Collaborative Effect of a Cold Surge and Tropical Intraseasonal Variation on a Heavy Rainfall in Central Vietnam

Satoru Yokoi[1], Jun Matsumoto[2,3]
[1]Center for Climate System Research, University of Tokyo, Japan
[2]Department of Geography, Tokyo Metropolitan University, Japan
[3]Institute of Observational Research for Global Change, Japan Agency for Marine-Earth Science and Technology, Japan
Correspondence: yokoi@ccsr.u-tokyo.ac.jp

INTRODUCTION

On 2-3 November 1999, a heavy rainfall event occurred in the coastal region of central Vietnam (Fig. 1). At Hue observation site, for example, precipitation in these two days reached 1841 mm (Fig. 2), which was the largest record in the last 50 years. In addition, precipitation amounts greater than 700 mm $(2days)^{-1}$ were recorded at Da Nang and Nong Son cities which are located southeast of Hue city. Hereafter, this event is called NOV99 for short. We study on synoptic-scale conditions over the South China Sea (SCS) to discuss mechanisms responsible for the heavy rainfall event through case study and composite analysis.

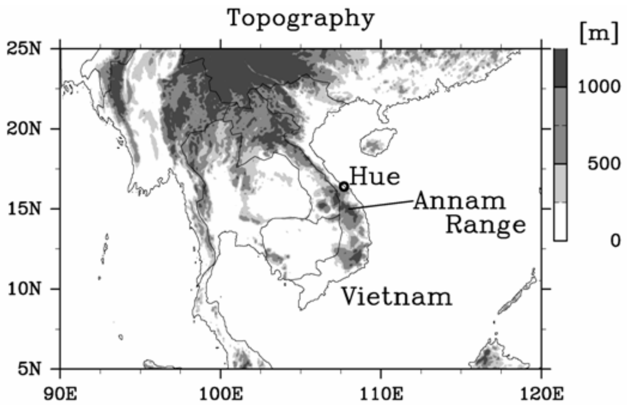

Figure 1 Topography.

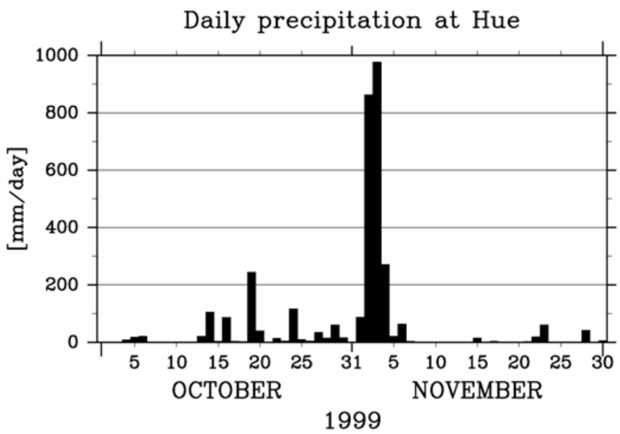

Figure 2 Daily precipitation at Hue site.

DATA

The atmospheric circulation dataset used in this study is the Japanese 25-year Re-Analysis (JRA-25, Onogi et al. 2007) provided by Japan Meteorological Agency (JMA) and Central Research Institute of Electric Power Industry (CRIEPI). This study also uses daily station rainfall data in eastern Indochina Peninsula (ICP). These data were routinely collected by the Department of Meteorology and Hydrology of Laos (8 stations), the Department of Meteorology of Cambodia (4 stations), and the National Hydrometeorological Service of Vietnam (52 stations).

SYNOPTIC-SCALE CONDITONS DURING THE EVENT

In this section, we will examine the synoptic-scale circulation field in the lower troposphere during the NOV99 event. The horizontal wind field at the 925-hPa level (Fig. 3) shows that strong northeasterly wind prevailed in northern part of the SCS whose speed was about twice greater than that of climatological northeasterly monsoon wind there. This stronger-than-usual wind was a result of a cold surge (CS). The northerly wind signal originated at 40N and propagated southward to reach the northern SCS on 2 November (Fig. 4a). This signal was accompanied to its south by a horizontal convergence (Fig. 4b) and to its north by a negative temperature anomaly from daily climatology (Fig. 4c). These characteristics are consistent with well-known CS features revealed by many researchers (e.g. Chang et al. 1979; Lau and Lau 1984; Compo et al. 1999).

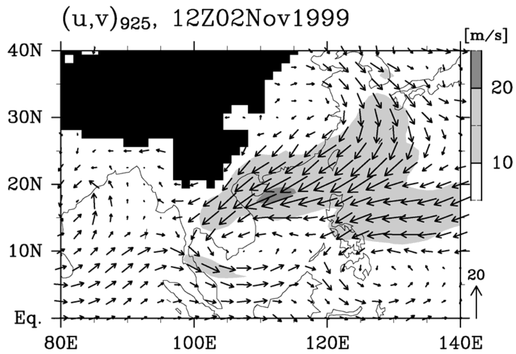

Figure 3 Horizontal wind (vector) and its speed (shadings) at the 925-hPa level at 1200 UTC 2 November 1999. Reference vector corresponds to value of 20 m s^{-1}.

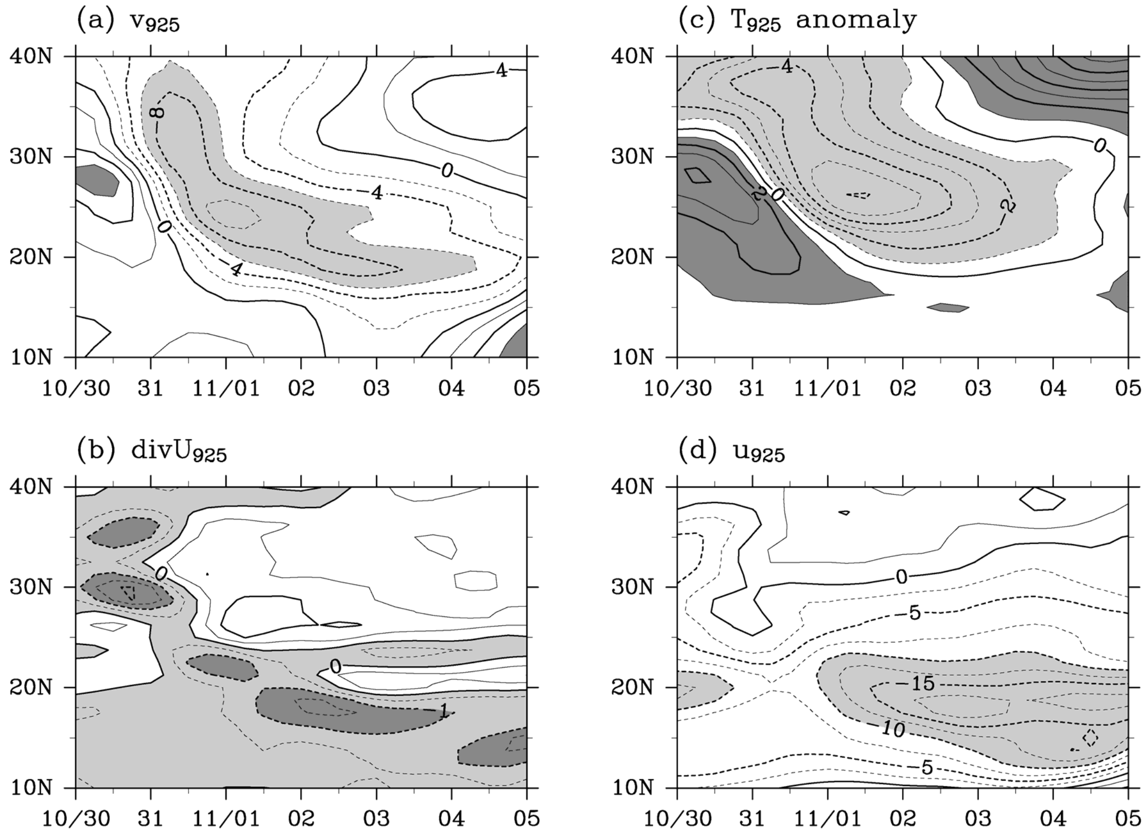

Figure 4 Time-latitude cross-section of (a) meridional wind [m s^{-1}], (b) horizontal divergence [s^{-1}], (c) temperature anomaly [K], and (d) zonal wind [m s^{-1}] at the 925-hPa level averaged in 110-120E.

One of the distinctive features of this CS was observed when the northerly wind signal reached the northern SCS. While ordinary CS signals propagate further southward to at least 10N (Chang et al. 1983), the signal of this CS stopped propagation and lingered at around 20N until 5 November (Fig. 4a). Concurrently, an easterly wind began to strengthen at the same latitude (Fig. 4d), resulting in stronger-than-usual northeasterly wind continuously blowing into the ICP against the Annam Range for a couple of days.

In order to discuss the reason for this lingering feature, Fig. 5a shows meridional wind anomaly from daily climatology at the 925-hPa level. A southerly wind anomaly was found over central SCS whose magnitude was 6 m s^{-1}. This southerly wind anomaly seemed to prevent the CS from propagating further southward, possibly through changing the dynamic balance on the meridional propagation of the CS. Since southward propagation speed of the CS in 20-25N can be estimated at 5 m s^{-1} from Fig. 4a, the southerly wind anomaly could block the southward propagation.

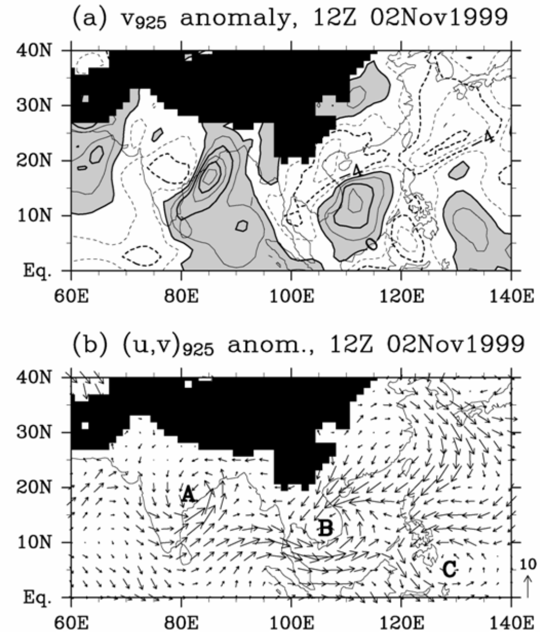

Figure 5 (a) Meridional wind anomaly (positive anomaly shaded) and (b) horizontal wind anomaly vector at the 925-hPa level at 1200 UTC 2 November 1999. Reference vector corresponds to value of 10 m s^{-1}.

In addition to the blocking effect, the southerly wind anomaly seemed to contribute to the heavy rainfall in the following two ways. First, the anomaly formed a strong horizontal convergence in the lower troposphere off central Vietnam in collaboration with the northeasterly wind of the CS (see Fig. 4b). Second, the anomaly tended to transport the warm and humid tropical air into the northern SCS, particularly prior to the arrival of the CS. These effects made the lower troposphere more unstable and favorable for convection.

This southerly wind anomaly was a component of a cyclonic circulation anomaly centered over southeastern ICP, which is marked as B in Fig. 5b. This circulation anomaly had a horizontal scale of about 2000 km, exhibited almost standing vertical structure below the 300-hPa level, and had propagated westward with a speed of 7-8 m s^{-1}. These spatiotemporal structures are considerably similar to that of the tropical depression-type disturbance (TDD) (Takayabu and Nitta 1993). In addition to this disturbance, there were two other TDDs marked as A and C in Fig. 5b, aligning in a west-northwest to east-southeast direction.

In the equatorial region, the large-scale circulation field was characterized by intraseasonal variation (ISV) with a 30-60-day timescale. The velocity potential anomaly field at the 150-hPa level (Fig. 6a) exhibited a zonal wavenumber 1 structure with a negative maximum over the maritime continent which represents active convection. This negative anomaly originated over the Indian Ocean in late September and propagated eastward (Fig. 6b). The relationship between the ISV convective signal centered over the maritime continent and the low-level circulation anomaly field in the subtropics shown in Fig. 5b is in good accordance with that of the ISV during boreal summer. This accordance suggests that the TDD train can be regarded as a result of a Rossby wave response to the equatorial ISV convective anomaly, as discussed in Kemball-Cook and Wang (2001).

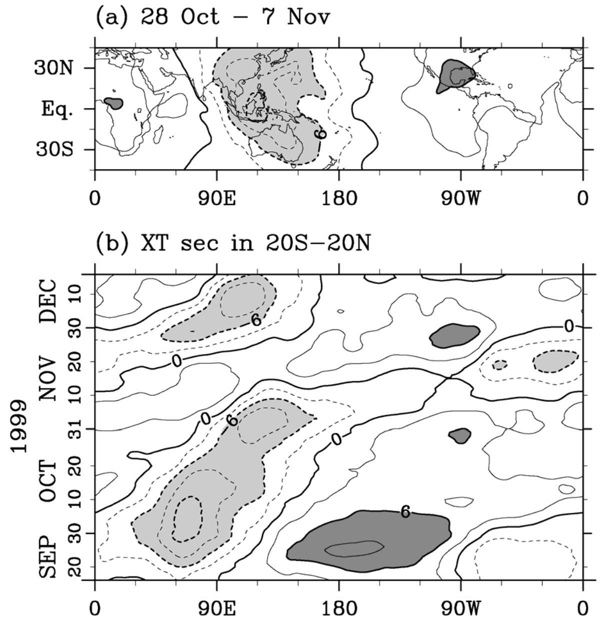

Figure 6 (a) Velocity potential anomaly at the 150-hPa level averaged over 11-day period from 28 October to 7 November 1999. Contour interval is $3x10^6$ m^2 s^{-1}. (b) Longitude-time cross-section of 11-day running mean velocity potential anomaly averaged in 20S-20N. Contour interval is the same as in (a).

COMPOSITE ANALYSIS

The case study suggests that coexistence of CS and TDD is important for the heavy rainfall occurrence in central Vietnam. In order to confirm this idea, we performed composite analysis. With the use of the JRA-25 data in the October-November periods of 1979-2002, we identified 33 cases where only a CS exists (CS-only), 62 cases where only a TDD exists (TDD-only), and 6 cases where both CS and TDD exist (CS-TDD). The composite horizontal wind anomaly over and around the SCS of CS-TDD cases at the 925-hPa level (Fig. 7) is quite similar to in Fig. 5b. Figure 8a-c shows composite precipitation in eastern part of the ICP for these three groups. CS-TDD is associated with much more rainfall than CS-only and TDD-only. Composite precipitation averaged in 9 coastal stations shown in Fig. 8e is 67.4 mm day^{-1} for CS-TDD, 24.1 mm day^{-1} for CS-only, and 40.8 mm day^{-1} for TDD-only. The differences between CS-TDD and the others are statistically significant at a 95% confidence level. In addition, composite precipitation of CS-only case is only comparable to the October-November climatology (Fig. 8d). Thus, we can conclude that a CS cannot independently cause heavy rainfall in central Vietnam.

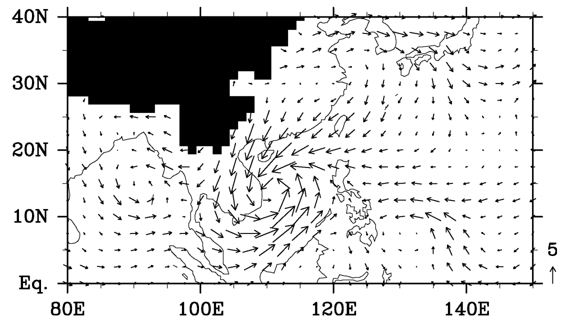

Figure 7 Composite horizontal wind anomaly of CS-TDD at the 925-hPa level. Reference vector corresponds to value of 5 m s^{-1}.

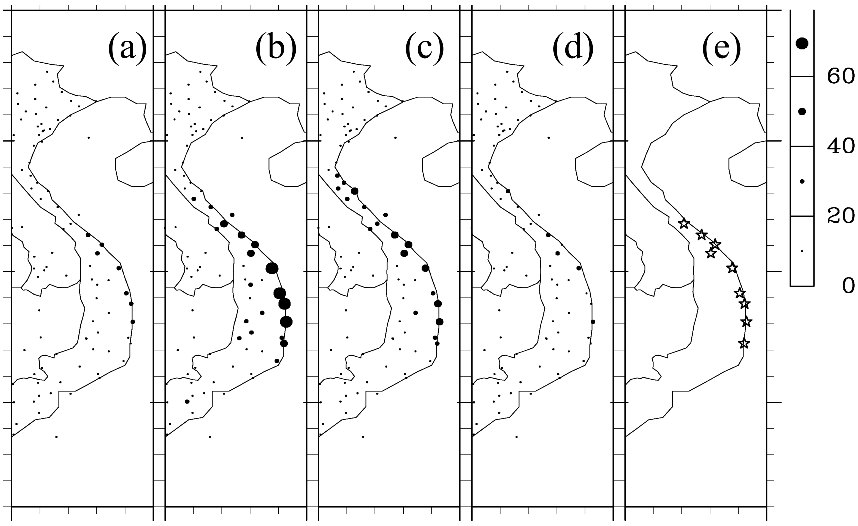

Figure 8 Composite precipitation [mm day^{-1}] of (a) CS-only, (b) CS-TDD, and (c) TDD-only. (d) October-November climatological precipitation [mm day^{-1}]. (e) Nine coastal stations.

CONCLUSIONS AND DISCUSSION

Through the case study and composite analysis, we can conclude that the collaborative effect of the CS and TDD is important for the heavy rainfall occurrence in central Vietnam. As to the NOV99 event, the TDD was associated with the tropical ISV.

It is interesting to note that the coexistence of the CS and TDD over central SCS is a peculiar feature during the October-November period. This is because almost all CSs are found in the period from middle October to March, while the TDDs are frequently observed in central SCS during October-November but hardly found in the following period (December-March). More detailed discussion on this matter is presented in Yokoi and Matsumoto (2008).

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