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DOPPLER RADAR ECHO CHARACTERISTICS FOR COLD AIR INTRUDING INTO TYPHOON CHANCHU

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Abstract: With Doppler radar data from Shantou and Xiamen and the National Centers for Environmental Prediction and the National Center for Atmospheric Research (NCEP/NCAR) reanalysis data, the characteristics of a short-term heavy rainstorm on 17 May 2006 caused by Typhoon Chanchu are studied. Doppler radar data indicates that during the period from 1800 to 1900 May 17, the azimuthal phases of the positive and negative radial wind maximums are asymmetric around the core radius of the typhoon, i.e., the radial wind on the left side of the track is anomalously larger than that on the right side. Studies show that this is induced by the intrusion of cold air (northeasterly wind), which is primarily located at the mid-lower layers, lower than 4 km; this is due to the intruding cold air that forces the atmosphere to uplift, enhancing the release of instability energy, which triggers the heavy precipitation. During the late stage of the cold air activity, the typhoon is rapidly weakened. Consistent with the radar-observed intrusion of cold air, the NCEP/NCAR reanalysis of wind data also shows that there are obvious large scalar wind values at the mid-lower layers (approximately 1–3 km) to the left of the typhoon center (1800 May 17), and in all regions—except those affected by the intruding cold air—the wind speeds on the right side of the track remain larger than those on the left side. Furthermore, the Rankine model results confirm that northeasterly cold air is introduced to the typhoon at the mid-lower layers to the left of the track. Calculations also point out that there exists a frontal zone with high θse that tilts from southeast to northwest with height and the super heavy rainstorm occurring in the south of Fujian province lies just near the frontal zone.

Key words: Typhoon Chanchu; cold air; Doppler radar data

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1 INTRODUCTION

Forecasting of wind distribution of a landfalling tropical cyclone (TC) is an operational challenge. It is of great importance since the circulation of a TC making landfall would incur huge losses and widespread damage on the coastal areas. As outlined in Willoughby et al.[1], one of the priorities of the US Weather Research Program on TC is to make skillful forecasts of gale- and hurricane-force wind radii out to 48 hours with 95% confidence. While there has been much improvement over the years in the forecasting of TC tracks, relatively slow progress was seen during the same period on the problem in question, primarily due to the complexities in the physical processes involved, and the inability of Numerical Weather Prediction (NWP) models to be run at a resolution high enough to adequately resolve the TC structure in an operational manner.

The increased friction over land has long been recognized as an important influence on the wind structure changes that occur at landfall. More recently, it has been recognized that the landfall-induced

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asymmetric friction provides a predominantly wave-number one forcing, as does the motion-induced asymmetry. Thus, the asymmetric boundary-layer wind structure in a stationary storm that is partly over land should be similar to that in a moving storm. Blackwell[2] presented an observational analysis of the flow in Hurricane Danny while it was nearly stationary at landfall on the US Gulf Coast, which showed a marked wind asymmetry, with a 41m/s maximum at about 500 m altitude in the offshore flow. This was in contrast to a 31 m s^{-1} maximum at 1500 m in the onshore flow. Kepert[3] argued that this asymmetry was similar to those in 3-dimensional models of a moving storm (Kepert[4], Kepert and Wang[5], and that the only essential difference was the source of the asymmetric frictional forcing: Motion or proximity to land. He presented model results, using the 3-dimensional boundary layer model of Kepert and Wang[5], which were in excellent agreement with Blackwell's observations. A subsequent study (Kepert[6]) investigated the response when a moving storm makes landfall; that is, both sources of asymmetric forcing are present. It was found that as the storm makes landfall, the motion-induced wind maximum in the right forward quadrant weakens, while a secondary maximum appears in the offshore flow to the left of the track (in the Northern Hemisphere)[3-6].

By using the amount of plane-observed data, Chen et al.[7] confirmed that the composite tangential and radial winds in the TC core exhibit obvious predominantly wave-number one asymmetry, and the maximum tangential wind in the Northern Hemisphere locates itself in the front right quadrant. The first factor of impacting TC movement is the external forcing that is the background large-scale steering circulation, and the second is the internal forcing, or the Coriolis force. The asymmetrical circulation within TC changes the direction of the maximum velocity[8].

Studies of the Doppler radar observation on Typhoon Aere (2004) show that, on the front-right side of the typhoon track, wind velocity was larger than that on the back-left side, which is verified by the Dual-Doppler radars, upper-air- and surface-observed winds[9]. In China, research on retrieving real wind information from radial wind velocity by single or multiple-Doppler radars has made much progress. This includes the retrieval of shear line systems above the meso-β scale and the dynamical and microphysical structures of the convective scale storm (among a few), which supply useful products for the real forecast operation [10-12]. As to the interaction between cold air and the typhoon, Chen and Meng[13] indicated that weak cold air could gather instability energy of vortex geopotential and allow for the development of the intense convection and reproduction of the weak vortex. Conversely, the strong cold air could completely rupture and fill the TC warm core structure[13].

The major impact of the cold air on the typhoon storm involves three aspects: Causing initial upward movement of the storm, causing vapor convection within the planet boundary layer and upward transportation, and eventually heavy storm, and triggering meso-scale perturbation on the convective line and its accompanied heavy rainfall. The intrusion of the weak cold air triggers the release of the instability energy and plays a key role in the storm [14]. Chen outlined seven amplification effects of cold air on the typhoon storm [15], which are formed in various ways, such as the effect of frontal lifting and cold air, potential instability, dynamics of both divergence and vorticity fields, baroclinic energy, transportation of upper-air cold trough, changes in typhoon track and rainfall distribution by cold trough, to name a few.

2 CHARACTERISTICS OF DOPPLER ECHOES OF CHANCHU

In Fig. 1f, at 1931 May 17, Typhoon Chanchu moves towards the northeast after landing. At a location 60 – 70 km northeast of the observation station in the southwest quadrant of the typhoon center, the maximum radial velocity of Doppler radar is –39 m/s; in the south quadrant, however, it is 39 m/s, except that its ambiguity area is significantly less than that of the other side, which indicates that on the right side of the typhoon path the Doppler velocity is less than that on the left side. According to the conclusion of Chen et al.[7], the tangential velocities on all layers (900 – 525 hPa) are consistently kept in the front-right quadrant. However, the radar observation goes against the previous conclusion of the lower-layer core radius (maximum velocity region): That is, the maximum negative radial velocity on the left side of the typhoon center is considerably larger than that on the right side, and this is no doubt an exception. Analyses suggest that this is caused by the cold air intrusion at the lower layer (northeast wind).

Further analyses (Fig. 1h) show that, at the location 70 km away from the observation station and 2 – 3 km above the surface, the negative radial velocity increases remarkably on the back-left side of the typhoon center. At the same time, at higher elevation angles (equivalent of 4.5 – 5 km in altitude), as indicated in Fig. 1g, the relative positions of both the maximum positive and maximum negative radial velocities are opposite, and the maximum value of positive radial velocity is larger than that of negative radial velocity by about 20 m/s. Analyses indicate that this is due to the lack of cold air intrusion over the mid-higher layer: Cold air intrusion only occurs over the lower layer, which can force the air to rise, enhance the intense convection of the spiral rain-belt within the typhoon, trigger heavy rain, and eventually cause much more precipitation.

By using the NCEP reanalysis data, the longitudinal vertical sections of wind speed crossing the typhoon center are made at 1200 and 1800 May 17 (See Fig. 2). Analyses show that at 1800, on the left (west) side of the typhoon path, there is an obvious center of high wind speed with a maximum value of 28 m/s, which is consistent with the result of radar observation.

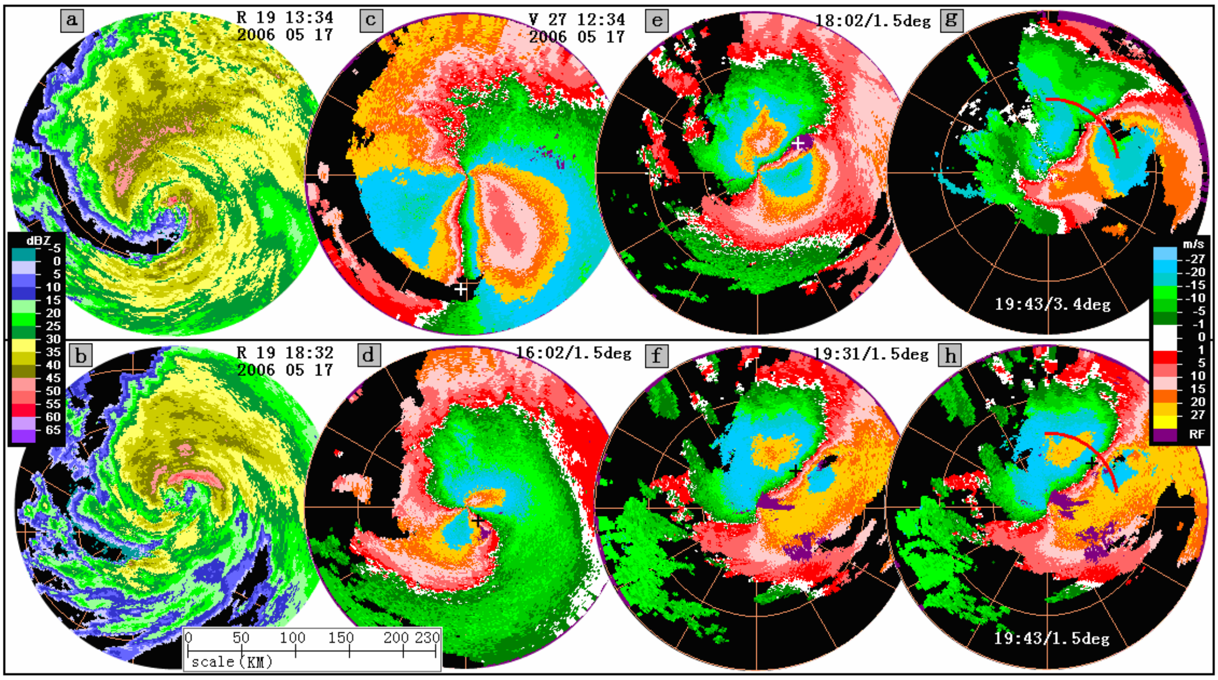

Fig.1 Radar scanning charts relative to Shantou for 17 May 2006. +: location of the typhoon center. a, b: reflectivity factors at an elevation of 1.5°; c – h: radial velocities.

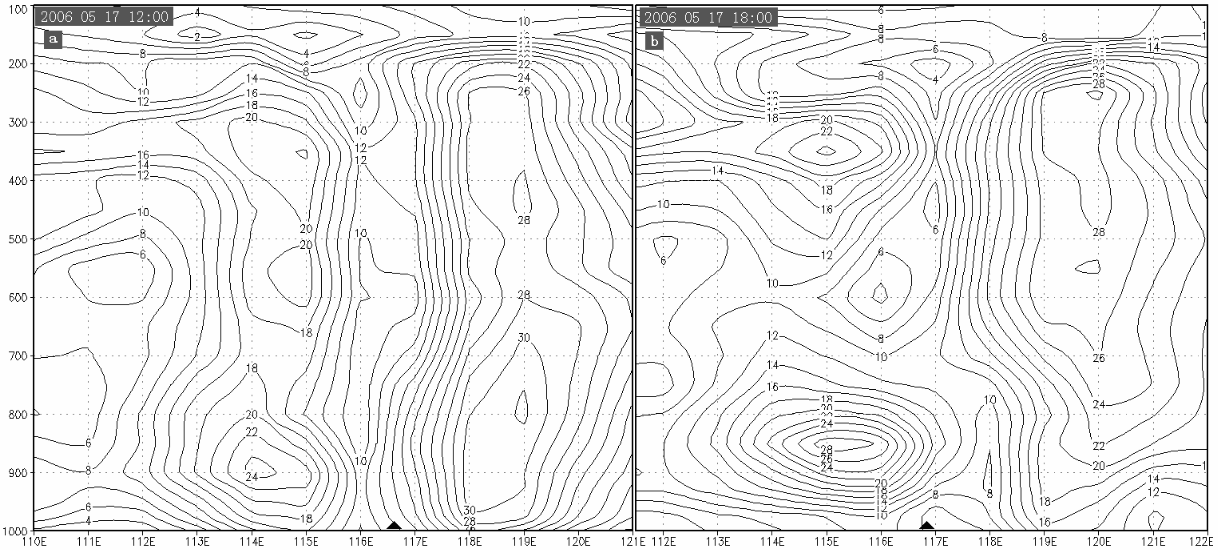

Fig.2 Vertical cross sections of whole wind speed based on NCEP data. ▲: center of the typhoon. a: 1200 May 17; b: 1800 May 17.

3 CONCLUSIONS

(1) Detections of Doppler radar show that, around the core radius of Typhoon Chanchu, the azimuthal phases of the positive and negative radial wind maximums are asymmetric, i.e., the radial wind on the left side of the track is anomalously larger than that on the right side, which is very unusual and

induced by the intrusion of cold air (northeasterly wind). Continuous velocity figures indicate that the cold air intrusion occurs at about 1800 May 17, and locates at the mid-lower layers (lower than 4 km), with no activities of cold air above 4 km in the Doppler radar radial velocity figures. This is due to the intruding cold air that can force the atmosphere to uplift, enhance releases of instability energy and finally trigger heavy rain, eventually causing much more precipitation in the Zhangzhou region, and thereby severe geological disasters. Both a strong precipitation echo strip and its strong convective echo cell are clearly presented on radar.

(2) Analyses of NCEP wind velocity distribution indicate that, at 1800 May 17, there are obvious large scalar wind values at the mid-lower layers (approximately 1 – 3 km) to the left of the typhoon center, denoting cold air intrusion. Additionally, in comparison to that at 1200, stronger wind occurs over a high level at 1800, which suggests the pumping intensification and convection enhancement, simultaneously. Consistent with the NCEP results (at about 1800), observed radial velocities over all layers at both Shantou and Xiamen show that, on the left side of the typhoon track, there is an obvious center of high wind speed due to cold air intrusion. Except for the region affected by this intrusion, the wind speeds at all layers on the right side of the track remain larger than those on the left side.

(3) Combining the Rankine model simulation with the radar observation, it can be further confirmed that the anomalously large wind velocity over the mid-lower layer at the left side of the typhoon track is the result of the intrusion of northeast cold air into the typhoon vortex. In fact, during this period, both the significant southwest background steering airflow and the northeast intruding cold air are present. On radar, this is reflected as showing that the maximum positive and negative radial velocities are comparable, and the negative velocity (left side) is a little larger than the positive velocity.

(4) At 1200 May 17, vertical cross figures of θse along 23°N and 117°E indicate that the dense θse stripe extends from the lower layer to the upper layer and tilts from east to west and from south to north. The front of the large dense θse appears below 850 hPa in the southern Fujian region where the super heavy storm occurs.

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REFERENCES:

[1] WILLOUGHBY H E, RAPPAPORT E N, MARKS F D. Hurricane Forecasting, the state of the art [R]. Paper submitted to the Hurricane Forecast socioeconomic working group, Pomona, 2005.
[2] BLACKWELL K G. The evolution of Hurricane Danny (1997) at landfall: Doppler-observed eyewall replacement, vortex contraction/intensification, and low-level wind maxima.[J]. Mon. Wea. Rev., 2000, 128(12): 4002-4 016.
[3] KEPERT J D. The impact of landfall on tropical cyclone boundary layer winds. [C]. 25th Conference on Hurricanes and Tropical Meteorology, Amer. Meteor. Soc., San Diego, California, 2002, 335-336.
[4] KEPERT J D. The dynamics of boundary layer jets within the tropical cyclone core. Part I: Lineartheory [J]. J. Atmos. Sci., 2001, 58(17): 2469-2484.
[5] KEPERT J D, WANG Y. The dynamics of boundary layer jets within the tropical cyclone core. Part II: Nonlinear enhancement [J]. J. Atmos. Sci., 2001, 58(17): 2485-2501.
[6] KEPERT J D. Modelling the tropical cyclone boundary layer wind-field at landfall. [R]. 14th BMRC Modelling Workshop: Modelling and Predicting Extreme Events, Melbourne, 2002: 81-84.
[7] CHEN Lian-shou, DONG Ke-qin, JIN Han-liang, et al. Global View on Tropical Cyclone [M]. Beijing: Meteorology Press, 1994, 40-52. (in Chinese).
[8] LIN Yuan-bi, TANG Ming-min, LU Sen-e, et al. Synoptic Meteorology [M]. Nanjing: Nanjing University Press, 1988: 225-228. (in Chinese).
[9] WEI Ying-zhi, TANG Da-zhang, XU Jian-min, et al. The asymmetric wind structure of typhoon Aere detected by Doppler radar [J]. J. Appl. Meteor. Sci., 2007, 18(3): 285-294. (in Chinese)
[10] WANG Feng-yun, WANG Yan-xiong, TAO Zu-yu. The study of mesoscale wind field detection technique for single Doppler weather radar [J]. J. Trop. Meteor., 2003, 19(3): 291-298. (in Chinese)
[11] GU Jian-feng, XUE Ji-shan, YAN Hong. A summarization of the four-dimensional variational Doppler radar analysis system [J]. J. Trop. Meteor., 2004, 20(1):1-13. (in Chinese).
[12] ZANG Zeng-liang, WU Hai-yan, HUANG Hong. A new method of the retrieval of horizontal divergence field with a single Doppler radar radial velocity data [J]. J. Trop. Meteor., 2007, 23(2): 146-152. (in Chinese)
[13] CHEN Lian-shou, MENG Zhi-yong. An overview on tropical cyclone research progress in China during the past ten years [J]. Chin. J. Atmos. Sci., 2001, 25: 420-432. (in Chinese)
[14] LI Jiang-nan, WANG An-yu, YANG Zhao-li, et al. Advancement in the study of typhoon rainstorm [J]. J. Trop. Meteor., 2003, 19(suppl.): 152-159. (in Chinese)
[15] CHEN Rui-shan. Typhoons [M]. Fuzhou: Fujian Science and Technology Press, 2002: 1-21, 479-588. (in Chinese)

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