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Application of a method for the automatic detection and Ground-Based Velocity Track Display (GBVTD) analysis of a tornado crossing the Hong Kong International Airport

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ABSTRACT

A weak tornado with a maximum Doppler velocity shear of about 40 m s^{-1} moved across the Hong Kong International Airport (HKIA) during the evening of 20 May 2002. The tornado caused damage equivalent to F0 on the Fujita Scale, based on a damage survey. The Doppler velocity data from the Hong Kong Terminal Doppler Weather Radar (TDWR) are studied using the Ground-Based Velocity Track Display (GBVTD) method of single Doppler analysis. The GBVTD analysis is able to clearly depict the development and decay of the tornado though it appears to underestimate its magnitude. In the pre-tornadic state, the wind field is characterized by inflow toward the center near the ground and upward motion near the center. When the tornado attains its maximum strength, an eye-like structure with a downdraft appears to form in the center. Several minutes later the tornado begins to decay and outflow dominates at low levels. Assuming cyclostrophic balance, the pressure drop 200 m from the center of the tornado at its maximum strength is calculated to be about 6 hPa. To estimate the maximum ground-relative wind speed of the tornado, the TDWR's Doppler velocities are adjusted for the ratio of the sample-volume size of the radar and the radius of the tornado, resulting in a peak wind speed of 28 m s^{-1}, consistent with the readings from a nearby ground-based anemometers and the F0 damage observed. An automatic tornado detection algorithm based on Doppler velocity difference (delta-V) and temporal and spatial continuity is applied to this event. The locations and the core flow radii of the tornado as determined by the automatic method and by subjective analysis agree closely.

1. Introduction

Situated in a subtropical coastal area, Hong Kong experiences severe weather including tropical cyclones, thunderstorms, squall lines and rain storms nearly every summer. However, tornadoes are relatively rare over the small territory (about 1100 km^2). Since systematic recording began in 1982, up to 2009 only nine tornadoes have been reported. Rain cells associated with some of the tornadoes have been detected by the long-range weather radars in Hong Kong at Tai Mo Shan and Tate's Cairn. However, since these radars are located at about 500–1000 m above mean sea level (AMSL), the near-surface structures of such tornadoes, especially below 1000 m AMSL, cannot be well resolved. Previous observational studies of tornado structure, mainly using mobile radar data over North America, have revealed that the most intense winds in tornadoes occur well below 1000 m AGL (e.g. Wurman et al., 1996, 2007c; Wurman and Gill, 2000; Wurman, 2002; Bluestein et al., 2004; Alexander and Wurman, 2005; Kosiba and Wurman, 2010). In addition, in order to obtain even approximate estimations of the intensity of potentially damaging winds near the surface, analyses of observations well below 1000 m AGL are required (Wurman and Alexander 2005; Wurman et al., 2007c). In addition, only tornadoes passing close to typical meteorological radars can be adequately resolved due to beam spreading

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(Wood and Brown, 2000; Wurman and Alexander, 2004). Detailed studies of the wind field structure in tornadoes outside of North America are rare.

The tornado which occurred during the night of 20 May 2002 is an exceptional case in which the complete history of the evolution of the tornado was captured by the Terminal Doppler Weather Radar (TDWR) installed in 1996 for detection of low-level wind shear at the Hong Kong International Airport (HKIA). The airport has a height of about 7 m AMSL and the TDWR antenna is at 60 m AMSL. The storm which spawned the tornado exhibited supercell characteristics and occurred in an environment conducive to supercell thunderstorm formation. In order to optimize for the detection of low-level wind shear encountered by aircraft arising from microbursts and gust fronts, the TDWR is situated close to sea level and it scans close to the ground (with the lowest elevation angle at 0.6 degrees). It also has relatively fine spatial and temporal resolutions (see Section 3). Moreover, ground-based anemometers operating inside and around HKIA measured surface winds near the tornado.

This paper presents an analysis of the tornado based on the available meteorological data. A description of the event is given in Section 2. Section 3 gives an account of the meteorological instruments considered in the present study. The major observations of TDWR and the surface-based meteorological equipment are described in Section 4. The TDWR data are analyzed using the Ground-Based Velocity Track Display (GBVTD) method (Lee et al., 1999), as described in Section 5. The automatic detection of the tornado based on TDWR data is discussed in Section 6. Conclusions are presented in Section 7.

2. Description of the event

During the middle of May 2002, a trough of low pressure lingered along the coast of southern China, bringing rainy weather to the region. At 850 hPa, cyclonic flow associated with a south-westerly jet affected the region. Short waves were present in the south-westerly flow in the middle troposphere, at the 700 and 500 hPa levels. At 200 hPa, divergence existed over the Hong Kong region.

Fig. 1, showing the 12:00 UTC upper air sounding obtained just prior to the tornado, resembles soundings taken in tornado-producing tropical cyclones (McCaul, 1991) suggesting that environmental conditions would support supercells. There is a deep saturated layer from just above the surface to 500 hPa, and instability from near the surface up to the tropopause. The Convective Available

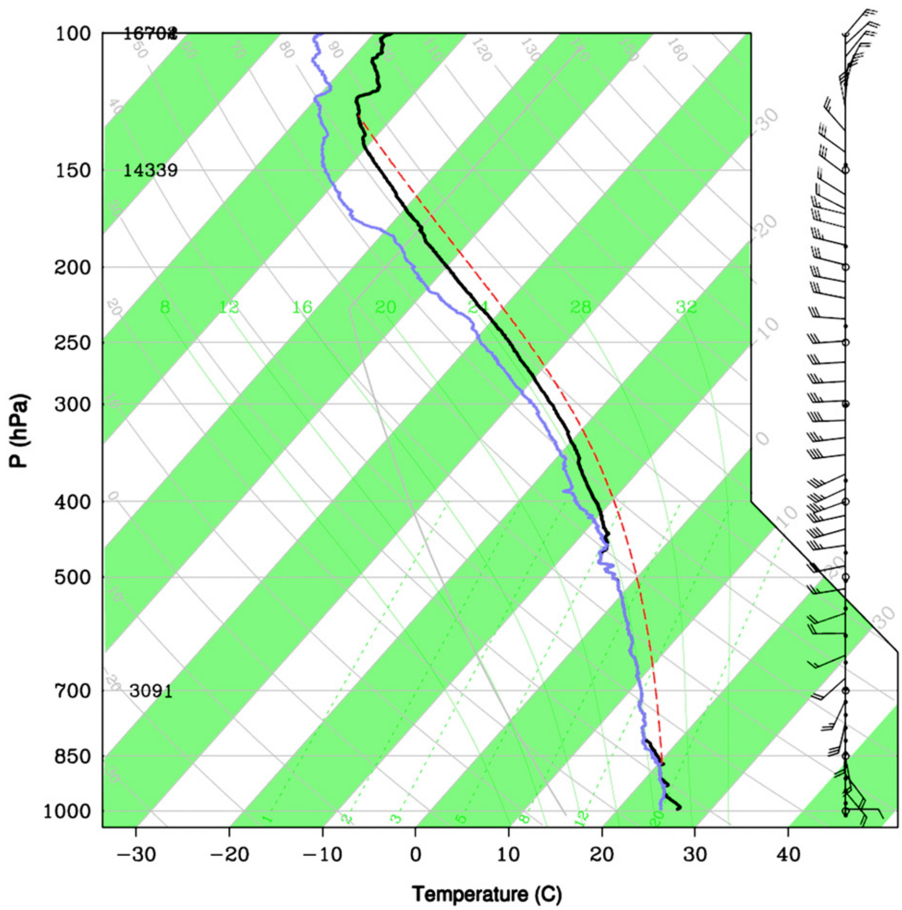

Fig. 1. Upper-air sounding from the Hong Kong International Airport at 1200 UTC on 20 May 2002, depicting profiles of temperature (black line), dew point (blue line), calculated parcel temperature (dashed red line) and wind barbs (speed in knots).