Characteristics of Radar Echoes formed by Seeding Experiment of Liquid Carbon Dioxide for Enhancing Winter-time Precipitation in the northern part of Kyushu, Japan

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(Dated: 19th August 2014)

1. Introduction

Because of the impact of global warming, many droughts (shortage of water) have broken out by extreme small amount rainfall in recent Japan. So far, in order to prevent these droughts, artificial rainfall methods with ‘dry ice (Shaefer, 1946)’ or ‘silver iodide (AgI) (Vonnegut,1947)’ have been widely used in Japan. However, these methods have many problems which a large amount of over cooling liquid in the cumulus cloud was not able to be converted into precipitation efficiently. So as to solve these problems, new artificial rainfall method was using the liquid carbon dioxide (LCD) was proposed by Fukuta (1996). This new method consists of the generations of ice particles by homogeneous nucleation using LCD and the subsequent more effective growth for ice particles without competition process.

This LCD method was applied to the super-cooled stratocumulus formed over Karatsu City in the northern part of Kyushu, Japan on December 26, 2013. As a result, these experiments succeeded, and the total amount of estimated radar precipitation of the seeded stratocumulus was approximation 0.1 million ton.

2. New seeding method using liquid carbon dioxide (LCD)

Strong evaporative cooling -90C as shown in Fukuta (1988) is caused by the injection of LCD materials into super-cooled convective clouds and the subsequent generation of approximately 10^{13} ice particles per gram of LCD materials by homogeneous nucleation. The number of artificially formed ice particles keeps approximately constant after the injection of LCD materials during the ascent of an artificially formed thermal. No competition process for limited super-cooled liquid water among ice particles occurs in the thermal. Therefore, the conservation of ice particles in the thermal provides an important advantage for effective growth of ice particles. From this point of view, LCD seeding method is still more advantageous than AgI seeding method, which causes competition process due to drastic increases in the number of ice particles in low temperature. In addition, in order to enhance the efficiency of seeding, seeding operation by an aircraft is designed to be carried out at a low super-cooled portion near 0C in a young developing cumulus as shown in Figure 1 and Figure 2 so that ice particles to grow effectively into enough size to fall out within a limited lifetime of convective clouds (e.g. cumuli). This method is called ‘Low Level Penetration Seeding of Homogeneous Ice Nucleant (LOLEPSHIN)’ as suggested by Fukuta (1999) (Figure 1).

3. Expected seeding effects

Two processes induced by LCD seeding were shown by Fukuta (1996, 1998). The first process is called ‘RETHIT’, which means Roll-up Expansion of Twin Horizontal Ice Crystal Thermal. On the other hand, the second process is called ‘FILAS’, which means Falling-growth Induced Lateral Air Spreading.

In the first ‘RETHIT’ process (Figure 2 a, b and c) ice particles from instantaneously by homogeneous nucleation after LCD seeding at a low altitude slightly less than 0C and the resultant artificially induced thermal starts to go up with latent heat release due to phase change of vapor into ice. The thermal takes the shape of the two-dimensional twin cylinders perpendicular to flight path and continues to go upward, with expending its volume at a constant vertical angle because of the continuous supply of buoyant energy generated by the latent heat release and the associated turbulent diffusion. The ice particles can grow into enough size to fall out and to be detected by meteorological radar with no or little competition among ice particles until the thermal arrives at the cloud top.

In the second ‘FILAS’ process (Figure 2 d, e and f) after the two thermals reach a stable layer, the falling ice particles more horizontally toward the both sides of the thermal due to lateral spreading. Then, the horizontally moving and falling ice particles cause artificial secondary upward motion in mature stage of vapor and the cloud volume continue to expand horizontally due to the existence of the stable layer around the cloud top until all of the available liquid cloud water for the ice particles in the convective clouds is converted into ice. In this stage, the ice particles continue to grow further by consuming additionally formed liquid cloud water by the secondary upward motion (Fukuta, 2000, Wakimizu, 2000, 2002).

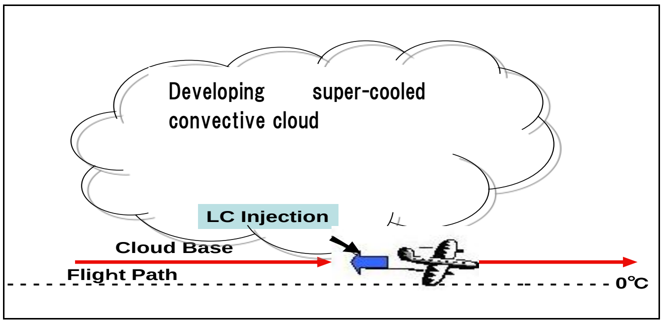
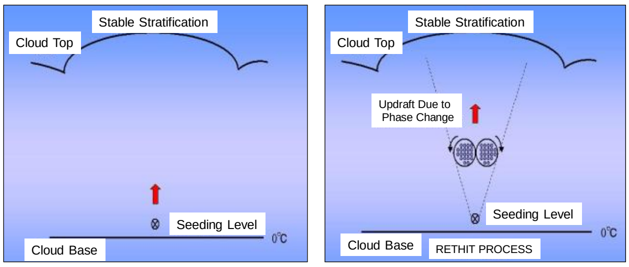
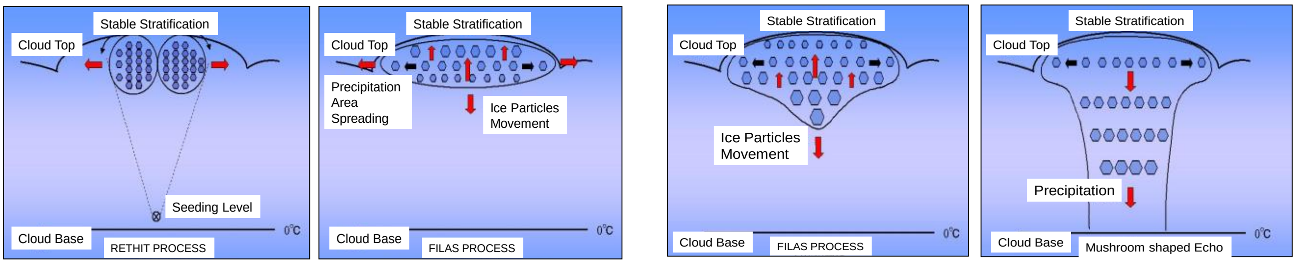


Figure 1: LOLEPSHIN



a b



c d e f

Figure 2: RETHIT process and FILAS process

4. Detail of LCD seeding experiment (December 26, 2013)

4.1 Weather condition

The weather condition of the experimental day was that the low pressure was near Korea Peninsula and it was the weak wintry pattern around Japan (Figure 3, 4). The air temperature of the ground in Fukuoka City was 7.3C. And the wind-speed and wind-direction of the ground in Fukuoka City were very weak and west-southwest (WSW). The wind-speed and wind-direction of the upper-layer (850hPa to 700hPa) above Fukuoka City were from 15ms^{-1} to 20ms^{-1} and west-southwest (WSW). The clouds existed by three layers with upper layer, middle layer, and lower layer. The objective cloud (stratocumulus) was comparatively thick of 1500m and was in the middle layer. The altitudes of objective cloud bottom and top were 1500m (air temperature 2.8C) and 3200m (-7.0C) (Figure 5, 6).

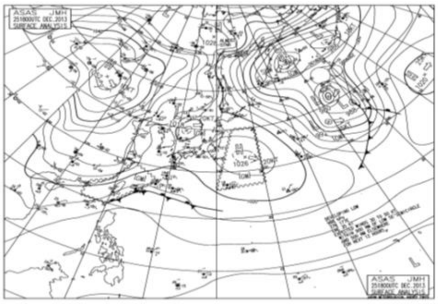


Figure 3: Surface Weather Chart.

(0300JSTDec.26, 2013)

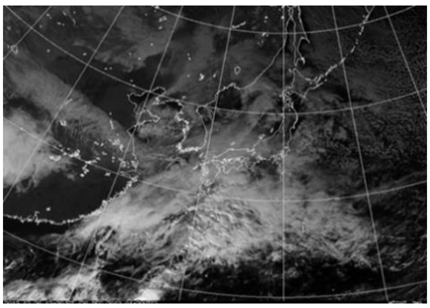


Figure 4: Image of meteorological satellite.

(1330JST Dec.26,2013)

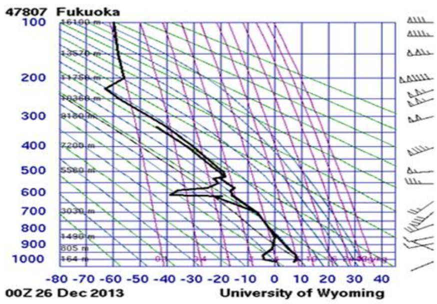


Figure 5: Aerological diagram(Fukuoka).

(0900JST Dec. 26, 2013)

4.2 LCD seeding experiment

The small airplane took off the Saga Airport in Saga City toward Karatsu City at 1300JST on December 26, 2013. The three LCD seeding experiments were carried out the supper-cooled clouds (stratocumuli) formed over Karatsu City in the northern part of Kyushu from 1335JST to 1345JST. Each time of the experiments was 120 seconds and each seeding rate of LCD was 11.1gs^{-1} (Figure 6, 7).

(1) The first LCD seeding experiment was carried out from the south-southeast (SSE) to north-northwest (NNW) over Karatsu City. The seeding altitude was 2480m (-2.1C) and the seeding time was 120 seconds (133524JST to 133724 JST).

(2) The second LCD seeding experiment was carried out from south-southeast (SSE) to north-northwest (NNW) in almost the same course as the first experiment. The seeding altitude was 2650m (-4.1C) and the seeding time was 120 seconds (133838JST to 134038JST).

(3) The last LCD seeding experiment was carried out from west-southwest (WSW) to east-northeast (ENE) over Karatsu City. This flight path was almost right-angled of the first and second flight pathes. The seeding altitude was 2596m (-3.3C) and the seeding time was 120 seconds (134211JST to 134411JST).

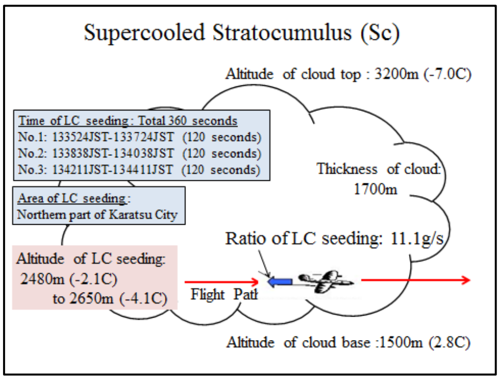


Figure 6: Conditions of supercooled stratocumulus seeded by airplane (Dec.26,2013).

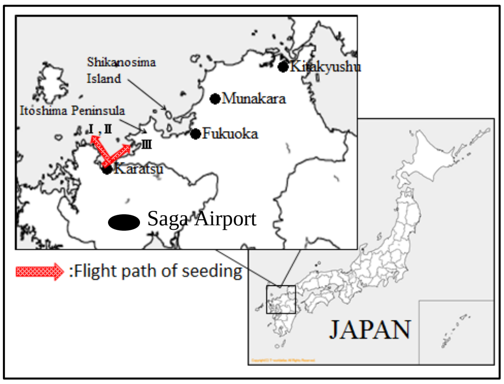


Figure 7: Seeding area and fright path.

4.3 Experimental result and consideration

After LCD seeding, the observation of seeded clouds from the aircraft and the analyses of the meteorological satellite data, JAM (Japan Meteorological Agency) radar echoes, the upper data and ground data (AMeDAS; Automated Meteorological Data Acquisition System) were executed. AMeDAS data are included data of ground air temperature, ground wind direction and speed, and precipitation.

As a result, the following matters turned out.

(1)As a result of the observation from the aircraft, the upsurge of the seeded cloud was able to be confirmed.

(2)The data of artificial precipitation at AMeDAS points were confirmed.

(3)The change of the seeded cloud was not able to be confirmed from the meteological satellite clearly by the upper-layer clouds, because the seeded cloud was in the middle-layer clouds.

(4)It can be inferred that ice particles formed by LCD seeding grew to the precipitation size and resultant rainfall was detected by the radar echoes approximately at 1430JST (45 min. after seeding) (Figure 9).

(5)This artificial radar echo appeared above the Shikanosima Island on the leeward Of Karatsu City. This distance between Karatsu City and the Shukanosima Island was about 50km.

(6)The artificial radar echo moved toward Munakata City from WSW to ENE at a speed of about 50kmh^{-1} and disappeared at 1540JST(115min. after seeding) (Figure 8).

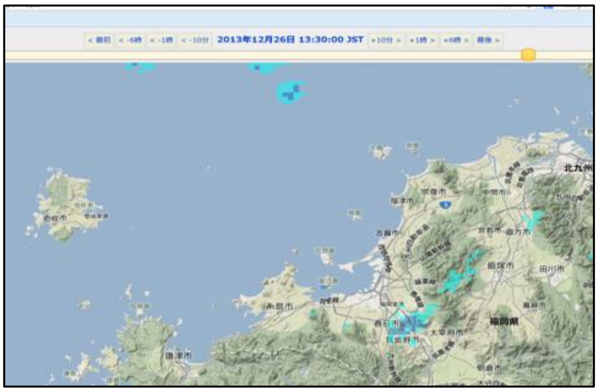
(7) The maximum area of artificial radar echoes was 400km^2 at Munakata City at 1500JST (75min. after seeding) (Figure 9).

(8) These LCD seeding experiments were succeeded and the total amount of estimated radar precipitation (Volume of artificial rainfall) was approximation 0.1 million ton (Figure 9).

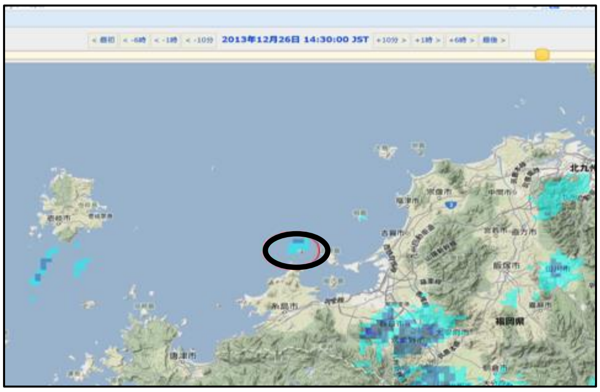
Because of these results, it is thought that the artificial rainfall experiment used LCD of the stratocumulus was succeeded for first time in winter in the northern part of Kyushu.

5. Conclusion

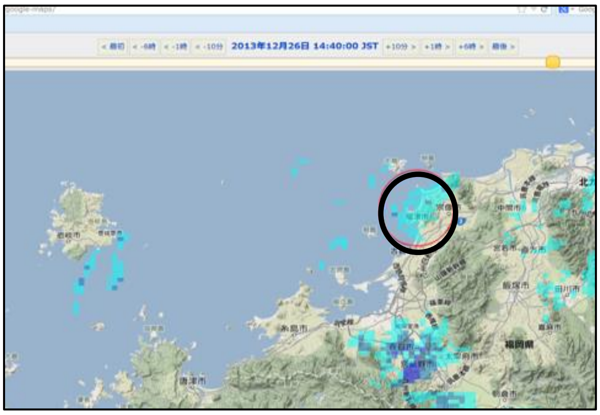
A precipitation augmentation experiment based on a new airborne liquid carbon dioxide (LCD) seeding at low level of super-cooled convective clouds (stratocumuli) was carried out three times at Karatsu City in northern Kyushu, Japan on December 26, 2013. The observed radar pictures confirmed artificial radar echoes. The maximum area of artificial radar echoes was 400km2 at 1500JST (75min. after seeding). These LCD seeding experiments were succeeded and the total amount of estimated radar precipitation (volume of artificial rainfall) was approximation 0.1 million ton. Because of these results, it is thought that the artificial rainfall experiment used LCD of the stratocumulus was succeeded for first time in winter in the northern part of Kyushu. This new seeding method can convert effectively large cloud volume into large amount of precipitation.



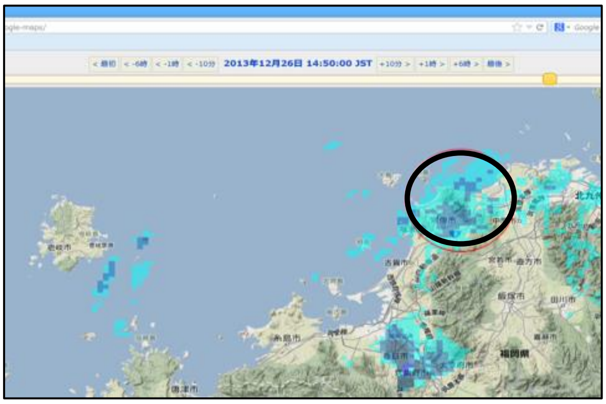
a.1330JST (5 min. before seeding)



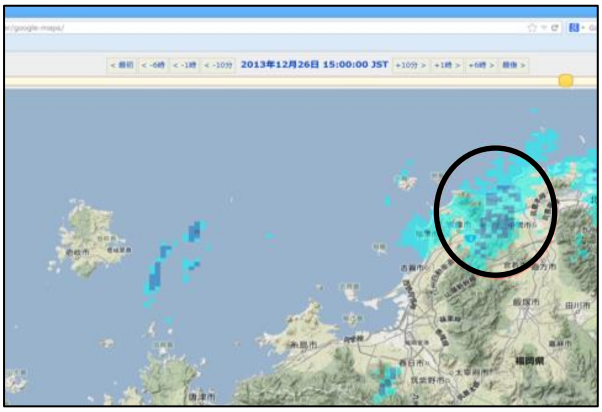
b.1430JST (45min. after seeding)



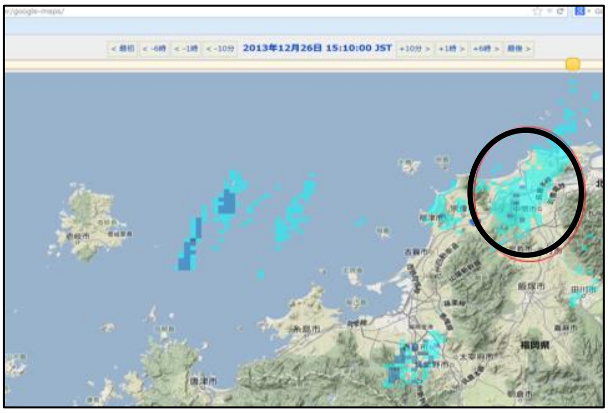
c.1440JST (55min. after seeding)



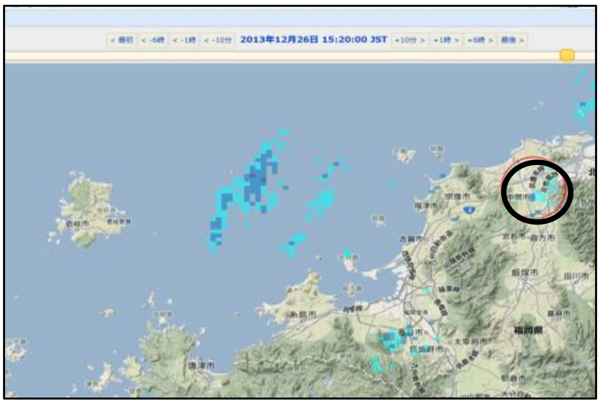
d.1450JST (65min. after seeding)



e. 1500JST (75min. after seeding)



f.1510JST (85min. after seeding)



g.1520JST (95min. after seeding)

Figure 8: PPI pictures of seeded stratocumulus ( )

(Dec.26,2013)

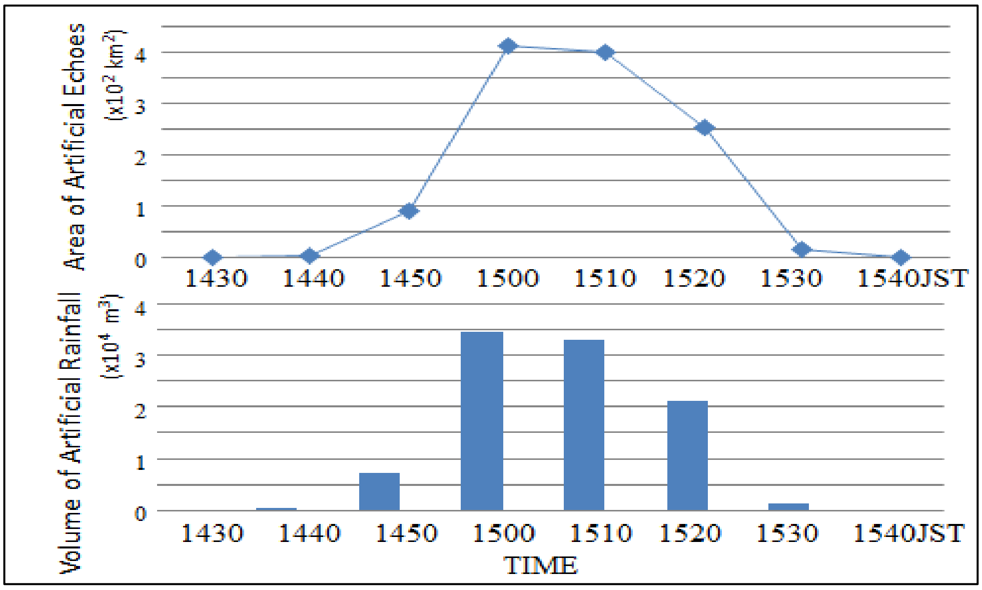


Figure 9: Variations of area of artificial echoes and volume of artificial precipitation (Dec.26, 2013)

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