IDENTIFICATION OF SMALL TORNADO EVENT USING WEATHER RADAR AND HIMAWARI-8 PRODUCTS (CASE STUDY: PUTING BELIUNG EVENT ON NOVEMBER 22, 2018 IN JAKARTA)

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ABSTRACT

Indonesia was shocked by a Puting Beliung or small tornado-like incident on November 22, 2018, in the Jakarta greater area. This incident caused many losses such as facilities damage due to falling trees. In this regard, a study was conducted to identify the hook echo or bow echo patterns in the radar reflectivity products, and mesocyclone patterns in the velocity products as the characteristic of the Puting Beliung event. The study required the Cengkareng C-Band radar data that was processed to produce CMAX, VCUT, and CAPPI (V) at 0.5 km, 1.0 km, and 1.5 km elevations overlaid by HWIND. The CMAX and VCUT radar products were used to identify the cloud structure that caused the event, by observing the highest reflectivity of the event-producing clouds. Next, the CAPPI products were overlaid by HWIND and used to identify the movement of the wind which was suspected to be the initial formation of a Puting Beliung at that location. This event was characterized by the presence of a mesocyclone pattern in the form of wind components and radial velocity. It was observed that there was a wind rotating in the Central Jakarta area which indicated a Puting Beliung in the area. The analysis of radar interpretation was then validated using Himawari-8 satellite imagery to detect the cumulonimbus clouds forming the Puting Beliung which occurred around 08.12 UTC. The cyclone-producing clouds grew rapidly with reflectivity value between 35 - 45 dBZ and wind speed up to 35 knots. Analysis of satellite imagery showed a significant decrease in top cloud temperature associated with formation of Cumulonimbus clouds that generating the Puting Beliung. However, in this case study the Puting Beliung was identified from the mesocyclone pattern of the rotating radial velocity component, but not from the hook echo or bow echo pattern.

Keywords: Puting Beliung, CMAX, VCUT, CAPPI, HWIND, Himawari-8

1. Introduction

Puting beliung is an extreme weather phenomenon that people must be aware of. In Indonesia, most tornadoes have a scale of F0 which is commonly called a *putting beliung* with wind speeds from 19 to 32 m/s [1]. Although this phenomenon lasts briefly, its impact can cause damage and losses large enough to fall victim to life. Based on BNPB (National Board for Disaster Management) data, there were 77 *puting beliung* incidents until November 2018 with total damage to 1801 buildings.

It should be noted that the incidence of *puting beliung* is very different from the strong winds that sometimes many Indonesians still have the wrong perception. A *puting beliung* is often associated with small-scale tornadoes, so this is also reinforced by the definition that a tornado is a column of rapidly rotating air, from cumulonimbus clouds, and is almost always observed as a funnel of clouds or tuba [2]. There are three phases of Cumulonimbus cloud formation, namely the growing phase, the adult phase and the disappearing phase, in the adult phase, there is an up and down flow of air and also a twisting shear current which under certain conditions the wind turbine tube can break through to the earth like an elephant's trunk, causing a tornado [3]. Not all Cumulonimbus clouds cause *puting beliung*, therefore it is necessary to identify the occurrence of the *puting beliung*, whether the wind is a *puting beliung* or not.

The transitional season from the rainy season to the dry season or vice versa is usually marked by sudden changes in weather from hot to rainy that could cause strong winds [4]. The natural factor that most influences the formation of hurricanes are the significant temperature difference between the land and the air surface near the clouds [5]. On tornado events always found convective clouds in the time before the incident, especially Cumulonimbus clouds. Other conditions, which are low air pressure, high humidity, rainfall, land conditions with sloping topography, and land use such as residential areas could also affect the formation of convective clouds and small tornadoes [6].

A tornado can form if several conditions are met, namely the existence of very cold cloud top temperature and the warm surface temperature representing a heat sink region of lower temperature aloft and a heat source of higher temperature in the air at the earth's surface, respectively, enough. surface heating to produce deep convection, the existence of enough water vapor is aloft indicated by high relative humidity, and there is a local anomaly surface wind speed to produce wind shear [7]. Storm clouds that produce tornadoes show higher reflectivity than other clouds, whereas tornadoes are usually represented by the shape of a six or hook shape echo [1]. *Puting Beliung* analysis using radar images observed a typical hook echo pattern with a maximum reflectivity of 50 to 55 dBZ and an interval of 7 kilometers [8].

Hook echo is generally up to several kilometers long and several hundred meters wide, which can be seen from the radar where the hook echo formation was due to a large convective tower extending into the levels of strong vertical wind shear, which produced cyclonic and anticyclonic flows at opposite ends of the tower — the cyclonic flow [9]. The phenomenon of *puting beliung* has been widely studied by several researchers. This study utilizes radar data as the main remote sensing tool for studying the phenomenon of *puting beliung* that occurs. Previous research states that *puting beliung* detection is done by looking at the shear associated with bow echo [10].

In the research of Fadillah using the Landsat 8 OLI image, this imagery is used to create surface air temperature parameters with image processing [11]. In the research of Harsa, the processed satellite image data from BMKG used the SATAID (Satellite Animation and Interactive Diagnosis) application data which can display data from satellite imagery on the Infrared (IR) channel, which is then carried out with qualitative interpretation to determine the position and temperature of the cloud from the current satellite image for the occurrence of the Puting Beliung [12]. While in this research used the Radar products data that validated using the Himawari-8 satellite image that was also processed by using the SATAID application.
Other studies of *puting beliung* present many problems due to their small size, short duration of events, and sometimes not identify in radar images regarding bow echo and hook echo that indicate the occurrence of *puting beliung*, so data and instruments that can be used to detect the characteristics are needed (pattern) a *puting beliung*. One of them is using weather radar to classify *puting beliung* patterns on the radar. This weather radar can provide weather information with high spatial and temporal resolution and with real-time data per 10 minutes. This research was conducted on November 22, 2018, in Jakarta with coordinates 6.1823084° S and 106.766424° E.

Although the *puting beliung* phenomenon in Jakarta does not cause casualties, a comprehensive analysis technique or method is needed to identify the *puting beliung* which occurs in Jakarta, to optimize mitigation efforts. Furthermore, this research is aimed at seeing the existence of a bow echo or hook echo pattern reflectivity on the *puting beliung* phenomenon in the Jakarta area. The method used in this research is the use of weather radar image data and Himawari-8 satellite imagery so that the structure and dynamics of *puting beliung* events can be known.

2. Methods

Data. The data used in this study is radar data from November 22, 2018 from 06.00 to 09.00 UTC, from the C-Band Cengkareng weather radar. The reflectivity is interpreted in CMAX, VCUT and CAPPI products, and the radial velocity in HWIND. Then for the validation of the supporting data used Himawari-8 satellite imagery. The radar data was obtained from the sub-division of weather radar image management of the Agency for Meteorology Climatology and Geophysics. While the satellite image data is obtained from the sub-division weather satellite image management of Agency for Meteorology Climatology and Geophysics.

This study is located in the Central Jakarta area with coordinates 6˚12'46' S and 106˚50'26' E on November 22, 2018, as shown in Figure 1.

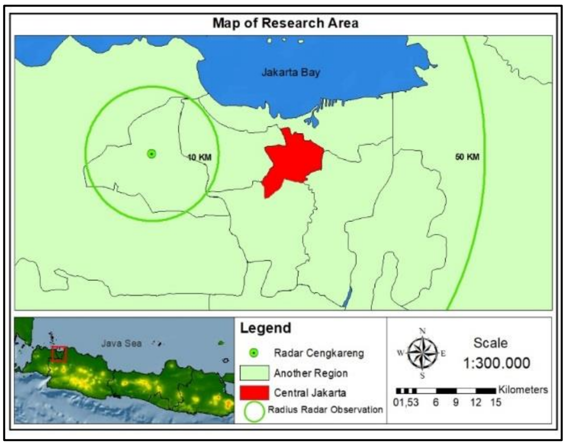


Figure 1. Research area in Central Jakarta

Methods. The method in this study is divided into two main stages, which are analysis of weather radar images and analysis of Himawari-8 satellite images. In this study, the authors used this type of research in the form of a case study that occurred in the Central Jakarta area when heavy rain and strong winds occurred which caused damage to several buildings and vehicles due to fallen trees on November 22, 2018. Radar (Radio Detecting and Ranging) which means radio distance detection and measurement is an active remote sensing tool. The radar will detect the presence of an object and measure the strength of the reflectivity of the object depending on the component size and mass [13].

Radar can provide data with good spatial and temporal resolution. Using the Rainbow software to process the Cengkareng C-Band weather radar data which has previously been converted. The data extensions originally were in the form of HDF which is processed using an HDF converter so that radar data is obtained in the form of dBZ, V, and W extensions which will produce a product with the following: CMAX (Column Max) which displays the maximum value of data, VCUT (Vertical Cut) product that used to display the results of radar images in a cross-section. Its purpose is to see how the data profile of clouds or other objects in the atmosphere vertically. CAPPI (Constant Altitude Plan Position Indicator) is a product with a horizontal slice through the atmosphere therefore a scan of the volume of the PPI at several elevation angles is required. HWIND (Horizontal Wind) product is a derivative product of CAPPI which shows the value of the horizontal wind direction in each layer according to what we want. This product is very helpful in analysing radial velocity.

The second step is to make comparisons between the results of the analysis using the weather radar image with the results from the satellite image which is then processed using Satellite Animation and Interactive Diagnosis (SATAID). SATAID is an application for displaying binary data from satellites into images developed as a contribution to the Japan Meteorological Agency (JMA) to the World Meteorological Organization (WMO) [12].

The use of visible channels to detect the presence of Cumulonimbus clouds during the day. Cool temperatures do not always indicate convective cloud tops but can also be indicated by high clouds such as Cirrus which are composed of ice crystals. Visible channels that use sunlight as pulses make albedo a method for determining cloud types. Albedo is the ratio between the amount of light reflected and received by the surface [14]. Objects that are whiter and denser in colour will reflect more visible light.

3. Result and Discussion

From the radar image of the CMAX product at 07.48 UTC the cloud beginning to form into the growing phase, it shows that the maximum reflectivity value reaches 45-60 dBZ. At 07.48 UTC, the core of the Cumulonimbus cloud cell is above the research domain area. This is indicated by the highest reflectivity values gathered in the region with a maximum reflectivity value of 50-60 dBZ. In the cross-section results, we can find multi-level signs of the Weak Echo Region (WER) this feature is part of some convective cell formation [15] in Figure 3. (a) which shows the change in reflectivity in the lower layer concave area. A radar echo that has a low reflectivity value is limited by a higher radar echo on one side indicating that there is a strong updraft in the area. A strong updraft will cause a strong downdraft resulting in a destructive wind phenomenon.

Radar Images (CMAX Product Analysis)

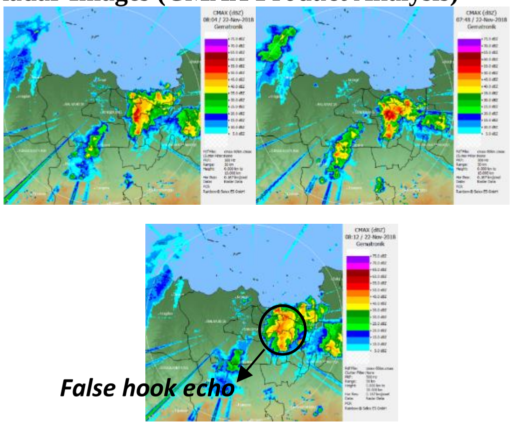


Figure 2. CMAX reflectivity at 07.48 UTC, 08.04 UTC, and 08.12 UTC in a row from left to right

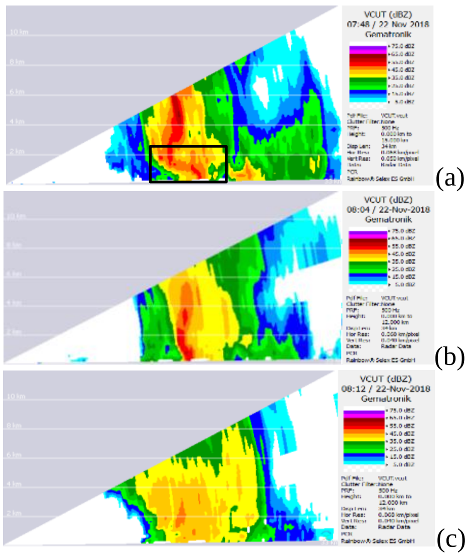


Figure 3. VCUT reflectivity at 07.48 UTC (a), 08.04 UTC (b), and 08.12 UTC (c)

Then at 08.04 UTC the cloud entered the mature phase, it was seen that the Cumulonimbus cell nucleus was spreading, indicating a very strong downdraft process, as indicated by the VCUT cross-section (Figure 3. b) which shows the maximum reflectivity value in the lower layer of the Cumulonimbus cloud. From the VCUT product display at 07.48 and 08.04 UTC, the highest average dBZ value is 50-60 dBZ which is located at an altitude of about 2 to 6 km from the ground. The height of the cloud cells that reaches an altitude of 9 km indicates that there are Cumulonimbus clouds in the area which are closely related to the process of a *puting beliung* during the growing phase of the Cumulonimbus cloud [1].

Meanwhile, at 08.12 UTC, the Cumulonimbus cloud cells were seen to be increasingly spreading and fragmented, indicating that the dissipation phase had begun. At 08.12 UTC, (Figure 2) a pattern that resembles a hook echo was seen near the research domain. However, the pattern of the echo is too large, and when viewed from its growth, the echo appears not from an evolutionary process so it cannot be determined as a hook echo pattern. The hook echo pattern is formed due to the evolution of clouds caused by wind rotation, not because of a collision between cloud cells [8], so the echo was identified as a false hook echo.

The CAPPI V product image at 08.12 UTC shows an intersection between two velocity values in opposite directions at an altitude of 1.0 km with an outbound value reaching 3 to 5 m/s and inbound values (-1) to (-6) m/s. This shows the movement of objects away from and closer to the radar and indicates that there is a swirling wind pattern in the area which is thought to be a mesocyclone pattern. The couplets of opposing velocity points towards the radar and away from the radar indicate the presence of the beginning appearance of a tornado [16].

The mesocyclone pattern is shown by the wind barb of the HWIND product at 07.48 UTC, 08.04 UTC, and 08.12 UTC at an altitude of 1 km shows the wind blowing with a rotating motion with a speed of 15 to 30 knots over the Central Jakarta area. Then the area is almost parallel to the center of the radar so that the detected wind speed is almost closer to the original and further strengthens the indication of a *puting beliung* event in the area.

Satellite Images. To support the results of radar analysis, in this study the results of HIMAWARI-8 Satellite Imagery are used. In processing the image, HIMAWARI is processed using SATAID (Satellite Animation and Interactive Diagnosis) software. SATAID is software used for visualization and manipulation of satellite image data, NWP (Numerical Weather Prediction), observations, and data [12]. Based on HIMAWARI-8 IR image data on November 22, 2018, at 07.37 UTC, convective clouds began to grow around the Jakarta area with a cloud peak temperature of (-55)°C. At 08.17 UTC, the Cumulonimbus cloud was growing, marked by the top cloud temperature reaching (-75) ° C.

(CAPPI V Overlay HWIND Data Analysis)

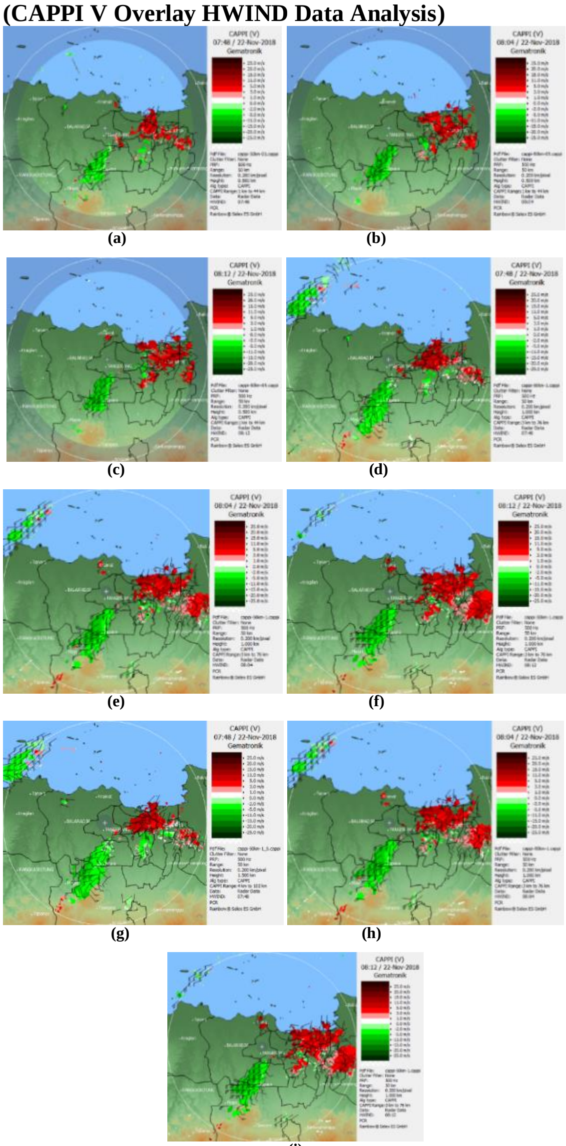


Figure 4. CAPPI V overlay HWIND elevation 0.5 km (a, b, c), 1.0 km (d, e, f), and 1.5 km (g, h, i) in a row from left to right at 07.48 UTC, 08.04 UTC, dan 08.12 UTC

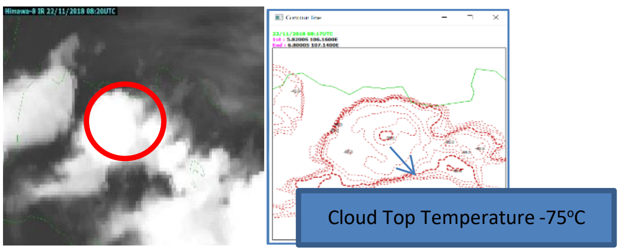
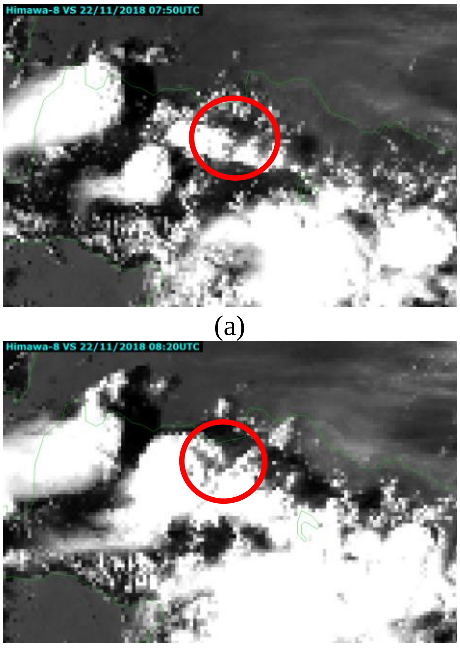


Figure 6. HIMAWARI-8 IR satellite images at 08.20 UTC

Figure 7. Time series HIMAWARI-8 IR satellite image 06.00 UTC to 09.00 UTC



(a)

(b)

Figure 8. HIMAWARI-8 VIS satellite images (a) 07.50 UTC and (b) 08.20 UTC

The time series of HIMAWARI-8 satellite imagery shows that the temperature change of the cloud tops has decreased significantly reaching (-75) °C at 08.17 UTC. This very significant drop in cloud top temperature indicates the formation of convective clouds in the form of Cumulonimbus clouds. The temperature rose slightly at 08.27 which is a sign that Cumulonimbus has entered the decay phase. Based on the results obtained, the *puting beliung* phenomenon can occur in the time range 07.37 UTC to 08.17 UTC because the process of the *puting beliung* is closely related to the growth and maturity phase of the Cumulonimbus cloud.

The Visible image from HIMAWARI-8 shows the presence of Cumulonimbus clouds which are identified by the texture of the cloud tops which are uneven or bumpy and erratic. This texture can be observed easily when sunlight slants down the cloud surface which becomes visible at 07.50 UTC. The texture of the cloud tops becomes more apparent as the cloud top height increases at 08.20 UTC which is indicated by a shadow above the lower cloud tops.

4. Conclusion

Based on the analysis of the radar image and the satellite image that has been done, it can be concluded several things including the following. Puting Beliung events in Jakarta are not shown from the hook or bow echo pattern. No hook echo was found on CMAX products, but from the mesocyclone pattern of wind rotations which is observed in radial velocity. While the presence of a hook or bow echo pattern itself is too difficult to observe, because Puting Beliung must be formed by a rotating wind that extends from the Cumulonimbus cloud. However, it can be interpreted that there was a false hook echo at 08.12 UTC, due to wind gusts from the Southwest. From the mesocyclone pattern in the form of wind components and radial velocity, it was suspected that there was a wind rotating in the Central Jakarta area which indicated a puting beliung in the area. Then based on the time series of the HIMAWARI-8 satellite image, it has been shown that the temperature of the cloud top has decreased significantly and reached (-75) ^{0}C at 08.17 UTC which indicated the presence of Cumulonimbus clouds in mature phase which was closely related to the puting beliung event. From the case study of the Puting Beliung in Jakarta on November 22, 2018, it can be seen that the Puting Beliung occurred when the Cumulonimbus cloud is in the transition stage of growth to mature phase, which indicated from the lowest cloud top temperature then supported by the pattern of mesocyclone or horizontal wind rotation in the cloud. But further research is still needed regarding the exact cause of the emergence of Puting Beliung so that in the future early warning can be published to prevent the fall of the victim due to a tornado phenomenon.

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