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Modification of misovortices during landfall in the Japan Sea coastal region

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ABSTRACT

Misovortices frequently occur near the coastline of the Japan Sea during wintertime cold air outbreaks, generally developing over the sea and moving inland. To clarify the behavior of misovortices during landfall, temporal changes in the intensity and tilt of 12 misovortices over the coastal region of the Japan Sea were investigated during the winters of 2010/11 and 2011/12 using an X-band Doppler radar. For 11 vortices whose diameters were more than twice the effective radar beamwidth, the temporal change in the peak tangential velocity at lower levels (averaged below 400 m AGL) was analyzed. It was found that 8 out of the 11 vortices decreased after progressing between 0 and 6 km inland. For the remaining three vortices, the patterns of Doppler velocity couplet became unclear between 0 and 5 km inland, suggesting that these vortices also decayed soon after landfall. For four of the vortices, for which the analysis of the temporal evolution of tilt with height was made possible by several successive volume scans, the forward tilt with height increased after landfall. This study showed that modification to both the intensity and tilt with height of misovortices occurred after landfall.

1. Introduction

The structures and generation mechanisms of tornadoes have been studied by various methods such as theoretical study, laboratory experiment, numerical experiment, and field observation (recent reviews of the above subjects can be found in Wurman et al., 2012; Bluestein, 2013; Rotunno, 2013; Davies-Jones, 2014). Surface roughness is one factor that has significant impact on the flow structure and intensity of a tornado, which has been investigated by these means (e.g., Church and Snow, 1993; Natarajan and Hangan, 2012). The coast is one place where the effects of surface roughness on a tornado may be examined observationally because the surface roughness experienced by these vortices changes considerably during their landfall. Thus, places where the landfall of waterspouts (i.e., tornadoes that form over a water surface) and misovortices are frequently observed can be suitable locations and "natural laboratories" where the effects of surface roughness on these vortices might be examined. Such areas are the southeast Florida Coast (e.g., Golden, 1977); Great Lakes of North America (e.g., Steiger et al., 2013); coastal areas in the Adriatic, Aegean, Ionian, and Baltic Seas in Europe (e.g., Sioutas et al., 2013); and coasts around the Japan Sea (e.g., Niino et al., 1997). A few examples of the landfall processes of a waterspout (e.g., Golden, 1968, 1971) and a tornado (e.g., Kobayashi et al., 2007) have been documented using time-sequenced photographs. However, a Doppler radar, which can reveal the inner characteristics of the vortices, has not been previously used to document their temporal evolution during landfall. Therefore, as an initial step, it is important to

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evaluate how the vortices are modified during landfall using a Doppler radar.

When tornadoes, waterspouts, and misovortices make landfall, they can cause damage (e.g., Inoue et al., 2011) and even fatalities (for waterspouts in the Ionian Sea, see Sioutas and Keul, 2007). For example, on September 17, 2006, an F2 tornado developed over the sea and made landfall over Nobeoka City, which is located on the east coast of Kyusyu Island, Japan, causing severe damage, including the overturning of railcars, and three fatalities (Mashiko et al., 2009). It is therefore important to clarify the landfall processes of these vortices, especially with regard to their strength, in places where these vortices frequently make landfall.

In Japan, tornado occurrence is concentrated in coastal regions (Niino et al., 1997). In winter, tornadoes, waterspouts, and misovortices associated with enhanced cumulus cloud activity occur near the coastline of the Japan Sea during cold air outbreaks over the warm sea surface. A statistical analysis of tornadoes and waterspouts in Japan from 1961–1993 has indicated that such winter-monsoon tornadoes constitute 12% of all occurring tornadoes (Niino et al., 1997). To further the understanding of these vortices, a radar-based observation campaign was undertaken in the coastal region of the Japan Sea during winter as part of “The Shonai Area Railroad Weather Project.” The Shonai area is located on the coast of the Japan Sea. The project was designed in 2007 to investigate the fine-scale structure of wind gusts using two X-band Doppler radars and a network of 26 surface weather stations, to develop an automatic strong-gust detection system for railroads (Kusunoki et al., 2008; Inoue et al., 2011; Nishihashi et al., 2013). One of the most notable findings was that most of the strong wind gusts during the winter season were related to the passage of misovortices (Kusunoki et al., 2009) and tornadoes (e.g., Inoue et al., 2011), and most of these had developed over the sea and subsequently made landfall. This indicates that our chosen observation area is a suitable location and a “natural laboratory” within which to examine the modification of vortices during landfall.

Two case studies examined the changes in the properties of tornadoes and misovortices during landfall in the Japan Sea coastal region. Kusunoki et al. (2011) showed that the forward tilt of a tornadic vortex increased with height during landfall; however, the detailed temporal evolution of the properties of the vortex during landfall was not considered. Inoue et al. (2011) reported the detailed temporal evolution of the properties of a tornado and a misovortex during landfall in the winter of 2007/2008, and showed that the peak tangential velocities of the vortices increased just before landfall and decreased soon after. However, they did not discuss the vertical structures of these phenomena because they operated a Doppler radar in a single plan position indicator (PPI) mode. In the current study, 12 vortices were detected making landfall during the winters of 2010/11 and 2011/12.

The purpose of this paper is to examine high-resolution Doppler radar observations to determine whether the 12 misovortices were modified during landfall. We focus on changes in the peak tangential velocity and tilt of the vortices. The remarkable advance made in this work over previous studies (e.g., Inoue et al., 2011; Kusunoki et al., 2011) is the investigation of the detailed temporal change in the vertical tilt of the misovortices during landfall using multiple PPI scans of a Doppler radar. Section 2 introduces the data collection and analysis procedure. Section 3 describes the environmental conditions and the characteristics of the misovortices. Section 4 provides the changes in the properties of the misovortices during landfall. A summary and conclusions are presented in Section 5.

2. Data collection and analysis procedure

2.1. Data collection

The collection of field data has been ongoing since October 2007 in the Shonai area, Yamagata Prefecture, Japan, which borders the Japan Sea (Fig. 1). This location provides a suitable setting for studying the landfall process of tornadoes and misovortices during winter. In the studied area, altitude is basically below 25 m height (some hilly area exists but at most of about 70 m height.) The studied Shonai plain is rural area and basically consists of fields of rice and other crops. The major facilities for the observations include X-band Doppler radar and a network of automated surface weather transmitters.

The Meteorological Research Institute installed a portable X-band Doppler radar (XPOD: X-band, Portable Doppler radar)

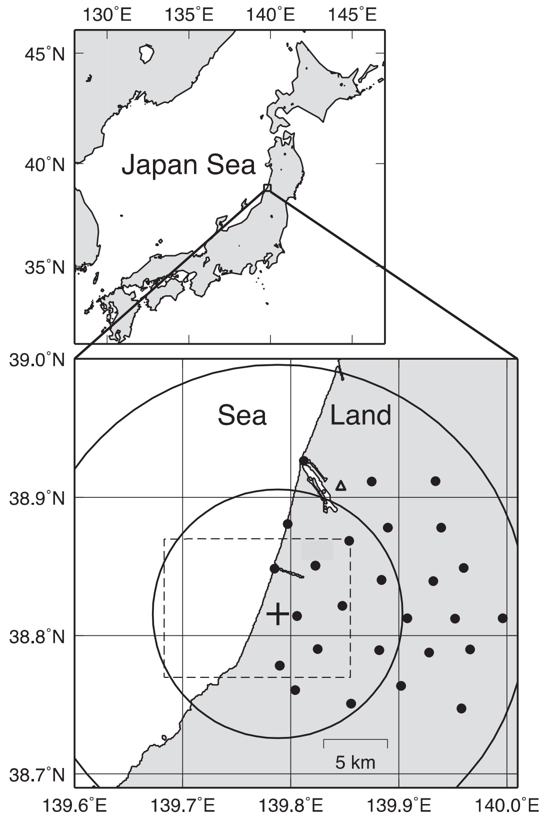

Fig. 1. (Top) Location of observation sites. (Bottom) The map shows the Shonai area. The plus sign and range circles represent the location of the X-band Doppler radar at Shonai airport (XPOD) and its observational range at radial intervals of 10 km, respectively. Dots denote the network of 26 surface automated weather stations. The triangle indicates the location of the wind profiler observation at JMA's Sakata Weather Station. The dashed rectangular region indicates the location of the region depicted in Fig. 4.