STUDY OF SINGLE- AND DOUBLE-MOMENT MICROPHYSIC SCHEME IMPACT ON LILI AND MANGGA TROPICAL CYCLONE PREDICTION

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ABSTRACT

In this study, prediction of tropical cyclones using the Weather Research and Forecasting (WRF) model was used to test the double-moment (DM) and single-moment (SM) microphysical parameterization schemes in event of Lili and Mangga Tropical Cyclones. Models with microphysical parameterization schemes WDM5, WDM6, WSM5, WSM6, and without microphysical parameterization schemes (CTL) were each tested against track predictions, the pressure value, and maximum wind speed. The results of track prediction show that the best schemes in the tropical cyclone case of Lili and Mangga is WSM6 and WDM6, respectively, with an average error value of 78.1 and 80.1 km. Based on the Taylor diagram, the prediction results of the pressure value and the maximum wind speed in case of Lili Tropical Cyclones get the WDM6 scheme as the best scheme. Meanwhile, the results of the pressure prediction at the cyclone center in the case of Mangga Tropical Cyclones show that the WDM6 scheme is the best. However, the prediction of maximum wind speed in Mangga tropical cyclones produces the CTL scheme as the best scheme. This study shows that DM dan SM microphysical parameterization schemes have a big impact on track prediction compare to pressure value and maximum wind speed variable.

Keywords: WRF, tropical cyclone, microphysics parameterization

1. Introduction

Tropical Cyclone is a low-pressure system with an average maximum wind speed of up to 34 knots near its center that grows over warm tropical waters with temperatures of more than 26.5 and has a cyclonic wind pattern [1]. According to Sosaidi and Ribudiyanto [2], the impact of tropical cyclones is divided into direct and indirect impacts. The direct impact occurs in the areas traversed by the tropical cyclone. Meanwhile, indirect impacts occur in areas that are not part of a tropical cyclone track, such as in Indonesia. As a tropical country in the equatorial region, the likelihood of tropical cyclones occurring in Indonesia is very small due to the small value of Coriolis and earth vortices [3].

The growth areas of tropical cyclones in the world are divided into 7 regions, 2 of which are located around Indonesia, namely the Southeast Indies (Southern Hemisphere 100-142 E) and the Southwest Pacific (Southern Hemisphere 142 E) [2]. One of the tropical cyclones that grow in the region is the tropical cyclone Lili in the Southwest Pacific and the tropical cyclone Mangga in the Southeast Indies. Tropical cyclone Lili began to be detected on 9 May 2019 at 6 UTC in the Banda Sea south of Ambon with a strength of more than 35 knots [4]. The impact of this cyclone was quite damaging to several areas in the Tanimbar islands due to heavy rains, increased wave height, and strong winds. Meanwhile, the tropical cyclone Mangga was detected on 21 May 2020 at 00 UTC around 1220 km southwest of Kerinci with air pressure at the centerof the cyclone of 998 hPa and a maximum wind speed of 32 knots [4]. The indirect impact of this cyclone has triggered an increase in wave height in several areas, such as the waters of Sumatra to East Nusa Tenggara.

Judging from these two cases, the author aims to study tropical cyclones Mango and Lili by using the Weather Research Forecasting (WRF) method. The use of WRF will focus on testing the microphysical parameterization of the cyclone prediction model. The microphysics parameterization in question is the single- and double-moment microphysics parameterization. So that at the end it can be seen which microphysical parameterization produces the best cyclone prediction. WRF is a mesoscale numerical weather model that is used to predict weather conditions or other meteorological phenomena [5]. Previously, Pattnaik et al. [6], conducted research on Rain-Rate Initialization, Cloud Microphysics, and Cloud Torques on Hurricane Intensity using WRF. The results obtained indicate that the use of the rain-rate initialization (RINIT) technique has a significant impact on the prediction of the structure, track, and intensity of hurricanes, but it is necessary to modify the microphysical parameterization using the WSM6 scheme. That is because calculations on microphysical parameterization use basic atmospheric equations involving radiation, internal heating/cooling in cloud microphysics [7].

Many researches on track prediction have been carried out outside the territory of Indonesia [8],[9],[10]. Several studies tested internal parameters that have a significant influence on the prediction of cyclones, hurricane, or typhoons occurring. Microphysics and cumulus parameterization are types of parameterization that have a significant effect on track prediction of tropical cyclones [11].

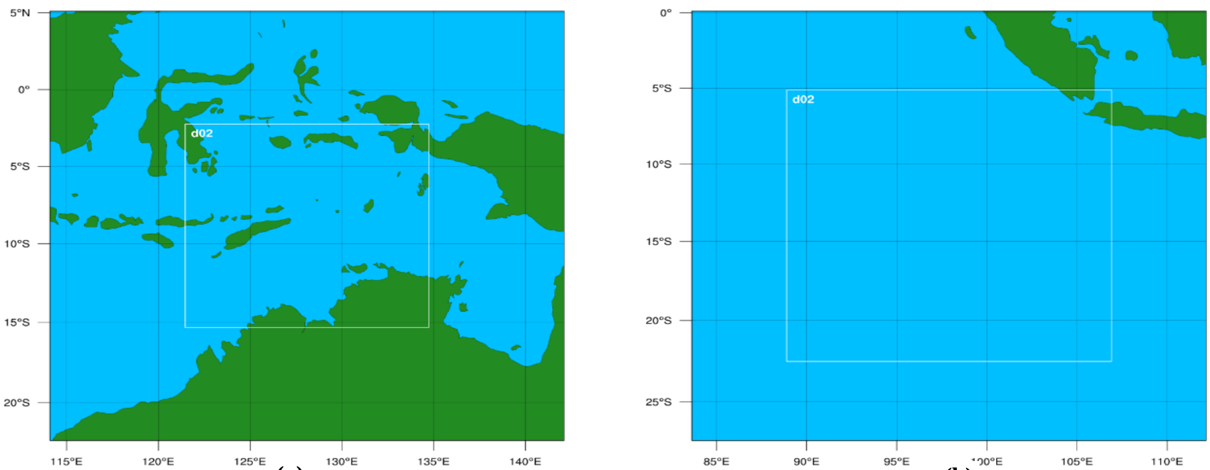
Li et al. [12], conducted a study on the effects of single- and double-moment (SM and DM) microphysics schemes on the Sarika super typhoon incident. The results show that the SM and DM schemes have a significant impact on the prediction of cyclone intensity. In addition, the SM scheme is considered to be more accurate in this case. In Indonesia, research on the microphysical parameterization of tropical cyclones is still very limited. Thus, this study discusses microphysical parameterization with a research question on how the impact of the use of the SM (WSM5 and WSM6) and DM (WDM5 and WDM6) schemes or without the microphysical scheme (CTL) on tropical cyclone Lili and Mangga events. These schemes were each tested against track predictions, pressure value, and maximum wind speed. The contents of this study are continued in experimental design in section 2, results and discussion are described in section 3, and conclusion in section 4.

2. Methods

The prediction of Tropical Cyclone Lili and Tropical Cyclone Mangga will be carried out using Weather Research and Forecast (WRF) version 3.9.1. This study will use each of the four microphysical parameterization schemes to test the sensitivity to predictions of Tropical Cyclone Lili and Tropical Cyclone Mangga. The four schemes consist of two single-moment schemes, namely WSM5 and WSM6, and two double-moment schemes, namely WDM5 and WDM6. For cumulus parameterization, the Betts - Miller - Janjic (BMJ) scheme is used, which is applied together with all tested microphysical schemes. The running time of the WRF model for Lili tropical cyclone and mango tropical cyclone is 51 hours and 0118 hours, respectively, with the output time interval being every 6 hours. The WRF model used uses two domains with the spatial resolution used is 30 km and 10 km as shown in Figure 1.

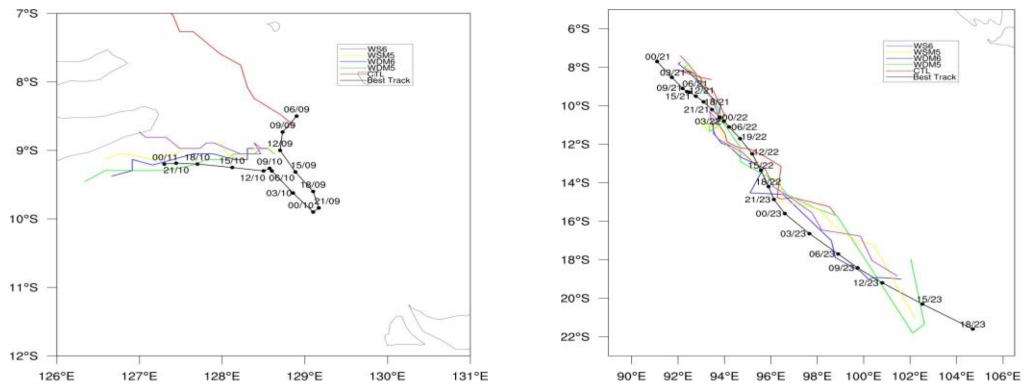
Global Forecasting System (GFS) data is used as the initial model data which has a resolution of 0.25 x 0.25 with a time interval of 3 hours. To verify the prediction results of the WRF model, data from the International Best Track Archive for Climate Stewardship (IBTrACS) were used [13]. The variables to be verified are the cyclone track, the pressure at the center of the cyclone, and the maximum wind speed.

Verification is used by taking into account the values of the root mean square error (RMSE), correlation coefficient (CORR), and standard deviation (SD) to be made into a Taylor chart to determine which parameterization scheme results in predictions of pressure at the centre of the cyclone and maximum wind speeds that are better than Tropical Cyclone Lili and Tropical Cyclone Mangga. The calculation of direct position error (DPE) is used to determine the error size of the track prediction against verification data by IBTrACS in kilometres (km). The DPE value will be used to calculate the skill forecast in percent which will state what percentage increase in the track prediction ability of each scheme when compared to the control model (CTL), which is a model without a microphysical parameterization scheme.



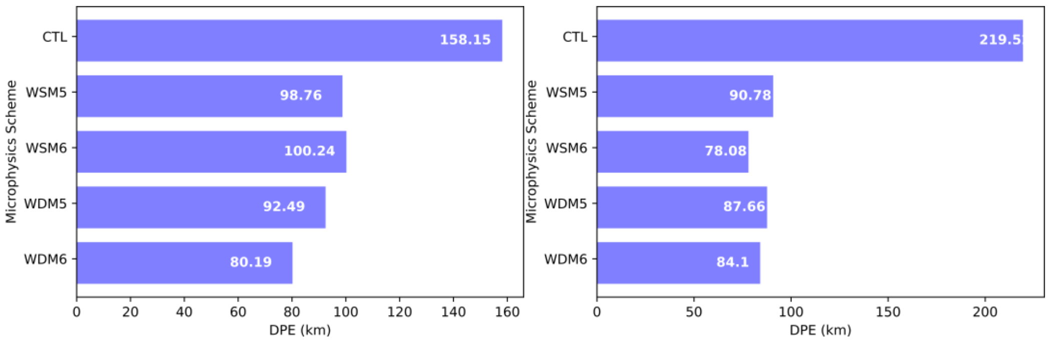
(a) **(b)**

Figure 1. The domain of the research area, (a) Tropical Cyclone Lili case and (b) Tropical Cyclone Mangga case.



(a) (b)

Figure 2. The track prediction results from (a) Tropical Cyclone Lili and (b) Tropical Cyclone Mangga.



(a) (b)

Figure 3. Bar plot of the average direct position error (DPE) value of (a)Tropical Cyclone Lili and (b) Tropical Cyclone Mangga

3. Result and Discussion

Cyclone track prediction result. The results of the cyclone track predictions from each microphysical parameterization scheme are shown in Figure 2. Based on the results of the track predictions for each cyclone, it is known that there is an increase in the predicted results when compared to schemes that do not use microphysical parameterization (CTL). The cyclone track is made by finding the location of the low-pressure centre which is marked with the lowest sea level pressure (slp) value generated by the WRF model of each scheme. The prediction results of Tropical Cyclone Lili tracks show that each microphysical scheme has difficulty predicting the starting point of the cyclone but begins to show a pattern that starts to be the same as the observation results. It can be seen that the CTL scheme that does not use microphysical parameterization results in tracks that are far off the mark from the observations. This is because the CTL scheme is unable to detect the lowest slp value along the track path based on the observation results.

The prediction results of the Tropical Cyclone Mangga track show quite different results, especially in the prediction of the starting point of the cyclone. Each of the schemes tested can produce a cyclone starting point close to the observed results. Over time the predictions, each of the schemes tested also show a pattern that tends to be the same as the observed results. The difference that occurs between the CTL scheme and other schemes is that the predicted range of tracks produced by CTL is much shorter and far from the observation results compared to the other schemes tested.

To find out the exact error from the track prediction, the direct position error (DPE) value is calculated. The predicted average DPE value generated by each scheme in each cyclone event tested is shown in Figure 3. It is known that in the case of Tropical Cyclone Lili (Figure 3a), the WSM6 scheme produces a lower DPE value which indicates that the prediction results in a smaller error with an average value of 78.08 km. This value indicates that the model with the WSM6 scheme produces an average difference in the centre point of the cyclone between the predicted and observed results as far as 78.08 km. These results are in line with research conducted by Sun et al. [14], who predicted the track of Typhoon Hagupit. their result is that the WSM5 and WSM6 prediction schemes produce a smaller average track prediction error different results are shown in the average DPE value generated from the predicted Tropical Cyclone Mangga track (Figure 3b). The WDM6 scheme produces a smaller average DPE when compared to other schemes tested. The average DPE value produced by WDM6 is 80.16 km.

Table 1. Skill score of the microphysics scheme model in Tropical Cyclone Lili.

Scheme	Skill Score (%)
WSM5	58.64
WSM6	64.43
WDM5	60.07
WDM6	61.69

Table 2. Skill score of the microphysics scheme model in Tropical Cyclone Mangga.

Scheme Skill Score (%)

Scheme	Skill Score (%)
WSM5	37.55
WSM6	36.61
WDM5	41.52
WDM6	49.29

When compared with research conducted by Li et al. [8] The results obtained from this study are different. In their research, the WDM5 scheme is a scheme that produces a lower average DPE than the other schemes tested, namely WSM5, WSM6, and WDM6. In this study, two different cyclone cases produced different schemes in producing a smaller average DPE value. This shows that the selection of the microphysical parameterization scheme to produce the best track prediction results varies in each cyclone case.

After knowing the average DPE results for each scheme being tested, the cyclone track forecast skill calculation is then performed to determine the increase in each scheme to the model without a microphysical scheme (CTL). The results of the skill forecast for each scheme are shown in Table 1 and Table 2. It is known that the average skill score for Tropical Cyclone Lili varies between 58.64 - 61.69 % with the WSM6 scheme being the scheme that produces the highest skill score and the WSM5 scheme the lowest skill score. The average skill score generated by each scheme in the case of Tropical Cyclone Mangga varies between 37.55 - 49.29 % with the WDM6 scheme being the scheme that produces the highest skill score and the WSM5 scheme also produces the lowest skill score. The skill score value shows an increase in the prediction accuracy of tropical cyclone tracks in percent against models without a microphysical scheme (CTL).

The prediction results of the pressure at the center of the cyclone and the maximum wind speed. The RMSE, CORR, and SD values are used to determine each point of the schematic being tested on the Taylor diagram. Figure 4 shows the Taylor Diagram produced by each scheme in the case of Tropical Cyclone Lili based on its sensitivity in predicting the pressure value at the center of the cyclone. The WSM5 scheme shown as number 1 in the Taylor Diagram is the best for predicting the pressure value at the center of a cyclone when compared to the other schemes tested. This is indicated by the point produced by the WSM5 scheme that is closest to zero (0). This result is in line with the research conducted by Chan et al. [11], who conducted a research on intensity prediction in six cyclone cases. They found that the prediction results of the WRF model with the WSM5 scheme produce a closer value than the best track data.

Different results are found in the Taylor Diagram produced in the case of the Tropical Cyclone Mangga (Figure 5). The WDM5 scheme marked with number 3 is the best scheme for predicting pressure values at the center of the Mango Tropical Cyclone when compared to other schemes. The results of the sensitivity test of each scheme for the maximum wind speed variable in the case of Tropical Cyclone Lili and Tropical Cyclone Mangga are shown in Figure 6 and Figure 7. The WDM5 scheme still produces better maximum wind speed prediction values when compared to other schemes in the case of the Tropical Cyclone Lili. A very different result was found in the case of the Mango Tropical Cyclone, where the CTL scheme was the one that produced better maximum wind speed predictions when compared to all the microphysical schemes tested.

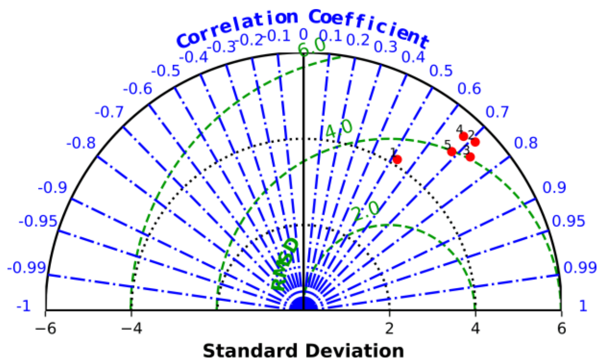


Figure 4. Taylor diagram test results variable pressure in the center of Tropical Cyclone Lili, 1: WSM5, 2: WSM6, 3: WDM5, 4: WDM6, 5: CTL.

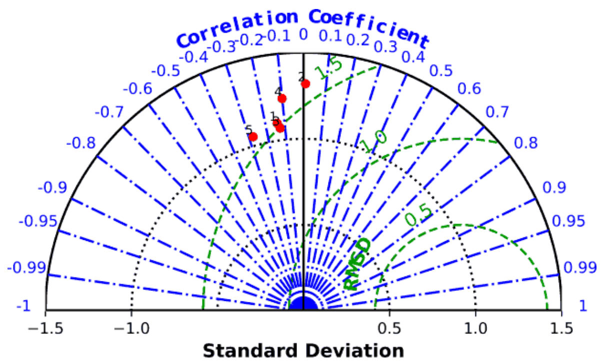


Figure 5. Taylor diagram test results variable pressure in the center of Tropical Cyclone Mangga

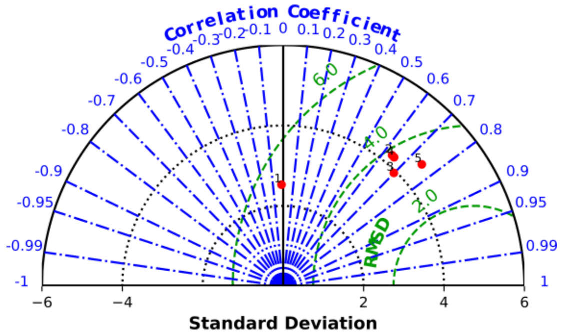


Figure 6. Taylor diagram test results variable maximum wind speed of Tropical Cyclone Lili

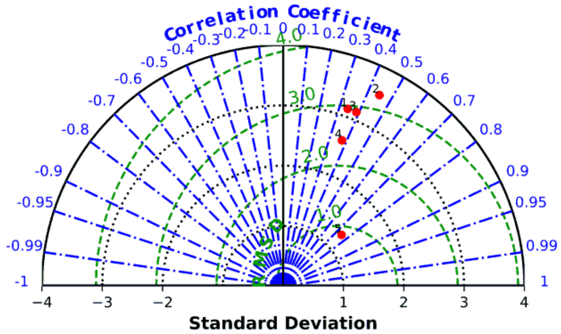


Figure 7. Taylor diagram test results variable maximum wind speed of Tropical Cyclone Mangga

From the prediction of the pressure value at the center of the cyclone and the maximum wind speed, it was found that the scheme that produced the best prediction was different from the result obtained from the cyclone track prediction. This shows that there is no dominant scheme in each test variable. In the case of Lili Tropical Cyclones, the WSM6 scheme produces the best track predictions while for the prediction of maximum wind pressure and speed, the WDM5 scheme is the one that produces the best predictions. In the case of the Mango Tropical Cyclone, the WDM6 scheme is the scheme that produces the best track predictions. Unlike the case of Tropical Cyclone Lili, the best predictions for the variable pressure and maximum wind speed are not generated from the same scheme, the WSM5 scheme can produce a better pressure prediction while for the best prediction the maximum wind speed variable is generated by the CTL scheme. This result is different when compared to the research conducted by Li et al. [8], where the WSM6 scheme is the best scheme while the WDM5 scheme is the worst at predicting the pressure at the center of the cyclone of the four schemes tested. For maximum wind speed prediction, the WSM6 scheme is the one that produces the best predictions. This shows that the selection of the best microphysical scheme is not the same for different cases, so it is necessary to test the parameterization scheme again to determine the best scheme, especially the microphysical parameterization scheme.

4. Conclusion

Based on the results and discussion in the previous chapter it can be concluded that, the effect of microphysical parameterization on track predictions is very significant, especially in the prediction of the starting point and the range of the cyclone points to the observed data with the increase in predictions varying between 37 - 64%.

Microphysics parameterization schemes produces better predictive value of the track variables when compared to scheme without microphysics parameterization. Also, the prediction results of the pressure at the center of the cyclone and the maximum wind speed indicate that the WDM5 scheme is the best scheme for the Tropical Cyclone Lili case, while for the Tropical Cyclone Mangga case, the WSM5 scheme can produce the best prediction of pressure and the CTL scheme for predicting maximum wind speed.

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