

Radar Data Characteristics of Two Severe Convective Systems Inflicting Massive Fatalities in China

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1 Introduction & Data

- The extraordinarily serious capsizing accident of the cruise ship, named Oriental Star, occurred at around 21:30 (Beijing Time), on June 1, 2015, in the Jianli (Hubei Province) section of the Yangtze River, causing 442 deaths.
- The wind damage survey over the surrounding land area of the accident showed the strongest gust wind speed greater than Beaufort 12. During 21:00-22:00, on June 1, the accident area suffered torrential rain, thunders and dense lightning flashes, and high winds.
- On June 23, 2016, a violent tornado occurred in Funing County of Jiangsu Province, inflicting 99 deaths and 846 injured. The tornado was rated EF4 based on the damage survey.
- New generation Doppler radar observations
- Geostationary meteorological satellite images
- Cloud-ground lightning
- Auto weather station observations
- Sounding data (Skew T-log p diagram)
- NCEP CFSR reanalysis data ($0.5^\circ \times 0.5^\circ$)

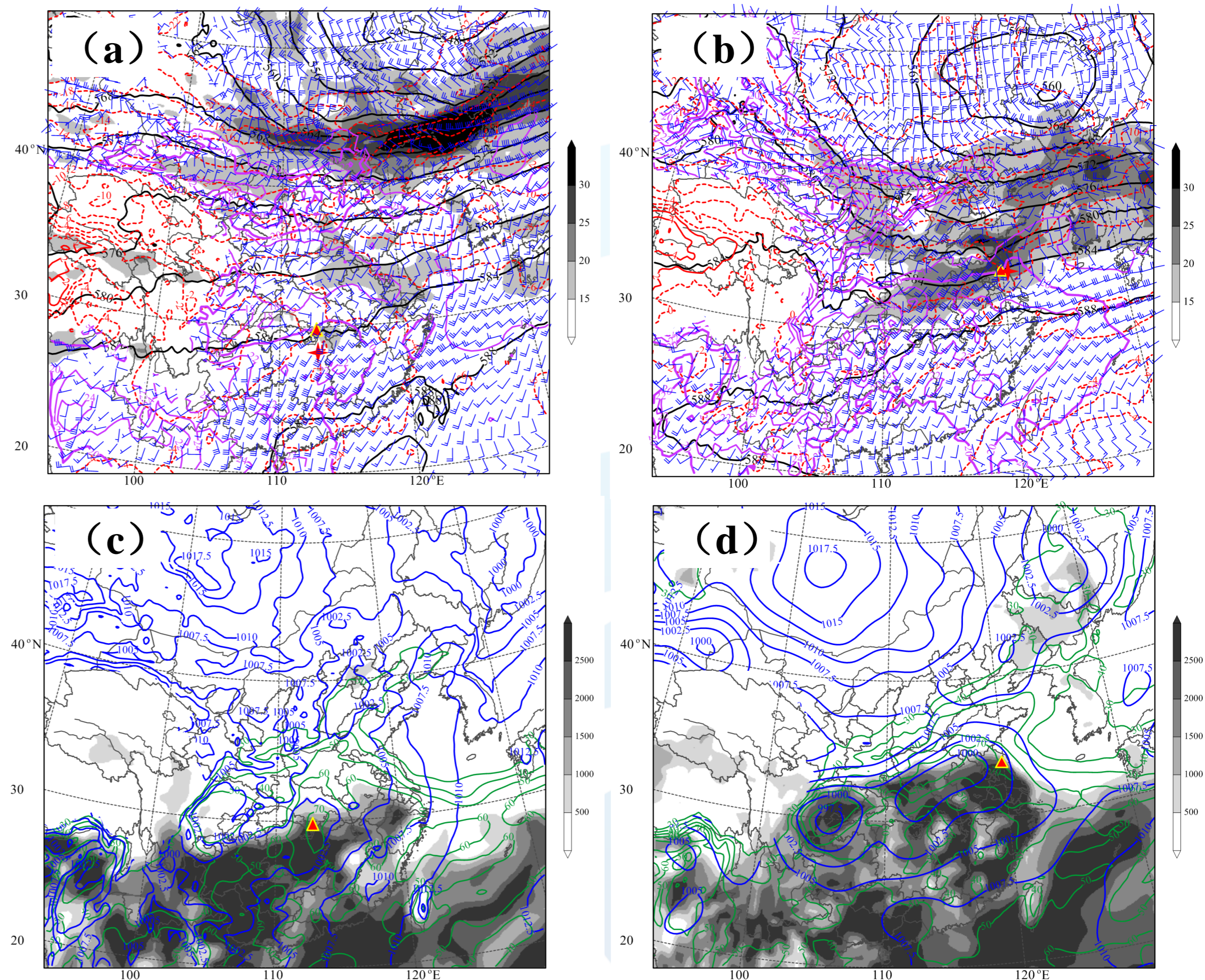


Fig. 2 Circulations and environmental conditions

(Figs. a and c are for 20BST June 1, 2015, and Figs. b and d are for 14BST June 23, 2016. Yellow triangles filled with red color indicate respectively “Oriental Star” capsizing location and Funing County. Red “+” denotes the nearest sounding station locations of the two events, and “+” in Fig. a denotes Changsha station, “+” in Fig. b Sheyang station. In Figs. a and b: black solid lines are 500 hPa geopotential height contour with 4 dgpm interval, unit: dgpm; red lines are 500 hPa isotherm with 2 °C interval, unit: °C; gray colors indicate ≥ 15 m/s wind speeds at 500 hPa with 5 m/s interval, unit: m/s; purple lines are 850 hPa isotherm with 2 °C interval and thick purple lines representing 20 °C isotherm, unit: °C; blue barbs are winds at 850 hPa with long line of 4 m/s and short line of 2 m/s. In figs c and d: blue contour for sea level pressure at 2.5 hPa intervals, unit: hPa; green contour for precipitable water at 10 mm interval, unit: mm; gray colors for CAPE at 500 J/kg interval, unit: J/kg)

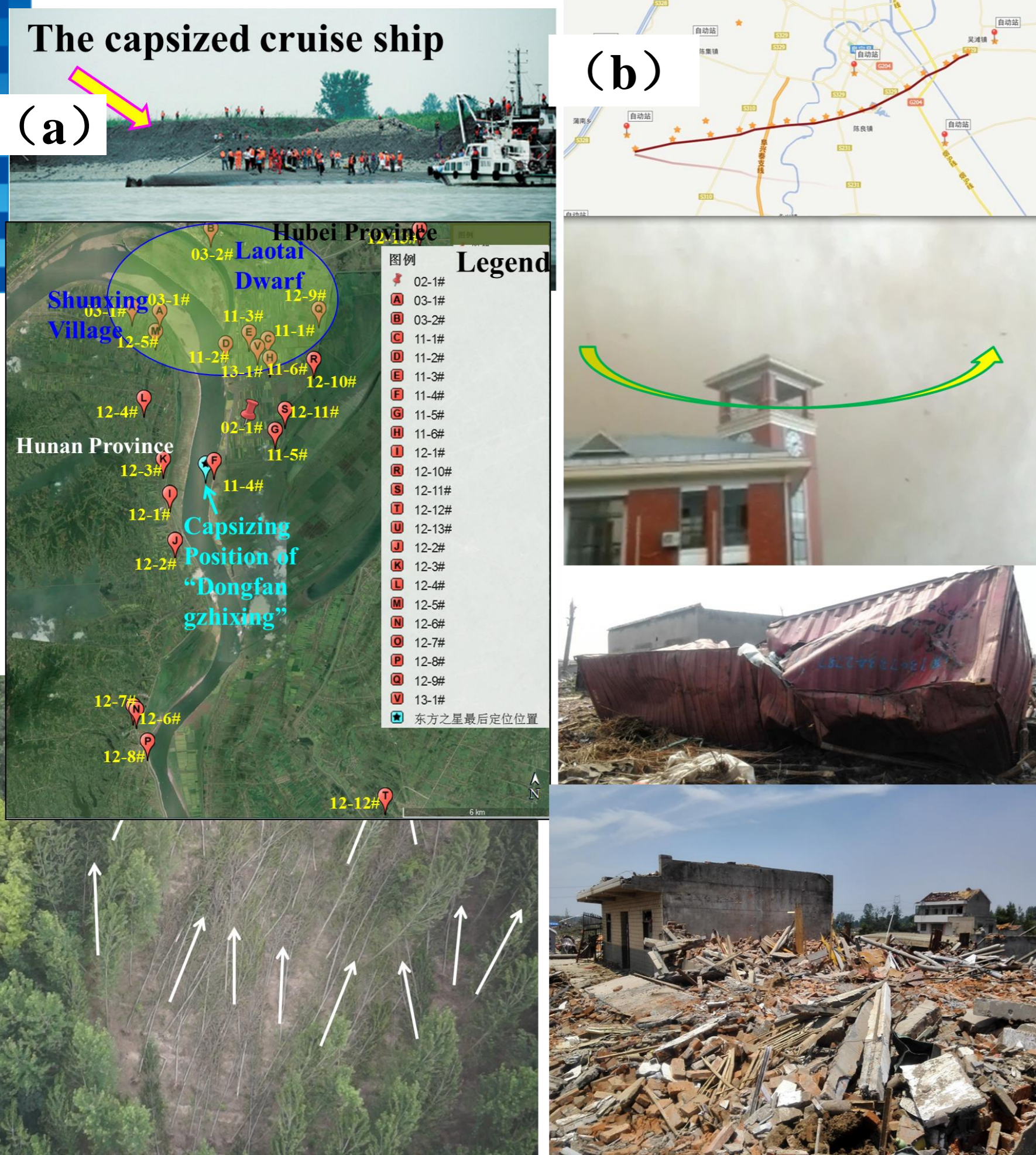


Fig. 1 Damage survey

- (a) 2015 Oriental Star capsizing event, damage track, and snapped trees; (b) 2016 Funing tornado damage track, tornado tuba cloud photo taken by one teacher at Wutan Primary School, a thrown container, and leveled houses

2 Circulations & Environmental Conditions

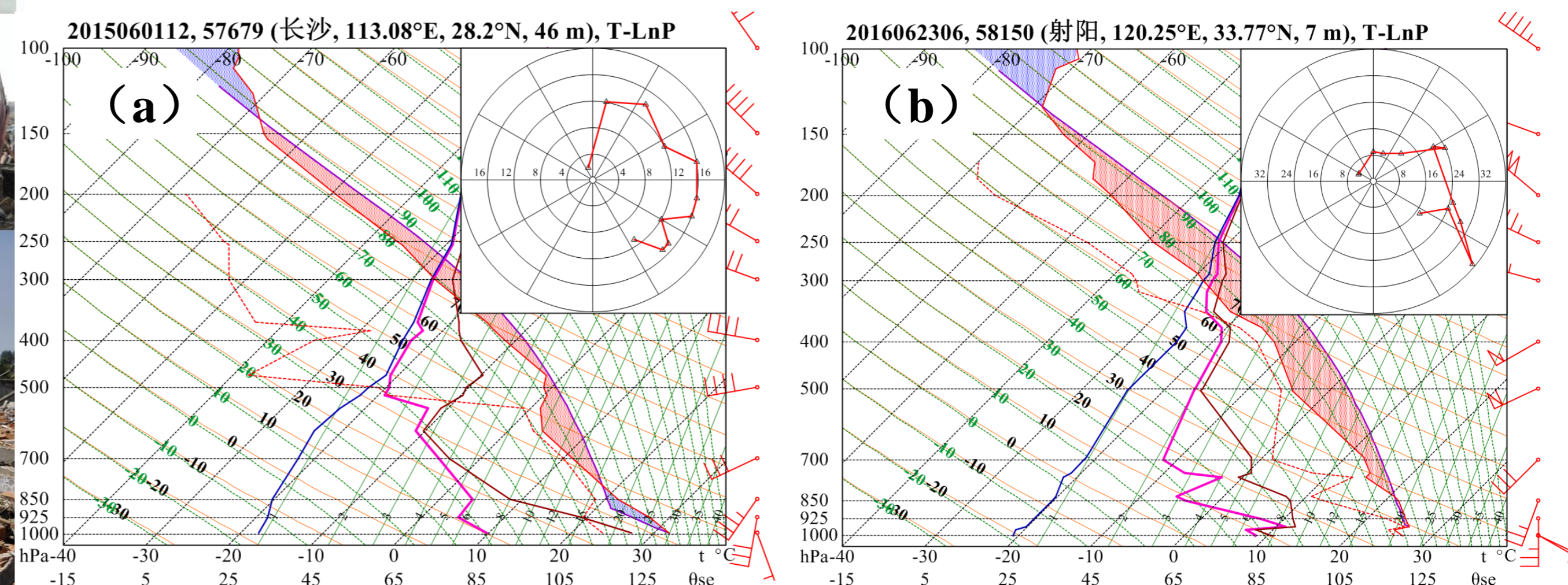


Fig. 3 Skew T-log p and hodograph for the two events

(Fig. a is Changsha sounding for 20 BST June 1, 2015, and b is Sheyang sounding for 14BST June 23, 2016; the sounding station locations are labeled in figure 2a and b. Red solid line is temperature profile, red dashed line dewpoint profile, blue solid line potential temperature profile, magenta solid line pseudo equivalent potential temperature profile, deep red solid line saturated pseudo equivalent potential temperature profile, and red filled area CAPE. Note that potential temperature, pseudo equivalent potential temperature and saturated pseudo equivalent potential temperature profile donot use skew temperature axis, but use the coordinate axis labeling θ_{se} ; red barbs are winds with triangle of 20 m/s, long line of 4 m/s, and short line of 2 m/s. Hodograph is located on the right top corner of the skew T-log p diagram, unit: m/s)



3 Structure of Convective Storms

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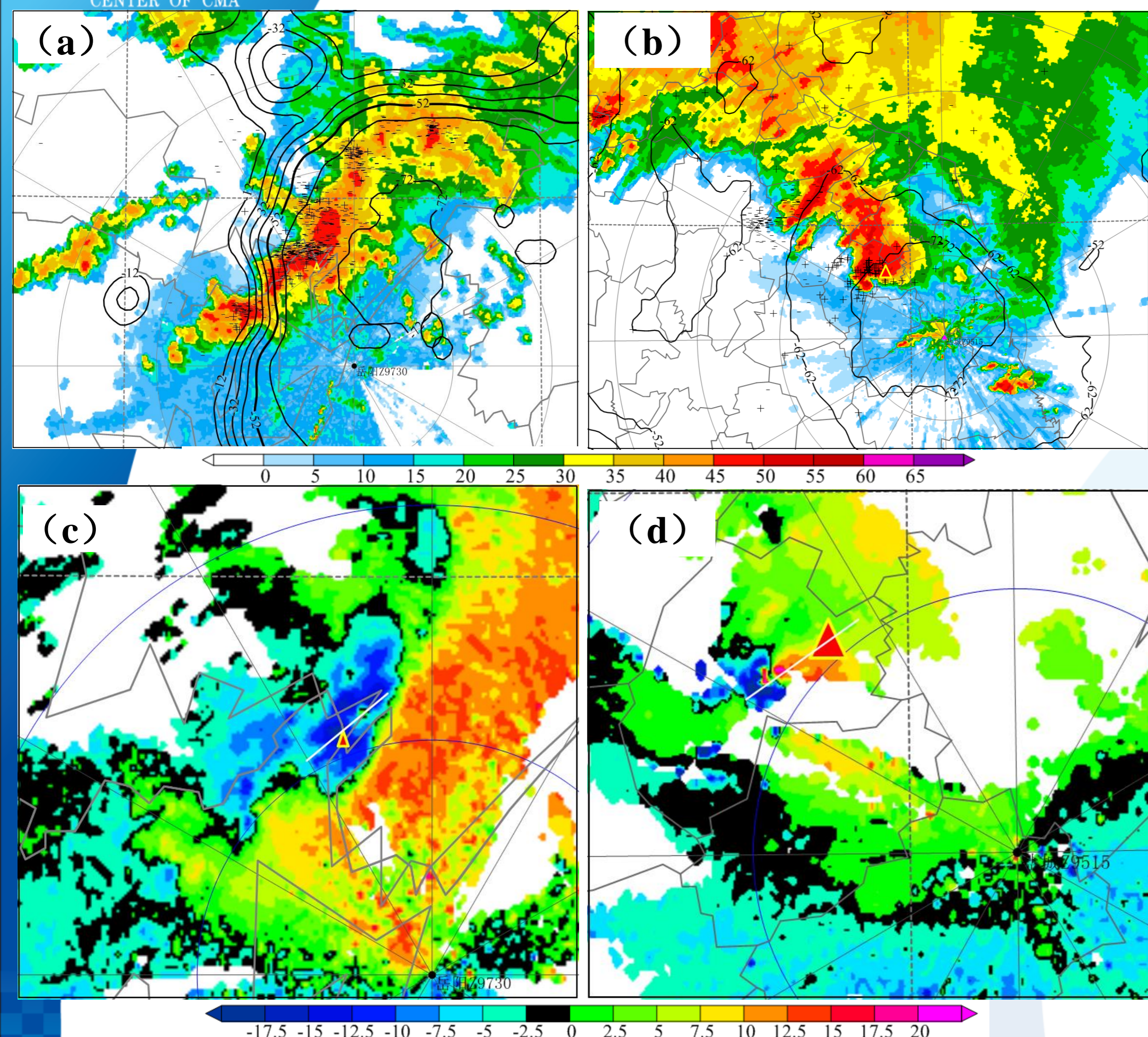


Fig. 4 Radar echoes, lightning flashes and infrared TBB for the two events

(Figs. a and c are Yueyang radar observations at 0.5° elevation for 21:26 BST June 1, 2015, but they have different geographical areas; Figs. b and d are Yancheng radar observations at 0.5° elevation for 14:30 BST June 23, 2016, but they also have different geographical areas. Yellow triangles filled with red color indicate respectively "Oriental Star" capsizing location and Funing County. In Figs. a and b, shaded colors are radar reflectivity, contours are FY2E TBB for 21:30 BST June 1, 2015, and FY2G TBB for 14:30 BST June 23, 2016, respectively, unit: $^\circ\text{C}$; "+" and "-" symbols represent cloud-ground lightning flashes for 21:00-21:30 BST June 1, 2015, and 14:00-14:30 BST June 23, 2016, respectively, where "+" denotes positive flashes, and "-" negative flashes. In figs c and d, shaded colors are radar radial velocities. Note that the positive radial velocities surrounded by the negative radial velocity zone of mesocyclone are velocity aliasing in Fig. d. The white solid lines in Figs. c and d are locations of vertical cross sections in Fig. 5)

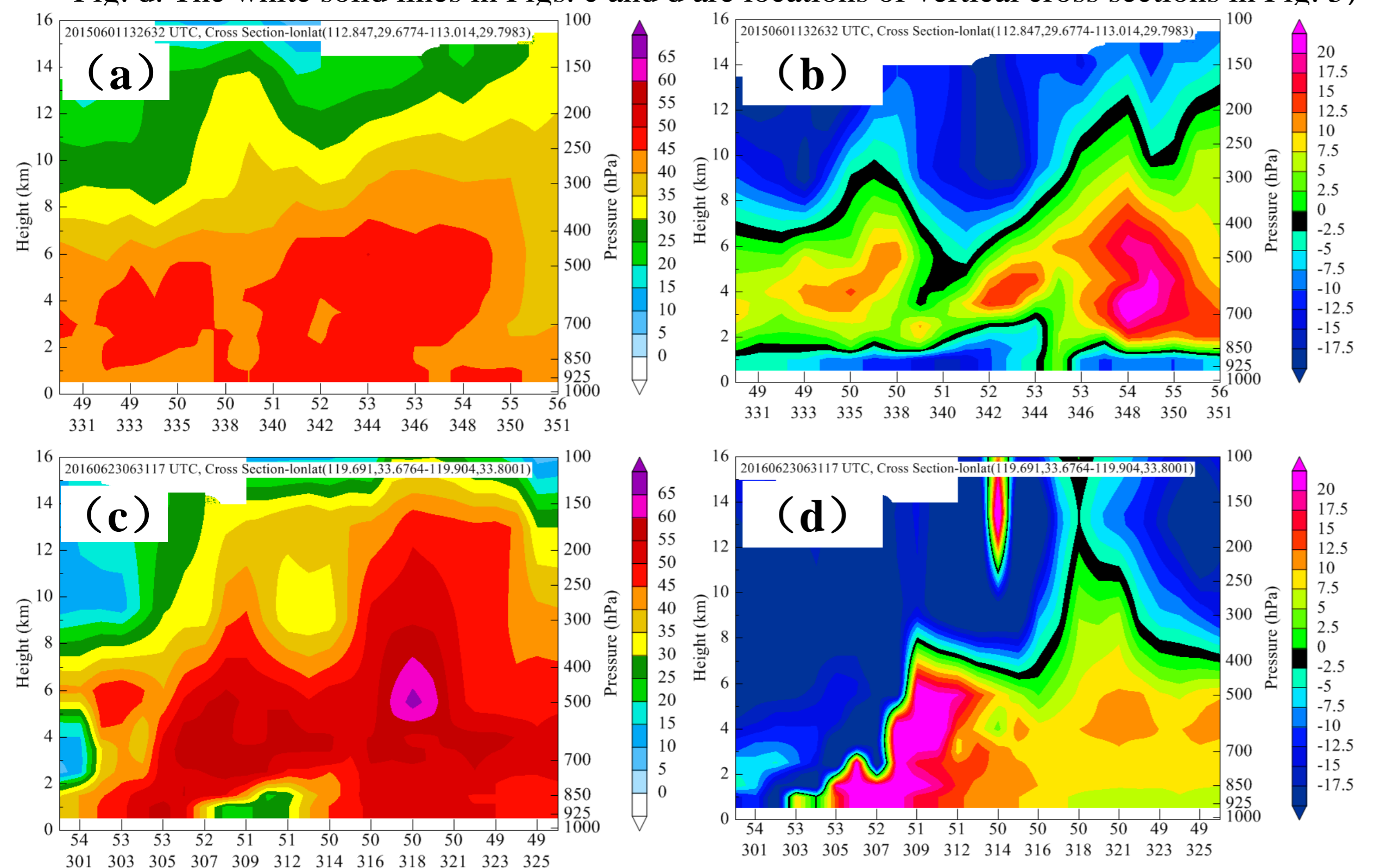


Fig. 5 Vertical cross sections of convective storms for the two events

(Figs. a and b are Yueyang radar observations for 21:26 BST June 1, 2015, Figs. c and d are Yancheng radar observations for 14:30 BST June 23, 2016. Figs. a and c are for reflectivity, and Figs. b and d for radial velocity. Note that, on the left side of Fig. d, two positive velocity areas below 2 km altitude and above 10 km altitude surrounded by negative radial velocity area are velocity aliasing. The top digits below the abscissa are distances from radar station, unit: km; and the bottom digits are azimuth angles, unit: $^\circ$, north 0° , and clockwise increase. Altitudes are on the left side of the ordinate, unit: km, and the corresponding pressures are on the right, unit: hPa)

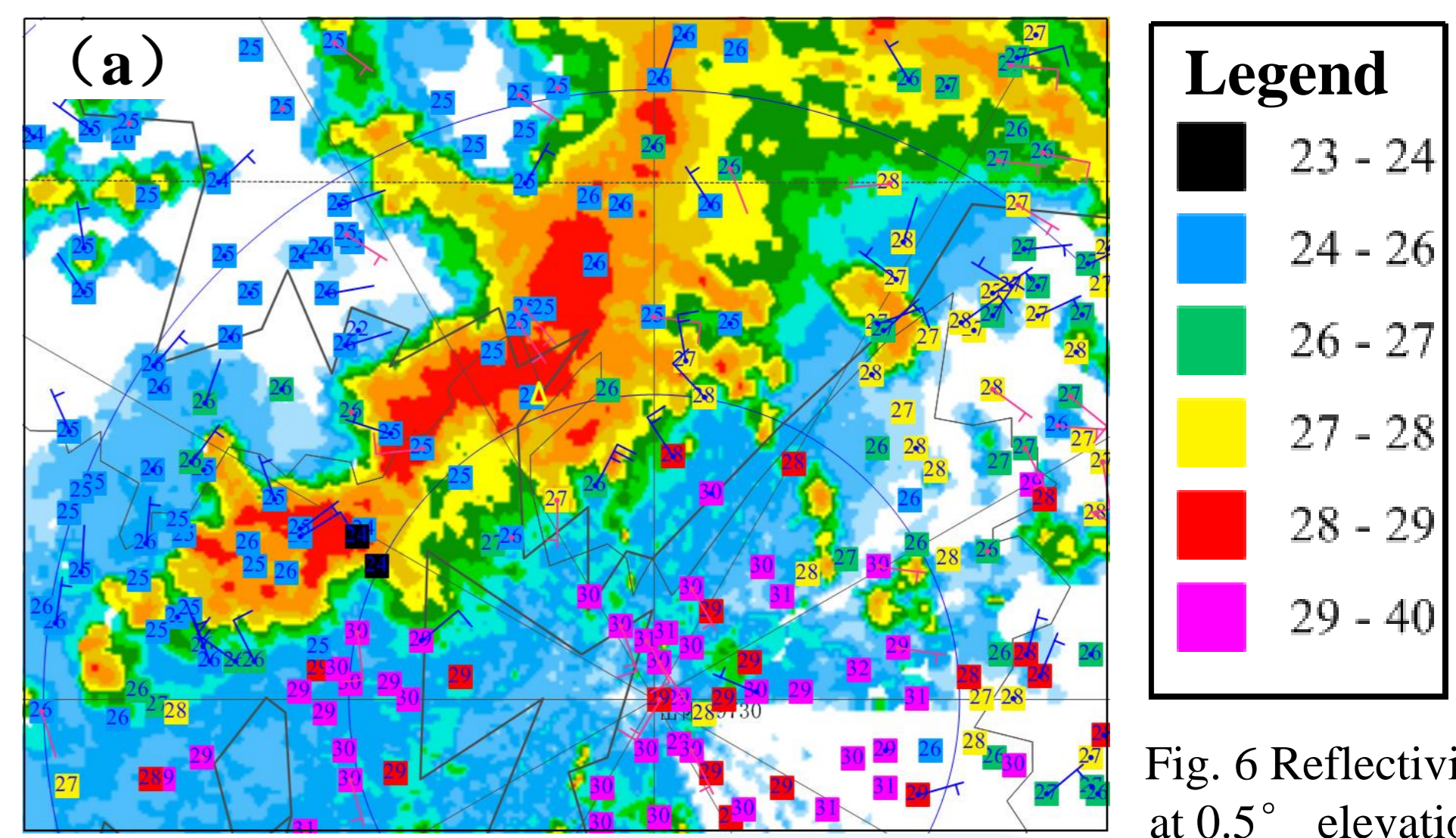


Fig. 6 Reflectivity at 0.5° elevation and AWS temperatures and winds

(In Fig. a, shaded colors are Yueyang radar reflectivity at 0.5° elevation for 21:26 BST June 1, 2015, rectangles with different colors labeled digits indicate air temperatures

from AWS for 22:00 BST, and barbs denote winds from AWS for 22:00 BST. In Fig. b, shaded colors are Yancheng radar reflectivity at 0.5° elevation for 14:30 BST June 23, 2016, rectangles with different colors labeled digits indicate air temperatures from AWS for 14:30 BST, and barbs denote winds from AWS for 14:30 BST. Barbs of wind are the same as Fig. 2, but southerly in red, northerly in blue or black. Yellow triangles filled with red color indicate respectively "Oriental Star" capsizing location and Funing County.)

4 Conclusions

- The "Oriental Star" capsizing event in 2015 and the Funing EF4 tornado in 2016 event are extremely rare damaging wind events caused by severe convective storms.
- The convective storms of both events occurred in the south side of cold eddy and the northwestern edge of the northwest Pacific subtropical high at 500 hPa, on the left and forward side of low-level jet and warm tongue at 850 hPa, and in the trough of sea level pressure. There were obvious warm advection and no obvious jet of the 2015 event at 500 hPa. However, the 2016 events occurred in the south edge of 500 hPa jet with weak temperature advection and very strong 0-6 km vertical wind shear (27.5 m/s) much greater than the 2015 event.
- The two events both occurred in the environment of high temperature (surface air temperature $> 26^\circ\text{C}$), high humidity (surface dewpoint $> 23^\circ\text{C}$, PW about 60 mm), high static energy (CAPE $> 1000\text{ J/kg}$) and larger low-level vertical wind shear. For the 2015 event, the dry layer in the middle troposphere is one of important environmental conditions, so DCAPE conducive to the ground high winds was bigger, but the environment had higher 0°C layer and smaller temperature lapse rate. The 2016 event had all the environmental conditions favorable for tornado: large CAPE ($> 2000\text{ J/kg}$), strong 0-6 km vertical wind shear (27.5 m/s), high low-level relative humidity (close to saturation), low lifting condensation level (CIN 12 J/kg), large 0-1 km vertical wind shear (about 8 m/s), besides, lower 0°C layer and larger temperature lapse rate is conducive to hail.
- Geostationary meteorological satellite infrared images show that the convective system caused the 2015 event was a quasi-circular meso- α -scale convective system, and the one producing the 2016 tornado was a typical mesoscale convective complex. Radar observations show that the 2015 convective storm is a meso- β -scale bow-shaped quasi-linear convective system with significant negative lightning flash, low mass center of reflectivity, and about 50 dBZ of the maximum reflectivity. However, the 2016 convective storm is a meso- β -scale classical supercell with significant positive lightning flash, hook echo and arch structure, high mass center of reflectivity, and about 65 dBZ of the maximum reflectivity.
- In the 2015 convective storm, there were multiple downburst areas below 1 km altitude with about 19 m/s of the largest radar radial velocity, strong rear inflow, a mesocyclone at about 5 km altitude, and a low-level weak mesovortex. The 2016 supercell storm had a strong mesocyclone and tornadic vortex signature with maximum rotational speed $> 26\text{ m/s}$ and its base height less than 1 km, and tilting northeastwards from bottom to top, and had a higher (about 8 km altitude) rear inflow. The 2016 supercell storm can be seen obvious rotation on the high-resolution satellite visible images.
- The cold outflow in the 2015 storm is stronger than that in the 2016 supercell storm (less than 4°C temperature difference), and the relatively weaker downdraft is one of the important mechanisms of the 2016 supercell that can produce the tornado.