Contribution of land use changes to meteorological parameters in Greater Jakarta: Case 17 January 2014

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Abstract. The impact of land use changes on meteorological parameters during a heavy rainfall event on 17 January 2014 in Greater Jakarta (GJ) was examined using the Weather Research and Forecasting (WRF) model. This study performed two experimental simulation methods. The first WRF simulation uses default land use (CTL). The second simulation applies the experiment by changing the size of urban and built-up land use (SCE). The Global Forecast System (GFS) data is applied to provide more realistic initial and boundary conditions for the nested model domains (3 km, 1 km). The simulations were initiated at 00:00 UTC January 13, 2014 and the period of modeling was equal to six days. The air temperature and the precipitation pattern in GJ shows a good agreement between the observed and simulated data. The results show a consistent significant contribution of urban development and accompany land use changes in air temperature and precipitation. According to the model simulation, urban and built-up land contributed about 6\% of heavy rainfall and about 0.2 degrees of air temperatures in the morning. Simulations indicate that new urban developments led to an intensification and expansion of the rain area. The results can support the decision-making of flooding and watershed management.

1. Introduction

An exceptionally heavy rainfall is a serious threat to human life and property. Even with the recent rapid improvements in numerical weather forecasting, the forecast of heavy rainfall events remains a problem for atmospheric modeling communities. Greater Jakarta (GJ) is a potentially active region for heavy rainfall events that can trigger flash floods [1-5]. In addition, the heavy rainfalls are particularly devastating, especially if they last a long time. This is also due to a densely populated and low-lying coast. It has a significant impact on the socio-economic conditions of the GJ bordering areas. The events that imply heavy flooding in GJ could be caused by the activity of mesoscale convection systems (MCSs).

Previous studies on MCS activity in Indonesia Maritime Continent (IMC) were performed using satellite observation data [6-11]. But it is still not fully understood about the predictability of the MCS. A recent study by Trismidianto [8] discusses MCC and is associated with its contribution to precipitation in IMC, but there is still no clarity of heavy or light rainfall. Meanwhile, Putri \textit{et al.} [11]
have only discussed seasonal variations of MCS in IMC where MCS on land tend to show a lower TBB minimum, larger size, and higher rainfall compared to MCS at sea.

In this study, the mesoscale model Weather Research and Forecasting - Advanced Research WRF (WRF-ARW) is used to simulate the meteorological features of a heavy rainfall event over GJ on January 17, 2014, and its sensitivity to study the effects of land use on predictive patterns. The sensitivity of the model simulations to the initial conditions is also examined on the basis of land use changes. A brief description of the model as well as the parameterization schemes and data used in the study are presented in Section 2. Model-simulated results together with the assessment of the performance of the model for different land uses are presented in Section 3 with the conclusions in Section 4.

2. Data and Methods

Version 3.5 of the non-hydrostatic regional numerical weather forecast system WRF-ARW was used for simulations. The WRF model is initialized and the boundary conditions (with the interval of 6 hours) are specified using the Global Forecast System (GFS) data. The GFS data have high spatial (0.5°) resolution for periods from 13 to 19 January 2014.

Three nested grids with one-way nesting were used, extending over 1,179 km x 1,179 km; 363 km x 363 km and 151 km x 151 km at 9; 3 and 1 km resolution as shown in Figure 1. The simulations were done for 27 vertical levels, the modeling period was 6 days, and the temporal resolution of the output data was 1 hour. The WRF model used the following schemes of parameterization of sub-grid processes: Lin et al. [12] for cloud microphysics; the RRTM scheme for longwave radiation [13]; the Dudhia scheme for shortwave radiation [14]; the BMJ scheme for the cumulus option [15-17] and the scheme of Yonsei University [18] for the boundary layer (Table 1).

The Lin et al. [12] 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. 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 rainfall [19]. In addition, the reason for choosing the YSU boundary layer scheme is that the YSU tends to give the deepest PBL.

The impact of land use changes on patterns of meteorological parameters on 17 January 2014 in GJ are examined using the Weather Research and Forecasting (WRF) model. This study conducted
two different land uses for experimental methods of simulation. The Global Forecast System (GFS) data is applied to the first model domain (9 km) with the purpose of provide a more realistic and desirable initial and boundary conditions for the nested model domains (3 km, 1 km). The reference experiment (CTL) was chosen as the standard model configuration described in the previous. Experiment SCE is the same as CTL configuration, except for the land use index modification (Figure 2). The SCE experiment is carried out by changing the land use index in most GJ urban and built-up land. This is done to see how urban heat islands affect local meteorological processes.

**Table 1.** Details of the WRF-ARW model specifications.

| Configurations               | Domain 1 | Domain 2 | Domain 3 |
|-----------------------------|----------|----------|----------|
| Center point longitude      | 106.749  |          |          |
| Center point 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   |

To evaluate the WRF performance, observations from 5 surface weather stations were used in the urban and surrounding GJ (indicated by a blue triangle in 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 work, 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:

\[
RMSE = \left( \frac{1}{n} \sum_{i=1}^{n} (x_i - y_i)^2 \right)^{1/2} \tag{1}
\]

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

\[
e_i = x_i - y_i \tag{3}
\]

with:
- \(n\) = number of samples
- \(x_i, y_i\) = individual samples with index \(i\)
- \(\bar{e}\) = error mean
Figure 2. Shading plots showing the reference experiment (a) and the SCE experiment (b), with different land use index in most of GJ. Blue triangles denote stations: Tanjung Priok (TJP), Soekarno-Hatta Cengkareng Airport (CGK), Kemayoran (KMO), Curug (CRG) and Citeko (CKO) for the inner modeling domain. Note that the maps in CTL and SCE are the computational grids used from the WRF simulations.

To diagnose the impact of land use on meteorological features, we plot the spatial map of surface temperature at 0700 LT on January 17, 2014. This technique is conducted by recording the spatial value of the surface temperature of CTL, SCE, and difference (CTL-SCE). It is commonly used to know the difference of a particular phenomenon in a particular area. In this case, this is done in a specified latitude range, i.e. 6.01°S - 6.76°S.

3. Results and Discussion

Figure 3 shows the simulated and observed surface air temperature for the five stations (blue triangles in Figure 2). The simulations capture the diurnal variation including the maximum and minimum temperatures during much of the period of the heavy rainfall event within approximately 0.2 °C of the different temperature. On day 2 of the simulation, a maximum temperature reaches about three hours later in the simulation than in the observed time. There is not a tendency of WRF simulation results to detect the peak of air temperature. In the startup period of the simulation on the fifth day, the simulated air temperature indicates an overestimation, except at Tanjung Priok Station. The temperature difference between the simulation result and the observation is less than 2 °C for the six simulation days (Table 2).

Figure 4 shows the simulated and observed sea level pressure (SLP) for the five stations. The simulations also capture the diurnal variation of SLP during the heavy rainfall event. On day 4 of the simulation, a maximum SLP reaches the urban area about 3 hours earlier in the simulation than the observed. There is a tendency of WRF simulation results to detect the peak of SLP lower than observed. In the starting period of the simulation on the fifth day, the simulated SLP indicates an underestimation. The SLP difference between the simulation result and the observation is less than 2 for the six simulation days (Table 2).
Figure 3. Simulated and observed of surface air temperatures at stations a) Tanjung Priok (TJP), Soekarno-Hatta, b) Cengkareng (CGK), c) Kemayoran (KMO), d) Curug (CRG) and e) Citeko (CKO) (observed: red dots, simulated: blue line). The data refer to the 13th - 19th of January 2014.

Figure 4. As in Figure 3 but for sea level pressure.
Table 2. Statistics showing root-mean-square error (RMSE) and standard deviation of the error (SDE) for each station between the simulation and observation results.

| Station        | Air temperature RMSE | SDE  | Sea level pressure RMSE | SDE  |
|----------------|-----------------------|------|-------------------------|------|
| Tanjung Priok  | 1.6                   | 1.6  | 1.5                     | 1.1  |
| Cengkareng     | 1.7                   | 1.7  | 1.4                     | 1.0  |
| Kemayoran      | 1.8                   | 1.8  | 1.5                     | 1.1  |
| Curug          | 1.8                   | 1.8  | 1.7                     | 1.2  |
| Citeko         | 1.7                   | 1.4  | 0.8                     | 0.8  |

Furthermore, the average diurnal temperature in CTL, SCE and CTL - SCE has been showed. There is indicated a contribution of land use change in air temperature increase in GJ at 01:00 WIB (Fig. 5). This is shown by the dominance of negative values the difference of CTL-SCE. The maximum difference is about 0.6 degrees and in GJ about 0.2 degrees. This means that land use change results in a temperature increase of about 0.2 degrees with simulated at 01:00 LT.

Figure 5. Diurnal means of air temperature for a) CTL, b) SCE and c) differences of CTL – SCE simulations at 0100 LT.

Figure 6. As in Figure 3 but for accumulated rainfall at periods 2200 – 0700 LT on 17 January 2014.
Figure 6. shows an accumulated rainfall for CTL and differences of CTL – SCE simulations periods 2200 – 0700 LT on 17 January 2014. There is a difference of up to 15 mm in the changed land use. The northern GJ has higher precipitation in the land-use change scenario compared to the south. The results suggest new urban developments caused an intensification and expansion of the area experiencing rainfall but mainly influenced early morning rainfall with increase of up to 15 mm.

4. Conclusions
The WRF simulations directed for 6 days from 13 January 2014 00 UTC until 19 January 2014 00 UTC. Commonly, measured air temperature and rainfall pattern in GJ region show a good promise between observed and simulated data. The results also indicate consistent significant contribution of urban development and associated land use changes to air temperature and rainfall. According to the model simulation, urban and built up land contributed about 6% in heavy rainfall in the morning and about 0.2 degrees of air temperature different. Simulations suggest new urban developments caused a strengthening and development of the area experiencing rainfall but mainly influenced morning rainfall with increase of up to 15 mm.

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