WRF-MODEL PARAMETERIZATION TEST FOR PREDICTING EXTREME HEAVY RAINFALL EVENT OVER KETAPANG REGENCY

Fazrul Rafsanjani Sadarang
Meteorological, Climatological, And Geophysical Agency (BMKG), Jl. Angkasa 1, No.2, Jakarta Pusat 10610
E-mail: fazrul.sadarang@bmkg.go.id

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ABSTRACT

Heavy rains that cause floods and landslides in the Ketapang Regency can be predicted by utilizing the weather research and forecast (WRF) model. The WRF model used, of course, needs to be configured to represent the conditions that exist in Ketapang Regency. This study evaluates the combination of cumulus and microphysics parameterization, producing the best prediction of 24-hour accumulated rainfall. The combination of cumulus and microphysics parameterization tested as many as 24 schemes which later will be obtained which combination can produce the best prediction of rainfall accumulation with the comparison of rainfall measured at the Observation Station of the Meteorology, Climatology, and Geophysics Agency (BMKG) in Ketapang Regency. The results show that combining the KF-Scheme cumulus parameterization scheme and the Kessler-Scheme microphysics can better predict 24-hour accumulated rainfall than other tested parameterization schemes. This result is based on the root mean square error (RMSE), which shows that this combination scheme produces the smallest value and large correlation coefficient (CORR). From this research, it can also be seen that cumulus parameterization has a more dominant role than microphysics parameterization.

Keywords: WRF model, heavy rain prediction, cumulus and microphysics parameterization

1. Introduction

Heavy rains are widespread in Indonesia and cause floods and landslides [1] [3]. This event is because Indonesia is located in the tropics, so it is an area that often forms mesoscale convective complexes [1]. One of the incidents of heavy rain that caused flooding and landslides occurred in Ketapang Regency (KK) and North Kayong Regency (KKU) on 13-14 July 2021. The rain was measured at one of the Meteorology, Climatology, and Geophysics Agency's (BMKG) observation stations in KK. It noted that the rain in those two days was ±75 mm/day. Rain with moderate to high intensity, which lasted for three days in almost all areas of KK and KKU, caused the water not to have time to seep into the ground and, in several locations, caused the soil to become prone to landslides.

Simulation and prediction of heavy rainfall events in the tropics are more complex than in high latitudes [4]. The way that can be done to simulate or predict meteorological phenomena is by utilizing numerical weather prediction (NWP), which can be done by utilizing lower computational costs and can cover a wide area. One of the utilization of NWP can be used weather research and forecast (WRF). WRF can simulate meteorological events from large-scale events such as tropical cyclones and moderate to small-scale events such as heavy rain [5]–[8].

Research utilizing the WRF model has been carried out by Martinez-Castro et al. [9], to simulate convective rain in the Peruvian region, which is also a tropical region. In his research, a microphysics parameterization scheme was tested, namely by Goddard, Morrison, Thompson, WSM6, Millbrandt, and Lin. From two convective rain simulation cases that were carried out, all the schemes tested produced a reasonable 24-hour rain estimate in the first case. However, different results were found in the 24-hour rain estimation made in the second case. Goddard and Millbrandt's scheme produce a 24-hour rain estimate lower than the comparative data (underestimated). Morrison's scheme is known as a scheme that can produce better simulations in both cases when compared to other microphysics schemes tested.

Testing of the microphysics parameterization scheme has also been carried out by Khadke and Pattnaik [8]. The research also examines the impact of the initial condition data on the case of heavy rain simulations in India. The results obtained from this study state that the selection of initial condition data and microphysics parameterization significantly affect the simulation results, especially in their impact on simulating the amount of water vapor at the lower to the upper level, thereby affecting the ability of the model to represent hydrometeor particles (supercooled water content in convective clouds).

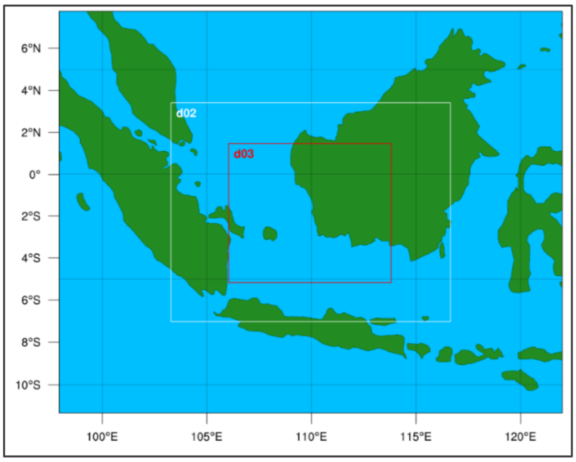

Figure 1. WRF model domain

Table 1. WRF model configuration

Configuration	Domain 1	Domain 2	Domain 3
Spatial resolution	27 km	9 km	3 km
Interval second model	10800 seconds		
Dimensions of the east – west grid	100	166	289
Dimensions of the south – north grid	80	130	247
Dimensions of the vertical grid	35		
Physics suite	*Tropical*		

Other studies have been conducted but focused on testing the cumulus parameterization of the WRF model to determine its effect on the simulation results of heavy rain events that occurred in mainland India by Budakoti et al. [10]. They tested seven schemes on the WRF model to determine which cumulus scheme gives better heavy rain simulation results. The seven schemes are Kain-Fritsch (KF), Bette's Miller Janjic (BMJ), Arakawa Schubert (USA), Tiedtke, Grell Freitas (GF), Multi-Scale Kain-Fritsch (MSKF), and newer-Tiedtke. The results of this study show that the WRF model using the cumulus KF scheme can simulate rain events that are close to the observations, followed by the MSKF and Tiedtke schemes. The WRF model can also simulate the cloud-burst phenomenon that occurs. This result shows that the choice of cumulus parameterization can positively impact the simulation results of heavy rain events in the Indian region.

Research that tested the parameterization scheme has also been conducted in Indonesia to test the sensitivity of microphysics parameterization for simulating the hail phenomenon in the Jakarta area by Djakaria [11]. Three microphysics schemes were tested in this study, namely the WSM3, WSM6, and Thompson schemes. The results show that the WSM6 and Thompson schemes can represent the pattern of solid convective cells when hail occurs in Jakarta quite well, but the area where hail falls is still different compared to the area observed by weather radar. The verification results' root means square error (RMSE) value shows that the Thompson scheme produces a smaller value. Hence, the resulting average error is smaller than the errors produced by the WSM3 and WSM6 schemes.

Previous research has yet to focus on the West Kalimantan region, where hydrometeorological disasters such as floods and small tornadoes are common, especially in Ketapang Regency, as stated by research conducted by Wibowo and Sadikin [12]. Therefore, this study will examine the sensitivity of the cumulus parameterization and microphysics of the WRF model to predict the occurrence of heavy rains that cause floods and landslides in Ketapang Regency so that the combined WRF model scheme with the best predictive results is obtained.

Table 2. Cumulus and microphysics combination schemes

Scheme	Cumulus	Microphysics	Scheme	Cumulus	Microphysics
cu1mp1	KF – scheme	Kessler	**cu2mp5**	BMJ – scheme	Ferrier
cu1mp2	KF – scheme	Lin et al.	**cu2mp6**	BMJ – scheme	WSM 6
cu1mp3	KF – scheme	WSM 3	**cu2mp7**	BMJ – scheme	Goddard
cu1mp4	KF – scheme	WSM 5	**cu2mp8**	BMJ – scheme	Thompson
cu1mp5	KF – scheme	Ferrier	**cu3mp1**	GFE – scheme	Kessler
cu1mp6	KF – scheme	WSM 6	**cu3mp2**	GFE – scheme	Lin et al.
cu1mp7	KF – scheme	Goddard	**cu3mp3**	GFE – scheme	WSM 3
cu1mp8	KF – scheme	Thompson	**cu3mp4**	GFE – scheme	WSM 5
cu2mp1	BMJ – scheme	Kessler	**cu3mp5**	GFE – scheme	Ferrier
cu2mp2	BMJ – scheme	Lin et al.	**cu3mp6**	GFE – scheme	WSM 6
cu2mp3	BMJ – scheme	WSM 3	**cu3mp7**	GFE – scheme	Goddard
cu2mp4	BMJ – scheme	WSM 5	**cu3mp8**	GFE – scheme	Thompson

2. Methods

This study utilizes the weather research and forecast (WRF) model version 4.2 to run a weather prediction model of 24 schemes. Each scheme will run on three domains with a resolution of 27.9.3 km each, as shown in Figure 1. The WRF model will run from 12 July 2021 at 12 UTC to 15 July 2021 at 12 UTC (72 hours). As initial condition data, data from the NCEP Global Forecast System (GFS) is used with a resolution of 0.25° x 0.25° [13]. Each model will run with the same configuration and only changes the cumulus and microphysics parameterization according to the specified scheme.

The parameterization scheme consists of three cumulus parameterization schemes and eight microphysics parameterization schemes, so the combination of the two will produce 24 combination cumulus and microphysics parameterization schemes. The choice of a combination of cumulus and microphysics schemes in this study was based on research related to heavy rain simulations using the WRF model in mainland China by Liu et al. [14] and Song and Sohn in mainland Korea [15]. This combination of schemes is then applied to cases of heavy rain in Indonesian regions, especially in the Ketapang Regency area, to find out which combination can predict rainfall better. The parameterization combinations used are shown in Table 2.

Each WRF model parameterization scheme will focus on producing a predictive value of the rainfall variable every three hours. This choice aligns with rainfall measurements carried out by the BMKG observation station. The rainfall resulting from the WRF model predictions will be compared with the rainfall values measured at the BMKG observation station, namely the Class III Meteorological Station Rahadi Oesman Ketapang (Stamet Ketapang). The two rainfall values generated by the WRF model parameterization scheme and the results of three-hour observations at the observation station will be used to calculate the root mean square error (RMSE) value and the correlation coefficient (CORR) value as a verification process for the prediction results of the WRF model. The WRF scheme that produces the smallest RMSE value and the most considerable CORR value will be the WRF model scheme that produces the best rainfall prediction compared to the other WRF model schemes tested.

3. Result and Discussion

Based on the WRF model running results, the rainfall chart for July 13-15, 2021, is shown in Figure 2. The rainfall on July 12, 2021, is not counted because the first 12 hours of running the WRF model are used as the spin-up time so that the predicted variables can be counted stably [16]. Therefore the value of the rainfall variable for each scheme will be calculated starting July 13, 2021, at 00 UTC.

The results of prediction schemes that use the cumulus KF (cu1) parameterization scheme can produce prediction results that are closer to the observations. The BMJ cumulus (cu2) parameterization scheme generally produces underestimated rainfall predictions, while the GFE (cu3) cumulus parameterization scheme shows the opposite result. These results align with research conducted by Budakoti et al. [10]; namely, the prediction results of 24-hour accumulated rainfall resulting from the KF cumulus parameterization scheme are closer to the observations, while the GFE scheme tends to produce overestimated predictions. Different results were found in the 24-hour accumulated rainfall produced by the BMJ cumulus parameterization; in his research, it was found that the predicted 24-hour rainfall showed overestimated results.

The choice of the microphysics parameterization scheme influences the 24-hour accumulated rainfall prediction results. Combining one microphysics parameterization with different cumulus parameterizations gives a very different impact. The combination of KF cumulus parameterization (cu1) and Kessler microphysics parameterization (mp1) can produce a rainfall accumulation graph close to the observed results. However, different results were obtained when the Kessler microphysics (mp1) parameterization scheme was combined with the BMJ (cu2) and GFE (cu3) cumulus parameterization schemes. When combined with cu2, the prediction results for the 24-hour accumulated rainfall of cu2mp1 tend to be underestimated, while cu3mp1 is overestimated. The same thing is found in different combinations of microphysics and cumulus parameterization schemes. These results differ from previous research conducted by Liu et al. [14], that the WSM6 microphysics parameterization scheme can simulate heavy rain events that occur in mainland China. This study's Kessler microphysics parameterization scheme was superior when predicting 24-hour accumulated rainfall compared to other microphysics parameterization schemes tested with a pair of KF cumulus parameterization schemes. The cumulus KF parameterization can produce better prediction results because it has been modified to calculate updraft events for deep convective cases, which generally occur in heavy rain events [17]. The KF scheme can properly consider warm clouds, including water vapor, cloud water, and rain, making it suitable for application in tropical regions [18].

In addition to paying attention to the results of the 24-hour rainfall accumulation graph, the calculation of the RMSE and CORR values was also carried out to verify the predicted results of the WRF model for each combination of the cumulus parameterization scheme and microphysics. The RMSE bar graph of each scheme is shown in Figure 3. It is known that the combination of cu1mp1 parameterization schemes produces a smaller value of 8.73. This value is smaller when compared to other parameterization schemes, which means that the combination of cu1mp1 parameterization schemes produces an average prediction error of 24 accumulated rainfall values of 8.73 mm/day. The graph also shows that the scheme that produces the most significant RMSE value is cu3mp1 of 53.16. In addition, the figure shows that the scheme using cu2 parameterization combined with any microphysics parameterization tested produces a smaller RMSE value when compared to the cu1 and cu3 pairs.

This result shows that the choice of cumulus and microphysics parameterization schemes is highly dependent on one another, so combining the two will produce very different predictive values. The overall model results show that with a 95% confidence level, the RMSE value of all model results is in the range of 19.30 – 28.69.

The CORR value of each parameterization scheme is also shown in Figure 4. It is known that the cu1mp1 combination scheme produces a value of 0.97. This value is less outstanding when compared to other schemes, namely cu2mp2, and cu2mp4, which produce a value of 1, and the cu3mp5 and cu3mp8 schemes which produce a value of 0.99. The CORR value is getting closer to number 1, indicating that the predicted results of the WRF model can follow the accumulated rainfall pattern recorded through direct observation. Although the cu2mp2, cu2mp4, cu3mp5, and cu3mp8 schemes can produce rainfall predictions that follow the observed rainfall pattern, the error value is still higher when compared to the cu1mp1 scheme.

Based on the analysis of the influence of the cumulus parameterization scheme and microphysics above, the cumulus parameterization scheme has a more significant role in the prediction results of the WRF model for cases of heavy rain in the KK area. This result is in line with research conducted by Hasan and Islam [7], that selecting a cumulus parameterization scheme has a more significant role when compared to a microphysics scheme when predicting heavy rain events that occur in the Bangladesh region using the WRF model.

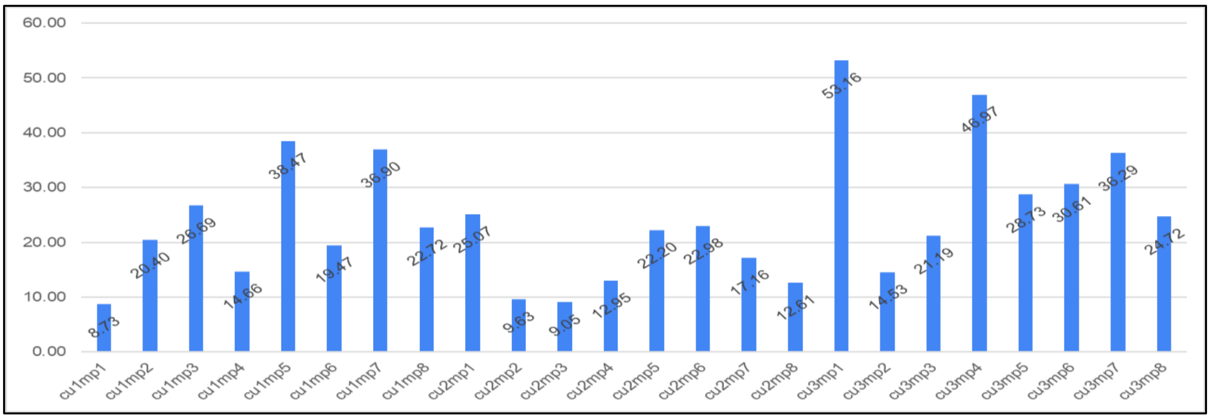

Figure 3. RMSE graph for each scheme of WRF model

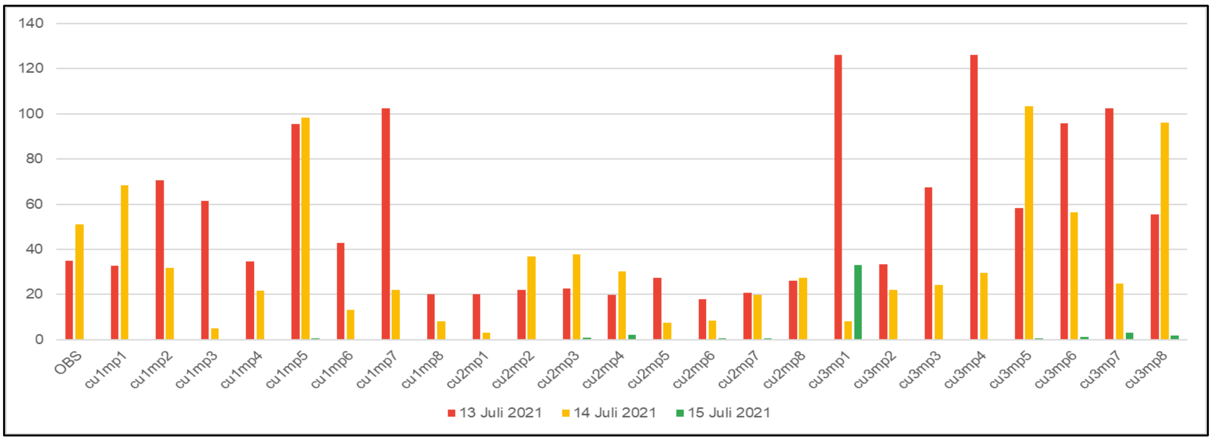

Figure 2. Rainfall graph for each scheme of WRF model

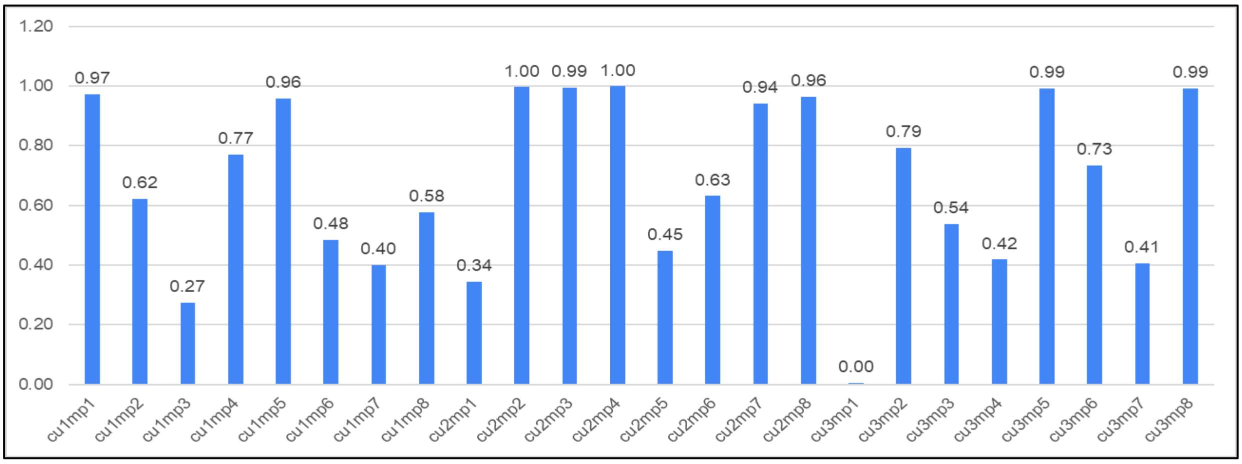

Figure 4. CORR graph for each scheme of WRF model

4. Conclusion

Based on the results and analysis that has been described, it is known that the prediction of the WRF model using the KF cumulus parameterization scheme and Kessler microphysics (cu1mp1) can produce 24-hour accumulated rainfall that is closer to the observed results based on a smaller RMSE value and a CORR value that is close to 1. It is also known that the choice of the cu2 scheme gives better consistency of results on RMSE and CORR values when paired with the mp2, mp3, and mp4 microphysics schemes. So it can be concluded that the WRF model with the cu1mp1 scheme can represent heavy rain conditions when floods and landslides occur in Ketapang Regency because it can predict rain events due to warm clouds and deep convective, which commonly occur during heavy rains in tropical regions.

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