Diagnostic Study of a Winter Snowstorm Event①

Shou Shaowen (寿绍文)
Nanjing Institute of Meteorology, Nanjing 210044
and *Zhu Aimin* (朱爱民)
State Meteorological Administration, Beijing 100081
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ABSTRACT

A diagnostic study of a winter snowstorm event was presented. The results showed that some factors were of importance to the formation of the snow gush. Most of the factors were similar to those for summer rain gush, while the temperature stratification structure was important to distinguish snow from rain.

Key words: Snowstorm, Formation, Diagnosis

I. INTRODUCTION

For the middle and lower reaches of the Changjiang River, winter snowstorm and summer rain gush are two major precipitation events of great hazard. However more efforts have been made towards rainstorm than towards heavy snowfall. This study is intended to explore the mechanisms of the snowstorm formation based on the diagnosis of a snowfall process.

II. OUTLINES OF THE WEATHER PROCESS

An exceptionally heavy snowfall occurred for 17–19 January 1984 on large scale over the Changjiang – Huaihe Rivers, and south of the Changjiang River, with about 20 mm of water and 15 cm snow depth for much of the region under consideration, 60–90 mm water and 40–50 cm snow depth in some places in Anhui and Jiangsu Provinces. This is the heaviest snowstorm event ever recorded for this region.

The precipitation process began with 17 January, maximizing on the next day and ended before noon of the 19 January. The 12–hour rainfall pattern shows that the rainfall as sleet took place mainly to the south of the Changjiang River at 0800 BST (Beijing Standard Time) January 17; at 2000 BST of the day the rain band extended into the Changjiang–Huaihe Valleys, precipitating snow; at 0800 BST of 18 January the intensity got enhanced quickly, forming a snowfall belt, with a rainfall greater than 20 mm in this area, centered around Shashi, Wuhan and Hefei Cities; later at 2000 BST of the day the snow belt was moved southwards to the belt of Changsha, Jiujiang and Hangzhou Cities with decreased strength, centered about Jiujiang City (26 mm) and Hangzhou (29 mm); at 0800 BST Of 19 January the snow belt was moved further southward with the rapidly lessened area and weakened intensity. At this time the snowfall process was almost close to end. From the above analysis we can see that, despite the fact that the event covered an extensive area and lasted quite long, the time– and

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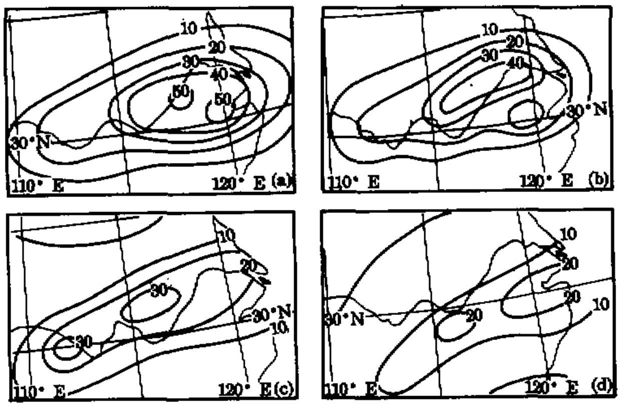

Fig.1. Pattern of 24-hour rainfall (mm) for January 18, 1984 (a), and snow depth (cm) for the following day (b), and the 12-hour rainfall (mm) distributions for 0300–1400 BST, January 18 (c) and 1500 BST, January 18 to 0200 BST, January 19 (d).

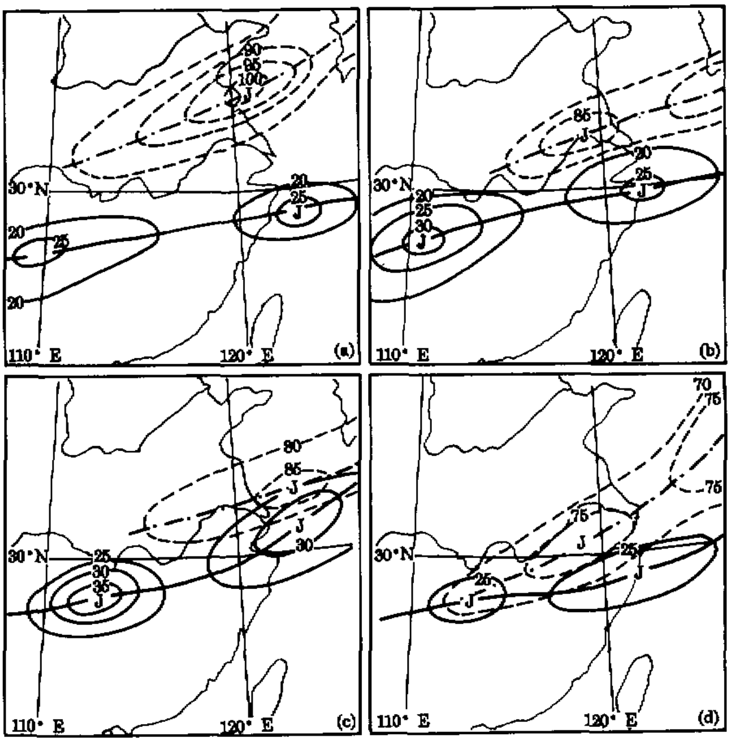

Fig.2. Positions of 200 (broken line) and 700 hPa (solid line) jetstream for January 17 and 18 of 1984, with isotaches in units of m / s · a) and b) give the condition of 0800 and 2000 BST January 17, respectively; c) and d) of 0800 and 2000 BST January 18, respectively.

space-scale features of the snowfall centers are obviously meso-scale.

During the process, the circulation patterns of high and lower latitudes over the Eurasian continent are marked by a steady situation. A 500 hPa broad trough stretches from the Balkhash Lake to the eastern-Asian coastal region, out of which came continually cold air that affected China. In 14-16 January a stronger cold air moved southward, causing a 6-10℃ drop in North and Northeast China and decreased to 0-2℃ south of the Changjiang River which formed a cold cushion in the lower troposphere. At 500 hPa level a southern-branch trough was moving towards the east at low latitudes, which left the Qinghai-Xizang (Tibet) Plateau on 17 January. At 850 hPa a vortex was developing and travelling eastwards in Southwest China and moved out of the Sichuan Basin at 2000 BST January 17 and quickened pace in the same direction along the shear line, which reached Anqing City at 0800 BST January 18 and brought about intense frontogenesis, leading to the climax of the event. Afterwards, the vortex weakened, travelling eastwards and over the sea the next day, implying the end of the weather process.

During this snowstorm process the 200- and 700-hPa jet streams showed remarkable changes in position. One can see from Fig.2 that at 0800 BST January 17 the 200 (700) hPa jet stream was positioned over the Huaihe River Basin (south of the Changjiang River) and for 2000 BST the former (latter) moved southwards (northwards) with their axis lines getting close; at 0800 BST January 18 the 700 hPa jet got considerably enhanced, crossing with the upper one; at 2000 BST both had their position shifting southwards. During the snowfall the major region of snowstorm was between the jet axes and moved with them.

III. DIVERGENCE, VERTICAL VELOCITY AND MOISTURE FIELD IN RELATION TO THE SNOWSTORM

At 0800 BST January 18 the 800 hPa convergence got significantly enhanced over the mid and lower reaches of the Changjiang River, centered around Wuhan and Anqing Cities with the intensity of $-7.8\times10^{-5}\ s^{-1}$ and $-6.7\times10^{-5}\ s^{-1}$, respectively. Located at the 200 hPa level over the belt is a divergence zone, centered around Anqing City at $6.5\times10^{-5}\ s^{-1}$. The

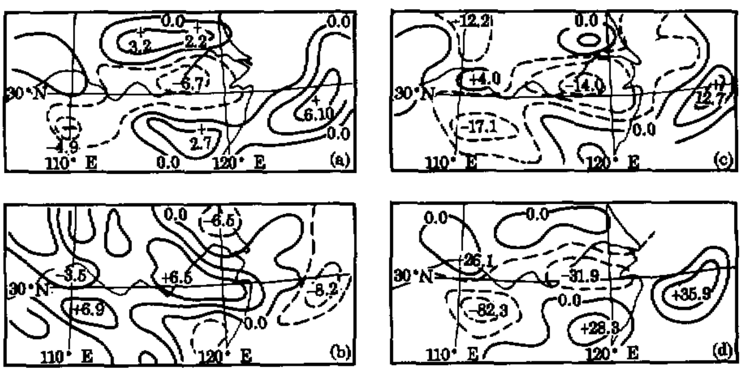

Fig.3. Distribution of divergence, vertical velocity and moisture flux divergence at 0800 BST January 18, 1984. (a) 800 hPa divergence ($10^{-5}s^{-1}$); (b) 200 hPa divergence ($10^{-5}S^{-1}$) (c) 700 hPa vertical velocity (10^{-3} hPa · s^{-1}); (d) 800 hPa moisture flux divergence (10^{-7}g / (cm^2 · hPa · s).

700 hPa vertical rising belt stretched from Wuhan to Anqing, with the vertical velocity center of -14.0×10^{-3} hPa • s^{-1}around Anqing together with another one at Changde City. The two updraft centers were in rough agreement with the regions of snow gust.

At 0800 BST January 18 the 850 hPa moisture flux and the flux convergence were considerably strengthened with the center at Anqing at -5.2×10^{-7} g / (cm^2 • hPa • s). For the flux divergence calculation was done of moisture advection and convergence terms constituting the divergence. Results show that the magnitude is much greater for the convergence than for the advection term.

The evolution of precipitation intensity and the area were in agreement with that of high level divergence, lower level convergence, vertical velocity and the moisture flux convergence during 0800 BST January 17 and 2000 BST January 19.

IV. RELATION BETWEEN FRONTOGENETICAL SECONDARY CIRCULATION AND SNOWSTORM

As stated earlier, frontogenesis is one of the causes for the enhancement of snowfall of 0800 BST January 18. We adopted the Sawyer–Eliassen frontal transversal secondary circulation equations to make a diagnosis of the secondary circulation at issue together with the exploration of its role in producing the snowstorm. The Sawyer–Eliassen Equations take the form

$$-r\frac{\partial\theta}{\partial p}\frac{\partial^2\psi}{\partial y^2}+2\frac{\partial m}{\partial p}\frac{\partial^2\psi}{\partial y\partial p}-\frac{\partial m}{\partial y}\frac{\partial^2\psi}{\partial p^2}=Q_g+Q_{ag}+Q_H\ , \tag{1}$$

where,

$$Q_g=-2J_{xy}(u_g,\theta)\ , \tag{2}$$

$$Q_{ag}=-\frac{\partial u_g}{\partial x}\frac{\partial u_a}{\partial p}+2r\frac{\partial\theta}{\partial x}\frac{\partial u_a}{\partial y}\ , \tag{3}$$

$$Q_H=-r\frac{\partial H}{\partial y}\ , \tag{4}$$

in which m = the absolute momentum. ψ = the streamfunction, u_g and V_g = the components of geostrophic wind, u_a and v_a = the components of ageostrophic wind, θ = the potential temperature, H = the heating effect, $r=\frac{R}{fp_0}(\frac{p_0}{p})^{c_p/c_v}$ ..

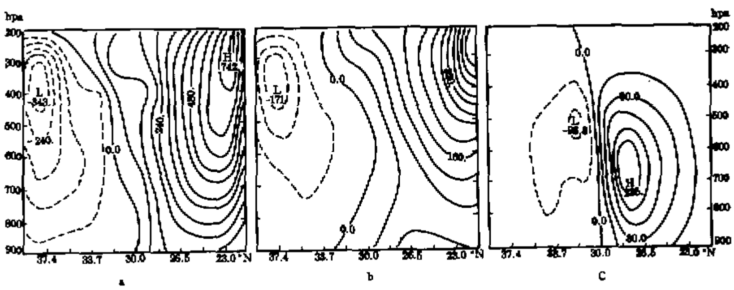

Fig.4. Plot of the secondary circulation produced by the forcing terms at 0800 BST on January 18 of 1984, with the circulation caused by geostrophic forcing (a), ageostrophic deformation (b) and *diabatic heating forcing (c).*

And it follows from Eq.(1) that the factors governing the secondary circulation are the term of geostrophic forcing (Q_g), of ageostrophic forcing (Q_{ag}) and of nonadiabatic heating (Q_H), which however vary in the contribution to the total circulation. Take for example the 117°E meriditional section with Anqing City at 0800 BST January 18. There effects of Q_g and Q_{ag} are comparable in magnitude and those of Q_H relatively smaller. Further, the geostrophic forcing may consist of geostrophic stretching deformation and shear deformation forcing, with the former being more important. This clarifies, to some extent, the close relation of the snow gush to the 200– and 700–hPa jet streams. Included in the ageostrophic forcing are vertical and horizontal shear deformation forcings of ageostrophic along the front, the latter contributing more to the total circulation of ageostrophic forcing.

As to the relation between the evolution of the secondary circulation and snowfall is remarkable. Fig.5 illustrates the circulation in the 117°E meridional section for 2000 BST January 17 to the same time of the next day. One can see that at 2000 BST of January 17 there were two circulation cells, the smaller one in the south and the big one in the north. The former was a 700 hPa anti–circulation with streamfunction evaluated at 161 m • hPa • s^{-1} located around 25°N and the latter centered near 30°N was a 500 hPa direct circulation at −462 m • hPa • s^{-1}. The direct circulation was stronger and the anti–circulation relatively weak. There were two updraft zones close to 30°N, one being 900–600 hPa interval between 30° and 26°N and other in 700–400 hPa extent between 34° and 31°N. At 0800 BST January 18 the most intense rising occurred around 700 to 500 hPa between 31° and 28°N with the two circulation cells significantly intensified. For 2000 BST January 18 the whole section was under the control of the strong anti–circulation, with three centers, one being at 400 hPa near 30°N and the other two at 700 and 30 hPa around 27°N, with the streamfunction of 566, 645 and 146 m • hPa • s^{-1}, respectively. The anti–circulation rising arm was north of 27°N, the maximum at 800–600 hPa between 30° and 27°N, a situation in rough concord with the snowfall band. The foregoing analysis indicates that 117°E total circulation developed in the following manner—at 0800 BST of January 17 the direct (opposite) circulation was intense (feeble) and later the former (latter) was getting weak (robust) and at 2000 BST of January 18 the latter became predominated. The evolution was closely dependent upon the strength of the front. The direct (opposite) circulation was intense (weak) at 2000 BST of January 17, implying strong horizontal temperature frontogenesis (HTFG), leading to the fact that the

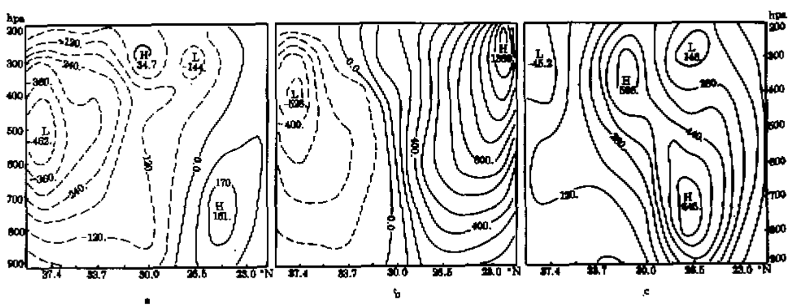

Fig.5. The secondary circulation in the 117°E meridional section for 2000 BST January 17, 1984 to the same hour of the following day; a) 2000 BST January 17; b) 0800 BST January 17; c) 0800 BST January 18.

lower–troposphere front began swift intensification. At 0800 BST of January 18 the strength of the direct circulation reached maximum, suggesting that HTFG was at climax, causing the strongest rising motion excited over the front, responsible for the heaviest snowfall. Meanwhile, anti–circulation became greatly strengthened and markedly predominant over the mid and lower catchment of the Changjiang River, implying that lower–level HTFG there weakened rapidly as vertival momentum frontogenesis became enhanced. By 2000 BST of January 18 the direct circulation was disintegrated almost completely whereas the opposite circulation, although still having absolute predominace, got remarkably weakened, especially at lower levels where a strong anti–circulation made appearance, suggesting that there occurred horizontal temperature frontolysis, leading to the first impaired front, in relation to which snowfall became greatly weakened.

V. TEMPERATURE STRATIFICATION IN RELATION TO THE SNOWSTORM

Now we consider the temperature stratification around the region of snow gush by examining the Anqing sounding curve close to the snowfall center at 0800 h of day 18. The stratification is characterized by i) warm mid levels and cold lower levels with mid–level inversion available that had maximum temperature of roughly 0°C and vertical extent of about 2,000 m; ii) a thick layer of near saturation ($T - T_d < 4$°C) extending from ground to 330 hPa with the cold top (depth) estimated at −35°C (~ 6,000 m); iii) The stratification was conditional stability , i.e., $\Delta\theta_{se}$ ($= \theta_{se500} - \theta_{se850}$) was positive, while it was conditional symmetric instable. Conditional symmetric instability (CSI) denotes the unsteadiness of slanting convection of the moist atmosphere. A dimensionless quantity S is taken to discriminate the CSI. In the coordinates (x,y,p),S takes the form

$$S = \frac{f+\zeta}{f} - \frac{1}{R_i} \ , \qquad R_i = \frac{g}{\theta_{se}}(\partial\theta_{se} / \partial z) / (\partial v / \partial z)^2 \tag{5}$$

where f is geostrophic vorticity, ζ is relative vorticity, U is the wind speed, R_i is Richardson number, θ_{se} is pseudo–equivalent temperature. $S < 0$ indicates the presence of the conditional symmetric instable in the atmosphere. The area of $S < 0$ is associated with slanting ascending and precipitation can be expected at the next sounding time in this region. For example, at 0800 BST January 18 on 800 hPa over Hangzhou to the East–China Sea there was a region of negative S marked by two centers, one around Zhoushan and the other over the sea. Accordingly about 2000 BST of January18 Hangzhou region had heavy snowfall (see Fig.1.d). At this time an instability area occurred in Central Jiangxi Province.

The formation of the temperature structure of the snowstorm region was related to the weather situation. As shown in the 850 hPa synoptic chart for 0800 BST January 18, a cold tongue stretches from Henan Province via the Changjiang–Hanshui Plain into western Hunan Province with the frontal zone located over the Nanling Mountains to southern Zhejiang Province. And the northly and northeastly flows were blowing in this region along the Changjiang River and south of it and southly flow to the south of the frontal line. Hence warm humid airflow coming from the south had to move up the low–level cold cushion towards the north, a condition that favored the snow gush. Moreover, warm mid level and thick saturation layer provided the snowfall with enough moisture. The mid level was warm but at or below 0℃ , which provided a condition for crystals from the upper levels to form snowflakes rather than rain drops in the mid level supercooled water layer. In addition, low–level cold allowed snowflakes to drop onto the ground unmelted.

VI. CONCLUDING REMARKS

The above analyses show that the following are of importance to the formation of the snow gush: 1) Extratropical-latitude eastern-Asian longwave trough was stable with splitted cold air marching towards the south and the developing southern-branch trough; 2) Upper- and lower-level jets got closer; 3) Low level convergence and high level divergence and low level moisture flux convergence enhanced; 4) Frontogenetical secondary circulation was intensified; 5) Conditionally symmetric instability existed; 6) The temperature stratification structure was favoable. Most of the above factors are similar to the situation of summer rain gush, while the last one is important to distinguish snow from rain.

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