Using the c-band Doppler weather radar data to reconstruct extreme rainfall event on 11th march 2018 in Bangka island, Indonesia

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Abstract. Extreme weather in the form of heavy rainfall hit Bangka Island, Indonesia on 10 - 11 March 2018 caused flooding in some areas such as in Pangkal Pinang and Muntok in Bangka Barat District, Air Asam Belinuy in Bangka Induk District, and Koba in Bangka Tengah District. Observation of weather conditions at Pangkal Pinang Meteorological Station on 10 March 2018 recorded temperature ranged from 23 to 25°C; relative humidity (RH) ranged from 91 to 100% and measured rainfall reached 84.4 mm/day. In Muntok, the measured rainfall reached 257.5 mm/day which exceeds the March average rainfall 250 mm/month. This study aims to reconstruct this extreme rainfall using C-Band Doppler weather radar centered in Palembang, South Sumatera Province with Python-wradlib library. Weather radar images were displayed in Constant Altitude Plan Position Indicator (CAPPI) and Quantitative Precipitation Estimation (QPE) temporal analysis was performed in areas of extreme rainfall by applying the Marshall-Palmer reflectivity-rain rate (Z-R) relationship. The analysis was conducted by observing the movement and growth of convective clouds through the Palembang radar over Bangka Island and identifying the regional extreme rainfall using Indonesia In-House Radar Integration System (IIRIS) over Sumatra Island. The results suggest that the reconstructed rainfall reached 236.7 mm/day for Muntok, 92.1 mm/day for Pangkal Pinang, 106.0 mm/day for Koba and 80.8 mm/day for Air Asam Belinuy. Although most of the location sites are more than 200 km from the radar center, both of the reconstructed and measured rainfall is well comparable.

1 Introduction

From 10 to 11 March 2018, extreme weather events have occurred in Bangka Island causing flooding in several areas such as Pangkal Pinang, Muntok in Bangka Barat, Air Asam Belinuy in Bangka Induk and Koba in Bangka Tengah District. Extreme weather events in the form of very heavy rainfall flushed Bangka Island since the night of March 10 until the morning of March 11, and then the flood began to inundate some locations reaching a height of 1.5 meters. The flood has caused some significant impacts.

The observation of weather conditions during extreme events occurring in Bangka Island at Pangkal Pinang Meteorological Station on March 10th 2018, recorded temperatures of 23-25°C, relative humidity ranges of 91-100% and measured rainfall reached 84.4 mm/day. In addition, rainfall in Koba Station reached 129 mm/day. The highest rainfall of 257.5 mm/day was measured in Muntok. This rainfall was considered extremely unusual because it exceeded the monthly average rainfall of March which is only about 250 mm/month (BMKG report). In Bangka Island, extreme rainfall occurs very likely due to the topographic contours and geographical location. The previous study showed a similar extreme rainfall event in Padang on June 16\textsuperscript{th} 2016, which was well observed by C-band weather radar in Minangkabau Station [1]. The opportunity for forming convective cloud is one of the possible causes of large area extreme rainfall based on regional and local factors [2].

The limited number of weather surface stations that operates 24 hours in Bangka Island makes extreme weather event is difficult to predict and analyse so that the user of remote sensing data such as weather radar observation is one of the solutions. A radar network in Indonesia containing 41 unit radars can greatly assist the analysis and prediction of convective clouds formation which could lead to extreme weather events. Weather radar is able to detect near real-time weather conditions and has high spatial resolution with radius coverage up to 240 km [3]. Weather radar can be used to provide early warning and analysis of extreme weather phenomena such as heavy rainfall, tornadoes, gusty and wind shear [4].

Extreme rainfall is closely related to the intensity and total measured rainfall and convective cloud movements. Rainfall measurements can be done by two different methods, using rain gauges and weather radar. The rain gauge directly measures the amount of rainfall that falls...
on the surface, while the weather radar estimates the size of the raindrops briefly at a certain distance and altitude. However, quantitative precipitation is not measured directly by radar but is estimated through radar reflectivity-rain rate (Z-R) relationship [5]. Improper Z-R relationships will result in considerable errors in estimation and forecasts of precipitation, although radar calibration has been performed [5].

This study aims to reconstruct the occurrence of extreme rainfall in Bangka Island on 10-11 March 2018 using weather radar data. Unfortunately, the only weather radar located in Pangkal Pinang meteorological station was out of service during that time, so that weather radar in Palembang, South Sumatera Province, were used. In addition, the Indonesia In-House Radar Integration System (IIRIS) is used to analyze the regional extreme rainfall over Sumatera Island. Comparison of the reconstructed and the measured rainfall at the surface are also conducted to investigate the radar performance. The measurement of rainfall on the weather radar is derived from the reflectivity value that we know as Z-R relationship.

2 Material and method

In this study, the Gematronic© C-band Doppler Palembang radar (104.702553 °E, 2.917444 °S and 28.0 meters above ground level) was used to reconstruct the extreme event with the maximum radius of 240 km covering most of Bangka Island (Fig. 1a). Radar data was recorded every 10 minutes in the volumetric format consisting of 4 position planning indicator (PPI) scan angles 0.5°, 1.5°, 2.7°, and 4.2° and each contains a reflectivity value in decibels (dBZ with dBZ = 10 log Z) (Fig. 1b). Radar data is processed using the Python-based open-source library wradlib [6,7]. Wradlib is one of the packages of Python programming languages developed by Postdam University and University of Stuttgart, Germany [8]. Wradlib has been widely used in the processing of weather radar data and its applications. One example of its use is for estimation rainfall from radar data showing good results in the estimation of river flow discharge and simulation of flood events in the Philippines [8,9,10]. Wradlib has an important function in the processing of weather radar data and allows performing Quantitative Precipitation Estimation (QPE) analysis based on weather radar data [1,11].

The reconstruction of extreme rain events from March 10-11, 2018 began with extracting PPI from volumetric weather radar data using wradlib. The extracted PPI was then filtered by clutter removal processes [12], which caused by non-meteorological factors such as the presence of objects on the surface of the earth (mountains, hills, tall buildings) or objects in the air (aircraft, birds, etc.). The attenuation correction was also applied using methods developed in 2009 [13]. After that, Constant Altitude PPI (CAPPI) reflectivity value was calculated from a height of 0.5 km to 10 km with a vertical resolution of 1.0 km. The altitude column maximum CAPPI (CAPPI_MAX) was extracted for each volumetric data. In the end, the radar data was converted into the NetCDF format in Cartesian coordinates [7,12]. In this study, the QPE value was derived from the Z-R relationship from Marshal and Palmer's study (Z = AR^2, A=200, b=1.6) [14].

![Fig. 1](image-url) (a) The Doppler C-band Palembang radar coverage (black solid-line) with the red dash-line box represents the Bangka Island and black symbols indicate the locations of the flood event with black circle is Muntok, black diamond is Air Asam Belinyu, black square is Pangkal Pinang station and black triangle is Koba station. Inner black dashed-line circles represent 50 and 100 km radius. (b) the scan angle strategy of the Palembang BMKG radar.

The weather radar images during the extreme rainfall event over Bangka Island are then analysed by investigating the movement and formation of convective clouds through the Palembang radar. Most of the locations of the flood event are about 200 km from the radar centre. The reconstruction of extreme rainfall event
on Bangka Island was conducted by processing radar data into QPE product and displayed in rainfall accumulation for 24 hours measured at each flood point on Bangka Island and compared with surface measurement data.

3 Results and discussion

Extreme rainfall is strongly associated with strong convective cloud growth. Cumulonimbus cloud (Cb) is a powerful convective cloud type that could cause bad weather. Cb was detected by the radar on 10-11 March 2018 and was the main cause of extreme weather in Bangka Island. Cb (indicated by high reflectivity) moves eastward from the eastern part of Sumatra Island to Bangka Island by the time (almost 12 hours on 10-11 March 2018), as shown in Figure 2.

Fig. 2. The hourly column maximum CAPPI reflectivity product (CAPPIMAX) of BMKG Palembang weather radar indicates MCS moving from Sumatra Island to Bangka Island on March 10, 2018 at 18:00 UTC (March 11, 2018 at 01.00 LT) until March 11 2018 at 05:00 UTC (March 11, 2018 at 12:00 LT).
Based on the cloud’s area and lifespan, this convective clouds system is also called the Mesoscale Convective System (MCS). The MCS phenomenon produces large areas of Cb (hundreds to thousands of km²) with longer lifespans (more than three hours) [15,16]. At this extreme rainfall, the Cb cloud system radius reaches > 100 km with a lifespan of up to > 10 hours in the area around Bangka Island before moving towards the Java Sea.

Figure 2 shows Cb cloud from MCS phenomenon in Sumatera Island had reflectivity values of 55-60 dBZ on March 10th 2018, at 18.00 UTC (11 March 2018 at 01.00 LT) extends to Bangka Island. The greater of reflectivity value indicates the higher the intensity of rainfall. The MCS started to enter Bangka Island on March 10th 2018, at 19:00 UTC (11 March 2018 at 02.00 LT) with Muntok was hit first by Cb clouds with some convective nucleus extends on the southwest coast of Bangka Island (convective nucleus marked with high reflectivity values).

On March 10th 2018, at 21:00 UTC (March 11th 2018, at 01.00 LT), MCS covered most of the entire area of Bangka Island. The reflectivity value reached 55-60 dBZ when MCS was in Bangka Island particularly in Muntok and Bangka Barat District. MCS lasted for 3 hours in Bangka Island and gradually decreased until it disappeared on March 11th 2018, at 05.00 UTC (March 11th 2018, at 12.00 LT). The long-term MCS cover in this region resulted in continuous rainfall causing flooding in areas such as Pangkal Pinang, Muntok, Koba and Air Asam Belinyu.

On the regional scale, heavy rainfall events were monitored through IIRIS BMKG over Sumatera Island (Fig. 3). A large scale of convective clouds was observed in the middle and the southern part of Sumatra Island, particularly in the west coast of Padang and Bengkulu, Barisan mountain range and east coast of Palembang (Fig. 3). Weather radar images were composited from radar Medan, Padang, Bengkulu, Palembang, and Lampung. Before entering Bangka Island (March 10th 2018, at 23:00 LT).

Cb clouds with high reflectivity of 60 dBZ have also been observed in West Sumatera (Padang), Bengkulu, South Sumatera (Palembang) and Lampung regions (Fig. 3a). Six hours later (March 11, 2018 at 05:00 LT), the Cb clouds covered most of Bangka Island as the MCS move eastward. The MCS intensity over West Sumatera and Lampung has been greatly reduced (Fig. 3b). The regional extreme rainfall that occurred on 10-11 March 2018 indicates a larger scale weather disturbance.

The analysis of global and regional weather disturbance on March 10th 2018, shows that the Madden Julian Oscillation (MJO) was in an active (wet) phase (phase 3) with amplitude of 1.2 over western part of Indonesia, the Indian Ocean Dipole Index (IOD) is -0.35, and the Southern Oscillation Index (SOI) is 10.2. The superposition of strong wet phase of MJO, negative IOD index supports weather disturbances that can increase rainfall intensity in the western part of Indonesia. In addition, a positive SOI (> 7) indicates the occurrence of the La Niña phenomenon.

The reconstruction of the accumulation rainfall that hit Bangka Island was done by converting the CAPPIMAX reflectivity product into rainfall intensity (mm/hr). Estimated rainfall rates were derived from the Marshall-Palmer (MP) Z-R relationships \((Z=200R^{1.6})\) for general precipitation. The accumulated rainfall is calculated from March 10, 2018 at 00.00 UTC (07.00 LT) to March, 11th 2018, at 05:20 UTC (12:20 LT). The QPE values derived from estimated rainfall rates can describe the situation at the locations of flood events in Bangka Island. The total QPE at the locations of flood events indicates that rainfall started at different times at each location (Fig. 4). The comparison between the accumulation of one day estimated rainfall (indicated by the red dashed line in Fig. 4) and the measured rainfall by rain gauges at the surface stations on March 11th 2018, at 00:00 UTC (07:00 LT) shows a good agreement. For instance, the estimated rainfall in Pangkal Pinang is 92.1 mm, while the measured rainfall is 84.4 mm/day in Pangkal Pinang Meteorology Station.
Fig. 4. The estimated accumulation rainfall on locations of flood event obtained from the conversion of maximum CAPPI reflectivity from March, 10 2018 at 00:00 UTC (07:00 LT) to March, 11 2018 at 05:20 UTC (12:20 LT) with colored symbols as observation data and a red dashed line indicating 00:00 UTC (07:00 LT) on March 11, 2018.

In addition, the estimated rainfall in Koba is 106.0 mm and Muntok is 236.7 mm, respectively. While, the measured rainfall is 129 mm and 257.5 mm in Koba Climatology Station and Muntok, respectively. In addition, the estimated rainfall in Air Asam Belinyu reached 80.8 mm. These results show that the daily estimated rainfall results are comparable to the observed rainfall by rain gauges at the surface station.

Figure 4 indicates that Muntok were firstly hit by rainfall followed by Air Asam Belinyu three hours later. Four hours later, Pangkal Pinang and Koba were hit by rainfall. Heavy rain is generally hit Bangka Island at above 18:00 UTC on March 10, 2018, but slightly different for Air Asam Belinyu. In Air Asam Belinyu, the rainfall accumulation reached 50 mm in an hour from 05.00 to 06.00 UTC on March 10, 2018. Another very interesting point is shown by the intensity of rainfall in Muntok which the rainfall accumulation from 18:00 UTC on March 10th, 2018, to 00:00 UTC March 11th, 2018, (6 hours) reached 200 mm with an average rainfall intensity of ~33 mm/hr.

4 Conclusion

The reconstruction of extreme rainfall events on 10-11 March, 2018 over Bangka Island using the maximum CAPPI product of Palembang weather radar shows that a convective cloud system, known as the MCS was the main cause of extreme rainfall in Bangka Island, which moves eastward from Sumatera Island to Bangka Island with a reflectivity of 60 dBZ. From the analysis of IRIS BMKG, extreme rainfall was also observed in West Sumatra, Bengkulu, South Sumatra, and Lampung. This regional extreme rainfall was likely due to the regional atmospheric disturbances by superposition of strong wet phase of MJO over the western part of Indonesia, negative IOD, and positive SOI.

The QPE values derived from the Marshall-Palmer Z-R relationship can well reconstruct the extreme rainfall over Bangka Island that caused flood events in several locations. The reconstructed of one-day rainfall on March 11th, 2018, at 00:00 UTC (07:00 LT) reached 80.8 mm in Air Asam Belinyu, 92.1 mm in Pangkal Pinang, 106.0 mm in Koba, and 236.7 mm in Muntok. Meanwhile, the measured rainfall is 84.4 mm/day in Pangkal Pinang Meteorology Station, 129 mm/day in Koba Climatology Station and 257.5 mm/day in Muntok. Although most of the location sites are more than 200 km from the radar center, both of the reconstructed and measured rainfall is well comparable.

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