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Study of atmospheric condition during the heavy rain event in Bojonegoro using weather research and forecasting (WRF) model: case study 9 February 2017

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Abstract. During 2016, there are frequent heavy rains in the Bojonegoro region, one of which is rain on 9 February 2016. The occurrence of heavy rainfall can cause the floods that inundate the settlements, rice fields, roads, and public facilities. This makes it important to analyze the atmospheric conditions during the heavy rainfall events in Bojonegoro. One of the analytical methods that can be used is using WRF-Advanced Research WRF (WRF-ARW) model. This study was conducted by comparing the rain analysis from WRF-ARW model with the Himawari-8 satellite imagery. The data used are Final Analysis (FNL) data for the WRF-ARW model and infrared (IR) channel for Himawari-8 satellite imagery. The data are processed into the time-series images and then analyzed descriptively. The meteorological parameters selected to be analyzed are relative humidity, vortices, divergences, air stability index, and precipitation. These parameters are expected to indicate the existence of a convective activity in Bojonegoro during the heavy rainfall event. The Himawari-8 satellite imagery shows that there is a cluster of convective clouds in Bojonegoro during the heavy rainfall event. The lowest value of the cloud top temperature indicates that the cluster of convective clouds is a cluster of Cumulonimbus cloud (CB).

Keywords: heavy rain, WRF-ARW, Himawari-8, convective cloud

1. Introduction

Indonesia is a tropical region that receives enough heat energy from the solar radiation. There are many weather patterns are formed caused by of its convective influence triggered by the heat energy from the solar radiation (Zakir et al., 2010). Indonesia consisted of a larger ocean area than the land. It makes the atmospheric condition over Indonesia region be moist because of the high relative humidity value.
This condition potentially causes the convective cloud growth frequently due to high evaporation in the Indonesian ocean.

Cloud is the atmospheric object that consists of the water drops in the atmosphere. Clouds grow from water vapour condensed by the hygroscopic particles such as salt or dust particles, usually called condensation nuclei. The clouds will grow if the air in each atmospheric level reaches the moist condition in a range of relative humidity value about 60-100%. Convective is a local-scale factor that important in cloud formation process. Convective clouds are clouds that occur due to lifted air over relatively hot surfaces, such as Cumulonimbus clouds and Cumulus clouds (Tjasyono, 2007).

One of the extreme phenomena that frequently occurred in Indonesia region is heavy rain. Bojonegoro is one of the district in East Java Province that located in -7.3175ºS and 111.7615ºE. Administratively, Bojonegoro location is adjacent to Tuban regency in the north, Lamongan regency in the east, Madiun, Nganjuk, and Jombang regencies in the south, Ngawi and Blora regencies (Central Java Province) in the west (Bojonegoro District Government, 2017).

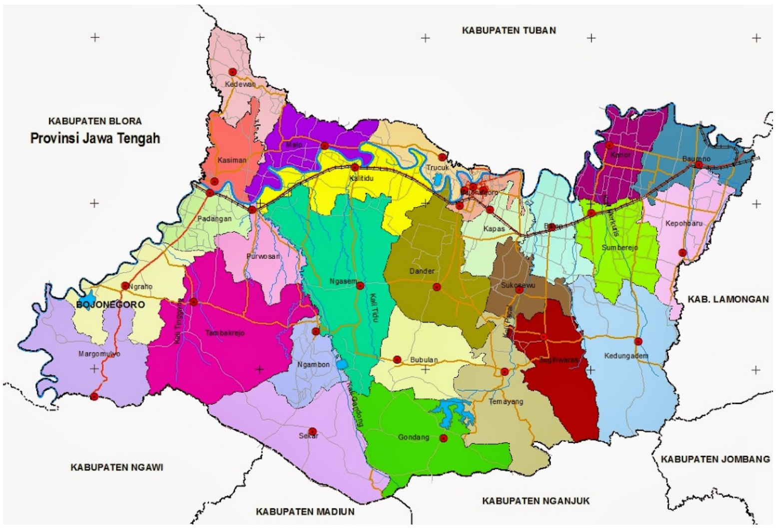

Figure 1. Bojonegoro administrative map (Bojonegoro Disctrict Government, 2017).

Analysing a weather phenomenon or event such as heavy rain requires data of meteorological parameters in the occurrence location or in the area adjacent to the occurrence location. But usually, the necessary data is difficult to obtain considering that there is no meteorological station in the region so the resulting data is not representative. To solve this problem, weather satellite data can serve as an alternative solution (Endarwin, 2012).

Rain can cause a disaster depending on the rain intensity and topography of the affected region. A topographic condition in Bojonegoro is dominated by land with a high slope of the land. So that the occurrence of the heavy rain continuously will cause the disaster such as landslide, floods, etc.

Table 1. Criteria of rainfall intensity over Indonesia region (BMKG, 2010)

Categories	Measured rainfall	
	mm/hour	mm/day
Slight rain	1-5	5-20
Moderate rain	5-10	20-50
Heavy rain	10-20	50-100
Very heavy rain	>20	>100

2. Material and methods

2.1. Research location

The research location is Bojonegoro and its surrounding region. This research location is based on the occurrence of heavy rain in Bojonegoro on 9 February 2016.

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2.2. Research data

2.2.1. Final Analysis (FNL) data. FNL consisted of a global meteorological data in every 6 hours. FNL data is downloaded from https://rda.ucar.edu. The FNL data used in this study are 24-hours FNL data consisted from 00 UTC on 9 February 2016 to 00 UTC on 10 February 2016.

2.2.2. Infrared (IR) channel of Himawari-8 satellite data. This study used the 24-hours Himawari-8 satellite data from 00 UTC to 24 UTC on 9 February 2016. The Himawari-8 satellite data used in this research accessed from Agency of Meteorological, Climatological, and Geophysics (BMKG), Jakarta.

The FNL data processed by using the WRF-ARW model to mapping the local-scale atmospheric condition during heavy rainfall events. The meteorological parameters as the output of WRF-ARW model are plotted by using The Grid Analysis and Display System (GrADS). The meteorological parameters from WRF-ARW model are used to interpret the atmospheric condition that supports the occurrence of heavy rain in Bojonegoro, such as the values of relative humidity, vortices, divergence. Meanwhile, the Himawari-8 satellite data processed by using the Satellite Animation and Interactive Diagnosis (SATAID) GMSLPD. The infrared channel data are used to show the time series and distribution of the value of cloud top temperature during the heavy rain event in Bojonegoro. The Himawari-8 satellite data used to identify the cloud type that caused the heavy rain in Bojonegoro on 9 February 2016.

2.3. Research method

The research method used in this study is the descriptive analysis method of atmospheric condition from WRF-ARW model supported by satellite image output from Himawari-8 satellite imagery. This study used the WRF-ARW model version 3.8.1 that the centre of the model scheme is in -7.3175ºS and 111.7615ºE as the centre of Bojonegoro region. The WRF-ARW model parameterization scheme used in this study detailed in Table 1 below.

Table 2. WRF-ARW model parameterization scheme used in this study

Parameterization	1st Domain	2nd Domain
Centre longitude	111.7615ºE	
Centre latitude	-7.3175ºS	
Horizontal dimension X	100	88
Vertical dimension Y	40	28
Grid-Point Resolution	10km	3.3km
Geographic data resolution	30s	30s
Time step	60	
Microphysics option	WRF Single-Moment 3 scheme	
Longwave radiation option	RRTM scheme	
Shortwave radiation option	Dudhia scheme	
Surface layer option	Monin-Okbuhov Similarity scheme	
Surface option	Noah Land Surface model	
Planetary Boundary Layer option	YSU scheme	
Cumulus option	Kain-Fritsch scheme	

3. Result and discussion

The heavy rain that occurred in Bojonegoro on 9 February 2016 indicates as a phenomenon caused by convective clouds. The convective cloud growth in Bojonegoro supported by the humid atmospheric condition from the surface layer to the upper air layer. The relative humidity value from the WRF-ARW model at 850hPa layer is about 78-84%, the 700hPa layer is about 87-93%, and the 500hPa layer is about 84-90%. The time series of relative humidity values in Bojonegoro on 9 February 2016 shows that the atmospheric condition is relatively wet so that there is much water vapour as the raw material of forming and growth processes of a convective cloud.

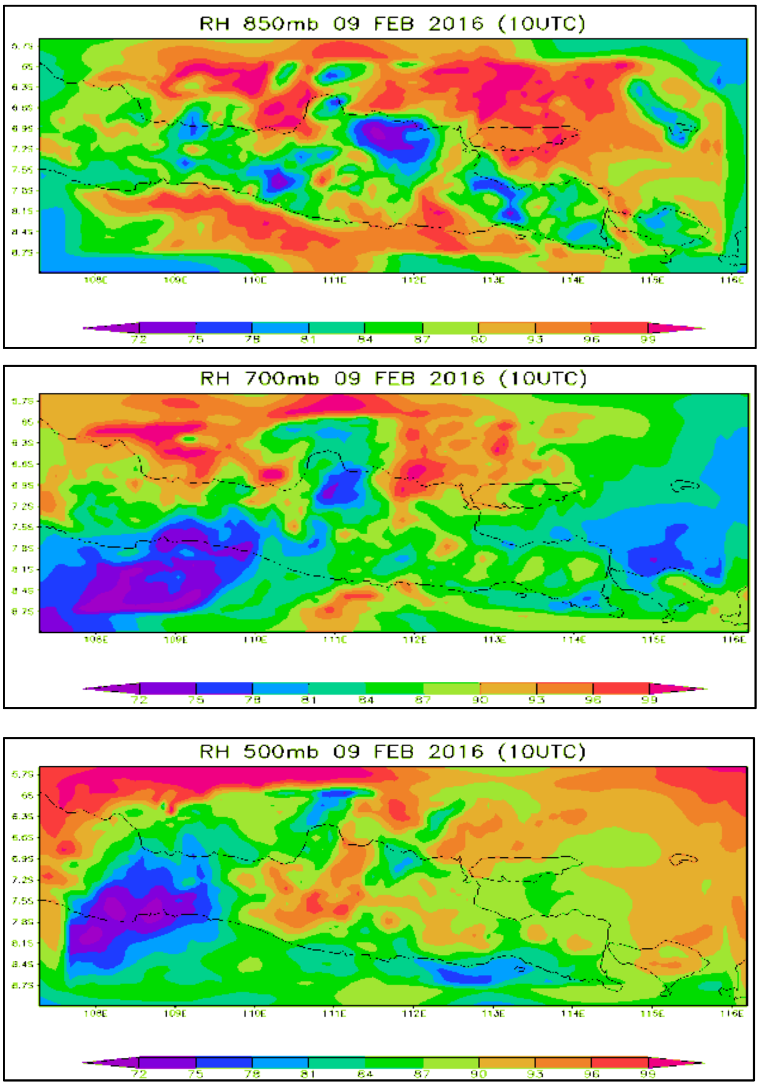

Figure 2. Relative humidity (RH) of 850hPa (top), 700hPa (middle), and 500hPa (bottom) at 10 UTC on 9 February 2016 in Bojonegoro region which obtained from the output of WRF-ARW model

Vorticity is a movement of air mass cyclonically. To support the convective activities, the vorticity value should be negative in the southern hemisphere and positive in the northern hemisphere. The negative vorticity indicates there are the convergence patterns in the atmosphere while the positive vorticity indicates the divergence patterns. The vorticity values from the WRF-ARW model during the heavy rain event in Bojonegoro shows the negative vorticity. It means that there are the convergence patterns in the atmosphere over Bojonegoro as the northern hemisphere. The vorticity in 850hPa layer is about -4/s to -1/s, in 700hPa layer is about -3/s to -2/s, and in 500hPa layer is about -3/s to -1/s. The convergence pattern means that the air masses move to the same point, so generally, in the affected areas of this convergence there are a lot of cloud growth and this condition cause the occurrence of the heavy rain in this region.

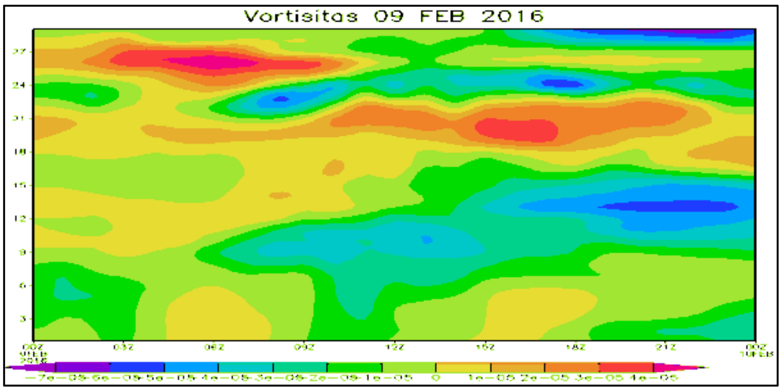

Figure 3. Time series of vorticity values in Bojonegoro on 9 February 2016 which obtained from the output of WRF-ARW model

Divergence is the parameter that indicates the spread of air masses. The WRF-ARW model output show divergence value over Bojonegoro during the heavy rain event is negative. The negative divergence means that the spread pattern of air masses in the atmosphere is convergent. The divergence value in 850hPa layer is about -3/s to -4/s, in 700hPa layers is about -2/s to -1/s, and in 500hPa layer is about -1/s to 0/s. The convergent pattern makes the air mass gathered in an area and there will grow a convective cloud over that region. This shows that in this region there is a convergent movement of air mass gathered into one so that the formation of convective clouds in the region.

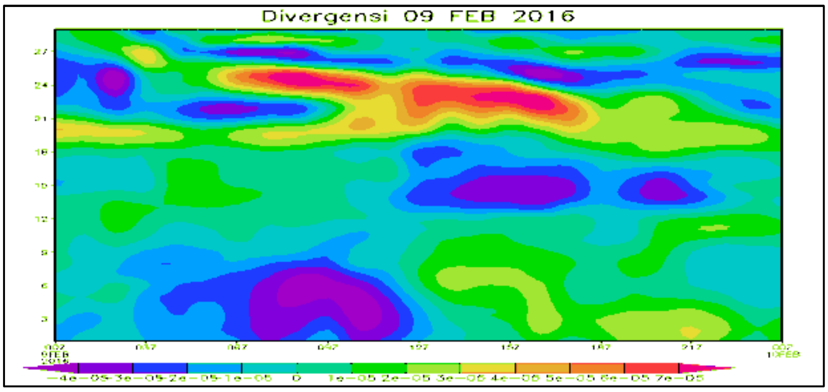

Figure 4. Time series of divergence values in Bojonegoro on 9 February 2016 which obtained from the output of WRF-ARW model

Wind is the movement of the air period in the horizontal direction caused by the difference in air pressure from one place to another. The wind moves from high-pressure area to low-pressure area. Wind speed and direction have an effect on the air mass and cloud movement. The results of WRF-ARW model output for wind at 925hPa layer indicates that the wind moves from west to east at a speed of 2-4kt. Generally, if the wind is blowing hard, then the cloud will move in the direction of the movement of the wind so it is unlikely the rain will fall in the region, but here the wind speed is categorized calm so that will not influence to the cloud movement. This condition causes the convective cloud which formed and growth over Bojonegoro region will stay and potentially caused heavy rain in Bojonegoro.

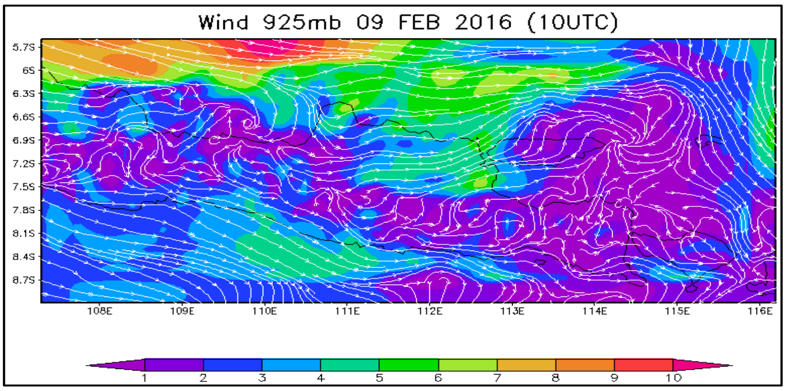

Figure 5. The wind condition in Bojonegoro on 9 February 2016 which obtained from the output of WRF-ARW model

According to BMKG as shown in Table 1, the rain categorized as a very heavy rain is if the measured rainfall more than 20mm/hour or 100mm/day. The rainfall analysis in the Bojonegoro region based on the WRF-ARW model output from 00 UTC to 01 UTC shows that there is a rainfall occurrence exceed 26 mm/hours in that area which indicated by the dark-black area. The rainfall map at 03 UTC to 04 UTC and 06 UTC to 07 UTC shows that the rainfall reach more than 26mm/hour. The heavy rainfall also measured at 09 UTC to 10 UTC. At 12 UTC to 13 UTC, the rain clouds have begun to shift away from Bojonegoro but rainfall continues to exceed 26mm/hour.

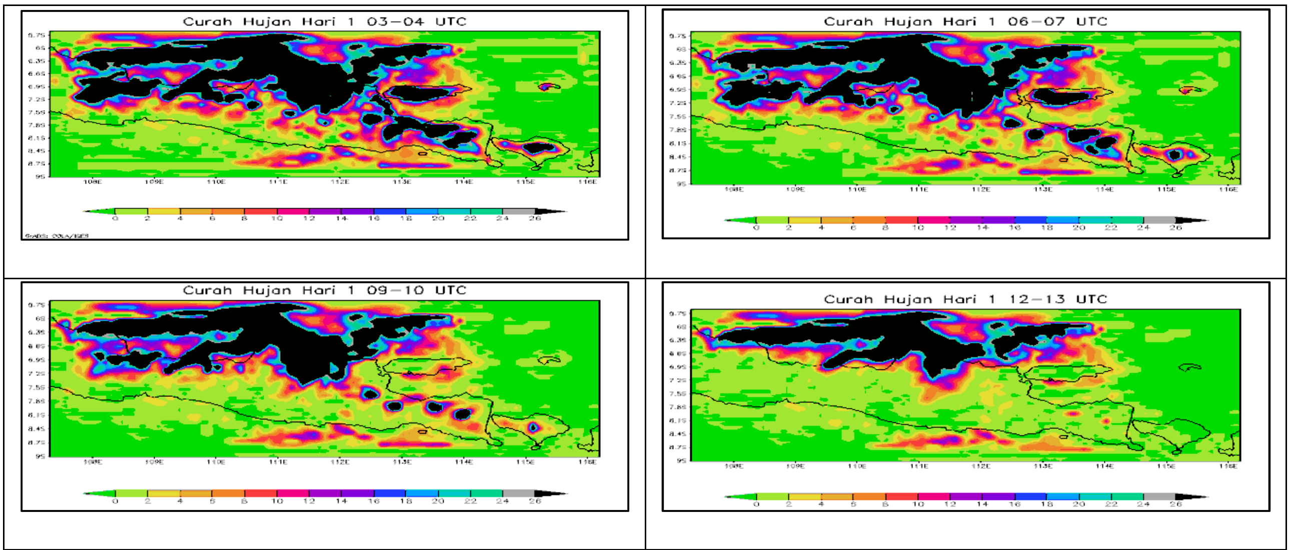

Figure 6. The rainfall map in Bojonegoro on 9 February 2016 which obtained from the output of WRF-ARW model

Cloud is a component that can’t be separated from human life. Cloud is one of the important components in the rain occurrence, especially the convective cloud. Cloud imagery from satellite data can be processed and analysed from GMSLPD. The recent studies usually use the infrared channel of Himawari-8 satellite imagery to identify the cloud type over a region. The heavy rain event that occurred in Bojonegoro can be analysed using Himawari-8 satellite imagery. The result of analyses from satellite image shows that convective cloud growth (cumulus stage) begins at 08 UTC and reach the mature stage at 10 UTC. The satellite imagery shows the bright-white clouds over the Bojonegoro region as the cluster of convective clouds.

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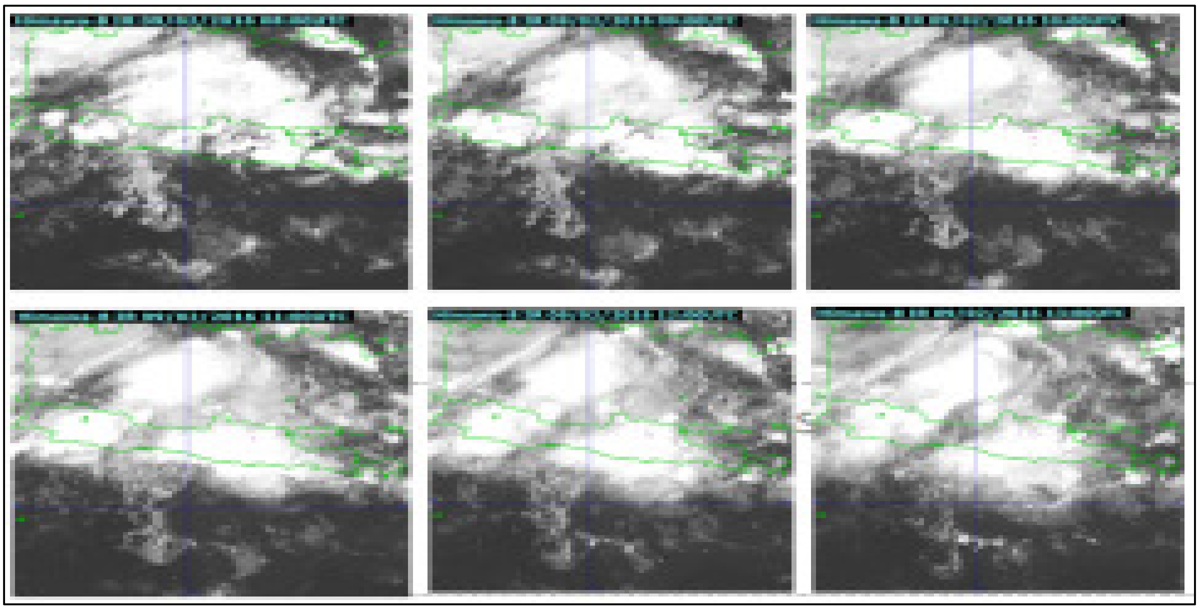

Figure 7. Imageries of infrared channel of Himawari-8 satellite over Bojonegoro region on 9 February 2016 which obtained from SATAID GMSLPD

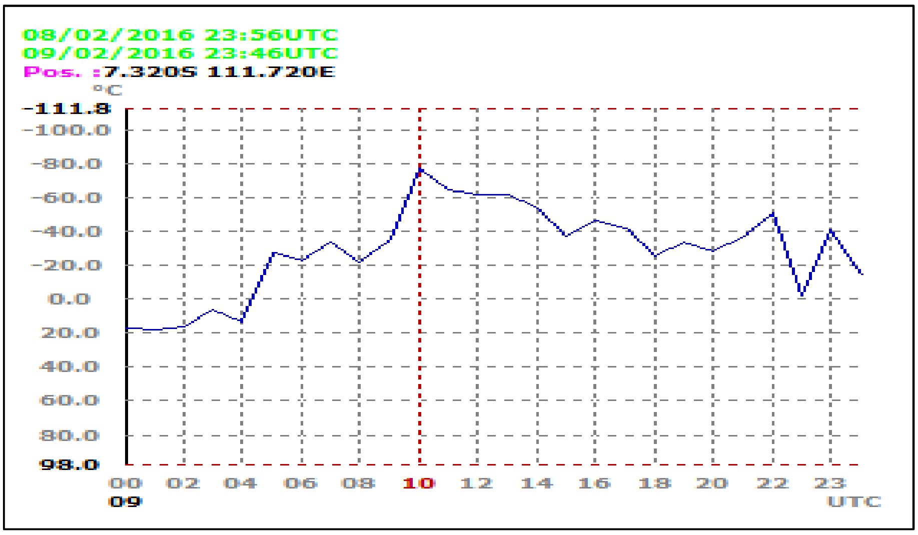

Figure 8. Time series of cloud top temperature over Bojonegoro region (7.320ºS 111.720ºE) on 9 February 2016 which obtained from the output of SATAID GMSLPD

The SATAID GMSLPD not only used to show the images of the clouds but also to show the time series of cloud top temperature over a region. In the previous study, the time series of cloud top temperature used to analyse the change of cloud top temperature and identify the cloud type. The time series of cloud top temperature shows that at 10 UTC the cloud over Bojonegoro region reaches the minimum temperature of -80ºC. This values of cloud top temperature indicate that the cloud is classified as a convective cloud, the Cumulonimbus cloud (CB), and the heavy rain that occurred in Bojonegoro are from this CB. At 12 UTC, the cloud top temperature begins to decrease to -60ºC indicating that the CB has begun to experience to the dissipation stage.

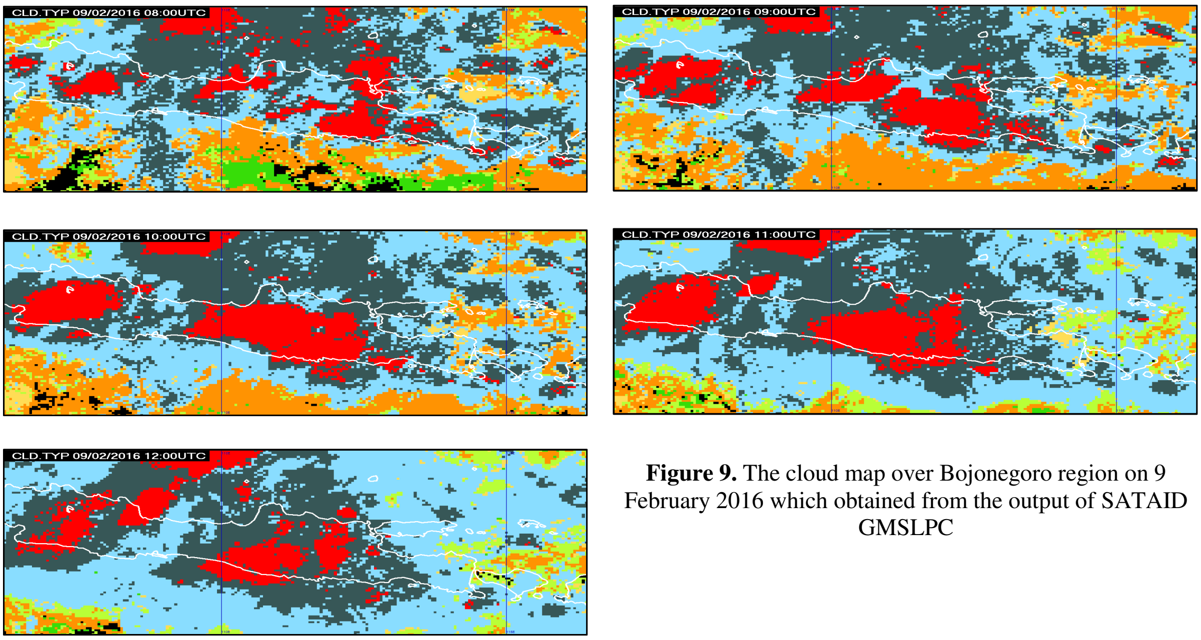

Figure 9. The cloud map over Bojonegoro region on 9 February 2016 which obtained from the output of SATAID GMSLPC

The SATAID GMSLPC is one of the SATAID software used to generate/show the cloud image processed from the Himawari-8 satellite data. The GMSLPC is also able to show the colour of the different cloud type. Based on cloud type identification using GMSLPC output, there is a cluster of convective clouds, categorized as the CB, which move from north to south as the result of wind movement effect. Observed at 10 UTC the cluster of CB entered the Bojonegoro region, indicated by the red colour, and continuously decreased until 12 UTC.

4. Conclusions

The results of this study indicate that there was heavy rain in Bojonegoro on February 9, 2016. The Himawari-8 satellite imagery shows that the heavy rain event came from the Cumulonimbus cloud (CB) over Bojonegoro region. The WRF-ARW model that using the parameter schemes according to the parameterization used in this study relatively can describe the atmospheric condition during that heavy rain event. The selected meteorological parameter such as the relative humidity, vorticity, divergence, and wind indicated the atmospheric condition that supports the convective activities over Bojonegoro region. But, to improve the accuracy in analysing the heavy rain events, a complete WRF-ARW parameterization scheme and the addition of the number of meteorological parameters analysed in some heavy rain events are needed.

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