NUMERICAL STUDY ON MICROPHYSICAL PROCESSES OF TWO DIFFERENT SNOWFALL CASES IN NORTH CHINA

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1. INTRODUCTION

Snowfall is very common in North China in winter and sometimes of negative effects on the traffic and power transmission in big cities. The weather systems inducing snowfall are various. Some are large scale cold frontal systems, for example the cold wave causing strong wind and snowfall during 23 - 24 Nov 1999 in Liaoning province. Some are small systems, for example the shallow trough system causing light snowfall during 7 - 8 Dec 2001 in Beijing city (Zhao et al., 2002; Sun et al., 2003). Some strong convective systems which not often occur also can bring thunder-snowstorms (Li et al., 1999). Many researches have been done about the weather and climate characteristics of snowfall (Wang et al., 1979; Yi et al., 1999; Wang et al., 1995). However, studies on snowfall are not as much as those on the rainfall. As same as the heavy rainfall in summer, it is also very complicated about the weather systems and physical processes of snowfall in winter. Nowadays the snowfall is still a challenge to weather forecast. So it is very necessary to pay more attention to the study of snowfall.

Recently some observations and simulations have shown that, the mixed-phase cloud process, in which ice phase coexisted with liquid phase, played the most important role in the development of heavy rainfall in South China and along the Yangtze River (Wang et al., 2002, 2003; Sun et al., 2003). However it is not sure whether the cloud process of snowfall in winter is the same as that of those heavy rainfalls due to lack of observations and numerical simulations. Both rainfall and snowfall are produced by the cloud microphysical processes under certain dynamical and thermal conditions. In addition to the hydrometeor phase in the cloud, the source and sinks for the generation of all hydrometeors are also very important. For heavy rainfall, the microphysical process is able to feedback significantly to the thermal and dynamical processes through latent heat and drag force. What is the feedback like for snowfall is also worthy of doing some researches.

In this paper, two different types of snowfall cases in North China are simulated, which are light snowfall during 7 - 8 Dec 2001 in Beijing city and strong wind and snowfall during 23 - 24 Nov 1999 in Liaoning province. These snowfalls brought large negative effects such as the traffic jam and power transmission break on big cities. Microphysical processes are mainly discussed. The hydrometeors and their source and sinks are analyzed and the feedback of microphysical processes to thermal and dynamical processes is preliminarily studied.

2. MODEL DESCRIPTION

In this study, the snowfalls are simulated using the PSU–NCAR non-hydrostatic, two-way interactive model MM5v3 (Grell, 1994). The model includes 6 explicit schemes, which are warm rain scheme, simple-ice scheme, mix-ice scheme, Goddard scheme, Reisner graupel scheme and Schultz scheme. The
microphysical processes of Reisner graupel scheme are more complicated (Reisner et al., 1998). After analyzing the source and sinks for each hydrometeor, the primary processes to form the hydrometeor can be found. The understanding of the cloud processes is also essential to the microphysical mechanism of precipitation.

3. CASE OF BEIJING SNOWFALL
3.1 Case overview and model design

On 6 Dec 2001, a cloud system moved from Qinghai province to the east, and arrived at Beijing at 0000 UTC 7 Dec. Nine hours later it moved out of Beijing. There were two deep troughs in the east and west sides of the East Asia at 500 hPa. The west flow dominated between the troughs from 40°N to 50°N. This situation last for two days which imply no strong cold air and change of the weather. Correspondingly with the cloud image, in the west flow a shallow trough moved from north-east side of the Tibet Plateau and passed through Beijing during 0000 UTC 7 Dec. This trough became stronger at low levels and a close center of 1440 gpm exists at 850 hPa. It began to snowfall when the trough came close to Beijing. The southwest flow of the trough sent the moist and warm air. Updraft and convergence ahead of the trough may be one of the trigger mechanisms of this snowfall.

The non-hydrostatic model MM5v3 was used for numerical simulation. Two nested-level domains were set. The outer coarse domain included 61×61 grid points with horizontal resolution of 45km covering the area of (28.2° – 52.2°N, 101.0° – 132.1°E); the same grid points for the fine-mesh domain but with 15km grid size covering the area of (36.0° – 44.0°N, 111.1° – 121.6°E). The model physical processes mainly include the Anthes–Kuo convective parameterization scheme, the Reisner scheme, the MRF PBL scheme and cloud radiation scheme. The model was initiated using the USA NCEP 1°×1° grid data as a “first guess” field. The simulation was started at 0000 UTC 7 Dec and ended at 0000 UTC 8 Dec 2001.

3.2 Simulations of snowfall

Snowfall occurred around Beijing and Hebei province because of the cloud moving on 7—8 Dec 2001. The observed maximum of snowfall was 1.8 mm. Snow occurred in Beijing mainly in the period of 0600 UTC – 1200 UTC 7 Dec. The 6-hour snowfalls of observations and simulations show that the snow band moved eastward along with the cloud system (Fig. 1). The simulated snowfall was in Shanxi province at 0600 UTC 7 Dec correspondingly with observation. At 1200 UTC 7 Dec, it moved eastward to Beijing with the maximum of 1.5 mm which was a bit less than observation. At 1400 UTC 7 Dec, it moved out of Beijing. The period of the strongest snowfall simulated was 0800 UTC – 0900 UTC 7 Dec. On the whole, the simulated results reproduced the snowfall’s movement and distribution successfully.

3.3 Phases of hydrometeors

The simulated results show that the temperature of the atmosphere was below 0°C and about -5°C near the ground. There were no liquid phase particles and the cloud was made up of ice and snow. Fig.2 shows the vertical sections along 40°N at 0600 UTC and 0900 UTC 7 Dec. The west wind in the middle and high levels between 700 hPa and 300 hPa was stronger than that in the low levels. Ice particles were transferred by the west wind so that ice
Fig 1. Observed(a-c) and simulated(d-f) rainfall (mm) for every 6 hours on 7 Dec 2001.

Fig 2. Cross section of ice phase particles (shaded, g/kg), water vapor (solid line, g/kg), temperature (dash line, °C) and wind vector along 40°N on 7 Dec 2001.
cloud inclined eastward with the height vertically. Ice cloud together with the snowfall center moved from the west to the east gradually. The distribution of water vapor was similar to ice particles. The maximum of water vapor was 1.6 g/kg. As for Beijing (40°N, 116.3°E), due to the vertical inclination of the cloud, it developed from the top to the bottom. The vertical section along 116.3°E shows the development clearly (Fig. 3). It did not start to snow at 0300 UTC 7 Dec. Ice particles distributed between 600–300 hPa at first. The maximum of snow was 0.035 g/kg. Correspondingly with the ice particles was the updraft with a maximum of 0.14 m/s between 750–300 hPa. At 0600 UTC, the ice cloud became thicker with the bottom at 900 hPa. The updraft sustained around the center area of ice particles. Subsequently with the eastward moving of snowfall, the center height of ice particles became lower, and ice and snow fell down to the ground at 0700 UTC indicating the start to snowfall in Beijing. Two hours later snow of Beijing became strongest with a maximum of 0.065 g/kg. The updraft turned weaker. Downdraft occurred at the north-side of snow area. At 1200 UTC, ice particles obviously became fewer. Cloud was dominated by the weak downdraft. Ice cloud began to dissipate. Snowfall stopped at 1500 UTC 7 Dec.

During this snowfall process, snow area moved from the west to the east, and the snowfall of Beijing started at 0700 UTC 7 Dec and ended at 1400 UTC 7 Dec with a maximum of 1.5 mm. The cloud was made up of ice and snow with nearly no super-cooled water and graupel. The horizontal scale of ice cloud was beyond 800 km and the magnitude of updraft was 0.1 m/s. It indicated this was a snowfall case caused by the cold stratus cloud. The layer of the cloud was a bit thin at the beginning. Afterwards the cloud’s top lifted and the bottom fell so that the cloud layer became thicker. Ice cloud changed from high cloud (0300 UTC) to middle cloud (0600 UTC) and fell down to the ground at last (0900 UTC). Updraft dominated in the formation the cloud. The ice particles number and cloud thickness became larger when the updraft was stronger (0300–0900 UTC).

3.4 Snow and its sources

In order to study the source and sinks for the formation of hydrometeors in a certain period, for example the strongest precipitation period, the hour-accumulative values of hydrometeors and their sources were calculated. These values also depicted for the changes in one hour, and the unit was g/kg·h⁻¹. At last a comparison of the source and sinks were made to understand what was the most important to the formation of hydrometeors.

Simulated results have shown that one-hour precipitation in Beijing was very strong during 0800–0900 UTC 7 Dec. The center position of snowfall was (40°N, 116.3°E) with a maximum of 0.4 mm·h⁻¹. Fig. 4 shows the vertical distribution of accumulative values of snow and its main sources at this center during this period. Snow increased mainly in the middle and low levels below 500 hPa. The maximum 0.236 g/kg·h⁻¹ was around 985 hPa near the ground. The major microphysical processes of snow were the depositional growth (psdep) and the collection of ice by snow (psaci). Their horizontal distributions were very similar to the snow’s (Figure not shown). Due to no cloud and rain water existed, the accretion of rain and cloud water did not work in the snowfall. In addition, the magnitude of conversion of ice to snow was so small that it could be
ignored. The generation of the depositional growth was larger than that of the collection of ice by snow. As a result, water vapor was the most important to snow formation in the strongest snowfall period.

3.5 Feedbacks of hydrometeors to dynamical and thermal processes

Two sensitive tests were done to research the feedback effects of the microphysical processes to dynamical and

Fig.3 Cross section of ice phase particles (shaded, g/kg), water vapor (solid line, g/kg), temperature (dash line, °C) and wind vector along 116.3°E on 7 Dec 2001

Fig.4 Vertical distribution at surface snowfall center (40°N, 116.3°E) of accumulative value of snow and its main sources from 0800 UTC to 0900 UTC 7 Dec 2001
thermal processes. The “heat test” was to neglect the latent heat in thermal process. The “drag test” was to neglect the drag force in vertical velocity equation. Other model parameters kept the same in each sensitive test.

The cloud developed strong at 0600 UTC 7 Dec. $\theta_e$ (Fig. 5a) and $w$ (Fig. 5b) of the control experiment show that, the atmosphere stratification was stable and the updraft area was in the middle-high levels between 700—200 hPa. The updraft center was around 450 hPa with a maximum of 0.12 m/s. Ice particles were at 850—300 hPa (Fig. 3b). The center area of ice was at 400—600 hPa correspondingly with updraft center. The center area of snow was a bit lower at 500—700 hPa. Using the results of two sensitive tests minus those of control experiment, the changes of thermal and dynamical values can be revealed. Below are the minus results of “heat test”. (1) As shown in Fig.5d, $\theta_e$ increased below 600 hPa and above 300 hPa, while deceased between 600—300 hPa. However the change value was very small with the maximum only 1.5 K. The vertical section for $\theta_e$ of “heat test” did not change much and still kept stable stratification (Figure not shown); (2) As for $w$ (Fig. 5e), though there were local small centers of increase and decrease, the decrease of $w$ in middle-high levels was the major effect. The maximum of decrease was 0.05 m/s; (3) The total precipitation decreased with a maximum of 0.5 mm (Fig. 5f). The results of “heat test” revealed that latent heat was able to enhance the updraft and precipitation. The minus results of “drag test” were described as follows. (1) $\theta_e$ decreased (Fig. 5g), but its value was smaller than that of the “heat test”. The maximum was only 0.09 K; (2) The maximum change of $w$ was 0.02 m/s which was smaller than that of the “heat test” too (Fig. 5h); (3) The total precipitation increased with a maximum of 0.1 mm (Fig. 5i). Contrarily, the drag force of ice particles was not strong, but it was still able to weaken the precipitation. Above analyses have shown that, it was lack of liquid water during this case and the phase changes were not strong, but latent heat was still released by the depositional growth of snow. The mass content of ice particles was not large, but the falling particles could induce drag force. As a result, the latent heat and drag force induced by hydrometeors had a certain effects on thermal and dynamical processes during this snowfall case. The effect of latent heat was more obvious than that of drag force.

4. CASE OF LIAONING SNOWFALL
4.1 Case overview and model design

On 22 Nov 1999, a cold frontal cloud system moved from Xinjiang Uygur Autonomous Region to the east, passed through most of the region north of the Yellow River and arrived at the Northeast China at 0000 UTC 24 Nov. During 22—23 Nov 1999, upper-level circulation was characterized by a ridge in the west of Ural Mountain and a deep trough in the east of Lake Baikal. In the west flow from 40°N to 50°N a shallow trough moved from the west side of Xinjiang Uygur Autonomous Region to the east. The meridional circulation was strengthened on 24 Nov 1999. A blocking high was set up at Ural Mountain and a cross trough was located in the west of Lake Baikal. The Northeast China was in the unstable area in front of the moving trough. On 25—26 Nov, the cross trough developed vertically inducing the cold air southward. The cold wave with strong wind and low temperature occurred in most area of China. The trough in North
China became stronger at 700 hPa. The southwest flow of the trough sent the moist of Bo Sea to the north. The wind at 850 hPa developed to be cyclonic flow. With the cold air enter the trough on 24—25 Nov, this cyclone moved to the northeast quickly which induced the strong wind and heavy snowfall in Liaoning province.

The non-hydrostatic model MM5v3 was used for numerical simulation. The model was initiated using the T106 of National Meteorological Center of China 1.125°×1.125° grid data as a “first guess” field. Two nested-level domains were set. The outer coarse domain included 73×73 grid points with horizontal resolution of 30km covering the area of (32.8°—52.2°N,111.0°—137.0°E); the fine-mesh domain included 91×91 grid points with 10km grid size covering the area of (38.0°—46.2N,118.0°—129.0°E). The model physical processes mainly include the Grell and KF convective parameterization scheme, the Reisner scheme, the MRF PBL scheme and cloud radiation scheme. The simulation was started at 1200 UTC 23 Nov and ended at 1200 UTC 24 Nov 1999.

4.2 Observations and simulations of snowfall
Snowfall with strong wind occurred in the most region of Liaoning province on 23 — 24 Nov 1999. This snowfall caused terrible effects on the traffic and power transmission. For example, in Shenyang city the airport was shut off and the electric power transmission stopped. From 1600 UTC 23 Nov to 0100 UTC 24 Nov was the period of rainfall or sleet-fall. Snowfall started at 0100 UTC and ended at 1000 UTC 24 Nov. Strong wind occurred near the ground. Snowfall was the main part of this precipitation. The observed precipitation increased from 1800 UTC 23 Nov (Fig.6 a-b). Snow band was of northeast-southwest orientation. The total 24-hour precipitation was 8 — 15 mm generally and 18—25 mm locally (Figure not shown). The atmosphere temperature was decreased by 20℃. Fig. 6c-d shows the simulated 6-hour precipitation. The simulated precipitation increased from 1800 UTC 23 Nov too. The simulated snowfall area was a bit south of observation, but the simulated snow-band was also of northeast-southwest orientation and its movement was basically consistent with observations. The maximum of simulated snowfall was 20 mm (Figure not shown).

4.3 Phases of hydrometeors

The cold air of this case was very strong and the atmosphere temperature decreased obviously. For example, the temperature of Xinmin station at 1200 UTC 23 was 11.2℃, while it was -11.3℃ at 1200 UTC 24. Fig.7 shows the vertical section along 125°E through the snowfall center. The isothermal lines were pushed southward by the cold air. The phase of hydrometeors was changed from the liquid to the solid.

At 1800 UTC 23, as shown in Fig. 7a-c, in the region south of 43.6°N the temperature below 750 hPa was above 0℃ and the wind blow to the north below 900 hPa; in the region north of 43.6°N the temperature was below 0℃ and the wind blow to the south below 900 hPa. The vertical 0℃ line could be seen as the frontal zone. The cloud water was in the warm region below 750 hPa. The horizontal scale of cloud water was 400 km and the maximum was 0.3 g/kg at 900 hPa. The rain water distributed correspondingly with cloud water but of smaller mass content 0.06 g/kg. Ice and snow mostly distributed in middle and high levels in the north. There existed no graupel in the simulated area. From the distributions of ice and liquid particles, ice particles were not important to precipitation at this time. Rain formation was mainly from the cloud water by warm rain processes in warm region.

At 0000 UTC 24, as shown in Fig. 7d-f, 0℃ isothermal line on the ground moved to 43°N due to the effects of cold air. The cloud top lifted to 700 hPa. The maximum of cloud water was 0.35 g/kg around 0℃ at 800 hPa. Super-cooled water emerged at this time with a small center of 0.1 g/kg at 600 hPa. Rain water moved southward with the maximum of 0.05 g/kg. The updraft in the cloud weakened to 0.08 m/s. Under the effects of cold air, ice moved southward quickly and became stronger and wider. The top of ice did not change much while the bottom extended down to 750 hPa. Several mass content centers of ice emerged, and the maximum was 0.12 g/kg at 300 hPa. As for snow, there were two mass content centers merging during its southward moving. Its horizontal scale decreased and vertical scale increased to 800 — 400 hPa. The maximum of snow was 0.14 g/kg at 650
hPa. Several new mass content centers of graupel emerged below 600 hPa. These centers were correspondingly with those of super-cooled water. The maximum of graupel was 0.016 g/kg. All ice particles strengthened at this time. The formation of graupel had close relationship with super-cooled cloud water.

At 0600 UTC 24, as shown in Fig. 7g-i, the strong cold air continuously moved to the south. 0°C isothermal line on the ground moved to 42.1°N. The cloud developed strong in vertical direction. The cloud top was at 600 hPa and there was a bit super-cooled water at 500 hPa. The maximum of cloud water was 0.45 g/kg near the 0°C layer. Rain water moved with cloud water with the maximum of 0.27 g/kg. The updraft in the cloud developed stronger with the maximum of 0.45 m/s at 700 hPa. The southward moving ice extended to the ground. The maximum of ice was 0.5 g/kg at 700 hPa. Snow fell down to the ground at 0400 UTC and increased to 0.4 g/kg. Graupel developed and merged immediately and fell down to the ground together with ice and snow. The maximum of graupel was 0.13 g/kg. Interestingly, the distributions of rain water and ice particles were divided by the 0°C isothermal line at 41.5°N vertically. Rain water was in the warm area below the 0°C line, while ice was in the cold area out of the 0°C line. Most snow and graupel were in the cold area, but there were a bit of unmelted snow and graupel extending to the warm area. To the north of 41.5°N, precipitation was induced by solid particles instead of liquid particles. The cloud was full of ice particles in addition to some cloud water. The temperature was lowered under 0°C. These results revealed that it was a rainfall changing to snowfall precipitation with obvious temperature decrease, which
was consistent with observations. To the south of 41.5°N, it was still rainfall. The hydrometeors of this region were of mixed-phase. The melting of ice particles played an important role in the formation of rain. The distribution of hydrometeors reflected the effects of temperature on precipitation. You et al. (2002) observed the snowfall in Xinjiang Uygur Autonomous Region and indicated that, different temperature of cloud top resulted in different types of snowfall. Some was drizzle, some was branch-shape snow and some was no liquid water. Their researches also revealed the relationship between precipitation and temperature.

After 0600 UTC 24, all hydrometeors moved southward quickly and nearly dissipated. At 1200 UTC 24, ice particles moved out of the simulated domain. Although new ice particles emerged in the north, they did not affect the snowfall in Liaoning province.

Fig. 7 Cross section of water substances (g/kg), temperature (long dash line, °C) and wind vector along 125°E at 1800 UTC 23(a-c), 0000 UTC 24(d-f), 0600 UTC 24 Nov 1999 (g-i). (a,d,g): cloud water (shaded with solid line) and water vapor (solid line), (b,e,h): graupel (shaded with solid line) and ice (dash line), (c,f,i): rain water (solid line) and snow (dash line)

4.4 Rain water, snow, graupel and its sources

The simulated rainfall became strongest during 0200 – 0300 UTC 24. Fig. 8 shows the distribution of rain and its sources in this period at rainfall center (41.7°N, 125°E). Rain mainly increased below 800 hPa with the maximum of 6.98 g/kg·h⁻¹ near the 0°C at 850 hPa. The melting of snow and graupel (p_smlt, p_gmlt)
and the collection of cloud water by rain (pracw) were of the most magnitude \(1\text{g/kg·h}^{-1}\) near the 0°C layer. They were in the similar distribution of rain. The collection of cloud water by rain was the major process below 0°C layer. Next were the conversion of cloud water (pccnr), the collection of cloud water by snow and graupel (psacw, pgacw). They were of the magnitude \(0.1\text{g/kg·h}^{-1}\). The enhanced melting of graupel by collection of rain and cloud water and the collection of snow by rain were of the smaller magnitude. These processes were not very important to rain formation.

![Fig.8 Vertical distribution at surface rainfall center(41.7°N,125°E) of accumulative value of rain(rnw) and its main sources from 0200 UTC to 0300 UTC 24 Nov 1999](image1)

0500—0600 UTC 24, rainfall moved to the south and the rainfall center above changed to snowfall. Ice particles developed strong. The temperature in vertical direction was under 0°C. Snow mainly increased below 500 hPa. The magnitude of snow was \(0.1—1\text{g/kg·h}^{-1}\) and the maximum was \(1.49\text{g/kg·h}^{-1}\) at 750 hPa (Fig.9). There were two negative values of the depositional growth of snow (psdep) in middle levels, because the values in the figure were the changes in one hour. Negative value depicted for the decrease of the depositional growth of snow. The depositional growth of snow, the collection of ice and cloud water by snow (psaci, pssacw) were the main processes. The processes associated with rain water were not important because there was nearly no rain water. The conversion of ice to snow was of small magnitude too. The values of snow sources of Liaoning case were larger those of Beijing case. Cloud water contributed to the formation of snow in Liaoning case while not in Beijing case. As for graupel, it mainly increased below 750 hPa. The magnitude of graupel was \(0.1—1\text{g/kg·h}^{-1}\) and the maximum was \(1.25\text{g/kg·h}^{-1}\) at 800 hPa (Fig. 10). The collection of cloud water by snow and graupel (pgsacw, pgacw) and the conversion of snow to graupel (psemb) were the main processes. They were of magnitude \(0.1\text{g/kg·h}^{-1}\). Next was the collection of cloud water by ice (pgiacw) with the magnitude \(0.01\text{g/kg·h}^{-1}\). Other processes such as the depositional growth of graupel were not very important to graupel formation.

![Fig.9 Vertical distribution at surface snowfall center (41.7°N,125°E) of accumulative value of snow and its main sources from 0500 UTC to 0600 UTC 24 Nov 1999](image2)
Some researchers also have studied the microphysical processes using the Reisner scheme of MM5. Colle et al. (2005) simulated the orographic precipitation on the 13–14 December 2001 in Oregon Cascades. Their results showed that, the major processes responsible to snow formation included the depositional growth of snow, the accretion of cloud water by snow, the collection of ice by snow and the conversion of ice to snow. The major processes responsible to graupel formation included the accretion of cloud water by snow and graupel, the conversion of ice to graupel and the accretion of rain water by graupel. The major processes responsible to rain water formation included the melting of snow and graupel and the collection of cloud water by rain water. These conclusions were basically consistent with the analyses results of hydrometeors and their sources above in this paper.

4.5 Feedbacks of hydrometeors to dynamical and thermal processes

The cloud developed strong at 0600 UTC 24 Nov. \( \theta_e \) (Fig. 11a) and \( w \) (Fig. 11b) of the control experiment show that, \( \theta_e \) lines were dense in the north of 40.5°N and the atmosphere stratification was unstable in the south of 40.5°N. The maximum of updraft was at 40.5°N in low levels. Along 40.5°N, 0°C line was at 800 hPa and mixed-phase particles co-existed to produce rainfall (Fig. 7g, h, i). Using the results of two sensitive tests minus those of control experiment, the changes of thermal and dynamical values can be revealed. Below are the minus results of “heat test”. (1) \( \theta_e \) increased in the north of 40.5°N (Fig. 11d), while in the south of 40.5°N, \( \theta_e \) increased at 800—600 hPa and decreased below 800 hPa. These revealed that latent heat released in the south of 40.5°N warm the air in low levels but cool in upper levels, which decreased the atmosphere stratification stability; (2) As for \( w \) (Fig. 11e), the updraft decreased at 40.5°N vertically. The latent heat strengthened the updraft there; (3) The total precipitation was smaller than that of control experiment (Fig. 11f). The latent heat was able to enhance precipitation. The minus results of “drag test” were described as follows. (1) \( \theta_e \) did not change much with the maximum of 0.6 K (Fig. 11g); (2) As for \( w \) (Fig. 11h), it increased below 600 hPa at 40.5°N, which revealed that the drag force retrained the updraft; (3) The total precipitation was larger than that of control experiment (Fig. 11i). So the drag force weakened the precipitation. Above analyses have shown that, the feedback of “heat test” was larger than that of “drag test”. More latent heat was released by more cloud particles during this case. The precipitation was rainfall first and then snowfall. The mass content of particles of this case was larger than that of Beijing case. The effects of latent heat and drag force on thermal and dynamical processes during this snowfall case were more obviously than those in Beijing case.
5. Comparison of two cases

Simulated results have been analyzed above about the light snowfall during 7 - 8 Dec 2001 in Beijing and the snowfall during 23 - 24 Nov 1999 in Liaoning province. Although they are both snowfall cases, there are some different characteristics between them. Comparison of the two cases is helpful to understand the microphysical mechanism of the two different kinds of snowfalls. In addition, the same grid size simulation of Beijing case was also conducted as that of Liaoning case. The precipitation and distributions of hydrometeors did not change much comparing to the results of original grid size simulation. Follows are the comparing results of two cases.

(1) The weather background is not same for the two cases. Beijing light snowfall was induced by shallow trough eastward moving, while Liaoning snowfall was induced by the cold wave and strong cold air. (2) Table 1 shows the comparison of the variables such as precipitation, updraft, hydrometeors, and so on. The total precipitation and updraft of Liaoning
snowfall were larger than Beijing snowfall. The cloud developed stronger in Liaoning case. The magnitude of hydrometeors of two cases was both 0.1 g/kg. The magnitude of one-hour accumulative sources of hydrometeors was 0.1 – 1 g/kg·h⁻¹, but the values of Liaoning case were 2 – 3 times larger than those of Beijing case. (3) The atmosphere temperature was under 0°C in Beijing snowfall. However in Liaoning case, there was a vertical interface of warm and cold air. In the north of the interface was the cold region, and in the south of the interface below 750 hPa was the warm region. The phase of particles of Beijing case was simple. There was no liquid water and graupel. The mixed-phase (vapor, liquid and solid phase) particles co-existed in Liaoning case. The precipitation included rainfall, snowfall and graupel-fall. These results reveal that the precipitation has close relationship with temperature. The cloud water and rain water are important to the formation of graupel. The temperature of Beijing case was so low that there was no liquid water and graupel. While it was of high temperature in Liaoning case so that liquid water and graupel emerged at the same time. These are the most difference between the two cases. (4) Sensitive tests have shown that the microphysical process is able to affect the thermal and dynamical processes of the two cases. The latent heat released by phase exchanging can enhance the precipitation and updraft. The drag force induced by particles falling can retrain the precipitation and updraft. The effects of latent heat are larger than that of the drag force. The atmosphere stratification was stable in Beijing case and the effect of latent heat was small. The atmosphere stratification was unstable and the latent heat strengthened the stratification stability. The microphysical processes in Liaoning case were more active than those in Beijing case. As a result, the feedback of Liaoning case was much stronger than Beijing case.

In addition, Sun et al. (2003) have done the similar analyses of the heavy rainfall on 8–9 Jun 1998 in South China. In that case the mixed-phase particles co-existed. The magnitude of updraft and hydrometeors were 1 m/s and 1–10 g/kg respectively of the convective cloud. The magnitude of snowfalls in this paper was 1 – 2 times smaller than the heavy rainfall.

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Table 1. The difference of variable maximum between Beijing case and Liaoning case
6. Conclusions

In this paper, two snowfall cases under different weather conditions in north China are simulated using the meso-scale model MM5. They are light snowfall during 7 - 8 Dec 2001 in Beijing city and strong wind and snowfall during 23 - 24 Nov 1999 in Liaoning province. The simulated results of microphysical processes are mainly discussed. The hydrometeors and their source and sinks under different weather backgrounds are described. The feedback effects of microphysical processes on the thermal and dynamic processes are also discussed. Comparisons were made between the results of two cases. Results have show:

(1) The distribution of hydrometeors has close relationship with temperature. In Liaoning snowfall case, liquid water was in the warm region below 0°C layer and the ice particles were mainly in the cold region above 0°C layer. There was also super-cooled water in cold region and unmelting snow and graupel near 0°C layer. The mixed-phase particles co-existed in Liaoning case. While in Beijing snowfall case, the temperature was below 0°C and there were only water vapor, ice and snow in the cloud.

(2) The same characteristics of source and sinks of two cases is that the depositional growth of snow and the collection of ice by snow are the main processes to the formation of snow. As for Liaoning case, the melting of snow and graupel and the collection of cloud water by rain water are the main processes to the formation of rain water. Graupel grows mainly through the collection of cloud water by snow and graupel and the conversion of snow to graupel. The super-cooled water is very important to graupel’s growth.

(3) The latent heat and drag force induced by hydrometeors have a certain effects on thermal and dynamical processes during this two snowfall cases. The latent heat affected little on the stable atmosphere stratification of Beijing case, but strengthened the unstable atmosphere stratification of Liaoning case. The latent heat enhanced the precipitation and updraft, but the drag force induced by particles falling retrained the precipitation and updraft. The effects of latent heat are larger than that of the drag force. The microphysical processes and the feedback effects in Liaoning case were more active than those in Beijing case. The intensity of the feedback effects is consistent with the activity of microphysical processes.

(4) This paper discussed the source and sinks of hydrometeors only in the strongest precipitation period. The characteristics of the microphysical processes in other period still need to be investigated.

BIBLIOGRAPHY


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