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A study of the formation mechanism of a long convection band over the Yellow Sea

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ABSTRACT

Observational and numerical investigations have been conducted to explain the formation of a long, quasi-stationary convection band (CB) that occurred over the Yellow Sea between August 1 and 2, 2008, in association with a synoptic-scale trough extending across the sea along the northwestern edge of the western Pacific subtropical high. The observations show that a line of weak echoes begins to appear over the Yellow Sea after 2030 UTC on August 1 and develops into a well-defined CB at approximately 0000 UTC on August 2, 2008. The life of the CB is divided into three stages: 1) initiation, 2) development, and 3) maturity. The initiation of the CB proceeds slowly and simultaneously along a long line over a period of approximately 2 h. The mature CB remains at nearly the same location until approximately 0300 UTC and is 10–20 km wide and greater than 300 km long. Both the observations and a numerical simulation show that the CB is initiated in an area of prevailing southwesterly surface winds to the south of an existing convection line, which is found to occur along or near a surface wind shift line. A cold pool or associated outflow is not observed at or near the existing convection line or the CB. The numerical simulation indicates that the convergence line along which the CB forms develops at the southern edge of a low-level convergence layer within a confluent flow associated with the extended trough. The formation of this convergence line appears to be related mainly to the southeastward movement of the low-level trough and convective circulation associated with an existing linear convective system.

1. Introduction

Convection bands (CBs) are often observed over the Yellow Sea and the Korean peninsula during the summer. These CBs are narrow bands of convective systems with no trailing stratiform precipitation (Lee and Kim, 2007) (e.g., Fig. 1). In general, they are 10–20 km wide and 100–300 km long, and tend to be quasi-stationary for several hours as embedded convective cells move along the band (Lee and Kim, 2007). Because of these features, a CB tends to concentrate a large amount of rainfall over a narrow area along the band, often causing serious losses of life and property. According to Lee and Kim (2007), CB-type heavy precipitation systems (HPSs) are one of the major types of heavy rainfall events over South Korea. However, forecasts of heavy rainfall associated with CB-type HPSs remain difficult, mainly due to the poor understanding of CB initiation processes.

Linear convective systems often form along the Meiyu/Baiu frontal zone in Eastern Asia. Several observational studies have noted that rainbands in the Meiyu/Baiu frontal zone bear a remarkable resemblance to midlatitude or tropical squall lines, which are characterized by convective updrafts and downdrafts at the leading edge and a rearward-extending trailing stratiform region (e.g., Chong et al., 1987; Geng et al., 2004; Ishihara et al., 1995; Wang et al., 1990). However, the structure of the linear convective systems along the Meiyu/Baiu frontal zones differs from that of CBs over the Korean peninsula. In general, CBs consist of a line of convective cells with no rearward-extending trailing stratiform region. Furthermore, CBs occur in both Changma (as the Meiyu in China and the Baiu in Japan) and post-Changma periods (including September). The Changma period generally commences in late June and ends in mid-July (Oh et al., 1997), similar to the Meiyu and Baiu, which begin in early to mid-June (Ding and Chan, 2005; Sampe and Xie, 2010). This discrepancy in the structure and environmental conditions between the CBs and the linear convective systems along the Meiyu/Baiu frontal zones implies that the initiation and development process of CBs may be different from those of the linear systems along the Meiyu/Baiu frontal zones.

Many studies suggest that linear triggers are of first-order importance in the formation of linearly organized mesoscale convective systems (MCSs) in the midlatitudes (Parker and Johnson, 2000) and that these triggers can be achieved by various air mass boundaries near the surface, such as fronts or outflow boundaries. Bluestein and Jain (1985) found that a significant percentage of squall lines in Oklahoma form in association with surface cold fronts and/or dry lines. Schumacher and Johnson (2005) found that one pattern of MCS organization (termed the "training line/adjoining stratiform," or TL/AS) often

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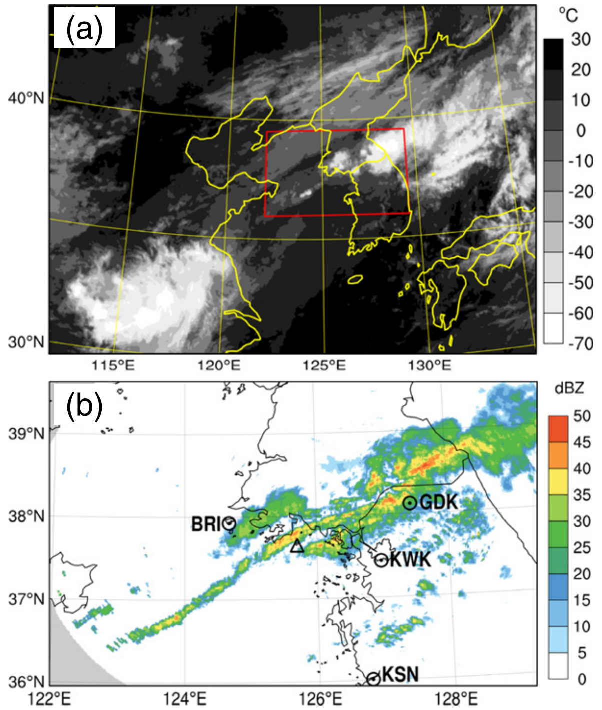

Fig. 1. (a) MTSAT-1R image and (b) CAPPI 1.5 km radar image from 0000 UTC on August 2, 2008. Satellite image is from 0030 UTC. The red box in (a) is the area of the radar image in (b). The radar image is derived from Baengnyeongdo (BRI), Gwangdeoksan (GDK), Gwanaksan (KWK), and Oseongsan (KSN) radar observations. The triangle indicates the location of the Daeyeonpyeong station.

forms on the cool side of and parallel to a pre-existing slow-moving synoptic boundary and that the other pattern (termed the "back-building/quasi-stationary," or BB) is more dependent on mesoscale and storm-scale processes and forcings, such as outflow boundaries.

In certain cases, linear convective systems form along a boundary-layer convergence line related to various processes. For example, Fankhauser (1974) demonstrated the presence of strong boundary layer convergence along a confluence asymptote prior to the appearance of a line of radar echoes in the USA. In the UK, Golding et al. (2005) and Warren et al. (2014) showed that convective initiation was maintained by lifting along a quasi-stationary boundary-layer convergence line because of a sea-breeze circulation along the west coast. In Japan and Taiwan, certain linear systems form along low-level convergence lines that are associated with various orographic effects (e.g., Adachi et al., 2004; Li et al., 1997; Yoshizaki et al., 2000).

Convection bands around the Korean peninsula are initiated mainly over the Yellow Sea where no significant terrain features exist. They also tend to form in large-scale confluence areas where no significant surface boundaries have been reported (e.g., Lee and Kim, 2007; Sun and Lee, 2002). Sun and Lee (2002) found that the CB developed through an interaction between convection and large-scale convergent flows. However, the formation mechanism of the low-level convergence line was not presented.

The convection band examined in this study occurred on August 1 and 2, 2008, and exhibited several typical features of CBs, such as a well-defined linear organization of convective systems, no trailing stratiform precipitation, and quasi-stationary behavior. Additionally, the CB initiated along an entire line across the Yellow Sea approximately simultaneously. This paper presents a case study of this CB with a focus on understanding the processes of CB initiation and development. Both observation data and numerical simulations are used in this study.

The structure of this paper is arranged as follows. In Section 2, the observational dataset and the setup of the modeling experiments are described. The synoptic-scale and mesoscale environment, initiation and evolution of the CB are analyzed in Section 3 using various observation data. In Section 4, numerical simulations are used to explain the initiation of the CB and its development into a well-defined CB. Section 5 presents a summary and conclusions.

2. Observational data and numerical model

2.1. Observational data

Observations were analyzed to describe the initiation and evolution of a CB that occurred over the Yellow Sea between approximately 2030 UTC on August 1 and 0600 UTC on August 2, 2008. The observational data used in this study include synoptic weather station and automatic weather station (AWS) data, rawinsonde data, radar images, buoy station data, multi-functional transport satellite (MTSAT) images, ocean surface wind data from the QuikSCAT (Fore et al., 2014), and NCEP climate forecast system reanalysis (CFSR) data (0.5° × 0.5°) (Saha et al., 2010). MTSAT images are provided by the Japan Meteorological Agency, and the QuikSCAT data used here is the JPL version 3 dataset distributed through PO.DAAC (SeaPAC, 2013). All other observation data are provided by the Korea Meteorological Administration (KMA).

Composite radar reflectivity at 1.5 km was obtained using the constant altitude plan position indicator (CAPPI) data from the Baengnyeongdo (BRI, C-band), Gwangdeoksan (GDK, S-band), Gwanaksan (KWK, S-band), and Oseongsan (KSN, S-band) radar stations operated by KMA. The radar data were interpolated in a Cartesian coordinate system with a horizontal grid interval of 1.0 km. The geography and the locations of important stations are shown in Fig. 2.

2.2. Numerical model and configurations

Numerical simulations were performed using the WRF model version 3.4.1 (Skamarock et al., 2008) to better understand the formation processes, structure, and development mechanism of the studied CB. A one-way nested grid system was used for three domains with 18-, 6-, and 2-km grids, for which time steps of 60, 20, and 10 s are used, respectively (Fig. 2). The three domains contained 151 × 151, 256 × 235, and 463 × 385 horizontal grid points, respectively, and all domains had 41 vertical layers with a terrain-following eta (η) coordinate. The model top was set at 50 hPa.

Improved modeling of clouds and precipitation processes can produce a more realistic simulation of mesoscale precipitation systems

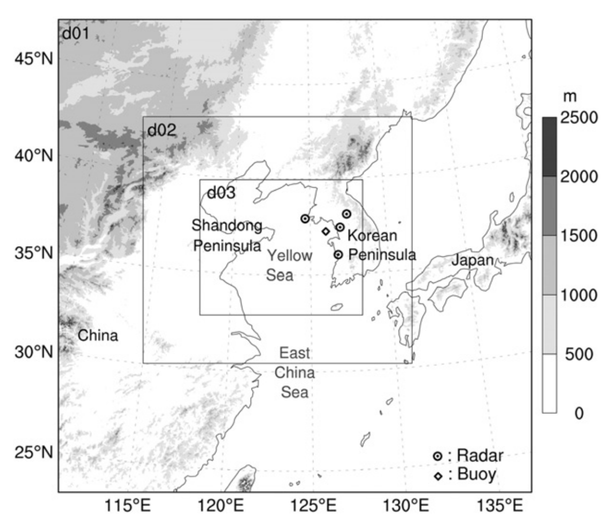

Fig. 2. The geography and topography (shaded, m) around the Korean peninsula. The circled dots and diamond indicate the locations of the radar sites and the buoy station, respectively, used in this study. Boxes show the three simulation domains with 18 (d01), 6 (d02), and 2 km (d03) grid sizes.