Convective and microphysics parameterization impact on simulating heavy rainfall in Semarang (case study on February 12\textsuperscript{th}, 2015)

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Abstract. The meteorological model WRF-ARW version 3.8.1 is used for simulating the heavy rainfall in Semarang that occurred on February 12\textsuperscript{th}, 2015. Two different convective schemes and two different microphysics scheme in a nested configuration were chosen. The sensitivity of those schemes in capturing the extreme weather event has been tested. GFS data were used for the initial and boundary condition. Verification on the twenty-four hours accumulated rainfall using GSMaP satellite data shows that Kain-Fritsch convective scheme and Lin microphysics scheme is the best combination scheme among the others. The combination also gives the highest success ratio value in placing high intensity rainfall area. Based on the ROC diagram, KF-Lin shows the best performance in detecting high intensity rainfall. However, the combination still has high bias value.

1. Introduction
Based on news from some electronic mass media, heavy rain occurred in Semarang City on Thursday, February 12, 2015. The rain started to fall around 15:00 LT. The high intensity rainfall resulted flood in some areas in Semarang City, such as Gajah Street, Citarum, Kota Lama, Bundaran Bubakan, Imam Bonjol Street, MT Haryono Street, and Cipto Street. One of the media, antaranews.com, mentioned that the water level reached 50-60 cm. Rainfall observation from 3 Meteorology Climatology and Geophysics Agency of Indonesia (BMKG) stations in Semarang also shows a high number. The 24-hours rainfall accumulation recorded in Semarang Climatology Station as much as 159 mm. Ahmad Yani Semarang Meteorological Station received 146 mm of rainfall. Meanwhile, the Semarang Maritime Meteorology Station recorded total rainfall on that day as much as 119.4 mm.

Heavy rain is one of the worst weather phenomena that could endanger public safety and cause harm. Analysis of the phenomenon needs to be done. The goal is to understand the atmospheric conditions during heavy rainfall events. A good understanding of atmospheric conditions is useful in making weather forecasts so that awareness of bad weather can be further improved.

One way to analyse the heavy rain phenomenon is by model simulation. The most widely used weather models in different regions of the world are Weather Research and Forecasting - Advanced Research WRF (WRF-ARW). WRF-ARW is a system of atmospheric simulation and numerical weather prediction aimed at research and operational purposes. This model is part of the WRF...
modelling system that includes the physical schema settings, numerical/dynamic options, and data initialisation (Skamarock et al., 2008). From these features, WRF-ARW users can parameterize the physical and dynamic processes. Each parameterization scheme has its own characters, advantages and disadvantages. Different regional conditions require different parameterization schemes as well. Therefore, it is necessary to test the existing parameterization scheme.

Several studies have been conducted related to parameterization scheme test and simulation. Kurniawan et al. (2014) tested some 3 convective schemes which were Kian-Fritsch (KF), Betts-Miller-Janjic (BMJ), and GrellDevenyi (GD). The research sites were Surabaya and Jakarta. Based on statistical calculations of correlation, RMSE, and Threat score, BMJ came out as the best convective schemes rather than KF and GD. Mercader et al. (2014) conducted a comparative study of convective and microphysics schemes to simulate rain in Catalonia. Verification was done by performing statistical calculations of POD, CSI, FAR, and Bias. Based on the verification done, it could be concluded that the best combination of scheme in the research is KF and Thompson scheme. Alam (2014) suggested that the combination of the KF-WSM6 scheme is the best combination in simulating heavy rain in Bangladesh. He found that the sharp peak of relative humidity up to 300 hPa has been simulated along the vertical line where maximum updraft has been found for all MPs coupled with KF and BMJ schemes. The simulated rain water and cloud water mixing ratio are the maximum at the position where the vertical velocity and reflectivity has also been maximum. The production of rain water mixing ratio depends on MP schemes as well as CP schemes. Rainfall depends on rain water mixing ratio between 950 and 500 hPa. Rain water mixing ratio above 500 hPa level has no effect on surface rain.

In this study, 4 experiments will be conducted involving 2 different convective schemes, KF and BMJ, and 2 different microphysics schemes, Lin and Thompson. This experiment aims to examine the effects of convective schemes and microphysics schemes in rain simulations. The second objective is to know which combination of parameterization schemes best describes the atmospheric conditions of heavy rain events in Semarang on February 12, 2015.

2. Synoptic situation
Based on the gradient wind map of February 12, 2015 in Figure 1 (a) it is seen that the wind that blows in Semarang region generally comes from the west. The disruption of wind convergence extending from Central Java to Nusa Tenggara Islands occurred at 00 UTC. Convergence is a confluence of winds from several different directions causing a decrease in wind speed. The slowdown causes the buildup of air mass that includes water vapour. The more air mass stacks in a place, the more water vapour collects in the place. The more moisture content in a place, the greater the potential for cloud growth, including rain-producing clouds. In addition, there is also a disturbance in the form of cyclonic rotation in the south of Java Island. The cyclonic pattern is formed in low pressure regions. Low air pressure can attract air masses in the surrounding areas. This also causes the formation of air mass at the lowpressure site. The cyclonic cycle still occurs at 12 UTC as shown in Figure 1 (b).

![Figure 1. Gradient Wind Analysis : (a) 00 UTC, (b) 12 UTC](image_url)
3. Model description

This research uses Weather Research and Forecasting Weather Research model - Advanced Research WRF (WRF-ARW) version 3.8.1. This model is used to perform downscaling, test the convective-microphysics parameterization schemes, and generate data to analyze atmospheric conditions. The model runs on 2 domains with a horizontal resolution of 27 km and 10 km. The first domain covers the island of Java and the surrounding waters. The second domain covers the area of Semarang and its surroundings.

![Figure 2. Research Domain](image)

The Global Centers of Environmental Prediction (NCEP) Global Forecast System (GFS) data is used as model initialization data. Detailed configuration of domain settings, physical condition, and overall dynamic condition of the model are presented in Table 1.

| **Table 1. Configuration Details** |
|-----------------------------------|
| **Dynamics**                      | Non-hydrostatic           |
| **Number of domains**             | 2                          |
| **Central point of domains**      | 6-58S 110-25E              |
| **Horizontal grid distance**      | Domain 1 = 27 km           |
|                                    | Domain 2 = 10 km           |
| **Initial and boundary condition**| GFS data (0.25° x 0.25°)   |
| **Convective parameterizations**  | Kain-Fritsch (KF) (Kain and Fritsch 1990, 1993; Kain 2004) |
|                                    | Betts-Miller-Janjic (BMJ) (Janjic 1994, 2000) |
| **Microphysics parameterizations**| Purdue Lin (Lin) (Lin et al. 1983) |
|                                    | Thompson (Thompson 2009)  |
| **Planetary boundary layer scheme**| *Asymmetrical Convective Model version 2* (ACM2) (Pleim 2007) |

To facilitate further discussion, Table 2 below presents a combination code of parameterization schemes.

| **Table 2. Combinations of Parameterization Schemes** |
|------------------------------------------------------|
| **Combination Code**                                 | **Configuration** |
| BL                                                   | BMJ-Lin          |
| BT                                                   | BMJ-Thompson     |
| KL                                                   | KF-Lin           |
| KT                                                   | KF-Thompson      |
4. Results and discussion

4.1 Rainfall

Figure 3. 24-hour accumulated rainfall from GSMaP and model output

Figure 3 above shows a visualization of the 24-hour rainfall accumulation from GSMaP and model output. Based on GSMaP satellite imagery, rain almost occurred throughout Java Island. Rain with intensity > 50 mm occurs in some areas such as Pekalongan Regency, Batang Regency, Kendal Regency, Semarang Regency, and Lumajang Regency. Furthermore, verification of the model simulation results of the observation results. Discussion of verification results focuses on rain with a minimum threshold of 50 mm.

Figure 4. Spatial verification: (a) Bias value, (b) Success ratio value, (c) ROC diagram

Based on the spatial verification, the four simulations performed give overestimate result. Simulations using KF result in greater bias values than simulations using BMJ. The use of the Thompson microphysics scheme also resulted in a greater bias value than the Lin scheme. In sum, the BMJ-Lin combination is the best combination in simulating the spatial distribution of rain. This can be seen from its smallest bias value among other combinations of 2.95 (Figure 4 (a)). When viewed from the ability to put the rain area correctly, the combination of KF-Lin gives the best results. This combination is capable of placing 11% of the rain area correctly (Figure 4 (b)). The best ability to correctly detect rain is also demonstrated by the combination of KF-Lin (Figure 4 (c)). This combination can detect rain events correctly by 37% with a percentage of wrong detection of 11%.

Figure 5. Three hourly rain rate between observation and model output
The next verification is point verification. Point verification is done by comparing observation data of rainfall per 3 hours from Semarang Climatology Station with model output (Figure 5). Model performance is judged by the correlation value and Root Mean Square Error (RMSE) value. The graph above shows that simulations using KF scheme generally predict the peak rain more quickly. Meanwhile, from the microphysics schemes used it can be seen that the average amount of rain produced by the Thompson scheme is more than the Lin scheme. Based on the point verification result, the BMJ-Thom and KF-Lin scheme combination come out as the best combination with the RMSE value as high as 0.47. However, the KF-Lin combination is better than BMJ-Thom because it has the smallest RMSE value of 24.22. The correlation and RMSE values are presented in Table 3 below.

|       | OBS-BL | OBS-BT | OBS-KL | OBS-KT |
|-------|--------|--------|--------|--------|
| Correlation | -0.30  | 0.47   | 0.47   | -0.06  |
| RMSE       | 32.93  | 24.71  | 24.22  | 36.00  |

4.2 Vertical velocity
Vertical velocity analysis is done temporally. This analysis is useful to know the ability of the model in predicting the time of updraft and downdraft which can identify the peak of rain. Based on observations of rainfall per 3 hours taken from the Semarang Climatology Station known that the peak of rain occurred at 12 UTC. The peak of rain is identified with the strong vertical mixing inside the cloud. This strong motion can be seen from the updraft and downdraft patterns that coexist with a fairly strong speed.

![Figure 6](Image)

**Figure 6.** Vertical velocity output: (a) BL, (b) BT, (c) KL, and (d) KT

Based on eyeball verification, the combination of BMJ-Thom scheme is obtained as the best combination in simulating vertical mixing in this event. The combination provides the prediction of time most closely related to the timing of the peak rain from observation at the station. Consistent with the previous discussion, at this output KF scheme predicts peak of rain earlier than BMJ scheme.

4.3 Vertical Temperature and Dew Point Profile
Vertical temperature and dew point profile are shown on Figure 7 below. This analysis aims to determine the suitability of the modelled atmospheric column with the actual atmospheric column. Vertical temperature data and vertical dew points between radio sound observations of Cengkareng Meteorological Station and Juanda Meteorological Station and the model output data were compared. Furthermore, verification is performed using correlation and RMSE calculations.
The results of temperature verification and vertical dew point indicate that there is a high suitability between model output and observation result. The correlation and RMSE values of the vertical temperature and dew point are shown in Table 4. The correlation values obtained from all simulations are close to 1. In addition, the RMSE values produced are also relatively small. This shows that there is a high degree of compatibility between the atmospheric columns of the model simulation results with the actual atmospheric column.

Table 4. Correlation and RMSE value of vertical temperature and dew point

|                  | CENGKARENG VERTICAL TEMPERATURE | JUANDA VERTICAL TEMPERATURE | CENGKARENG VERTICAL DEW POINT | JUANDA VERTICAL DEW POINT |
|------------------|---------------------------------|----------------------------|-------------------------------|---------------------------|
|                  | OBS-BL                          | OBS-BT                     | OBS-KL                        | OBS-KT                    |
| Korelasi         |                                |                            |                               |                           |
|                  | 0.999859                        | 0.999805                   | 0.999705                      | 0.9998                    |
| RMSE             | 0.708011                        | 0.892969                   | 0.88922                       | 0.762908                  |
|                  |                                |                            |                               |                           |
|                  | JUANDA VERTICAL TEMPERATURE     |                            |                               |                           |
| Korelasi         |                                |                            |                               |                           |
|                  | 0.999642                        | 0.999615                   | 0.99977                       | 0.999888                  |
| RMSE             | 1.08686                        | 1.05613                    | 0.814338                      | 0.543924                  |
|                  |                                |                            |                               |                           |
|                  | CENGKARENG VERTICAL DEW POINT  |                            |                               |                           |
| Korelasi         |                                |                            |                               |                           |
|                  | 0.965032                        | 0.967481                   | 0.971826                      | 0.973722                  |
| RMSE             | 6.696516                        | 6.704629                   | 6.163298                      | 6.056866                  |
|                  |                                |                            |                               |                           |
|                  | JUANDA VERTICAL DEW POINT       |                            |                               |                           |
| Korelasi         |                                |                            |                               |                           |
|                  | 0.976391                        | 0.975215                   | 0.97259                       | 0.976369                  |
| RMSE             | 6.376116                        | 6.436792                   | 6.52231                      | 6.186052                  |

4.4 Geopotential Height

Apart from the vertical temperature profile, the suitability between the model and atmospheric columns is actually also viewed from the geopotential height profile. Comparative data were taken from rasond observations at Cengkareng Meteorological Station and Juanda Meteorological Station. The analysis and verification of these profiles were the same as the analysis and verification of vertical temperature profiles. Graph of regression of geopotential height between model output and observation results is shown in Figure 8 below.
Juanda Meteorological Station and the model output data indicate conformity. The correlation value of geopotential altitude generated by all the combination schemes in both Cengkareng and Surabaya points ranges from 0.99 to 1. The result of verification of the complete geopotential height is presented in Table 5 below.

|                      | CENGKARENG | JUANDA |
|----------------------|------------|--------|
|                      | OBS-BL     | OBS-BT | OBS-KL | OBS-KT |
| **Korelasi**         | 0.999999   | 0.999999 | 0.999999 | 0.999999 |
| **RMSE**             | 11.39204   | 11.96733 | 11.11217 | 12.33897 |
|                      | 1          | 1      | 1      | 1      |
| **RMSE**             | 9.376029   | 9.023434 | 8.642838 | 9.049607 |

5. Conclusion
In spatial verification, KF convective scheme results greater bias value than BMJ convective scheme. Beside, Thompson microphysics scheme also delivers higher bias value than Lin microphysics scheme. In sum, BMJ-Lin is the best combination in simulating the spatial distribution of rain. However, that combination cannot put the high intensity rainfall area as good as KF-Li. KF-Lin is the best combination that is able to locate the high intensity rainfall area. Based on the ROC diagram, KF-Lin shows the best performance among the other combinations in detecting the high intensity rainfall correctly.

In point verification, simulations with KF causes the peak of rain occurs earlier than simulation with BMJ. From the microphysics parameterisation impact, in average Thompson scheme produces more rainfall than Lin scheme. KF-Lin combination shows the highest correlation value with the lowest RMSE value among the other combination.

The same impact of KF also seen in vertical velocity simulation result. All simulations using KF predict the peak of rain more quickly. The best result in this simulation obtained from BMJ-Thom combination. The combination can predict the peak of rain time closest to peak of rain time from observation at the station.

From the vertical temperature and geopotential height verification, it can be concluded that there is a high conformity between the modelled atmosphere column and the real atmosphere column. It can be seen from the correlation value of all simulations close to 1.

Finally, the best scheme combination on simulating the heavy rainfall in Semarang, February 12th, 2015, refers to KF-Lin combination.

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