Development and Validation of Heavy Rainfall Prediction Method Considering the Urban Activity Information in Jakarta, Indonesia

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Synopsis

In this study, we estimated the urban activity information in Jakarta, and introduced them into a cloud-resolving meteorological model. Application of the model to the heat island of Jakarta on a sunny day (16th September 2012) shows that global land cover classification data is not sufficient for reproducing the heat island over Jakarta, and more detailed land cover information can clearly improve the simulation accuracy of heat islands. After application to a heavy rainfall event in Jakarta in 2013 (from 15th to 17th January), results indicate that surface friction determination should be improved.

Keywords: Urban activity information, Cloud resolving model, Heavy rainfall, Heat island, Jakarta

1. Introduction

In recent years, the population in Jakarta has increased rapidly along with economic development in Indonesia. In 2011 the population reached 9.5 million in Jakarta itself and 2,224 million in the entire Jakarta metropolitan area (Jabodetabek). The rapid expansion of urban areas in Jakarta is a result of this rapid increase in population and is thought to have played a role in recent, and frequent, torrential rain disasters. Therefore, heavy rainfall prediction considering urban activity information is an urgent task in this region.

However, in the megacities of developing countries, including Jakarta, existing urban activity data (artificial land cover, anthropogenic heat, building height distribution) is not sufficient.

Therefore, it has not been possible to predict heavy rainfall using this information.

In order to resolve this issue, a heavy rainfall prediction method using urban activity information in Jakarta has been developed and validated in this study. The method is based on a cloud resolving meteorological model that takes into account urban activities (Souma et al., 2013). To estimate urban activity information, various statistical data and satellite remote sensing have been used.

2. Estimation of urban activity information in Jakarta

For distribution of artificial land cover, estimated results from Landsat satellite data (Widyasamratri, 2014) were embedded in the global

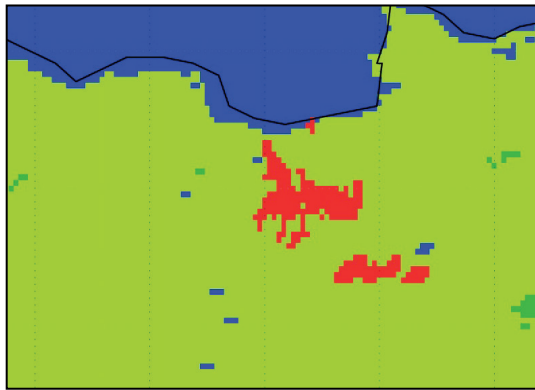land cover data set (Global Land Cover Characterization ver2; GLCC).

Fig. 1 Global land cover data set (GLCC). Blue: water, red: urban area, green: tall trees, yellow-green: shrub.
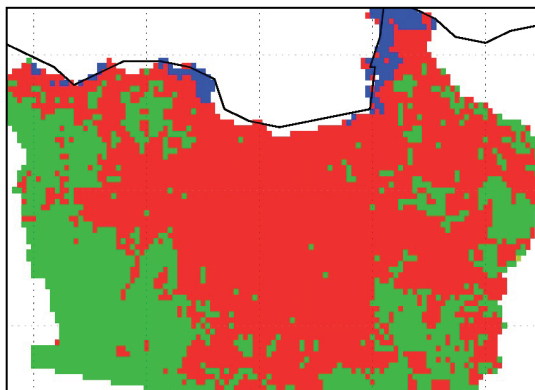

Fig. 2 1 km mesh land cover classification around Jakarta in 2006 obtained from a detailed (30 m) land cover classification using Landsat (Widyasamratri, 2014).

Widyasamratri (2014) used the Landsat satellite ETM + sensor image to estimate the detailed (30 m) land cover classification around Jakarta in 2006. They applied a supervised classification for the image and, as training data, used mobile observation and field survey results from 2012, which were obtained by the University of Yamanashi. In this study, the dominant land cover classification in a 1 km mesh was derived from the dataset of Widyasamratri (2014), and the urban area was overwritten to GLCC data.

In this study, the distribution of anthropogenic heat in Jakarta was estimated by assuming the same energy consumption patterns as the Tokyo metropolitan area (the population is similar to the Jakarta metropolitan area). Daily averaged anthropogenic heat in the Kanto region of Japan based on Seno et al. (2004), and global 5 km mesh population density distribution data (Gridded population of the World version 3; GPW) were compared, and a linear regression equation was estimated (Figure 2). To estimate the anthropogenic heat quantity, the population density in GPW was multiplied by the anthropogenic heat in the mesh, according to the linear regression equation.
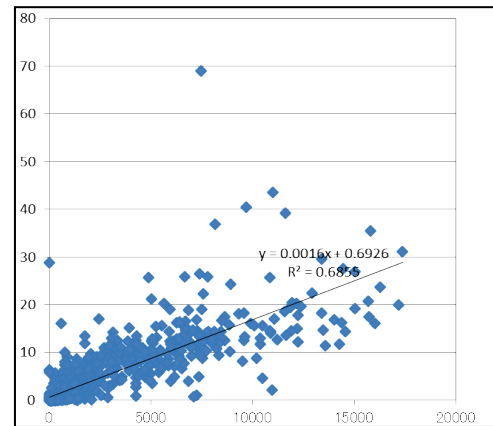

Fig. 3 Scatter diagram showing anthropogenic heat and population density. 5 km mesh daily averaged anthropogenic heat (sensible heat; W/m^2) in the Kanto region of Japan is shown on the vertical axis. 5 km mesh population density (people/25 km^2) according to the GPW is shown on the horizontal axis.
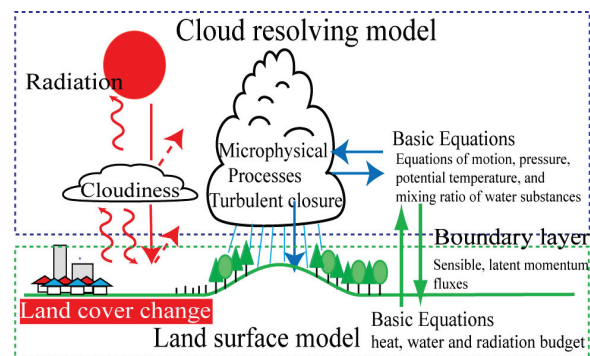

Fig. 4 Conceptual diagram of CReSiBUC (Souma et al., 2013b).

3. Use of estimated urban activity information for prediction of heavy rainfall

The urban activity information estimated in Section 2 were employed in heavy rainfall prediction using CReSiBUC (Souma et al., 2013a; 2013b), which is a cloud resolving meteorological

model that takes into account urban activities. In CReSiBUC, the Cloud Resolving Storm Simulator (CReSS; Tsuboki and Sakakibara, 2002; 2007), developed at Nagoya University, was used as the atmospheric model. The Simple Biosphere model including Urban Canopy (SiBUC; Tanaka, 2004), developed by Kyoto University, was used as the land surface processes model. The Land surface processes model SiBUC consists of three sub-models: green areas, water bodies, and urban areas. In the urban area sub-model, heat, water, and momentum transport to the atmosphere from the ground surface were calculated considering the anthropogenic heat distribution discharged from air-conditioning and automobiles, artificial land cover such as asphalt, and the urban geometry.

In the urban area sub-model, the existence of puddles on roofs, walls, and roads was considered. The heat balance was not solved for puddles, and the temperature of puddles was assumed to be equal to the temperature of roofs, walls, and roads. The latent heat flux caused by evaporation was taken into account in solving the heat budget.

4. Application of the model to the heat island of Jakarta

To reproduce the effects of urban activities on heavy rainfall, it is necessary to reproduce the heat island phenomenon in urban areas prior to heavy rainfall. Therefore, the heavy rainfall prediction method considering urban activity information was applied to a typical dry season sunny day during an intensive observation period carried out by the University of Yamanashi (from September to October 2012; Widyasamuratri et al., 2014).

The calculations were performed with a horizontal resolution of approximately 2 km within the domain shown in Figure 5 (320 ×240 grid) using CReSiBUCver1.5. The number of vertical layers was set to 45, and the vertical resolution was set to an average of 300 m.

The actual initial and boundary conditions of the atmospheric variables were derived using JCDAS re-analysis data (spatial resolution 1.25°). Data from the Group for High Resolution Sea Surface Temperature (GHRSST) was used to set the initial sea surface temperature, and the Normalized

Difference Vegetation Index (NDVI) obtained from the SPOT satellite vegetation sensor was used to set the leaf area index (LAI). The digital soil map of the world provided by the Food and Agriculture Organization of the United Nations (FAO) was used to set the percentage of sand and clay. The thickness of the soil layer and the root layer, the vegetation coverage, and the green leaf rate were given according to the recommended values in the Global Soil Wetness Project 2 (GSWP2).

The initial time of the simulation was 12 UTC (Jakarta standard time is UTC +7 hours) and the calculation period was 35 hours. The building height in the area was assumed to be uniformly low-rise residential (adjusted to Nagahama City in Shiga Prefecture in Japan; Tanaka et al., 1998).
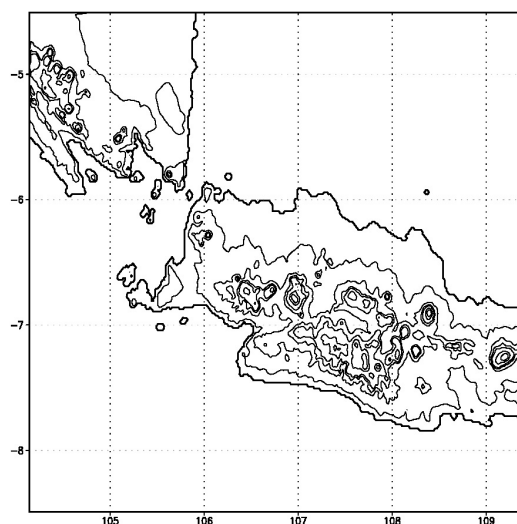

Fig. 5 Simulation domain used in this study.

In the first simulation, only the GLCC was considered in order to set the land cover, and anthropogenic heat was assumed to be zero (hereafter referred to as "GLCC"). In the second simulation, combined land cover data considering both Landsat and GLCC was considered in order to set the land cover, and anthropogenic heat was assumed to be zero (hereafter referred to as "COMB"). In the third simulation, the same land cover as COMB was used and the estimated anthropogenic heat distribution in Section 2 was also considered (hereafter referred to as "AHFP").

The simulated temperature values in three experiments were compared with the observed values at 7 observation sites obtained by the

University of Yamanashi (every 5 minutes; Widyasamratri et al, 2014). Temperature values of the atmospheric bottom layer were obtained at the closest mesh to the observation sites.
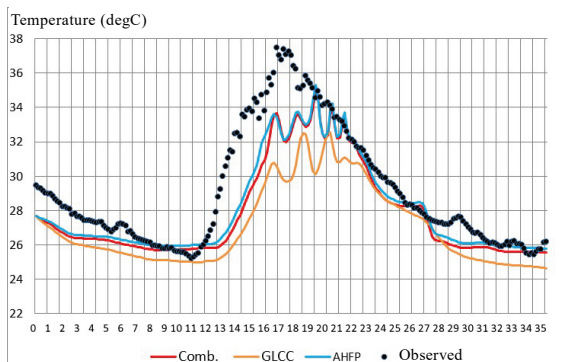

Fig. 6 Time series (16/09/2012) of simulated and observed temperature at the Kramat Jati (Jakarta) site from the fixed-point observations carried out by the University of Yamanashi in 2012. The horizontal axis indicates the hours from the initial time (00UTC).
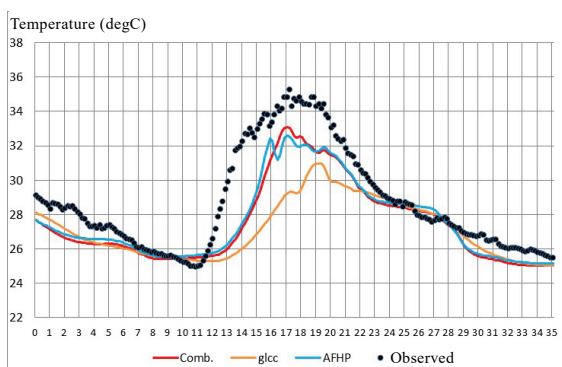

Fig. 7 Time series (16/09/12) of simulated and observed temperature at the Tangerang site from the fixed-point observations carried out by the University of Yamanashi in 2012. The horizontal axis indicates the hours from the initial time (00UTC).

Figures 6 and 7 show the observed and simulated temperature at the representative sites (Kramat Jati in Jakarta, and Tangerang). It can be seen that the temperature in the "COMB" experiment was higher than that in the "GLCC" as well as closer to the observed value. The temperature in the "AHFP" experiment was higher than those in the "GLCC" and "COMB" experiments and closer to the observed value, but the difference between "AHFP" and "COMB" was

smaller than the difference between "COMB" and "GLCC".

In summary, the "GLCC" experiment apparently underestimated temperature compared to observed values, and introduction of the combined land cover data considering both Landsat and GLCC greatly improved the temperature accuracy. The introduction of anthropogenic heat data also improved the accuracy of the simulated temperature, but the impact was smaller than the impact of the land cover data.

5. Application of the model to heavy rainfall in Jakarta

In the next step, the developed method was applied to a heavy rainfall event that occurred in Jakarta in January 2013. In this event, inundation occurred around the Ciliwung River in Jakarta from the 15th to 18th January 2013 and more than 40 people were killed (Kure et al., 2013). Intense rainfall was observed around Jakarta from the 15th to 17th January 2013. Land and sea breeze circulation over Java Island, the Asian winter monsoon, and the Madden-Julian Oscillation (MJO) are all thought to have resulted in the intense rainfall (Wu et al., 2013).

In this study, simulations were carried out for 35 hours from 12 UTC (19 LST) on the 14th, 15th, and 16th January 2013 using the CReSiBUCver2.4.0. The calculations were performed with a horizontal resolution of approximately 2 km within the domain shown in Figure 5 (320 ×240 grid). The actual initial and boundary conditions of the atmospheric variables were the same as in Section 4; however, the percentage of sand and clay, the thickness of the soil and root layers, the vegetation coverage, and the green leaf rate were obtained from Ecoclimap (Champeaux et al., 2005). For the land cover, combined land cover data considering both Landsat and GLCC were used, as explained in Section2. The distribution of anthropogenic heat was also determined as in Section 2.

Figures 8 and 9 show the simulated 1 hour accumulated precipitation and wind speed at 21 LST and 22 LST on the 17th January 2013, respectively. Compared to the radar reflectivity

observed by C-band radar (Wu et al., 2013), the existence of precipitation was reproduced over Jakarta in the simulations. The location of strong precipitation tends to shift to the leeward direction. This feature was seen not only on the 17th January, but also on the 15th and 16th January. It is suggested that surface friction was underestimated in this study due to assuming a low-rise residential area for the building height distribution.
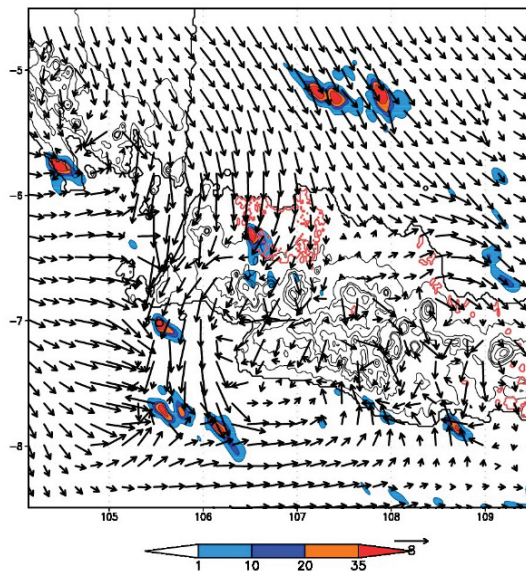

Fig. 8 1 hour accumulated precipitation (mm) and wind speed (arrows; m/s) at 21 LST on 17th January 2013.
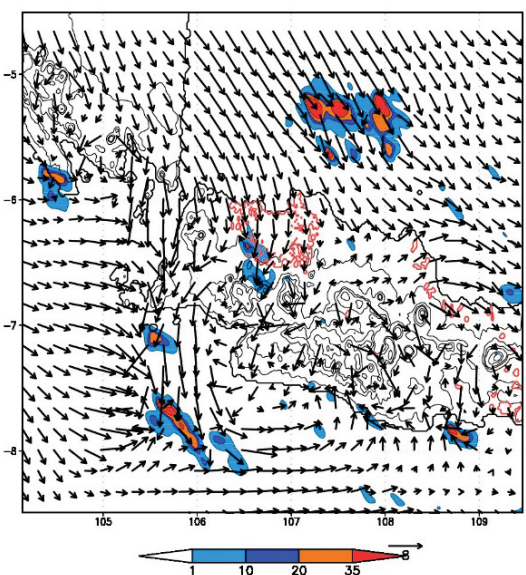

Fig. 9 1 hour accumulated precipitation (mm) and wind speed (arrows; m/s) at 22 LST on of 17th January 2013.

6. Summary

In this study, we developed a heavy rainfall prediction method considering the urban activity information in Jakarta, Indonesia. In this method, urban activity information is estimated using statistical data and satellite remote sensing, and the estimated information is introduced into a cloud resolving meteorological model that uses detailed urban features to predict heavy rainfall.

Firstly, we simulated the heat island observed over Jakarta on a sunny day (16th September 2012). The results indicate that global land cover classification data is not sufficient to reproduce the heat island over Jakarta, and that more detailed land cover information can clearly improve the simulation accuracy of heat islands.

Next, we simulated a heavy rainfall event in Jakarta in 2013 (from 15th to 17th January) using the developed method. The simulated rainfall was shifted slightly leeward compared to observed precipitation radar data near Jakarta. This indicates that surface friction in the simulations was underestimated.

We suggest that the underestimation in surface friction was caused by assuming a low-rise residential area for the building height distribution in this study. In future studies, a more detailed building height distribution using satellite remote sensing is required for heavy rainfall simulation.

References

Champeaux, J. L., Masson, V. and Chauvin, F. (2005): ECOCLIMAP: a global database of land surface parameters at 1 km resolution, Meteorological Applications, 12(1), pp. 29-32.

Kure, S., Muhari, A., Fukutani, Y., Bricker, J., Udo, K., and Mano, A. (2013): Characteristics of the January 2013 Flood in Jakarta, Indonesia, Proceedings of annual conference, Japan Society of Hydrology and Water Resources (in Japanese with English abstract).

Senoo, H., Kanda, M., Kinouchi, T., and Hagishima, A. (2004): Estimation of anthropogenic heat and vapor emission and the impact on local meteorology, Annual Journal of Hydraulic Engineering, Vol. 48, pp. 169-174 (in Japanese with English abstract).

Souma, K., Tanaka, K., Suetsugi, T., Sunada, K., Tsuboki, K., Shinoda, T., Wang, Y., Sakakibara, A., Hasegawa, K., Moteki, Q. and Nakakita, (2013a): A comparison between the effects of artificial land cover and anthropogenic heat on a localized heavy rain event in 2008 in Zoshigaya, Tokyo, Japan, Journal of Geophysical Research, 118, pp.11,600-11,610, doi:10.1002/jgrd.50850.

Souma, K., Sunada, K., Suetsugi, T., and Tanaka, K. (2013b): Use of ensemble simultions to evaluate the urban effect on a localized heavy rainfall event in Tokyo, Japan, Journal of Hydro-environment Research, 7 (4), pp.228-235, doi:10.1016/j.jher.2013.05.001.

Syahir Bin Md Din, M., Souma, K., Widyasamratri, H., Suetsugi, T. (2015): Urban heat island simulation over Jakarta, Indonesia, using a cloud resolving model, Proceedings of Japan Society of Civil Engineering Annual Meeting, CS2-017 (DVD).

Tanaka, K., Nakakita, E., and Ikebuchi, S. (1998): Land-surface parameterization in the Lake Biwa Project, Annual Journal of Hydraulic Engineering, Vol. 42, pp.79-84 (in Japanese with English abstract).

Tanaka, K. (2004), Development of the new land surface scheme SiBUC commonly applicable to basin water management and numerical weather prediction model. Ph.D. dissertation, Kyoto University.

Tsuboki, K., and Sakakibara, A. (2002), Large-scale parallel computing of Cloud Resolving Storm Simulator, High Performance Computing. Zima H. P. et al., eds., Springer: Germany. 243–259.

Tsuboki, K., and Sakakibara, A. (2007), Numerical prediction of high-impact weather systems, Seventeenth International Hydrological Program (IHP) Training Course, 246 pp.

Widyasamratri, H. (2014): Analysis of the urban thermal environment associated with socio economic conditions in Jakarta, Indonesia using satellite remote sensing, Doctoral Dissertation, University of Yamanashi, p.70.

Widyasamratri, H., Souma, K., Suetsugi, T., Ishidaira, H., Ichikawa, Y., Kobayashi, H., Inagaki, I., Kakizawa, K. (2014): Heat and dry island observed over Jakarta, Indonesia, in 2012, International Association of Hydrological Sciences Publication, 364, pp.140-144.

Wu, P., Arbain, A. A., Mori, S., Hamada, J., Hattori, M., Syamsudin, F. and Yamanaka, M. D. (2013): The Effects of an Active Phase of the Madden-Julian Oscillation on the Extreme Precipitation Event over Western Java Island in January 2013, SOLA, Vol. 9, 79−83, doi:10.2151/sola.2013-018.