The Freezing Precipitation over the Middle-Lower Reaches of the Yangtze River during February–March 2009

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Abstract In this paper, the authors analyze the quasi-stationary fronts, surface conditions, and atmospheric stratification processes associated with a freezing precipitation event over the middle-lower reaches of the Yangtze River, especially in the Dabie mountain during February–March 2009. The long duration of freezing precipitation was primarily caused by stationary and anomalous synoptic weather patterns, such as a blocking high pressure in the northern branch and a trough in the southern branch of the westerlies, which resulted in the encounter cold air from northern China and warm moisture from the south. The east-west-oriented, quasi-stationary front (or shear line) found in central China was mostly responsible for producing the precipitation. The warm layer and near-surface frozen layer were located in the lower troposphere along the front zone. Although the warm layer (> 0ºC) existed along the whole front, a surface temperature less than 0ºC appeared only over the lower-middle reaches of the Yangtze River, especially in the Dabie mountain. Therefore, the surface temperature was the main influencing factor, as the freezing precipitation only happened over the Dabie mountain.

Keywords: freezing precipitation, quasi-stationary front, stratification, warm layer

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1 Introduction

Freezing precipitation, including freezing drizzle (FZDZ), freezing rain (FZRA), and ice pellets (IPE) (Carrière et al., 2000; Bernstein, 2000), is a major weather hazard that can cause severe socioeconomic loss. Continuous precipitation occurred over central China from 15 February to 4 March 2009. The 24 hour maximal precipitation of 95.5 mm was reported in Xiuning county, Anhui Province. The duration and intensity of this process rarely appear in the later winter. During the long-duration precipitation, freezing precipitation occurred on 26–27 February and 1–2 March 2009, and induced damage to transportation, electric power lines, communication systems, agriculture, and forestry in the Dabie mountain. The Dabie mountain are located at the border of Henan, Hubei, and Anhui provinces (Fig. 1, 30°10′–32°30′N, 112°40′–117°10′E). Their altitude is generally 500–800 m and the highest peak reaches 1729 m. In China, freezing precipitation occurs most frequently over Guizhou Province, followed by regions in Hunan, Jiangxi, Hubei, Henan, Anhui, and Jiangsu provinces. Freezing precipitation appears infrequently over the Dabie mountain, which is why we analyze the freezing precipitation event that occurred there in 2009.

Given the adverse impact of freezing precipitation on human activities, many studies have been conducted to understand the synoptic systems and weather conditions for freezing precipitation events. For various regions in North America and Europe, the emphasis over the past few decades with respect to predicting freezing precipitation or precipitation types has followed three main ideas. First, attempts have been made to develop statistical models (e.g., critical thresholds, regression, Model Output Statistics (MOS), synoptic weather types, or patterns) to improve the accuracy of short-term freezing precipitation forecasts. The second is analyzing the climatology of freezing precipitation (Carrière et al., 2000; Changnon and Karl, 2003; Cortinas Jr. et al., 2004; Houston and Changnon, 2007). The third is the study of individual freezing precipitation events and composite analyses of the mechanism of freezing precipitation (Bernstein, 2000; Coleman and Marwitz, 2002; Forbes et al., 1987; Rauber et al., 2000; Stewart, 1985, 1992; Stewart and King, 1987).

Freezing precipitation over southern China in 2008 has been studied by Tao and Wei (2008), Zhao and Sun (2008), and Sun and Zhao (2008). Differences and similarities exist between the above-mentioned case in 2008 and the present case. The obvious difference is that the freezing rainfall zone in the former concentrated in the upper reaches of the Yangtze River, rather than in the lower reaches, as in later cases. In this paper, in order to better understand the freezing rainfall over the lower reaches of the Yangtze River, we will analyze the weather systems and mechanisms associated with the freezing precipitation in February-March 2009.

2 Data and methods

The synoptic settings conducive to sustaining freezing precipitation and snowfall were investigated using the NCEP (National Center for Environmental Prediction, US) reanalysis grid of 1°×1° data. The pseudo-equivalent potential temperature, moisture flux used in vertical cross

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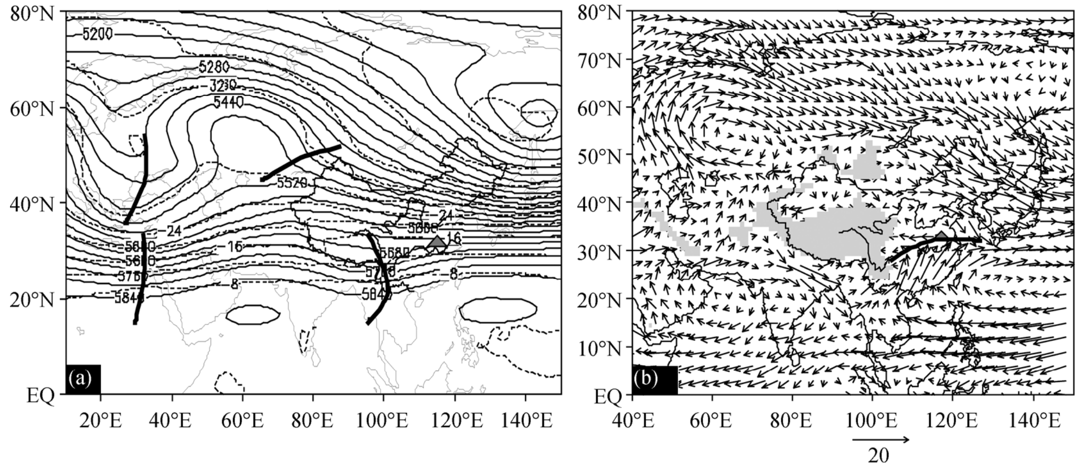

Figure 1 (a) The average geopotential height (units: gpm) and temperature (units: ºC) at 500 hPa from 15 February to 4 March 2009; the bold black line is the trough axis; (b) the average wind at 850 hPa (units: m s^{-1}) from 15 February to 4 March 2009; the black bold line is the shear line, the shading represents the terrain > 1500 m. The triangle indicates the Dabie mountain.

section analyses on front were calculated using NCEP data. The radiosonde data were analyzed to examine the evolution of the large-scale thermodynamic and kinematic fields. The three-hourly interval surface observation data was used to clarify the relationship between freezing precipitation and surface temperature, humidity, and the wind field. The radiosonde and surface data in China were provided by the China Meteorological Administration (CMA).

3 Circulation and weather systems related to the freezing precipitation

The averaged geopotential height and temperature at 500 hPa from 15 February to 4 March 2009 indicate that a blocking high pressure developed near the Ural Mountains (Fig. 1a). To the east, an east-northeast to west-southwest trending trough was maintained, which was the main source of cold air. A deep trough appeared on the west side of a blocking high pressure, which favored the maintenance of the trough in the southern branch of the westerlies. A trough stagnated in Yunnan Province and the Indo-China peninsula, and transported abundant moisture to southern China, which was very favorable to the occurrence of continuous precipitation. The most obvious characteristic in the wind field at 850 hPa was the maintenance of a shear line related to a quasi-stationary front (Fig. 1b), which is unusual in the winter. The maintenance of the quasi-stationary front provided advantageous conditions for the occurrence of the rain-snow band in central China.

In summary, between 15 February and 4 March 2009, the general circulation presented continuously anomalous characteristics, and the shear line and quasi-stationary front were maintained in the Yangtze River Basin and southern China for a long period, which provided an advantageous environment for the formation of the rain-snow event. The circulation of the long-duration precipitation was similar to that in January–February 2008 (Zhao and Sun, 2008). These authors indicated that the long duration of freezing precipitation was primarily caused by quasi-stationary blocking high pressure and the trough in the southern branch of the westerlies at 500 hPa, together with the east-west oriented quasi-stationary front (or shear line) at 850 hPa. Why did the freezing precipitation only occur over the Dabei mountain on 26–27 February and 1–2 March? In the following, we focus on the freezing precipitation during 26–27 February.

4 Atmospheric conditions associated with freezing precipitation

4.1 The quasi-stationary front

A quasi-stationary front (shear line) extended east-west or northeast-southwest to the south or along the Yangtze River Basin during this long-duration precipitation, which was similar to the quasi-stationary front in February 2008 (Sun and Zhao, 2008). However, the freezing precipitation only occurred over the middle and lower reaches, especially areas of the Dabie mountain, rather than Guizhou and Hunan provinces, so we analyzed the difference between different segments of the front through vertical cross-sectional analysis.

Figures 2 and 3 show vertical cross-sections of the pseudo-equivalent potential temperature (θ_{se}), the moisture flux, and the temperature from 25 to 27 February along 110°E (representing the situation without freezing precipitation) and 116°E (representing the situation with freezing precipitation), respectively. The maximum zone of the horizontal gradient between the two isolines (295–320 K) of θ_{se} is recognized as the frontal zone. The isolines of θ_{se} were denser in the west section of the front than in its east section, and the moisture flux in the west section reached a maximum of 18 g s^{-1} cm^{-1} hPa^{-1}, which was stronger than that in its eastern section (Fig. 2). We found that the front already existed on 25 February, but the warm layer (> 0ºC) could not be found (Figs. 2a, 2d, 3a, and 3d). The warm layer (> 0ºC) of 600–900 hPa at 27–30°N appeared during 26–27 February, and the surface temperature was much higher than 0ºC (Figs. 3b and 3c), so the freezing precipitation did not form in the west-

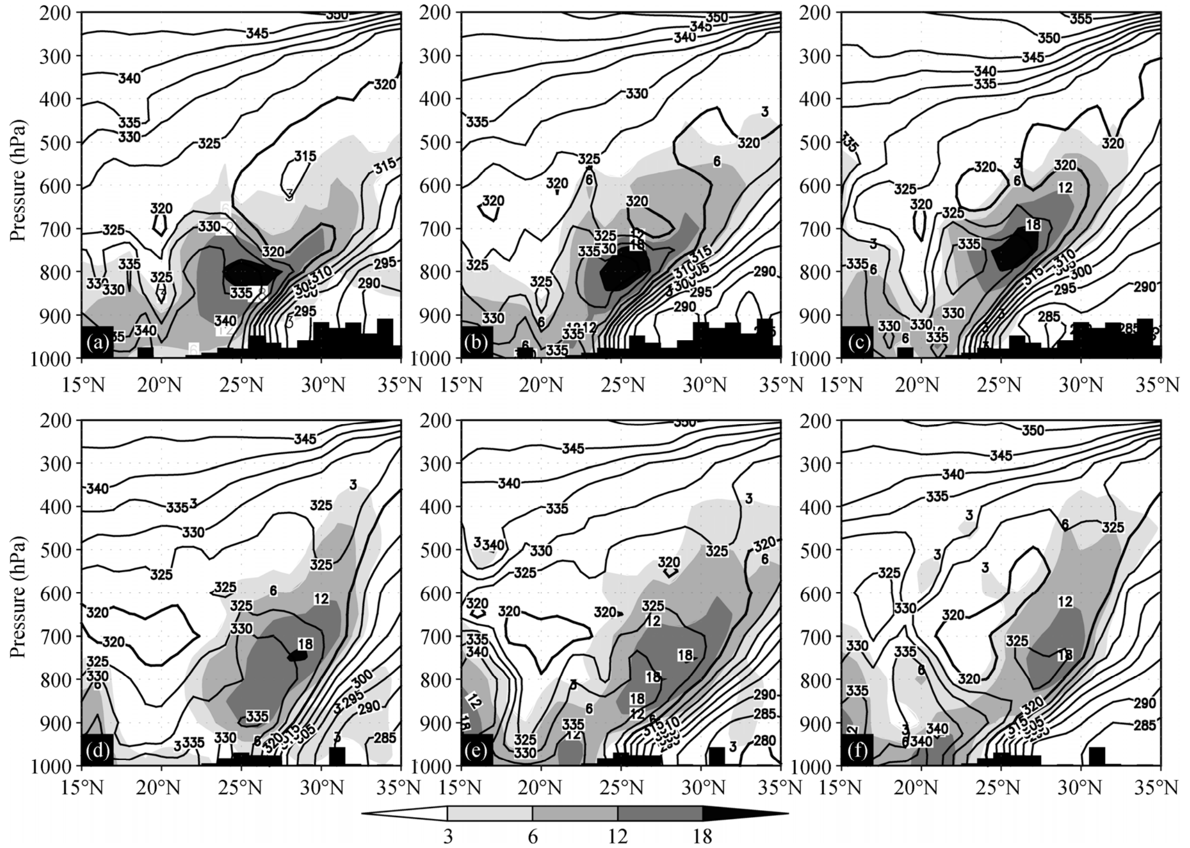

Figure 2 Vertical cross-section of the pseudo-equivalent potential temperature (solid, units: K) and moisture flux (shaded, units: g s^{-1} cm^{-1} hPa^{-1}) along 110°E (upper panel) and 116ºE (lower panel) from 0000 UTC 25 to 0000 UTC 27 February 2009; dark shaded area represents the terrain: (a) and (d) 0000 UTC 25 February; (b) and (e) 0000 UTC 26 February; (c) and (f) 0000 UTC 27 February.

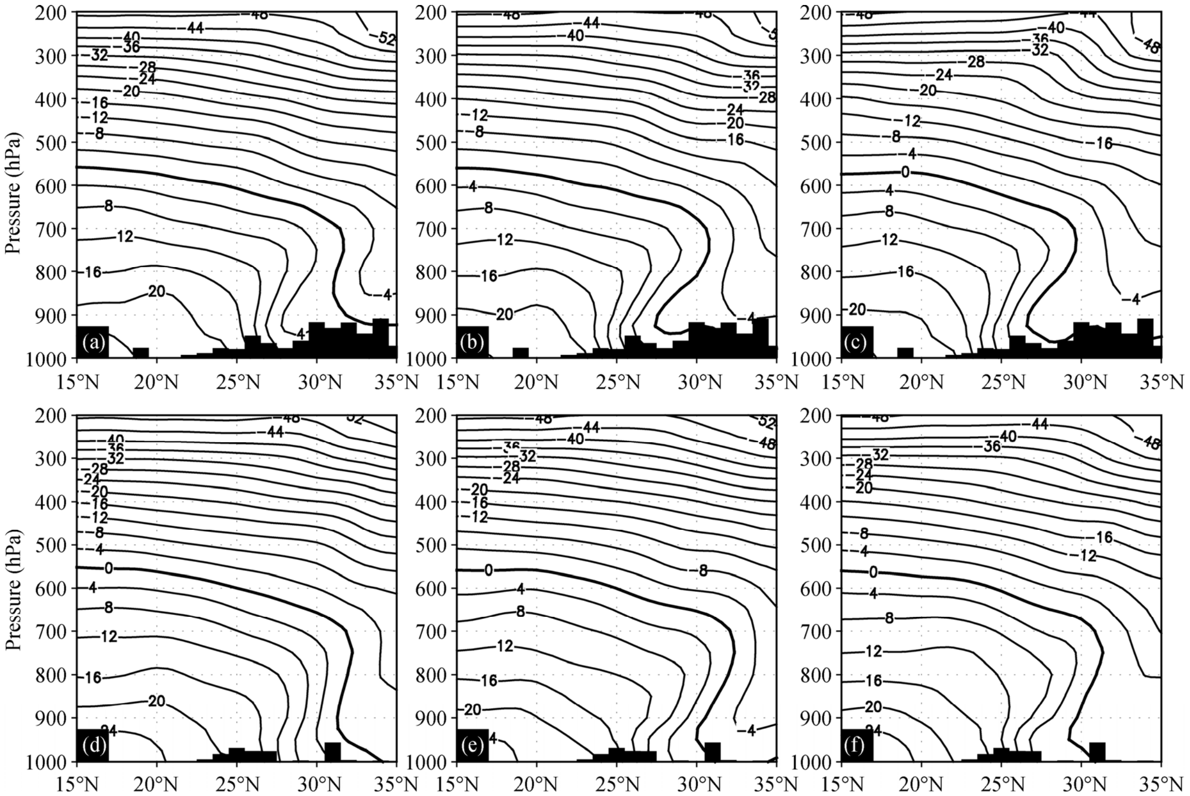

Figure 3 Vertical cross-section of temperature (solid, units: ºC) along 110°E (upper panel) and 116°E (lower panel) from 0000 UTC 25 to 0000 UTC 27 February 2009; dark shaded area represents the terrain: (a) and (d) 0000 UTC 25 February; (b) and (e) 0000 UTC 26 February; (c) and (f) 0000 UTC 27 February.

ern section of the front. However, the warm layer (> 0ºC) of 600–900 hPa at 30–32°N appeared during 26–27 February, and the surface temperature was slightly lower than 0ºC in the eastern section of the front (Figs. 3d and 3e), therefore, the freezing precipitation in the eastern section of the front at 30–32°N appeared Dabie mountain; in other words, the freezing precipitation area was to the north of the surface front zone.

As we know, these conditions were very favorable for the formation of freezing precipitation: there was a freezing layer in the middle troposphere, and a warm layer (melting layer) and an inversion below the freezing layer, a thin layer below 0ºC above the surface could be found. Thus, although the moisture flux and stronger front occurred in the western section of the front, freezing precipitation occurred only in its eastern section; the main reason for this was that the surface temperature in the east section below 0ºC. In the following, we use the observational data from CMA to analyze the stratification and surface conditions associated with freezing precipitation.

4.2 Stratification and surface conditions associated with freezing precipitation

Here, three-hourly interval surface observation data were used to study the relationship between freezing precipitation, surface temperature, humidity, and the wind field. Sun and Zhao (2008) analyzed the horizontal distribution of precipitation type and surface temperature (not shown) and pointed out that freezing precipitation appeared in the region where the surface temperature was between 0ºC to −3ºC with a weak northerly wind. Figure 4 represents the horizontal distribution of surface temperature and weather phenomena (freezing precipitation). It was found that the isoline of 0ºC at the surface was located at 35°N on 25 February, but no warm layer was found there (Fig. 3d), so freezing precipitation did not occur (Fig. 4a). The isothermal line of 0ºC then moved south to area in the Dabie mountain, and freezing precipitation appeared on 26 February (Fig. 4b). The analysis of synoptic circulation indicates that the cold air from the north invaded the middle and lower reaches of the Yangtze River (not shown). According to the report of the Meteorological Bureau of Anhui Province, the freezing precipitation occurred over the Dabie mountain at an altitude above 300 m. Unfortunately, the altitude of the standard observation station over the Dabie mountain in Anhui Province is below 100 m, so observations over the mountains could not be obtained from routine CMA observation data. Figure 5 shows the surface temperature, dew-point temperature, wind field, and 6-hour precipitation at Huoshan (station number 58314, 31°24′N, 116°19′E, altitude of 72.7 m), Tongcheng (station number 58319, 31°04′N, 116°57′E, altitude of 81.8 m), and Anqing (station number 58424, 30°32′ N, 117°03′ E, altitude of 19.6 m) from 21 February to 5 March 2009, three stations located at the foot of the Dabie mountain. The surface temperature decreased to 2ºC during 26–27 February, and another relatively lower surface temperature appeared on 2 March, at which time freezing precipitation was again reported. The dew-point depression for all stations was 1–3ºC, and for most of them was lower than 2ºC during 26–27 February and 2 March. According to the lapse rate of temperature, the temperature could have decreased with altitude to 0ºC above 300 m. The surface wind direction was north or northeast and the wind speed was 0–4 m s^{-1}.

Although the vertical distribution of the temperature was analyzed using NCEP data (Fig. 3), these were reanalysis data. The radiosonde station Anqing, located very near the Dabie mountain was used to diagnose the stratification while freezing precipitation occurred (Fig. 6). The cloud top (defined as the first level above the low-level cloud layer where the dew-point depression exceeded 3ºC) was much higher than the warm layer (> 0ºC) at about 500 hPa, with the cloud top temperature of −10ºC and a warm layer located at 700–800 hPa. The hodograph suggested a synoptic pattern with a low-level northeasterly wind, and a southwesterly wind aloft, which meant that warm advection existed in the lower troposphere and was favorable to the formation of a warm layer. The temperature below the warm layer decreased quickly and formed a cold layer (< 0ºC).

5 Summary and conclusions

In this paper, we investigate the mechanisms of formation of freezing precipitation over the Dabie mountain during February–March 2009 that caused the most se-

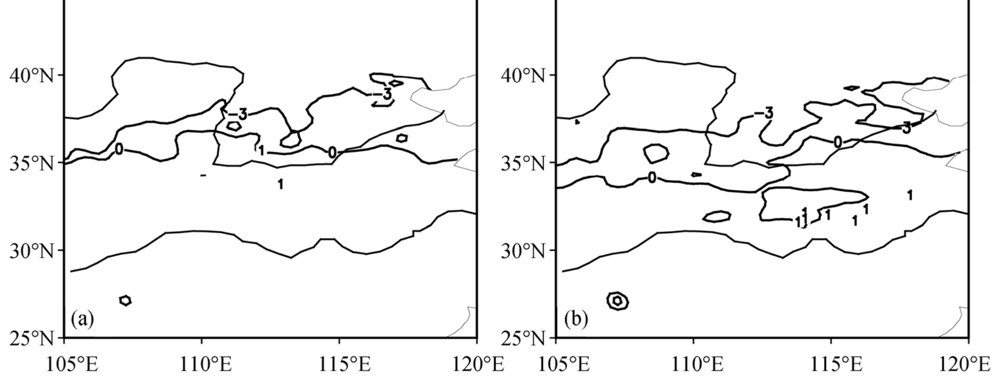

Figure 4 Surface temperature (solid line, units: ºC) and freezing rain (number 1) on 25–26 February 2009. (a) 0000 UTC 25; (b) 0000 UTC 26.

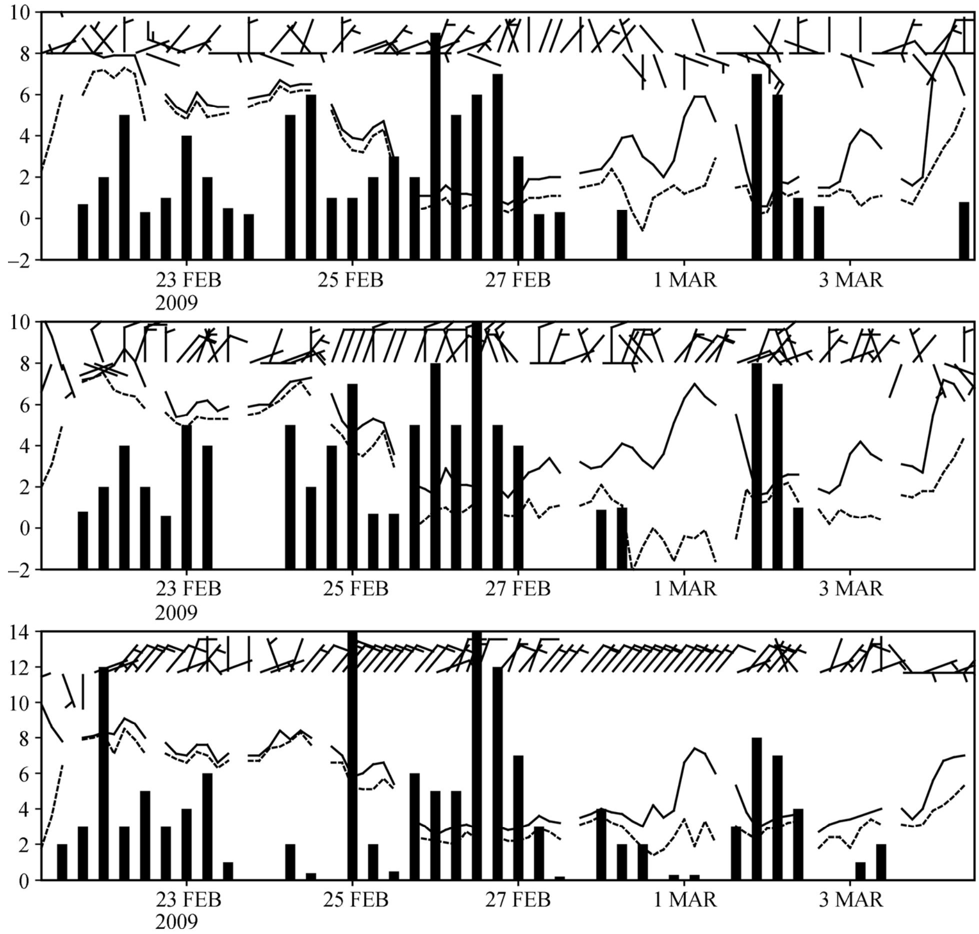

Figure 5 The surface temperature (solid line, units: ºC), dew-point temperature (dashed line, units: ºC), wind field (half barb: 2.5 m s^{-1}; full barb:5.0 m s^{-1}), and 6-hour precipitation (units: mm) from 21 February to 5 March 2009.

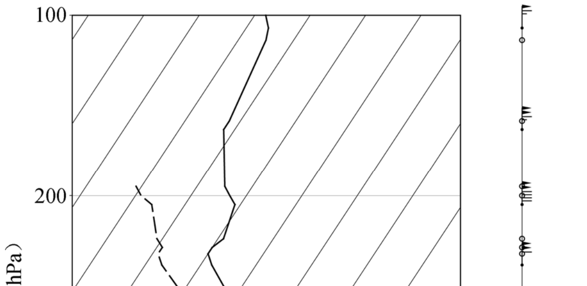

Figure 6 The individual skew *T*-log*p* radiosonde observation from Anqing on 0000 UTC 26 February, temperature (solid line), dew-point temperature (dashed line, units: ºC), wind barb on the right (half barb: 2.5 m s^{-1}; full barb: 5.0 m s^{-1}; flag: 20.0 m s^{-1}).

vere damage since 1961. We focus on the synoptic conditions, the surface conditions, and sounding profiles favorable for the occurrence of freezing precipitation. The long-period anomaly of the atmospheric circulation was one of the important reasons for the continuous precipitation. The east-west-oriented quasi-stationary front located in the Yangtze River Basin was the most important system producing long-duration precipitation. The strongest warm moisture convergence occurred at the front location from surface to the middle troposphere above, which enhanced the formation, development, and persistence of freezing precipitation. A warm layer and a near-surface frozen layer existed along the front, which is similar to the situation during freezing precipitation over southern China in February–March 2008 (Sun and Zhao, 2008). Although a warm layer (> 0ºC) existed along the front, the surface temperature was below 0ºC over the Dabie mountain. From this analysis, the mechanism of freezing precipitation in 2009 was similar to that in 2008 (Zhao and Sun, 2008; Sun and Zhao, 2008).

Although the formation mechanism of freezing precipitation during February 2009 was reasonably understood through the analysis of observation data, the formation of freezing precipitation was very sensitive to certain key influencing factors: the thickness of the warm layer, the near-surface frozen layer, and the surface temperature.

As a result, the accurate prediction of freezing precipitation is very difficult and requires further investigation.

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