IOP Conference Series: Earth and Environmental Science

PAPER • **OPEN ACCESS**

Inter-comparison of multiple Global Climate Model (GCM) data based on spatial pattern of rainfall over Indonesia

To cite this article: Elania Aflahah *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **284** 012017

Inter-comparison of multiple Global Climate Model (GCM) data based on spatial pattern of rainfall over Indonesia

Elania Aflahah[1], Arnida Lailatul Latifah[2], Rahmat Hidayat[3], Rini Hidayati[3], Andi Ihwan[1]

[1]Applied Climatology Study Program, Graduate School, Bogor Agricultural University, Bogor 16680
[2]Laboratorium of High-Performance Computing, Research Center for Informatics, Indonesian Institute of Sciences, Bogor, West Java 16916
[3]Department of Geophysics and Meteorology, Bogor Agricultural University, Bogor 16680

Email: elaniaaflahah@gmail.com

Abstract. The Coupled Model Inter-comparison Project Phase 5 (CMIP5) is the output of many coupled atmosphere-ocean of global climate models (GCMs) and widely used for climate research, especially for driving regional climate model. There are more than 40 CMIP5 GCMs data available, but no single model can be considered as the best for every region. The use of CMIP5 GCMs data for rainfall projection in Indonesia is important to improve the accuracy of the monthly and seasonal rainfall forecast. Then, this study evaluates the capability of the CMIP5 GCMs data for Indonesia region by quantitatively comparing the spatial pattern of the precipitation mean and standard deviation of the CMIP5 data against GPCP, GPCC, and CRU data in the period 1980-2005. Furthermore, the composite analysis is conducted to observe the model performance in reproducing the precipitation characteristic over some areas in Indonesia. In conclusion, the models NorESM1-M, NorESM1-ME, GFDL-ESM2M, CSIRO-MK3-6-0 perform the rainfall mean better than others, while the standard deviation of the rainfall show that the models NorESM1-M, BNU-ESM, CMCC-CMS are superior in which NorESM1-M gives the best performance. The annual precipitation pattern of the model NorESM1-M over various areas in Indonesia is also highly correlated with the observations. Thus, the most suitable model for Indonesia region is NorESM1-M.

1. Introduction

In the last decade, climate models have been developed by integrating several components such as land, vegetation, sea, and other factors (paired models). Working Group on Coupled Modeling (WGCM) developed a Model Inter-Comparison Project Phase 5 Phase 5 (CMIP5) which is a series of experiments various climate models coordinated within the forecast period of historical scenarios and various scenarios. CMIP5 is the fifth phase of CMIP developed under the World Climate Research Program (WCRP), which provides a framework for the coordinated climate change experiments over the next few years promises to yield new insights about the climate system and the processes responsible for climate change and variability [1].

In CMIP5, the global climate models (GCMs) serves as the main tool for studying and understanding climate change [2]. There are more than 40 GCMs that have their own performance and uncertainty on specific area. In addition, the selection of the most adequate model also depends on the specific purpose, i.e. studies focus on extreme wave heights during the winter or during the summer ice melt [3]. Then use of GCMs for specific area needs to be examined. Many previous studies investigate the performance of GCMs for various areas in which precipitation and temperature are the most widely evaluated variables. The study of Perez *et. al* [3] evaluate the ability of GCMs to reproduce three characteristics: synoptic climatology Historically, inter-annual variation and consistency of future projections in the Northeast Atlantic. Yoo and Cho [4] compared 20 GCMs precipitation prediction (rcp8.5) over global domain for the period 2006-2014 and resulted that NoRESM-1M model is the most like GPCP. On the other hand, Samadi *et. al* [5] obtained Hadley Centre Coupled Model version 3 (HadCM3) as the best GCM for Kermanshah synoptic station, Iran. Su *et. al* [6] study the performance of 24 GCMs precipitation and temperature in CMIP5 above the eastern Tibetan Plateau (TP) by comparing the model output with terrestrial observations for the period 1961-2005.

This study aims to evaluate the capability of the CMIP5 GCMs data for Indonesia region whose complex tropical climate. In this paper, we concern to the analysis of the climatological mean of the rainfall, so that the extreme events from such ENSO effect will not be discussed here. The historical experiments of multiple GCMs in CMIP5 are evaluated for the period of 1980-2005. We focus on precipitation as one of the most essential variables in tropics. The seasonal variability from each model is evaluated from the spatial patterns of the precipitation mean and standard deviation within 25 years against various observation data. Since the precipitation in Indonesia varies and depends on the monsoonal, equatorial, and local effects [7], we also investigate the annual cycle of the GCMs precipitation over Java, Sumatera, and Kalimantan that represent different precipitation type in Indonesia

2. Methodology

In this research we select the Indonesia region (6°N - 11°S and 95°E – 141°E) for our domain interest. We use the mean and the standard deviation of the precipitation from the output of decadal experiments CMIP5 during 1980-2005. For evaluation we use three observation data: Global Precipitation Climatology Project (GPCP) v2.3, Global Precipitation Climate Centre (GPCC) v8, Climate Research Unit (CRU) precipitation obtained from (http://climexp.knmi.nl/). We evaluate the precipitation from 40 Global Climate Models (GCMs) in CMIP5 as listed in table 1, but only six GCMs are further analyzed, namely BNU-ESM, CMCC, CSIRO, GFDL, NorESM1-M and NorESM1-ME.

We analyse the model performance based on the spatial pattern and the temporal correlation methods between the observational data and GCM models. For the spatial analysis, we qualitatively compare the climatological seasonal mean and standard deviation of the GCMs precipitation against the observations within the period 1980-2005. There are four seasons: December-January-February (DJF), March-April-May (MAM), June-July-August (JJA), and September-October-November (SON).

Furthermore, temporal analysis conducted by comparing annual cycle of the precipitation mean over three subdomains, namely Java, Sumatera, and Kalimantan whose different precipitation characteristic.

Table 1. Analysed CMIP5 GCMs names, institutions, countries, resolutions [1].

Model	Institution	Country	LAT x LON, layer
ACCESS1.0	CSIRO-BOM	Australia	1.25° x 1.9°, L38
ACCESS1.3	CSIRO-BOM	Australia	1.25° x 1.9°, L38
BCC-CSM1.1	Beijing Climate Center	China	2.8° x 2.8°, L26
BCC-CSM1.1(m)	Beijing Climate Center	China	1.12° x 1.12°, L26
BNU-ESM	College of Global Change and Earth System Science	China	2.8° x 2.8°, L26

IOP Conf. Series: Earth and Environmental Science **284** (2019) 012017 doi:10.1088/1755-1315/284/1/012017

Model	Institution	Country	LAT x LON, layer
CanCM4	Canadian Centre for Climate Modelling and Analysis	Canada	2.8°x 2.8°, L35
CanESM2	Canadian Centre for Climate Modelling and Analysis	Canada	2.8° 9 2.8°, L35
CCSM4 3-3	National Center for Atmospheric Research	USA	0.94° x 1.25°, L26
CMCC-CM	Centro Euro-Mediterraneo per I Cambiamenti Climatici	Italy	0.75° x 0.75°, L31
CMCC-CEMS	Centro Euro-Mediterraneo per I Cambiamenti Climatici	Italy	1.9° x 1.9°, L95
CMCC-CMS	Centro Euro-Mediterraneo per I Cambiamenti Climatici	Italy	1.9° x 1.9°, L95
CNRM-CM5	Centre National de Recherches Me´te´orologiques	France	1.4° x 1.4°, L31
CSIRO-Mk3.6.0	CSIRO-QCCCE	Australia	1.9° x 1.9°, L18
EC-EARTH	EC-EARTH consortium	Various	1.1°x 1.1°, L62
FGOALS-g2	LASG-CESS	China	2.8°x 2.8°, L26
GFDL-CM3	NOAA Geophysical Fluid Dynamics Laboratory	USA	2° x 2.5°, L48
GFDL-ESM2G	NOAA Geophysical Fluid Dynamics Laboratory	USA	2° x 2.5°, L48
GFDL-ESM2M	NOAA Geophysical Fluid Dynamics Laboratory	USA	2°x 2.5°, L48
GISS-E2-H	NASA Goddard Institute for Space Studies	USA	2° x 2.5°, L40
GISS-E2-R	NASA Goddard Institute for Space Studies	USA	2° x 2.5°, L40
HadCM3	Met Office Hadley Centre	UK	2.5° x 3.75°, L19
HadGEM2-AO	Met Office Hadley Centre	UK	1.25° x 1.9°, L38
HadGEM2-CC	Met Office Hadley Centre	UK	1.25° x 1.9°, L60
HadGEM2-ES	Met Office Hadley Centre	UK	1.25° x 1.9°, L60
INM-CM4	Institute for Numerical Mathematics	Russia	1.5° x 2°, L21
IPSL-CM5A-LR	Institut Pierre-Simon Laplace	France	1.9° x 3.75°, L39
IPSL-CM5A-MR	Institut Pierre-Simon Laplace	France	1.25° x 2.5°, L39
IPSL-CM5B-LR	Institut Pierre-Simon Laplace	France	1.9° x 3.75°, L39
MIROC-ESM	MIROC	Japan	2.8° x 2.8°, L80
MIROC-ESM-CHEM	MIROC	Japan	2.8° x 2.8°, L80
MIROC5	MIROC	Japan	1.4° x 1.4°, L40
MPI-ESM-LR	Max-Planck-Institut for Meteorologie	Germany	1.9° x 1.9°, L47
MPI-ESM-MR	Max-Planck-Institut for Meteorologie	Germany	1.9° x 1.9°, L95
MPI-ESM-P	Max-Planck-Institut for Meteorologie	Germany	1.9° x 1.9°, L47
MRI-CGCM3	Meteorological Research Institute	Japan	1.1° x 1.1°, L48
MRI-ESM1	Meteorological Research Institute	Japan	1.1° x 1.1°, L48
NorESM1-M	Norwegian Climate Centre	Norway	1.9° x 2.5°, L26
NorESM1-ME	Norwegian Climate Centre	Norway	1.9° x 2.5°, L26

3. Results and analysis

Precipitation in Indonesia is influenced by the monsoon which is driven by the presence of high pressure cells and low pressure cells in the continents of Asia and Australia alternately. In the months of DJF, in Northern Hemisphere winter occurs due to high pressure cells occurring in Asian Continent, while in Southern Hemisphere at the same time summer occurs. As a result, low pressure cells occur in Australian continent. The differences of the air pressure in the two continents make the wind blowing from high pressure in Asia towards the low pressure in Australia. This wind is called the western monsoon or northwest monsoon. On the contrary, in JJA season there is low pressure in Asia and high-pressure cells in Australia, then the wind blows from Australian to Asia continent. This wind is called east monsoon or southeast monsoon. Due to the differences of the saturation properties of the air masses (wind), west monsoon is usually more humid and results heavy rain than east monsoon. In east monsoon the air moves over the sea in short distances, while in west monsoon the air flow moves over the sea with a considerable distance, so that the air mass of the west monsoon contains more moisture and causes a lot of rain than the east monsoon [8].

3.1. Climatological analysis of the spatial precipitation pattern analysis

In this research we occupy 40 GCMs precipitation data as shown in table 1 to be evaluated against three observational data, i.e. GPCP, GPCC, and CRU. Based on the spatial pattern of the climatological of seasonal precipitation (for both mean and standard deviation) over 25 years (1980-2005), there are six models perform quite well in some regions over Indonesia for one or more seasons. Figure 1-6 show the climatological of seasonal precipitation pattern from the six GCMs, while the observational data GPCP, GPCC, and CRU are respectively shown in figure 7-9. From the six GCMs, only the Norwegian models represent the monsoon behaviour over Indonesia. The others cannot show the wet and dry season clearly; the spatial pattern of the precipitation seems similar for all seasons. This is also observed even for CRU observational data.

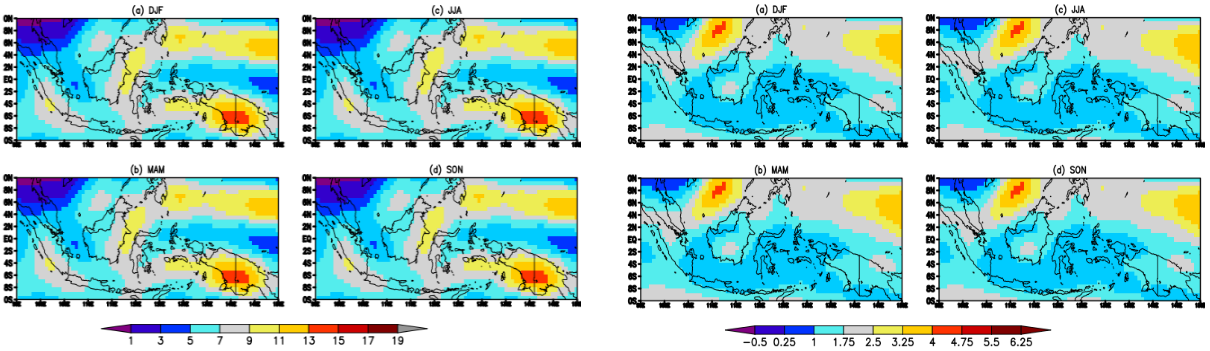

Figure 1. BNU-ESM seasonal precipitation over 1980-2005: mean (left) and standard deviation (right).

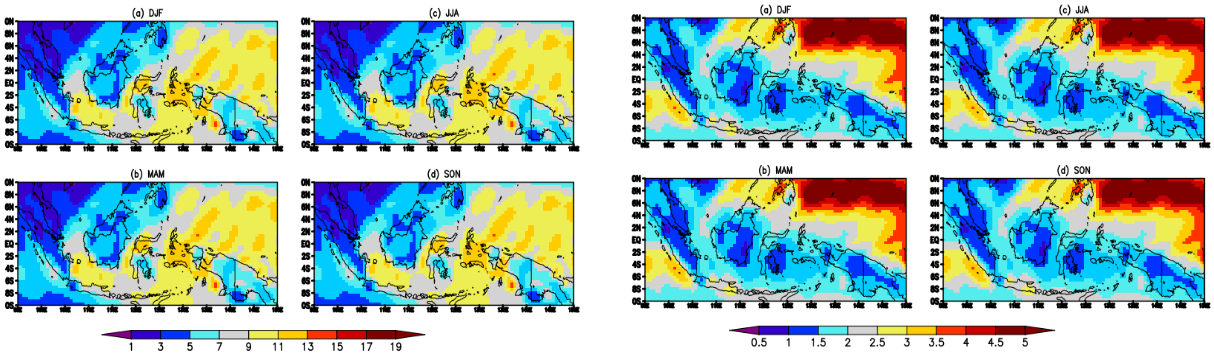

Figure 2. Same as figure 1 for CMCC-CMS.

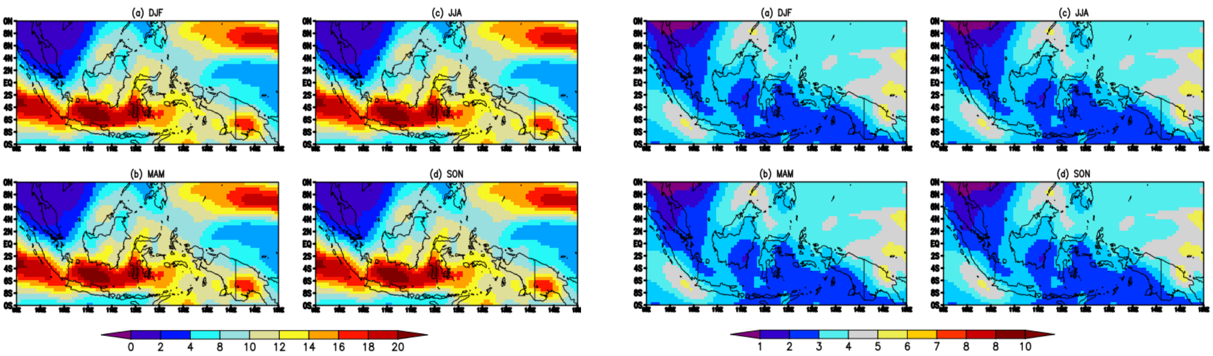

Figure 3. Same as figure 1 for CSIRO-Mk3-6-0.

IOP Conf. Series: Earth and Environmental Science **284** (2019) 012017 doi:10.1088/1755-1315/284/1/012017

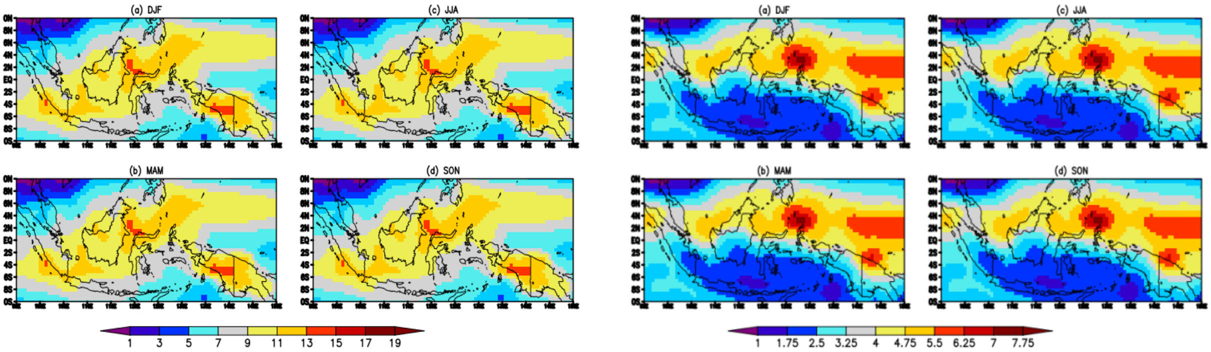

Figure 4. Same as figure 1 for GFDL-ESM2M.

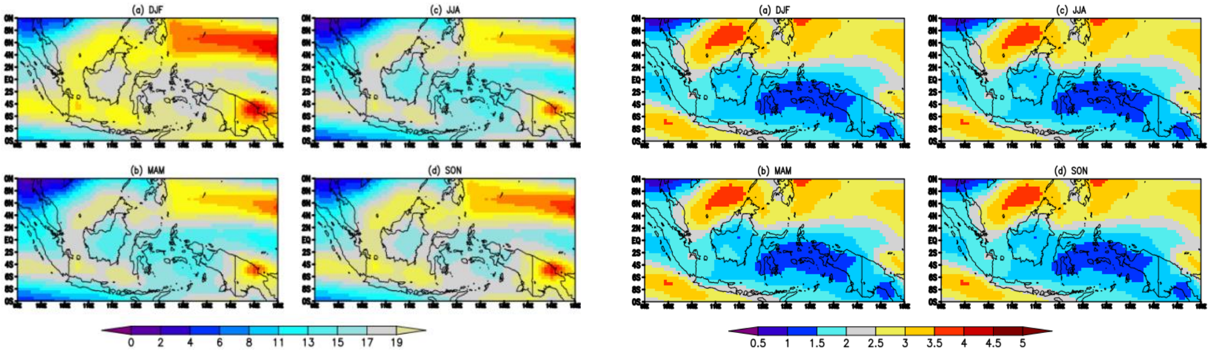

Figure 5. Same as figure 1 for NorESM1-M.

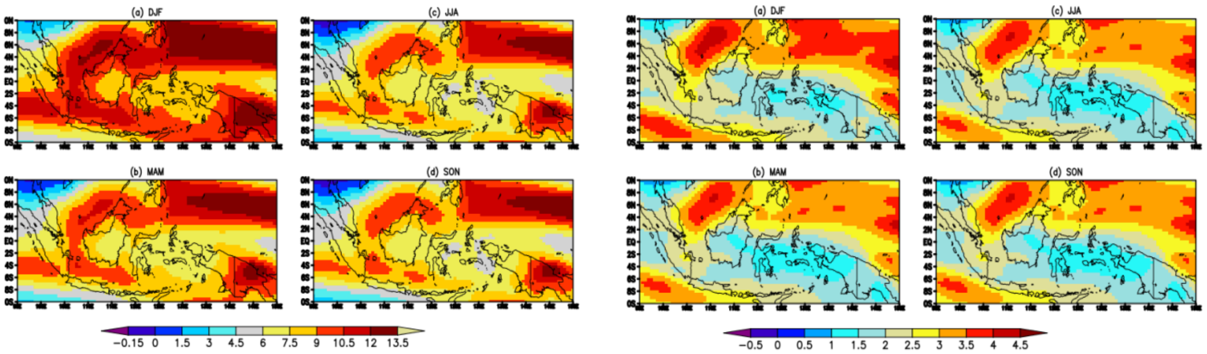

Figure 6. Same as figure 1 for NorESM1-ME.

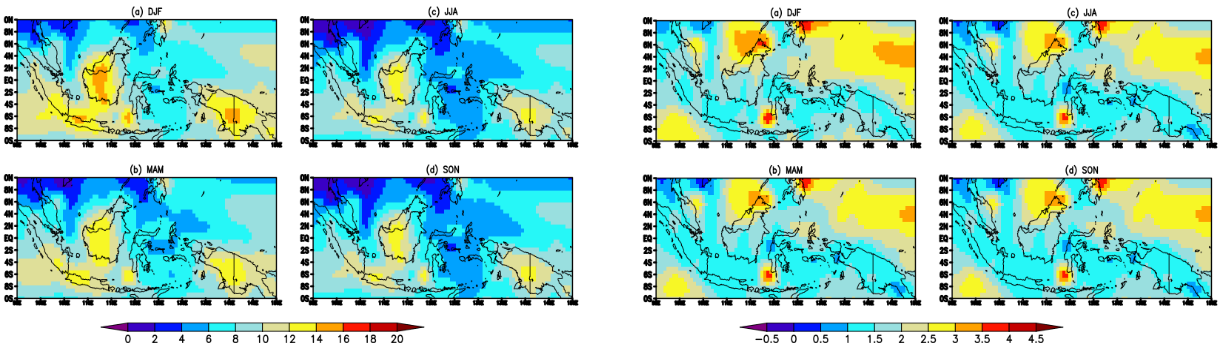

Figure 7. Global Precipitation Climate Project (GPCP) seasonal precipitation over 1980-2005: mean (left) and standard deviation (right).

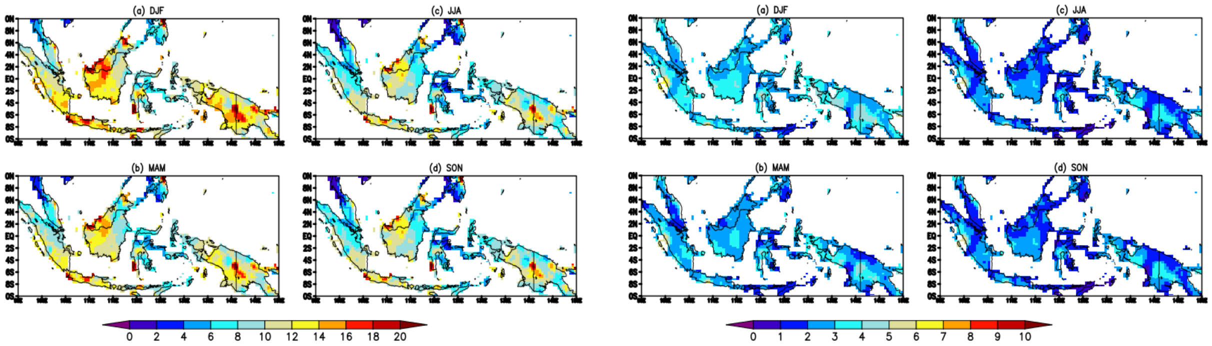

Figure 8. Same as figure 7 for Global Precipitation Climate Centre (GPCC).

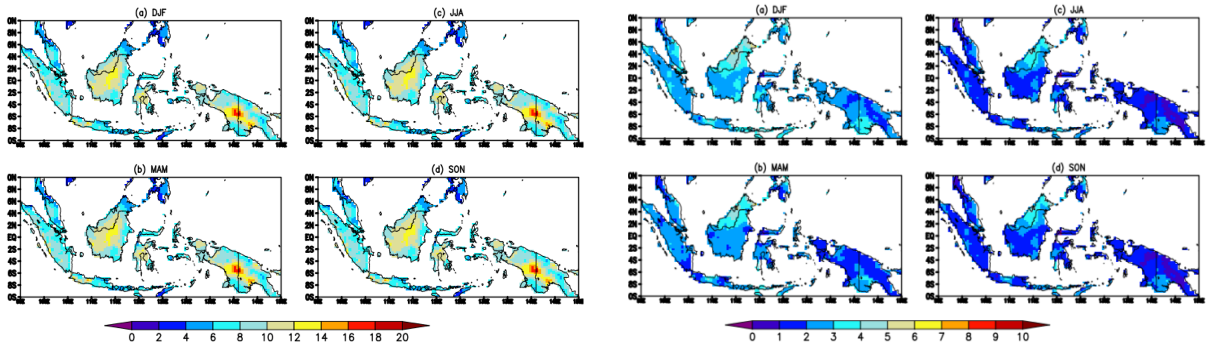

Figure 9. Same as figure 1 for Climate Research Unit (CRU).

3.2. Composite analysis of monthly mean precipitation

The occurrence of the rain in the areas of Indonesia depends on several important physical factors, i.e. latitude, altitude, wind pattern (of the trade winds and the monsoon), distribution landscape and waters. These factors, together or a combination of two or more factors will affect the variety and type of precipitation. The areas coinciding with the equator generally have high precipitation and two times of rain period in a year, so-called a bimodal precipitation pattern. For areas farther from the equator to the south and southeast, the dry season gradually becomes longer [9].

According to Tjasyono [10] the influence of physiographic factors in Indonesia region and its surroundings on climate elements has resulted in 3 (three) types of precipitation, i.e. equatorial, monsoonal and local precipitation. The type of equatorial precipitation occurs due to the movement of convergence zone towards the north and south following the pseudo-sun movement. Convergence zone is a meeting of two air masses (wind) derived from the two hemispheres, then of air is moving upwards. Its position is relatively narrow and is at a low latitude and is known as the Inter-tropical Convergence Zone (ITCZ). The monsoonal precipitation is mostly influenced by the monsoon (Monsoon West) and the local type is more influenced by the condition of the local physical environment, namely landscape as a source of evaporation and high or mountains as rain catchment areas. The type of monsoon rain in Indonesia is characterized by a clear difference between the period of the rainy season and the dry season in a year. This type of rain occurs in the southern part of Indonesia, such as the southern tip of Sumatra, Java, Bali, Nusa Tenggara and southern Maluku [11].

In addition to the spatial analysis in which the performance of the models is hardly visible, we conduct a composite analysis of the monthly mean precipitation. We analyze three subdomains, i.e. Sumatera, Kalimantan and Java that can represent various type of precipitation in Indonesia.

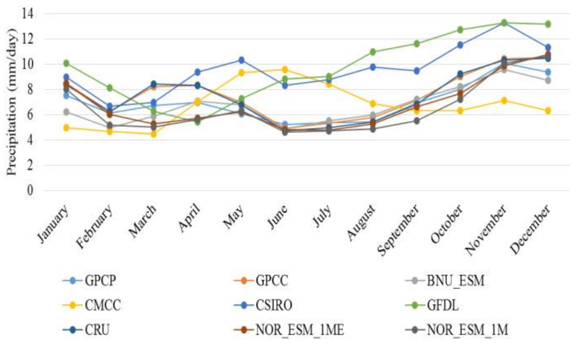

Figure 10. Annual cycle of the monthly mean precipitation during 1980-2005 in Sumatera.

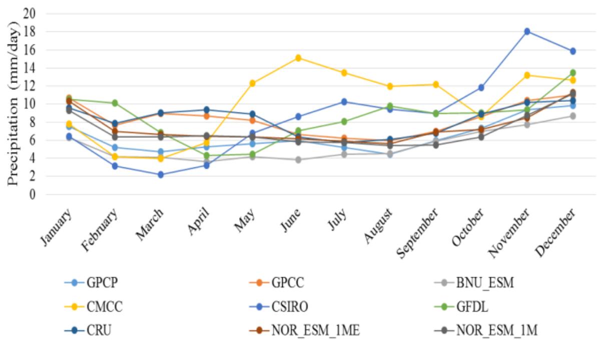

Figure 11. Annual cycle of the monthly mean precipitation during 1980-2005 in Kalimantan.

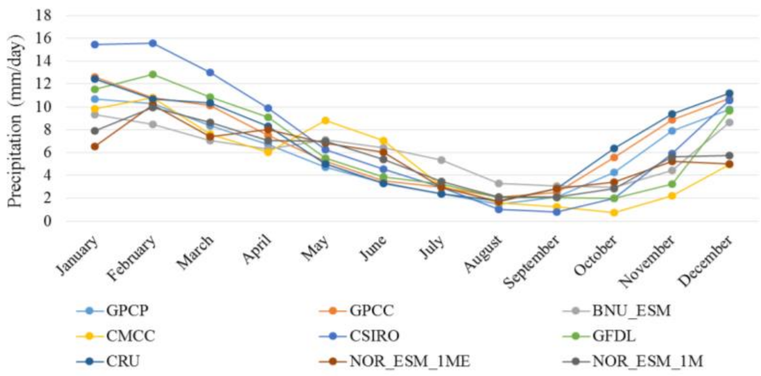

Figure 12. Annual cycle of the monthly mean rainfall during 1980-2005 in Java.

Based on figure 10-12, the GCMs perform really well in reproducing the annual cycle of the precipitation in Java. The monsoonal precipitation pattern is clearly shown in Java from both the observational data and the GCMs, see figure 12. The rainy season occurs in December-February, and the dry season occurs in August-September. The monsoonal pattern is also shown in Sumatera, but it is not as strong as in Java since some of the areas have equatorial precipitation. Figure 10 shows that CMCC, CSIRO and GFDL model cannot follow the precipitation pattern in Sumatera. These models also deviate much from the observation in Kalimantan, see figure 11. Other models, namely BNU_ESM, NorESM1-ME and NorESM1-M reproduce the Kalimantan precipitation pattern well even though some deviations are observed in the period March to May. These all agree with the correlation as shown in table 2.

For more detailed comparison, we measure the correlation of the precipitation annual cycle between the observational data and GCMs as shown in table 2. In Java, CMCC model perform the worst, while CSIRO and GFDL performs best with correlation 0.91 and 0.85 respectively. In Sumatera and Kalimantan, the highest correlation is obtained by the Norwegian model, but BNU-ESM model also gives high correlation. Therefore, for all subdomains the high correlation is achieved by three GCMs, BNU-ESM, NorESM1-ME and NorESM1-M in which NorESM1-M as the superior (0.84). Whereas, CSIRO would be the best choice for climate analysis in Java and NorESM1-M is more suitable for Sumatera and Kalimantan.

Table 2. Correlation between observational data and GCMs in three subdomains (Sumatera, Kalimantan and Java).

Island	Observation Data	GCM					
		BNU_ESM	CMCC	CSIRO	GFDL	NorESM1-ME	NorESM1-M
Java	GPCP	0.79	0.64	0.93	0.87	0.72	0.82
	GPCC	0.76	0.60	0.92	0.86	0.68	0.79
	CRU	0.70	0.54	0.88	0.83	0.66	0.76
	Mean	**0.75**	0.59	**0.91**	**0.85**	0.69	**0.79**
Sumatera	GPCP	0.91	-0.32	0.71	0.61	0.93	0.93
	GPCC	0.87	-0.40	0.63	0.44	0.87	0.88
	CRU	0.84	-0.43	0.59	0.40	0.84	0.85
	Mean	**0.87**	-0.38	0.64	0.48	**0.88**	**0.89**
Kalimantan	GPCP	0.93	0.32	0.78	0.59	0.85	0.87
	GPCC	0.68	-0.23	0.28	0.33	0.86	0.89
	CRU	0.55	-0.33	0.19	0.14	0.71	0.77
	Mean	**0.72**	-0.08	0.42	0.35	**0.81**	**0.84**
	Total mean	**0.78**	0.04	0.66	0.56	**0.79**	**0.84**

Based on the composite analysis and the correlation of the precipitation annual cycle, each area/ island in Indonesia has their own characteristic, so that only few GCMs can follow. Nevertheless, mostly GCMs reproduce the monsoonal annual cycle in Java. Different from Java where the precipitation is only monsoonal, the precipitation in Sumatera and Kalimantan are the combination of monsoonal, equatorial, and the local pattern [12]. This may lead to the difficulty of the GCMs to model the precipitation pattern in these areas.

4. Conclusion

This research compared 40 GCMs precipitation data for the period of 1980-2005 with three observation data (GPCP, GPCC, and CRU) over Indonesia domain. Based on the 25 years mean of the spatial precipitation pattern, the models NorESM1-M, NorESM1-ME, GFDL, CSIRO have similar spatial pattern with the observations almost for all seasons. Meanwhile the models BNU_ESM, CMCC, and NorESM1-M showed similar standard deviation of the precipitation pattern. Then further analysis was done by investigating the annual temporal pattern of the precipitation from the six GCMs (BNU_ESM, CMCC, CSIRO, GFDL, Nor_ESM1-M and NorESM1-ME) over the subdomains Java, Sumatera, and Kalimantan. As a result, all the models perform well the temporal annual pattern over Java except CMCC model. The highest correlation (0.91) was obtained by CSIRO model. In Sumatera and Kalimantan, only BNU-ESM and Norwegian models follow the temporal pattern of the observation precipitation data, in which NorESM1-M gave the best performance with correlation 0.89 for Sumatera and 0.84 for Kalimantan.

References

[1] Taylor K E, Stourer R J, and Meehl G A 2011 An overview of CMIP5 and the experiment design *Meteorology. Soc*. doi:10.1175/BAMS-D-1100094.1.
[2] Miao C, Duan Q, Sun Q, Huang Y, Kong D, Yang T, Ye A, Di A and Gong W 2014 Assessment of CMIP5 climate models and projected temperature changes over Northern Eurasia *Environmental Research Letters* **9** 5

[3] Perez J, Menendez M, Mendez F J and Losada I J 2014 Evaluating the performance of CMIP3 and CMIP5 global climate models over the north-east Atlantic region *Clim Dyn* **43** 2663–2680

[4] Yoo C and Cho E 2017 Comparison of GCM precipitation predictions with their RMSEs and pattern correlation coefficients *Water* **10** 28

[5] Samadi S Z, Sagareswar G and Tajiki M 2010 Comparison of General Circulation Models: Methodology for selecting the best GCM in Kermanshah Synoptic Station Iran *Int. J. Global Warming* **2** 4 pp 347–365

[6] Su F, Duan X, Chen D, Hao Z and Cuo L 2013 Evaluation of the Global Climate Models in the CMIP5 over the Tibetan Plateau *J. Climate* **26** 3187–3208

[7] Aldrian E and Susanto R D 2003 Identification of three dominant precipitation regions within Indonesia and their relationship to sea surface temperature *Int. J.Clim.* **23** 1425–1452

[8] Hermawan E 2003 The Characteristics of Indian Ocean Dipole Mode Premiliminary Study of the Monsoon Variability in the Western Part of Indonesian Region *Jurnal Sains Dirgantara* **1** 1 pp 65-75

[9] Bannu 2003 Analisis Interaksi Monsun, Enso, dan Dipole Mode serta Kaitannya dengan Variabilitas Curah Hujan dan Angin Permukaan di Benua Maritim Indonesia *Tesis Magister* pada GM ITB Bandung.

[10] Tjasjono B 2004 Klimatologi Umum. Penerbit ITB Bandung. Ebert EE and McBride JL 2000 Methods for Verifying Spasial Forecast *J. Hydrol.* **239** 179–202

[11] Prawirowardoyo S 1996 Meteorologi. Penerbit ITB. Bandung.

[12] Tukidin 2010 Karakteristik Curah Hujan di Indonesia *J. Geografi* **7** 2