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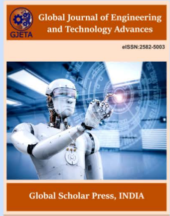

(Research Article)

Tropical convective cloud growth models for hydrometeorological disaster mitigation in Indonesia

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Abstract

Heavy rain in Semarang on 1 January 2020 caused flooding. The existence of heavy rain cannot be separated from the dynamics of weather parameters which are closely related to the convection process and cloud formation. In this paper research has been conducted using Weather Research and Forecasting (WRF), to analyze the growth patterns of convective clouds as an effort to mitigate the initial events of extreme rainfall disasters. Several weather parameters that support cloud growth are very significant, namely the parameter values that support the convection process to form convective clouds (Cumulonimbus). The results of the model show that there has been extreme rainfall which can be used as initial mitigation of hydrometeorological disasters.

Keywords: Heavy Rainfall; Flood Hazard; Cloud Growth; Global Model; Hydrometeorological disasters.

1. Introduction

The Convection activity for the tropics occurs when cloud growth over the oceans is more active than on land, with large variations, as is rainfall. Judging from the dynamics of rain clouds, the Indonesian Maritime Continent receives sensible heat (insolation) and latent heat of condensation due to changes in water vapor in large quantities, so the type of cloud that appears is a convective cloud or cumuliform clouds. The vertical wind shear and the convergence of the lower troposphere are weak, and then the rain in the monsoon area is caused by Cb clouds (cumulonimbus) or cumulus cranes [1, 2]. Cloud dynamics such as the above are very important to study, In terms of dynamics and macrophysics, and microphysics, the cloud growth process is an influential variable for short-term climate predictions. Therefore, the daily rainfall cycle and regional variations are very important to study, especially in tropical areas. This tropical rain involves a massive increase in latent heat evaporation and energy so that the equatorial region becomes a general circulation generator in the atmosphere [3, 4, 5].

The occurrence of rain begins with the process of rising humid air so that it cools down, and then condenses into water droplets which will then gather to form clouds. The gravitational force and updraft on clouds play the most dominant role and cause downward and upward movement. Large grains from the condensation core of the cloud have a relatively higher rate of fall when compared to smaller grains. Due to turbulence in the cloud, these large grains will hit the smaller grains and then combine to get a larger size. This process will take place repeatedly so that the grain size will continue to increase beyond its critical size, where gravity can overcome the updraft and come out like rain clouds [6, 7]. The growth of a cloud until it reaches maturity and becomes rain requires a large amount of condensation core, water vapor, energy. Generally, condensation cores are readily available in large clouds.

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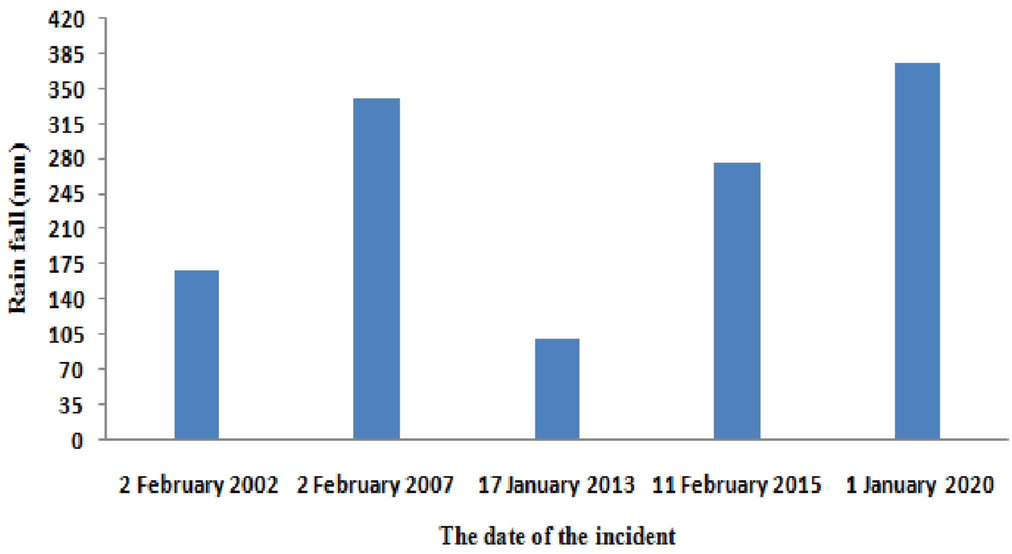

Figure 1 The maximum rainfall for Jakarta Floods for the period 2002 to 2020 [8]

In this paper, a convective cloud growth model has been carried out in Jakarta on 1 January 2020 where on that date is the highest rainfall during the decade 2002 to 2020 with an altitude reaching 377 mm. According to the Meteorology, Climatology and Geophysics Agency, the classification of rain includes light, heavy and extreme rain. Rain with an intensity of more than 50 mm/day is categorized as extreme. The rainfall data, the floods that occurred in Jakarta on 1 January 2020 were floods caused by extreme rainfall with an intensity exceeding the extreme threshold values set by BMKG. Model simulation to perform cloud growth analysis using the WRF numerical weather model, as validation of the model results used Himawari satellite data on 1 January 2020 as shown in Fig. 1, [8].

2. Material and methods

The data used in this study is the Global Forecast System (GFS) data dated 1 January 2020 with a 3-hour temporal resolution and has a spatial resolution of 0.50x0.50 which is downloaded via https: //www.ncdc. The noaa.gov website. / data-access / model-data / model-datasets / global-forecast-system-gfs, TRMM data which has a spatial resolution of 0.25O x 0.25O and a temporal resolution of 3 hours, which will be used to verify rainfall spatially. TRMM data is rainfall forecast data from several satellites orbiting around the tropics.

The rainfall data used is monthly and daily rainfall data sourced from CHIRPS which is obtained through the website https://iridl.ldeo.columbia.edu/SOURCES/.UCSB/.CHIRPS/.v2p0/.monthly/.global/.precipitation/.

The most recent development in research and weather forecasting and which tends to be more observational in terms of dynamics and physical processes of the atmosphere is the WRF (Weather Research Forecast) model, where the WRF model is a multi-institutional effort to develop mesosystem assimilation and forecasting of scale data that are more accurate, efficient and measurable. The WRF model is a development of the latest generation mesoscale data assimilation and forecasting system, which provides more understanding and forecasting of the mesoscale climate change system. In this case, the model will include further data assimilation and classification techniques, at a mesoscale of climate change whose applications have various applications ranging from research to forecasting operations. The operational area required for the model boundary covers a distance of 1 - 10 km in a horizontal direction [9].

The application of the WRF model to dynamic rain cloud analysis in Jakarta, where the WRF model has developed a next-generation model of mesoscale assimilation system forecasting to assist in understanding and forecasting mesoscale rain systems. The WRF model is applied in various problems that include several advantages, among others [10].

- Modeling using vertical coordinates following the field, hydrostatic pressure with a constant pressure surface peak model. The horizontal grid is the Arakawa-C grid.
- The model time integration scheme uses the third-order Runge-Kutta scheme, and the spatial discretization uses the second and sixth-order schemes.

- This model supports ideal and real data applications with a wide choice of lateral and upper boundary conditions.
- Calculation of microphysics (microphysics)
- Parameterization of cumulus clouds (cumulus parameterization).

The data model in the form of final analysis (FNL) data used in this analysis is on 1 January 2020 data taken from NCEP-NCAR which is used as WRF input data [11].

3. Results

In the tropics, most of the rain is generally produced by cumulus clouds. This type of cloud grows due to convection, which is the rise of moist air to a higher altitude when water vapor condenses and changes phase into cloud grains. Small cumulus clouds are 600 - 1500 m high, and cloud tops are 500 - 6000 m high. Convective cumulus clouds can develop into thunder clouds, causing heavy rain, icebergs, lightning, and thunder. This type of cloud is called Cumulonimbus, which is a cloud with a large vertical thickness, and a high cloud top and low cloud top temperature. At the cumulus level, the surrounding air enters through the sides and follows the upward movement of the airflow. The more water vapor that is carried by the air currents upward, the more water vapor condenses into cloud grains and the more raindrops can leave the cloud base and fall to the earth's surface as rain. After the cumulus level ends when the cloud descends most of the time, the cloud will fall into the cloud causing resistance as the air flows downwards and evaporative cooling occurs. Cloud growth continues until it reaches adulthood and finally enters the stage of death. With damage to the upward airflow, the cloud loses its condensing water source so that the cloud cells will eventually die leaving the remaining clouds [12].

The study of cloud dynamics in Indonesia will be carried out based on the application of numerical weather models. Weather Research and Forecasting, which is open-source software developed by the National Center for Atmospheric Research (NCAR) in the United States, is an advanced generation model of the mesoscale numerical weather prediction system designed to serve the prediction of atmospheric research and operational needs. This model features multiple dynamic cores, a 3-dimensional variation data assimilation (3DVAR) system, and a software architecture that enables parallel computing and system extensibility. WWF's are suitable for a wide range of applications ranging from meters to thousands of kilometers [9].

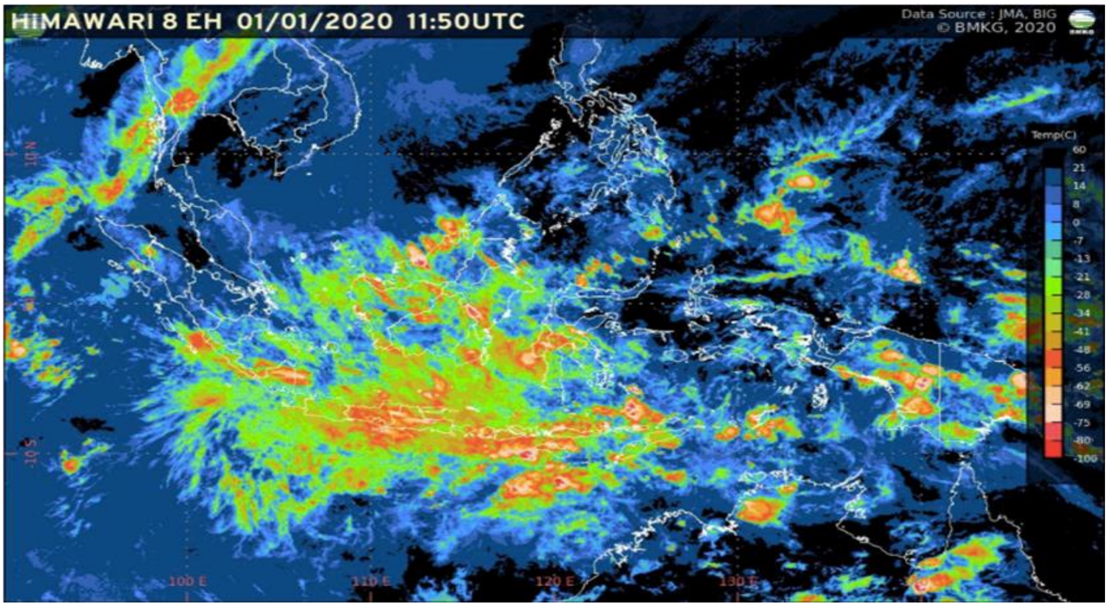

Figure 2 Himawari satellite 1 January 2020 in the Jakarta area [8].

Based on the Himawari satellite data at the time of extreme rainfall, it can be seen that the convective cloud growth pattern is quite massive. As is known, the convective cloud cover for the Jakarta area is shown in Fig. 2, at 11.50 UTC on 1 January 2020.

3.1. Regional Weather Model Analysis (WRF).

To see the cloud growth pattern, QCLOUD calculation is used, namely the calculation of cloud water in the WRF model. From the simulation results of horizontal and vertical cloud cover models (Fig. 3 and Fig. 4), it can be analyzed that the maximum conditions occur according to data from 1 January 2020 as model input data, as can be seen from the convective cloud cover growth pattern.

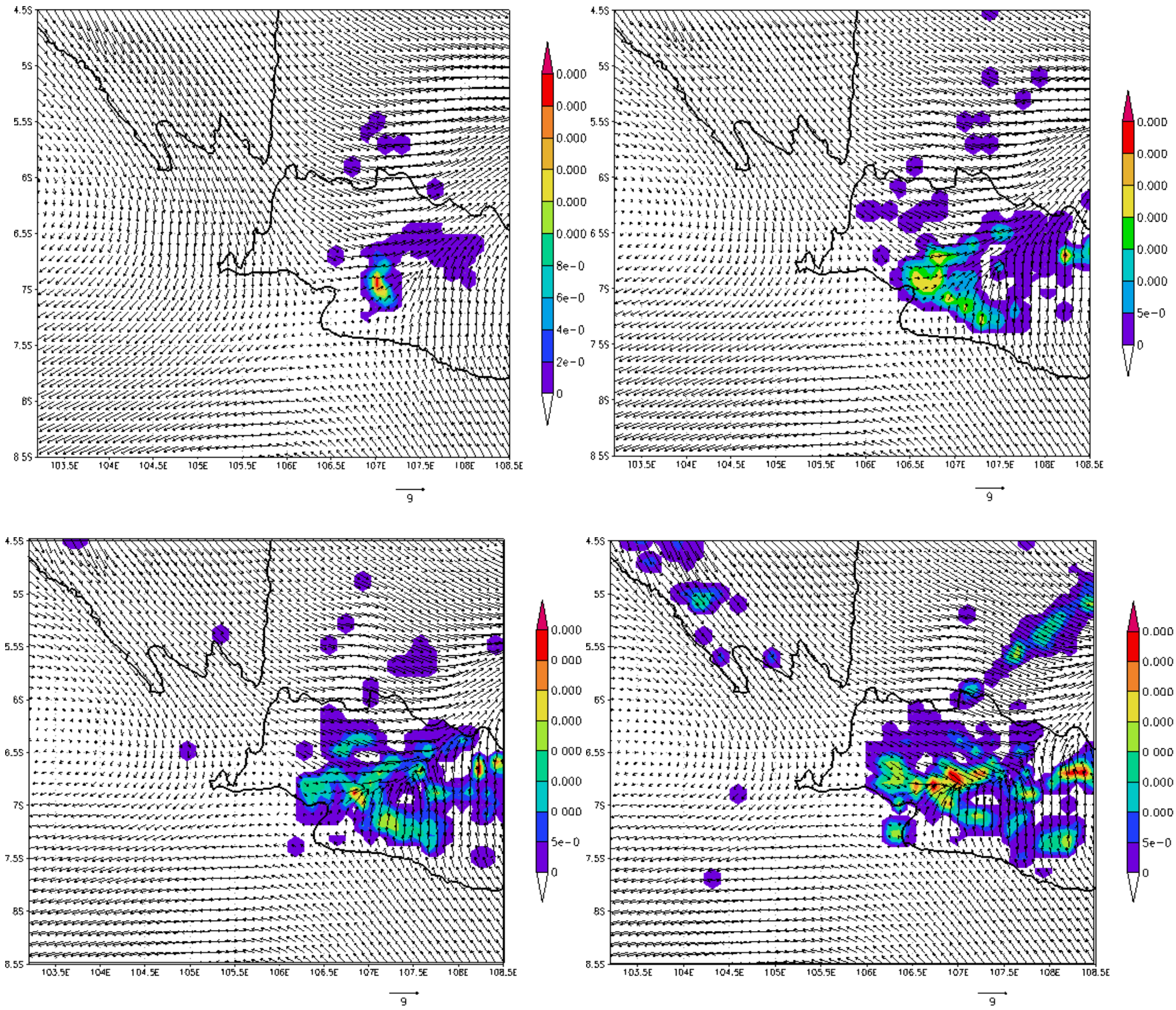

Figure 3 Simulation 3 hours 03.00 - 09.00 UTC Horizontal rain cloud data (kg/kg) on 1 January 2020 the convective cloud growth pattern was seen in the simulation starting at 03.00 UTC which occurred in Jakarta and its surroundings until 18.00UTC.

Convective cloud growth will produce rainfall caused by convection currents due to surface heating by solar radiation, wind convergence, or due to physical forces (updraft) when the wind passes through mountainous areas. Convection rainfall has a higher intensity than stratiform rainfall, occurring on a limited space scale between 10-20 km2 depending on the dimensions of the convection cell itself. In the tropics, convection clouds and convection rain are dominant, for land areas after midday, while for marine areas convection occurs during the day with the help of sea convection at night [13].

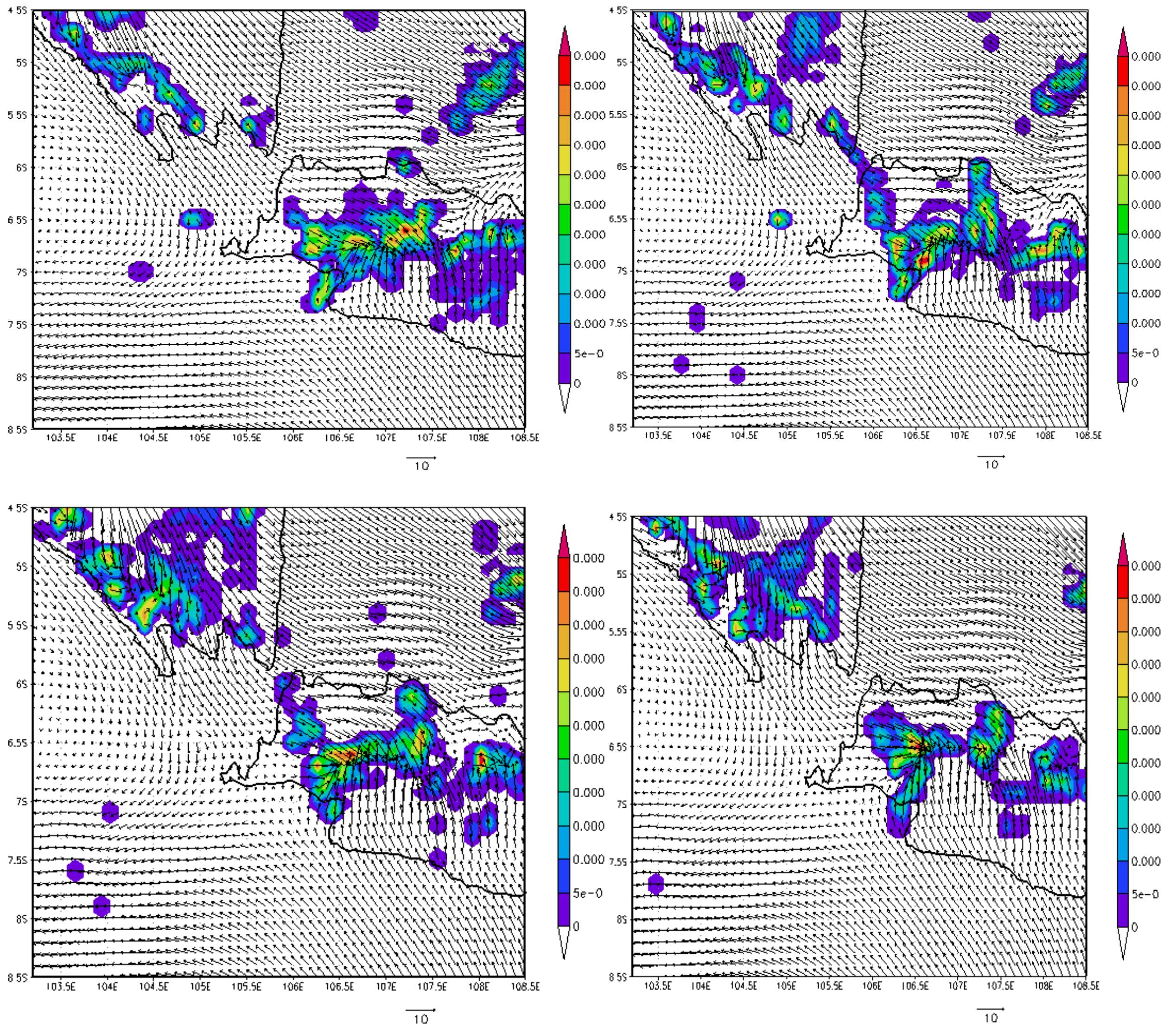

Figure 4 Simulation 3 hours 09.00 - 18.00 UTC Horizontal rain cloud data (kg/kg) on 1 January 2020 the convective cloud growth pattern was seen in the simulation starting at 03.00 UTC which occurred in Jakarta and its surroundings until 18.00UTC.

4. Discussion

Analysis based on cloud simulation results for the Jakarta area and high-intensity rainfall that occurs until dawn, shows that the extreme rainfall for 1 January 2020 is not solely due to thermal convection (convection due to heating during the day). . Another analysis for this is that at night there will be cooling in the mainland of Jakarta which will encourage the development of convection cells above the Jakarta coast which has the potential to produce rain. The stronger the convection current (Fig. 3 and Fig. 4) and the thicker the clouds formed, the greater the intensity of the rain produced.

Judging from the dynamics of rain clouds fluctuations in rainfall in the tropics, especially Jakarta is mostly caused by the Cb cloud. This is because the Indonesian Maritime Continent generally experiences insolation and latent heat due to condensation. Rainfall in tropical areas especially Jakarta is mostly caused by Cb clouds. This is because in general, the Indonesian maritime continent receives sensible heat (insolation) and latent heat due to condensation caused by a large amount of water vapor phase changes. Convective or "cumuliform" clouds occur. If the vertical wind shear and the convergence of the lower troposphere are weak, then the rain in the monsoon is caused by Cb clouds (cumulonimbus) or cumulus cranes. The rain produced by Cb clouds is heavy (rain). Convective rain occurs after maximum sun exposure, usually after midnight. Convective rain starts with heavy rain (rain) when the clouds reach maturity then ends with light rain when the clouds reach a level of dissipation [14, 15].

Effects such as the growth of large cloud nuclei on maritime continents can have important implications for the resulting fluctuations in rainfall. Therefore, the dynamic process of rain clouds is very important to analyze the changes in the resulting rainfall fluctuation patterns. The dynamics of rain clouds in Indonesia, especially Jakarta, are very dependent on changing seasons, in December - January - February, usually, the rainy season starts around the first decade of November. In these months the intertropical convergence zone (ICZ: Intertropical Convergence Zone) and the apparent motion of the sun are above the southern hemisphere so that due to frequent summer there will be depression, storms, or tropical cyclones. The ICZ band and tropical storms cause convergence of humid tropical air masses that will move vertically so that the carried water vapor will change its liquid phase (cloud droplets) through a condensation process [16, 17].

The monsoon wind circulation pattern plays an important role in the formation of zonal winds in Jakarta, both in the form of west winds in the rainy season and east winds in the dry season. According to [18], the difference in seasons is indicated by changes in wind speed. In the dry season, the wind speed is less than 6 ms^{-1} with a very weak meridional component, while in the rainy season the wind speed of more than 6 ms^{-1} is dominant from the north. The large-scale convection during the active monsoon period causes a large variability with wind speed so that the center of convection around Serpong can be affected by horizontal wind variations around 4ms^{-1} while local rainfall is only caused by surrounding disturbances. The intensity of the rain is quite larges, generally, the sky is cloudy so that the resulting rain has a lower intensity than the heavy rain in general. The problems mentioned above indicate the influence of climate changes [19, 20, 21].

Based on statistical data on the occurrence of natural disasters during the period 2000 to 2020, floods occupy the first level of the number of events [22]. Referring to the natural disaster data, it is an obligation and it is necessary for every search for solutions and modeling, cloud growth variables as the main input. For the tropics, research on convective clouds is important.

5. Conclusion

The occurrence of extreme rainfall in Jakarta as above is more caused by anomalous changes in atmospheric dynamics from the growth of convective clouds which simultaneously with orographic clouds can affect the occurrence of extreme rain.

Simulation of cloud dynamics causing flooding in Jakarta in 2020 using the WRF model, as input based on FNL data. The results of the analysis found that there were large convective cloud growth conditions, which resulted in extreme rainfall.

Compliance with ethical standards

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Disclosure of conflict of interest

This research not a conflict of interest.

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