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Migration of contact binary cyclones and atmospheric river: Case of explosive extratropical cyclones in East Asia on December 16, 2014

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ABSTRACT

Contact binary cyclones have been observed often in the marginal sea areas of East Asia; however, their explosive development and related moisture transport are not understood fully. This study investigated explosive extratropical binary cyclones that occurred near Japan on December 16, 2014, to elucidate both their explosive development and their efficient transport of moisture northward. The northernmost of the binary cyclones developed with a central pressure fall of 24 hPa during a 24-h period. It remained over the Japan Sea, where a trough and an area of high potential vorticity were located at 300 hPa. The southernmost of the binary cyclones developed explosively with a central pressure fall of 58 hPa during a 24-h period. It traveled rapidly around the northern low in a counterclockwise direction. The contact binary cyclones accompanied a tributary atmospheric river and moist delta, which aided the rapid development of the southern low. The tributary atmospheric river was formed by the regional convergence of humid air parcels that were modified by the surface moisture flux around the cold front (though the atmospheric river was extended from the tropical Pacific Ocean). As the southern low developed, northward moisture transport was predominant along the atmospheric river. In the explosive binary cyclones, the influence of latent heat release differed between the two contact lows. While the northern low was coupled with the upper-level trough over the Japan Sea, the southern surface low, which revolved around the northern low, was intensified both by the latent heat release and by the warm horizontal thermal advection and the vorticity advection along a front. Condensational latent heating did not influence substantially the pressure drop of the northern low, whereas it contributed considerably to the formation of the southern low and to the enhancement of the northward moisture transport along the atmospheric river.

1. Introduction

Binary cyclones, which consist of pairs of cyclones, have been observed at mid- and high latitudes. Ziv and Alpert (1995) and Renfrew et al. (1997) have investigated the binary rotations of such cyclone pairs. Ziv and Alpert (2003) discussed contact binary rotation from the perspective of potential vorticity (PV) and they highlighted that mid-latitude binary systems are associated with at least one upper-level PV anomaly. Such binary cyclones have been observed often in the marginal sea areas of East Asia, where extratropical cyclones follow two distinct tracks: along the southern coast of Japan and across the Japan Sea (e.g., Adachi and Kimura, 2007). Yamamoto (2012), who reported on twin extratropical cyclones in the presence of a single jet in October 2001, found heavy precipitation mechanisms associated with the rapid merging of the weak twin cyclones. In several cases, explosive binary cyclones have been observed in the presence of one or more upper-level jet. The migration and development characteristics of binary cyclones can have substantial influence on severe weather in Japan. However, the dynamics of such explosive binary cyclones within

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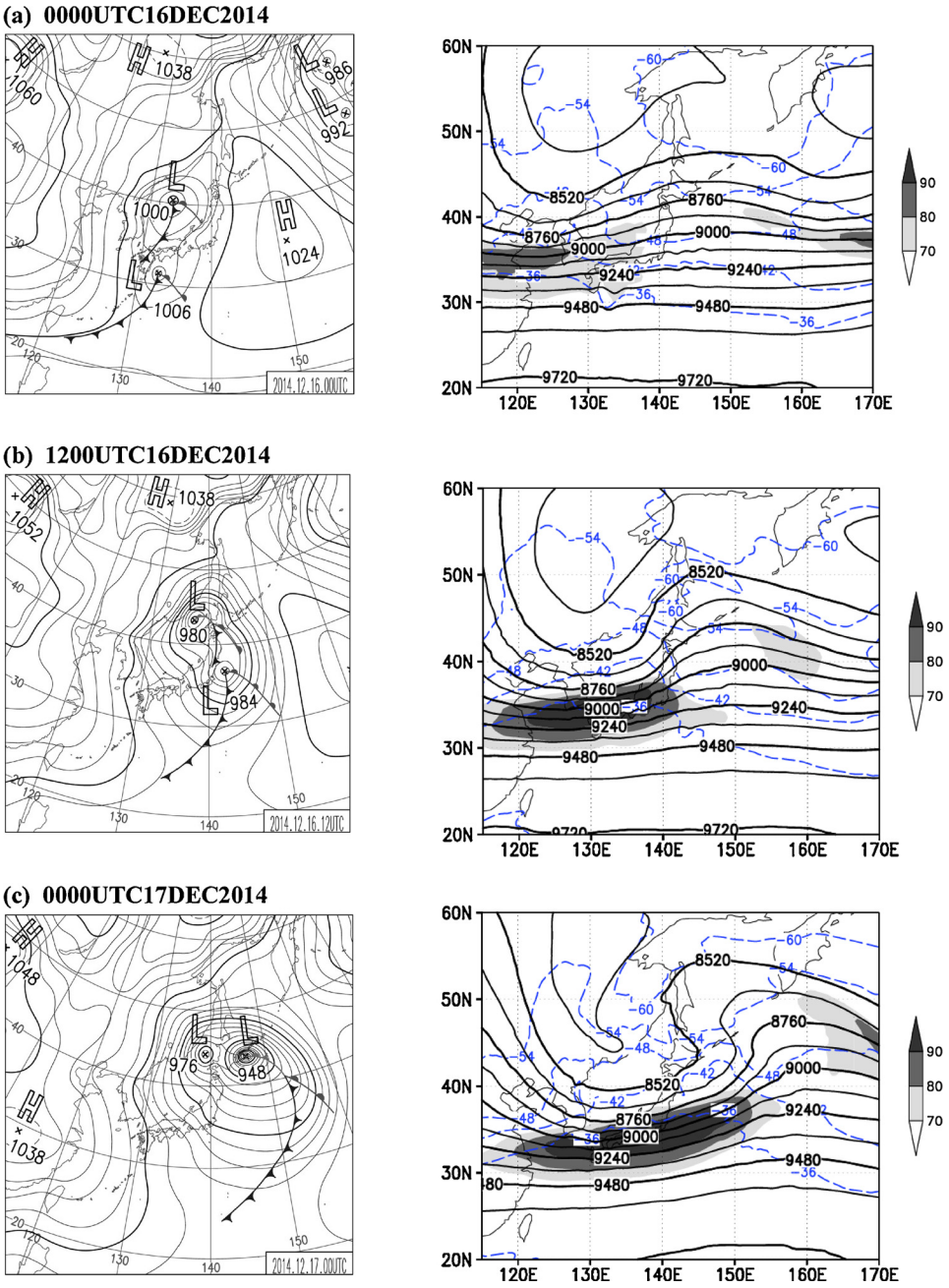

Fig. 1. Horizontal distributions of the Japan Meteorological Agency (JMA) weather charts at the surface (left-hand side) and JMA GSM geopotential height at 300-hPa (m, solid curves) (right-hand side): (a) 0000 UTC and (b) 1200 UTC on December 16 and (c) 0000 UTC on December 17, 2014. Dashed curve and shading indicate air temperature (°C) and horizontal wind magnitude (m s^{-1}), respectively.

a baroclinic fluid have yet to be understood fully, although the dynamical interactions of binary tropical cyclones (e.g., Fujiwara, 1923) have been investigated within barotropic fluids (Chang, 1983).

Generally, explosive cyclogenesis is influenced by upper-level PV and condensational latent heat release (e.g., Chen et al., 1983; Hoskins et al., 1985; Takayabu, 1991; Reed et al., 1993; Kuwano-Yoshida and Asuma, 2008; Fu et al., 2014; Hirata et al., 2015, 2016; Heo et al., 2015), together with sea surface temperature conditions (e.g., Xie et al., 2002; Yamamoto and Hirose, 2007; Katsafados et al., 2011; Booth et al., 2012; Yamamoto, 2013). In particular, upper-level PV and condensational latent heat release could complicate the dynamics of binary explosive cyclones through different rates of pressure fall, which could lead to the asymmetric structure and merging of the two cyclones. However, these dynamical effects on explosive binary lows have not been examined fully.

On December 16, 2014, a very strong extratropical cyclone with a 24-h pressure drop of 2.96 Bergeron (> 50 hPa) was observed