

IDENTIFYING PRECURSOR CONDITION FOR “PUTING BELIUNG” EVENT IN PANGKALPINANG

IDENTIFIKASI KONDISI AWAL PERISTIWA PUTING BELIUNG DI PANGKALPINANG

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ABSTRAK

Tulisan ini membahas upaya untuk mengidentifikasi kondisi awal kejadian puting beliung atau kejadian seperti tornado yang terjadi di kota Pangkalpinang pada 9 Januari 2008. Analisis telah dilakukan berdasarkan pada asumsi teori dynamic pipe effect tornado genesis. Beberapa data yang diperoleh dari pengamatan permukaan serta data citra satelit digunakan untuk mengidentifikasi sinyal kehadiran puting beliung. Hasil analisis menunjukkan bahwa peristiwa puting beliung dipicu oleh adanya angin geser pada ketinggian rendah yang didukung oleh kondisi permukaan yang kondusif seperti adanya uap air yang cukup tinggi ditunjukkan dengan kelembapan udara yang relatif tinggi, pemanasan permukaan cukup yang dilanjutkan dengan pendinginan cepat di atmosfer yang menghasilkan konveksi skala luas, serta adanya inisiasi anomali lokal kecepatan angin permukaan yang menghasilkan geser angin. Prekursor yang diungkap dalam kajian ini adalah meningkatnya kelembapan relatif dengan cepat satu jam sebelum kejadian, bersama dengan penurunan yang cepat pada suhu dan munculnya anomali “tanduk” tekanan.

Kata kunci: *Puting beliung, Pangkalpinang, Aliran konveksi, Geser angin, Prekursor*

ABSTRACT

This paper discusses an effort to identify the precursor condition for “puting beliung” or tornado-like event which was occurred in Pangkalpinang town on January 9, 2008. The analyses has been done based on the dynamic pipe effect of tornado genesis theory. Several data obtained from surface observation as well as the advantage of satellite data image were used to identify signal of presence of puting beliung. The result indicates that the puting beliung event was triggered by the presence of low level wind shear which was supported by favorable surface condition such as the existing of enough water vapor aloft indicated by high relative humidity, enough surface heating to initiate a rapid cooling of the atmosphere to produce deep convection, and there is an initiation of a local anomaly surface wind speed to produce low level wind shear. Revealed surface precursor for puting beliung in Pangkalpinang are the rapid increasing the relative humidity one hour in advance, together with rapid drop in temperature and the presence of “horn-like” pressure anomaly.

Keywords: *Puting beliung, Tornado, Pangkalpinang, Deep convection, Low level wind shear, Precursor*

INTRODUCTION

On January 9, 2008, a severe *puting beliung* hit the dense settlement in Pangkalpinang town, destroying 282 houses and infrastructure, and causing one casualty. Social office of Pangkalpinang, stated that the damaged infrastructure included the vital public facility such as Bakti Timah Hospital. The resident reported “there was suddenly a voice like the sound of kazoos, the bed shaking and a moment later came the falling tile, household furnishings override. Heavy rain ran down the home that is off the roof-tiled”.¹

Puting beliung which has happened in Pangkalpinang is well known local terminology used in Indonesia for whirly wind or tornado or even for misguided perception for wind gust or wind storm phenomena. *Puting beliung* event has often been published by media but there was no scientific proof yet describing the physical processes or its mechanisms. The problem is that either media or people use the term of “*puting beliung*” to mention both of wind gust (a short burst of high speed wind, what we so called as “*angin kencang*”) and tornado-like (a destructive wind storm occurring on land preceded by a thunderstorm and a wall cloud, which is, the most appropriate with definition of “*angin ribut*” or “*puting beliung*”). However, meteorologists define the two phenomena in two different descriptions. Windstorm is defined as a storm marked by high wind with little or no precipitation, while a tornado is described as the most destructive of storms and its appearance is that of a dark, funnel-shaped cyclone.²

Pangkalpinang town is situated geographically at 2°8' South Latitude, 106°8' East Longitude and is the capital of Bangka Belitung Province. The province of Bangka Belitung is located between 104°50'–109°30' East Longitude and 0°50'–4°10' South Latitude, with its total area of 81,724.54 km². Accordingly, this province is figured by mostly plane area with scattered valley and hilly area under 1,000 meters. The region is bordered by Bangka Strait in the west, Karimata Strait in the east, the South China Sea is to the north, and the Java Sea is to the south (Figure 1). Climatologically, Bangka is classified as tropical climate influenced by monsoon circulation with the heaviest rainfall is around 2,500 mm per annum and its average temperature between 25–26°C.³ In addition, Bangka-Belitung has very dynamic weather due to the abundant of water vapor sourced from evaporation since it is surrounded by sea water.

The aim of this research is to investigate the condition which has triggered *puting beliung* occurred on January 9, 2008 in Pangkalpinang. The candidate precursor such as air temperature, surface pressure, relative humidity, cloud condition, and wind profile is examined due to its rapid changes in prior *puting beliung* event or its evolution in diurnal variation.

Since we used the tornado-like as the appropriate definition for describing the *puting beliung* event, we look at tornado genesis theory to approach or to describe this *puting beliung* event. Tornado is a small-scale (microscale) structure, less than one mile wide and, in most cases, less

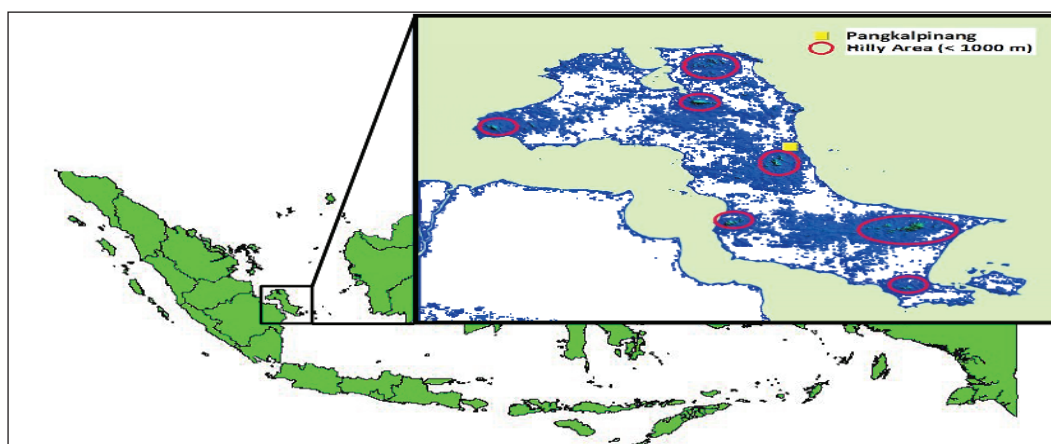


Figure 1. The area of interest in Indonesian map which is described in this paper. Insert: the geographical situation of Bangka Island

than half mile wide, short-lived and rarely last no longer than half an hour. Because of the small size, short longevity, very dangerous winds and unpredictable, tornadoes are more poorly understood than any atmospheric phenomenon. However, there are some viable approaches to obtain a better understanding of tornadoes. These include field study, analytical solution of the relevant equation, numerical modeling and laboratory simulation.⁴ Tornadoes, waterspouts and dust devils are sometimes considered to be atmospheric heat engines, transforming heat energy difference (dQ , dT) between a heat source of higher temperature in the air on the earth's surface and a heat sink region of lower temperature aloft, into kinetic energy and into wind flow v and work W .⁵

The large scale characteristic of tornado is classified into four type: The first one is an extremely strong swirling ground level wind speeds ranging from about 75 mph or about 34 ms^{-1} (Fujita scale, F1), up to over 224 mph (100 ms^{-1}) in severe tornadoes (F4), and up to 300 mph (134 ms^{-1}) in super cell storms (F5). The second is the visible, rope-like funnel of the tornado or "twister", is not the entire swirl of wind, but is only the condensed cloud of water droplets which forms when the air in the whirl has expanded and cooled in the lower pressure which prevails towards the center of the funnel until the relative humidity has reached 100%. The third type is the visible funnel cloud emerges from the base of a storm cloud at a height of typically around one or two thousand meters, and the funnel then extends lower and lower towards the earth's surface. And the fourth one is the general air mass in which the

storm is always very convectively unstable with warm moist air at the ground and cool air aloft.

The tornado type which often strikes in some region in Indonesia is the third type, and often called as *puting beliung*. However, it is still difficult to find a scientific description based on physical analysis about tornado in Indonesia. Literally, there are several theories explaining the initiation process of tornado. Those theories are: rear-flank downdraft (RFD theory),⁶ baroclinic processes theory,⁷ advection of shear vortices (ASV theory),⁸ rear inflow jets (RIJ theory),⁹ book-end vortex (BEV theory),¹⁰ the dynamic pipe effect (DPE theory),¹¹ and boundaries and buoyancy (BB theory).¹²

In this paper, only tornado genesis based on the dynamic pipe effect theory (DPE) will be explored and examined. This theory also adopted by NOAA in their guidance of tornado disaster. The DPE theory describes that tornado is developed under three stages¹³ as shown in Figure 2. The first stage is the condition before thunderstorms developed. The indication for this stage is the change in wind direction and an increase in wind speed with increasing height which created an invisible, horizontal spinning effect in the lower atmosphere due to horizontal vorticity (Figure 2a). The first stage is followed by the second, which is indicated by the rising air within the thunderstorm updraft which tilts the rotating air from horizontal to vertical (Figure 2b). The third stage is the manifestation of an area of rotation, 2-6 miles wide, which then extends through much of the storm (Figure 2c).

Based on this theory, it is proposed that the surface vertical wind shear and intensive convec-

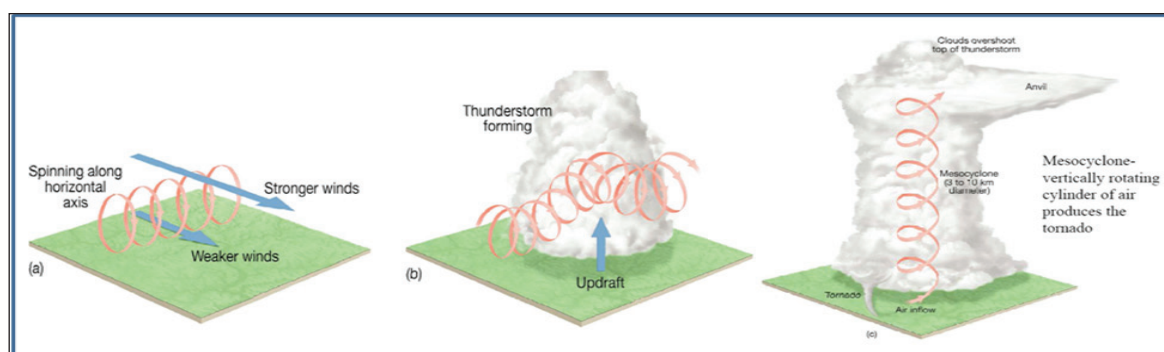


Figure 2. The development of a tornado based on DPE tornado-genesis theory. (a) before development, (b) thunderstorm forming, and (c) a mature tornado. ¹³

tion are responsible as a trigger or a precursor for developing tornado. However, the rotation area of a *puting beliung* is far too small compared to the real tornado as in America. However, the physical mechanism for both phenomenon is similar.

In America, the vast majority of tornadoes occur in the Tornado Alley region, although they can occur nearly anywhere in North America. Tornado also occasionally occurs in south-central Asia, like Malaysia, Philippines, Indonesia, etc. In the recent climate, some scholars suggest that an increase in the sea surface temperature of a source region due to global warming increases atmospheric moisture content, and therefore, can fuel an increase in severe weather and tornado activity. However, any such effect is not yet identifiable due to the complexity, local nature of storms, and database quality issues. Some evidence suggest that the ENSO (El Nino or La Nina) is weakly correlated with changes in tornado activity. Ashton and Schaefer from NOAA/NWS Storm Prediction Center imply that ENSO induces preferred patterns for organized tornado activity, like other climate related weather patterns, only set the background state for tornado activity. In any particular situation, meteorological forces may interact in such way as to cause organized tornadoes to occur in atypical places.¹⁴

Indonesia, as a tropical country and its maritime-continent feature, has potentially intensive convection due to abundant water vapor, which can be a suited pre-condition for this phenomenon. Additionally, the air-sea-land local circulation which is interacting with regional circulation may also potentially triggers surface vertical wind shear. Thus, the identification of surface vertical wind shear is the crucial point on investigating a tornado. In order to analyze this aspect spatially, upper air data is important to figure out the condition of the stratified atmosphere. Unfortunately, upper air observation networks in Indonesia is not enough to cover its wide region. However, the case of tornado in Pangkalpinang on January 9, 2008 offers the opportunity to examine this theory, since the Pangkalpinang weather station observes the upper air twice per day includes hourly surface observation.

METHOD

In order to achieve the aim of this research, we used observational data as well as information from local residents. The information is gathered by interviewing people who saw *puting beliung* manifestation directly and about weather condition before and during tornado event. As the *puting beliung* event crossed the dense settlement, many people experienced this phenomenon. Unfortunately, no one documented the appearance of the whirly wind event, and therefore, we cannot visualize the figure of that event here.

Observational data includes relevant surface meteorological parameters or such an atmospheric observation using radio sonde or satellite meteorology data from the daily record support meteorologist to identify favorable environment for tornado development. Daily observed rainfall accumulation, surface air temperature, relative humidity and visual observation of cloud type which have been analyzed in this research are obtained from BMKG's Pangkalpinang Weather Station.

We expect to point out a brief condition supporting intensive convection processes. In order to localize storm cloud, MTSAT satellite image data is analyzed by using SATAID software¹⁵ to identify the minimum temperature of the top of the cloud and to identify the peak time of the cloud development. The analysis using SATAID derived from satellite image has also been done to extract the temperature data converted from brightness value of satellite images. Furthermore, we used a vertical wind data derived from atmospheric sounding measurement to recognize potential vertical wind shear which is hypothesized as a trigger in tornado development event based on DPE tornado-genesis theory. The vertical wind profile is obtained from morning upper air observation (07.00 Local Time) from Pangkalpinang Weather Station and has been analyzed by using RAOB 5.7 software.¹⁶

RESULT AND DISCUSSION

Society Perception

Some residents revealed that they saw a funnel form emerging from a black-massive cloud. This confirms that a tornado had been developed

perfectly. The tip of funnel touches down the ground and flies some light object whirly to the air. Based on their explanation, tornado was formed about 5–10 minutes before a heavy rain occurred. In fact, this tornado had crossed some villages which then damaged 282 houses (Figure 3a) and caused 1 casualty. Some trees were also fallen due to its strong wind (Figure 3b). The tornado's track was expected about 1 kilometer. According to the criteria classified by Storm Prediction Center of USA based on Fujita scale, this condition is classified as moderate damage and associated to the scale of F0 to F1. The F1 scale is characterized by some incident such as: peels surface off roofs; mobile homes pushed off foundations or overturned; moving autos pushed off the roads; attached garages may be destroyed; branches broken off trees; shallow-rooted trees pushed over; and sign boards damaged.¹⁶

Observed Surface Condition

Based on the extreme weather remark recorded by Pangkalpinang weather station, there was a strong wind observed on the *puting beliung*

(tornado) day, firstly at 12.25 LT or WIB (05.25 UTC) with the speed of 16 knots blowing from the southeast direction. The Pangkalpinang weather station is located at the distance of 10 kilometres from the location where the *puting beliung* struck the settlement. Thunderstorms were heard first at 11.35 LT (04.35 UTC) by the observer and two hours later, heavy rain with the intensity of 27.1 mm/hours occurred at about 13.00 LT (06.00 UTC) as seen on Figure 4 (first arrow). The *puting beliung* event was occurred at around the time of the first storm. From Figure 4, it was expected there were two storm events on January 9 due to heavy rain event. The first storm was around at noon as mentioned earlier, and the second, the worst storm condition, was around 16.00 LT (09.00 UTC) or afternoon with a rainfall intensity about 76 mm/hour. However, there was no such event of *puting beliung* in the second storm as has been reported following the first heavy rainfall event. It was in agreement with the story of the time as told by the residents. And, it is indeed that the rainfall on January 9 was the heaviest compared to the rainfall intensity two days before which were occurred in the same time range.

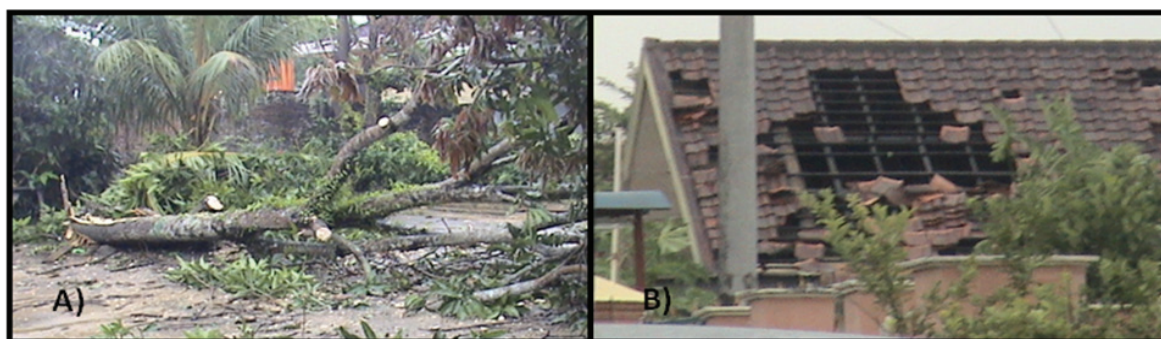


Figure 3. Surface condition after *puting beliung* (tornado) January 9, 2008 hit Pangkalpinang: a fallen tree stricken by strong wind (A), and damaged roof of concrete wall house type associated to F1 tornado scale (B).

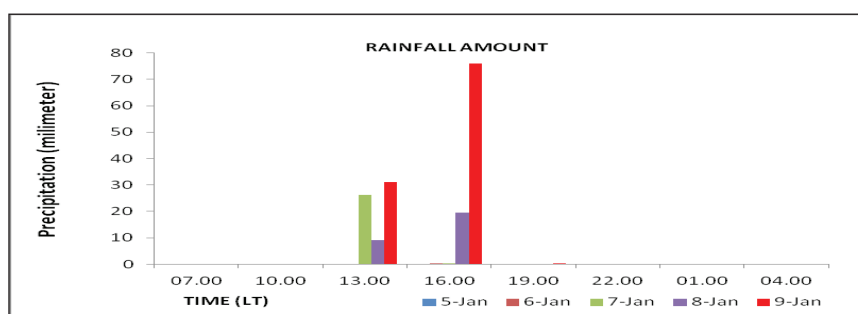


Figure 4. Diurnal variability of three hourly rainfall accumulation from January 5 to 9, 2008. The red bar described the precipitation during *puting beliung* day on January 9, 2008.

The detail of the surface pressure, air temperature, and relative humidity are analyzed for four days before and during the tornado day to identify “the signal” of the *puting beliung*. Some scholars in Indonesia stated about the sign of *puting beliung* based on weather condition in the previous day. Here we will examine those hypotheses to understand more about *puting beliung*.

Figure 5 shows a semi diurnal variation of the surface pressure before and during the event. Generally, the surface pressure in Pangkalpinang fluctuated between high and low during the day. The high pressure appeared in the morning (10.00 LT/03.00 UTC) with 1013.5 mb and in the night time (23.00 LT/15.00 UTC), while the low pressure has two peaks during the afternoon (16.00 LT/09.00 UTC) at 1008 -1009 mb and before sunrise (04.00 LT/21.00 UTC). During the tornado event, it can be seen that the pressure tends to be lower than the previous date in the same time range. However, there was an anomaly in the morning, that is, the appearance of unusual highest pressure at 13.00 LT which is seen as a “horn like”, rising one hour after the pressure tends to decrease started at 10.00 LT (see the arrow sign on the solid brown line). The pressure leap in this case is somehow associated with the first storm and the heavy rainfall event of 27.1 mm. However after it arose, the pressure suddenly dropped to minimum in the afternoon. The rising pressure locally and dropped pressure suddenly may create a region with lowest pressure than its surrounding, and pull the wind blow into this area with high speed due to closely isobar. The

minimum pressure occurred in the same time with the heaviest rainfall intensity, but, it is not happen in all cases such as the days with no rain, in which the pressure is getting down even more deeper.

The phenomena of rapid pressure increase and rapid pressure drop is also coinciding with air temperature data as shown in Figure 6. On January 9, the temperature dropped very rapidly right after 12.00 LT from 30°C to 22°C, dropped about 8°C in 2 hours, which is unusual condition compared to previous date (from 30.5°C to 24.5°C). Moreover, it seems that the temperature tend to stay cool at 23°C. This behaviour is completely different with the condition with days no rain on January 5 and 6, and is the cooler than two rainy days before. This condition may indicates the surface response on the deep convection created aloft that is the rising air within the thunderstorm updraft as theoretically proposed in PDE tornado genesis theory. The deep convection was triggered by morning to afternoon surface heating due the temperature gradient exceeds 5°C, however, before heavy storm event during 13.00–16.00 LT, it changed into rapid drop condition as has been mentioned. The heavy storm followed deep convection represents the sink air which has higher density and potential energy manifested into down slope wind. As we know from the ideal gas law that density (D) per molar mass (MM) is the function of pressure (P) and inversely to the temperature (T). Thus, when the temperature drops too much, the air will sink because of gravitational forces greater than buoyant forces.

Normally, if there is no rain, the diurnal variation of the temperature is increasing from

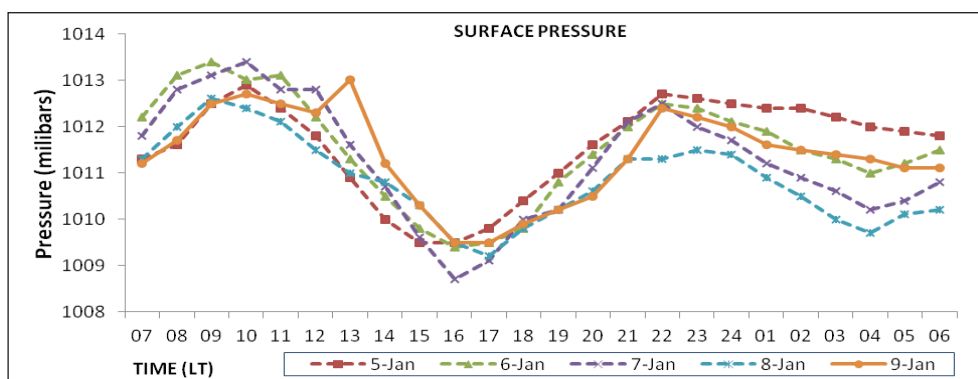


Figure 5. Diurnal variability of surface pressure from January 5 to 9, 2008. The solid line (dashed line) indicated surface pressure during *puting beliung* day on January 9, 2008 (days without *puting beliung*).

morning to afternoon due to surface heating, and decreasing afterward due to incoming night time when the surface release the heat. This is true due to the fact in relative humidity data as shown in Figure 7, which described that relative humidity behaviour is in opposite with the diurnal evolution of the temperature, that is, the air is very humid in the night to morning time (up to 95%), and then decreasing from the morning to afternoon due to surface heating up to 55%, and rising up again from the afternoon to night. It says that during night, in Pangkalpinang, the water vapor in the air is much higher and cools the atmosphere until it breaks in the morning after the ground heated by the sun radiation which then heats the atmosphere above surface and reduces the humidity.

The amount of humidity found in the air varies because two important factors that is evaporation and condensation. This process is mainly caused by absorption of solar radiation and the subsequent generation of heat at the ocean's

surface. In our atmosphere, water vapor is converted back into liquid form when air masses lose heat energy and cool. This process is responsible for the development of most clouds and also produces the rain that falls to the Earth's surface. This explained the fact about the time of rainfall in Pangkalpinang which is mostly occurred afternoon after the air has enough water content due to evaporation from surrounding water. On January 9, it is seen that the air contained much more water vapor during afternoon to the night as it was also supported by the condition in two previous days which is also very humid; however, the relative humidity was much higher during *puting beliung* day.

Based on those pictures, we can presume that the *puting beliung* followed by heavy rainfall at noon (13.00 LT) is prefaced by the rapid increasing the relative humidity one hour in advance, together with rapid changes in temperature and pressure anomaly. However, the condition in

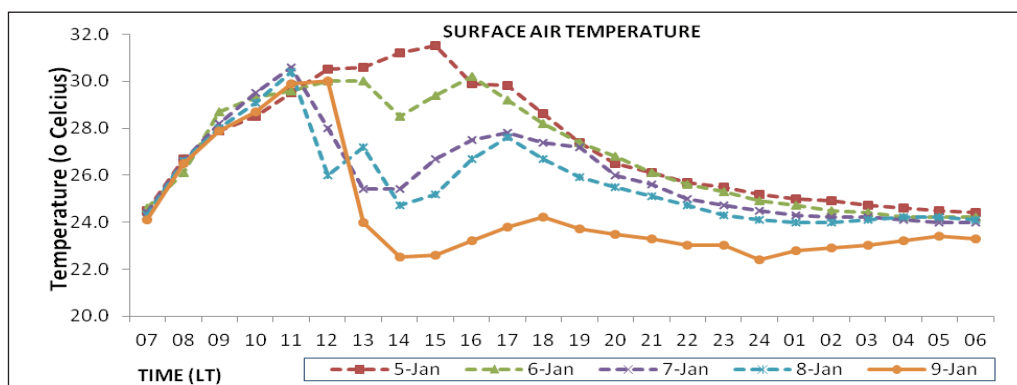


Figure 6. Diurnal variability of surface air temperature from January 5 to 9, 2008. The solid line (dashed line) indicated surface air temperature during *puting beliung* day on January 9, 2008 (days without *puting beliung*).

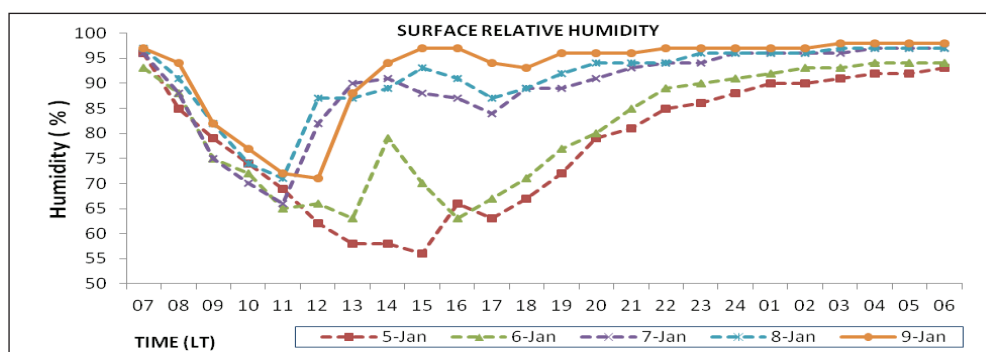


Figure 7. Diurnal variability of surface relative humidity from January 5 to 9, 2008. The solid line (dashed line) indicated surface relative humidity during *puting beliung* day on January 9, 2008 (days without *puting beliung*).

one or two days in advanced have contribution to feed up the favorable conditions in triggering tornado event such as air humidity indicating enough water vapor aloft, enough surface heating to produce a deep convection, and there is such condition in sudden pressure drop to initiate a local anomaly surface wind speed.

The precursor analyses of these surface conditions will be very convinced if there are available data from some other *puting beliung* events. However, this is very difficult since *puting beliung* event usually happens far away from weather station.

MTSAT Satellite Image Analysis

The objective of satellite data analysis is to achieve an atmospheric view of cloud distribution and to identify the extent of storm cloud. It also enables us to know the development process of storm cloud by plotting top cloud temperature in term of time evolution. Figure 8 shows a satellite view of MTSAT Infrared describing the cloud cover condition above Bangka Island from January 5 to 9, mostly at noon.

As it can be seen, the appearance of storm cloud is signed by the white pixel covered most

of southern part of the Bangka Island on January 9 (Figure 8). The white pixel on IR image is associated with the cool cloud top layer which also correspondences to a massive and dense cloud body of VIS image (not shown). This proves that there was a huge storm cloud of cumulonimbus (Cb) type over Bangka Island which cloud be potential to be an apparent cloud for *puting beliung*. This cloud develops continuously up to 12.00–14.00 UTC and tends to move toward north.

Figure 9 describes the spatial cloud top temperature at 11.00 LT. The very cold temperature exceeds -60°C actually located in the west of Pangkalpinang city rather than exactly above the city. However, the *puting beliung* has been observed in the down town. This fact actually explain as in the DPE theory that anvil cloud (part of the cloud top which is the icy upper portions of cumulonimbus thunderstorm) is formed by a rising of air in the lower portions of the atmosphere in the west side of Pangkalpinang while the wall cloud was in the east above the city. When the rising air reaches 40,000–60,000 or more feet, it tends to spread out in a characteristic anvil shape. Within a severe storm, moisture is

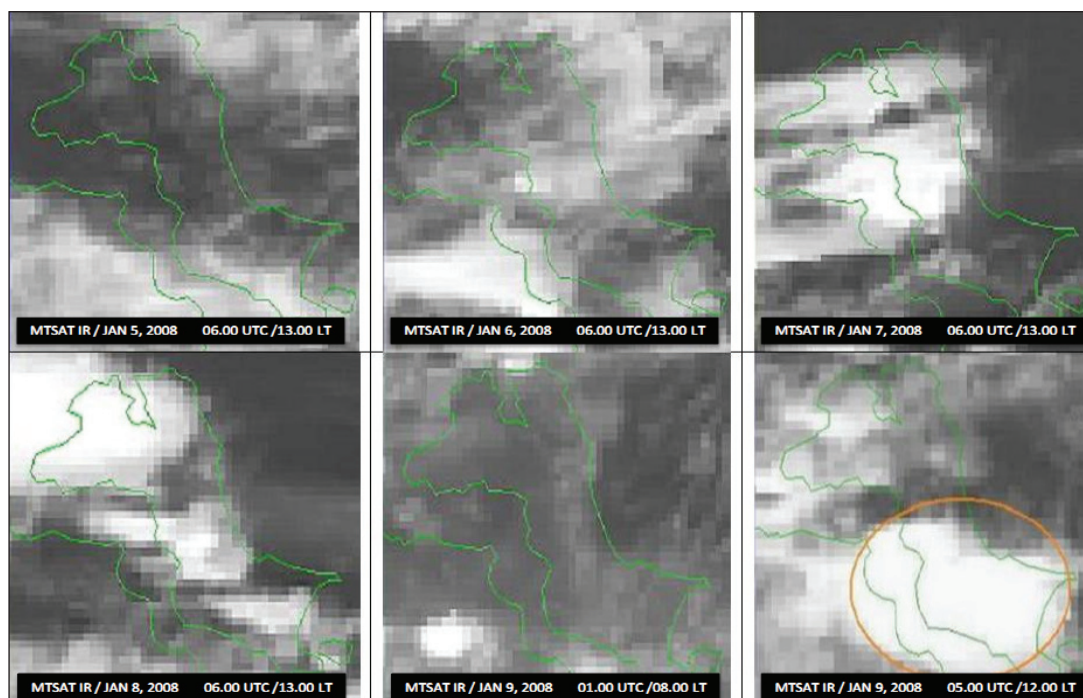


Figure 8. Cloud cover derived from MTSAT Infrared from January 5 to 9, 2008. The brown circle indicates the brightness cloud during *puting beliung* (tornado) day on January 9, 2008 at 12.00 LT.

transported from the lower troposphere to deep into the upper troposphere. Generally, the taller the cumulonimbus cloud, the more severe the storm will be. And usually, the down slope wind and storm will occur in the wall cloud side.

The analysis of cloud top temperature over Pangkalpinang town is taken by point the coordinate of the Pangkalpinang weather station on the top of the cloud as shown in Figure 10. The analysis shows that peak of development processes of this storm cloud is around 13.00–14.00 LT when the top of the cloud was very cool reached up to -60°C , which has been cooled rapidly after 12.00 LT. The very cold cloud top layer indicated the super cell cloud has been developed perfectly with an anvil in the west

side. The temperature of the anvil is frigid cold. Moreover, the data also confirms us that this cloud reaches over Pangkalpinang town on that time when it moves toward north as explained before. Related to the DPE theory, this very cold cloud top temperature (-60°C) and the warm surface temperature (30°C) represented a heat sink region of lower temperature aloft and a heat source of higher temperature in the air at the earth's surface, respectively, which further transform this heat energy differences into a kinetic energy and into wind flow v and work W .⁵ This kinetic energy produced turbulence containing microburst or very strong downdraft which is very danger to the surface.

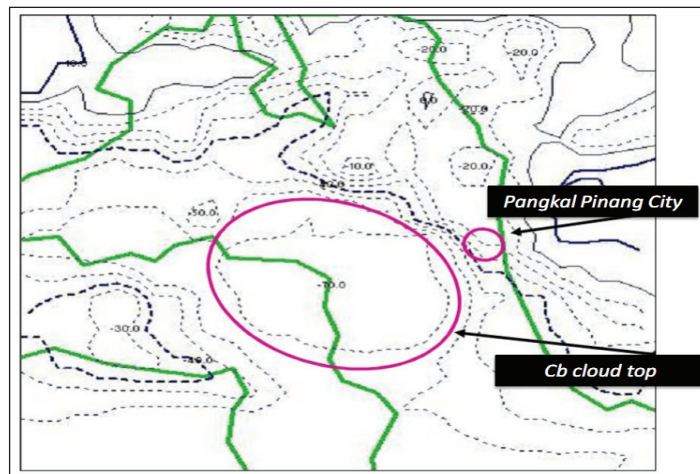


Figure 9. Represented spatial cloud top temperature derived from MTSAT Infrared during *puting beliung* (tornado) day on January 9, 2008 at 05.00 UTC/11.00 LT.

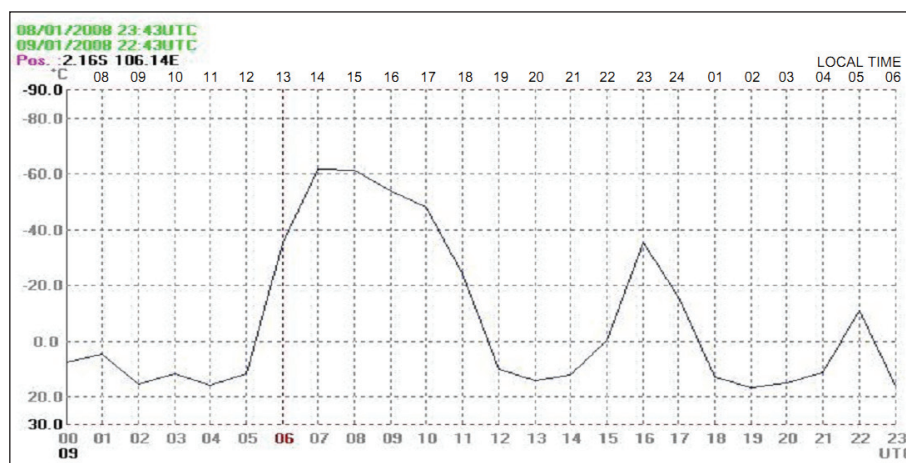


Figure 10. Cloud top temperature derived from MTSAT Visible satellite image during *puting beliung* (tornado) day January 9, 2008.

Upper Air Observation

Vertical wind profile data in Figure 11 exhibits the information about the level of tropopause and vertical wind pattern. On January 9, the height of tropopause is around 45,000 feet or around 14 km above earth's surface (see Figure 10a), indicating the maximum height up to which the top of convective cloud can reach. At the tropopause level, wind blew from the east with 35–50 knots wind speed. While in the middle level, wind speed tends to be lower, about 5–20 knots with direction ranges from south to west. In the near surface, surprisingly, winds blew with various both direction and speed. They are even stronger than the middle level winds. It can be presumed that this unusual vertical pattern figured the strong air instability at that time and enabled convective cloud to develop intensively.

Furthermore, investigation in the near surface wind is important to identify the existing of vertical wind shear which is expected as a trigger of this tornado event. To detect the anomaly of near surface wind pattern on January 9, vertical wind from January 7–12 was plotted as shown in Figure 10b. Fortunately, the analysis shows a truly strange wind pattern on the tornado day compared to the other days. Before and after January 9, the tornado day, near surface winds blew from the similar direction which was west to northwest. However, on January 9, there was a strong wind reached up to 30 knots in speed blowing from

southeast at the level of 2,000–3,000 feet above surface. In contrast to those winds, from surface up to 2,000 feet, winds blew with wind speed of 5 knots only. The strong wind speed in the upper level was due to a divergence flow which is also very important in the development of convective cloud as the puller of the air from the top.

This pattern strongly indicates a vertical low level wind shear phenomenon in which the direction and the speed of two levels are significantly different over a short distance. This condition is appropriate with the first stage of the DPE theory genesis in which an increase in wind speed with increasing height create an invisible, horizontal spinning effect in the lower atmosphere. In relation to surface observation, we can presume that the low level wind shear has also strong relation with the rapid changes in pressure, temperature and relative humidity, the presence of convective type cloud (cumulonimbus type) as has been analyzed in the previous part. The surface condition which is favorable for development of deep and rapid convection can further develop into super cell or cumulonimbus cloud. However, the surface atmospheric background condition 1–2 days has also contributed to the development of the super cell. The thunderstorm resulted from super cell may produce a downdraft, the most dangerous shear conditions associated with the outflow of a thunderstorm. The gust front frequently may extends 10 to 15 miles away from the thunderstorm.

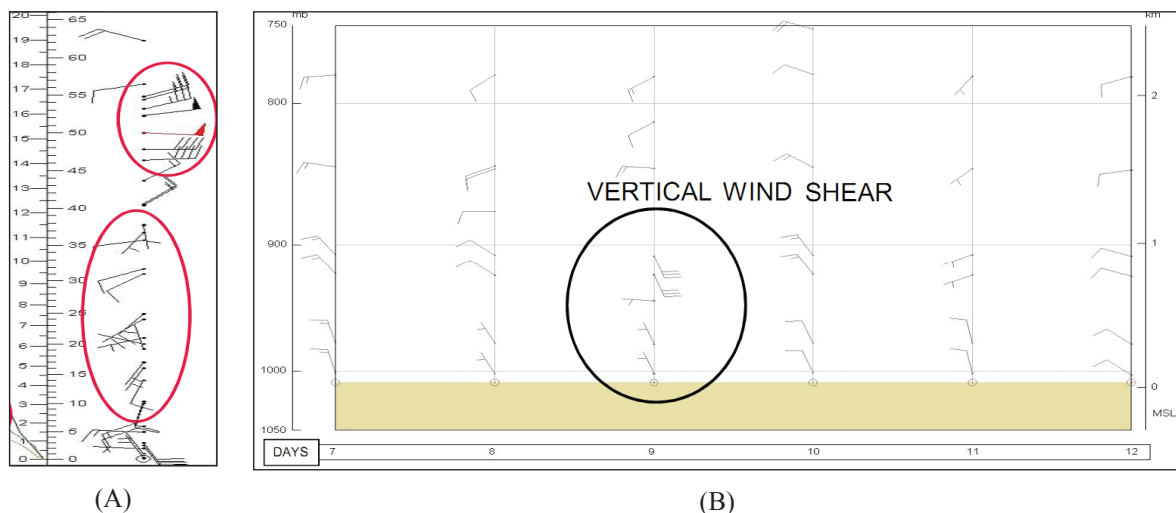


Figure 11. Vertical wind profile derived from atmospheric sounding on 9 January at 07.00 LT (A) and daily averaged profile from 7–12 January 2008 (B). The red circles in (A) shows a wind shear between two atmospheric layer and the black circle in (B) shows wind shear which is also seen in daily averaged wind profile during the tornado day.

Extreme wind shears of 10 knots per 100 feet of altitude have been measured immediately behind the gust front, while horizontal wind shears of 40 knots per mile have been recorded across the gust front. In addition to the tremendous speed shears reached, the most severe thunderstorms produce directional shears of 90° to 180°.

CONCLUSION

From the analyses and discussion, we can conclude that the most prominent parameter in triggering tornado or *puting beliung* event in Pangkalpinang on January 9, 2008, is the presence of low level wind shear which is supported by favorable condition. Those favorable condition such as the existence of very cold cloud top temperature and the warm surface temperature represented 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 a deep convection, the existing of enough water vapor aloft indicated by high relative humidity, and there is an initiation of a local anomaly surface wind speed to produce wind shear. A deep convection then produces further turbulence containing microburst or very strong downdraft which is very danger to the surface. In order to have better understanding for identifying tornadoes and rotating thunderstorms (super cells), it is needed to complement this finding by exploring more of atmospheric sounding data such as the precipitable water vapor in the atmosphere, convective available potential energy (CAPE), as well as using the utility of doppler radar.

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REFERENCES

- ¹Tornado mengamuk. 2008. Bangka Pos, 11 Januari 2008: 6.
- ²(<http://en.wikipedia.org/wiki/Storm>, accessed on June 13th, 2011)
- ³(<http://www.visitbangkabelitung.com/iklim-dan-topografi>, accessed on June 13th, 2011).
- ⁴Church, C.R., Snow, J.T., Baker, G.L., and Agee, E.M. 1979. Characteristics of Tornado-Like Vortices as a Function of Swirl Ratio: A Laboratory Investigation. *Journal of the atmospheric science*: 1.756–1.776.
- ⁵Power A.B. 2008. Tornado-genesis by an Isentropic Energy Transformation. Available at (www.energycompressibility.info/.../Tornado%20Genesis%20PDF%20II.pdf).
- ⁶Markowski and Paul M. 2002. "Hook echos and Rear-Flank Downdrafts:A Review". *Monthly Weather Review (Boston: American Meteorological Society)* 130 (4): 852–876.
- ⁷Smith, R. K. and Ulrich, W and Sneddon, G. 2000. On the dynamics of hurricane-like vortices in vertical-shear flows. *Quarterly Journal of the Royal Meteorological Society*, 126 (569): 2.653–2.670.
- ⁸Rasmussen, Erik N. and Richardson, Scott and Straka, Jerry M. and Markowski, Paul M. and Blanchard, David O. 2000. The Association of Significant Tornadoes with a Baroclinic Boundary on 2 June 1995. *Monthly Weather Review*, 128 (1): 174–191.
- ⁹Houze and Smull. 1987. Rear Inflow in Squall Lines with Trailing Stratiform Precipitation. *Monthly Weather Review*, 115: 2.869–2.889.
- ¹⁰Pfost, Russell L., Alan E. Gerard, 1997. "Bookend Vortex" Induced Tornadoes along the Natchez Trace. *Weather Forecasting*, 12: 572–580.
- ¹¹Trapp, R. Jeffrey, Robert Davies-Jones, 1997. Tornado genesis with and without a Dynamic Pipe Effect. *Journal of Atmospheric Sciences*, 54: 113–133.
- ¹²Agee, E.M. and Boltz, R.C. 2005. An Overview of Tornado genesis and Vortex Structure. The report of undergraduate honors research. Available at (www.purdue.edu/eas/mct/pdf/Tornado%20Genesis.pdf, accessed on June 13th, 2011).
- ¹³NOAA. 1992. Tornado: Nature's Most Violent Storm. An preparedness guide. (www.nssl.noaa.gov/edu/safety/tornado.pdf, accessed on June 13th, 2011).

¹⁴Ashton, R.C. and Joseph T. Schefer. 2008. The Relation of El Nino Southern Oscillation (ENSO) to Winter Tornado Outbreaks. 19th Conference on Probability and Statistics. American Meteorological Society.

¹⁵(<http://mscweb.kishou.go.jp/VRL/sataid/index.htm>, accessed on June 13th, 2011)

¹⁶(<http://www.raob.com/>, accessed on June 13th, 2011).

¹⁷Fujita Tornado Damage Scale, NOAA *Storm Prediction Center*, <http://www.spc.noaa.gov/>, accessed on June 13th, 2011.