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Assimilation of Weather Radar Data Using WRF 3DVar Modelling for Rainfall Prediction

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Abstract. Data assimilation is one method of improving the initial condition of the atmosphere in numerical weather predictions. The weather-based radar data assimilation, which generates high-resolution data of about 250 meters with coverage of hundreds of kilometers, is expected to improve the quality of weather forecasts and analysis, especially in determining the precipitation forecasting or Quantitative Precipitation Forecasting (QPF). This study aims to investigate the role of assimilation of Doppler weather radar data in mesoscale models for the forecast of heavy rain events occurring in the Greater Jakarta area on 20 February 2017 and 13 June 2017. For this purpose, the reflectivity data and radial radar speeds obtained from weather radar Tangerang will be assimilated with the 3DVar system into the Weather Research Forecasting (WRF) numerical model version 3.9.1 and Tropical Physics Suite parameterized configuration recommended for the tropics. The output of assimilation model of radar data and without assimilation of the numerical model of WRF is verified by point and spatial with some observation data of Automatic Weather System (AWS) and GSMAP rainfall in Jabodetabek region. In general, the WRF model assimilation of radar data provides a better simulation of spatial rain events and better points compared to the WRF model without assimilation.

Keywords : Quantitative Precipitation Forecasting, WRF, Doppler, AWS.

1. Introduction

One of the weather modeling systems is the Numerical Weather Prediction (NWP). The NWP responds to the challenge with the scientific method required in predicting in complex environments [1]. In recent years, NWP has always been the Weather Research and Forecasting (WRF) meso scale model. The advantages of WRF are efficient and flexible because it can be used in laptops for various interactions with meter scales up to thousands of kilometers [2]. In addition, WRF includes open source, model configurations that can be customized and tailored to the research needs. In the WRF model, there are several ways to increase the weather prediction value. One of them is by assimilating data. Assimilation of data is done by improving the data as input model by calculating the data into the grid system model [2].

WRF Data Assimilation (WRFDA) is a special WRF program to assimilate data. WRFDA has several assimilation techniques, including Three Variable Dimensions (3DVar), Four Dimensional Variational (4DVar), and Ensemble Kalman Filter (EnKF). From various studies, 3DVar is considered to have the best performance of all types of techniques with good efficiency [3]. Data that can be assimilated in WRFDA are surface air, satellite and radar data. One of the most frequent researches is the assimilation of radar data. Excess radar data compared to other data is having high resolution (higher



resolution than meso scale resolution model) with wide coverage. By this, assimilation of radar data is expected to be used.

Outside Indonesia, Xiao et al. assimilated 3DVar radar data using radial velocity data [4]. The study said that the assimilation of radial velocity data can improve the ability of predicting quantitative rainfall or Quantitative Precipitation Forecasting (QPF) in the short term. Furthermore, research on the assimilation of 3DVar radar data uses two data, i.e. radial velocity and radar reflectivity data [5, 6]. Based on these studies, the assimilation of radial velocity data and radar reflectivity has a positive effect on QPF capability by using one of the two radar data.

In Indonesia, Satrya (2012) conducted research on the assimilation of 3DVar radar data (reflectivity and velocity) in Bandung area. In conclusion, the largest sampling technique on radar data reflectivity as a WRFDA input is the best in virtualizing heavy rain [6]. The same research has conducted by Paski and Gustari (2017) in Lampung area [7]. In conclusion, the largest sampling technique on radar data reflectivity as a WRFDA input is the best in virtualizing heavy rain. In addition, Paski et al. (2017) also conducted a recent engineering study on the assimilation of 3DVar radar data in Jakarta using products from the reflectivity radar data, i.e. Constant Altitude Plan Position Indicator (CAPPI) as the assimilation data of WRFDA which was better information compared to the WRF model without assimilation [7].

The use of CAPPI in radar assimilation is something new in Indonesia. Therefore, it is interesting to conduct research on the assimilation of 3DVar radar data technique using CAPPI data. The difference with previous research is the comparison test between the CAPPI data assimilation performance model, radial velocity, reflectivity, and the combination of reflectivity and radial velocity in terms of data that successfully initiated WRF model for heavy rain events in Jabodetabek. The most possible model improvement is to increase the predicted value of heavy rainfall and temporality.

2. Data and Methodology

In this study some primary data are used, Global Forecast System (GFS) is used as initial data model and C-Band Doppler Radar (CDR) data is used as observation data. The data used in model verification in this research are Global Satellite Mapping of Precipitation (GSMaP) data for spatial analysis and observational data from the meteorological station owned BMKG around Jakarta region including Cengkareng, Pondok Betung, Kemayoran, Tanjung Periuk, and Citeko for point analysis.

WRF model for this research uses a three domain configuration. The third domain or the last domain has a resolution of three kilometers and covering Jabodetabek area. Domain is not created too large to decrease model run time. Model parameterization configuration uses tropical configuration in WRF 3.9.1 for tropical Indonesia. Weather assimilation model is obtained from the package of WRFDA with 3DVar technique using radar data as observation.

Radar volumetric (.vol) volumetric data is converted into two types of formats, the polar coordinates netCDF and csv using EDGE applications because of the EEC doppler weather radar of the EEC type. Then, both types of radar data formats will each go through different processes. The polar coordinates netCDF radar data will be processed with the wradlib-python application to convert the format into netCDF cartesian coordinates, as well as process the data into a netCDF format CAPPI product. The CAPPI calculation specifications have been designed in accordance with research from Permana et al. (2016) [8]. Furthermore, CAPPI netCDF format data is processed by taking the maximum sampling value in one grid model of 3 km x 3 km (according to the domain of previous *.ctl) using the R Studio application [7]. The output data of the R application will result in the output of radar data in ASCII format or according to the WRFDA application input format.

In csv format data, separate data is based on elevation or sweep. In each sweep, the data is also separated based on reflectivity (Z), radial (V), spectral width (W) and filter unfilled (U) reflectivity. This research uses Z and V data as assimilation data. Csv radar data formats will be processed in numerical data analysis and computing applications to combine Z and V data in one .txt format file. The combined data Z and V (.txt) will be processed by the largest sampling technique on a 3 km x 3 km grid (according to the domain of previous *.ctl) using numerical data analysis and computation applications [6,9,10]. The output data of the R application will result in the output of radar data in ASCII format or according to the WRFDA application input format.

3. Result and Discussion

3.1 The Effect of Radar Data Assimilation on WRF Parameter

Effect of radar data assimilation on WRF is to improve the initial WRF (WRFinput) data more accurately. Here is a table that specifies what WRF parameters are improved on each model of radar data assimilation.

2017-06-12_12:00:00	33	2017-06-12_12:00:00	19
104.597	250.0	104.597	25.0
0.148	0	14.820	0
0.586	0	14.820	0
0.086	0	104.597	25.0
0.656	0	12.037	0
104.597	250.0	12.037	0
0.992	0	10.513	0
104.841	250.0	10.513	0
0.094	0	104.841	25.0
0.070	0	9.053	0
0.102	0	9.053	0
0.047	0	6.063	0

(a) (b)

Figure 1. Differences in Z value on reflectivity data (a) and CAPPI data (b).

Table 1. The effect of assimilating radar data on WRF initial data

WRF Data Assimilation	WRF Parameter			
	Temperature	Humidity	Mixing Ratio	Wind
CAPPI	√	√	√	√
Reflectivity (Z)	√	√	√	-
Radial Velocity (V)	-	-	√	√
Combination of Reflectivity (Z) & Radial Velocity (V)	√	√	√	√

WRF with assimilation CAPPI and Z have the same data type, i.e. data reflectivity, only in CAPPI data is reflectivity data at certain fixed height, while Z data is data reflectivity of all volume scanning. In 3DVAR's WRF system, CAPPI assimilation has a larger value than the Z assimilation (figure 1) therefore we change the wind parameters through negative temperature change scheme, since Z assimilation is not able to change the wind parameter.

3.1.1 Temperature Parameter

In the 3DVAR WRF assimilation, initial air temperature data improvements are calculated from warm-rain schemes using reflectivity data or CAPPI. Air temperature parameters play a role in the convection process where the higher the temperature, the greater the convection process that is likely to the occurrence of heavy rain.

Figure 2 shows the difference of WRF initial data for surface air temperature parameters between WRF without assimilation and WRF with assimilation on February 20, 2017 (rainy season). In the southeast-to-west study area, the CAPPI assimilated WRF air temperature (Figure 2b) gets warmer than WRF without assimilation (Figure 2a), ranging from 24-22 °C to 26-27 °C, as did study areas such as Kemayoran, Tanjung Periuk, Pondok Betung, and Cengkareng, where the area of warmer temperatures is widespread. In Figure 4.10c, the WRF Z assimilation also changes the air temperature to warmer in the southeast to the west of the study area. However, the temperature of study areas such as Kemayoran, Tanjung Periuk, Pondok Betung, and Cengkareng are getting colder. Meanwhile, in Figure 4.1e, the WRF assimilation of the Z & V combination (figure 2d) is no different than the WRF Z assimilation. In addition, the WRF V assimilation (figure 2d) does not change at all the air temperature parameters.

Figure 3 shows the difference of WRF initial data for surface air temperature parameters between WRF without assimilation and WRF assimilation on June 13, 2017 (dry season). When viewing Figure 3b, it can be seen clearly that the warmer surface air temperature expansion in WRF CAPPI assimilation such as Kemayoran, Tanjung Periuk, Pondok Betung and Cengkareng areas near the radar, ranges from 26 - 26,5°C to 27 - 27,5°C. However, the special Citeko area does not change temperature. In the WRF Z assimilation (figure 4.12c) and Z assimilation & V combinations (figure 3d) also gets warmer the greater the temperature, while only in the southwest region of study and the special Citeko region away from the radar location display the cooler air temperature. Meanwhile, the WRF V assimilation (figure 3d) does not change the air temperature parameters at all.

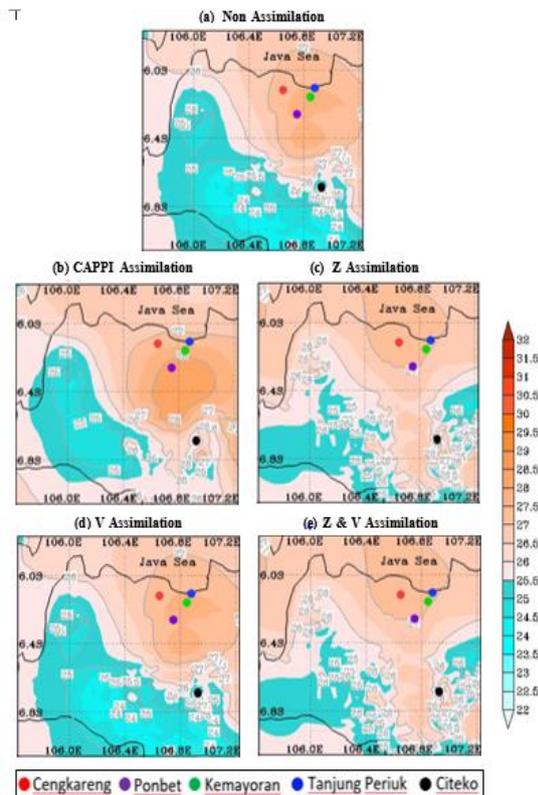


Figure 2. Initial data of surface air temperature parameter in case of heavy rains on February 20, 2017.

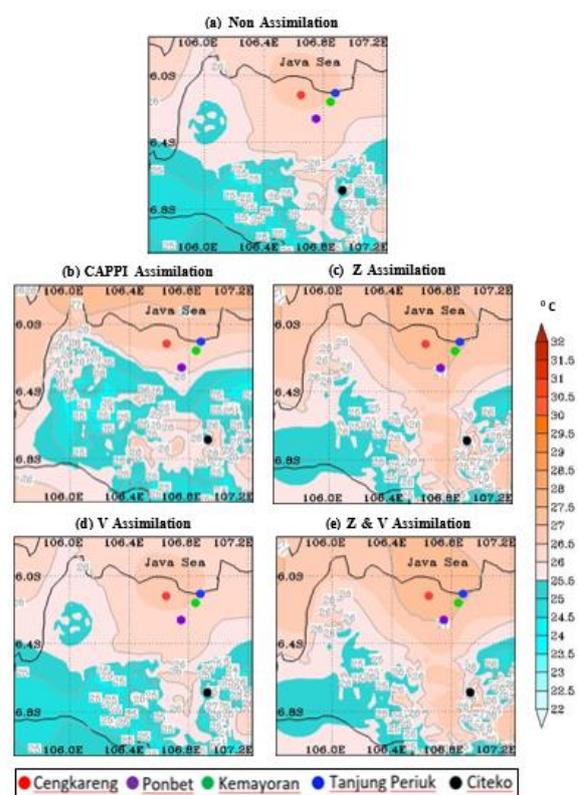


Figure 3. Initial data of surface air temperature parameter in case of heavy rains on June 13, 2017

3.1.2 Humidity Parameter

The humidity parameter is the concentration of water vapor in the atmosphere. In this study, we will examine the air humidity in the 850 mb layer because if the value is high, then it indicates the moisture content is large enough for convective cloud growth process that has the potential to cause moderate to heavy rain.

Figure 4 shows the initial data difference on the 850 mb layer moisture parameters between WRF without assimilation and WRF with assimilation on February 20, 2017 (rainy season). Compared to WRF without assimilation (Figure 4a), WRF CAPPI assimilation (Figure 4b) and Z assimilation (figure 4c) do not change significantly. However, generally the air gets damper so it can be ascertained that rainfall will be high as well. Location of value changes occurring in areas near radar such as Kemayoran, Tanjung Periuk, Pondok Betung, and Cengkareng by 84% to 86%. Similarly, areas far from radar like Citeko, the humidity value is getting higher, i.e. 96% to 98%. Meanwhile, air humidity improvements in WRF Z assimilation & V combination (figure 4e) are similar to WRF Z assimilation, while WRF V assimilation (figure 4d) shows no change at all or equal to WRF without assimilation.

Figure 5 shows the initial data difference for the 850 mb layer air humidity parameter between WRF without assimilation and WRF assimilation on June 13, 2017 (dry season). In the northern area of study including Kemayoran, Tanjung Periuk, Pondok Betung, and Cengkareng areas, the CAPPI assimilation WRF air humidity (Fig. 5b) changed more humidly than WRF without assimilation (figure 5a). However, the southern region including Citeko region did not change significantly. In WRF Z assimilation (figure 5d), there is no significant difference, as did with WRF Z assimilation & V combination (figure 5e) which is similar to WRF assimilation Z. Meanwhile, WRF V assimilation (figure 5d) has not changed at all.

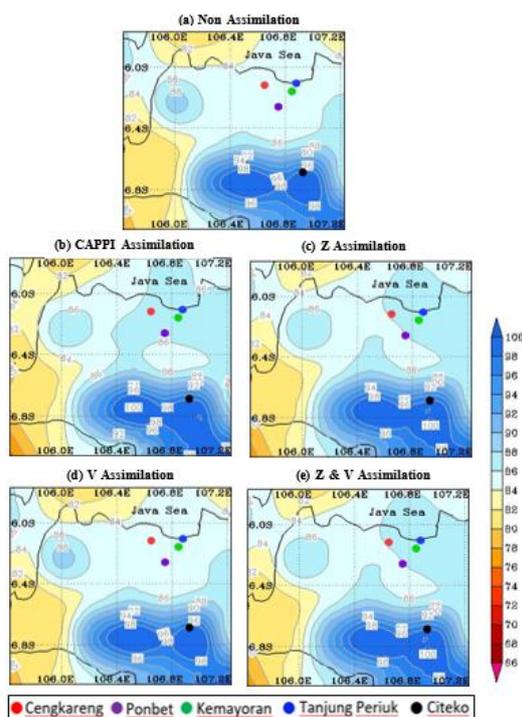


Figure 4. Initial data of 850 mb air humidity parameter in the case of heavy rains on February 20, 2017

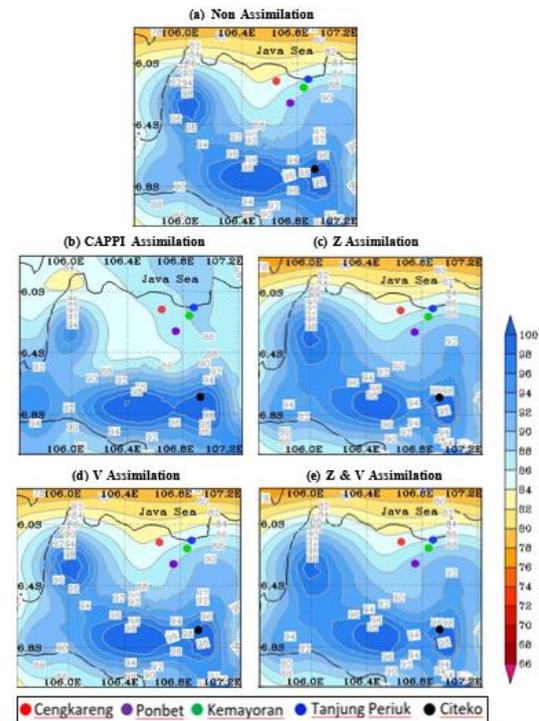


Figure 5. Initial data of 850 mb air humidity parameter in the case of heavy rains on June 13, 2017

3.1.3 Water Vapor Mixing Ratio Parameter

The parameter of the water vapor mixing ratio is the ratio of moisture mass to the dry air mass present in one particular volume [11]. The value of this mixing ratio also represents the moisture content of the moisture present in the air that the higher the mixing ratio, the greater the chance of rain.

Figure 6 shows the initial data difference for the water vapor mixing ratio between WRF without assimilation and WRF assimilation on February 20, 2017 (rainy season). Compared to WRF without assimilation (Figure 6a), significant changes in water vapor mixing in WRF assimilation of CAPPI (figure 6b), Z assimilation (figure 6c), and Z assimilation & V combination (figure 6d) are shown in the western region study. In areas close to radar sites such as Kemayoran, Tanjung Periuk, Pondok Betung, and Cengkareng, there is an increase in mixing ratio from 0.0132 to 0.0136 in WRF Z assimilation and Z assimilation & V combination, whereas 0.014 in WRF CAPPI assimilation). This increase indicates the higher moisture content of the water or wetter conditions that there is more potential for heavy rains. In contrast, areas far from radar such as Citeko display decrease in the value of mixing ratios, from 0.0152 to 0.014 in WRF assimilation of CAPPI, Z assimilation, and Z assimilation & V combination. Furthermore, WRF V assimilation (figure 6d) no change is detected at all in mixing ratio.

Figure 7 shows the initial data difference for the water vapor mixing ratio between WRF without assimilation and WRF assimilation on June 13, 2017 (dry season). Compared to WRF without assimilation (Figure 7a), significant changes in water vapor mixing in WRF assimilation of CAPPI

(figure 7b), Z assimilation (figure 7c), and Z assimilation & V combination (figure 7e) in the northern region such as Kemayoran, Tanjung Periuk, Pondok Betung, and Cengkareng, there was an increase in mixing ratio from 0.0128 - 0.0136 to 0.0132 - 0.014 in the WRF Z assimilation and Z assimilation & V combination, whereas 0.0136-0.0144 on WRF CAPPI assimilation (tend to be larger). Likewise, Citeko increases the value of mixing ratio, from 0.014 – 0.0148 to 0.0148 – 0.0152 at WRF assimilation CAPPI, Z assimilation, and assimilation of combination of Z & V). Furthermore, in WRF V assimilation (figure 7d), there is no change in the mixing ratio at all.

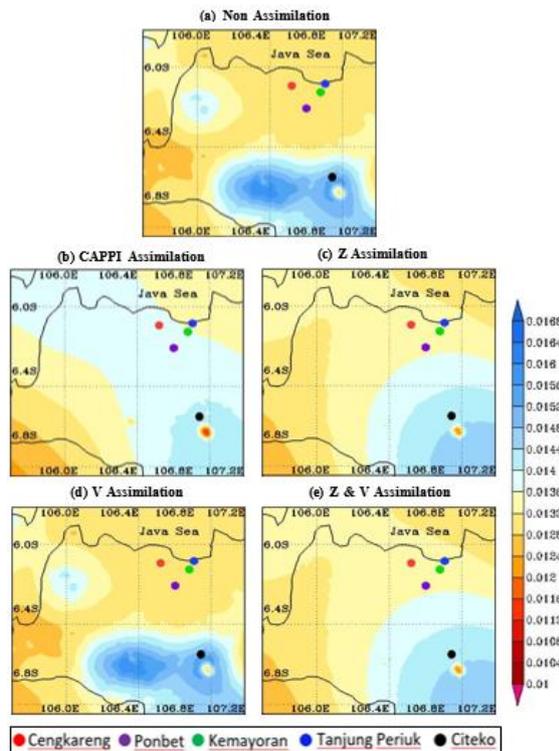


Figure 6. Initial data of 850 mb water vapor mixing ratio parameter in the case of heavy rains on February 20, 2017

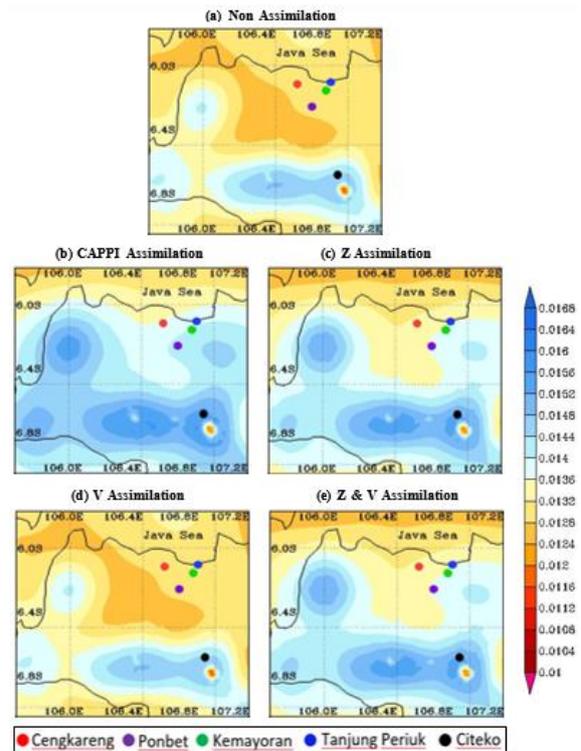


Figure 7. Initial data of 850 mb water vapor mixing ratio parameter in the case of heavy rains on June 13, 2017

3.1.4 Wind Parameter

The wind parameter acts as vapor mass supply from the outside or as humidity transport. In WRF 3DVAR assimilation, the initial wind data improvement is calculated from CAPPI data and radial velocity. CAPPI data assimilated through negative temperature change, while assimilation of radial velocity data directly from wind parameter element u , v , w .

Figure 8 shows the initial data difference on 850 mb layer wind parameters on February 20, 2017 (rainy season). Spatially, the CAPPI assimilation WRF (Figure 8b), V assimilation (Figure 8d) and Z assimilation & V combinations (Fig. 8e) significantly alter the wind parameters, shows that calm wind speed is widespread in most Southwest Jabodetabek and middle area. This indicates that convective cloud growth is not hindered by the wind. Kemayoran area, Tanjung Periuk, Pondok Betung, and Cengkareng (near radar location) wind speed also weakened, namely Cengkareng and Pondok Betung from 10 knots to 8 knots and Kemayoran and Tanjung Periuk areas from 14 knots to 10 knots. Meanwhile Citeko, away from the radar location did not change significantly, i.e. calm wind speed on WRF without assimilation and WRF with other assimilation. Meanwhile, wind direction parameters did not change significantly in each WRF assimilation. Furthermore, the WRF Z assimilation (figure 8b) does not change wind parameters in both direction and speed.

Figure 9 shows the initial data difference on 850 mb layer wind parameters between WRF without assimilation and WRF assimilation on June 13, 2017 (dry season). Compared to WRF without assimilation (Figure 9a), the CAPPI assimilation WRF wind parameter (Figure 9b), V assimilation (Figure 9d), and Z assimilation & V combinations (Figure 9e) change significantly. Generally, wind speeds of CAPPI assimilation WRF, V assimilation and Z assimilation & V combination are weakened, except in CAPPI assimilation WRF, wind speed of Tanjung Periuk, Kemayoran, Citeko region are unchanged, while in WRF V assimilation and Z assimilation & V combination only Citeko that does not change. Meanwhile, wind direction parameters did not change significantly in each WRF assimilation. Furthermore, the WRF Z assimilation (figure 9b) does not change the wind.

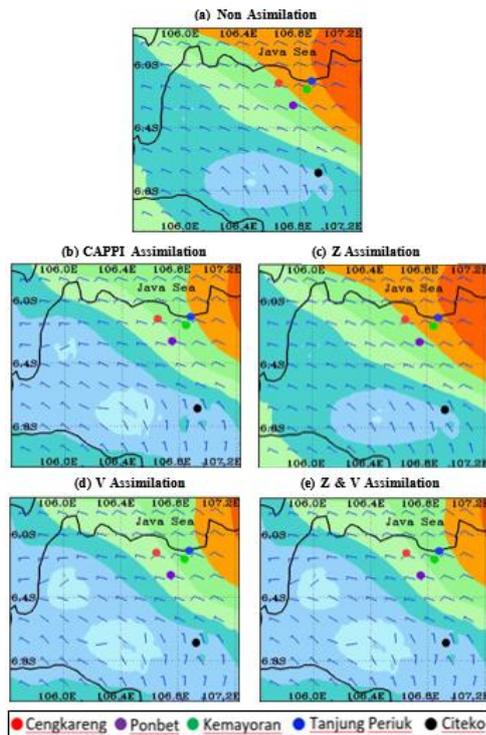


Figure 8. Initial data of 850 mb wind parameter in the case of heavy rains on February 20, 2017

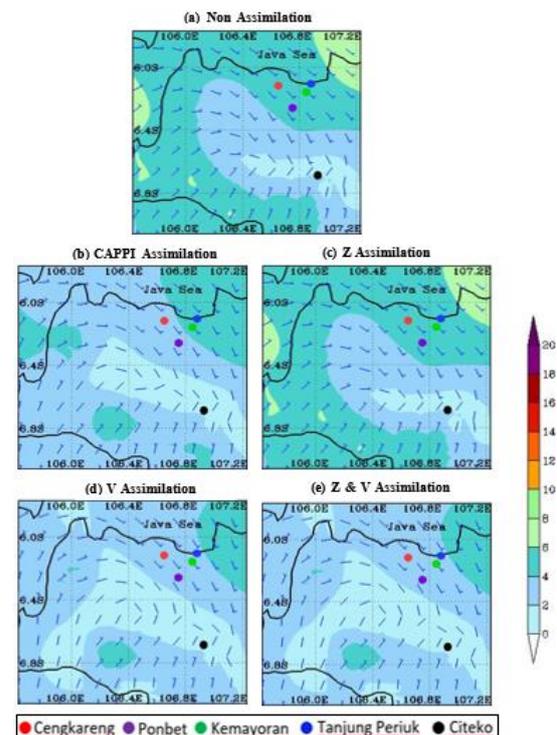


Figure 9. Initial data of 850 mb wind parameter in the case of heavy rains on June 13, 2017

3.2 Analysis and Verification of Spatial Rain Distribution

3.2.1 The case of heavy rains on 20 February 2017

Based on Figure 10, it shows the rainfall simulation results and the amount of rainfall between GSMAP observation data and the simulation results using WRF without assimilation, WRF assimilation CAPPI, WRF Z assimilation, WRF V assimilation, and WRF assimilation combination Z & V on 20 February 2017. GSMAP data (figure a) shows the rainfall of Jabodetabek area dominated by moderate rain (20 - 50 mm). However, the southern part of Bogor area displays light rain (<20 mm). In addition, the western and eastern parts of Jabodetabek show heavy rains (50 to 100 mm), namely southwestern Tangerang, northern Bogor, eastern Depok, eastern Bekasi, southwestern Bekasi and most of Java Sea.

Compared to GSMAP observation data, the moderate WRF rainfall area without assimilation (Figure 10b) is narrowed. As a result, the area of light rain extends and turns to be in the northwest and northeast of Jabodetabek, which is in most of Tangerang, West Jakarta, South Jakarta, western Depok, and the southeast and northeast of Bekasi. Likewise, the area of heavy rain also change places and slightly narrowed in the southern region of Greater Jakarta, which is in Bogor.

Compared to WRF without assimilation, WRF spatial rainfall assimilation does not change significantly, but generally the broad-range rainfall area in WRF with assimilation is wider than WRF without assimilation, as well as higher rainfall. The area of moderate - heavy rain remains narrower than GSMAP data. The highest rainfall is in WRF CAPPI assimilation (figure 10c) and assimilation of Z & V combination (figure 10f) occurring in the southeastern part of Jabodetabek, the northeastern Bogor and southeastern Bekasi. In addition, the WRF's light-weight CAPPI assimilation area and the Z & V combination assimilation in northwest Jabodetabek also appear to be narrowing.

In the WRF Z assimilation (figure 10d), the light rain area also narrows in the northwest part of Jabodetabek and the heavy rain area is seen in the southeastern part of Jabodetabek, Bogor and surrounding areas. Meanwhile, the light rain area in WRF V assimilation (figure 10e) extends to the south of Jabodetabek, i.e. in most areas of Bogor. However, the area of heavy rain on WRF V assimilation is almost absent in Jabodetabek area. In general, the simulated GSMAP rain-simulation results are similar to WRF assimilation, differ only in rain intensity with the most superior models are WRF assimilation of CAPPI and Z assimilation & V combination because it is more susceptible to heavy rainfall than other WRF assimilation.

3.2.2 The case of heavy rains on June 13, 2017

Based on Figure 11, it shows the rainfall simulation results and the amount of rainfall between the GSMAP observation data and the simulation results using WRF without assimilation, WRF assimilation CAPPI, WRF Z assimilation, WRF V assimilation, and WRF assimilation combination Z & V on June 13, 2017. GSMAP observation data (Figure 11a) shows that almost all Jabodetabek areas are dominated by light rain (<20 mm), except for moderate rainfall (20 - 50 mm) in most of western and western part of Bogor. Then, there is no rain in a small part of northern Bekasi. In addition, there is heavy rain (50 - 100 mm) in the Greater Jakarta area and surrounding areas.

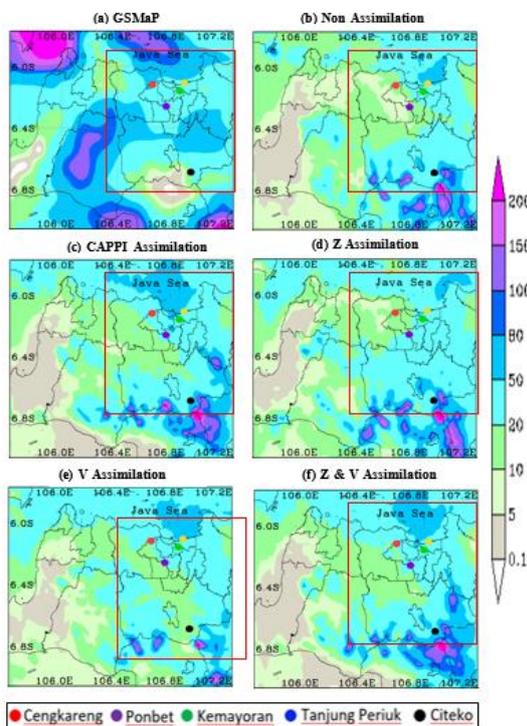


Figure 10. Spatial rain distribution in the case of heavy rains on February 20, 2017

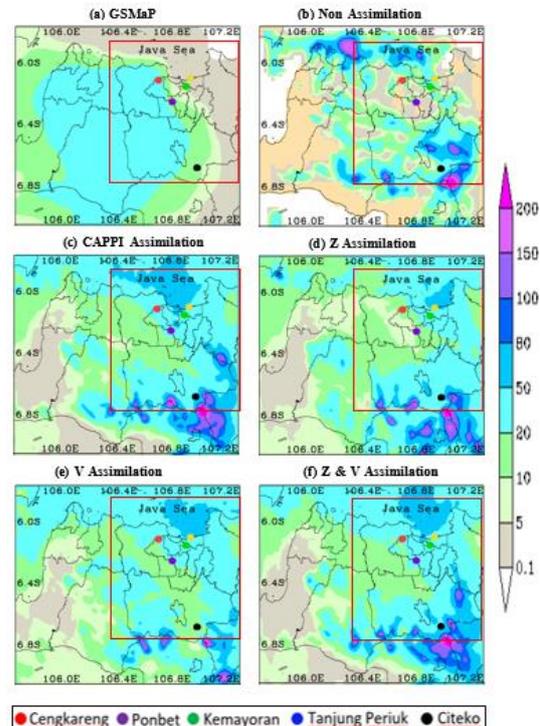


Figure 11. Spatial rain distribution in the case of heavy rains on June 13, 2017

Compared to the GSMAP observation data, the distribution of WRF rainfall without assimilation (Figure 11b) is significantly different. WRF rain distribution without assimilation looks uneven and there is heavy rain in some areas of eastern Bogor and northern Java Sea and parts of southern Bogor. In contrast, the distribution of WRF CAPPI assimilation area (Figure 11c), Z assimilation (figure 11d), V assimilation (figure 11e), and Z assimilation & V combination (Figure 11f) look similar to GSMAP observation data but bulk intensity of the rain is different that it is quite different compared to WRF without assimilation. In the four models of WRF assimilation, rainfall is dominated by moderate rain, while light rain occurs in most of western part of Tangerang and part of western Bogor where according to GSMAP observation data of the area occurs moderate rain. Then, the WRF specific V assimilation area of light rain extends to the southern part of Bogor. However, in general the widest area of light rain occurred in WRF Z assimilation. In addition, in the four WRF assimilation, there was heavy rain in Jabodetabek area, namely in the southern part of Bogor. While in fact, according to GSMAP data there is no heavy rain at all in the Greater Jakarta area. The largest density of heavy rainfall occurs in WRF CAPPI assimilation that it has the greatest amount of rainfall than any other.

3.3 Rain Dichotomy Verification (yes / no)

In this discussion, we will analyze and verify skill prediction based on the 5-point observation of the rainfall from the nearest to the farthest from the radar. This is done because the further distance the radar observation, the greater the beam radar is formed and ultimately impact on the sensitivity and accuracy of radar parameters used for data assimilation. Based on a summary of the results of verification of prediction skills on dichotomy yes / no on the observation area (table 2), the best PC, POD, and FAR skills also occur in WRF assimilation CAPPI and assimilation of Z and V combination data. In addition, WRF assimilation radar data is generally good for station areas closer to radar sources such as Cengkareng within 5.31 km, Pondok Betung within 15.28 km, Kemayoran within 21.65 km, and Tanjung Periuk within 26.85 km compared to areas farther from radar sources such as Citeko which is 66.6 km from the radar source and also the topographic area is hilly (mountainous). This can be seen from the skills of PC, POD, and FAR in the region which has always been the worst with an average of the lowest PC value of around 0.52, the average POD value is at least 0.76, and the average FAR value is the lowest height of 0.5.

Table 2. Forecast Verification

Skill	Region	WRF model best order					Average
		1	2	3	4	5	
PC	Cengkareng	S1	S4	S3	S2	S0	0,85
	Pondok Betung	S1	S4	S3	S2	S0	0,79
	Kemayoran	S4	S1	S2	S3	S0	0,67
	Tanjung Periuk	S1	S4	S2	S3	S0	0,64
	Citeko	S1	S4	S2	S3	S0	0,52
POD	Cengkareng	S1	S4	S3	S2	S0	0,85
	Pondok Betung	S1	S4	S3	S2	S0	0,9
	Kemayoran	S4	S1	S2	S3	S0	0,96
	Tanjung Periuk	S1	S4	S3	S2	S0	0,86
	Citeko	S4	S1	S2	S3	S0	0,76
FAR	Cengkareng	S1	S4	S3	S2	S0	0,4
	Pondok Betung	S1	S4	S2	S3	S0	0,36
	Kemayoran	S1	S4	S3	S2	S0	0,39
	Tanjung Periuk	S1	S4	S3	S2	S0	0,42
	Citeko	S1	S4	S3	S2	S0	0,5

Information :

S0 : WRF without assimilation
 S1 : WRF CAPPI data assimilation
 S2 : WRF Z data assimilation

S3 : WRF V data assimilation
 S4 : WRF Z and V combination data assimilation

4. Conclusion

Based on the results of the research described in the previous chapter, some conclusions can be drawn as follows; In general, the WRF model assimilates radar data given to spatial rainfall event simulations and better points compared to the WRF model without assimilation where the rain prediction performance will be more visible in areas close to the radar and not obstructed from fixed objects such as mountains or hills, also more visible during the rainy season. From the four WRF model assimilation radar data conducted in this study, it can be concluded that the best sequence of WRF improvements is WRF assimilation of CAPPI data, Z & V data assimilation, V data assimilation, and Z data assimilation.

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