Local influences on occurrences of freezing rain and precipitation icing in Japan

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Abstract - **We have investigated the regional distributions of occurrences of freezing precipitation (rain, drizzle) and ice pellets, and the atmospheric conditions during freezing rain by using surface meteorological data of Japan Meteorological Agency during the last 15 winter seasons (November, 1989 – May, 2004).**

In Japan, the most of freezing rain and ice pellets have been occurred in the inland basins in the northern Chubu region, and the plains on the Pacific Ocean side of northern Kanto. In inland basins, the wind is gentle and humidity is near saturation, but in the plains, there is a tendency with moderate wind and low relative humidity. The calculation of heat balance on the surface of water, which has not frozen yet on exposed objects, shows that the sensible heat flux and latent heat flux for cooling in plains on the Pacific Ocean side are larger than those in inland basins. Therefore, in plains on the Pacific Ocean side, icing would make easy to develop by large cooling flux.

I. INTORODUCTION

Freezing rain with a supercooled state is frozen on the obstacles such as power lines and trees at the ground, and could cause the traffic accidents or power failure.

In general, it is necessary for freezing rain to be occurred that a warm air layer to melt snowflakes exist above a cold air layer which acts to supercool descending raindrops near the ground. This vertical atmospheric structure has been known for a long time, and it is called “melting process”. When raindrops refreeze before reaching the ground, ice pellets are observed.

In addition, although temperature in the atmosphere is everywhere colder than 0 ^{o}C, supercooled water drops grow through the condensation and/or the collision coalescence process (i.e., “warm rain process”). However, freezing drizzle forms most often through these processes [1], [2].

A climatological regional distribution on the occurrences of freezing rain and/or precipitation icing will be demanded for an assumption of damage areas and countermeasure for these phenomena. Such regional distribution has been already obtained for North America [3], [4] and Europe [5], and were examined for the relationship with local influences [6] and synoptic scale situations [7], [8].

In this paper, we have investigated the spatial distribution of the occurrences of freezing precipitation (rain, drizzle) and ice pellets in Japan, and examined the regional differences of surface meteorological condition during freezing rain and thermodynamical condition on icing development.

II. DATA

We used the surface meteorological data for hydrometeors and hourly observations (air temperature, relative humidity, wind speed, air pressure, precipitation) provided by Japan Meteorological Agency. These data were obtained from 153 observatories in Japan (Fig. 1). The observations of freezing rain, freezing drizzle and ice pellets are included in the hydrometeors data, and the appearance time and the end time of these precipitation types are recorded in this data.

We defined the winter season as period from November to May, and analyzed on 15 winter seasons for November 1989 to May 2004.

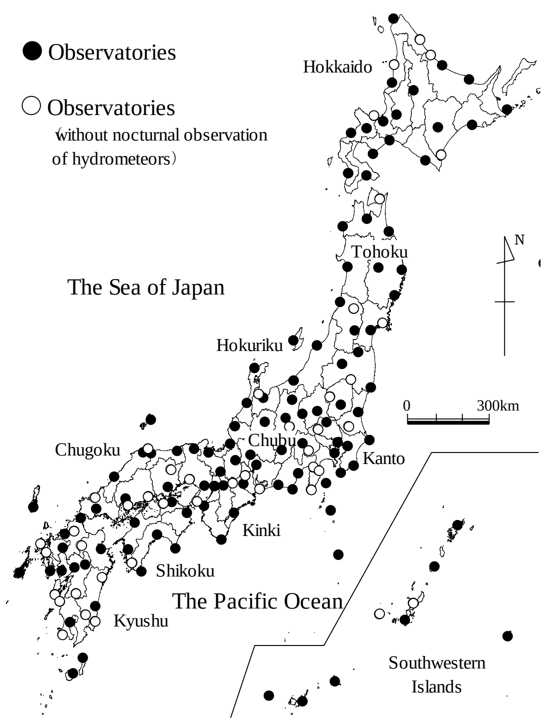

Fig. 1. Geographical distribution of observatories of Japan Meteorological Agency. Open circles (O) means the observatories that hydrometeors are recoded at daytime only (8:30 – 17:00 JST).

III. METHODOLOGY

A. Occurrence Rates of Freezing Precipitation

According to Japan Meteorological Agency, freezing rain is defined as precipitation in liquid form but freezes upon impact to form a coating of glaze upon the ground and on exposed objects. In case of diameter of raindrops less than 0.5 mm, this rain is called as freezing drizzle. An ice pellet is a type of precipitation consisting of transparent pellets of ice with spherical and/or irregular in sharp, 5 mm or less in diameter.

The numbers of times of freezing rain, freezing drizzle and ice pellets observed as above definition were examined in each observatory (Fig. 1). In case of these precipitation types were observed continuously over two days, we counted one time as individual precipitation event.

In 43 observatories (open circles in Fig. 1), because the observation of hydrometeors is carried out in daytime only (8:30 – 17:00 JST), there is a possibility to be recorded fewer than an actual number of occurrences. However, the measures for the difference of observation time in each observatories were not done, these observatories are annotated by the under line in following figures. Moreover, many of these observatories (31 observatories) had been changed human view observation of hydrometeors to automatic system by using of visibility meter, so that we examined except the period of the automatic observation.

Occurrence rates for freezing rain, freezing drizzle and ice pellets were obtained that the number of these precipitation events were divided by the number of winter seasons.

B. Wind Speed at the 10m Heights above Ground

Wind speed V (m/s) has been observed at different height above ground z (m) in each observatory. In this analysis, wind speed at 10 m height above ground V_{10} (m/s) were estimated by using the logarithmic law as (1).

$$V_{10} = V \frac{\ln(10/z_0)}{\ln(z/z_0)} \quad (1)$$

Where z_0 is the roughness (m). The roughness in each observatory has been already obtained by [9]. Additionally, although vertical profile of wind speed is also influenced by atmospheric stability, this effect was not considered.

C. Heat Fluxes on the Surface of Glaze

A concept of heat flux on surface of glaze covered thin water film, which has not frozen yet on exposed objects, had been proposed by [10]. We used also this concept as follows.

Sensible heat flux Q_s (W/m^2) and latent heat flux Q_l (W/m^2) were obtained from surface meteorological observation of air temperature T (^{o}C), wind speed V_{10} (m/s), relative humidity RH (%), air pressure P_a (hPa), and diameter of object as circular cylinder D (m).

$$Q_s = -h_a dT \quad (2)$$

$$Q_l = -L_e h_v dW \quad (3)$$

Where dT is temperature difference between glaze surface (assuming 0 ^{o}C) and air (^{o}C), dW is difference between water vapor density of air and equilibrium water vapor density at glaze surface (kg/m^3), L_e is latent heat of vaporization for water (J/kg). According to [10], Heat transfer coefficient h_a (W/m^2 ^{o}C) and vapor transfer coefficient h_v (m/s) between air and glaze surface are calculated by using of relation with the Reynolds number R_e obtained from wind speed V_{10} and diameter of object D.

$$N_u = -h_a D/k_a = f(R_e) \quad (4)$$

$$S_h = -h_v D/k_v = f(R_e) \quad (5)$$

Where N_u is the Nusselt number, S_h is the Sherwood number, k_a is thermal conductivity of air (W/m^{o}C), k_v is coefficient of molecular diffusion of water vapor in air (m^2/s). In this study, diameter D of object was assumed to be 0.01 m (= 1 cm).

Because other heat fluxes, for example radiation heat flux, does not affect as effectively as above two heat fluxes [10], in this paper, the sensible and latent heat fluxes were considered as major factor on icing development.

IV. RESULTS

A. Regional Distributions of Occurrence Rates for Freezing Precipitation

Fig. 2 – 4 shows the regional distributions of occurrence rates of freezing rain, ice pellets and freezing drizzle in Japan. The Southwestern Islands are excluded from the figures because there was no observation of these precipitation types during the last 15 winter seasons. The name of stations underlined in the figures means the observatories where the hydrometeors observe in daytime only.

The occurrence rate of freezing rain (Fig. 2) is high with 0.2 or more in the inland basins from Chubu region to Tohoku region, and the plains on the Pacific Ocean side in the northern Tohoku region. In these regions, the freezing rain

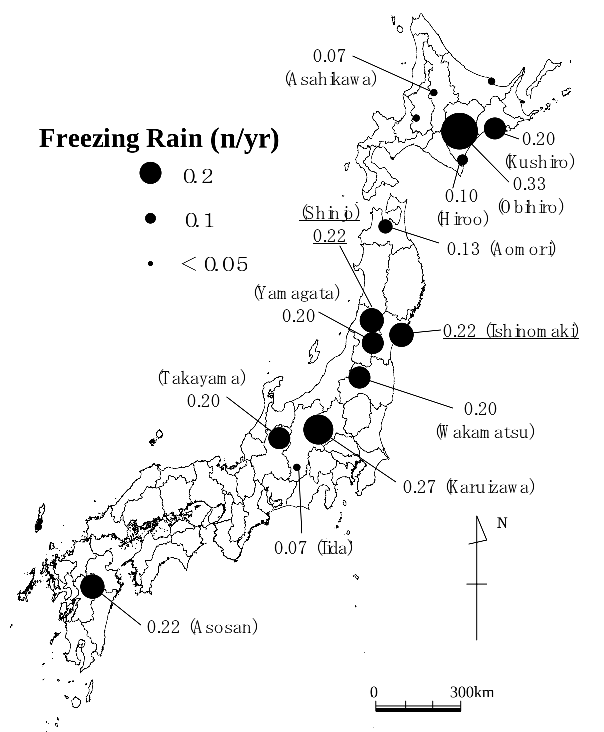

Fig. 2. Regional distribution of occurrence rate for freezing rain. Underline means the observatories that hydrometeors are recoded at daytime only.

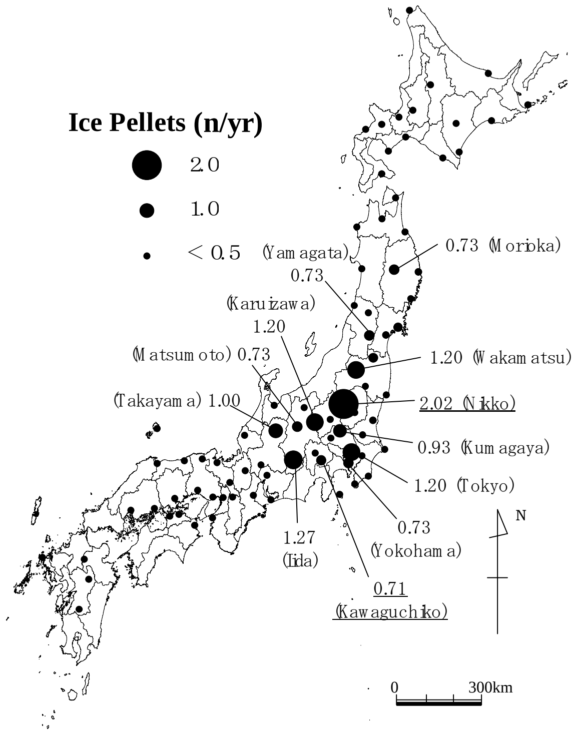

Fig. 3. Regional distribution of occurrence rate for ice pellets. Underline means the observatories that hydrometeors are recoded at daytime only.

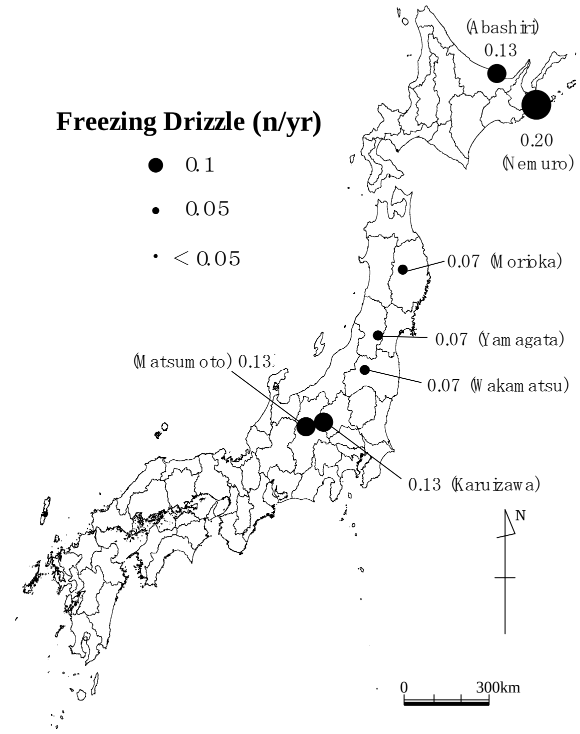

Fig. 4. Regional distribution of occurrence rate for freezing drizzle.

occurs once in 4 or 5 years. The southernmost observatory where the freezing rain occurred is Asosan in Kyushu, it suggest a possibility that freezing rain occurs in regions where snowfall is not commonly.

As shown in Fig. 3, the ice pellets had been observed in the whole Japan except the Southwestern Islands. The regions that the high occurrence rate of ice pellets are Kanto region and the inland basins from Chubu to Tohoku. In these regions, the ice pellets occurs once or more in every winter season. The feature compared with regional distribution of freezing rain (Fig. 2) is high occurrence rate in Kanto region, and the ice pellets falls in every year in spite of no observation of freezing rain at observatories in Kanto region during the past 15 winters.

Although not the all ice pellets events cause the glaze phenomenon, atmospheric condition required for occurrence of ice pellets is similar to that of freezing rain, and there are many cases that ice pellets falls with freezing rain. Therefore, from the regional distributions of occurrences of freezing rain and ice pellets (Fig. 2 and Fig. 3), we would conclude that the high possibility for occurring glaze phenomenon in the inland basin in the northern Chubu region, and the plains on the Pacific Ocean side of northern Kanto region.

In Fig. 4, freezing drizzle had been observed in eastern Hokkaido and Chubu region, but it occurred in a few time. An atmospheric structure and formation process for freezing drizzle is not same as that for freezing rain. However, the regional distributions of freezing rain, ice pellets and freezing drizzle (Fig. 2 – 4) shows similar patterns, and suggests a climatological and/or geographical factors for occurrences of these precipitation types.

B. Surface Meteorological Conditions during Freezing Rain

As above mentioned, the freezing rain and ice pellets occurs commonly in the inland basins in the northern Chubu region, and the plains on the Pacific Ocean side of northern Kanto. We paid attention to both regions, and examined for surface meteorological conditions during freezing rain on 7 observatories (Asahikawa, Shinjo, Wakamatsu, Yamagata, Takayama and Iida) located in the inland basins, and 4 observatories (Obihiro, Kushiro, Hiroo and Ishinomaki) located in the plains on the Pacific Ocean side. These observatories have many meteorological hourly data for the high frequency or long duration of freezing rain phenomena.

Fig. 5 shows the relation between mean relative humidity and mean wind speed during freezing rain in both regions. In inland basins, wind is gentle and humidity is near saturation, but in the plains, there is a tendency with moderate wind (2 – 3 m/s) and low relative humidity.

Fig. 6 indicates the mean surface air temperature and mean dew point temperature when freezing rain occurs. In both regions, the mean air temperatures are in the same range of 0 to –2 ^{o}C, although the air temperatures in the inland basins tends slightly low. Even if the air temperature is above freezing point, the dew point temperature is blow 0^{o}C. Therefore, not only the air temperature condition, but also the moisture condition of atmosphere will affect both states of supercooling raindrops and glaze formation.

C. Thermodynamical Conditions during Freezing Rain

The differences of surface meteorological conditions in both regions would involve a local influence on development of icing on structure at the ground.

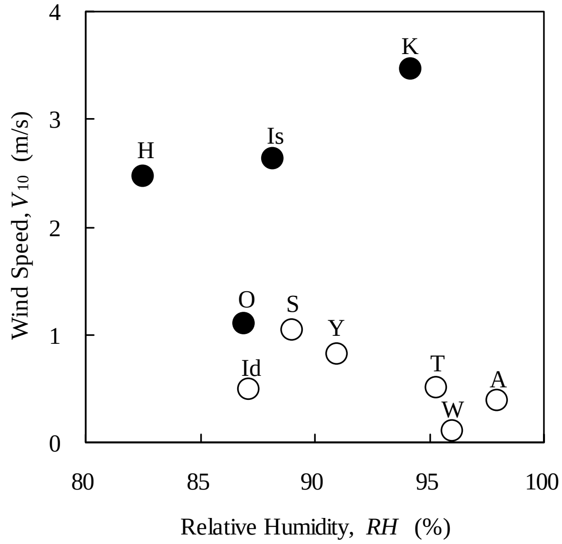

Fig. 5. Means of wind speed and relative humidity during freezing rain fall. Dots means the observatories (O: Obihiro, K: Kushiro, H: Hiroo and Is: Ishinomaki) located in plains on Pacific Ocean side, and open circles means the observatories (A: Asahikawa, S: Shinjo, W: Wakamatsu, Y: Yamagata, T: Takayama and Id: Iida) located in inland basins.

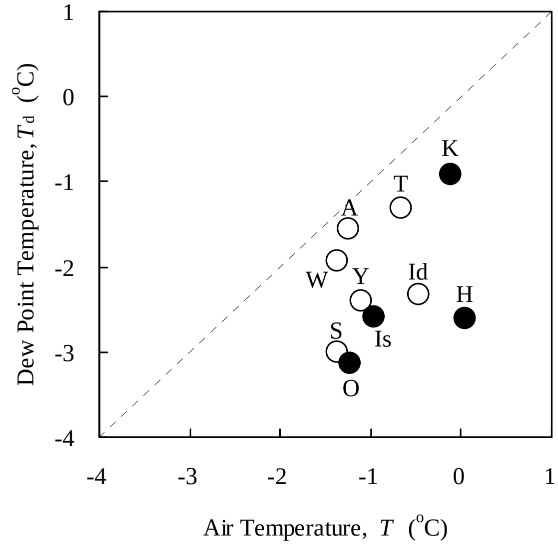

Fig. 6. Means of air temperature and dew point temperature during freezing rain fall. Dotted line means saturation. Plots in this figure are the same as Fig. 5.

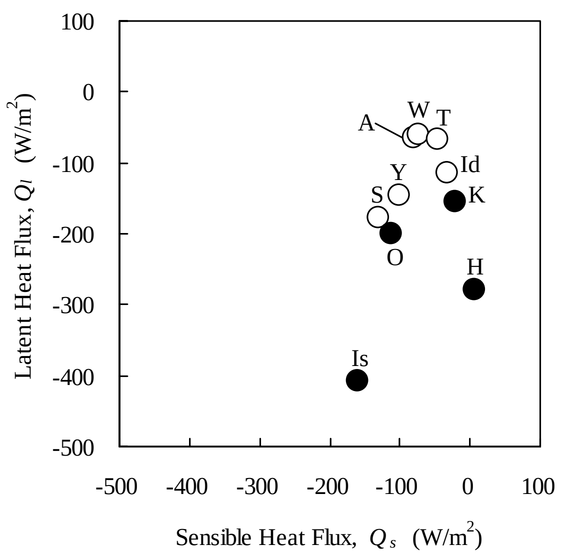

Fig. 7. Means of sensible heat flux and latent heat flux on surface of glaze during freezing rain fall. Plots are the same as Fig. 5.

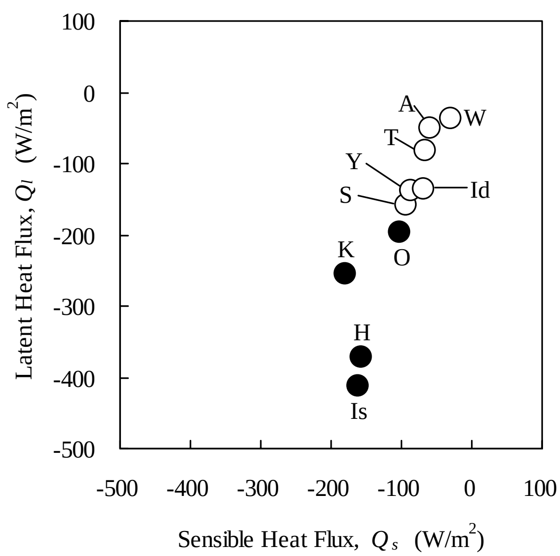

Fig. 8. Means of sensible heat flux and latent heat flux on surface of glaze assuming that air temperatures are –1 °C in all freezing rain cases. Plots are the same as Fig. 5.

Fig. 7 shows the means of sensible heat flux and latent heat flux on surface of glaze that were estimated from surface meteorological data during freezing rain. The latent heat fluxes in the plains on the Pacific Ocean side are larger negative values than that in the inland basins. This results from surface meteorological features in the plains such as low relative humidity and moderate wind (2 – 3 m/s).

In contrast, the sensible heat fluxes in both regions are the same range, although the large negative values of sensible heat fluxes in the plains would be also expected from strong wind compared with that in the basins. The effect of wind would be counterbalanced with temperature effects due to relatively low air temperature in the inland basins.

Then, to examine the influences for glaze formation caused by the differences of wind speed and relative humidity in both regions, the sensible and latent heat fluxes were calculated again on condition that air temperature is –1 °C in all freezing rain cases, assuming that relative humidity at air temperature of –1 °C. This results in Fig. 8. This figure suggests that if freezing rain fall as the same air temperature situation in both regions, in the plains on the Pacific Ocean side, both fluxes of sensible heat and latent heat are larger negative value than those in the inland basins. Consequently, in the plains on the Pacific Ocean side, the icing would make easy to develop by large cooling flux.

V. DISCUSSION

A. On the Distributions of Freezing Precipitation

It should be noted that the regional distributions of occurrences of freezing precipitation and ice pellets shown in this paper are based on point evaluation at each meteorological observatories, and not explained a regional detail without no observation area. Even if synoptic situation required for occurrence of freezing precipitation is formed, the area where these precipitation fall tends local and narrow area. For example, high frequency of glaze occurrence in the northern slope of Mt. Yatsugatake in Chubu region has been exhibited by disaster record due to glaze [11] and theoretical analysis [12], but such regional detailed distribution is not expressed. Moreover, there are few cases of freezing rain and ice pellets in the region on the Sea of Japan side, but freezing rain event in Nagaoka located in plain on the Sea of Japan side has been reported by [13].

In this study, the feature of distributions that the most of freezing rain and ice pellets occurs in northern Chubu region, agree well with regional feature in frequency of disaster due to glaze phenomenon investigated by [11].

B. Local Meteorology with respect to Freezing Rain

The difference of surface meteorological condition when freezing rain occurs in the inland basins and the plains on the Pacific Ocean side will be caused by the difference of formation process of cold air layer near the ground for supercooling raindrops. According to [14], the formation of cold air layer is strongly influenced by local meteorology and geographical features. In the inland basins, a cold air reservoir within each basin plays an important role in the formation of the cold air layer near the ground. In contrast, in the plains on the Pacific Ocean sides, the cold air advection with relative dry from inland peculiar to these plains contributes to forming the cold air layer. Therefore, in the inland basins, the wind is gentle and humidity is near saturation, but in the plains, there is a tendency with moderate wind and low relative humidity.

The local wind due to cold air drainage from inland area in the plains on the Pacific Ocean side are dominant air flow near the ground when synoptic surface low pressure system moves eastward along southern coast in these regions [15]. In particular, in Kanto Plain, the cold air layer near the ground develop well by nocturnal cold air flow from inland mountain area, and the air flow maintains during daytime [16], [17].

In the inland regions, geographical features strongly influence on the formation of cold air layer such as cold air reservoir within basins, cold air trapping along valleys [6], [7] and mountains barriers for surface cold air layer from synoptic warm air advection [12].

C. Disaster due to Freezing Rain in Japan

In Japan, many cases of forest damage and traffic accident caused by the freezing rain has been reported as local phenomenon, however there is no serious damage with heavy ice accumulation in wide area such as events reported in North America. As for reason, the disaster due to glaze in Japan would results from meteorological features during freezing rain such as its short duration, light precipitation and weak wind.

Recently, freezing rain event with strong wind (6 – 10 m/s) has been reported in Hokkaido, and net fence of baseball field was collapsed by weight of ice accumulation and high wind pressure [18]. Moreover, ice pellets accumulated on ground with depth of about 15 cm in other area of Hokkaido [19]. In our future task, climatological trends in Japan that whether freezing rain event with serious damage increases or not would be examined.

In addition to this, we will also propose a forecasting by using thermodynamical parameters considered on atmospheric vertical structure required for melting snow particle and refreezing raindrop [20].

VI. CONCLUSION

We have investigated the regional distributions of occurrences of freezing precipitation (rain, drizzle) and ice pellets by using surface meteorological data during the last 15 winter seasons (November, 1989 – May, 2004), and examined the regional differences of surface meteorological condition during freezing rain and thermodynamical condition on icing development. The main results are as follows.

(a) The most of freezing rain and ice pellets have been occurred in the inland basins in the northern Chubu region, and the plains on the Pacific Ocean side of northern Kanto.

(b) In inland basins, the wind is gentle and humidity is near saturation. On the other hand, in the plains on the Pacific Ocean side, there is a tendency with moderate wind and low relative humidity.

(c) The calculation of heat balance on the surface of water, which has not frozen yet on exposed objects, shows that the sensible heat flux and latent heat flux for cooling in the plains on the Pacific Ocean side are larger than those in the inland basins.

(d) Therefore, in the plains on the Pacific Ocean side, icing would make easy to develop by large cooling flux.

VII. REFERENCES

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