Numerical experiment on the sensitivity of precipitation enhancement to cloud seeding position for the winter orographic cloud in Japan

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1. Introduction

Many research and operational projects in precipitation enhancement by cloud seeding are taking place in many countries. The effect of cloud seeding on surface precipitation should be dependent on the method of seeding. In the methodology of cloud seeding, it is important to choice the seeding material, seeding rate, and seeding position, adequately. Meteorological Research Institute (MRI), Japan Meteorological Agency (JMA) has been studying the feasibility of cloud seeding technique to enhance the winter snowfall in Echigo mountains which is the main reservoir for Tokyo metropolitan area. In this study, dry ice pellet is selected as a seeding material for its efficiency to induce the desirable change in the winter orographic cloud. The authors are studying the sensitivity of surface snowfall enhancement to the seeding position in order to find the optimal position to maximize the seeding effect, using the JMA's nonhydrostatic model (JMA-NHM; Saito *et al.*, 2006).

2. Model

The JMA-NHM has five categories of liquid and solid water substances: cloud water, rain, cloud ice, snow, and graupel, as described in Ikawa and Saito (1991). The two-moment bulk parameterization scheme, which prognoses both the mixing ratio and number concentration, is applied to the three categories of solid hydrometeor, while one-moment scheme, which prognoses only mixing ratio, is applied to the two categories of liquid hydrometeor, in this study. A cloud seeding scheme is newly implemented in the NHM so as to explicitly simulate the airborne seeding, deposition and fall of dry ice pellets, and generation of ice crystals.

3. Design of numerical experiment

a. Setup for simulation

The model domain covers the area of 200 km × 200 km centered at the dam catchment with a horizontal resolution of 1 km (1km-NHM), as shown in Fig. 1a. This domain is nested into the outer model which has the area of 1000 km × 1000 km centered at the offing of Niigata prefecture with a horizontal resolution of 5 km. The top height of the model domains is about 22 km. Fifty variable vertical layers are employed for both models. The regional analysis data (RANAL) provided by JMA were used as initial and boundary conditions for the outer model.

The initial time in 1km-NHM was set 3 hours after the initiation of outer model and the last 6-hour data in 9-hour integration time were used for analysis to avoid a spin-up effect. Control and seeding runs are conducted with the 1km-NHM. Cloud seeding is started at 2 hours after the beginning of seeding run, as shown in Fig. 1b. Seeding rate is set to 3 kg min^{-1} in the present study.

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Table 1 Meteorological parameters in the 14 cases selected from two winter seasons of 2006 and 2007.

case	wind vector(U,V)	WS	LWP	T_{Q_c}	Q_c/Q_t	$Ttop$
200512251200	(22.6, -9.0)	23.9	0.147	-13.3	0.23	-20.1
200601101200	(7.2, -5.3)	9.8	0.063	-11.9	0.11	-20.7
200601171200	(14.5, -7.4)	15.9	0.114	-13.0	0.30	-14.2
200601221800	(14.5, -13.4)	19.1	0.098	-15.3	0.24	-17.5
200601250000	(10.9, -5.4)	12.3	0.111	-12.6	0.32	-14.0
200602031200	(12.8, -12.1)	16.7	0.064	-15.2	0.12	-22.7
200601220000	(21.7, -8.3)	23.6	0.095	-12.8	0.12	-25.3
200512120600	(4.6, -9.7)	11.6	0.095	-10.8	0.10	-27.9
200603060000	(12.4, -0.7)	12.7	0.253	-2.3	0.45	-22.1
200603281800	(20.3, -7.4)	21.1	0.093	-13.6	0.17	-11.0
200701101200	(12.4, -5.8)	13.6	0.259	-10.7	0.55	-13.2
200703121200	(21.9, -9.0)	23.2	0.305	-10.9	0.68	-12.3
200703170000	(7.9, -8.3)	11.1	0.096	-11.3	0.23	-13.8
200701070000	(23.8, -14.3)	27.3	0.284	-8.6	0.30	-21.7

where U and V (ms^{-1}) are the horizontal components of wind vector, WS (ms^{-1}) is wind speed, LWP (mm) is liquid water path, T (^oC) is cloud-water-mass-weighted temperature, Qc/Qt is mass ratio of cloud water to total water of hydrometeors, and $Ttop$ (^oC) is cloud top temperature.

b. Sensitivity experiment

In order to investigate the sensitivity of seeding effect to seeding position, at least 4 runs were conducted as well as a control run with changing the position of seeding with an 8-km interval along the search line directed upwind from Yagisawa dam. Figure 2 shows the arrangement of seeding positions along the search line indicated with the broken line AB in Fig. 1a. The flight level of seeding aircraft is assumed to be 2600 m roughly corresponding to the top of winter snow cloud in this area, except for over the high mountain area less than 16 km distant from Yagisawa dam where the flight level is assumed to be 3200 m since the cloud top becomes higher than over lower land. This sequence of simulations was performed for each of the 14 cases which are subjectively selected in two winter seasons so that the meteorological parameters in environment are dispersed over the possible ranges of their values. The search line changes so as to be along the environmental wind direction of each case. The meteorological parameters in environment are defined as those averaged over the rectangle area in domain2 of Fig. 1a and from 1- to 3-km height in the present study. The two winter seasons correspond to the terms from December 1, 2005 to March 31, 2006 and from December 1, 2006 to March 31, 2007. The selected cases are listed in Table 1.

4. Result

Figure 3 shows the examples of results from sensitivity experiments. It is found that the seeding effects on surface precipitation amount in dam catchment change depending on the distance from Yagisawa dam to seeding position. Although the interval of seeding position is relatively coarse, we assume that the optimal seeding positions to maximize the seeding effect are approximated by the positions of the

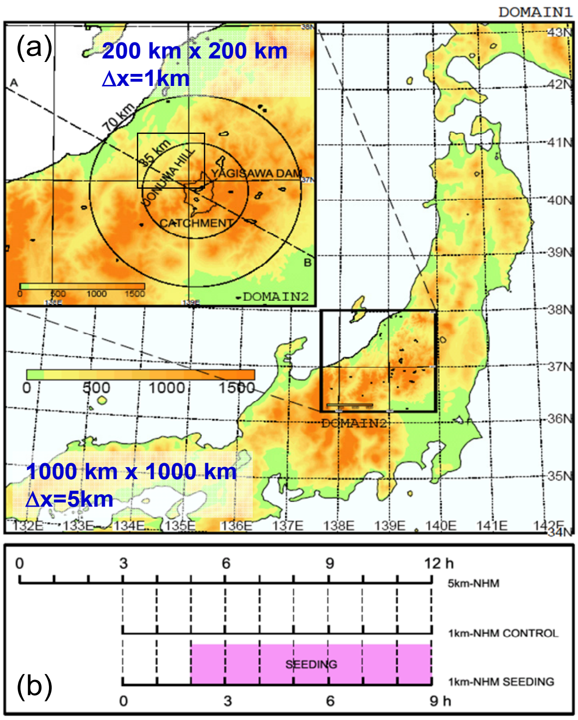

Fig. 1 (a) Calculation domains and (b) time integration sequences. The rectangle in domain 2 corresponds to the area over which the meteorological parameters are averaged to make the representative values of meteorological parameters in the environment.

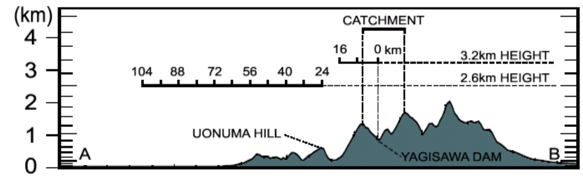

Fig. 2 Seeding positions along the broken line AB in Fig. 1a.

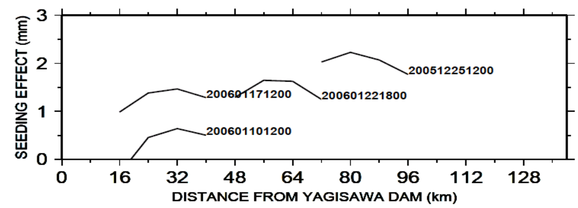

Fig. 3 Examples of results from sensitivity experiments. The ordinate indicates the seeding effect on surface precipitation in dam catchment. The abscissa indicates the distance from Yagisawa dam to seeding position. Number indicates the initial time (UTC) of outer model for each case.

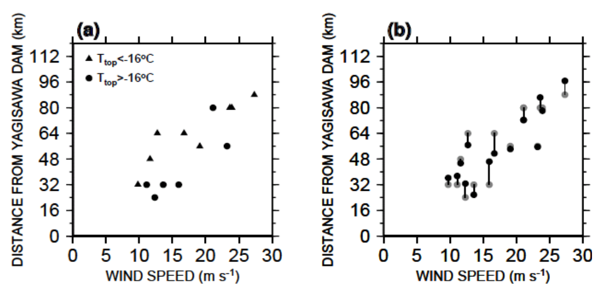

Fig. 4 (a) Relationship between environmental wind speed and optimal seeding position for the 14 cases. (b) Comparison between the true optimal seeding positions (black) and those estimated by multi-regression model (grey).

maximum found in Fig. 3. Figure 4a shows the relationship between environmental wind speed and optimal seeding position in the 14 cases. It is found that the optimal seeding position has a correlation with the wind speed and that other factors independent of wind speed should have an effect as well.

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 \qquad (1)$$

We applied a multi-linear-regression model with five variables (Eq. 1) to estimate the optimal seeding position based on meteorological condition, so that the optimal seeding positions in other cases can be estimated with the regression model. The five variables x_1 to x_5 in Eq. (1) are the environmental values of wind speed, liquid water path, cloud-water-mass-weighted temperature, mass ratio of cloud water to total water of hydrometeors, and cloud top temperature, respectively. The coefficients β_0 to β_5 in Eq. (1) are determined as 51.4, 4.08, -71.5, 3.73, -39.4, and 0.0885, respectively, as a result of regression analysis. Figure 4b shows the true optimal positions (black), same to those in Fig. 4a, and those estimated by the established regression model (grey). Differences between the true and estimated positions are found to be less than a couple of interval of seeding position in sensitivity experiments. The standard deviation of differences is 7.7 km. This is sufficiently smaller than the representative scale in the sensitivity of the seeding effect, namely, several tens km (Fig. 3), which indicates the efficacy of the regression model to estimate optimal seeding position.

5. Summary

The regression model to estimate optimal seeding position is established in the present study. This model is based on only the 14 cases in two winter seasons. It should be verified if the regression model would well estimate the optimal seeding position for winter orographic cloud in many and unspecified cases. The dependence of seeding effect on the seeding rate should be investigated as well to make the optimal seeding technique more effective.

References

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