A Method for Numerical Forecast of the Distribution of Snowfall in the Ishikari Plain

Yoshiharu SHIOTSUKI* and Choji MAGONO

Abstract

A method for numerical forcast of the distribution of snowfall in the Ishikari Plain is described in this paper. The snow cloud which is formed by the vigorous supply of latent and sensible heats of water of the Japan Sea is simulated under the one dimensional diffusion model. The initial and boundary conditions used in this model are the air temperature and relative humidity of the Siberian Continent, and the sea water temperature of the Japan Sea. The obtained cloud is represented by the distribution of liquid water content and air temperature. The snowfall amount on the Ishikari Plain is calculated by the liquid water content taking account of the size distribution of the precipitation elements among the cloud. A computed distribution of the precipitation intensity over the Ishikari Plain is generally similar to the observed distribution. The present method may be useful to the forecasting of the snowfall distribution from winter monsoon clouds over the Ishikari Plain, in spite that the model is one dimensional.

1. Introduction

The snowfall distribution over the Ishikari Plain has been researched by many investigators. Magono[1] reviewed those works and suggested the possibility of forecasting the snowfall distribution over the Ishikari Plain. The aim of this paper is to find a method of numerical forecast of the snowfall distribution in the Ishikari Plain. There are two representative numerical models for simulating the winter monsoon; Asai[2] showed the average weather condition over the Japan Sea in winter monsoon by his diffussion model. By this one dimensional model the vertical feature of the snow cloud is well represented. On the other hand, recently Lavoie[3] reported a result of simulation of the snowfall distribution over the lee shores of the Great Lakes. His model is the three dimensional and well represents the horizontal distribution of snowfall.

But his model can not describe the details of the vertical structure of the cloud which may be important in case of the snow cloud, because the shape of precipitation element is sensitively dependent on the air temperature.

The authors will adopt the Asai's diffusion model in this paper. Our procedures for numerical forecast of the snowfall distribution in the Ishikari Plain are as follows. (1) The vertical structure of continental air mass which outbursts into Japan Sea is represented by the sounding data at Terney or Vladivostok on the Siberian continent. (2) The snow cloud which is formed on the Japan Sea is simulated by the Asai's model. (3) After the simulated cloud arrives over the seashore of the Ishikari Plain, the cloud-physical process is taken into account for determining the distribution of snowfall in the Ishikari Plain.

2. Numerical procedures and cases

The calculation procedures adopted for making the snow clouds are very same as in Asai's numerical experiments. The basic equations are as follows,

$$
\left.\begin{aligned}
U\frac{\partial \theta}{\partial x} &= \frac{\partial}{\partial z}\left(K_\theta \frac{\partial \theta}{\partial z}\right) + Q \\
U\frac{\partial q}{\partial x} &= \frac{\partial}{\partial z}\left(K_q \frac{\partial q}{\partial z}\right) - M \\
U\frac{\partial m}{\partial x} &= \frac{\partial}{\partial z}\left(K_m \frac{\partial m}{\partial z}\right) + M
\end{aligned}\right\} \quad (1)
$$

where θ; potential temperature, U; wind velocity along x-direction, z; height, q; specific humidity, m; liquid (solid) water content, Q; rate of heating due to condensation (sublimation) or rate of cooling due to evaporation (sublimation) of liquid (solid) water, M; rate of condensation (sublimation), K_θ, K_q, K_m; the eddy exchange coefficients for sensible heat, water vapor and liquid (solid) water, respectively. $K_\theta = K_q = K$, and $K_m = 0$ are assumed in the present experiment. The boundary conditions are prescribed by Eq. 2.

$$
\left.\begin{aligned}
F_s &= \rho C_p C U(\theta_1 - \theta_2) \\
F_v &= \rho C U(q_1 - q_2)
\end{aligned}\right\} \quad (2)
$$

where θ_1 and q_1 denote the potential temperature and the saturated specific humidity at $z=0$, while θ_2 and q_2 represent the potential temperature and the specific humidity at $z=20$ m. C is the transfer coefficient. C_p and ρ are the specific heat of air at constant pressure and the density of air, respectively.

Concerning with the coefficient of eddy exchange K, we use the equation that is assumed to depend only on the static stability, $K=K^*\{-\alpha(\partial\theta/\partial z)\}$ (Fisher & Caplan[4]), where $K^*(=10\ \mathrm{m^2/sec})$ is the exchange coefficient for the case of the adiabatic conditions and α is the constant. Also the lower boundary conditions were given, as shown in Eq. 2, by the fluxes of sensible heat and water vapor from the sea surface. Those equations are charaterized by the transfer coefficient C. According to the results of Asai's experiment, the combination of three parameters such as $C=0.0018$, $K^*=10$ and $\alpha=500$ forms the most developed cloud of which top height at Wajima (800 km far from Vladivostock) is 1.8 km. On the other hand, the height of the top of snow cloud has frequently observed 2～3 km over Ishikari Bay where the continental air mass travels over the Japan Sea about 400 km which is only half of Asai's case. Asai pointed out in his paper that the increase of transfer coefficient C was very effective in increasing the heat supplied from the sea when associated with an appropriate increase of exchange coefficient in the layer adjacent to the boundary layer. Thus, it may be expected that the combination of larger values C and K^* can make up the more developed cloud. We used the above combination of $C=0.0018$ and $K^*=10$ as the standard case (STD), the combination of $C=0.0036$ and $K^*=20$ as the X2 case, and the combination of $C=0.0072$ and $K^*=40$ as the X4 case, respectively. The value of α was given by 500 m/°C for all cases.

The other initial and boundary conditions were prepared in this work as follows;

a) *the atmospheric layer*; 8 km in depth and 400 km in horizontal distance to approximate the fetch of Japan Sea from Terney at the coast of Siberian continent to the shore of Ishikari Bay. As the given change of sea surface temperature, as described below, is quite same as the condition of Asai's experiment, the computation of all cases will be carried out to the 800 km point for comparison with the results of Asai's experiment.

b) *the initial inversion layer at the continent*; the isothermal layer below 700 mb and the adiabatic lapse change above it. Changing the air temperature of the isothermal layer to three grades of –20°C, –25°C and –30°C, and also the relative humidity throughout the whole layer to three grades of 80%, 50% and 30%, respectively.

c) *the sea surface water temperature*; the linear change for the fetch of 400 km between the seashores of the continent (0°C) and Ishikari Bay (5°C) according to Hokkaido Regional Fisheries Research Laboratory[5].

d) *the wind velocity along the fetch*; two kinds of the values 10 m/s and 15 m/s throughout the whole layer.

e) *the calculation scheme*; the forward difference method along the direction of flow was adopted, and the space difference $\Delta X = 100$ m was taken in order to satisfy the computational stability criterion.

3. Results of calculation

The results of various kinds of cases under the present numerical experiments were obtained. From those figures we may describe, as follows, some characteristics of the formed clouds as compared with those frequently observed over Ishikari plain.

a) *Size of clouds*; Fig. 1(a) shows the results of the vertical distribution of the exchange coefficient (K m²/sec), the air temperature (T°C) and the liquid water content (M g/m³) at the points of 400 km (symbolized by ▲ (STD) and ●(X2)) and 800 km (symbolized by △(STD) and ○(X2)), when the initial air temperature of inversion layer and the initial humidity throughout the whole layr were given by –20°C and 80%, respectively. Also in this figure, a result (at 800 km point) of Asai's experiment of which initial and boundary conditions are quite same as those of the present STD case is shown by the dotted line. Comparing the result of present case (STD at 800 km point) with Asai's case, we can see no difference of profiles between them except for K below 500 m. The difference of K below 500 m is caused by that while we adopted the previously described K equation, Asai used only first two of the expanded termes of the exponential part of K equation. But, this may not be considered so serious difference as far as we see the similar profiles of cloud each other. As seen in the figure, the cloud top already reaches towards 2 km in the case X2 at 400 km point (Ishikari). The effect of adopting larger values of K to make larger clouds is thus recognzied. Of course, the cloud size is also dependent on the initial temperature and humidity of outbursting air mass. But those effect were not so dominant as compared with those of K values.
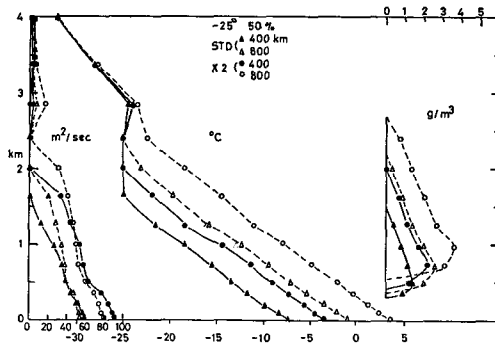
b) *Air temperature*;

The air temperature near the ground and the conservation of the inversion layer near 700 mb are well expressed as seen in Fig. 1. The cases of the initial air temperature between –20° ∼ –25°C and the humidity between 80 ∼ 50% are corresponding to the typical outburst of continental air mass. As shown in the cases of X2 of Fig. 1, the obtained air temperature near the
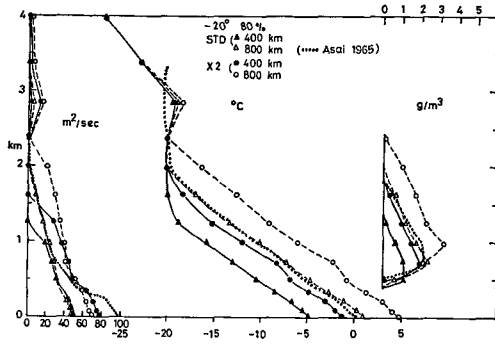
(a)
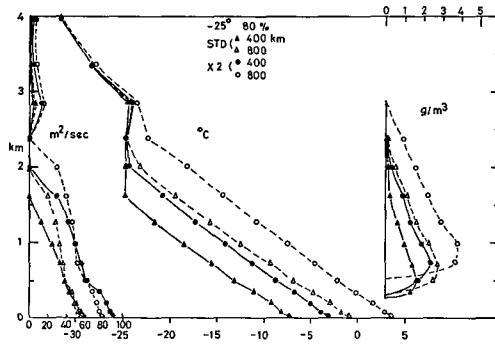
(b)

(c)

Fig. 1   The vertical distributions on the exchange coefficient, temperature and liquid
water content of the computed clouds.   The symbols of black triangle and
circle are those of 400 km point for the cases of STD and X2, respectively.
The white symbols are those of 800 km point.
a)   the case of −20°C and 80% of the initial conditions of the conteinent stable
layer.   b)   the case of −25°C and 80%.   c)   the case of −25°C and 50%.

(a)
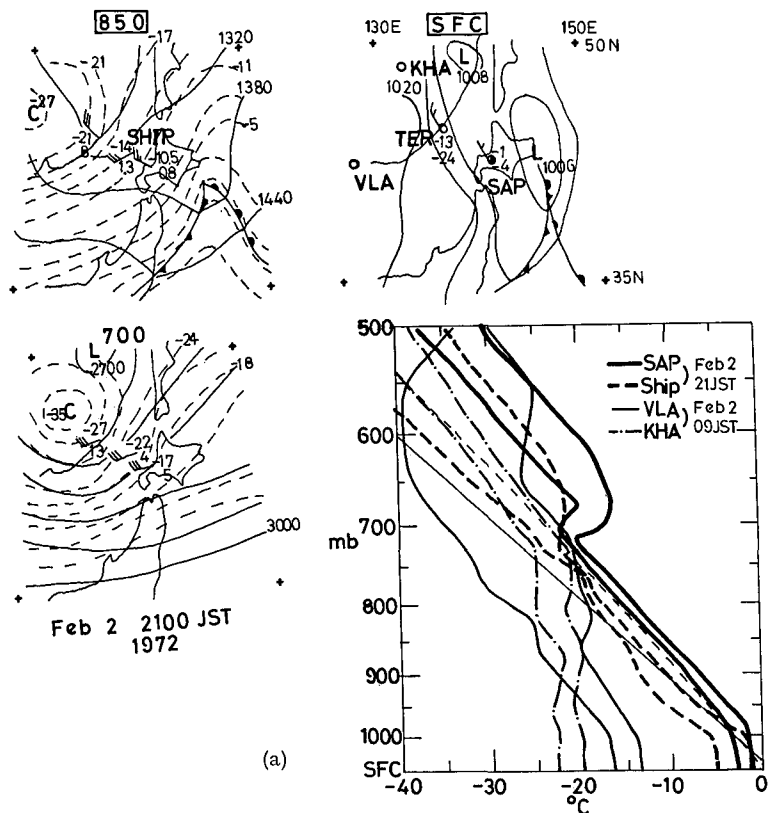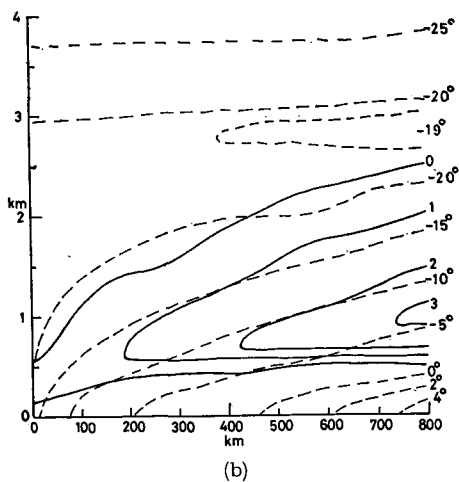
Fig. 2 a) The weather charts of three
levels and the sounding profiles
at Khabalovsk (KHA), Vlad-
ivostok (VLA), Ship, and
Sapporo (SAP) on Feb. 2, 1972.
Two lines of each point are the
temperature and the dew point
temperature, respectively. Thin
solid and broken lines are those
of dry adiabatic and wet adia-
batic.

b) The cross section of the change
of liquid water content (solid
line) and temperature (broken
line) computed from the seas-
hore to 800 km point over the
Japan Sea for the case of –20°C,
80% and X2.

(b)

ground at 400 km and 800 km point are about $-5°$ and $+3°C$, respectively, which are very near to those observed in the time of typical outburst. Otherwise, using the sounding data of the ship KEIFŪ which were obtained by the special observations during SAPPORO OLYMPIC, we can compare the temperature profile over the Japan Sea and those of Sapporo.   The observation ship KEIFŪ was situated at north-westward 100 km point far from the shore of Ishikari Bay.   Fig. 2(a) shows an example of soundings when rather weak outburst was occured on Feb. 2nd, 1972.   As shown in the figure, the air temperature of inversion layer (near 700 mb) and the humidity at the continent are nearly $-20°C$ and 80%, respectively.   And throughout inversion layer the temperature difference between two points of ship and Sapporo is about $2\sim3°C$ at any height levels.

Fig. 2(b) shows the vertical crosssection of air temperature and liquid water content along the wind, computed for the case of $-20°C$, 80% and X2. From the figure, the temperature difference between two points of 300 km (ship) and 420 km (Sapporo) is seen about $2\sim3°C$ within the inversion layer.

Furthermore, as will be described later, the computed surface temperature decrease of $2°C$ between 400 km (the shore of Ishikari Bay) and 420 km (Sapporo) shows the actual temperature difference observed at Ishikari Plain. Thus, it may be said that the present model can express well the feature of air temperature.

c) *Liquid water content within cloud*:   As seen in the profiles of the liquid water content in Figs. 1 and 2, generally the part of maximum value of liquid water content is formed near the bottom of the cloud.   This may be a characteristic with the present diffusion model without effect of vertical motion of air.   As far as we are concerned with the snow clouds over Ishikari Plain during winter monsoon, nevertheless, those profiles of liquid water content could be used as the standard profile according to the following reasons.   Magono and his colleagues have frequently observed that the falling snow particles grow according to the principle of Nakaya's Ta-S diagram. That is to say the cloud is consisted of the groups of snow particles stratified depending on the air temperature.   Furthermore, they have frequently found that the clouds suddenly decay on arriving over the seashore of Ishikari Bay and bring a lot of a mounts of graupel and rimed crystal around there.   This may mean that the part near the bottom of the cloud has much liquid water content that is favorable for making those heavier snow particles.   The maximum amount of liquid water content is computed about $1.5\sim2$ g/m^3 as

shown in the cases of X2 of Fig. 1.   According to the observations of snowsonde by Magono and Lee[6], the value of 1 g/m^3 was obtained within the band clouds of winter monsoon, in spite of that the sonde did not pass through the center part of the band.   Moreover, as shown in Fig. 3, the reflectivity intensity VST (IS06, $Z \sim 10^5$mm^6/m^3) echo, frequently observed within the band clouds of winter monsoon over Ishikari plain, is converted to the liquid water content more than 1 g/m^3 by means of Z-M relation derived by Sekhon and Srivastava[7].   Thus, the computed value of 2 g/m^3 may be well expected in the center part of the band clouds of winter monsoon.
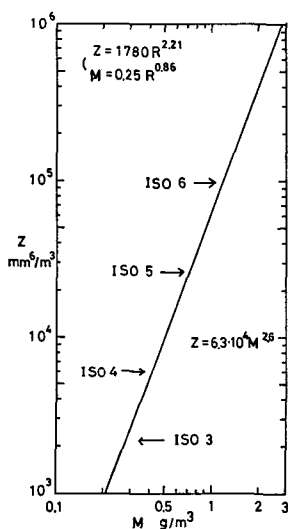

Fig. 3   The determination of M from the echoes of each isolevel (ISO) obtained by the weather radar of Sapporo Meteorological Observatory, by use of the Z-M relation of Sekhon and Srivastava (1970).

d)   *Effect of wind velocity*;   In computations of Figs. 1 and 2, we gave a uniform wind velocity of 10m/sec throughout the whole layer of the considered atmosphere in the present experiment.   Although the value of 10m/s is well known as the typical wind velocity in the time of winter monsoon cloud landing over Ishikari Plain, we must check here the effect on cloud formation in case of using some different wind velocity.   Fig. 4 indicates a comparison of the profiles of exchange coefficient, temperature and liquid water content at 400 km point (case: $-25°$C, 50%, X2), when adopting two different velocities of 10m/sec (solid line) and 15m/s (black circle).   As is seen in the figure, the difference between two cases of wind velocity may not be raised as a serious problem.

e)   *Cooling effect of the surface of land*;   Magono[1] pointed out that the

temperature contrast between the surfaces of Ishikari Bay and Ishikari Plain was very great in the change of activity of the cloud passing through over the seashore of Ishikari Bay.   In Fig. 4, also the effect of those temperature contrast is shown, when the land surface temperature was given by −5°C after 400 km (seashore).   Where, the point of 420 km is corresponding to Sapporo 20 km inland from the shore.   In the profiles of the distributions of temperature and liquid water content, the noticeable change can not be seen except for the temperature near the ground at 420 km point, where the temperature in case of considering the effect of land surface temperature decreases about 2°C as compared with the temperature at the shore.   This 2°C temperature fall has been often observed actually.
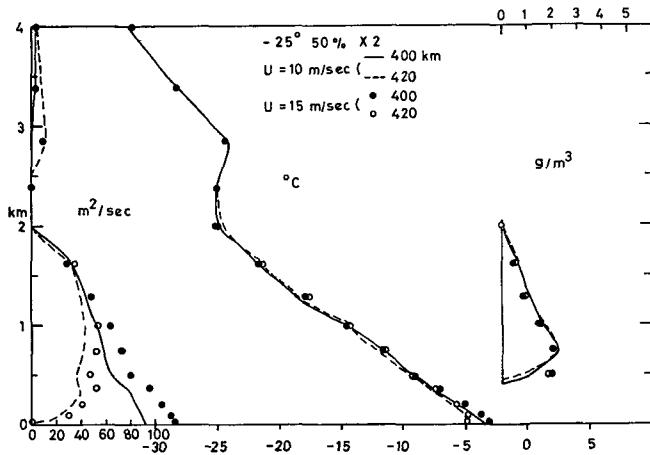

Fig. 4   The changes of cloud profiles occurved due to the change of wind velocity from 10m/s to 15m/s, and due to the sudden change of surface temperature from +5°C to −5°C at the seashore of Ishikari Bay (400 km point).   The 420 km point is corresponding to Sapporo 20 km inland from the shore.

But, the significant change is seen in the vertical distribution of exchange coefficient K.   Below 1.6 km level, the values of K at each level on 420 km point suddenly decrease and those profiles are constant or increasing type with height as compared with the decreasing type of those at 400 km point.   This means that the rapid decreasing of upward transfer by diffusion may occur within the cloud, resulting in the decay of cloud on arriving over the land.

4. Estimation of one dimensional distribution of precipitation amount over Ishikari Plain

4-1 *Determination of relationship between liquid water content and precipitation rate;*

If a mean falling velocity of a group of snow particles among cloud is determined by a certain method, the precipitation rate from those groups can be easily obtained by multiplying the liquid water content of the group by its mean falling velocity.   It is a key that the shape of snow crystal depends on the air temperature, and the size of snow crystal depends on the liquid water content of atmosphere, respectively.

Magono[1] used in his paper the representative values of falling velocity of snow crystals according to the temperature within cloud, considering the representative of snow crystal of each type from the past numerous observations.

On the other hand, several works have been reported on the size distribution for some kinds of snow particle, from which can be derived various kinds of snow parameter such as M (liquid water content) – R (precipitation rate) of our present concerns.   Anyway, it may be said that the mean fall velocity $(\overline{V})$ of the group of snow particles among the cloud depends on the air temperature and liquid water content, which are very two physical factors describing the computed cloud in the present experiment.   In the following paragraphs, we make an attempt to get a reasonable relation of $\overline{V}$-M at each type of snow particle.

Recently, Shiotsuki[8] proposed an equation which is applicable to almost all kinds of size distribution of various types of precipitation.

$$N_D = 10^3 \frac{6M}{\rho\pi} D^{-3} \frac{1}{\sqrt{2\pi}\,\sigma} e^{-\frac{(D-\overline{D})^2}{2\sigma^2}} \qquad (3)$$

where N_D; space number density m^{-3} mm^{-1}, M; liquid water content g/m^3, ρ; density of water g/cm^3, D; drop diameter or melted drop diameter of precipitation element mm, $\overline{D}$; average diameter mm, σ; standard deviation of $\overline{D}$ mm. From Eq. 3, the following relations are derived.

$$\overline{V} = k\overline{D}^n \qquad (4)$$

$$R = 3.6\times10^{-2} M\overline{V} \qquad (5)$$

$$Z = 1.91\times10^3 M\overline{D}^3 \left\{1 + 3\left(\frac{\sigma}{\overline{D}}\right)^2\right\} \qquad (6)$$

where $\bar{V}$; mean falling velocity of the precipitation element cm/sec, k, n; parameters of the falling velocity equation $V=kD^n$ (D in mm), R; precipitation rate mm/hr, Z; radar reflectivity mm^6/m^3.

As shown in the paper of Shiotsuki[8], $\sigma\text{-}\bar{D}$ relation $\sigma=1/2\bar{D}$ may be adopted in the present case which contains the precipitation types of snow crystal, snowflake and graupel.   From Eqs. 5, 6 and this $\sigma\text{-}\bar{D}$ relation,

$$\frac{Z}{R} = \frac{9.29\times10^4}{k}\bar{D}^{3-n} \tag{7}$$

is derived.

Many papers on the $Z\text{-}R$ realtion ($Z=BR^\beta$) for snow particles have been hitherto reproted.   On the other hand, Kajikawa[9] recently reviewed various kinds of equation $V=kD^n$ for each shape of snow crystal and rimed crystal, and for each of snowflake and graupel.   Taking the representative $Z\text{-}R$ and $V\text{-}D$ relations from those papers for every type of snow particle, we can derive $\bar{V}\text{-}M$ and $R\text{-}M$ relations by use of eqs. 7, 4 and 5.

Table 1 shows the list of combination of $Z\text{-}R$ and $V\text{-}D$ relations, and the derived $\bar{V}\text{-}M$ and $R\text{-}M$ relations for each type of snow particles.   In the table, also the temperature ranges for each kind of particle are written referring the temperature conditions described in the papers of those authors in Table 1 and others.   Especially the beginning temperature of $-10°C$ for snowflake is determined by Magono's[10] thought.

Table 1.

Particle	Z-R		V-D		$\bar{V}$-M	R-M	T °C
	B	β	k	n			
Single crystal	950	1.5	7.56 ×10	0.75	$\bar{V}=8.34$ $\times10M^{1.20}$ $(M\leq0.08\ g/m^3)$*	$R=3.00M^{1.20}$	$T<-13°C$
	Ishikawa, et al.[11]						
Rimed crystal	1500	1.5	1.03 ×10²	0.80	$\bar{V}=1.74$ $\times10^2M^{0.22}$ $(M\leq0.08\ g/m^3)$*	$R=6.25M^{1.22}$	$-10°C\sim$ $-13°C$
	Fujiwara, et al.[12]						
Snowflake	2000	2.0	9.80 ×10	0.31	$\bar{V}=1.28$ $\times10^2M^{0.13}$	$R=4.59M^{1.13}$	$+1°C\sim$ $-10°C$
	Gunn & Marshall[13]						
Graupel	700	1.5	1.76 ×10²	0.83	$\bar{V}=2.39$ $\times10^2M^{0.24}$	$R=8.60M^{1.24}$	$+3°C\sim$ $-10°C$
	Fujiwara, et al.[12]						

*; The equations of $V\text{-}M$ and $R\text{-}M$ are applicable in case that M is less than 0.08 g/m³.   When the value of M is larger than 0.08 g/m³, the value of V is same as of $M=0.08$ g/m³, and R is calculated by eq. (5) using this V value.

As written in the table, the $\bar{V}$-M and R-M relations for the cases of single crystal and rimed crystal are limited within the range of liquid water content smaller than 0.08 g/m³. This is because that it is observed very rare for them to grow to size with fall speed larger than 50 cm/sec and 100 cm/sec, respectively. These values are corresponding to $M=0.08$ in each $\bar{V}$-M relation. Hence, when the liquid water content of the groups of single crystal or rimed crystal is larger than this value, the R-M relation is such obtained by giving the constant value of $\bar{V}$ (50 cm/sec for single crystal or 100 cm/sec for rimed crystal) into Eq. 5. As shown in Fig. 5, thus we may have reasonable $\bar{V}$-M and R-M relations for precipitation of each snow particle, for they are not determined simply only by temperature, but taking into account of liquid water content. In the following section, those R-M relations will be adopted to convert the liquid water content to the precipitation rate.
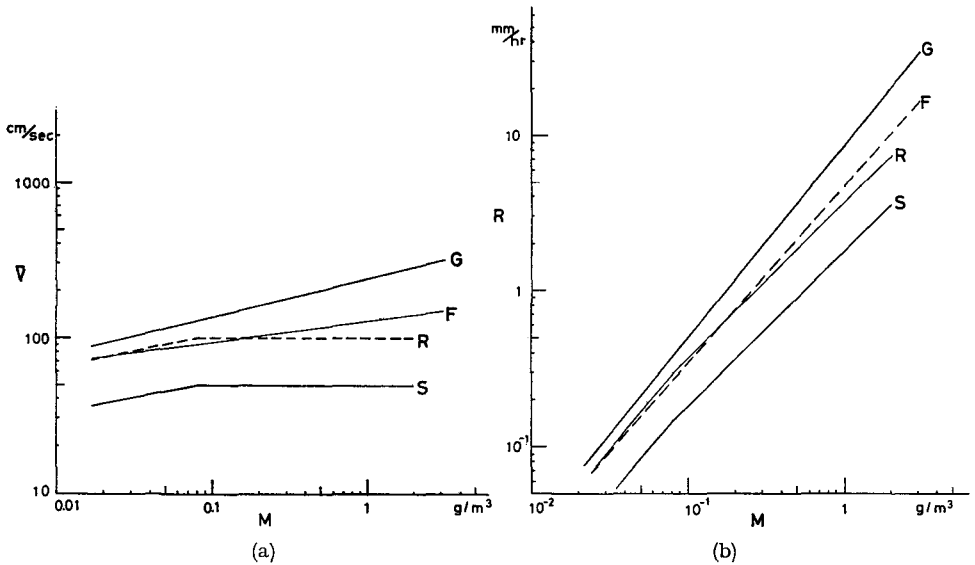

Fig. 5   The relations of $\bar{V}$-M (figure (a)) and R-M (figure (b)) for each type of snow
         particles (S; single crystal, R; rimed crystal, F; snowflake and G; graupel).

4–2   *One dimensional distribution of snowfall from the computed clouds;*

Fig. 6 displays the obtained one dimensional distribution of precipitation rate from the seashore towards inland along the wind from the computed clouds. For these the following conditions were assumed with the R-M
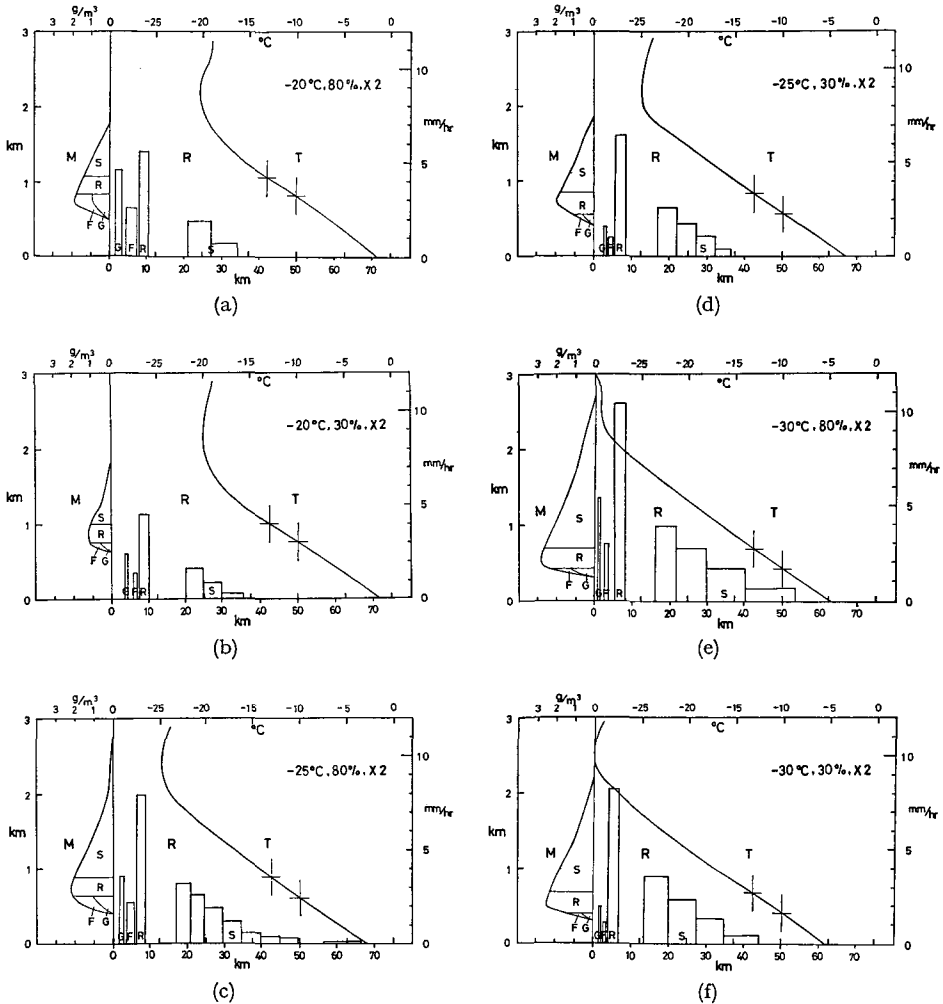
Fig. 6 The one dimensional snowfall distributions derived from the calculated clouds.
The snowfall amount are shown by histograms in precipitation rate (mm/hr).
Figs. a)~f) are those of the cases described in the figure, but all cases for X2.

relations described in the preceding section.

(1) All of snow particles within the cloud begin to fall immediately after the cloud arrives over the seashore.   Then it is assumed that all of the liquid water of the cloud has already been formed in some solid particle. Such typical example of cloud deformation is introduced in the paper of Magono[1].

(2) The shape of snow particle is determined by the temperature range described in Table 1. As seen in the table, the temperature ranges for snowflake and graupel are almost same to each other. In this case, the liquid water content is divided equally to contribute into two groups of snowflake and graupel.

(3) The wind speed is 10m/sec homogeneously throughout the air layer.

Fig. 6 is those cases of X2 which may be best representing the winter monsoon cloud over Ishikari Plain. As seen in the figures, the size and the liquid water content of cloud increases according to the decrease of the initial temperature of continental air mass. And in the cases with the same initial humidity of the continental air mass is not so significant as compared with the change of initial temperature. It is very interesting that in any cases the heavier particles such as graupel, snowflake and rimed crystal fall on the land surface within near 10 km far from the seashore, and the region of fall of single crystal is apart inland about 10 km far from those of the heavier particles. It is needless to say the precipitation amount is more in the snowfall region near the seashore but it is generally narrower than the inland snowfall region of single crystal. The heaviest part of the snowfall region of inland is seen near 20 km point from the seashore. In the next section, we will discuss those characteristics of the one dimensional feature of snowfall distribution obtained from the computed cloud, comparing with those of the actually observed in Ishikari plain.

5. Considerations

The considerations on the results of one dimensional snowfall distribution obtained in the preceding section are made individually according to the terms of the location of snowfall region, the shape of snow particle, the snowfall amount, and some discussions.
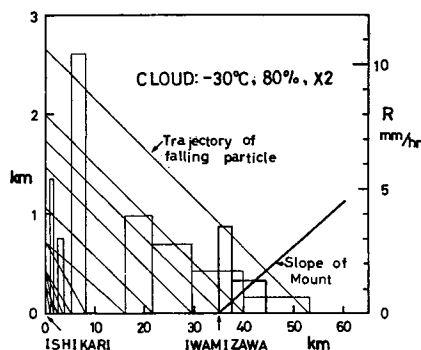
5-1 *Location of snowfall region*;

Recently Ishikawa, et al.[14], from the data of the daily snowfall amount on the numerous points in Ishikari Plain, found the wave length of 10 km on the distribution of main snowfall regions along the wind direction during winter monsoon season. It can be seen from the figures of their report that those main snowfall regions are generally situated at the seashore of Ishikari Bay and two points of 20 km and 30 km inland from the shore. These characteristics are also recognized in other papers (Kikuchi, et al.[15],[16]). The first two main regions of snowfall may be considered due to sedimentation

of snow particles corresponding to two regions of snowfall with maximum rate as described in the preceding section.   This may be understood by the observations of the type of snow particles falling in those parts of Ishikari Plain, as will be soon described in the next term.   On the third part of main snowfall, Lee, et al.[17] considered the effect of the convergence of the wind system in the inland of Ishikari Plain.   That is produced by the colliding of monsoon with a southerly wind in the inland.   Magono[1] named the cocentration effect of snowfall by decrease in wind speed as stagnant effect. The above described convergence effect may be included in this stagnant effect.

On the other hand, in the central part of Ishikari Plain, the 30~40 km point from the seashore is situated at the west foot of the mountain area.   In those places, Magono[1] pointed out the existence of barrier effect that the snowfall occurs only in front of the mountain without being carried over the mountain.   Fig. 7 shows an example of barrier effect applied to the case of Fig. 6(c) (-25°C, 80%, X2), when the cloud travelling along the line from Ishikari Town to Iwamizawa City over the central part of Ishikari Plain. As seen in the figure, the third peak of snowfall amount may be born at the foot of mountain.   If two effects of stagnant and barrier are superposed, the third region of maximum snowfall will be more significant.

Fig. 7   The barrier effect of mountain on the snowfall inland.   The change of distribution of snowfall amount is shown by thick solid line of histograms.   Those of thin solid line are same ones as Fig. 6 e).

5-2   *The shape of snow particles at the main snowfall regions;*
According to the numerous replica observations of snow particles made by Magono and his cloud physics group in Ishikari Plain (for example, Kikuchi[18], Kajikawa[19]), the winter mosoon cloud in band structure generally bring the heavier snow particles such as graupel, snowflake and the rimed crystal on the region near the seashore, and the other single crystal on the region inland far

from the seashore.   Especially Kikuchi[18] found that the location of those
heavier snow particles corresponds well with the appearance of strong echo by
radar.   The results in Fig. 6 may well reappear those characteristics of the
distribution of snow particle type in Ishikari Plain.

5-3 *Precipitation rate of snow particles from the winter monsoon clouds;*

Higuchi[20] noted that the turbulent diffusion of snow crystals from a
cloud would occur during their drift.   This effect is not considered in our
present model as explained in the basic equation.   Also at present in converting
liquid water content of cloud to precipitation rate on the ground, those
effect is not taken into account.   But, as far as here we are concerned with
the heavy snowfall distribution or the concentration of falling snow particles,
the neglect of this effect may be admitted.   According to the observations (for
instance, Muramatsu, et al.[21]), the typical continuation time of heavy snowfall
is about 10 hours in a day even if the developed winter monsoon cloud band
is staying over Ishikari Plain.   If this is applied to each case of Fig. 6, the
maximum daily amount of precipitation will be estimated as 50~100 mm
near the seashore, and 20~40 mm at the point of 10 km inland from it.
These values have been frequently observed in Ishikari Plain during the
heavy snowfall time of winter monsoon. (Muramatsu, et al.[21], Lee, et al.[17]
Kikuchi, et al.[16]).

5-4 *An example of the application of the present method to the forecast of snowfall*
     over Ishikari Plain;

Fig. 8 shows an example of forecast of snowfall distribution by the present
method, applying to the snowfall on Dec. 21, 1972.   As seen in the figure, the
air temperature and humidity of the stable layer on the continent are −20°~
−25°C and 60~70%, respectively.   Those conditions are included among the
of (a), (b), (c), (d) of Fig. 6, where the wind velocity throughout the whole
layer is assumed as 10m/sec.   The actual wind at Sapporo is 15 knot at 850 mb
level, and 35 knot at 700 mb level, respectively.   Therefore the mean wind
speed in the cloud may be considered nearly 10m/sec.   From those of Fig. 6,
the peak value of the precipitation rate is determined as about 6 mm/hr at the
10 km point, and 2.5 mm/hr at the 20 km point from the seashore, respectively.
Fig. 8(c) shows the actual snowfall distribution of the Ishikari Plain on this
day.   The snowfall region appears fairly in band shape due to the typical
structure of the band of winter monsoon cloud as seen in the radar sketch in
Fig. 8(d).

The observed snowfall amount along the direction of this cloud band is such
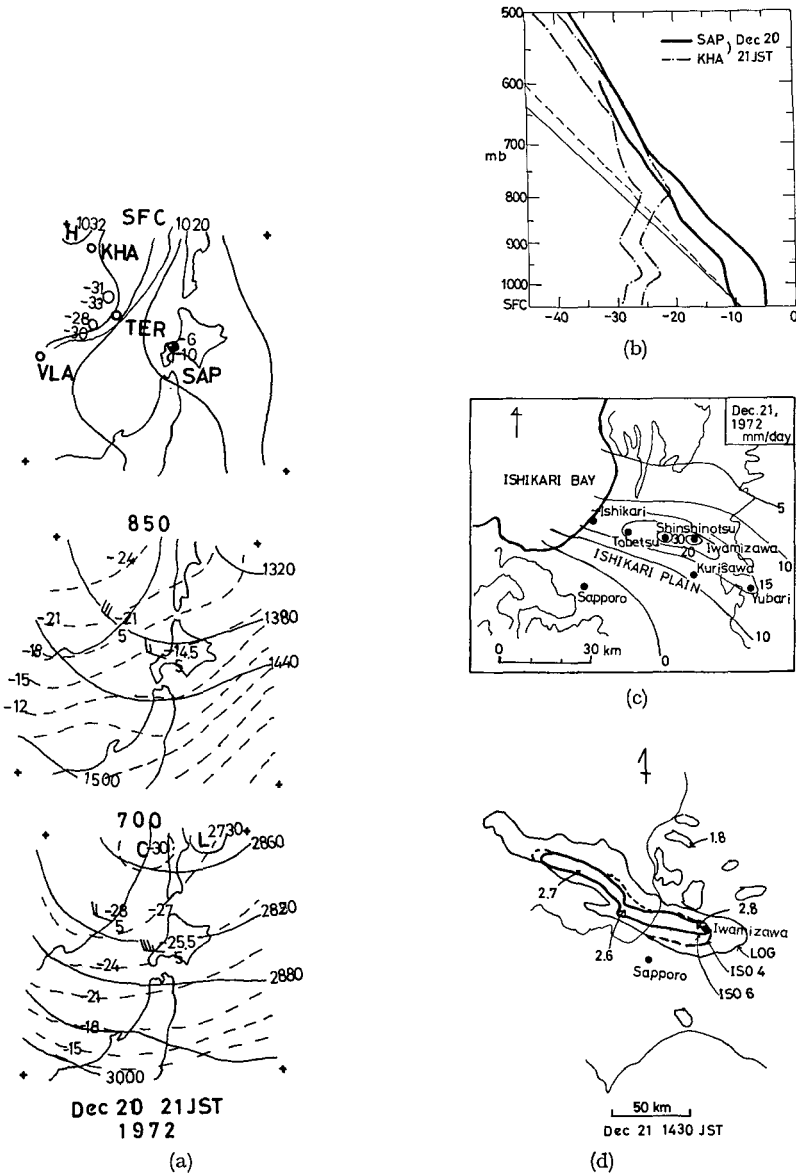
Fig. 8   The weather conditions in case of the snowfall on 21, Dec., 1972.
    a)   The weather charts of three levels.
    b)   The emagrams for KHA (Khabalovsk) and SAP (Sapporo).
    c)   The distribution of daily snowfall over Ishikari Plain. (mm/day)
    d)   The radar sketch at 1430 JST.   LOG~ISO6 show isoecho level.
    Numerals indicate the height of echo top in km.

as 16 mm/day at the shore (Ishikari), 22 mm/day at the 12 km point (Tobetsu), 39 mm/day at the 25 km point (Shinshinotsu), 34 mm/day at the 35 km point (Iwamizawa), 11 mm/day at the 40 km point (Kurisawa), and 15 mm/ day at the 55 km point (Yubari) from the shore, respectively. Those amounts are fairly expected from the present forecast. But the main snowfall region on this day are situated at those of the 25 km and 35 km point that may be different from the forecast.

However, the distance of 10 km between two points of main snowfall region is in good accordance with the forecast. It may be considered that the assumption of the decaying point of cloud on the seashore should be changed in the present case. According to the radar observation as shown in the figure, the strong echo (ISO 4 and ISO 6) is suddenly diminished over Iwamizawa (35 km point) and the echo height is seen as 2.8 km even over the 30 km point inland. Thus, it may be said that the cloud begins to decay inland far from the shore due to the unexpected vigorous activity of the cloud. That may be related to the band structure of snow clouds in the Ishikari Plain where the remarkable horizontal convergence of wind must be caused. Noting the distance of 10 km between two main snowfall points, we can not help considering the mean beginning point of the cloud decay was near at the 15 km point from the shore on this day.

On the other hand, if the duration time of snowfall is assumed as 10 hours, the snowfall amount of those main points is about 60 mm and 25 mm, corresponding to the observation values of 39 mm and 34 mm, respectively. This may mean that the cloud sometimes invade deeply into inland and begin to decay near at the 10 km upwind point from Iwamizawa. On this day, even over near Iwamizawa the heavy snow particles such as graupel, rimed crystal and snowflake might have been observed frequently. Otherwise, the another effect of stagnant, as described before, may be considered to be possible, because Iwamizawa is situated at the foot of mountain.

Thus it may be said that the present method can generally represent the snowfall distribution with location and amount, although the cloud model is one dimensional which shows merely the average condition of winter monsoon. The precise forecast of snowfall distribution using the present method, therefore, must be performed taking into account of the informations such as wind, change of cloud activity, and shape of snow particle. Especially the radar observation of cloud will offer the important and useful informations for them.

6. Concluding remarks

A forecast of the snowfall distribution over the Ishikari Plain was attempted using the diffusion model developed by Asai[2] and the numerous observational facts revealed by Magono and his colleagues (Magono[1]). In converting the liquid water content within cloud to the precipitation rate, the equation of size distribution which was recently proposed by Shiotsuki[8] was applied. The obtained results may be considered as a reasonable feature of one dimensional distribution of snowfall over the Ishikari Plain. By this method we may forecast the snowfall distribution over the Ishikari Plain during the winter monsoon period only using the data of air temperature and humidity of the stable layer on the Siberian continent. But due to that the model is one dimensional and includes many assumptions, it is recommended to use together with the informations of the wind system, the change of the cloud activity, and the change of the type of falling snow particles on the Ishikari Plain. The necessity of radar observation is strongly required. The authors think that the effect of horizontal convergence of wind in the Ishikari Plain should be directly added into the present method in the next work.

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