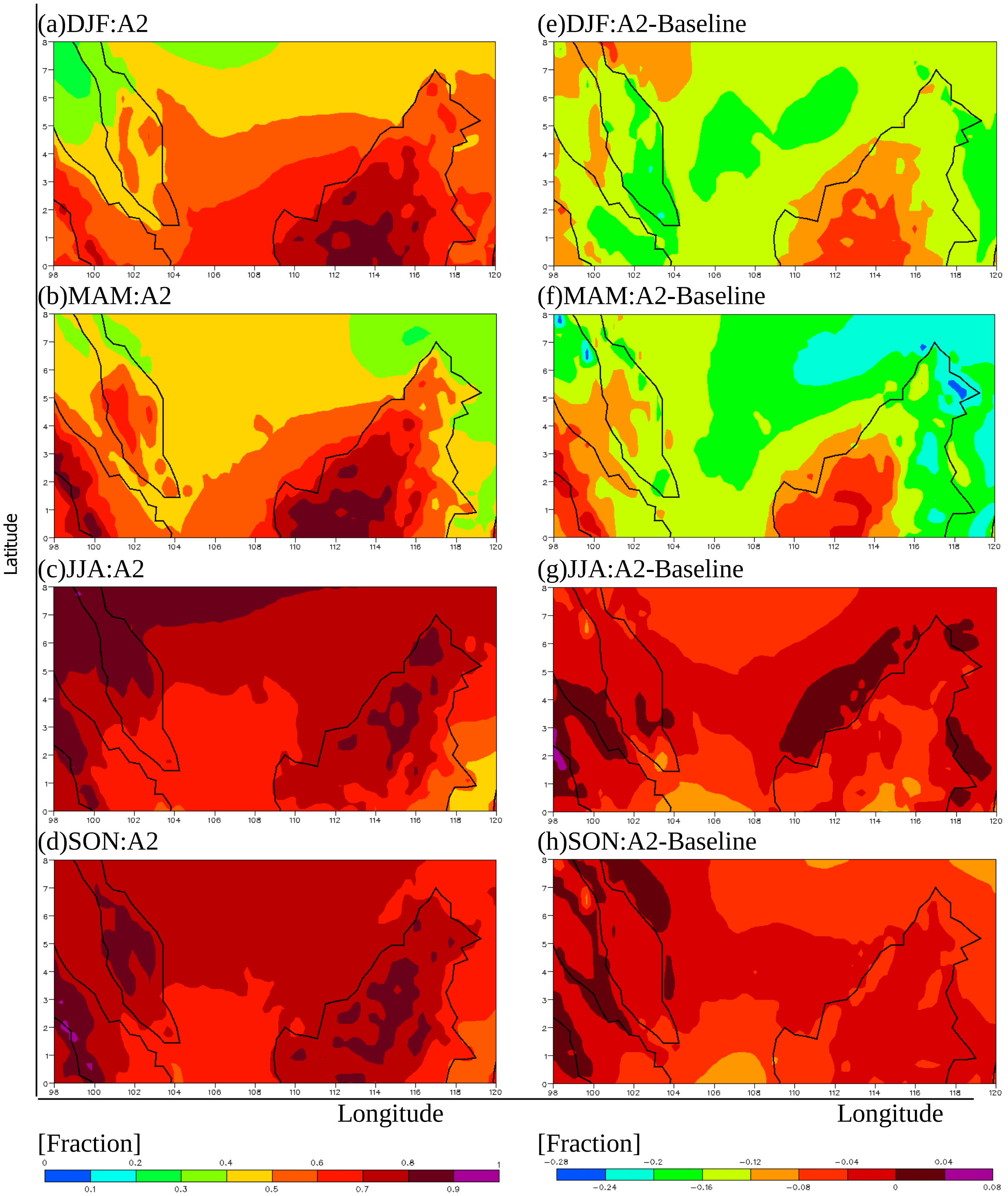

Figure 8. SRES A2: Seasonal mean variables of cloud fraction during DJF (December to February), MAM (March to May), JJA (June to August) and SON (September to November), and the changes of precipitation compared to SRES Baseline (A2-Baseline).

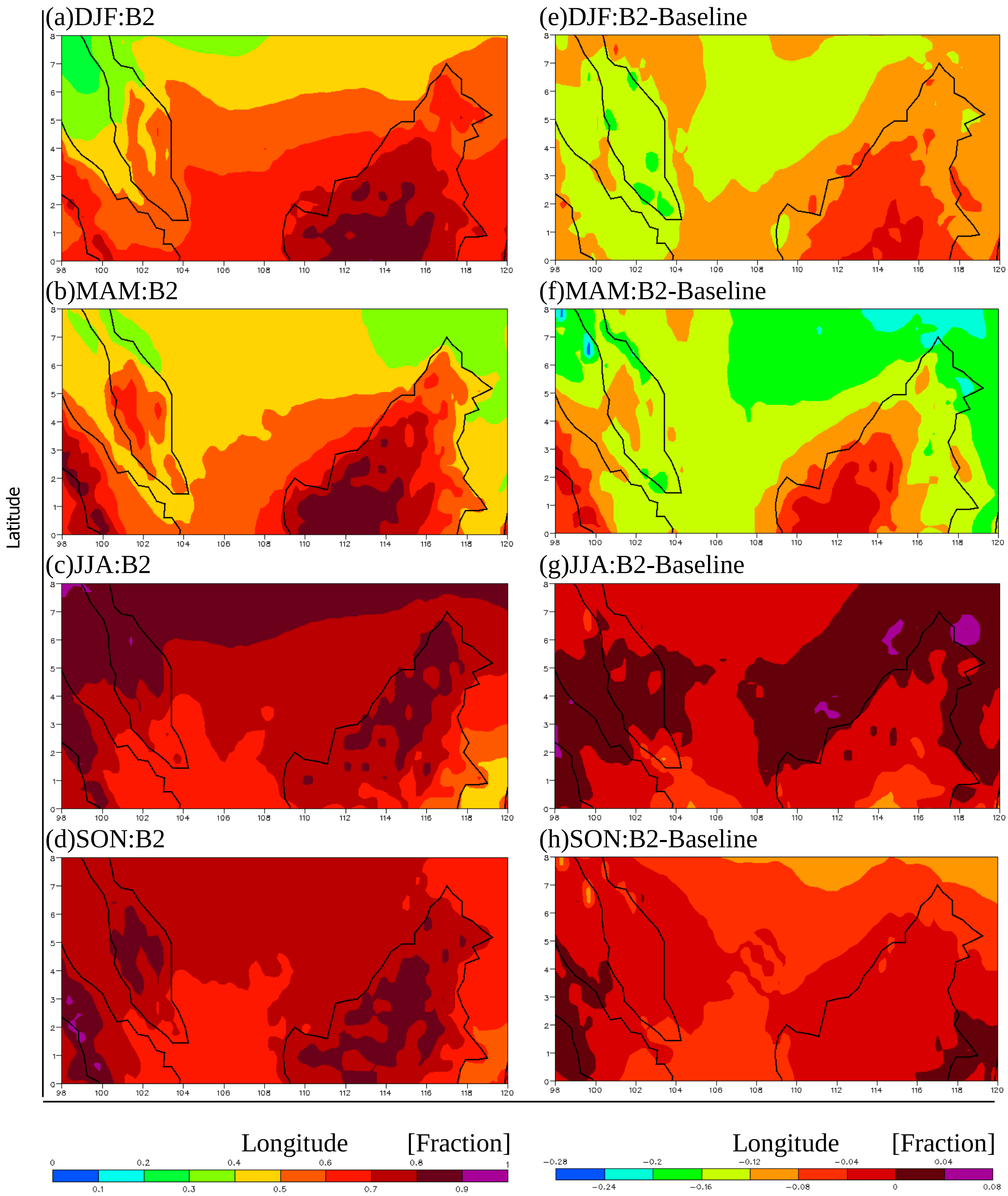

Figure 9. SRES B2: Seasonal mean variables of cloud fraction during DJF (December to February), MAM (March to May), JJA (June to August) and SON (September to November), and the changes of precipitation compared to SRES Baseline (B2-Baseline).

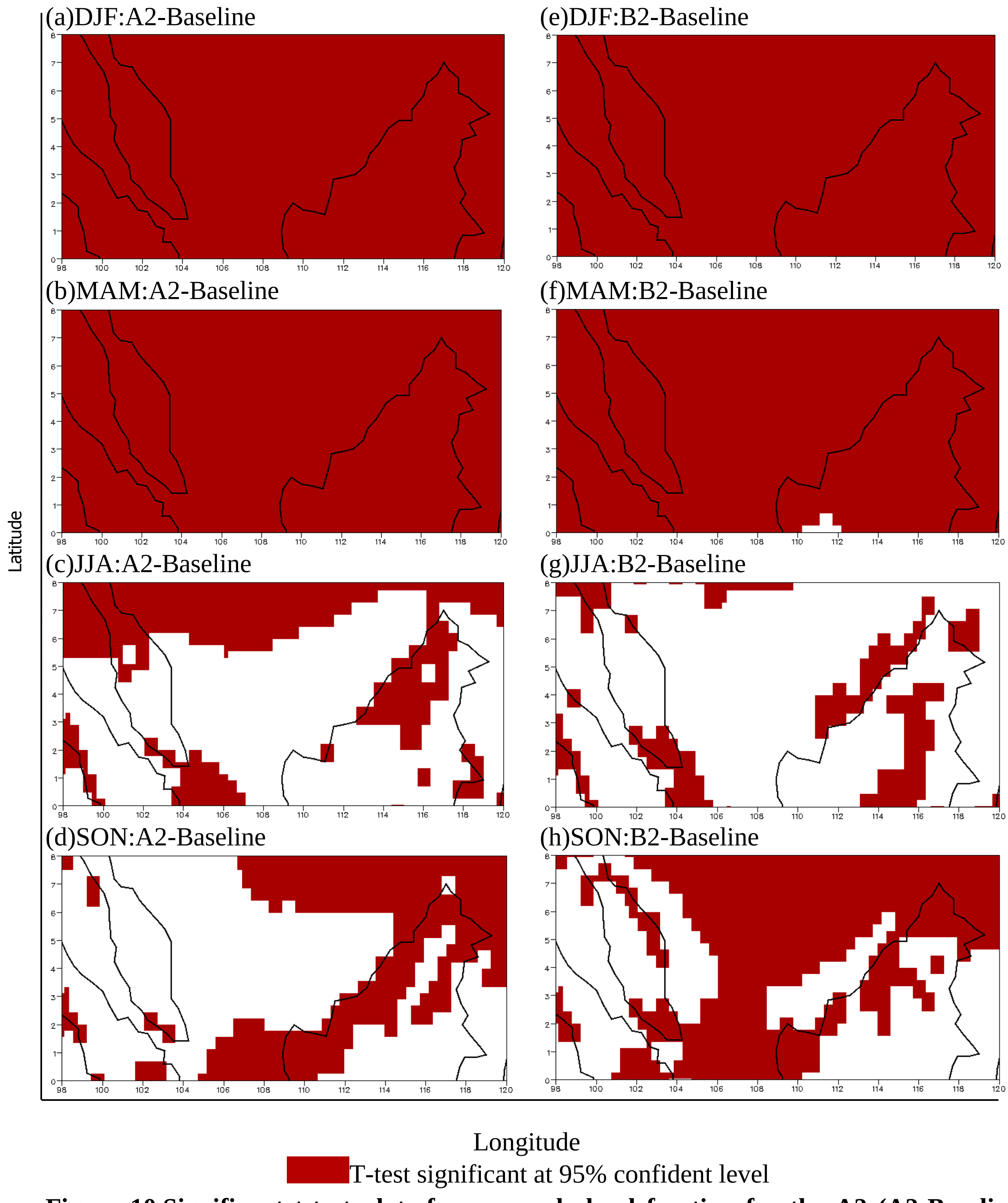

Figure 10.Significant t-test plots for seasonal cloud fraction for the A2 (A2-Baseline) (left panel) and B2 (B2-Baseline) (right panel) climate scenarios relative to the Baseline scenario.

CONCLUSION

The high-resolution PRECIS-RCM, developed by the Hadley Centre, was used in this study for the purpose of climate change investigation over the Malaysian sub-region under the A2 and the B2 scenarios. The RCM data was compared with an ERA40-reanalysis dataset in order to evaluate the performance of the model. From the obtained results, the following conclusions were made:

1. The PRECIS-RCM could perform well in simulating future climate trend. Most of the investigated variables were generally well evaluated.
2. All of the scenarios have similar patterns of mean solar radiation. The season of JJA reached higher solar radiation than DJF under the baseline, the A2 and the B2 scenarios. Relative to the baseline scenario, the seasonal mean of solar radiation increased by 12Wm^{-2} (5.4%) during DJF and 5Wm^{-2} (2.1%) during JJA under the A2 scenario. The changes of solar radiation increased about 10Wm^{-2} (4.5%) during DJF and 3Wm^{-2} (1.3%) during JJA under the B2 scenario. The increments were significant at 95% confidence level across most of the land area.
3. In the future projections of the A2 and the B2 scenarios, there was less cloud relative to the baseline scenario. However, there were some exceptions where the B2 scenario had more cloud than the baseline and the A2 scenarios from July to September. The total cloud fraction of JJA was higher than DJF for all of the scenarios. Relative to the baseline scenario, the change of total fraction over Malaysia indicated a reduction about 0.14 (20.5%) during DJF and 0.032 (4.2%) during JJA under the A2 scenario. The same patterns were observed in the B2 scenario where there was less cloud during DJF (0.57) and more cloud during JJA (0.75). Significant changes were observed over the whole domain of investigation during DJF under both scenarios.

REFERENCES

Ahrens, C. D. 2009. *Meteorology Today: An Introduction to Weather Climate and the Environment Ninth Edition*. Belmont: Brooks/Cole Cengage Learning.

Giorgi, F. &Bi, X. 2005.Regional Changes in Surface Climate Interannual Variability for the 21st Century from Ensembles of Global Model Simulations.*Geophyisical Research Letter*, **32**(13): L13701, doi:10.1029/2005GL023002.

Gordon, C. C., Cooper C., Senior, C. A., Banks, H., Gregory, J. M., Mitchell, J. F.B.,& Wood, R. A. 2000. The Simulation of SST, Sea Ice Extents and Ocean Heat Transport in a Version of the Hadley Centre Coupled Model without Flux Adjustment. *Climate Dynamics*, **16**:147-168.

Hudson, D. A. & Jones, R. G. 2002.*Regional Climate Model Simulations of Present-day and Future Climate over Southern Africa using HadAM3H*. Hadley Centre Techncal Note 38, Met. Office, UK.

IPCC (Intergovernmental Panel on Climate Change).2000. *Emissions Scenarios. (Eds. N. Nakicenovic et al.)*Cambridge University Press, Cambridge, UK.

IPCC (Intergovernmental Panel on Climate Change).2007. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning (eds.)]*.Cambridge University Press, Cambridge, UK.

Jones, R. G., Noguer, M., Hassel, D. C., Hudson, D., Wilson, S. S., Jenkins, G. J., &Mitchell, J. F. B. 2004.*Generating High Resolution Climate Change Scenarios using PRECIS*.Met Office Hadley Centre. Exeter.

Klemen, B. 2006.Climate *Change Scenarios for Macedonia.Report from* University of Nova Gorcia, Centre For Atmospheric Research. Slovenia.

Marengo, J. A., Jones, R., Alves, L. M., and Valverde, M. C. 2009.Future Change of Temperature and Precipitation Extremes in South America as derived from the PRECIS Regional Climate Modeling System, *International Journal of Climatology,* **29**(15): 2241-2255, DOI: 10.1002/joc.1863.

McGregor, J. L., Katzfey, J. J.,& Nguyen, K. C. 1998.*Fine Resolution Simulations of Climate Change for Southeast Asia. Final Report for a Research Project commissioned by Southeast Asian Regional Committee for START (SARCS), Aspendale*, Vic.: CSIRO Atmospheric Research. VI, 15, 35pp.

Mearns, L. O., Giorgi, F., McDaniel, L.,& Shields, C. 2003.Climate Scenarios for the Southeastern United States. *Climate Change*,**60**:7-35.

Met Office. 2002. *PRECIS-Update 2002 Providing Regional Climates for Impacts Studies*. Hadley Centre London Road Bracknell Berkshire RG12 2SY United Kingdom.

Met Office. 2010. *The PRECIS Regional Climate Modelling System. PRECIS Tutorials: Worksheets from the UK PRECIS Workshop 2010*. September 2010, University of Reading, United Kingdom.

Ojha, S. & Kumar, A. 2010.A Pilot Study to Develop Forecasting Models for Predicting Hourly Ozone Concentration near Cincinnati, Ohio. *Advances in Environmental Research*, Vol. 8, Chapter 9, Nova Science Publishers, Inc.

Sentian, J. & Kong, S. S. K. 2013.High Resolution Climate Change Projection Under SRES A2 Scenario during Summer and Winter Monsoons over Southeast Asia using PRECIS Regional Climate Modeling system. *SIJ Transactions on Computer Science Engineering & its Applications (CSEA), The Standard International Journals (The SIJ)*, **1(4)**:163-173.

Sentian, J., MacKenzie, R. A.,& Hewitt, C. N. 2009.*Regional Climate Change Modelling in Southeast Asia: Technical report No. 3/7.*Lancaster Environmental Centre.University of Lancaster.

Uppala, S. M., KÅllberg, P. W., Simmons, A. J., Andrae, U., Da Costa Bechtold, V., Fiorino, M., Gibson, J. K., Haseler, J., Hernandez, A., Kelly, G. A., Li, X., Onogi, K., Saarinen, S., Sokka, N., Allan, R. P., Andersson, E., Arpe, K., Balmaseda, M. A., Beljaars, A. C. M., Van De Berg, L., Bidlot, J., Bormann, N., Caires, S., Chevallier, F., Dethof, A., Dragosavac, M., Fisher, M., Fuentes, M., Hagemann, S., Hólm, E., Hoskins, B. J., Isaksen, L., Janssen, P. A. E. M., Jenne, R., Mcnally, A. P., Mahfouf, J. F., Morcrette, J. J., Rayner, N. A., Saunders, R. W., Simon, P., Sterl, A., Trenberth, K. E., Untch, A., Vasiljevic, D., Viterbo, P., and Woollen, J., 2005. The ERA-40 Re-analysis. *Quarterly Journal of the Royal Meteorological Society*, **131**: 2961-3012. http://dx.doi.org/10.1256/qj.04.176.

Uppala, S., Dee, D., Kobayashi, S., & Simmons, A. 2005.*Evolution of Reanalysis at ECMWF.European Centre for Medium-Range Weather Forecasts*, United Kingdom.

Von Storch, H. & Navarra, A. 1995.*Analysis of Climate Variability.Applications of Statistical Techniques*.Springer, Berlin Heildelberg New York Barcelona Budapest Hong Kong London Milan Paris Tokyo ,pp 334.

Wilson, S., Hassell, D., Hein, D., Jones, R.,& Taylor, R. 2011.*Installing and Using Hadley Centre Regional Climate Modeling System PRECIS. Ver 1.9.3 (Technical Manual)*