The Impact of Trans-equatorial Monsoon Flow on the Formation of Repeated Torrential Rains over Java Island

Peiming Wu[1], Masayuki Hara[1], Hironori Fudeyasu[1], Manabu D. Yamanaka[1], Jun Matsumoto[1], Fadli Syamsudin[2], Reni Sulistyowati[2], and Yusuf S. Djajadihardja[2]
[1]*Japan Agency for Marine-Earth Science and Technology, Yokosuka, Japan*
[2]*Agency for the Assessment and Application of Technology, BPPT, Indonesia*

Abstract

Torrential rains that repeatedly occurred over Java Island causing widespread floods in late January and early February 2007 coincided with a strong and persistent trans-equatorial monsoon flow from the Northern Hemisphere. While convections develop frequently over the island's mountainous areas in the afternoon, convections over the northern plains are active during the night and morning hours. The strong trans-equatorial monsoon flow with an upper southeasterly wind produces a strong low-level vertical shear of wind and dry mid-level environment over the island. These conditions allow the severe convections to occur repeatedly for days and to sustain for an extended period of time. The results suggest that the trans-equatorial monsoon flow plays a principal role in the formation of the repeated torrential rains. The probability of occurrence of a strong and persistent trans-equatorial monsoon flow that causes torrential rains and widespread floods over Java Island is estimated to be once every 5-10 years.

1. Introduction

During the Asian winter monsoon cold-air outbreaks from the Eurasian Continent accompanied by rapid drop in air temperature and increase of surface pressure across much of Southeast Asia are an important aspect of the intraseasonal variability of the winter monsoon system (e.g., Ramage 1971; Garreaud 2001). Often the cold surges enhance convection over the South China Sea, in the region of north of Borneo and along the Indo-China coast because of the intense low-level wind convergence along their leading edge (Compo et al. 1999; Chang et al. 2005). Love (1985) suggested that winter hemisphere subtropical cold surges enhance monsoon westerly flow in the summer hemisphere. On rare occasions, a strong and persistent cold surge can help to create a large background cyclonic vorticity at the equator in the equatorial tropical cyclone formation (Chang et al. 2003).

As the cold surge moves southward into the near-equatorial tropics, strong surface heat-fluxes weaken the cold air anomalies, and the surge may lose its 'cold' character. Previous analyses on the cold surges showed that the pressure surges originated from the Northern Hemisphere mid-latitude can be traced only to as far south as 10°N (e.g., Compo et al. 1999). However, strong northerly wind can blow to lower latitudes and can even penetrate into the Southern Hemisphere. The sea surface wind vectors measured by NASA's Quick Scatterometer (QuikSCAT) on 31 January 2007 are shown in Fig. 1. A strong northeasterly winter monsoon flow with a wind speed greater than 10 m s^{-1} was observed over the South China Sea, and a strong northerly winds over the Karimata Strait and over the Java Sea in the Southern Hemisphere. As will be shown in section 2, this strong trans-equatorial monsoon flow persisted for more than one week in late January and early February 2007.

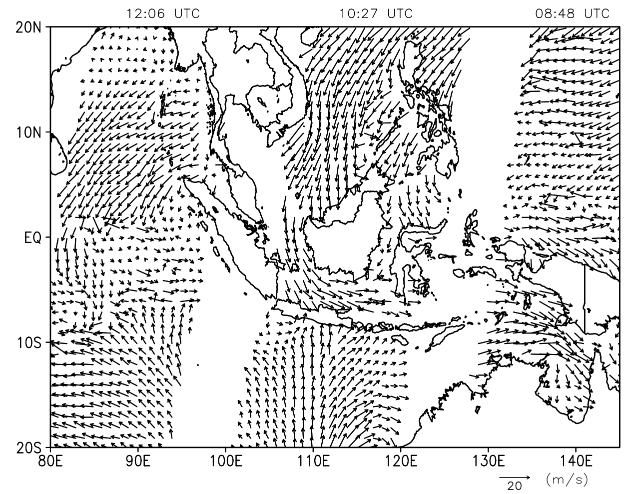

Fig. 1. Sea surface wind vectors measured by NASA's Quick Scatterometer for 31 January 2007.

Torrential rains repeatedly occurred over Java Island during the period from late January to early February 2007, resulting in one of the worst flooding events in recorded history in the Indonesian capital of Jakarta and surrounding areas. Prior analyses of the cold surges were focused mainly on the structure and evolution of the surges in different regions. How the trans-equatorial monsoon flow affects the occurrence of torrential rain over Java Island in the Southern Hemisphere is unknown. Relevant phenomena include the Madden and Julian Oscillation (MJO), which significantly affects tropical weather, especially in the Indian and western Pacific Ocean regions. An active MJO can cause enhanced convection over the island for an extended period of time. However, the period during late January to early February 2007 when the torrential rains occurred over the island was not in a MJO active phase. In this study, we investigate the influence of the trans-equatorial monsoon flow on the formation of the repeated torrential rains over the island using QuikSCAT sea surface winds, GMS infrared images, radar observation and balloon sounding data for the period from late January to early February 2007.

2. Occurrence of trans-equatorial monsoon flow from the Northern Hemisphere

We investigated the occurrence of the trans-equatorial monsoon flow from the Northern Hemisphere in the boreal winter season using QuikSCAT sea surface winds for the 8-years from October 1999 to March 2007. (The

Corresponding author: Peiming Wu, Japan Agency for Marine-Earth Science and Technology, Natsushima-cho 2-15, Yokosuka-City, Kanagawa 237-0061, Japan. E-mail: pmwu@jamstec.go.jp.

QuikSCAT sea surface winds are available only since 1999). In almost every year during 1999 to 2007, a trans-equatorial monsoon flow occurred during the period from late December to mid-February. In 2002 and 2007, a similarly strong and persistent trans-equatorial monsoon flow occurred in late January and early February. In both years, the trans-equatorial monsoon flow caused torrential rains and widespread floods over Java Island. However, except for 2002 and 2007, the trans-equatorial monsoon flow was relatively weak, and continued only for 2–3 days each time (not shown). Therefore the probability of occurrence of a strong and persistent trans-equatorial monsoon flow that causes torrential rains and widespread floods over Java Island is estimated to be once every 5–10 years.

Time variation of the Asian winter monsoon flow over the South China Sea, over the Karimata Strait and the Java Sea in the Southern Hemisphere is shown in Fig. 2 as a time-latitude diagram of the meridional winds from QuikSCAT sea surface winds along 108°E for the period from October 2006 to March 2007. This longitude is representative of the region from 106 to 110°E. The strong northerly wind events occurred five times over the South China Sea: in late October to early November, in the beginning and middle of December 2006, in the middle of January, and in late January to early February 2007. Among them, in the first four times the strong northerly winds occurred only over the South China Sea. However, in the last and strongest event, which occurred from 28 January, the strong northerly monsoon flow blew across the equator, and penetrated into the northern part of Java Island in the Southern Hemisphere. This strong trans-equatorial monsoon flow persisted for more than one week during the period from late January to early February 2007.

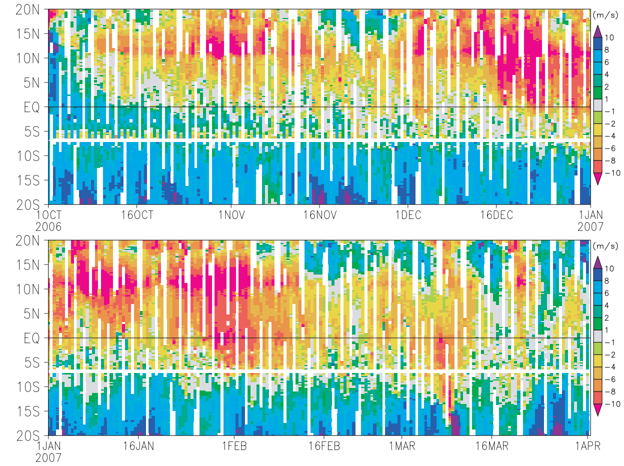

Fig. 2. Time-latitude diagram showing the meridional winds from QuikSCAT sea surface winds along 108°E.

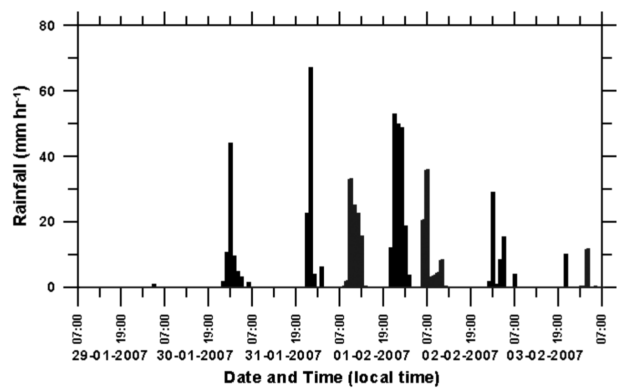

Fig. 3. Hourly rainfall observed at Pondok Betung Meteorological Observatory, Jakarta in Java Island during 29 January to 3 February 2007.

3. Spatiotemporal variation of severe convection/rainfall over Java Island

As mentioned previously, intense precipitation repeatedly occurred over Java Island in late January and early February 2007. Figure 3 shows the hourly rainfall observed at Pondok Betung Meteorological Observatory, Jakarta in Java Island (Fig. 4) during 29 January to 3 February 2007. The four-day total rainfall during 30 January to 2 February reached 589.0 mm. It is noteworthy that the rainfall exhibits a pronounced diurnal cycle. The precipitation was regularly initiated in the night during 2000 to 2200 LT, and continued for 4–5 hours. The rains stopped falling in the early morning, occurred again after 3–4 hours and continued until around noon on 1 and 2 February 2007.

We examined the spatiotemporal variation of convection in and around Java Island using infrared (IR) images from the Geostationary Meteorological Satellite (GMS) MTSAT-1R. The three-day images for 31 January to 3 February, 2007 that typify the diurnal cycle are shown in Fig. 5. It can be seen that by 1200 LT in the morning, there are few clouds over the land on most parts of Java Island (the top panels). As the day progresses, convections are very active over the southern mountain areas of the island (1700 LT, the middle panels). At the later time, convections occur over the northern plains during night (the bottom panels). The convections migrate to the Java Sea during the late night to early morning period.

The above results from the MTSAT-1R infrared (IR) images showed that while a number of convections develop frequently over the mountainous areas of Java Island in the afternoon, convections are active over the plains during the night and early morning. GMS infrared (IR) images cannot provide a distribution of rainfall on the ground. However, radar observation can give a detail distribution of rainfall near the ground and evolution of storms. The X band radar Plan Position Indicator (PPI) reflectivity display at the 0.5-degree elevation angle obtained at Pondok Betung Meteorological Observatory, Jakarta for 1600, 1900, 2000 LT on 1 February and 0300 LT on 2 February 2007 is shown in Fig. 6.

Initially, in the afternoon (1600 LT) the rains were predominantly over the mountainous areas of Java Island, approximately 40–70 km south of the Pondok Betung radar site. By 1900 LT the rains over the mountains are decreasing, and a broken line of convections initiated over the northern plains near the mountain foot. By 2000 LT the rains over the mountains disappeared, and convections over the plains had solidified into a line orientated west-east, extending for about 100 km. The precipitation system was tracked within ~10 km south and approaching the Pondok Betung radar site. Very heavy rainfall with intensities of 53.0, 50.0 and 49.0 mm h^{-1} was measured on the ground at the Pondok Betung radar site at 2200, 2300 and 0000 LT, respectively. Subsequently, the reflectivity pattern continuously showed a line of storms, migrating northward to the Java Sea during the nighttime. The propagation speed of the precipitation system was close to ~3 m s^{-1}, much slower than the speed observed in typical mid-latitude squall lines. In addition to the example shown above in this section, a similar result of the regular occurrence of afternoon rains over the mountainous areas of Java Island, night and morning rains over the plains

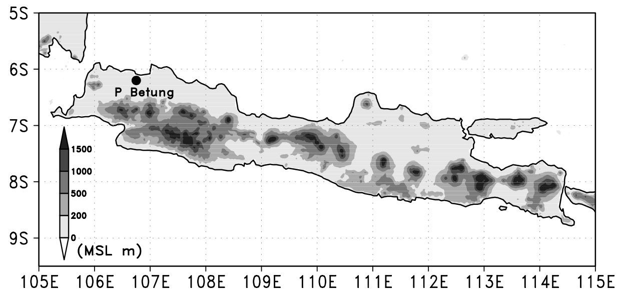

Fig. 4. The topography of Java Island and location of Pondok Betung (black circle), Jakarta, where radar observations were conducted. The shades denote terrain elevation.

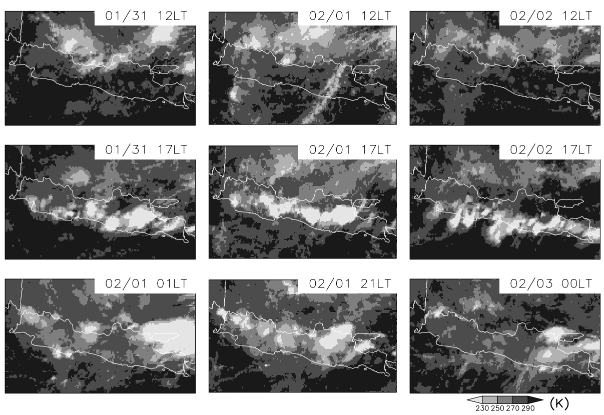

Fig. 5. GMS satellite infrared (IR) images over Java Island for 31 January to 3 February 2007. These images were made using the infrared channel of MTSAT-1R image, which has a spatial resolution of 5 km.

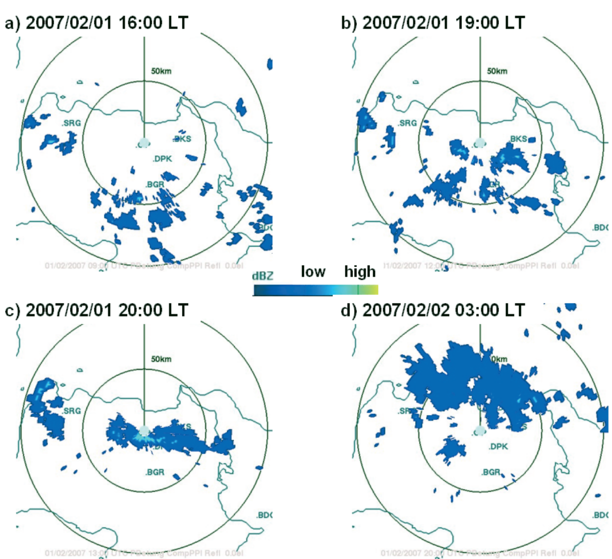

Fig. 6. The X band radar Plan Position Indicator (PPI) reflectivity display at the 0.5-degree elevation angle obtained at Pondok Betung Meteorological Observatory, Jakarta for a) 1600, b) 1900, c) 2000 LT on 1 February and d) 0300 LT on 2 February 2007.

were also observed on 31 January 2007 (not shown).

A wind blows up the slope of a hill or mountain due to solar heating of the land during daytime. An upslope wind forms because the air over a mountain becomes warmer than the surrounding atmosphere at the same levels. The upslope wind produces a wind convergence, which in turn induces an enhancement of moisture and rising atmospheric motion, causing the formation of cloud over the mountain in the late afternoon. As shown in Fig. 5 and 6, a number of convections developed over the southern mountain areas of Java Island in the late afternoon. This afternoon convection over the mountains may result from the enhancement of moisture by thermally induced local circulations, similar to that which occurred over Sumatra Island (Wu et al. 2003).

Tucker and Crook (1999) suggested cold air flowing down the lee slope as a mechanism for the generation of mesoscale convective system, the cold air in their study originated as the outflow from convections that developed earlier over the lee slope of the Rocky Mountains. Satomura (2000) reported a similar triggering and propagation of late afternoon and evening squall lines near the lee-side foot by the outflow from previous mountain convections over the Indo-China Peninsula. It is expected that when convections over the mountains of Java Island dissipate in the late afternoon and evening, cold surface outflow that is induced by the convections flows down the mountain slope. These surface outflow winds create an intensive low-level wind convergence, lift the warm moist air near the surface, and initiate the convections over the northern plains near the mountain foot, similar to those that occurred over the Indo-China Peninsula (Satomura 2000). As a result, the severe convections developed repeatedly over the northern plains of the island in the nighttime as depicted by the radar observations shown in Fig. 6.

4. Influence of trans-equatorial monsoon flow on the formation of severe, long-lived convection over Java Island

The results from radar observations in the previous section indicated that the nighttime convection was triggered over the northern plains near the mountain foot in Java Island. The well-organized convections were quite severe and sustained for an extended period of 8–9 hours until the early morning of the next day. The severe, long-lived convections propagated northward, bringing about the heavy rainfall over the northern plains of the island during the night and morning hours.

Balloon soundings were performed twice a day at Soekarno-Hatta International Airport, Jakarta in Java Island. The Skew-T Log-P diagrams for 1200 UTC (1900 LT) on 31 January and 1 February 2007 are shown in Fig. 7. The 1200 UTC soundings on 31 January and 1 February indicated the Convective Available Potential Energy (CAPE) values of 1651.0 and 2202.8 J kg^{-1}, respectively. The high CAPE represents the potential for a high maximum speed of updraft leading to the strong convections. Both the two dewpoint profiles indicated the existence of a distinct dry layer at the mid-level of ~600–300 hPa. The existence of the mid-level dry layer represents a strong convective instability over the island. Meanwhile, the wind profiles indicated that while southeasterly wind prevailed in the upper atmosphere (higher than about 700 hPa), there was a layer of northwest winds in the levels lower than about 800 hPa. The wind directions at the altitudes of 900 and 700 hPa are almost in the opposite directions, with a large vertical wind shear of 15 m s^{-1} through the 900–700 hPa layers. The low-level northwesterly winds were a result of the strong trans-equatorial monsoon flow from the Northern Hemisphere, as shown previously in Figs. 1 and 2.

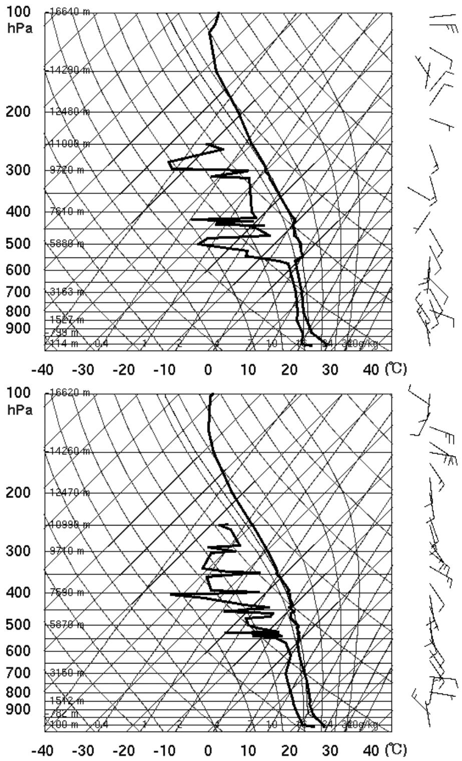

Fig. 7. The Skew-T Log-P diagrams obtained at Jakarta for 1200 UTC (1900 LT) on (upper) 31 January and (lower) 1 February 2007. The right line in each of the plots is the temperature profile, and the left line is the dewpoint profile. The winds are plotted as wind barbs with height on the right edge of the plots.

Low-level wind shear is a favorable and necessary condition for convection maintained by downdraft. Rotunno et al. (1988) suggested that squall-line strength and longevity is most sensitive to the strength of the component of low-level (0–3 km AGL) ambient vertical wind shear perpendicular to squall-line orientation. Usually, during the boreal winter the vertical shear of wind over Java Island is relatively weak in the absence of a trans-equatorial monsoon flow from the Northern Hemisphere. However, as shown in Fig. 7, results from balloon soundings obtained at Jakarta indicated a strong vertical wind shear in the low-levels on 31 January and 1 February 2007. As described previously, the strong trans-equatorial monsoon flow caused the low-level northwesterly winds over the island. This strong and persistent trans-equatorial monsoon flow induced an intensive low-level wind convergence along its leading edge over the island. Simultaneously, the low-level northwesterly flow with the upper southeasterly wind produced a strong low-level vertical shear of wind over the island for days. Theses conditions allow the convections to be organized and to sustain for an extended period of time. As a result, the torrential rains occurred repeatedly for several days over the island, which resulted in the widespread floods over Jakarta and surrounding areas in late January and early February 2007.

5. Summary

Torrential rains that repeatedly occurred over Java Island causing widespread floods during late January and early February 2007 coincided with a strong and persistent trans-equatorial monsoon flow from the Northern Hemisphere. The precipitation/convection over the island exhibits a pronounced diurnal cycle. While convections develop frequently over the island's mountainous areas in the afternoon, convections over the northern plains are active during the night and morning hours. The strong trans-equatorial monsoon flow and the upper southeasterly wind produce a strong low-level vertical shear of wind and a strong dry-air intrusion at the mid-level over the island. The strong low-level vertical shear of wind, wet lower and dry mid-level layer conditions allow the severe convections to occur repeatedly for days and to sustain for an extended period of time. The results suggest a possibility that the trans-equatorial monsoon flow interacts with thermally and convectively induced diurnal changes in the boundary-layer wind over the island, enhancing the convections over the mountains in the afternoon, and over the plains in the night and morning. The trans-equatorial monsoon flow plays a principal role in the formation of the repeated torrential rains over Java Island.

Acknowledgments

We are deeply grateful to Drs. Jie Li, Hiroki Tokinaga and Dennis G. Dye of Japan Agency for Marine-Earth Science and Technology, for their invaluable comments and support on this study. Thanks are also due to Messrs Urip Haryoko, Suhatno and Marjuki, the Meteorological and Geophysical Agency of Indonesia (BMG) for providing the rain data and radar images used in Figs. 3 and 6. The infrared Satellite data used in Fig. 5 are provided by Kochi University, Japan. The balloon sounding data used in Fig. 7 are provided by University of Wyoming. Data are available at weather.uwyo.edu. QuikScat data are produced by Remote Sensing Systems and sponsored by the NASA Ocean Vector Winds Science Team. Data are available at www.remss.com.

References

Chang, C.-P., C. Liu, and H. Kuo, 2003: Typhoon Vamei: An equatorial tropical cyclone formation, *Geophys. Res. Lett.*, **30**(3), 1150, doi:10.1029/2002GL016365.

Chang, C. P., P. A. Harr, and H. J. Chen, 2005: Synoptic disturbances over the equatorial South China Sea and western Maritime Continent during boreal winter. *Mon. Wea. Rev.*, **133**, 489–503.

Compo, G. P., G. N. Kiladis, and P. J. Webster, 1999: The horizontal and vertical structure of east Asian winter monsoon pressure surges. *Quart. J. Roy. Meteor. Soc.*, **125**, 29–54.

Garreaud, R. D., 2001: Subtropical cold surges: Regional aspects and global distribution. *Int. J. Climatol.*, **21**, 1181–1197.

Love, G., 1985: Cross-equatorial influence of winter hemisphere subtropical cold surges. *Mon. Wea. Rev.*, **113**, 1487–1498.

Ramage, C. S., 1971: Monsoon Meteorology. Academic Press, 296 pp.

Rotunno, R., J. B. Klemp, and M. L. Weisman, 1988: A theory for strong, long-lived squall lines. *J. Atmos. Sci.*, **45**, 463–485.

Satomura, T., 2000: Diurnal variation of precipitation over the Indo-China Peninsula: Two-dimensional numerical simulation. *J. Meteor. Soc. Japan*, **78**, 461–475.

Tucker, D. F., and N. A. Crook, 1999: The generation of a mesoscale convective system from mountain convection. *Mon. Wea. Rev.*, **127**, 1259–1273.

Wu, P., J. Hamada, S. Mori, Y. I. Tauhid, M. D. Yamanaka, and F. Kimura, 2003: Diurnal variation of precipitable water over a mountainous area of Sumatra Island. *J. Appl. Meteor.*, **42**, 1107–1115.

Manuscript received 30 May 2007, accepted 29 August 2007
SOLA: http://www.jstage.jst.go.jp/browse/sola/