

The Impact of Intraseasonal Oscillations in the Tropical Atmosphere on the Formation of Extreme Central Vietnam Precipitation

Peiming Wu¹, Yoshiki Fukutomi¹, and Jun Matsumoto^{1,2}

¹Research Institute for Global Chang, JAMSTEC, Yokosuka, Japan

²Department of Geography, Tokyo Metropolitan University, Hachioji, Japan

Abstract

The present study examined the atmospheric circulations leading to the extraordinary heavy precipitation event that occurred in central Vietnam during 2–5 October 2010. Results from an analysis of data from the Japan Meteorological Agency Climate Data Assimilation System (JCDAS) showed that the combined effects of a westward-propagating synoptic-scale tropical disturbance from the western Pacific and the eastward propagation of a strong active phase of the Madden Julian Oscillation (MJO) from the Indian Ocean were the primary causes. Investigation of MJO activities during the wet season in the region for the 30 years from 1981 to 2010 revealed that the intraseasonal oscillations in the tropical atmosphere are an important factor in the formation of extreme precipitation events in central Vietnam.

1. Introduction

Central Vietnam is located on the eastern margin of the Indochinese Peninsula, to the west of the South China Sea (Fig. 1). The Annamite Range runs parallel to the central Vietnam coast, with a narrow plain between the mountains and the coast. Central Vietnam receives the bulk of its annual rainfall in the regional wet season from September to November. In most years heavy rainfall occurs in the wet season and causes severe flooding and great damage. One such unusually heavy rainfall event occurred in early October 2010, marked by continuous heavy rain over a large area at a rate of more than 100 mm per day for four consecutive days 2–5 October. Daily rainfalls of 208.3, 410.7 and 104.4 mm were observed at Hue Meteorological Observatory on 2, 3 and 4 October (Fig. 2). Most observation points in northern central Vietnam recorded total rainfalls of more than 500 mm over the four days, resulting in the most disastrous flood that has ever been experienced in central Vietnam. At least 59 people lost their lives and tens of thousands of houses and large areas of crop field were inundated.

Yokoi and Matsumoto (2008) investigated the synoptic-scale atmospheric conditions over the South China Sea that caused heavy rainfall in central Vietnam in early November 1999. Their results showed that a northerly wind anomaly from winter monsoon cold surge in the lower troposphere, together with a southerly wind anomaly over the central South China Sea played key roles in the heavy rain event. Similar results were obtained from an investigation of the causes of an extreme rain event in northern Vietnam in October 2008, showing that tropical disturbances and the Asian winter monsoon play major roles in extreme precipitation events (Wu et al. 2011).

The Madden-Julian Oscillation (MJO) (Madden and Julian 1994), or intraseasonal oscillation, is the largest element of 30-day to 90-day intraseasonal variability in the tropical atmosphere. It is characterized by an eastward progression of large regions of both enhanced and suppressed tropical rainfall that mainly occurs over

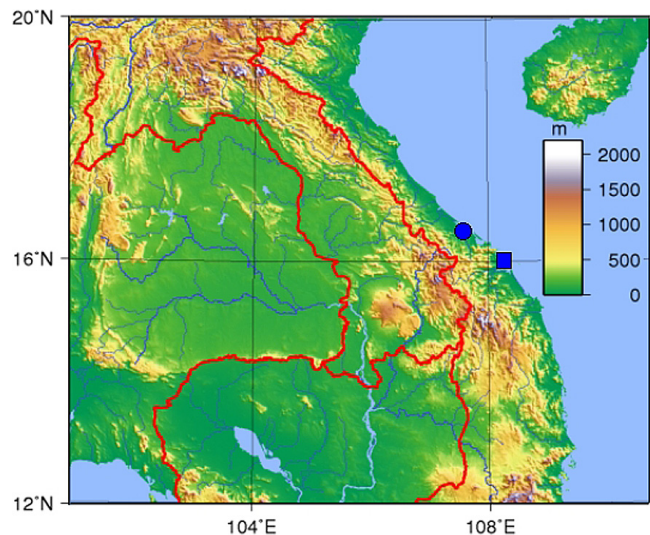


Fig. 1. Topography of central Vietnam and surroundings, and location of Hue (circle) and Da Nang (square) Meteorological Observatory. Shading denotes terrain elevation.

the Indian Ocean and Pacific Ocean. The MJO significantly affects the atmospheric circulation throughout the global tropics and subtropics, particularly in the Maritime Continent, and in western and central Pacific tropical regions. As Vietnam is located in the tropics and borders the Maritime Continent to the south, the MJO would be expected to exert a strong influence on precipitation in the region. However, exactly how it influences extreme heavy rain events in central Vietnam is not well understood.

In this study, the cause of the extremely heavy precipitation event in central Vietnam on 2–5 October 2010 was investigated, focusing on the impact of the MJO on the atmospheric circulations by analyzing data from the Japan Meteorological Agency Climate Data Assimilation System (JCDAS).

2. Occurrence of a westward-propagating tropical disturbance from the western Pacific

Horizontal winds at the 850 hPa level from the JCDAS data indicate that, beginning on 27 September 2010, a cyclonic disturbance accompanied by a rain area developed near Palau in the western Pacific Ocean (not shown). Over the following four days, it moved in a west-northwesterly direction, passing over the Philippines and the South China Sea, and approaching central Vietnam.

To track the tropical disturbance during its development and westward movement, a sequence of vorticity anomalies at the 850 hPa level was calculated for the 10 days from 25 September to 4 October 2010, using a 2- to 10-day band pass filter (Fig. 3). From 25 to 27 September, southerly anomalies and an anticyclonic circulation over the Philippines and the South China Sea were travel-

Corresponding author: Peiming Wu, Research Institute for Global Chang, JAMSTEC, Natsushima 2-15, Yokosuka, Kanagawa 237-0061, Japan. E-mail: pmwu@jamstec.go.jp. ©2012, the Meteorological Society of Japan.

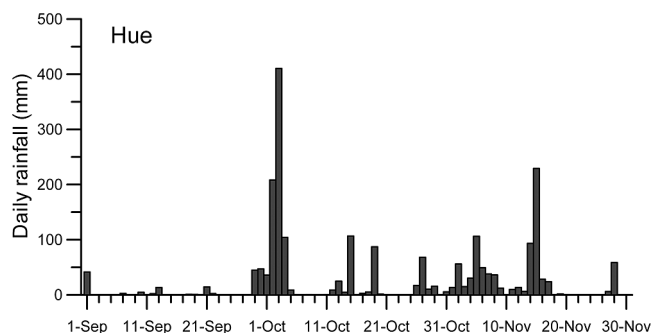


Fig. 2. Time series of daily rainfall (mm) observed at Hue Meteorological Observatory (16.433°N, 107.583°E) in central Vietnam for 1 September to 30 November 2010.

ing westward. On 27 September, the anticyclonic circulation was followed by a cyclonic disturbance centered near 7°N140°E which developed quickly in the subsequent three days and moved west-northwestwards towards central Vietnam. Then, on 4 October, the disturbance center made landfall in central Vietnam.

As the disturbance was approaching the eastern coast of Vietnam, four consecutive days of heavy rainfall, with over 100 mm of rain per day, were observed in central Vietnam from 2 to 5 October 2010. The disturbance then persisted for another five days, slowly moving to Hanan Island and causing nine days of heavy rainfall of over 100 mm daily from 1 to 9 October. To summarize, a westward-propagating synoptic-scale tropical disturbance from the western Pacific was a main factor of the extreme precipitation event, similar to those reported by Yokoi and Matsumoto (2008) as the main cause of an extreme rain event in central Vietnam in November 1999, and by Wu et al. (2011) in northern Vietnam in October 2008.

3. MJO activity in the tropical atmosphere and occurrences of heavy precipitation events in central Vietnam

Every year between September and November, westward-propagating synoptic-scale tropical disturbances from the western Pacific make landfall or strike the eastern coast of the Indochinese Peninsula, causing heavy precipitation in central Vietnam. So why did this unusually heavy extreme precipitation event occur in early October 2010 when a tropical disturbance struck the region? To answer this question, intraseasonal variations in the tropical atmosphere and occurrences of heavy precipitation events in central Vietnam were investigated in the present study.

As the annual wet season in central Vietnam occurs over the three months from September to November, we investigated MJO activity in the tropical atmosphere during those three months for the 30 years from 1981 to 2010. To assess the relative position and strength of the MJO, an all-season real-time multivariate MJO index was used; see <http://cawcr.gov.au/staff/mwheeler/maproom/RMM/>. The index is based on the first two empirical orthogonal functions (EOFs) of the combined fields for the near-equatorially-averaged 850 hPa and 200 hPa zonal winds, and satellite observations of outgoing longwave radiation (OLR) data (Wheeler and Hendon 2004). The results showed that periods of subseasonal variability or weak to moderate MJO activity took place from September to November in most years from 1981 to 2010 (not shown). However, strong and coherent MJO activities (defined as having an amplitude greater than 2.5 with current phase 3 or 4 continuing for more than two days) were only observed in the five years 1988, 1998, 1999, 2008 and 2010.

As mentioned previously, the MJO is characterized by an eastward progression of large regions of both enhanced and suppressed tropical rainfall. Along with these variations, distinct pat-

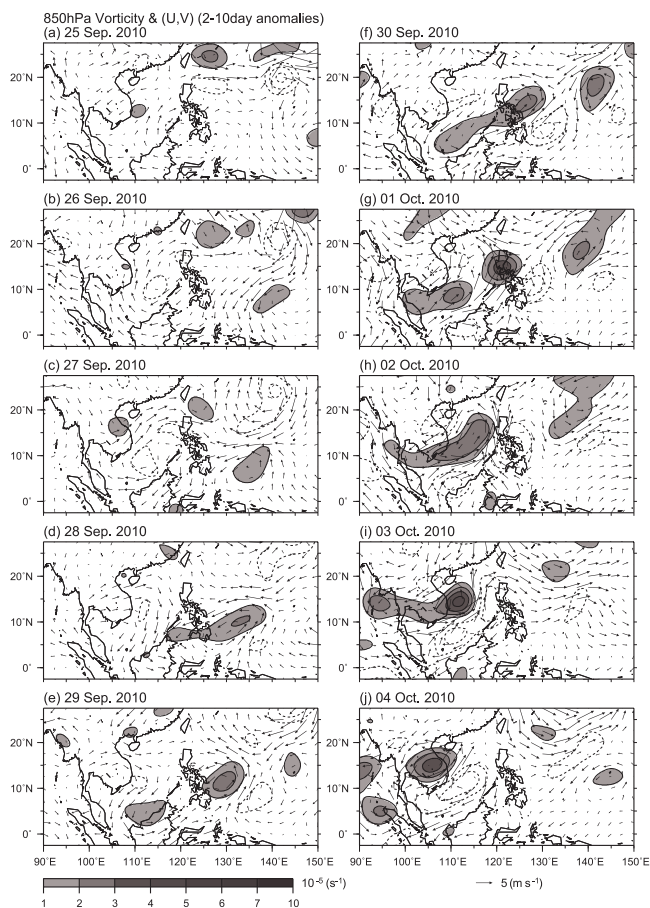


Fig. 3. Evolution of 2-day to 10-day bandpass-filtered 850 hPa winds and vorticity anomalies for 25 September–4 October 2010. Solid contours and shaded areas indicate cyclonic anomalies. Dashed contours represent anticyclonic anomalies. The zero contour has been omitted for clarity. Anomalies are departures from the 1981–2010 daily means.

terns of lower- and upper-level atmospheric circulation anomalies were evident in the tropics and subtropics (Madden and Julian 1994). The 200 hPa velocity potential, which is a derived quantity that isolates the divergent component of the wind at upper levels of the atmosphere and generally corresponds to large regions in which tropical convection tends to be enhanced (or suppressed), is often used to track the development and migration of the MJO. Figure 4 illustrates time longitude plots of 200-hPa velocity potential anomalies during September–November for the five years of strong MJO activity for the 30 years from 1981 to 2010. These clearly indicated a robust MJO activity in these five years, with large negative anomalies and eastward propagation (blue shading, favorable conditions for precipitation). The negative anomalies were typically first evident over the Indian Ocean, and remained in evidence as they propagated over the Maritime Continent region and the western tropical Pacific. Two comparatively strong, coherent MJO events occurred in 2008 and 2010, with larger negative anomalies and more coherent eastward propagation than in other years.

Daily rainfall records at Hue and at Da Nang Meteorological Observatory in central Vietnam were examined for the September–November wet season for each of the five years of strong MJO activity. These indicated that four or more consecutive days of rainfall with maximum daily precipitation greater than 100 mm occurred during each of the strong MJO events at the time of the eastward propagation of the active phase of the MJO over the

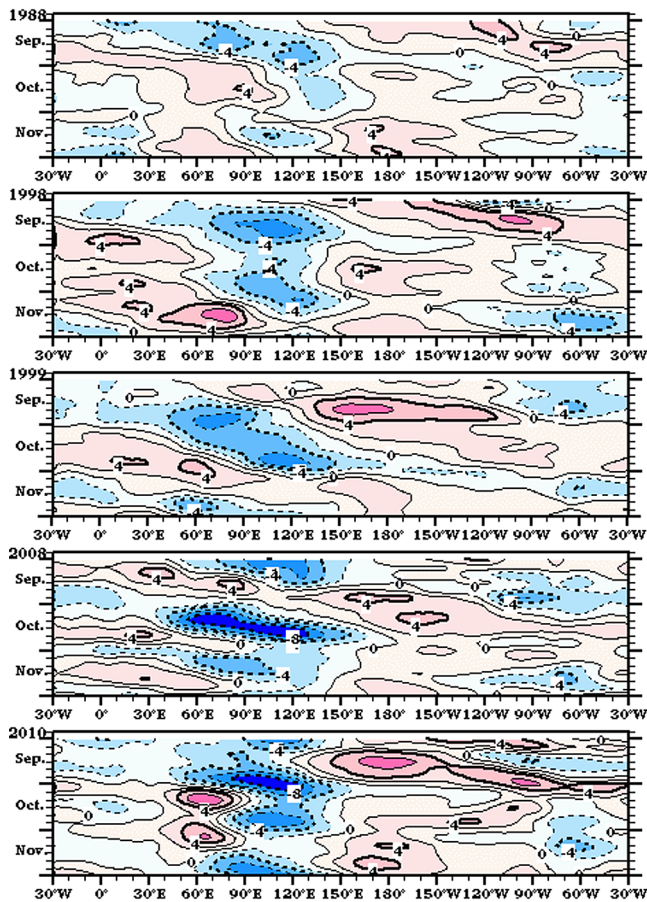


Fig. 4. Time-longitude cross-sections of the five-day running mean of 200 hPa velocity potential anomalies during September–November for the five years of strong MJO activity for the 30 years from 1981 to 2010, averaged over latitude 5°S to 5°N. Contour intervals are $2 \times 10^6 \text{ m}^2 \text{ s}^{-1}$. Anomalies are departures from the 1981–2010 five-day means.

eastern Indian Ocean through the Maritime Continent region (MJO current phase 3 or 4, in which anomalous large-scale upper-level divergences were centered across the Maritime Continent region). Daily rainfalls of 16.0, 30.6 and 111.0 mm were observed at Hue Meteorological Observatory in central Vietnam for 17, 18 and 19 September 1988. Daily rainfalls of 90.2, 103.4 and 34.2 mm were observed at the same observatory for 28, 29 and 30 September 1998; daily rainfalls of 863.7, 977.6 and 272.1 mm were observed at the same observatory for 2, 3 and 4 November 1999, as reported by Yokoi and Matsumoto (2008); and four consecutive days of heavy rainfall at more than 100 mm per day were recorded in central Vietnam on 2 to 5 October 2010.

The MJO strengthened in early September 2008 (Fig. 4) and eastward propagation was observed from September through October (The amplitude of the MJO index greater than 2.5 with current phase 3 or 4 continued during 19 to 25 October 2008). Wu et al. (2011) investigated the causes of the extreme heavy precipitation event in northern Vietnam in October 2008. Their results (their Fig. 4) showed that in late October 2008, when the strong and coherent MJO activities passed over the Maritime Continent, a tropical disturbance developed over the southern South China Sea. However, the close approach of the disturbance to central Vietnam and its strong influence on heavy rainfall in the region took place during 28 to 31 October, after the MJO activity had weakened (its amplitude decreased to less than 2.0 after 28 October), and its center had progressed to the eastern part of the Maritime

Continent region. Daily rainfalls of 51.1, 38.0 and 68.1 mm were observed at Da Nang Meteorological Observatory for 23, 24 and 25 October 2008. Although the strong MJO activity caused a long period of heavy rain on the eastern Vietnam coast in late October 2008, no extreme event occurred in central Vietnam at that time.

To summarize, strong MJO activities occurred during the September–November wet season in five of the 30 years from 1981 to 2010. In each case, a strong MJO episode was accompanied by a long spell of heavy rain in central Vietnam. Unusual extreme precipitation events in November 1999 and October 2010 occurred at the same time as strong MJO activity. Although a strong active phase of the MJO can cause a long spell of heavy rain in central Vietnam, widespread heavy rain over an extended period tends to occur when an active phase of the MJO coincides with a westward propagating synoptic-scale tropical disturbance from the western Pacific.

4. Influences of the MJO on atmospheric circulation and extreme central Vietnam precipitation events

The strongest and most coherent MJO activity in 2010 occurred during late September (Fig. 4), as anomalies increased and eastward propagation was seen through mid-October (The amplitude of the MJO index greater than 2.5 with current phase 3 or 4 continued during 2 to 11 October 2010). Eastward propagation of an active phase of the MJO from the Indian Ocean significantly affects atmospheric circulation in the Maritime Continent and western Pacific regions. Five-day 850 hPa stream function anomalies and wind anomaly vectors are shown in Fig. 5. During the five days 28 September to 2 October 2010, cyclonic circulation anomalies were evident on either side of the equator over the eastern Indian Ocean. Then, over the next five days (3–7 October), the cyclonic circulation anomalies strengthened and moved eastward, and large westerly anomalies were observed across the equatorial Indian Ocean. Note that with the eastward propagation of the active phase of the MJO, southwesterly wind anomalies were evident from northern Sumatra Island to the southern part of the Indochinese Peninsula. Meanwhile, large anticyclonic circulation anomalies were evident over the central-western North Pacific, caused by increased strength and westward extension of the North Pacific subtropical anticyclone (not shown). The contour lines of the stream function anomaly in Fig. 5 are closely spaced across the Philippine Sea and the northern South China Sea, and corresponding easterly anomalies were evident.

As discussed, westward-propagating tropical disturbances are a main factor of heavy rainfall events in the region. The MJO-related impacts on extreme precipitation events are thought to be linked to the development and maintenance of westward-propagating tropical disturbances. Sobel and Maloney (2000) computed barotropic wave activity flux divergence over the western Pacific for different phases of the MJO, and showed that barotropic wave accumulation may be enhanced during active periods of the MJO. In summer, the southwestern monsoon wind prevails over the Indochinese Peninsula and the South China Sea. The general character of westerlies meeting easterlies somewhere near the monsoon trough region is always present (Holland 1995). Wave accumulation is an important mechanism in the development of tropical depression-type (TD-type) disturbances over the Northwestern Pacific due to strong, large-scale convergence in the lower troposphere (e.g., Sobel and Bretherton 1999).

The summer monsoon in the region withdraws in September. Northeasterly winter monsoon gradually takes place from October. However, in early October 2010, at the time of the heavy rain event in central Vietnam, with the eastward propagation of the strong active convective phase of the MJO, large westerly anomalies were observed across the eastern Indian Ocean and the Indochina Peninsula (Fig. 5). Convergence of the zonal winds was evident over the South China Sea. The above results suggest that a possible mechanism for the MJO influences on tropical disturbances is a wave energy accumulation. Besides wave accumula-

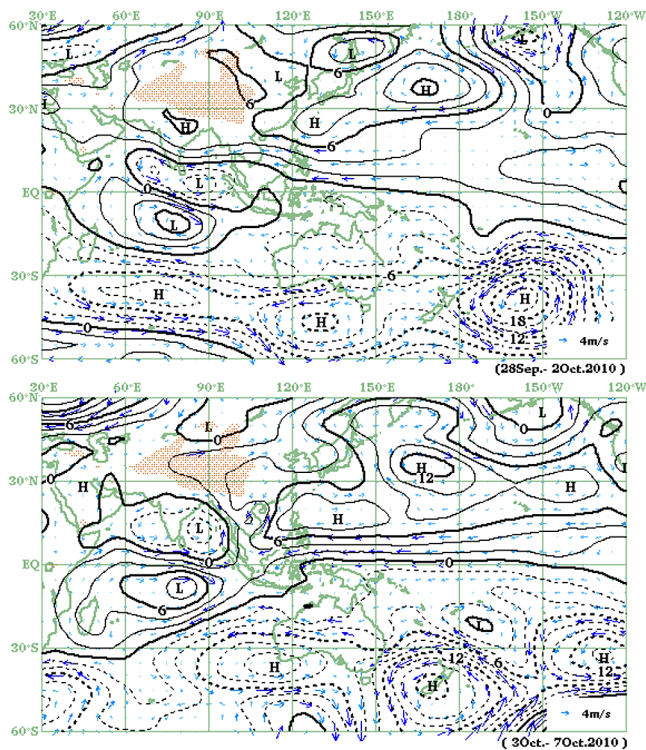


Fig. 5. Five-day mean 850 hPa stream function anomalies and wind anomaly vectors for 28 September–2 October and for 3 October–7 October 2010. The contours show stream function anomalies at intervals of $2 \times 10^6 \text{ m}^2 \text{ s}^{-1}$. Anomalies are departures from the 1981–2010 five-day means.

tion, many other factors such as barotropic instability, latent and sensible heat fluxes through ocean surface, and cumulus convection can also contribute to the intensification and maintenance of tropical disturbances. Further studies employing numerical experiments with the aid of regional circulation models are needed to reveal the detailed physical mechanism by which the MJO induces extreme precipitation in the region.

5. Summary

The present study investigated the atmospheric circulations leading to the unusual widespread heavy precipitation event that occurred in central Vietnam in early October 2010, by analyzing data from the Japan Meteorological Agency Climate Data Assimilation System (JCDAS). The results show that a westward-propagating synoptic-scale tropical disturbance from the western Pacific was the primary cause of the extreme event. Meanwhile, eastward propagation of a strong active phase of the MJO from the Indian Ocean provided conditions that were conducive to the growth and

maintenance of tropical disturbances. A possible mechanism by which the MJO impacts extreme central Vietnam precipitation is a wave energy accumulation that is enhanced by an active phase of the MJO.

Investigation of MJO activity during wet seasons in the region for the 30 years from 1981 to 2010 showed that extended period of heavy rain occurred in central Vietnam during strong MJO activities, and two extraordinary extreme precipitation events in November 1999 and October 2010 coincided with a strong active phase of the MJO and a westward-propagating synoptic-scale tropical disturbance from the western Pacific. We have argued that the intraseasonal oscillations in the tropical atmosphere are an important factor in the formation of heavy precipitation in central Vietnam. It is noted that the MJO is only one of many factors contributing to the formation of heavy precipitation in central Vietnam. Simultaneous occurrences of an active phase of the MJO with other factors such as a westward-propagating tropical disturbance and the strong northeasterly winter monsoon are favorable conditions for extreme heavy precipitation in the region.

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References

- Holland, G. J., 1995: Scale interaction in the western Pacific monsoon. *Meteor. Atmos. Phys.*, **56**, 57–79.
- Madden, R. A., and P. R. Julian, 1994: Observations of the 40–50-Day tropical oscillation – A review. *Mon. Wea. Rev.*, **122**, 814–837.
- Sobel, A. H., and C. S. Bretherton, 1999: Development of synoptic-scale disturbances over the summertime tropical northwest Pacific. *J. Atmos. Sci.*, **56**, 3106–3127.
- Sobel, A. H., and E. D. Maloney, 2000: Effect of ENSO and the MJO on western north Pacific tropical cyclones. *Geophys. Res. Lett.*, **27**, 1739–1742.
- Wheeler, M., and H. Hendon, 2004: An all-season real-time multivariate MJO index: Development of an index for monitoring and prediction. *Mon. Wea. Rev.*, **132**, 1917–1932.
- Wu, P., Y. Fukutomi, and J. Matsumoto, 2011: An observational study of the extremely heavy rain event in northern Vietnam during 30 October–1 November 2008. *J. Meteor. Soc. Japan*, **89A**, 331–344.
- Yokoi, S., and J. Matsumoto, 2008: Collaborative effects of cold surge and tropical depression-type disturbance on heavy rainfall in central Vietnam. *Mon. Wea. Rev.*, **136**, 3275–3287.

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