Simulation of Mesoscale Convective System Propagation in Greater Jakarta during 13 - 19 January 2014

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Abstract. The simulation of the mesoscale convection system (MCS) during the 13 - 19 January 2014 was conducted for Greater Jakarta (GJ) using the Weather Research and Forecasting (WRF) model. In this study, WRF simulations were carried out for different sizes of urban and built-up area, which in the experiment (SCE) wider than the standard (CTL) simulations. The results of the two WRF simulations are evaluated against the surface observations. The comparison of the measured wind speed and direction in the GJ area shows a reasonable result between observed and simulated data. The results showed a consistent significant contribution of urban and built-up development to wind speed. The significantly increasing wind speed was up to 3 ms⁻¹. There is no persistent variation in the wind speed and direction of each station. Simulations suggest that the new urban developments caused an intensification and expansion of MCS propagation. The SCE simulation provided a stronger convective cloud system that spreads from south to north.

1. Introduction

In the period from January 13 to 19, 2014, a flood event occurred in Greater Jakarta (GJ), which was caused by a complex heavy rainfall with a special hydrological situation. However, this paper is not prepared to examine the hydrological aspects of the flash flood problem. The heavy rains are usually implicated by mesoscale convection systems (MCSs) [1-5]. MCS are features of complexly organized convective clouds that vary in size and last for hours, creating an adjacent precipitation area of approximately 100 km in the horizontal direction [6]. Consequently, the prediction of MCS is a critical and problematic activity.

There have been several studies on MCS in Indonesia that used infrared satellite observation data [7-12] to fully discuss the general characteristics of MCS. But it is not completely understood about the predictability of the MCS. We need a specific method to understand it. There are two important parts where much of the effort is spent in predicting MCSs, i.e.: the initiation of convection and the evolution of the upscale. One part refers to the requirement to parameterize convection with a
sufficiently high resolution in the meantime. Research and operational of numerical weather prediction (NWP) models now have the ability to run a large region in grid intervals of 1 to 4 km.

The MCS propagation was simulated by realistic data using grid spacings ranging from 1 km to 9 km with an emphasis on 1 km to determine the impact of land use on the simulation pattern. A mesoscale Weather Research and Forecasting (WRF) version 3 [13] model was used to simulate the characteristics associated with MCS propagation over GJ periods from 13 to 19 January 2014 and to investigate its sensitivity to the effects of different land uses on simulation patterns.

2. Data and Methods

The WRF model with the Advanced Research WRF (ARW) dynamics core, version 3.5, was used to perform the simulations. The set of grids spacing (horizontal resolution) used was from smallest to largest in km: 1, 3 and 9 (Figure 1). The model domain range along a west-east orientation was 131 km, 121 km, 151 km wide and 27 vertical levels. Initial and boundary conditions are determined by the global forecasting data of the Global Forecast System (GFS). The GFS data have a spatial and temporal resolution of 0.5 x 0.5 and 6 hours.

![Figure 1](image.png)

**Figure 1.** The topography of the grid domain (d01 denotes a resolution of 9 km, d02 denotes a resolution of 3 km and d03 a resolution of 1 km).

The previous study on the simulation of MCS using WRF, conducted by Choi et al. [4] over Goyang city, in the western central region of the Korean Peninsula. They used several model configurations in the simulation. Due to location differences and previous mid-latitude research, we construct various experimental model configurations than previous studies. Although Weisman et al. [14] concluded that 4 km grid spacing is insufficient to require a convective parameterization scheme for solving deep convection and squall lines, so a cumulus scheme must be implemented. The WRF model used the following schemes of sub-grid parameterization: Lin et al. [15] for cloud microphysics; the RRTM scheme for long-wave radiation [16]; the Dudhia scheme for shortwave radiation [17]; the BMJ scheme for the cumulus option [18-21]; the Yonsei University scheme [22] for the boundary layer (Table 1).

The Lin et al. [15] scheme is a single moment scheme in which only the mass mixing ratio of each hydrometeor species is transmitted with the number density estimated using an exponential size distribution function. The reason for using the RRTM and Dudhia schemes for longwave and
shortwave radiation, respectively, is their simplicity and well established in most forecast models [23]. Most cumulus parameterizations should not be used for grid resolutions less than 10 km. But in this case, we used the BMJ scheme because BMJ has significantly increased the coverage of lighter rains [24]. In addition, the reason for choosing YSU scheme for the boundary layer is that YSU tends to give the deepest PBL.

Table 1. Details of the WRF-ARW model configurations

| Configurations                  | Domain 1 | Domain 2 | Domain 3 |
|--------------------------------|----------|----------|----------|
| Centerpoint longitude          | 106.749  |          |          |
| Centerpoint latitude           | -6.168   |          |          |
| Horizontal grid dimension X    | 131      | 121      | 151      |
| Horizontal grid dimension Y    | 131      | 121      | 151      |
| Horizontal grid resolution     | 9 km     | 3 km     | 1 km     |
| Number of vertical level       | 27       | 27       | 27       |
| Microphysics                   | Lin et al. | Lin et al. | Lin et al. |
| Planetary boundary layer       | YSU      | YSU      | YSU      |
| Cumulus parameterization       | BMJ      | BMJ      | BMJ      |
| Longwave radiation scheme      | RRTM     | RRTM     | RRTM     |
| Shortwave radiation scheme     | Dudhia   | Dudhia   | Dudhia   |

Figure 2. Shading plots showing the land use type of the reference experiment (left) and the SCE experiment (right) with land use change in most of the GJ area. Blue filled triangles denote stations: Tanjung Priok (TJP), Soekarno-Hatta Cengkareng Airport (CGK), Kemayoran (KMO), Curug (CRG) and Citeko (CKO) for the inner modeling domain.

In this study we examine the two experiments with different land use. The reference experiment (CTL) was chosen as the standard model configuration described in the previous section. The experiment (SCE) is the same as CTL configuration except land use index modification. The SCE experiment is performed by changing the land use index in most of the GJ area to urban and built-up land (black shading, see Figure 2). This is done to see how urban heat islands influence the local
meteorological processes. Land use change certainly does not directly affect the meteorological parameters. But the land use changes in the patterns of urban heat island (UHI) and characterizes the thermal properties of the soil to represent a rapid urbanization in GJ. Thus, we simulate both the CTL and EXP experiments to gain a deep understanding of the effects of land use change on MCS features.

To evaluate WRF, observations data from five surface weather stations in the city and surrounding area were used (Figure 2). The data are available in the Database Center of the Indonesian Agency for Meteorological Climatology and Geophysics (BMKG). The available data are hourly observed surface wind speed and wind direction. In this paper, a statistical approach is used to obtain a quantitative comparison. The following equation is the root mean square error (RMSE) and standard deviation of the error (SDE) as the intended method:

\[ RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (x_i - y_i)^2} \]  

\[ SDE = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (e_i - \bar{e})^2} \]  

where:
- \( n \) = number of samples
- \( x_i, y_i \) = individual samples with index \( i \)
- \( \bar{e} \) = error mean

To diagnose MCS propagation, we applied Hovmoller diagrams [25] with cloud top temperature (CTT) and water vapor mixing ratio variables. This technique is used by plotting the time versus longitude or latitude. This technique is commonly used to know the movement of a particular phenomenon in a certain area. In this case, it had been applied to a specified latitude and longitude, i.e. 106.7°E – 107.0°E and 6.01°S - 6.76°S.

3. Results and Discussions
Figure 3 shows the simulated and observed surface wind speed for 5 locations (triangle in Figure 2). The simulations capture the diurnal variation pattern for most of the simulation period. There was a tendency for WRF that does not always capture the highest average wind speed, as observed at all stations. In most cases, WRF performs overestimate simulation comparing to the recorded wind speed, except that a rural reference site is underestimated at Citeko, i.e. the wind speed on the 6th day. The simulated and observed wind speed difference is approximately 2 m s\(^{-1}\) for the six-day simulation (Table 2). On day 3 of the simulation, a sudden increase in wind speed was observed in the afternoon, resulting in a low wind speed in the morning simulation (Figure 3).

The results for the wind direction (Figure 4) show that WRF captures the flow direction for most days for all stations. During the 4th day of the simulation, the typical pattern over Curug and Citeko is not clearly defined, and the simulated wind direction differs at times significantly from the observed data. The RMSE and SDE for wind direction are mostly in the range of ± 60°, which is reasonably well.
Figure 3. Simulated and observed surface wind speed at Tanjung Priok (TJP), Soekarno-Hatta, Cengkareng (CGK), Kemayoran (KMO), Curug (CRG) and Citeko (CKO) stations (observed: red dots; simulated: blue line). The dates are for the 13 - 19 January 2014.

Figure 4. Simulated and observed surface wind direction at Tanjung Priok (TJP), Soekarno-Hatta, Cengkareng (CGK), Kemayoran (KMO), Curug (CRG) and Citeko (CKO) stations (observed: red dots; simulated: blue line). The dates are for the 13 - 19 January 2014.
Overall, the results of the WRF model suggest that the urban near-surface variables are sufficiently well represented to perform the sensitivity analysis to study the impact of land use change on the mesoscale convective system propagation.

**Table 2.** The statistical measures of root-mean-square error (RMSE) and standard deviation of the error (SDE) for each station for the simulation periods.

| Stations      | Wind speed | Wind direction |
|---------------|------------|----------------|
|               | RMSE | SDE | RMSE | SDE |
| Tanjung Priok | 3.6  | 2.2 | 59.8 | 59.0 |
| Cengkareng   | 2.9  | 2.8 | 68.3 | 68.1 |
| Kemayoran    | 2.3  | 1.7 | 69.9 | 69.9 |
| Curug         | 2.6  | 1.9 | 121.1| 120.4|
| Citeko        | 2.7  | 2.4 | 118.4| 101.3|

Differences in simulated wind characteristics between land use scenarios were used as a measure of land use effects on convective cloud propagation. Here, the focus is on the CTT and water vapor mixing ratio since they represent the existence of an MCS. The size of the wind speed and the change of direction varied at the stations and at different times during each station (Figures 5 and 6). The results indicate that new urban developments can cause an intensification and expansion of MCS propagation, but mainly affect wind speed with an increase of up to 3 ms$^{-1}$.

**Figure 5.** Simulated surface wind speed for control (CTL) and experiment (SCE) land use at the Tanjung Priok (TJP), Soekarno-Hatta Airport Cengkareng (CGK), Kemayoran (KMO), Curug (CRG) and Citeko (CKO) station (control: blue line; experiment: red dots). The dates are for the 13 - 19 January 2014.
Figure 6. Simulated surface wind direction for control (CTL) and experiment (SCE) land use at the Tanjung Priok (TJP), Soekarno-Hatta Airport Cengkareng (CGK), Kemayoran (KMO), Curug (CRG) and Citeko (CKO) station (control: blue line; experiment: red dots). The dates are for the 13 - 19 January 2014.

To illustrate the effects of land use change on MCS propagation over time, the Hovmoller diagram showed a cross-sectional time versus latitude plot that was formed over GJ with an average length of 106.7°E - 107.0°E. Figure 7 shows the Hovmoller diagram of CTT. Difference diagrams allow a comparison between the CTL and SCE simulated of CTT. The SCE simulation shows more significant CTT when the system moves north than south. This shows the contribution of land use change to the water vapor pattern that is being moved into the study area.

Figure 7. The Hovmoller diagrams of control (CTL) and experiment (SCE) land use for simulated cloud top temperature averaged at longitude 106.7°E – 107.0°E. The dates are for the 13 - 19 January 2014.
There is addition and reduction of CTT at the SCE experiment. For example, at the night of 13 January 2014 CTT was reduced, while at the evening of 15 January 2014 CTT was increased. The same case is also seen in the mixing ratio (Fig. 8). There are inconsistent increases and decreases in the mixing ratio. Simulations indicate that scenario experiments provide a higher convective cloud system as they move from south to north. Based on the simulations, the new urban development caused an intensification and expansion of the area where convective clouds are created.

![Figure 8. The Hovmoller diagrams of control (CTL) and experiment (SCE) land use for simulated water vapor mixing ratio averaged at longitude 106.7°E – 107.0°E. The dates are for the 13 - 19 January 2014.](image)

**Table 3.** Daily rainfall over the GJ periods 13 – 19 January 2014

| Date | Tj.Priok | Cengkareng | Kemayoran | Curug | Citeko |
|------|----------|------------|-----------|-------|--------|
| 13   | 10.2     | 20.8       | 20.8      | 31.4  | 13.4   |
| 14   | 44       | 36         | 25        | 32    | 16.3   |
| 15   | 6.7      | 23         | 9.5       | 25    | 35.1   |
| 16   | 67.4     | 58         | 31        | 16.3  | 5.1    |
| 17   | **150**  | 72         | **234**   | 3     | **130**|
| 18   | 57       | **108**    | 95        | 9.5   | 48.1   |
| 19   | 11.4     | 8.1        | 13.5      | 0.5   | 31     |

As a result, in heavy rainfall on January 17, 2014 (Table 3), the linear MCS developed from the north and several convective cells could be responsible for the flash flood within the MCS event. In this case, the SCE experiment (both CTT and mixing ratio) yields reducing convective cells that could reduce heavy rainfall.
4. Conclusions

Numerical simulation of MCS during heavy rainfall event periods January 13 - 19, 2014 are investigated for GJ area using the WRF model. In this study, two experimental WRF simulations were carried out for different size of urban and built-up area, i.e. the wider size on the SCE simulation than the CTL. The results of the both WRF simulation are evaluated compared to the surface observations. Comparison of measured wind speed and direction in GJ area show a reasonable result between observed and simulated data. There are no tendency of wind speed and direction variation each station. Simulations suggest that scenario experiments provide a higher convective cloud system when moving from south than north. The numerical simulation of MCS during heavy rain event periods January 13 - 19, 2014 has been examined with the WRF model for the GJ. In this study, two experimental WRF simulations were carried out for different sizes of urban and built-up areas; H. The larger size in the SCE simulation than the CTL. The results of the two WRF simulations are evaluated in comparison to the surface observations. The comparison of the measured wind speed and direction in the GJ range shows a reasonable result between observed and simulated data. There is no tendency of wind speed and direction change of each station. Simulations indicate that scenario experiments provide a higher convective cloud system as they move from south to north.

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