Investigations of precipitation icing events in Hokkaido on February 22–23, 2004 using field data and mesoscale analysis

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***Abstract*— A severe ice storm struck west Hokkaido in the evening of February 22, 2004, and reached east Hokkaido the next morning. Field studies reveal that glaze covered a wide area around south and central Sorachi, north Hidaka, and Nemuro subprefecture regions. We have investigated the precipitation icing event and employed mesoscale analysis to estimate the freezing rain area. The temperature profile of Sapporo in the evening of February 22 is typical of freezing rain: the presence of a melting layer and subfreezing layer at the top and bottom, respectively, of the lower atmospheric boundary layer. This structure is found in the temperature profile obtained at Nemuro the next morning. We have designed a microphysics scheme for the snow melting process and raindrop supercooling process. The freezing rain area is calculated using the mesoscale objective analysis data and digital elevation dataset. The icing event has been investigated using the surface meteorological data and the distribution of anemometers that had failed due to icing. The freezing rain area estimated by the microphysics scheme is consistent with the icing area inferred from the field survey, meteorological data, and anemometer distribution.**

I. Introduction

A severe ice storm struck west Hokkaido Island in the evening of February 22, 2004, and reached east Hokkaido the next morning. The storm caused heavy rain, ice pellets, wet snow, and dry snow in the other regions of Hokkaido at the same time. Heavy ice/snow accretion and strong wind affected the electric power supply, shut down transportation, and damaged agriculture; i.e., plastic greenhouses collapsed, birches were bent, larch branches were broken, and many tree trunks were crushed. The net fence of a baseball field at Iwamizawa campus, Hokkaido University of Education, collapsed due to the weight of accumulated ice and high wind pressure (Fig. 1).

In Japan, the most occurrences of freezing rain have been observed in the inland basins in Honshu Island or east Hokkaido, and the recordings of the freezing rain in the other areas of Hokkaido are rare [1]. Moreover, many cases of forest damage and traffic accidents caused by the freezing rain have been reported as local phenomenon with weak wind. On the other hand, freezing rain and strong winds have been recorded throughout Hokkaido in this case.

In this research, the precipitation icing event is investigated using surface meteorological data and the distribution of anemometers that had failed due to the icing. We also estimate the freezing rain area by employing mesoscale analysis.

Fig. 1. Collapsed baseball field fence at Hokkaido University of Education.

Fig. 2. Observation routes and locations of subprefecture in Hokkaido.

II. Data

We have used the surface meteorological data, hourly observations, and synoptic weather charts provided by the

Japan Meteorological Agency. The rawinsonde observation data at Wakkanai, Sapporo, Nemuro, and Misawa have been used for the temperature profiles. We have also referred to the anemometer data of national road weather telemeters provided by the Hokkaido Regional Development Bureau.

Mesoscale objective analysis (MOA) data compiled by the Japan Meteorological Agency includes air temperatures, relative humidity, and heights of standard pressure levels (e.g., 950, 900, and 850 hPa) over grid points on a 10 km mesh, and the data is recorded at 0300, 0900, 1500, and 2100 JST. The altitude above sea level of each grid point is obtained from the digital elevation model (DEM) compiled by the Geographical Survey Institute of Japan.

Fig. 2 shows the field observation routes. The field observation of Sorachi subprefecture was carried out on February 24. However, the field observation of Hidaka and Kamikawa subprefectures was not carried out immediately; the damage to trees and structures was investigated in April and May. We also conducted a survey for obtaining information regarding the icing event at Hidaka, Kamikawa and Nemuro subprefectures.

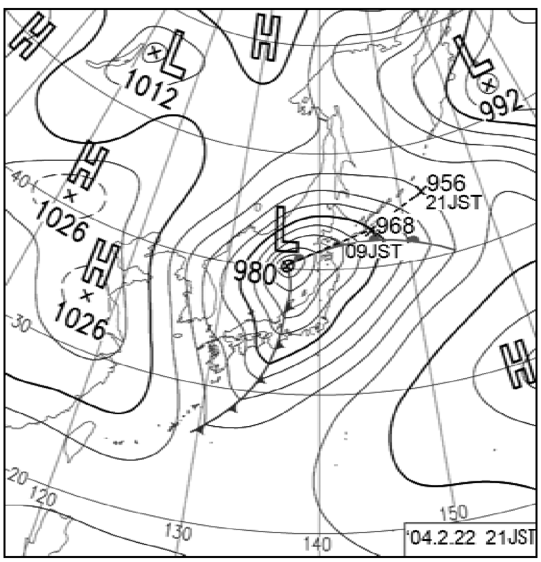

Fig. 3. Synoptic weather chart around Japan at 2100JST on February 22, 2004. by the Japan Meteorological Agency.

III. Features of the Ice Storm

A. Synopsis

Fig. 3 shows the synoptic weather chart around Japan at 2100 JST on February 22, 2004. An atmospheric depression, located at the Sea of Japan on the morning of February 22, was passing through in the east-northeast direction along the south coast of Hokkaido while brewing drastically. Rain and wet snow fell through warm and moist air during the passage of the depression. This caused heavy snowfall in Abashiri subprefecture on February 22, and the amount of snowfall exceeded 80 cm. Snow avalanches were recorded in north Nemuro and north Sorachi subprefecture regions [2]. On the other hand, avalanches comprising ice pellets were observed at Notsuka pass, which is located on the southern Hidaka mountain range [3]. A severe storm was observed throughout Hokkaido after the passage of the depression on February 23.

The temperature profile affects a variety of precipitation types. The presence of a melting layer aloft and a subfreezing layer below is necessary for the formation of freezing rain or ice pellets [4]. Fig. 4 indicates the temperature profile of Sapporo (N43.1°, E141.3°) in the evening of February 22. This profile is typical of freezing rain: the presence of a melting layer and subfreezing layer at the top and bottom, respectively, of the lower atmospheric boundary layer (500 m). On the other hand, the warm inversion layer is not found in the temperature profile of Wakkanai (N45.4°, E141.7°), and the subfreezing layer was not formed at Misawa (N40.7°, E141.4°). This structure is found in the temperature profile of Nemuro (N43.3°, E145.6°) obtained the next morning (Fig. 5). The melting layer is not found in the temperature profile of Nemuro at 2100 JST on February 22. The typical temperature profile of the freezing rain was recorded at 0300 JST on February 23: the melting layer from 800 to 1200 m asl and the subfreezing layer below 800 m. This tendency was observed until 0900 JST, after which the warm inversion layer disappeared. It is clear that the freezing rain area shifted from west Hokkaido to east Hokkaido during the passage of the depression.

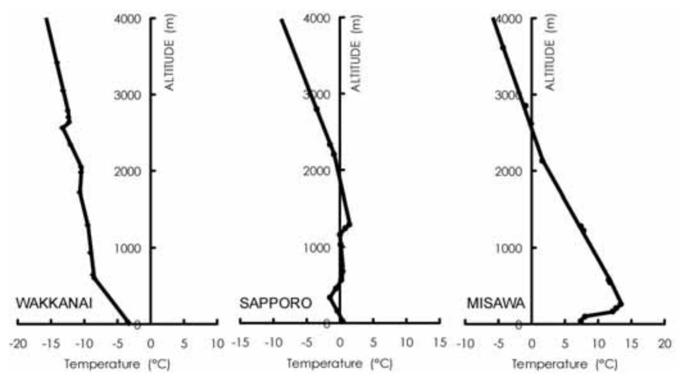

Fig. 4. Temperature profiles at 2100JST on February 22. left: Wakkanai, middle: Sapporo, right: Misawa.

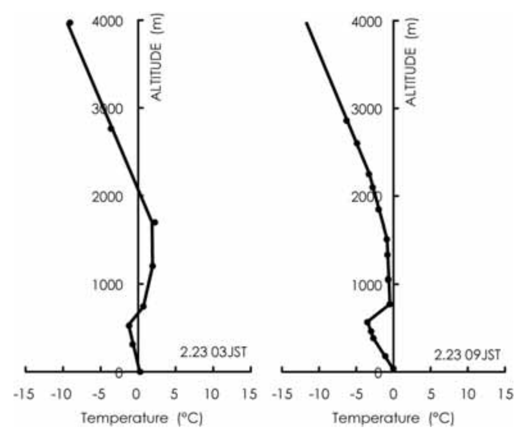

Fig. 5. Temperature profiles on February 23 at Nemuro. left: 0300JST, right: 0900JST

B. Sorachi Subprefecture

The field observation revealed that glaze covered a wide area around south and central Sorachi. From the data of hydrometeor, temperature, and precipitation, we infer that the freezing rain occurred from 1930 JST on February 22 to 0500 JST on February 23 [5].

Fig. 6 shows an image of the glaze in central Sorachi on February 23. Fig. 7 shows the polarized thin section of the glaze on a branch. The black part is the branch and it is clear that ice crystals grew from the inside to the outside. Glaze was also observed between Sunagawa (central Sorachi) and Iwamizawa (south Sorachi) on February 24. The damage due to wet snow accretion instead of ice accretion was recorded in north Sorachi subprefecture.

Fig. 6. A photograph of the glaze in central Sorachi on February 23.

Fig. 7. The polarized thin section of the glaze on a branch. The black part is the branch.

C. Hidaka and Kamikawa Subprefectures

These subprefectures are located in inland Hokkaido. Hidaka town (280 m asl), which is at the junction of routes 237 and 274, was mainly damaged by heavy icing on birches, larches, and arborvitaes. Traces of heavy icing were present even during the investigation in April 2007. Fig. 8 shows that many arborvitaes were broken by the weight of ice accretion and strong wind. A large distribution of bent birches was found along the Mukawa River at Fukuyama (170 m asl), which is located 15 km to the west of Hidaka. However, the traces of heavy icing were not found at the pass between Fukuyama and Hidaka, which is located at an altitude of approximately 500 m asl. The traces of heavy icing were also not found at Nissyo pass (1100 m asl, 27 km to the east of Hidaka). On the other hand, bent or broken trees were found throughout Hidaka pass (500 m asl), which is located 4 km to the north of Hidaka. From these investigations, it is inferred that heavy ice accretion occurred at the subprefecture below approximately 500 m asl.

Shimukappu, the southernmost village of Kamikawa subprefecture, was the northernmost point of the freezing rain. The damage due to wet snow accretion instead of ice accretion was recorded in Kamikawa subprefecture.

Fig. 8. Broken arborvitaes by the weight of ice accretion and strong wind.

D. Nemuro Subprefecture

The damage to the electric power supply by heavy ice accretion in Nemuro prefecture was recorded on February 23. Glaze was observed in the areas of the region extending from the Nemuro Peninsula to southeast Kushiro subprefecture neighboring Nemuro.

The following results were obtained after the investigations of the precipitation icing events in Hokkaido on February 22–23. The temperature profile indicates that the freezing rain in west Hokkaido occurred from the evening of February 22 through the next morning. The glaze intensified in central and south Sorachi and northwest Hidaka in low-altitude areas (below approximately 500 m asl). On the other hand, the glaze in Nemuro intensified on the morning of February 23 because the occurrence of the typical temperature profile of the freezing rain was delayed.

Fig. 9. The anemometer completely covered by glaze. February 23.

IV. Estimation of Ice Accretion Area by Failed Anemometer Data

Fig. 9 shows an anemometer positioned on the roof of Iwamizawa Campus, Hokkaido University of Education. It was completely covered by glaze; therefore, wind speed data could not be recorded after the icing event because the sensor did not contain any countermeasure for the ice accretion. There was a lack of wind speed data at the Iwamizawa weather station, although the anemometer contained a heating system and was maintained manually whenever the icing occurred. The concept of the estimation of ice accretion area is as follows. The anemometer of the automated meteorological data acquisition system (AMeDAS) by the Japan Meteorological Agency did not contain countermeasures for the ice accretion; therefore, the lack of anemometer data was considered to be caused by the ice accretion. We used surface meteorological data that included hydrometeor. The plot of the distribution of the failed anemometers recorded at 0500 JST on February 23 is shown in Fig. 10. This plot included the anemometers that failed due to the wet snow accretion; therefore, we verified the data with the surface meteorological data, and the snow accretion data was removed from the plots in Fig. 11. Additional data obtained from the road weather telemeter data provided by the Hokkaido Regional Development Bureau is plotted in Fig. 11. The area encircled by the black line in the plots indicates the ice accretion area. According to the plots, ice accretion occurred in central and south Sorachi and the boundary between Hidaka and Kamikawa. Ice accretion also occurred in the entire Nemuro Peninsula and east Kushiro subprefecture, as indicated by the black line encircling these regions in Fig. 11.

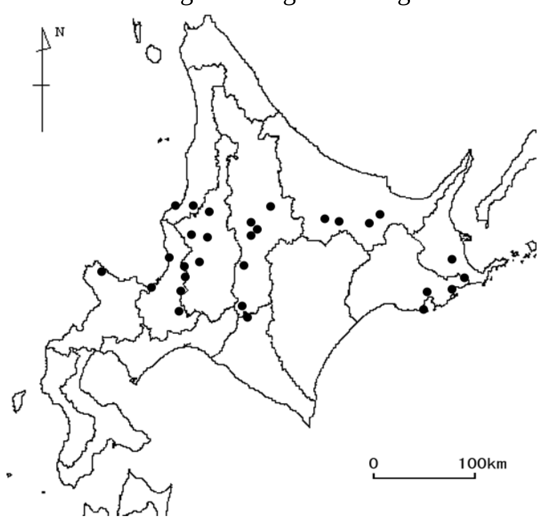

Fig. 10. The distribution of the failed anemometers recorded at 0500JST on February 23.

V. Estimation of Geographical Distribution of Freezing Rain Considering Microphysics

A. Concept of Estimation

The regional distributions of the freezing rain that occurred on February 22–23, 2004, can be estimated by the method shown in Fig. 12. This method considers the thermodynamical conditions required for the melting of snow particles within the melting layer and the freezing of raindrops within the subfreezing layer. We define the melting layer as an air layer in which the air temperature is above 0 °C and the subfreezing layer as an air layer in which the air temperature is below 0 °C and which exists below the melting layer. This estimation is based on the mean air temperatures (*Tm*, *Tf*), mean density of water vapor (*Pm*, *Pf*) calculated from relative humidity, and depths (*Dm*, *Df*) of the melting and subfreezing layers. These parameters can be calculated for each grid point by using the MOA.

Fig. 11. The ice accretion area estimated by the surface meteorological data and the distribution of failed anemometers. ●: AMeDAS, Δ: Road weather telemeter.

B. Melting of Snow Particles

According to [6], the heat balance between snow particles and environmental air on a solid ice surface by assuming a spherical shape with radius r_i can be expressed as

$$-4\pi r_i^{\,2}\rho_i L_m \frac{dr_i}{dt} = 4\pi r_i k_a f_h \Delta T + 4\pi r_i L_s D_v f_v \Delta P \tag{1}$$

where ρ_i is the density of a snow particle with an ice-skeleton structure, ΔT and ΔP are the temperature and water vapor density differences between the surface of the snow particle and environmental air, L_m and L_s are the latent heats of the melting and sublimation of ice, k_a is the thermal conductivity of air, D_v is the coefficient of water vapor diffusion in air, and f_h and f_v are the ventilation coefficients of the heat and water vapor transfers.

f_h and f_v can be equal [6], [7]; therefore, the ventilation coefficient f_i of the water vapor transfer on the surface of ice particles, defined as $f_i \equiv f_h \approx f_v$, was determined by [8]. Rewriting (1) by focusing on the rate of decrease in the radius of the snow particle gives

$$\frac{dr_i}{dt} = -\frac{f_i}{r_i \rho_i L_m}\left(k_a \Delta T + L_s D_v \Delta P\right). \tag{2}$$

The substitution of T_m and P_m of the melting layer in (2) and using a time step of 0.1 s in the calculations yields the rate of decrease in the radius due to melting. t_m is defined as the time necessary for the complete melting of the snow particle as r_i approaches 0. By referring to [7], [9] in the calculation, we assume that the temperature on surface of the snow particle is 0 °C, and ρ_i is 0.030 g·cm^{-3}. r_i is calculated based on ρ_i and the liquid water drop radius r_{w0}. Any change in the mass of the snow particle caused by sublimation is neglected.

The depth D'_m of the melting layer required for the complete melting of the snow particle can be obtained from t_m and the fall velocity U_i of the snow particles estimated by [10], and it is expressed as

$$D'_m = t_m U_i \quad . \tag{3}$$

A comparison of D'_m and D_m obtained from the MOA will decide the thermal condition, i.e., whether or not the snow particle will melt completely. If $D'_m \leq D_m$, the snow particle will melt completely and turn into a raindrop. If $D'_m > D_m$, the snow particle will either melt partially or not melt at all and reach the ground as the snow includes wet snow (Fig. 12).

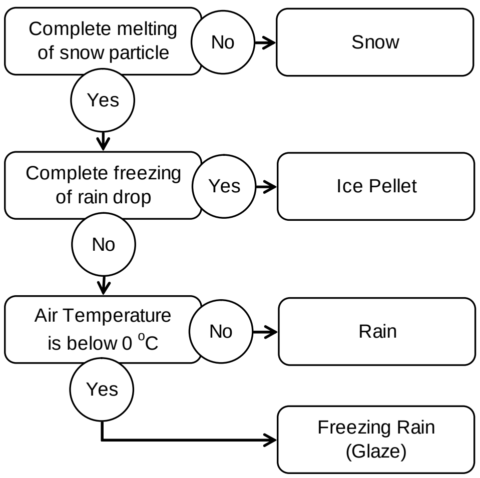

Fig. 12. Flowchart of distinguishing precipitation types.

C. *Freezing of Raindrops*

As the raindrops freeze, an initial nucleation that lasts for a relatively short time occurs with a fraction $(1-c_w \Delta T/L_m)$ of the water volume yet to be frozen [6], where c_w is the specific heat of water. We assume that the raindrops begin to freeze on the spherical surface, resulting in an internal liquid water part with radius r_w and spherical ice envelopment with radius r_{w0}. The heat balance between the raindrop and environmental air at the ice surface of the raindrop is expressed by [6].

$$4\pi r_w^{\,2} \rho_w L_m \frac{dr_w}{dt}\left(1-\frac{c_w \Delta T}{L_m}\right) = 4\pi r_{w0} k_a f_h \Delta T + 4\pi r_{w0} L_s D_v f_v \Delta P \tag{4}$$

where ρ_w is the density of liquid water.

As mentioned in the previous section, the ventilation coefficient f_w of the raindrop for the water vapor transfer on the surface of the liquid water droplets, obtained from [6], is defined as $f_w \equiv f_h \approx f_v$. Rewriting (4), the rate of decrease in the radius of the liquid water part of a freezing raindrop is expressed as follows:

$$\frac{dr_w}{dt} = \frac{f_w r_{w0}}{\rho_w L_m r_w^{\,2}\left(1-c_w \Delta T/L_m\right)}\left(k_a \Delta T + L_s D_v \Delta P\right) \quad . \tag{5}$$

The substitution of T_f and P_f of the subfreezing layer in (5) and using a time step of 0.1 s in the calculations yields the rate of decrease in the radius of the liquid water part due to freezing. As r_w approaches 0, we consider that the raindrop is completely frozen, and t_f is defined as the time necessary for the complete freezing of the raindrop. The temperature on the surface of the raindrop was assumed to be 0 °C, and the function $(1-c_w \Delta T/L_m)$ was considered only at the initial time at which the raindrop began to freeze. The mass change in the raindrops due to sublimation was neglected.

The depth D'_f of the subfreezing layer required for the complete freezing of a raindrop is derived from t_f and the fall velocity U_w of the raindrop given by [11].

$$D'_f = t_f U_w \tag{6}$$

A comparison of D'_f and D_f obtained from the MOA will decide the thermal condition, i.e., whether or not the raindrop will freeze completely. If $D'_f \leq D_f$, the raindrop will freeze completely and turn into ice pellets. If $D'_f > D_f$, the supercooling of the raindrop will be maintained and the raindrop will reach the ground as the freezing rain includes the case of the partial refreezing of the raindrop (Fig. 12).

D. *Condition at the Surface*

The occurrence of freezing rain is influenced by the air temperature near the surface. If the air temperature at the surface is above 0 °C, the raindrops will be warmed up rapidly and the supercooling state will be not maintained. The third test for discriminating between freezing rain and rain is to observe whether the air temperature at the surface is above or below 0 °C (Fig. 12).

E. *Distinguishing of Precipitation Types*

By using the three discrimination tests described above, precipitation types, including freezing rain and ice pellets at the surface, can be determined. If both the melting and subfreezing layers are present, the melting state of the snow particles and the freezing state of the raindrops is estimated by the methods in Sections *B* and *C*. In the case that only a melting layer exists near the surface, it can be determined whether the precipitation will be snow or rain by using the melting discrimination in Section *B*. Only snow will fall, as the air temperature is below 0 °C everywhere.

The discrimination tests were performed on liquid water droplets with three different radii, i.e., r_{w0} = 0.25, 0.50, and 1.00 mm, by referring to the radius of the ice pellets observed in Tokachi subprefecture on February 22–23, 2004 [3]. If the results of all the three cases were be the same, the precipitation type would be considered to be a single state, and if the results of all the three cases were to be different, the precipitation type would be considered to be a combination state, for example, freezing rain with ice pellets.

F. *Results of Estimation*

The results of the estimation of the areas where the freezing rain and ice pellets occurred are shown in Fig. 13. Freezing rain was observed in central Ishikari, central and south Sorachi, and north Hidaka subprefecture regions at both

2100 JST on February 22 (Fig. 13 A) and 0300 JST on February 23 (Fig. 13 B). In east Hokkaido, neither freezing rain nor ice pellets were observed at 2100 JST on February 22. Freezing rain and ice pellets were observed along the Pacific coast at 0300 JST on February 23. These results are consistent with the observation results shown in Fig. 11.

Freezing rain was observed in the Shakotan Peninsula; however, there was no evidence for ice accretion in this area. On the other hand, ice pellets were observed in east Hidaka subprefecture for a long time [3], although freezing rain was not observed. Since these areas are mountainous, two factors are considered as the cause of this discrepancy. The first is the difficulty of observation. The observation of the mountainous area is limited along the pass; consequently, it appears possible that the freezing rain may not have been recorded. The second is the accuracy of the MOA data of the mountainous area. In the current stage of the MOA, the accuracy of this data might not be sufficient for the estimation of the precipitation type.

VI. Conclusions

We have investigated the precipitation icing event that occurred on February 22–23, 2004, by using the surface meteorological data and the distribution of anemometers that had failed due to icing. The field studies reveal that glaze covered a wide area around south and central Sorachi, north Hidaka, and Nemuro subprefecture regions. The distribution of the failed anemometers on the morning of February 23 corresponds to the results of the field observation.

Mesoscale analysis has been employed to estimate the freezing rain area. We have designed a microphysics scheme for the snow melting process and raindrop supercooling process, and the freezing rain area has been calculated using the MOA. The freezing rain area estimated by the microphysics scheme is consistent with the icing area inferred from the field survey, meteorological data, and anemometer distribution.

VII. Acknowledgment

We express our gratitude to M. Aida, T. Kawabuchi, H. Yoneda, Y. Nakai, T. Yamada, H. Tajima, and the staffs of the National Hidaka Youth Outdoor Learning Center for providing valuable information. We are also grateful to Emeritus Prof. N. Maeno of Hokkaido University for useful comments. We also thank S. Adachi of the University of Tsukuba for his assistance in the collection of the ice accretion event data.

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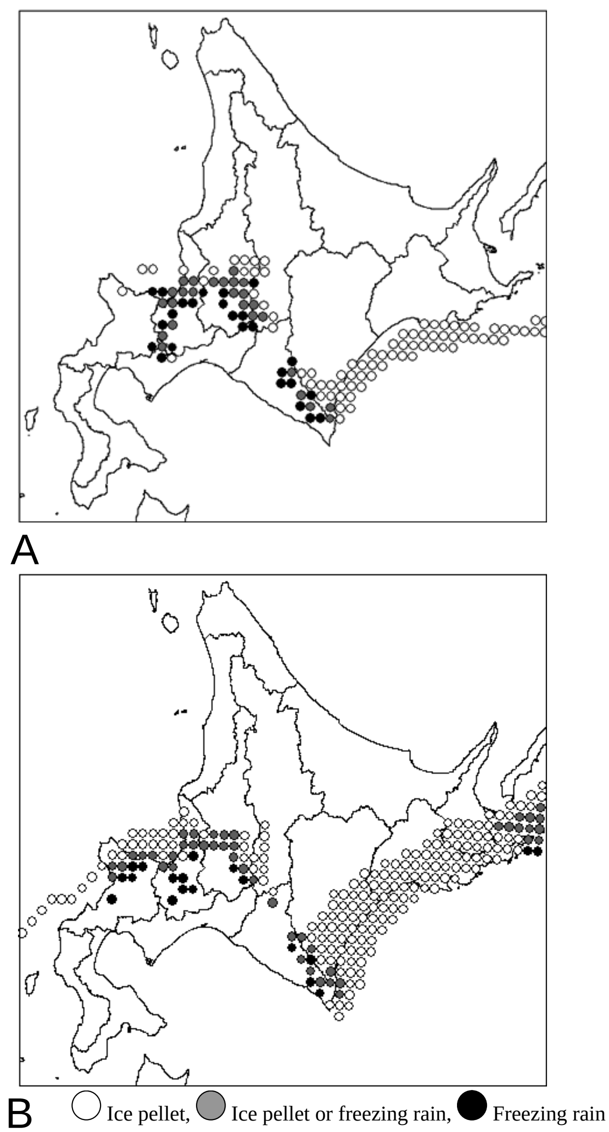

Fig. 13. Estimated distribution of freezing rain and ice pellet. A: 2100JST on February 22, B: 0300JST on February 23.