## Japanese Cloud Seeding Experiments for Precipitation Augmentation (JCSEPA)
## --- New Approaches and Some Results from Wintertime and Summertime Weather Modification Programs ---

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### 1. Introduction

In populated areas of central and western part of Japan, we have had a potential problem of water shortage. For the last twenty years, we had the problem of water shortage almost every two or three years, especially in Kanto and Shikoku district.

In the summer of 2006, MRI, in cooperation with 10 other research organizations, launched the five-year research project (2006-2011) "Japanese Cloud Seeding Experiments for Precipitation Augmentation (JCSEPA)" to aim drought mitigation and water resources management. We carried out summertime weather modification project around Sameura Dam and wintertime project around Yagisawa Dam. Sameura dam is the main water supply for Shikoku district, where they have droughts most frequently in Japan. Yagisawa dam is one of main water supplies for Tokyo Metropolitan area.

In this paper some results from our wintertime and summertime weather modification projects are briefly described.

### 2. Outline of JCSEPA

Our project, JCSEPA, is made of 4 sub-programs; analytical study by using past meteorological and hydrological data, remote sensing study by using multi-wavelength active and passive sensors, airborne and ground-based in-situ measurement study, meteorological and hydrological numerical modeling study and cloud chamber experiments (Fig. 1).

JCSEPA has three main goals. The first one is

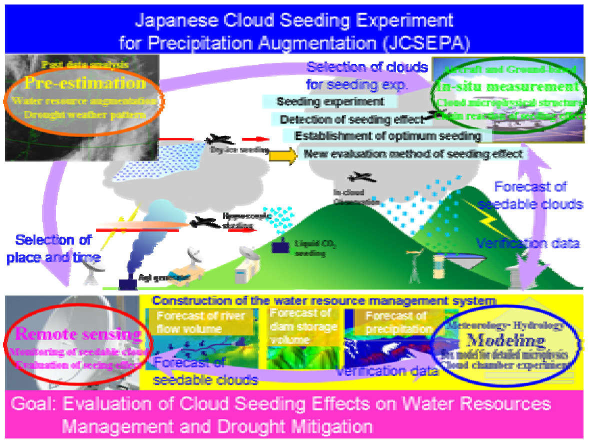


Fig. 1 Outline of JCSEPA

to investigate the causes of drought at different areas in Japan by analyzing past meteorological and hydrological data and identify typical weather pattern during drought. The second one is to develop a sophisticated weather modification technology for orographic snow clouds. The third one is to investigate the possibility of rain enhancement by hygroscopic seeding (hygroscopic flare and salt micro-powder) in warm season.

### 3. Wintertime weather modification technology

In the central and northern parts of Japan, where large portions of water resources rely on snow-melted water from mountain areas, little snow in winter and subsequent little rainfall in Baiu season bring about a serious problem of water shortage. We investigated the effectiveness of snowpack augmentation as a preventive measure for drought mitigation.

If we evaluate and/or predict seedable clouds quantitatively and seed clouds with high seedabilies selectively, we can save seeding time and materials. Figure 2 shows the appearance frequency of clouds with different seedability ranks calcurated by the multple-regression method, which is based on the relation between windward meteorological and microphysical parameters and the simulated enhancement of the catchment precipitation. The sum of appearance frequencies for clouds with seedability ranks A to E reached 20 ~ 30 % of the time.

Seeding experiments using an instrumented aircraft demonstrated that additional precipitation particles were produced in clouds with supercooled cloud droplets 20 ~ 30 min. after dry-ice pellet seeding. Ice crystal concentrations in seeding curtains were initially more than 1000 particles/L and decreased to ~ 100 particles/L in 20 ~ 30 min. due to turbulent diffusion and aggregation (Fig. 3). Figure 4 shows radar reflectivity calculated from 2D images in seeding curtains and their surroundings as a function of the distance from mountain peak. The calculated radar reflectivity in seeding curtains increased by 3 ~ 5 dBZ as compared with their surroundings. Simultaneous radar observations sometimes showed a significant increase in dBZ in seeding curtains.

Cloud seeding with dry ice pellets in the numerical model is simulated in a realistic way, by predicting dry ice pellet concentrations, and calculating evaporation rate of dry ice pellet and production rate of ice crystals. Figure 5 shows the seeding effect during the whole winter of 2006/2007. Warm color indicates an increase in accumulated precipitation and cold color a decrease due to cloud seeding. Over the catchment area, cloud seeding causes an increase in seasonal surface precipitation by 17%. We may have much more increase in seasonal surface precipitation if we apply the optimum seeding method.

We evaluate the effects of cloud seeing on Dam water storage by using a combination of NHM and land surface model, which represent snowpack, snowmelt and runoff processes as well as land-atmosphere exchange processes. With

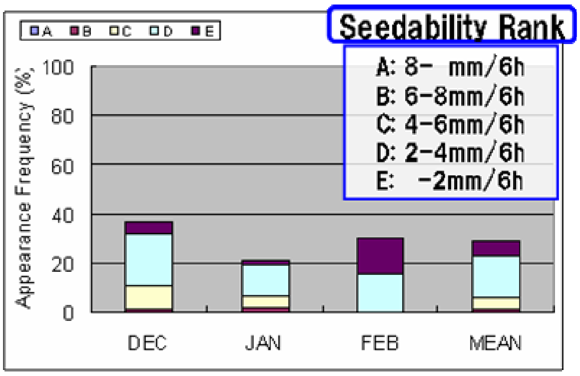


Fig. 2 Appearance frequency of clouds with different seedabilities.

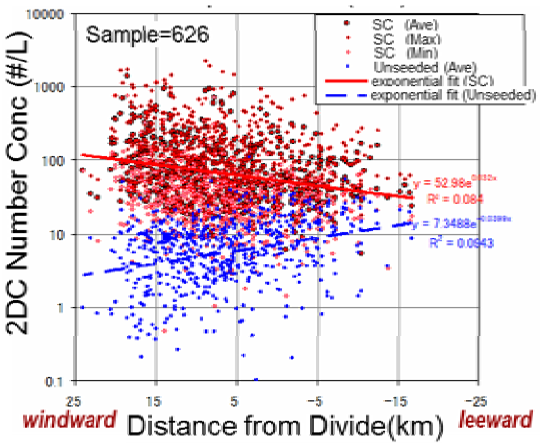


Fig. 3 Evolution of ice crystal number concentrations in seeding curtains (red) and their surrounding (blue) as a function of the distance from the devide.

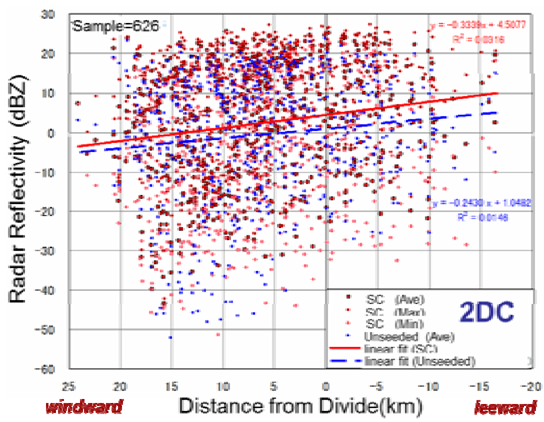


Fig. 4 The same as Fig. 3 except for radar reflectivities calculated from 2DC images

the cloud seeding during the whole winter season, dam water storage increases from 70 % to 100 % at the end of June (Fig. 6).

## 4. Summertime weather modification technology

For the last four years, we also have carried out a basic study on hygroscopic seeding through dynamic cloud chamber experiments, numerical seeding experiments and small-scale field seeding experiments.

We have tested salt (NaCl) micro-powder and hygroscopic flare as seeding materials so far. Salt micro-powder includes chemical compounds other than sodium chloride to prevent particles from sticking together.

Figure 7 shows an example of hygroscopic seeding experiment in the dynamic cloud chamber. Upper panel shows a time evolution of number concentrations of particles larger than 0.3 microns in black, larger than 1 micrometers in red and larger than 10 micrometers in green for the unseeded case. For the seeded case, droplets larger than 10 microns show up much earlier than the unseeded case.

By using the hybrid cloud-microphysics model, we investigated the effect of hygroscopic seeding on surface precipitation. This model can simulate the activation process of CCN, including giant CCN precisely although dynamic frame of cloud model is prescribed. Interactions between microphysics and dynamics are not included, so we look at seeding effect only from the microphysical viewpoint.

All types of hygroscopic seeding materials produce significant positive effects only for clouds with large updraft velocity ( w > 0.5 ms-1) at early stage of their life cycle.

NaCl micro-powder with log-normal size distribution (mode radius of 0.5um) produced significant positive seeding effects by increasing the number of large droplets and decreasing the total number of cloud droplets if total mass of seeding particles is large enough. On the other hand, hygroscopic flare particles (CaCl2) with bi-modal log-normal size distribution (mode radii of 0.1 and 0.8 um) usually produce slightly negative seeding

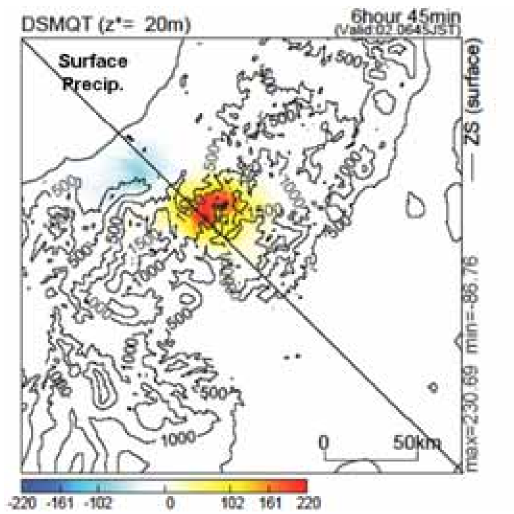


Fig. 5 Seeding effect on seasonal surface precipitation.

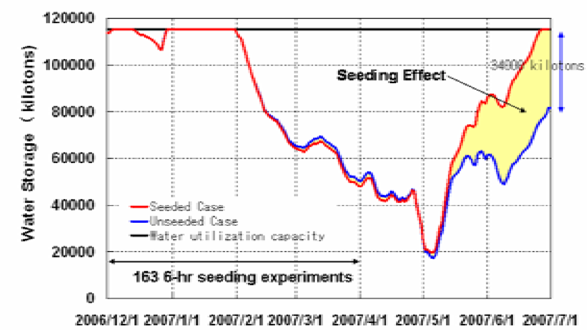


Fig. 6 Dam water storage for the seeded case (red) and unseeded case (blue).

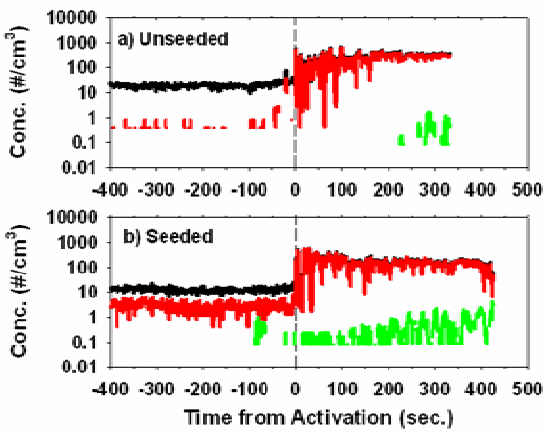


Fig. 7 Time evolution of number concentrations of particles larger than 0.3 mm (black), larger than 1 mm (red) and larger than 10 mm (green) for unseeded (upper panel) and seeded (lower panel) cases.

effects due to large increase in total number of cloud droplets although the onset of surface precipitation is advanced for 10 - 20 min. due to direct formation of raindrop embryos (Fig. 8).

Seeding effects on the total surface precipitation are sensitive to BGCCN, seeding particles and cloud types. Especially for hygroscopic flare seeding, slight changes in size distributions of BGCCN and seeding particles could change even the sign of seeding effects. Therefore more intensive study is needed for better understanding of hygroscopic seeding

In order to investigate the effects of hygroscopic seeding on real clouds and the relation between BGCCN and microphysical structures of unseeded clouds, we have carried out aircraft observations. Regarding hygroscopic seeding in real clouds, what we can do at present is to detect a broadening of initial cloud droplet size distribution toward larger sizes. Only from aircraft seeding experiments, it is rather difficult to trace a chain reaction of microphysical processes, leading to an additional rain formation.

Lastly Figure 9 shows preliminary results for the appearance frequency of summertime clouds suitable for cloud seeding in qualitative sense. We defined cloud types based on cloud top temperature and cloud thickness obtained from a combination of several active and passive remote sensor data. Results show that about 10 percents of clouds may have possibility for hygroscopic seeding and another 10 percents of clouds for glaciogenic seeding. We are still continuing to improve the algorisms for a better evaluation of summertime seedable clouds.

## 5. Conclusion

As a part of JCSEPA, we have developed a sophisticated weather modification technology for orographic snow clouds; a monitoring technique for quantitative evaluation of seedable clouds, physical and statistical evaluation techniques of seeding effects, and. water resource forecast system combining NHM and hydrological model. By using these techniques, it is shown that glaciogenic (dry-ice pellet) seeding of mixed-phased orographic clouds forming over the windward mountains of Yagisawa Dam is effective

We have also investigated the possibility of rain enhancement by hygroscopic seeding (hygroscopic flare and salt micro-powder) in warm season on the basis of laboratory experiments, numerical simulations, monitoring of seedable clouds and small-scale airborne seeding experiments. The results we obtained so far showed that hygroscopic seeding of warm clouds may be effective under limited conditions

Hygroscopic seeding of cold, convective clouds is reported to be effective although there remain many arguments about the effectiveness. More intensive study is needed to conclude the effectiveness of hygroscopic seeding of warm and cold clouds.

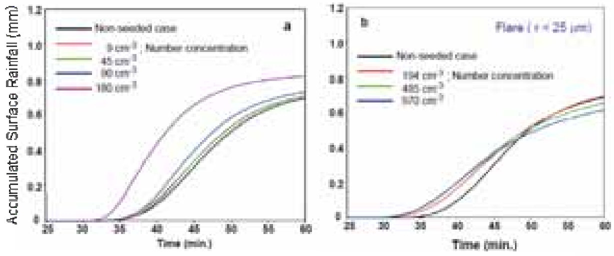


Fig. 8 Accumulated surface rainfall as a function of elapsed time for salt micro-powder seeding (left) and hygroscopic flare seeding (right).

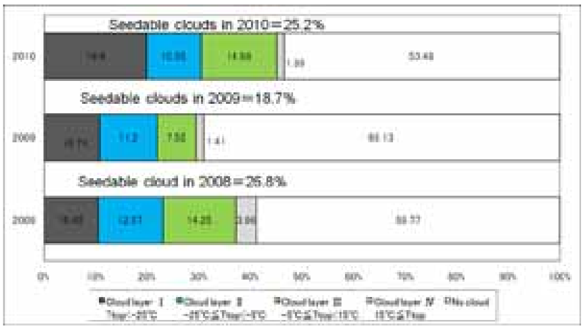


Fig. 9 Appearance frequency of clouds suitable for glaciogenic (-25C<T<-5C) and hygroscopic (-5C<T<15C) seeding.