AN INVESTIGATION OF WINTER RAINFALL AND SNOWFALL IN THE MOUNTAIN AND COAST

HYO CHOI

Department of Atmospheric Environmental Sciences
Kangnung National University, Kangnung 210-702, Korea
du8392@hanmail.net

The case study of snowfall in the mountainous coastal region of Korea had been undertaken from 09:00 UTC December 6, 2002 through 12:00 UTC December 9, 2002, using 3D-numerical model, MM5 V3.5 with NCEP data inserted as initial input data for the model. During the snowfall period, north-easterly wind and easterly wind in a high-pressure system in north and a low pressure in south of Korean peninsula prevail in the eastern mountainous coastal region and sensible heat flux induced a great amount of evaporation from the sea surface. This wind could drive the moisture transported from the East Sea-coastal area toward the top of mountain in the west and uplifted moisture should be cooled down and saturated, under westerly cool air masses, resulting in the formation of ice and rain particles inside low cloud. Snowfall band coincided with minimum sensible heat flux band or zero value area, where maximum cooling of air parcels occurred. This snowfall band also directly coincided with the area of relative humidity of 100%. As air temperature at the level of cloud base was below 0°C, water droplet of cloud formed ice crystal phase like snow. As stratocumulus type low clouds moved down toward the ground surface of coastal area, the falling droplets remained snow phase without melting of snow due to the short distance to the ground. Vertical distribution of total cloud mixing ratio, air temperature and relative humidity gave detail information on the height of cloud formation, the determination of snowfall or rainfall of droplets and snowfall area. Under north-westerly wind parallel to the coast, moisture advection became very weak, resulting a small amount snow or no snow in the coast.

1. Introduction

The driving mechanisms on snowfall or winter rainfall are basically similar, but the prediction of snowfall is quite different from one of rainfall. It is generally due to the reason how much cooling is necessary to make for the formation of snowfall. In the recent years, frequent snowfalls have taken in the mountainous coastal area in Korea. In the coastal sites, we classified three categories such as category 1-the positions of high pressure system in the north China and low-pressure system in the south sea of Korea, category 2-the passage of trough in the behind region of high pressure through the eastern coastal sea and category 3-the coupled a high pressure in north and a low pressure in south with later another high pressure in west and a low pressure in east influence of strong easterly wind from the East Sea.[1,2]

In this study, the case of category 1 was mainly investigated in detail using a three-dimensional (3D) nonhydrostatical numerical model called MM5 model, Version 3.5 and driving mechanism on the formation of snow fall was mainly focused.

2. Numerical Method and Data

A 3D nonhydrostatic grid point model of MM5, Version 3.5 with NECP data in a terrain following coordinate system was adopted for 4 days numerical simulation on meteorological phenomena from 09:00 LST, December 6 to 12:00 LST, December 9, 2002 by PC Pentium 4 with one-way triple nesting at Kangnung National University. There were 22 levels in the vertical spread from 10 m to 10 km with sequentially larger intervals between levels with increasing altitude.

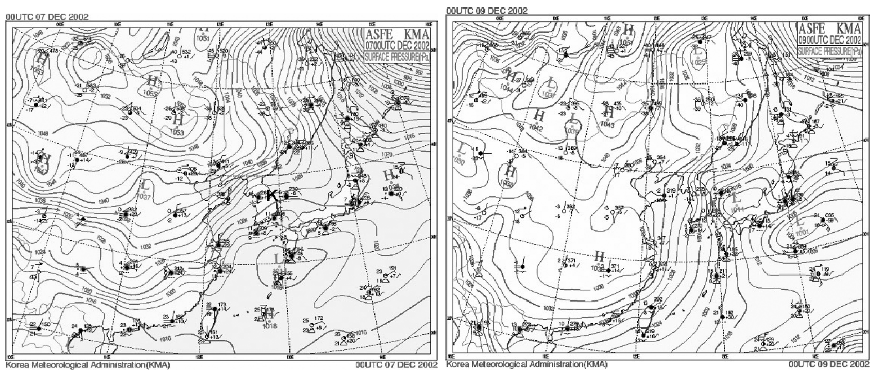
In the numerical process, a triple nesting were made with grid numbers of 125×105 with horizontal 27 km interval and vertical grid number of 23 in the coarse domain and in the second domain, grid number of 82×82 with 9 km interval and in the third domain, grid number 61×61 with 3 km interval. 9 km. About 2.50° interval terrain date was used for the largest domain and then the 0.9 km interval data was used for fine mesh domain.

MRF method was adopted for boundary layer process in the planetary boundary layer, and simple ice method for the prediction was also considered. Horizontal and vertical wind and air temperature fields, 3 h accumulated snowfall amount, mixing ratio inside snow, relative humidity, and sensible heat flux were evaluated for understanding snowfall event.

3. Results

3.1. *Beginning stage of snowfall in the coast*

At the beginning stage of snowfall event from 12:00 LST to 18:00 LST, on December 7, a high-pressure system in the north (north-eastern China) and a low-pressure system in the south (below Kyusu, Japan) on the weather map in the north eastern Asia influenced the whole Korean peninsula.



(a) (b)

Fig. 1. (a) Surface weather map near Kangnung city (K) at 09:00 LST December 7 (a high pressure in north and a low in south of Korean peninsula; beginning time of snowfall) and (b) 9, 2002 (a high in west and a low in east; ending time).

Under such pressure system, north-easterly wind and easterly wind prevailed near the Kangnung city (here, K) in the eastern mountainous coastal region (Fig. 1).

In Fig. 2, easterly wind near Kangnung city (K) could induce a great amount of moisture from the East Sea toward Kangnung city and then the induced moisture further went to the top of mountain, called Taegulyung of 868 m height (T).[3–5] From vertical profiles of wind, air temperature and relative humidity in Fig. 3, the moisture driven by easterly wind should be cooled down during its uprising toward the mountain top and saturated. The saturated water vapors formed a great stratocumulus cloud near the right-hand side of the mountain top under the influence of westerly wind in the upwind side confronting an easterly upslope wind along the eastern slope of the mountain.

The base of the cloud existed near the eastern top of Mt. Taegulyung at about 600 m and extending to 1.9 km height and spreading toward the sea near the upper level of 1 km at 12:00 LST and 18:00 LST, December 7, 2002. Thus, Gangwon Regional Meteorological Administration (GRMA) located in Kangnung city reported the event of snowfall measured at Taegulyung Meteorological Office near the top of the mountain at 12:00 LST, December 7, and six hours later, at 18:00 LST, Kangnung city in the eastern basin near the coast had snowfall under the extension of 100% relative humidity area over the ground of the city (Fig. 3).

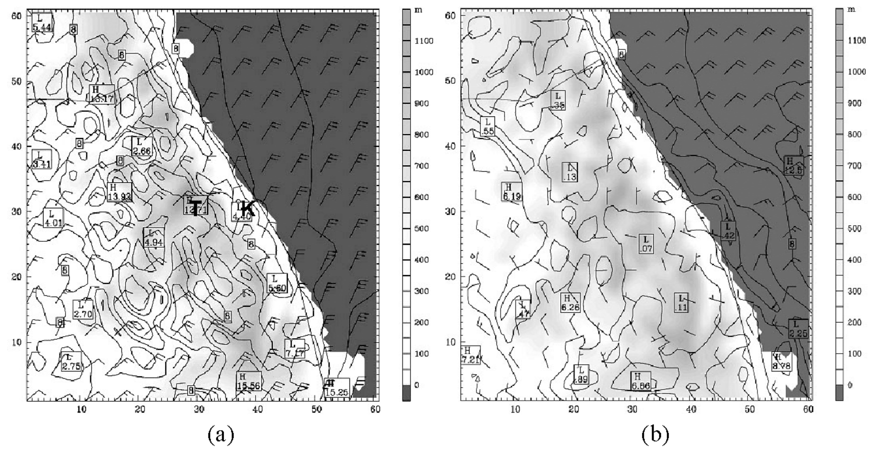


Fig. 2. (a) Surface wind (m/s) in a fine mesh domain at 18:00 LST, December 7, 2002 at the beginning time of snowfall at Kangnung city. (b) 06:00 LST December 9 at the ending time of snowfall. Dark grey area, T and K indicate the East Sea, Mt. Taegualung and Kangnung city.

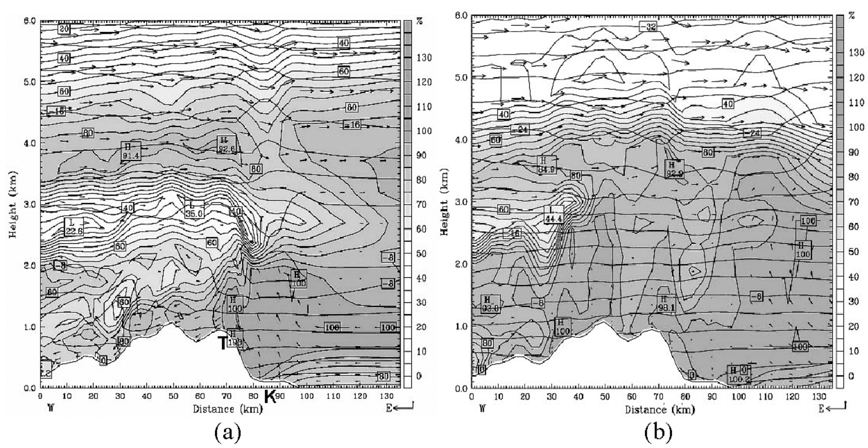
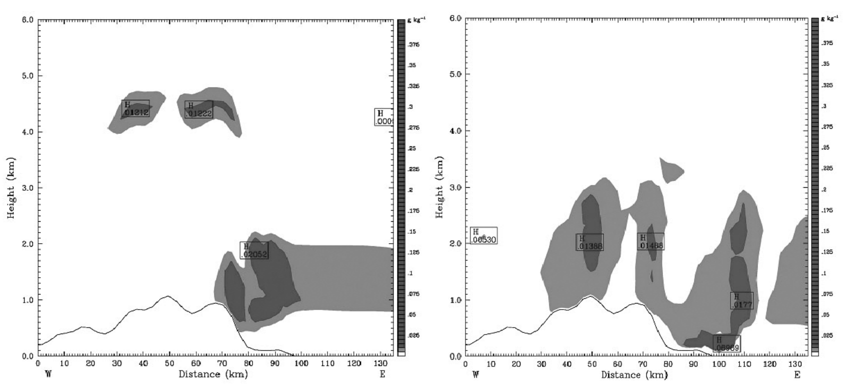


Fig. 3. Vertical profiles of wind (m/s), relative humidity (%) and air temperature (°C) at (a) 18:00 LST, December 7, (b) 18:00 LST, December 8, 2002. T and K denote Mt. Taegulyung and Kangnung city.

As air temperature near the cloud base was below −2°C at 18:00 LST December 7, droplets falling from the cloud base toward the ground of the city should be minute ice crystals and the droplets reaching the ground surface with air temperature of 2°C might be snow without melting of snow due to their short falling distances of about 700 m or rain due to their melting processes or snow mixed with rain like sleet. Kangung city had new snow of 0.1 cm corresponding to rainfall amount of 7 mm. However, GRMA reported Kangnung city had snow instead of rain.

As times went on, easterly wind became stronger and 100% relative humidity area also extended vertically and horizontally, making the cloud to be larger. From the vertical profile of total cloud mixing ratio (g/kg), which represented water content within cloud, the cloud base also became lower and lower and finally it reached less than 50 m height over the ground in Kangnung city, especially around 18:00 LST, December 8. As the base of a great stratocumulus cloud reached the ground surface of the city in Figs. 3 and 4 and air temperature near the ground was 0°C, droplets falling from the cloud toward the ground should be snow without melting of snow. From 06:00 LST through 18:00 LST, the city had continuously new snows with a maximum amount of 3.4 cm and an accumulated amount of snow was 9.2 cm.

Generally speaking, the area of 100% relative humidity over the ground surface from the vertical profiles of wind, relative humidity and air temperature in Fig. 3 coincided with the area of cloud formation in showing total cloud mixing ratio in Fig. 4. As the cloud base was below 0°C, the droplets in cloud were ice crystals. However, the possibility of droplets falling down to the ground to be snow should depend upon no melting of droplets composed of ice crystals under a short distance to the ground surface.



(a) (b)

Fig. 4. As sown in Fig. 3, except for total cloud mixing ratio (g/kg).

1st Reading

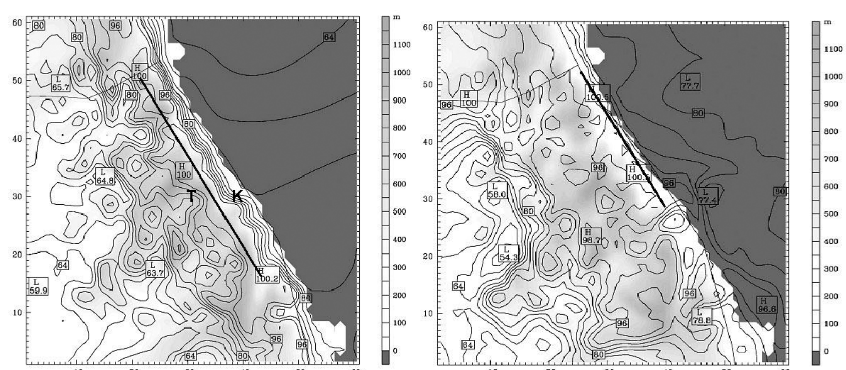
March 3, 2006 17:9 WSPC/SPI-B368 Advances in Geosciences Vol. 5 ch14

If cloud droplets fall down toward the ground with air temperature greater than 0°C like 3°C at 18:00 LST December 8, they become rain. As the cloud droplets of ice phase close to the ground surface of the city, the phase of snow was changed into the phase of rain, through melting process of ice crystal to be water due to air temperature over than 0°C. However, when the distance between the cloud base and the ground is very close, snow phase of droplets still remains snow phase, but when the distance is far, snow phase is changed into rain phase.

A relative humidity band of 100% near the ground surface lay along the coast from south-east to north-west and coincided with rainfall amount band along the coast (Figs. 5 and 6). Simultaneously, these two kinds of bands also coincided with minimum values of sensible heat fluxes near the surface (Fig. 7).

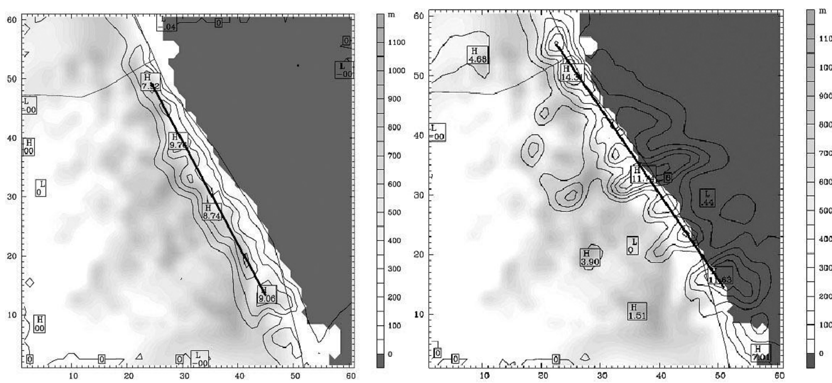
In the open sea, sensible heat flux was very big with a maximum value of 320 W/m^2, which implied a great amount of water vapor to be evaporated from the sea surface into the atmosphere, due to the temperature difference between sea water (about 8°C) and air temperature (about 2–3°C) near the sea surface. The sensible heat fluxes became smaller closing to the coast. In the coastal inland, the fluxes were zero or negative value, due to very small temperature difference between air temperature and ground surface temperature, implying the cooling of air masses by the cold ground surface.

Thus a great amount of moisture driven by easterly wind from the sea into the inland basin and further the mountain side should be cooled down



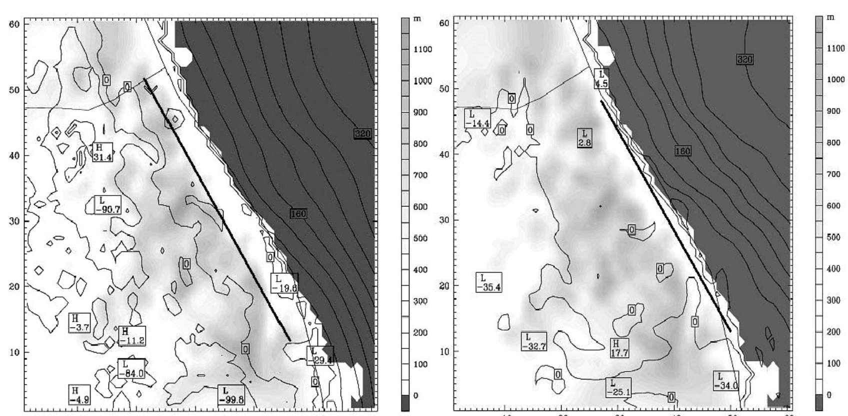
(a) (b)

Fig. 5. (a) Relative humidity (%) at 10 m height over the ground surface at 18:00 LST, December 7, 2002 and (b) 18:00 LST, December 8. T and K denote Mt. Taegulyung and Kangnung city.



(a) (b)

Fig. 6. As shown in Fig. 5, except for rainfall amount (mm) (a) at 18:00 LST, December 7, 2002 and (b) 18:00 LST, December 8.



(a) (b)

Fig. 7. As shown in Fig. 5, except for (a) sensible heat flux (W/m^2) at 18:00 LST, December 7, 2002 and (b) 18:00 LST, December 8.

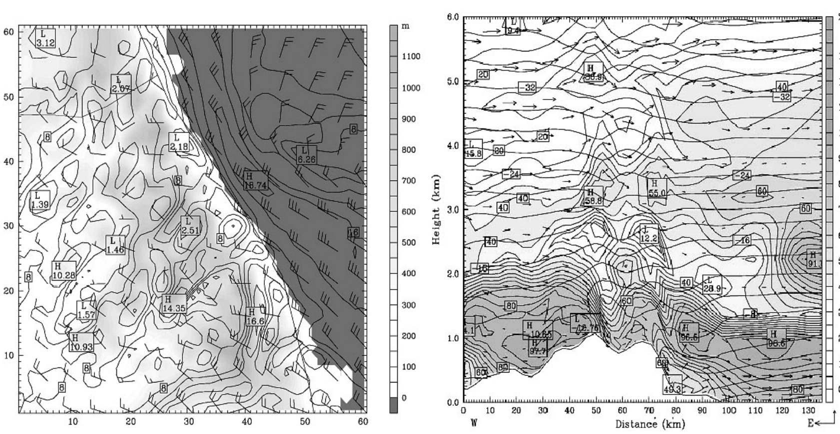
by cold ground surface and adiabatic cooling processes during their uprising toward the mountain top, showing the saturation of transported moisture. The saturated moisture formed a great low cloud like stratocumulus on the mountain top and the cloud was observed in the right hand side of the mountain top under westerly wind in the upwind side of the mountain.

3.2. *Ending stage of snowfall in the coast*

After 18:00 LST, December 8, snowfall band (or rainfall band) moved from the coastal inland toward the coastal sea, as time went on. As north-easterly wind prevailed during the snowfall period was gradually changed into northerly or north-westerly before 09:00 LST, December 9, onshore wind was confined to the only coast and became weak under the westerly wind from the upwind side of the mountain toward the coast, resulting in the movement of snowfall band into the coast (Fig. 8).

Similar to the case of snowfall, snowfall band directly coincided with the area of relative humidity of 100% and simultaneously, the area of minimum sensible heat flux. Under the northerly and north-westerly winds, moisture advection from the sea into the inland became weaker and weaker, inducing the formation of a small amount of clouds or no cloud in the inland basin like Kangnung city.

From 09:00 LST, December 9, north-westerly wind parallel to the coastal line could not induce sufficient amount of moisture advection from the sea into the inland basin and further the top of the mountain, resulting in the formation of small amounts of clouds in the coast (or no cloud) and sequentially, no snowfall occurred in the city (Fig. 9).



(a) (b)

Fig. 8. (a) Surface wind (m/s) at 10m height over the ground surface at 06:00 LST December 9 near the ending time of snowfall. (b) Vertical profiles of wind (m/s), relative humidity (%) and air temperature (°C).

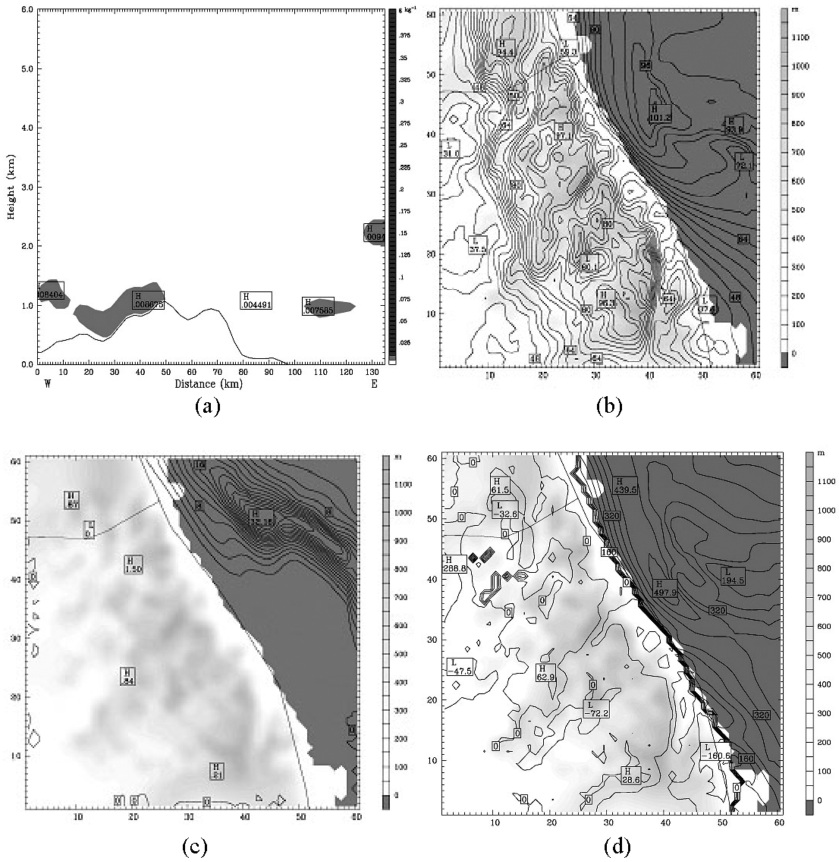


Fig. 9. (a) Vertical profiles of total cloud mixing ratio (g/kg). (b) relative humidity (%), (c) rainfall amount (mm) and (d) sensible heat flux (W/m^2) at 10 m height over the ground surface, respectively.

Even if north-westerly wind coming from northern China made air parcels be cooled down, generally air parcels with a small amount of moisture in winter could not be saturated, resulting in no existence of snowfall in the coastal region.

3.3. *Comparison of precipitation and snowfall*

Through 78 h numerical simulation with NCEP data sets, numerical simulation results of winter rainfall amounts were compared with precipitation and

Table 1. Comparison of calculated precipitation (mm) to observed ones at Kangnung city from December 7–9, 2002. ( ) denotes snowfall amount.

Date	Comparison	12:00	18:00	00:00	06:00	12:00	18:00	00:00	06:00
12/07 to 12/08	Observed (snow amount)	6.6 (0.0)	7.0 (0.1)	3.0 (0.2)	3.5 (2.8)	6.5 (3.4)	4.0 (0.1)	1.2 (0.2)	4.6 (8.6)
	Calculated	4.5	7.0	2.0	2.0	6.5	8.0	1.0	0.0

snowfall amounts measured at Gangwon Regional Meteorological Administration located in Kangnung city. The general tendency of calculated rainfall amounts well matched with observed ones, except for two cases. As at 18:00 LST, December 8, the cloud base very closed to the ground surface of the city, ice droplets falling toward the ground became rain droplets at air temperature of 3°C, through melting process of ice crystal to be water. Thus the reason why observed snowfall amount was too small with 0.2 cm might be attributed to melting of snow into rain, and result in calculated precipitation amount to be twice greater than observed one (Table 1).

When both calculated and observed wind directions at 06:00 LST, December 9 was north-westerly (340°) parallel to the coast and this wind did not induce sufficient moisture advection from the sea into the coast to make a great cloud, showing calculated value of precipitation to be zero and resulting in a great discrepancy to observed one. Probably, this discrepancy might be due to the exaggeration or reduction of moisture modification by the model, under unknown local effect or by a couple hours faster movement of calculated snowfall band (or rainfall band) by the model toward the coast than the observed one. Even if partial discrepancy between calculated and observed ones still existed, the general tendency of calculated rainfall amount well matched with observed one, it may be due to the

4. Conclusions

During the snowfall period, north-easterly wind and easterly wind under the existence of a high pressure system in north and a low pressure in south of Korean peninsula prevail in the eastern mountainous coastal region and sensible heat flux induced a great amount of evaporation from the sea surface into the lower atmosphere. Then north-easterly could induce a great amount of moisture from the sea toward the top of mountain in the west. The uplifted moisture should be cooled down and saturated, resulting in the formation of ice and rain particles inside low cloud and sequentially a great cloud, resulting in falling of snow from the cloud base. Snowfall band (or rainfall band) near the surface coincided with the area of minimum sensible heat flux and it directly coincided with the area of relative humidity of 100%. Under air temperature below 0°C near cloud base, water droplets falling from stratocumulus type low cloud could form ice crystal phase like snow.

However, as the low cloud moved down toward the ground surface of coastal area in the east, snow phase of falling droplet was changed into rain phase of droplet under higher air temperature over than 0°C. If the distance from the cloud base to the ground was too close, the droplet still remained snow phase, showing snowfall in the coastal basin. As north-easterly wind was gradually changed into northerly or north-westerly in the coastal sea near the ending stage of snowfall and onshore wind was confined to the only coast and the moisture advection from the coastal sea into the inland became weaker, resulting in the movement of snowfall band into the coastal sea and finally no snowfall in the coastal inland basin like a coastal city.

Acknowledgments

The author thanks Korean Meteorological Administration for the research on "Gangwon region heavy snowfall prediction skill development of 2002–2005".

References

1. E. Shon and M. Ahn, *Proc. Korean Meteor. Soc.* (2004) 154.
2. Y. Lee and L. Mahrt, *Proc. Korean Meteor. Soc.* (2004) 172.
3. A. Bamzai and J. Shukla, *J. Climate* **12** (1999) 3117.
4. H. Choi, *Meteor. & Atmos. Phys.* **87** (2004) 93.
5. H. Choi, Y. Zhang and Takahashi, *Meteor. & Atmos. Phys.* **87** (2004) 109.