Evolution and Development Mechanisms of an Arc-Shaped Strong Squall Line Occurring along the South Side of a Cold Vortex

Poster2-70

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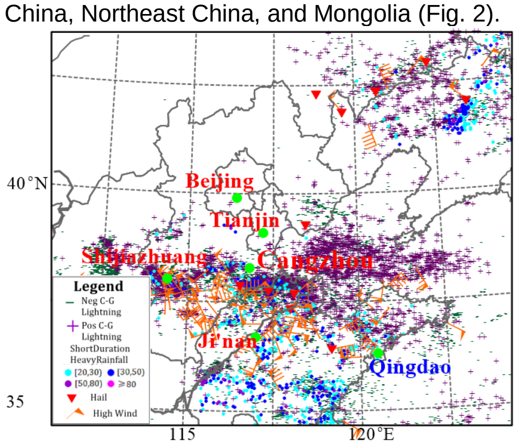
1. INTRODUCTION

Based on NCEP (National Centers of Environmental Prediction) analysis data and various observations from automatic weather stations, cloud-to-ground lightning positioning system, geostationary meteorological satellites, and weather radars, this paper uses "ingredient-based" method to have comprehensively analyzed environmental conditions, evolution characteristics, trigger and development mechanisms, and forecasting difficulties of a long-lived arc-shaped squall line that swept the southeastern part of Hebei Province and most of Shandong Province on 30 June, 2016.

2. SEVERE CONVECTIVE WEATHER AND SYNOPTIC ENVIRONMENT

During the morning and midnight hours of 30 June 2016, a severe convective weather outbreak affected North China (Fig. 1). The observed maximum wind speed at Shouguang of Shandong Province reached 33 m/s, and hailstones with diameter greater than 2 cm were observed at many meteorological stations. Four squall lines occurred during the period, and they caused the widespread severe convective weather over North China. The squall line C (hereafter the squall line) in Fig. 1b is that we will focus on in this paper.

The arc-shaped strong squall line occurred along the south side of a cold vortex whose center was located in East Siberia. The cold vortex affected North China, Northeast China, and Mongolia (Fig. 2).



(a)

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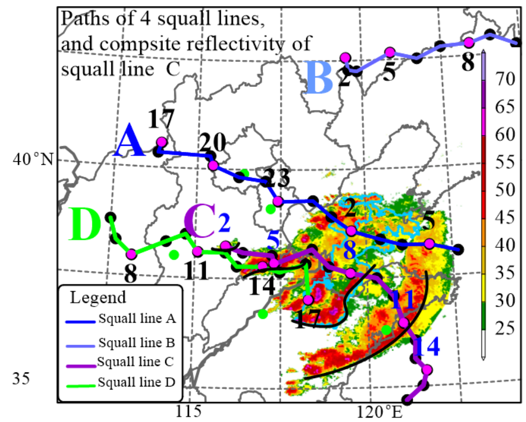


(b)

Fig. 1 Convective weather and paths of 4 squall lines (Green dots represent cities of Beijing, Tianjin, Shijiazhuang, Ji'nan and Qingdao, respectively)
(a) Distribution of severe convective weather at meteorological stations and cloud-to-ground lightning from 00 UTC June 30 to 00 UTC July 1, 2016 (red triangles present hail; light blue, blue, purple and magenta dots represent hourly precipitation of 20–29.9 mm, 30–49.9 mm, 50–79.9 mm and no less than 80 mm, respectively; green minus signs represent negative cloud-to-ground lightning, purple plus signs represent positive cloud-to-ground lightning); (b) Paths (marked by numbers, with solid lines which have purple or black dots on them) of 4 squall line systems (marked A, B, C, and D, respectively) and composite radar reflectivity of squall line C at different hours (02, 05, 08 and 11 UTC; thick solid lines denote the leading edge of squall line C; the numbers labeled are UTC time every 3 hours; squall line A was initiated at 17 UTC on 29 June.)

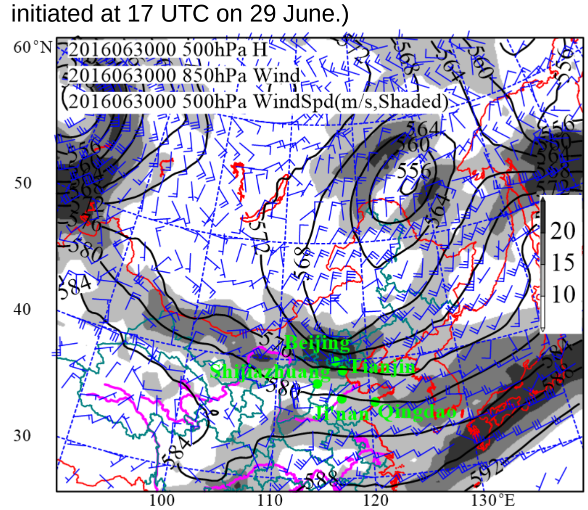


Fig. 2 Synoptic patterns at 00UTC on June 30 (Green dots represent the locations of Beijing, Tianjin, Shijiazhuang, Ji'nan, Qingdao, respectively; black solid lines are contours of geopotential height at 500 hPa, unit is dagpm and interval 4 dagpm; gray levels show wind speed of 500 hPa; blue barbs are for 850 hPa)

3. ENVIROMENTAL CONDITIONS

Convective available potential energy (CAPE) above 4000 J/kg and 0–6 km vertical wind shear with moderate intensity are very favorable for the development of supercell storms, large hail, high winds and the maintenance of the squall line. Level of the wet bulb temperature zero (WBZ) at 3.6 km altitude was in favor of large hail. Low relative humidity, dewpoint deficit of the middle troposphere up to 28 ℃, larger vertical temperature lapse rate and downdraft convective available potential energy (DCAPE) favored very much bow echoes and high winds. Convective inhibition energy (CIN) ≥200 J/kg inhibited the earlier convection.

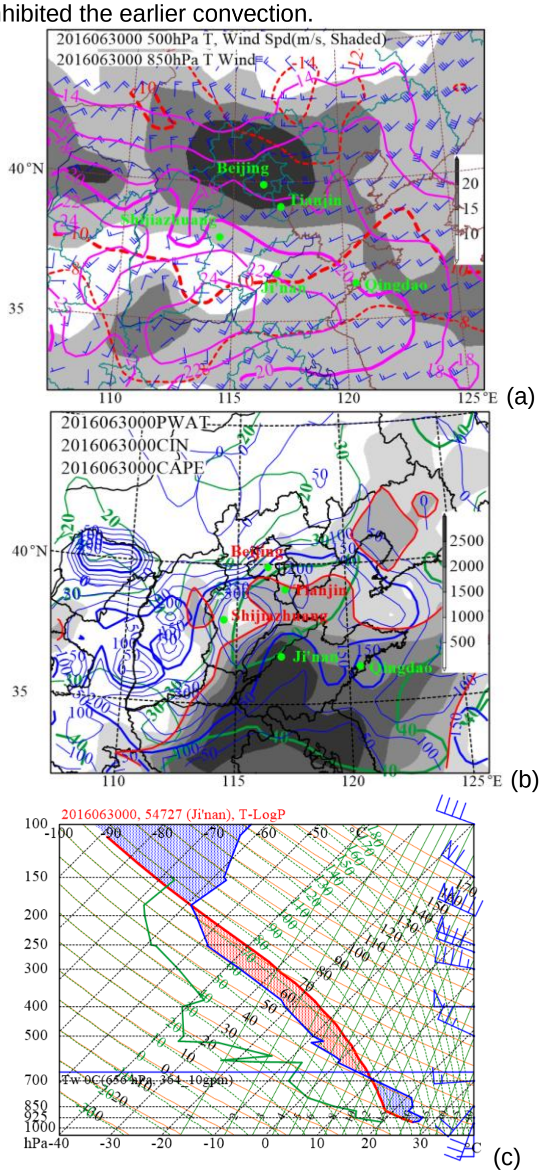


Fig. 3 Synotic patterns (a), environmental conditions (b) and Skew T-log p diagram of sounding at Zhangqiu station near Ji'nan (c) at 00UTC June 30 (Green dots represent cities of Beijing, Tianjin, Shijiazhuang, Ji'nan, Qingdao, respectively. In Fig a, red dotted lines are isotherms of 500 hPa, unit is ℃, interval is 2 ℃, and 20℃ isotherms are thick; blue wind bards are at 850 hPa with long line of 4 m/s, and short line of 2 m/s. In Fig. b, green solid lines are contours of precipitable water content, unit is mm, interval is 10 mm, and 40 mm isolines are thick; gray shaded areas represent CAPE, unit is J/kg, interval is 500 J/kg, and red solid lines are isolines of 1000 J/kg; blue solid lines are contours of CIN at 50 J/kg intervals, unit is J/kg, and thick blue solid lines are isolines of 150 J/kg. In Fig. c, thick blue solid line denotes temperature, green solid line represents dewpoint and the red one is the lifting curve, blue barbs are winds with triangle of 20 m/s, long line of 4 m/s, and short line of 2 m/s.)

4. TRIGGER MECHANISM

The convection initiation of the squall line was triggered from a cumulus line under the impacts together with higher CAPE and less CIN made by increased surface temperature and humidity, significantly enhanced surface convergence line by the outflow of existing convective storms, enhanced convergence of boundary layer by the low-level southwesterly jet and the moving eastwards low-level northwesterly.

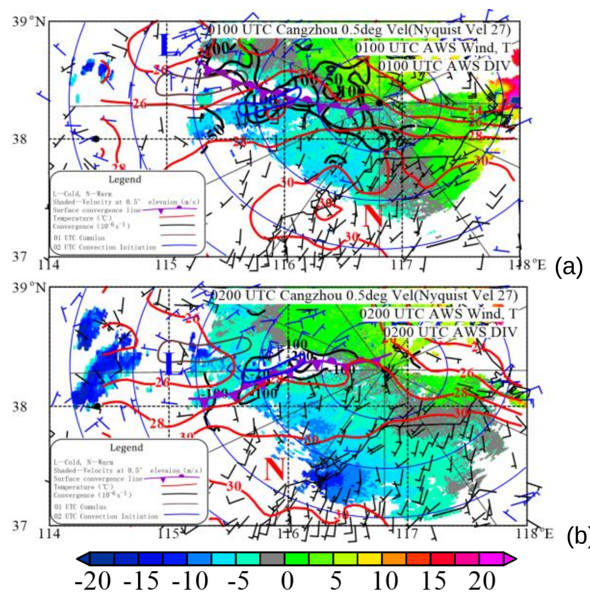


Fig. 4 Radial velocity of Cangzhou radar at 0.5 ° elevation, winds, divergence and temperatures of automatic weather stations for 01 UTC (a), 02 UTC (b) June 30

(Black dots indicate locations of Cangzhou radar station and Shijiazhuang City; radial velocity is shaded, unit is m/s; blue barbs represent northerly; black barbs are southerly)

5. EVOLUTION

Infrared temperature of black body (TBB) shows that the squall line developed from a linear cumulus line to a quasi-circular mesoscale convective complex, with mainly positive lightning and high winds in the low TBB area. Visible cloud images show that it had coarse texture, significant overshooting and rotation feature.

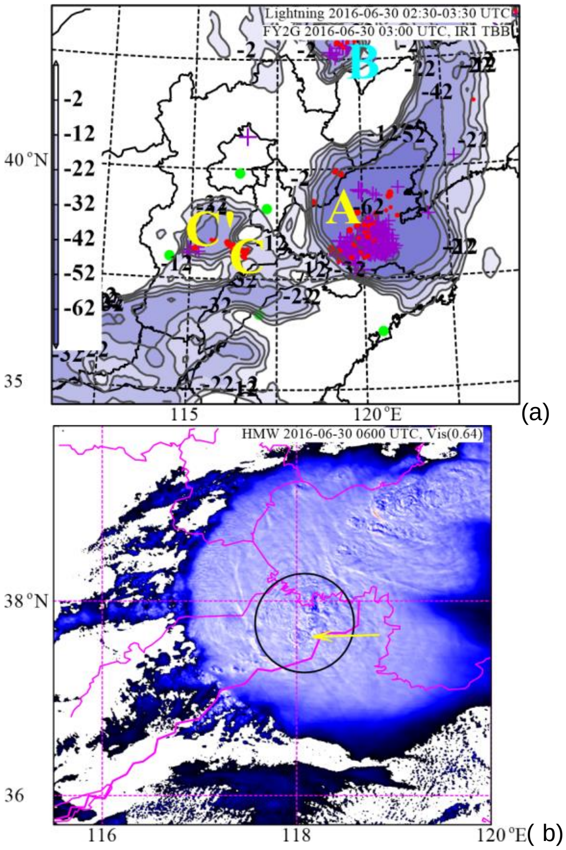


Fig. 5 Observations from geostationary meteorological satellites on June 30

(a) TBB of FY2G and lightning for 03 UTC, (b) Enhanced visible image of Hamawari8 for 06 UTC

(Green dots represent the locations of Beijing, Tianjin, Shijiazhuang, Ji'nan, and Qingdao, respectively. In Fig. a, TBB is shaded and contoured using gray solid lines, unit: ℃. A, B, C' and C denote different MCSs, respectively. Lightning for 0230–0330 UTC is given, and red dots represent negative lightning, purple plus signs denote positive lightning. In Fig. b, black circle and yellow arrow indicate obvious rotations)

Radar observations show that the squall line developed from a meso-β-scale linear convective system to a meso-α-scale arc-shaped squall line with significant overhang echoes, bounded weak echo regions, mesocyclones, mesovortices, strong rear inflows, rear inflow notches, front inflow notches, mid-altitude radial convergences in mature stage, and extreme value of vertical integrated liquid, which are characteristics of storms producing large hail and high winds. And it was organized into an asymmetric carrot-like mode in the mature stage because of new convective storms initiated along the west side and the upper-level diffluent flows.

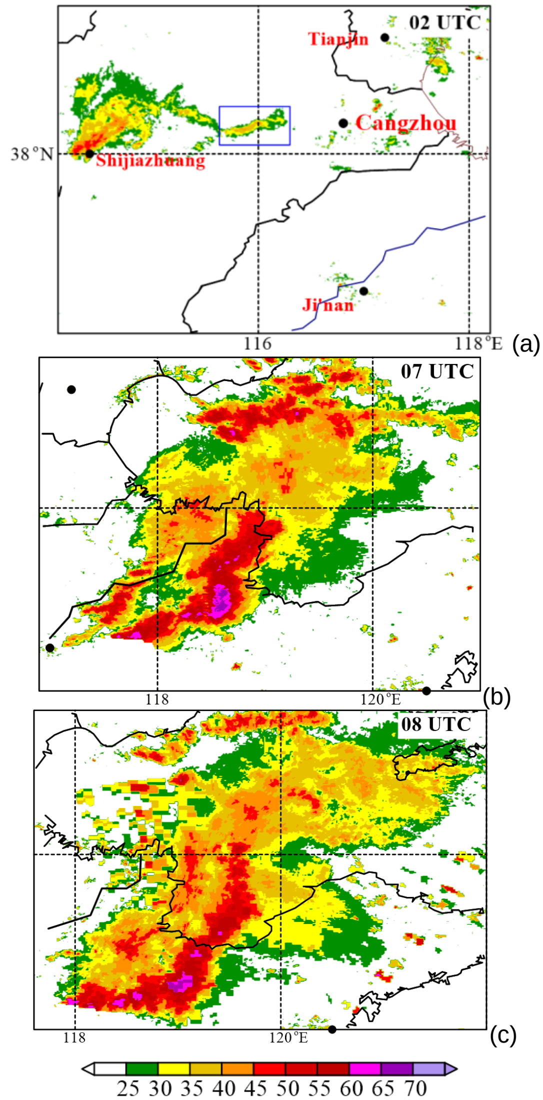
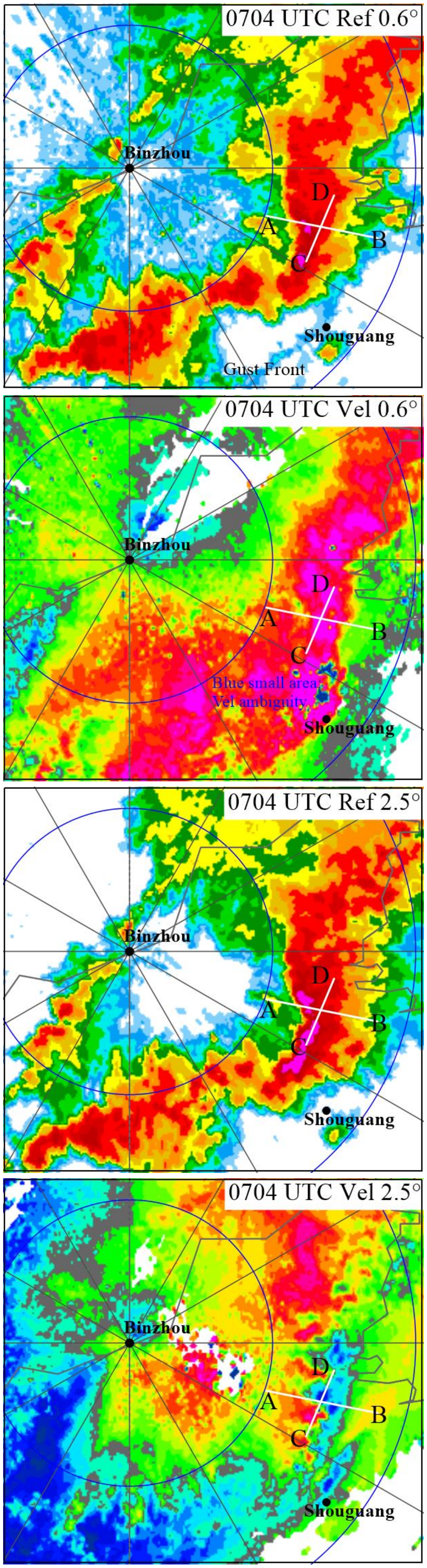


Fig. 6 Radar composite reflectivity no less than 25dBZ on June 30, 2016

(a) 02 UTC; (b) 07 UTC; (c) 08 UTC

(Black dots represent the locations of Tianjin, Shijiazhuang, Ji'nan and Qingdao, respectively. Blue rectangle in Fig. a denotes the location of the initial convective system; color bars of the Figs. are the same)

Intense downdraft induced by high dewpoint deficit of the middle troposphere and strong rear inflow were the main causes for the formation of the bow echoes. The main cause of maintaining the squall line and bow echoes is the intense front inflow formed behind leading convergence line of the squall line.



(a)
(b)
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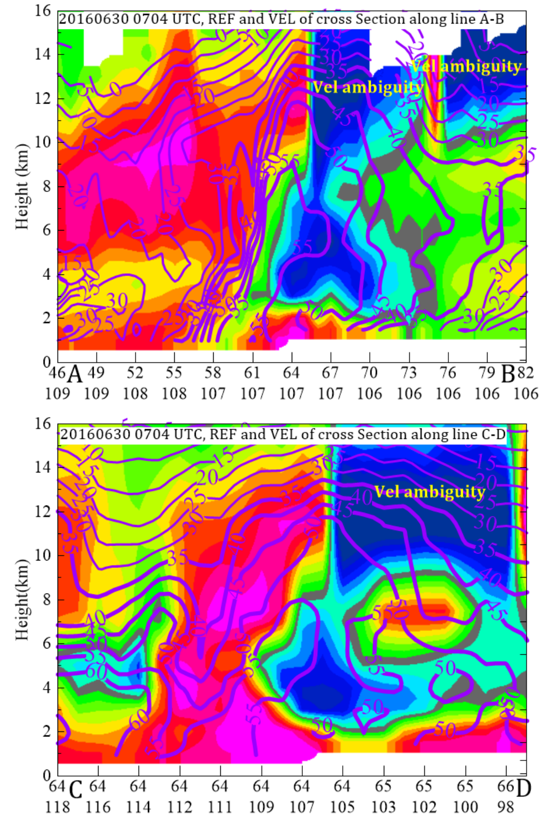

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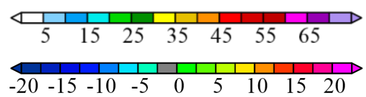

reflectivity color bar
velocity color bar

Fig. 5 Radar reflectivity and radial velocity from Binzhou radar at 0704 UTC on June 30, 2016
(Figs. a and b are for 0.6° elevation, Figs. c and d for 2.5° elevation; Figs. e and f are vertical cross sections. Reflectivity is shaded in Figs. a and c, and radial velocity is shaded in Fig. b, d, e and f. In Figs. e and f, the upper numbers labeled below the abscissa are the distance away from Binzhou radar station, unit: km; the lower numbers are the azimuth angles, unit degree; the numbers on the left ordinate are altitude above sea level, unit is km)

Weaker 500-hPa winds in the initial stage of the squall line, larger CIN in the early morning, later CIN sharply decreasing, and weaker trigger conditions are the difficulties of forecasting the squall line.

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