Rainfall Scenario of West Nusa Tenggara in 2040 Based on CCAM RCP 4.5

A Nurlatifah, S B Sipayung and B Siswanto
Center of Atmospheric Science and Technology, National Institute of Aeronautics and Space
e-mail: amalianurlatifah92@gmail.com

Abstract. Climate change is one of the global issues with a broad impact to society. Because of its importance, there is a need to build a prediction system that can support mitigation, adaptation or prevention of climate change. West Nusa Tenggara (NTB) is an area where most of the population relies on agriculture for their livelihood so that the availability of rainwater becomes very important for daily survival. In this research, rainfall in NTB was predicted by CCAM (Conformal Cubic Atmospheric Model) model based on RCP (Recent Concentration Pathways) 4.5 scenario. Based on the verification results, the CCAM model was proven to perform fairly well in estimating rainfall in NTB in 2014-2016. This is evidenced by the high correlation coefficient between CCAM and observed rainfall data in several locations such as Kuripan, Kumbe, and Gunung Sari which reached 0.57, 0.51, and 0.51 respectively. In January 2040 places such as Bima, Sumbawa Besar and parts of Lombok Island are predicted to have a decrease in rainfall when compared to that in January 2018. The decrease ranges from 40-120 mm in one month. While in Kumbe and Kuripan, rainfall is predicted to increase, with an increase of about 0-40 mm in one month. In August 2040 rainfall is predicted to generally rise in NTB with an increase of up to 40 mm in one month.

Keywords: rainfall, climate change, CCAM, RCP 4.5.

1. Introduction
Today climate change is becoming one of the most discussed global issues. This is because climate change can affect many sectors of the global community, for example rising temperatures and changing climatic patterns that lead to changes in water availability, food security, and comfort of residence [1][2][3][4]. Climate change is a global phenomenon triggered by human activities primarily related to the use of fossil fuels and land use change [5] and can cause long-term effects, especially the rise in global temperatures that lead to increased extreme weather phenomenon and hydro meteorological disaster [6][7]. Due to the importance of these issues and widespread impacts, systems are required that can support mitigation, adaptation, or prevention of climate change, one of them is predictions system using scenarios and climate models. Because of this, researchers today have developed many climate change scenarios, one of them is Representative Concentration Pathways (RCPs).

Representative Concentration Pathways (RCPs) is a measure of the fourth greenhouse gasses emissions trajectory used by the IPCC in its 5th Assessment Report in 2014 [8]. RCP itself is a measure of radiative forcing level for 2100 [9]. Radiative forcing is estimated by forcing from greenhouse gases and some other forcing agents against the air that causes global warming [9]. In this case RCP 4.5 is moderate in terms of magnitude of radiative forcing that is above RCP 2.6 and below RCP 6 and RCP 8.5. The number 4.5 here shows the radiative forcing stabilization scale of 4.5 Watt / meter² (equivalent
to 650 ppm CO2) in 2100 [10][11][12]. The RCP scenario itself is widely aggregated and used in climate modelling using GCM to project future climatic conditions due to increase in concentrations of greenhouse gases as has been planned in RCP [13]. NTB is one of the areas in Indonesia where climate is much influenced by monsoon and trade wind, so that in this region the season changes every 6 months [14]. NTB is one of the poorest provinces in Indonesia where people rely heavily on agriculture and irrigation for their livelihoods [15]. Therefore, the availability of water becomes one of the most important factors in this region. This study aims to determine the impact of climate change on rainfall in NTB since rainfall is one of the most crucial source of water for the livelihood of the people of NTB.

2. Data and Methods
The data used in this study include

2.1. Data

2.1.1. Observation data of station rainfall
The rainfall observation data used in this study includes 14 rainfall cultivator stations belonging to PUSAIR (Water Resources Research and Development Center) scattered throughout the Nusa Tenggara Barat region in 2014-2016. The fourteen stations include station rainfall data used to identify rainfall patterns in Nusa Tenggara Barat and to validate CCAM model results.

2.1.2. GFS Data
GFS (Global Forecasting System) is the data used as an input to the model. These data are produced by NCEP (National Center for Environmental Prediction) and contain many atmospheric parameters such as temperature, wind, rainfall, soil moisture and atmospheric ozone concentrations [16].

Figure 1. Research Flowchart
2.2. Methods
In this research, climate simulation was conducted using the CCAM model. GFS data was used as an input to the CCAM model, and CCAM output was verified by observation data. After ensuring that the CCAM output data is sufficient, then the rainfall condition was projected in NTB based on the CCAM model with scenario RCP 4.5. In general, this research follows a procedure as shown in figure 1. For this research, the spatial resolution that used from CCAM is monthly resolution and spatial resolution is 14 km (0.125°).

2.2.1. Modelling with CCAM
CCAM (Conformal Cubic Atmospheric Model) is a global atmospheric model developed for climate modelling and regional climate downscaling [17][18]. This model implements a quasi-uniform grid, or principle of projecting the earth's surface into a cube panel [19]. Therefore, this model does not require lateral boundaries in the process of its running. In CCAM, the grid stretch is set by a Schmidt transform (figure 2). This model uses a lagrangian advection system approach with horizontal bicubic interpolation [20][21].

![Figure 2](image-url)

Figure 2. Examples of C48 Global Conformal Cubic Grids that have been stretched according to Schmidt transformation (S=3.3), producing approximate resolution 200 km (average worldwide) and 60 km in around Australia [19].

2.2.2. Validation by Using Correlation and RMSE
Pearson correlation is a measure of correlation or linear relationship between two variables. The value ranges from -1 to +1. The correlation value is calculated by the following formula:

\[ r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{n\sum x^2 - (\sum x)^2}[n\sum y^2 - (\sum y)^2]} \]  

Where x is the observed data and y is the model data. Here is the meaning of Pearson correlation value (table 1):

| R value | Meaning                                      |
|---------|----------------------------------------------|
| r > 0.5 | Both variables are strongly correlated positively |
| 0 < r < 0.5 | Both variables are weakly correlated positively |
| r = 0 | Both variables are not correlated |
| -0.5 < r < 0 | Both variables are weakly correlated negatively |
| r < -1 | Both variables are strongly correlated negatively |
RMSE is the average value of the sum of squares error, it can also state the size of the error generated by a forecast model. A low RMSE value indicates that the variation of the value generated by a forecast model approaches the variation in its observed value [22]. The RMSE value is formulated as follows [23]:

\[ RMSE = \sqrt{\frac{\sum_{i=1}^{N}(f_i - O_i)^2}{N}} \]  

(2)

Where \( f_i \) is the forecast generated by the model and \( O \) is the observed value.

3. Results and Discussion

Based on monthly rainfall observation data at fourteen rainfall stations owned by PUSAIR, it can be seen that the pattern of rainfall in West Nusa Tenggara generally shows a monsoonal pattern as expressed by Kirono et al. [14]. The peak of the rainy season generally occurs in December and the lowest rainfall occurs in August and September (figure 3). In December to March rainfall is relatively high, whereas in May rainfall begins to decrease.

![Rainfall Composite in West Nusa Tenggara 2014-2016 Based on Observation Data](image)

Rainfall pattern according to CCAM model also shows similar result. It can be seen that the rainfall pattern in NTB according to CCAM model also follows the monsoonal pattern where the peak rainfall occurs in December and the lowest rainfall occurs in August and September (figure 4). To be able to quantify the difference between the model and the observation, then the correlation and RMSE values of the model and observation was calculated.

Based on the description in figure 3 that shows the rainfall pattern in NTB based on observation data and figure 4 that shows the rainfall pattern in NTB based on CCAM modelling results, it can be seen that there is similar pattern of rainfall between CCAM model and that of observation data. Based on this result, it can be concluded that CCAM model can simulate monsoonal rainfall pattern in West Nusa Tenggara. To reinforce this statement and to demonstrate the performance of the CCAM model in estimating rainfall in West Nusa Tenggara, the correlation and RMSE values between model and observation were calculated. The calculation of the correlation value is intended to calculate the
similarity of the patterns between the precipitation described by the CCAM model and the observed rainfall. While RMSE is calculated to describe difference between CCAM model and observation.

Figure 4. Rainfall Composite in NTB 2014–2016 Based on CCAM Output

Figure 5 shows the correlation result with the highest correlation between observation and CCAM in Kuripan with a correlation value of 0.57. This value is relatively high even though Gulliford categorizes it into the medium to high correlation category. In this case, the value of 0.57 indicates the CCAM climate model can simulate the rainfall pattern in Kuripan quite well. The smallest correlation is found in Dompu with a correlation value of 0.065.

Figure 5. Rainfall Correlation Between Insitu Data and CCAM

For RMSE, the average value is 24.5. When compared with the average rainfall in NTB that ranges up to 200 mm in one month, then this value is relatively small. This means the error bias or the difference between the value of the observation measurement and the CCAM data is not too large. The correlation value between CCAM and observation in Kuripan is also the highest correlation value. Therefore, based on correlation and RMSE values, it can be concluded that the CCAM simulation results in Kuripan is better than in other regions.
It can be seen from figure 7 that CCAM rainfall trend in Kuripan is quite similar to observation. A large difference only occurs from April 2015 to September 2015. At certain points, there is small difference.

From the description above, it can be seen that CCAM RCP 4.5 performs well in describing the condition of rainfall in Nusa Tenggara Barat. Furthermore, after evaluating the performance of CCAM in simulating rainfall, the model was used to project future rainfall based on climate change scenario RCP 4.5-January 2018 and August 2018 were selected to describe wet and dry months in current conditions in West Nusa Tenggara based on the CCAM model. Projection is done until 2040 each in January 2040 and August 2040.

Figure 8a shows that in January 2018, rainfall in the Indian Ocean to the south of NTB is predicted to reach 400 mm. However, the rainfall in the mainland of Nusa Tenggara Barat on the island of Lombok is about 80-240 mm. While on the island of Sumbawa, rainfall is about 120-240 mm, and at the point around the District of Bima reaches 80 mm.

Figure 8b shows that in January 2040, the rainfall generally tends to decrease. Rainfall in Central and North Lombok is around 40-200 mm. On the island of Sumbawa rainfall decreased to about 40-120 mm in Bima, Sumbawa Besar, and part of Lombok Island. Indications of declining rainfall occurred in the Indian Ocean to the south of NTB where rainfall decreased to about 320 mm. Thus, from both figures it can be seen that there is an indication of rainfall decrease in some areas in Nusa Tenggara on January 2040 compared to that in January 2018.
Figure 8. Rainfall in NTB (on mm) based on CCAM output in January (a) 2018, (b) 2040

Figure 9a shows that generally the rainfall in most of West Nusa Tenggara in August 2018 is around 5-20 mm. Relatively high rainfall in this month only occurred in Bima that reached 40 mm. Figure 9b shows that rainfall in West Nusa Tenggara has increased in some areas such as South Lombok, Sumbawa, Bima and Bali Sea is about 40 mm. Thus, from both figures, it can be seen that there is an indication of the increase of rainfall in August 2040 compared with that in August 2018.

Figure 9. Rainfall in NTB (on mm) based on CCAM output in August (a) 2018, (b) 2040

For further indication whether there is a change in rainfall in NTB, an analysis of trends in rainfall scenarios was projected by CCAM with RCP 4.5. This analysis is performed on CCAM projection at 3 points which has the highest rainfall correlation with observation data and the lowest RMSE. In other words, 3 points that has the best CCAM performance were selected. This trend analysis was conducted in Kuripan, Kumbe, and Gunung Sari.

In January, it is estimated that in some areas the rainfall will decrease. It can also be seen in the linear regression of rainfall trend line in January from 2018-2040 where the slope at Gunung Sari is negative (table 2). This means that the rainfall in Gunung Sari will decrease by -0.0001 mm per month from 2018 to 2040. In contrast to Gunung Sari, rainfall in Kumbe and Kuripan is expected to increase. It is characterized by slope of rainfall trend line regression in January in 2018 to 2040 which is positive in these locations (table 2).
Table 2. The value of slope and linear regression intercept of rainfall January 2018-2040

| No | Location | Slope   | Intercept |
|----|----------|---------|-----------|
| 1  | Gunung Sari | -0.0001 | 306.88    |
| 2  | Kumbe    | 0.0071  | -42.526   |
| 3  | Kuripan  | 0.0004  | 257.44    |

Based on spatial analysis, it is estimated that rainfall in NTB will generally increase in August 2040 compared to August 2018. In trend line analysis, the slope trend line for August rainfall is positive in two points (table 3). This means that in all these points rainfall in August is expected to continue to rise until August 2040.

Table 3. The value of slope and linear regression intercept of rainfall January 2018-2040

| No | Location | Slope   | Intercept |
|----|----------|---------|-----------|
| 1  | Gunung Sari | 0.003   | -122.7    |
| 2  | Kumbe    | 0.0039  | -154.67   |

4. Conclusions
The pattern of rainfall in West Nusa Tenggara based on observation and CCAM data shows monsoonal pattern. This means that rainfall in NTB generally reaches a maximum in December and reaches a minimum in August and September. Both the observation data and CCAM show a similar pattern, the Kuripan rainfall correlation reached 0.64. This indicates that CCAM can well simulate rainfall in NTB especially in the Kuripan region. In August 2040 rainfall is projected to increase based on the output of RCP 4.5 scenario by CCAM when compared to that in August 2018. This is shown by the results of the CCAM spatial plot that shows rainfall will increase in the area of South Lombok, Sumbawa, Bima, and Bali Sea with an increase of about 40 mm in August 2040 compared with that in August 2018. This result is also supported by the plot trend line which shows its positive slope in Gunung Sari, Kumbe and Kuripan. While in January 2040, spatially it is estimated that there are some areas where rainfall will decrease compared to that in January 2018, for example in Kabupaten Bima, Sumbawa Besar, Gunung Sari, and part of Lombok Island. Climate change indicated can change the hydrological cycle in the world so that the rainfall in some areas can decrease and vice versa, in other area the impact of climate change is increasing the rainfall.

Acknowledgments
Author wish to thank to the Centre of Atmospheric Science and Technology who has provided material support in the form of facilities so that the writer can complete this research.

References
[1] Rosenzweig C, Iglesias A, Yang X B, Epstein P R, Chivian E 2001 Climate Change and Extreme Weather Events; Implications for Food Production, Plant Diseases, and Pests. Global Change and Human Health, December 2001, Volume 2, Issue 2, pp 90–104.
[2] Piao S, Ciais P, Huang Y, Shen Z, Peng S., Li J., Zhou L., Liu H., Ma Y., Ding Y., Friedlingstein, P., Liu C., Tan K., Yu Y., Zhang T. & Fang J. 2010. The impacts of climate change on water resources and agriculture in China. Nature volume 467, pages 43–51 (02 September 2010). doi:10.1038/nature09364
[3] Turral H, Burke J, Faurès J M 2011 Climate change, water and food security. FAO water reports. ISBN : 9789251067956.
[4] Charles J, Vörösmarty, Green P, Salisbury J, Lammers R B 2000 Global Water Resources: Vulnerability from Climate Change and Population Growth. Science 16 March 2018 Vol 359, Issue 6381.
[5] Harmoni A 2005 DAMPAK SOSIAL EKONOMI PERUBAHAN IKLIM. Proceeding, Seminar Nasional PESAT 2005. ISSN 18582559.

[6] Schipper L and Pelling M 2006 Disaster risk, climate change and international development: scope for, and challenges to, integration. Disasters Volume 30, Issue 1, March 2006, Pages 19–38.

[7] O’Brien G, O’Keefe P, Rose J, Wisn B 2006 Climate change and disaster management. Disasters Volume 30, Issue 1, March 2006, Pages 64–80.

[8] Moss R, Babiker M, Brinkman S, Calvo E, Carter T, Edmonds J, Elgizouli I, Emori S, Erda L, Hibbard KA 2008 Towards new scenarios for analysis of emissions, climate change, impacts, and response strategies. IPCC Expert Meeting Report on New Scenarios. Intergovernmental Panel on Climate Change,

[9] van Vuuren D P, Edmonds J, Kainuma M, Riahi K, Thomson A, Hibbard K, Hurtt G C, Kram T, Krey V, Lamarque J F, Masui T, Meinshausen M, Nakicenovic N, Smith S J, Rose S K 2011 The representative concentration pathways: an overview. Climatic Change November 2011, 109:5.

[10] Clarke L, Edmonds J, Jacoby H, Pitcher H, Reilly J, Richels R 2007 Scenarios of the greenhouse gas emission and atmospheric concentrations. Sub-report 2.1A of Synthesis and Assessment Product 2.1 by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Washington, USA, Department of Energy, Office of Biological & Environmental Research, p 154.

[11] Smith S J, Wigley T M L 2006 Multi-gas Forcing stabilisation with the MiniCAM. Energ J (Special Issue 3): 373–391.

[12] Wise M A, Calvin K V, Thomson A M, Clarke L E, Bond-Lamberty B, Sands R D, Smith S J, Janetos AC, Edmonds JA 2009 Implications of limiting CO$_2$ concentrations for land use and energy. Science 324:1183–1186

[13] Knutti R and Sedláček J 2013 Robustness and uncertainties in the new CMIP5 climate model projections. Nature Climate Change volume 3, pages 369–373 (2013).

[14] Kirono D G C, Butler J R A, McGregor J L, Ripaldi A, Katzfeya J, Nguyen K 2016 Historical and future seasonal rainfall variability in Nusa Tenggara Barat Province, Indonesia: Implications for the agriculture and water sectors. Climate Risk Management Volume 12, 2016, Pages 45-58.

[15] Butler J R A, Suadnya W, Puspadi K, Sutaryono Y, Wise R M, Skewes T D, Kirono D, Bohensky E L, Handayani T, Habibi P, Kisman M, Suharto I, Supartarningsih S, Ripaldi A, Fachry A, Yanuwarti Y, Abbas G, Duggan K, Ash A 2014 Framing the application of adaptation pathways for rural livelihoods and global change in Eastern Indonesian islands. Global Environ. Change 28, 368–382

[16] https://www.ncdc.noaa.gov/data-access/model-data/model-datasets/global-forcast-system-gfs

[17] McGregor J L, Dix M R 2008 An Updated Description of the Conformal-Cubic Atmospheric Model. In: Hamilton K., Ohfuji W. (eds) High Resolution Numerical Modelling of the Atmosphere and Ocean. Springer, New York, NY

[18] McGregor J L, Dix M R 2005 CCAM: Geometric aspects and dynamical formulation. CSIRO Marine and Atmospheric Research Technical Report 70.

[19] Thatcher M and McGregor J L 2008 Using a Scale-Selective Filter for Dynamical Downscaling with the Conformal Cubic Atmospheric Model. Ametosc. https://doi.org/10.1175/2008MWR2599.1

[20] McGregor J L 1996 Semi-Lagrangian advection on conformal-cubic grids. Mon Weather Rev 124: 1311-1322.

[21] McGregor J L 1993 Economical determination of departure points for semi-Lagrangian models. Mon Weather Rev., 121, 221-230.

[22] Makridakis S 1982 The Accuracy of Extrapolative (Time Series Methods): Results of a Forecasting Competition, Journal of Forecasting, Vol. 1, No. 2, pp. 111-153

[23] Barnston A G 1992 Correspondence among the Correlation, RMSE, and Heidke Forecast Verification Measures: Refinement of the Heidke Score. Ametosc. Dec 1992. https://doi.org/10.1175/1520-0434(1992)007<0699:CATCRA>2.0.CO;2