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Artificial Rainfall by the Seeding of Liquid Carbon Dioxide near Miyake and Mikura Islands of Izu Islands in 2012 and 2013

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Abstract: An artificial rainfall experiment was carried out by an aircraft seeding operation of liquid carbon dioxide (LCD) with the seeding rate of 5 g/s on February 27, 2012 and March 14, 2013 near Miyake and Mikura Islands of Izu Islands in Tokyo, Japan. The development of convective cloud was significant 0.5 to 1 hour after the seeding near Miyake Island and reached to the heights of 4000 m on Feb. 27, 2012. Artificial cloud appeared and rain was recognized by eye around Mikura Island, and it was presumed that the amount of rain increased on the mountainous area. The artificial cloud echoes were successfully recognized about 1.5 hour later after the seeding as a chain-type cloud echo at ENE of Mikura Island on radar echo. The echo height reached on 3000 m to 5000 m when the artificial cloud moved to leeward side of Miyake Island. The development of cloud was after 0.5 hour of the seeding near Miyake Island and reached to height of about 3000 m on Mar. 14, 2013. Rain clouds with the rain stream under the cloud, *i.e*., virga were found at Mikura Island after 1 hour of the seeding. The trail and hole of disappeared cloud were found after about 1 hour and 2 hour later, respectively. It was recognized that seeding rate of liquid carbon dioxide with about 5 g/s was suitable in a little inside convective cloud with air temperature below -5°C.

Key Words: Aircraft seeding, Artificial rainfall, Convective cloud, Liquid carbon dioxide, Miyake and Mikura Islands

1. Introduction

A global water crisis is predicted in the 21st century. The water demand continues to increase as the population increases and the demand may outpace the supply. Droughts and other water-related problems are increasing in frequency as an instance of abnormal weather due to global warming. Water deficits are already extant or expected to occur around the world. New and effective techniques for producing artificial rainfall are being sought to contribute the world's water needs. It is hoped that an effective technique will also protect against desertification in green arid and desert areas.

There are several techniques for artificial rainfall such as the seeding of dry ice, seeding of silver iodide, and the scattering of liquids such as water, salt water and so on. However, these methods present a small amount of water. An artificial rainfall technique of liquid carbon dioxide (LCD) was invented by Fukuta (1988), and was proven successful at Fukuoka on Feb. 2, 1999 as the first effective rainfall production. There are successful results on Feb. 2 and Oct. 27, 1999, Feb. 4 and Nov. 7, 2006, Jan. 8 and 17, 2007, Jan. 24, 2009 (Maki *et al*., 2012) and other results included (Maki *et al*., 2013a, b). Main objectives of this paper are that direct and indirect effects by the seeding are made clear, particularly topographical effect.

2. Materials and Methods

The LCD technique developed by Fukuta (1988) is as follows. LCD seeding is done by aircraft in an air layer in which the temperature is below 0°C and a little inside a cloud at its bottom. The LCD at -90°C changes instantaneously to ice crystals (10^{13} or ten trillion particles per 1 g CO_2) (Fukuta, 1988; Fukuta *et al*., 2000). These ice crystals connect with the ambient air vapor and produce snow or rain.

The LCD technique was used in experiments operated around Miyake Island (34° 7'N, 139° 31'E) and Mikura Island (33° 53' N, 139° 36' E) of the Izu Islands of Tokyo in Japan. The aircraft used was a Beechcraft of Diamond Air Service.

We flew from Nagoya to Miyake Island and LCD was seeded on about 5 km west side from Miyake shore on Feb. 27, 2012, and 10 km from Miyake and Mikura Islands on Mar. 14, 2013 and flew back to Nagoya.

The LCD was seeded from a nozzle on the bottom of the aircraft at the rate of 5-6 g/s. We flew around Miyake and Mikura Islands for 1 h to evaluate the effects of the seeding, observed the rain and took photos.

The seeding rate was about 5 g/s and seeding times were 2 series with each 10 minute-operation. The total weight of CO_2 was 6.7 kg in about 20 min at 5 g/s of seeding rate. The seeding areas were at about 10 km north from Miyake Island

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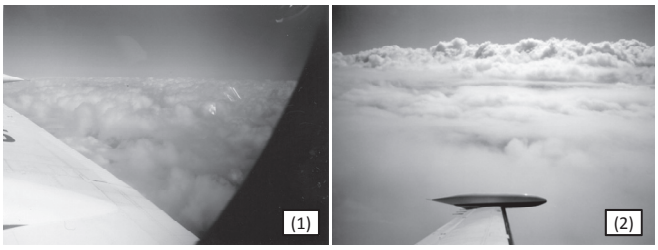

Fig. 1. Undeveloped cloud (1) and Developing cloud (2) by the seeding of liquid carbon dioxide on Feb. 27, 2012.

and at about 10 km north east from Mikura Island.

3. Results and Discussion

3.1. Experiment results on Feb. 27, 2012 and discussion

On Feb. 27, 2012, the seeding height near the bottom of a main cloud layer was 2130 m for the first seeding and 2290 m for the next three seedings. The seeding times were about 9 min. The cloud bottom was 1830 m and the cloud top was 2960 m making the cloud thickness 1130 m. There were two layers of cloud. One was main cloud and the other was a separate and sparse cloud under the main cloud at about 1000 m. The thickness of two layers included separated cloud was about 2000 m. The wind direction was SW and the wind speed was 8.2 m/s at 2100 m, and the air temperature was -4.0°C at 2130 m and -5.5°C at 2290 m. The wind direction and speed were W and 8.7 m/s at 3050 m and WNW, 18.5 m/s at 3660 m, respectively.

On Feb. 27, the seeded cloud moved in an ENE direction after the seeding and the artificial cloud appeared. The photos at about 1 h later shown in **Figure 1(1)** and **(2)** as an undeveloped and developing cloud present natural cloud and artificial developed cloud with rain. A cloud developed quickly, the development of convective cloud was significant after 0.5 to 1 h of the seeding at the easterly leeward side of Miyake Island and an artificial cloud reached to the heights of 3500 m and 4000 m at 0.5 h and 1 h after the seeding, respectively.

The artificial cloud moved further, and it was raining under the cloud recognized by eye. A virga, *i.e.*, rain cloud as cloud with rain, was also found at a lower layer under the seeded cloud. The virga reached around Mikura at about 1 h after the seeding, moved by a NNE-NE wind around 1500 m high. We could observe the cloud by eye, and the aircraft flew through and over the cloud as shown in the photos (Fig. 1). We detected the rain hitting on a front window. These convective clouds recognized by eye during a flying were evaluated by the wind direction and wind speed concerned to cloud heights and virga.

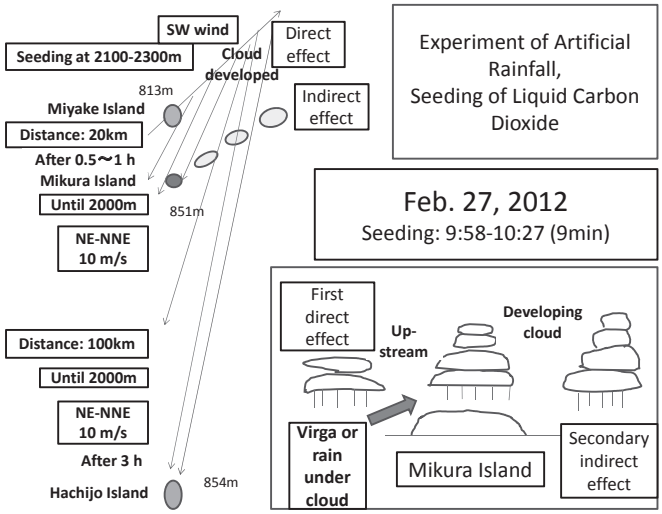

Fig. 2. Models of the wind direction and wind speed affected on artificial rainfall of LCD seeding around Miyake Island and of the effect to Mikura and Hachijo Islands.

It was rain in the mountain area of Mikura Island but there was no rain in surrounding lowland area. This must be due to the differences of mountain shape, elevation and cloud forest.

The virga was moved ENE by SW-SSW winds for 0.5 h, and the high humidity air mass rose up and was developed into a higher cloud by the upwind based on the topography of Mikura (**Fig. 2**). Artificial cloud developed by seeding of LCD and developed more by the topographic effect of Mikura. The topography is important for the formation of cloud by upwind along the mountain slope.

The shape of Mikura Island is a sharp trapezoid, the area over 500 m is relatively large and the island's total area is 20.55 km^2. The highest point is Miyama Mountain at 851 m high. The bottom of the artificial cloud and virga that moved to Mikura was almost the same height as the peak of Mikura, and it could easily cover the island. Thus, the mountainous area of Mikura could be covered by rain. These phenomena are agreed with the appearance of topographic cloud and rain (Seto *et al*., 2011).

The radar image is shown in **Figure 3** and there is no image at 10:00 (Fig. 3) to 11:00. The cloud developed as an ENE line- or chain-type typically after 11:10 and became high and thick by 11:30 (Fig. 3) to 12:10. The cloud could be seen by radar clearly, and the radar echoes reached 3000-5000 m. And the artificial cloud disappeared until 14:00 after 3 h.

The possibility of artificial rainfall by LCD was very high and remarkable. The artificial cloud development is important, that is the cloud with the virga rose up along the slope of the island, and the cloud developed further. The cloud was transported by a SW wind around 2200 m and moved in an ENE direction. It eventually rose and appeared on the radar image as a chain-type cloud (Fig. 3). Such a phenomenon of the clouds appeared in about 1 h and

Fig. 3. Radar cloud echoes at 10:00 and 11:30 Feb. 27, 2012 around Miyake, Mikura and Hachijo Islands (JMA).

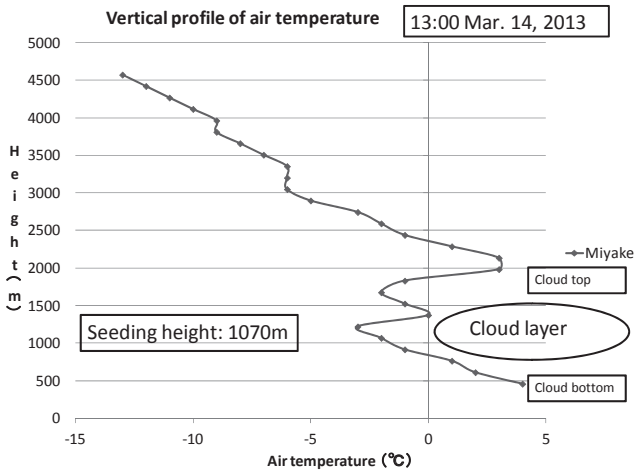

Fig. 4. Vertical profile of air temperature with inversion layer on Mar. 14, 2012.

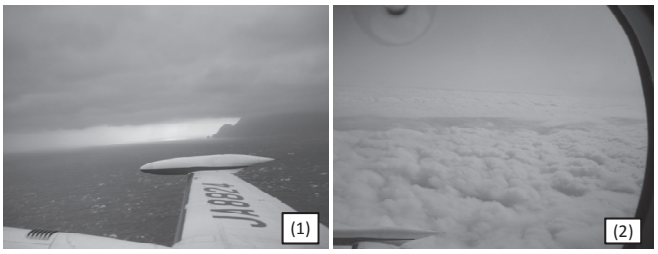

Fig. 5. Convective cloud and virga (1) and disapperared cloud by the seeding (2) near Mikura Island on Mar. 14, 2013.

disappeared in about 3 h is an expected result as an artificial effect. If the seeding was not done artificially, these clouds were not found at all we presumed and concluded. We concluded that the cloud was successfully developed by the seeding of LCD.

The amount of rain or water was estimated as 1 million ton by the direct effect of LCD seeding around the main area of 10 km width and 100 km length with precipitation intensity about 2 mm/h. The efficiency of LCD for rain was predicted 3 million ton per 1 kg LCD. So, it was presumed roughly 100 times of rain comparing with old three methods of dry ice, AgI and salt-water seeding.

3.2. Experiment results on Mar. 14, 2013 and discussion

Phase 1: The seeding area was about 10 km north of Miyake Island and the direction of WSW to ENE at 2 times of 3 and 3 min and the direction of S to N at 1 time of 4 min which seeding path was like a sign of inequality (≠). The seeding time was at 13:29 to 13:46. The height of the seeding cloud was 1070 m, air temperature was -2 to -1°C, wind direction was NE and wind speed was 15.4 m/s. The height of top cloud was 1940 m, where air temperature, wind direction and wind speed +2.0°C, WSW and 9.1 m/s, respectively. The height of bottom of the cloud was 580 m, + 2.3°C, E and 17.0 m/s. The thickness of cloud was rather thin of 1360 m.

Phase 2: The seeding area was about 10 km north of Mikura Island. The seeding of LCD was done as the direction from NW to SE at 2 times of 3 and 3 min and the direction of S to N as 1 time of 4 min which seeding path was like a sign of inequality (≠). The seeding time was at 14:03-14:22. The seeding height was 1070 m and -2 to -1°C, NE, 15.4 m/s. The height of the top cloud was 2060 m, -1.0°C, WSW, 7.7 m/s. The height of the bottom cloud was 670 m, +5.0°C, ENE and 20.6 m/s. The thickness of the cloud was 1390 m. The thickness of cloud was thin of about 1400 m.

The inversion layer was recognized at 1200 to 2200 m, significantly at the level of 2000 to 2200 m that was shown in **Figure 4**. The air mass with rain under the cloud, *i.e.*, virga was found at the west side of Mikura Island shown as in the photo of **Figure 5(1)**.

It was probably rain under the cloud layer from 2000 to 600 m. The cloud was destroyed as an artificial rain, and the width was about 2 km as a flight length of 50 km in a trace during about 20 min. The cloud disappeared like a trench shown as in the photo of Figure 5**(2)**. It was interesting result that was found at 2 halls of disappeared cloud at about 1 h latter of seeding, and that the diameter of 1 hall combined from

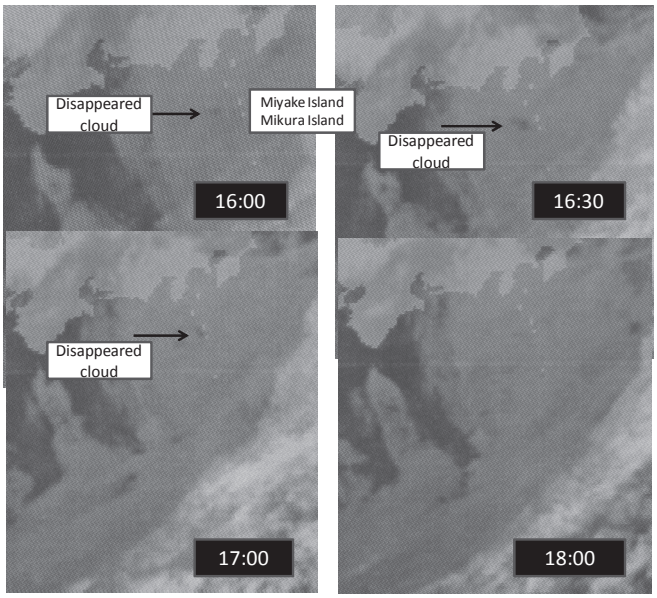

Fig. 6. Satellite cloud images of disappeared clouds at 16:00, 16:30 and 17:00 and of recovered cloud at 18:00 near Miyake and Mikura Islands.

Table 1. Comparison of experiments on February 27 and March 14, 2013.

Date	Experimental conditions	Experimental results
Feb. 27, 2012	Seeding height 2200 m	Cloud with rain, i.e., virga found
	Cloud thickness 2000 m	Cloud developed at 3000-5000 m high
	Seeding air temperature -5℃	Chain type cloud as secondary effect
	Cumulus and no inversion	Estimated rain amount 1.0 million ton
Mar. 14, 2013	Seeding height 1100 m	Cloud with rain, i.e., virga found
	Cloud thickness 1400 m	Cloud developed at 2000 m high
	Seeding air temperature -2℃	Cloud disappeared as a trail and hole
	Stratocumulus and inversion	Estimated rain amount 1.8 million ton

2 halls of disappeared cloud area was about 50 km after about 2 h latter shown in **Figure 6**.

The wind direction near the bottom cloud was easterly wind and the wind speed was strong at 17.0 to 21.0 m/s. The shear of wind direction and wind speed was large at the higher and lower levels.

The wind direction at the higher level was westerly wind. The wind direction was NE and wind speed was 15.0 m/s at the seeding height of 1070 m.

The amount of precipitation was presumed about 0.1 million ton with the precipitation intensity of 1 mm/h as a disappeared area of 2 km width and 50 km length of by after about 1 h as a first affection. The total amount of precipitation of disappeared cloud was presumed 2.0 million ton with the precipitation intensity of 1 mm/h as a disappeared area of 50 km diameter by after about 2 h as a second affection. Another estimation is 0.15-1.5 (mean 0.8) million ton as the water content of Stratus cloud is 0.05-0.5 g/m^3. The cloud physics estimation is 2.7 million ton. Then, the average is about 1.8 million ton.

The experiment condition was not so perfect, but the artificial rain presumed to be successful and the changing efficiency of rain was high. **Table 1** shows the experimental conditions and main results.

4. Conclusion

(1) The development of artificial convective cloud was significant after 0.5 to 1 hour of the seeding at the easterly leeward side of Miyake Island and reached to the height of 4000 m on Feb. 27, 2012. It was concluded that the cloud was successfully developed by the artificial seeding of LCD.

(2) The artificial clouds appeared 0.5 to 1 h after the seeding at Mikura Island. The amount of rain increased on the mountain area. The artificial cloud echoes were recognized on the radar echo on Feb. 27. It was observed that the height of chain-type cloud echo reached on 3000 m to 5000 m, when the artificial cloud moved to the ENE leeward side of Mikura Island.

(3) The experiment on March 14, 2013 was successfully shown in as a photo and a satellite image of disappeared cloud by the seeding of LCD and inversion layer.

References

Fukuta N. (1988): *Meteorological Engineering -new method of meteorological control-, Meteorological Research Note*. pp.213.

Fukuta N., Wakimizu K., Nishiyama K., Suzuki Y., Yoshikoshi H. (2000): Large unique radar echoes in a new, self-enhancing cloud seeding. *Atmos. Res.*, **55**: 271-273.

Maki T., Suzuki Y., Wakimizu K., Nishiyama K. (2012): *Artificial Rainfall-from countermeasure of drought to water resources*. Gihodo Shuppan, pp.176 (in Japanese).

Maki T., Morita O., Suzuki Y., Wakimizu K. (2013a): Artificial Rainfall Produced by Seeding with Liquid Carbon Dioxide at Miyake and Mikura Islands, Japan. *Journal of Developments in Sustainable Agriculture*, **8**(1): 13-24.

Maki T., Morita O., Suzuki Y., Wakimizu K. (2013b): Artificial rainfall technique based on the aircraft seeding of liquid carbon dioxide near Miyake and Mikura Islands, Tokyo, Japan. *J. Agricultural Meteorology*, **69**(3): 147-157.

Seto J., Tomine K., Wakimizu K., Nishiyama K. (2011): Artificial cloud seeding using liquid carbon dioxide: Comparisons of experimental data and numerical analyses. *J. Applied Meteorology and Climatology*, **50**: 1417-1431.