P2.5 EVALUATION OF WEATHER MODIFICATION BY AIRCRAFT IN GUANGXI BY THE USE OF CINDAR

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1. INTRODUTION

Since Schaefer(1946) and Vonnegut(1947) found that much ice crystals can be generated by exposed the dry ice(CO_2) or silver iodide to the supercooled cloud, weather modification activities have been carried out almost around the world. Some experimental cases reported that the clouds changed significantly after seeding. For examples, a hole developed over the entire affected area within 1 hour after the stratus clouds were seeded over New England with dry ice (Schaefer,1946). A 3 kilometer width hole was also observed at the top of the stratus cloud over Stansbury Island in Utah 10-20 minutes after the seeding with liquid CO_2 at the altitude of 1.5 kilometer (Fukuta,1987,see Fig.1). Cloud holes were also observed by NOAA-14 after the seeding over Shanxi Province in China (Rosenfeld Daniel,2004). However, due to the huge variety of natural precipitation which is usually bigger than the artificial rate , the artificial signals is always subsumed by large natural variation, and besides , there are no enough rain gauges to obtain the rain data, so disputation existed over the issue of artificial effects. Some case studies have reported that the cloud developed after seeding, accompanied by an increase in precipitation(e.g. English and Marwitz. 1981) whereas others have reported a decrease in precipitation or no precipitation due to an increase in the number of ice crystals (Hobbs and Politovich. 1980). However, many studies led to inconclusive results (e.g. Gagin and Neumann.1981)。

There are two methods to evaluate weather modification, of which are statistics and physics. The statistical method is not practical because it takes much time and money to show the statistical results. On the other hand, the physical method is to seek the clues or “signals” to evaluate the artificial effects.

CINDAR is the most important detecting tool for seeding operation in Guangxi. After the glaciogenic cloud seeding, the supercooled cloud droplets are transferred to ice crystals, and go through a series of complex processes before precipitation generation. In the early stage of ice crystals’ growing, due to the small size of ice particles (10 micron or so) and Rayleigh scattering, less attenuation is generated by the CINDAR’s electromagnetic wave, so it is difficult to detect the phase’s changing in clouds. As the ice particles grow more larger, the backward cross section of all the particles in clouds will change significantly, thus result in the changing of the mean basic reflectivity rate (MBRR) on radar echo.

In this study, evaluation of the weather modification which was carried out by aircraft on 16 February 2008 in Guangxi province will be conducted by the physical method, through the CINDAR’ s observation at different elevation angle, jointly with the precise flight track recorded by the Global Positioning System(GPS) device. The targeted regions were determined along the flight track, while the corresponding controlled regions were determined in isometry of the radar site, therefore the radar echo over both of the targeted region and the controlled region were of the same altitude and temperature.

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Fig.1 The macroscopical change of cloud after seeding

2. SYNOPTIC SITUATION

At 8:00 AM on 16 February 2008, the stationary front of Southern China was located on the middle of Hainan Island , and a cold high-pressure ridge situated the area of southern China. The 850 hPa shear line retreated to Guizhou province and the mid of Hunan province. Large amount of Stratus cloud was formed over Guangxi by the moisture blew from the low level southern wind in the Beibu Wan. A 500 hPa trough move to Guizhou province and the west of Guangxi, bringing the cloud wind from Sichuan Basin to impact Guangxi area.

3. SEEDING PROCESS

At 13:00 PM on 2 February 2008, The CINDAR at Liuzhou observed that a large amount of precipitation echo with the strength of 20-40 DBZ in the area of Liuzhou, Xinbin, Guigang, Linshan, Fusui and Mashan The cloud top was close to 6 kilometer with the thickness of 5.5 kilometer. The cloud moved to the east at a speed of 20-25 km.hr^{-1}.The precipitation rate was about 3.5 mmhr^{-1}. The aircraft took off at 14:00 PM, and seeded with silver iodide over the area of Nanning, Chongzuo, Qinzhou, Guigang and Laibin at the altitude of 3600 meter, with the environmental temperature of -6 ℃. The aircraft's was icing seriously on the wing during the seeding flight which indicated the abundance of supercooled liquid water content, and it was snowing in the cloud.

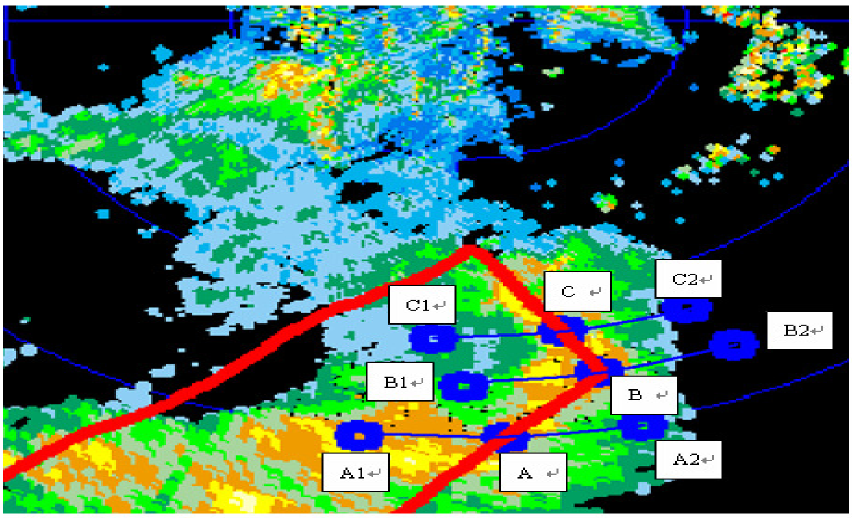

Fig.2 The seeding track and the basic reflectivity rate observed by Liuzhou CINDAR at 16:01 on 16 February,2008. (The blue circles indicate the sampling regions)

On the plan position indicator(PPI) of CINDAR, which showed the cloud echo and the flight track recorded by GPS (see Fig.2) ,three space points of A(22.89°N, 109.41°E）, B(23.11°N, 109.60°E)，C(23.25°N, 109.53°E) were selected on the flight track, These points are in the middle of the echo. Due to the large variety of physical parameters in the cloud, the targeted regions were determined to be the three circles with radii of 4 kilometer and the central points of A, B, C, of which the total area were about 50 km^2. The seeding aircraft passed through A, B and C points at the time of 15:37, 15:44, 15:49 respectively. According to the results of weather modification experiments in the world, significant changing of the seeded cloud in macroscopy were conducted within 1 hour, due to the changes of phase, composition and particle size in the cloud. Therefore, discussion of the echoes' characteristics were within 1 hour. Considering of the western wind in the seeding altitude and the echoes moving speed , the impacting distance of silver iodide was estimated to be 10-20 km. Like the determination of the targeted regions of A, B and C, six controlled regions (A1,A2,B1,B2,C1,C2) were determined on both sides of A, B and C respectively, and the distances between the controlled regions and the targeted region were 30 kilometer. The targeted region and the controlled regions are isometric to the CINDAR site of Liuzhou, so that they are at the same altitude and do not impact to each other.

The distance from the targeted and controlled region to the CINDAR site was about 115 to 150 kilometer. In order to get the feature of CINDAR's echo on warm cloud (warmer than 0 ℃) and cold cloud (colder than 0 ℃), data of CINDAR's detection at elevation angle of 0.5 and 1.5 degree were adopted in the discussion. In the former or the warmer case, the altitude of the center of electromagnetic beam from CINDAR over A,B,C were 3km, 2.6km, 2.2km respectively, and the temperature of them were 2℃, 3℃ and 4℃ respectively, according to the atmospheric sounding on Nanning station at 8:00 AM. While in the later or the colder case, the altitude of the center of electromagnetic beam from CINDAR over A,B,C were 5.7km, 4.8km, 4.2km respectively, and the temperature of them were -8℃,-8℃ and -7℃ respectively. Since the cross section width of CINDAR electromagnetic beam over A,B,C was about 2.5km, 2.1km, 1.9km respectively, the echoes at elevation angle of 0.5 and 1.5 degree might be referred to the reflection of the warmer cloud and rain region and the supercooled cloud and ice region respectively.

4. ANALYSIS OF THE CINDAR ECHOES

4.1 *Mean Basic Reflectivity Rate(MBRR) of CINDAR echo over the seeding region with the time sequence*

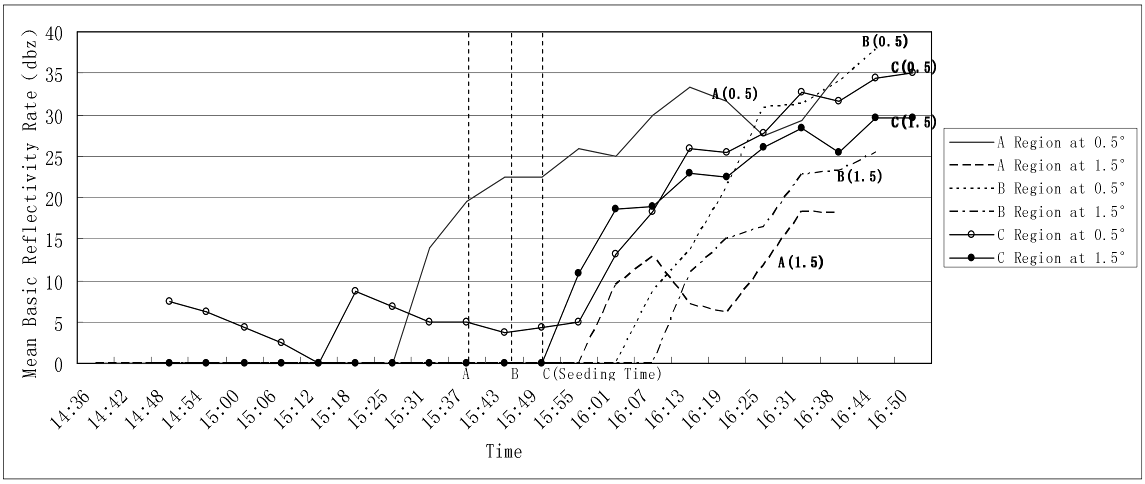

Fig.3 Mean basic reflectivity rate (MBRR) over region A,B and C during 14:50-16:50 on 16 Feb.2008.Profile A(0.5) is the MBRR over region A with the radar elevation angle of 0.5 degree, and profile A(1.5) is the MBRR on region A with the radar elevation angle of 1.5 degree，the rest are the likes)

Data of MBRR over the A,B,C region were used for the time 1 hour before seeding and 1 hour after seeding. Analysis of the variation trend of MBRR were conducted during these two hours. (see Fig.3). It may be found that:

i. All the three profiles of MBRR at elevation angle of 0.5 degree showed a strengthen trend after seeding over A,B,C region. Value of profile A(0.5) was 20 dBz when seeding at 15:37, then it rose to be maximum of 34 dBz in 42 minutes , with the strengthen rate of 70%. Profile B(0.5) started from 0 dBz when seeding at 15:44, then the initial echo appeared in 17 minutes, and climbed to the maximum of 37.8 dBz in 49 minutes. Profile C(0.5) maintained 4 to 5 dBz of weak echo for 30 minutes before seeding, and began to strengthen in 6 minutes. It reached the maximum of 33 dBz in 49 minutes with the strengthened rate of 660%.

ii. All the three profiles of MBRR at elevation angle of 1.5 degree also revealed a strengthen trend after seeding over A,B and C region. For all of the three regions, there were no echoes when seeding. Initial echo over A region (Profile A(1.5)) appeared in 22 minutes, and climbed to the secondary peak of 13 dBz in another 13 minutes, while initial echoes over B and C region started in 23 and 6 minutes, then reached the maximum of 25.4 and 28.8 dBz in 37 and 36 minutes respectively.

iii. The development of MBRR on the supercooled cloud layer over A,B,C seeded region were more quickly than on the warm layer, or the fluctuations of MBRR at CINDAR;s elevation angle of 1.5 degree were generally advanced than that of 0.5 degree. For example, the summit of profile A(1.5) was at 16:07 , then it declined, while profile A(0.5) reached the summit at 16:13, with 6 minutes behind of profile A(1.5). Cases over B and C region also showed a similar trending.

Variation of MBRR over A,B,C region reflected the microphysical changes after seeding operation, and the chain reaction of particle composition that happened in both of supercooled layer and warm layer. (i) Radar echoes over the seeded region will have a strengthened trending 10 to 20 minutes after seeding, no matter in the supercooled layer or in the warm layer. (ii) Echoes summit on the supercooled layer were generally advanced to that on the warm layer, revealing that the raindrops and the large cloud-drops in the lower and warm layer come from the transformation and developing of the supercooled cloud-drops and ice crystals. (iii) The distance between the center of radar’s emission electromagnetic beam at elevation angle of 1.5 degree and that of 0.5 degree was 2.7km,2.2km and 2km respectively, and the difference of time when echo reached summit over the seeded region were within 10 minutes, suggesting that the transformation of little cloud drops or ice crystals to large cloud drops or raindrops may be completed in a very short time.

4.2 *Comparison for the CINDAR echoes over the targeted region and the controlled region*

Figure 4 shows the profiles of MBRR over the targeted region A and its controlled regions A1 and A2. Due to the large variation in space for cloud development, there was a big difference for CINDAR echoes over A, A1and A2 region at a specify time. In the supercooled cloud layer, it took 12 minutes for echoes over targeted region A to rise from 0 dBz to 12 dBz, meanwhile, it took 33 minutes and 26 minutes respectively, for echoes over the controlled region A1,A2 to rise to the same amplitude. In the warm cloud layer, echoes over region A kept strengthening for over 1 hour after seeding.

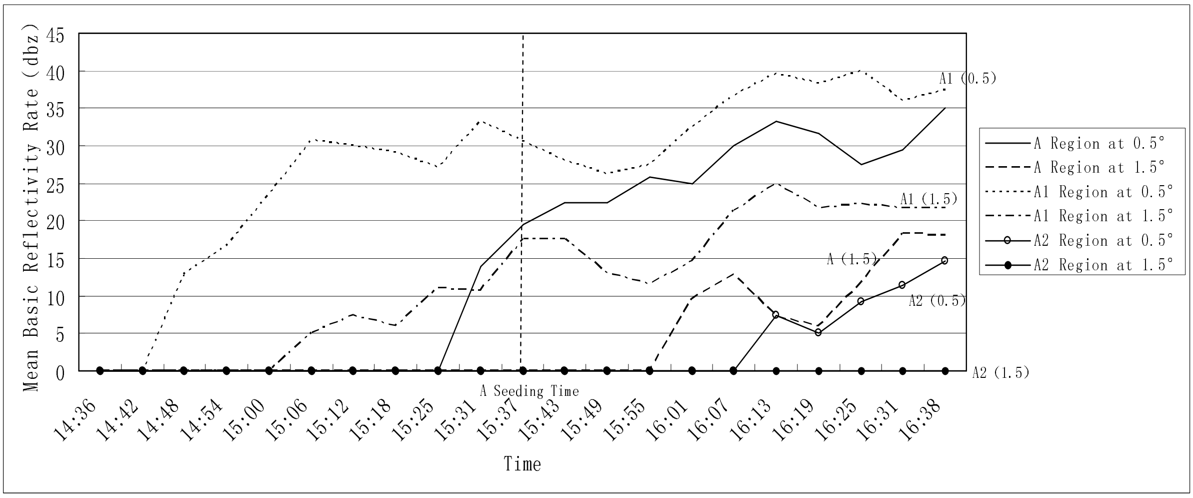

Fig.4 Variation trends of the MBRR

over the targeted region A and the controlled region A1,A2

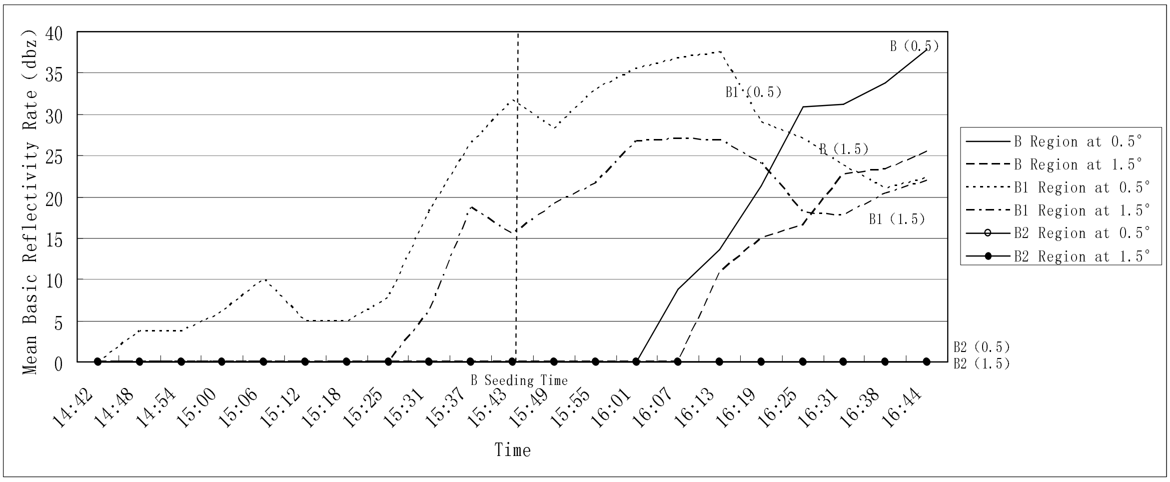

Fig.5 Variation trends of the MBRR over the targeted region B and the controlled region B1,B2

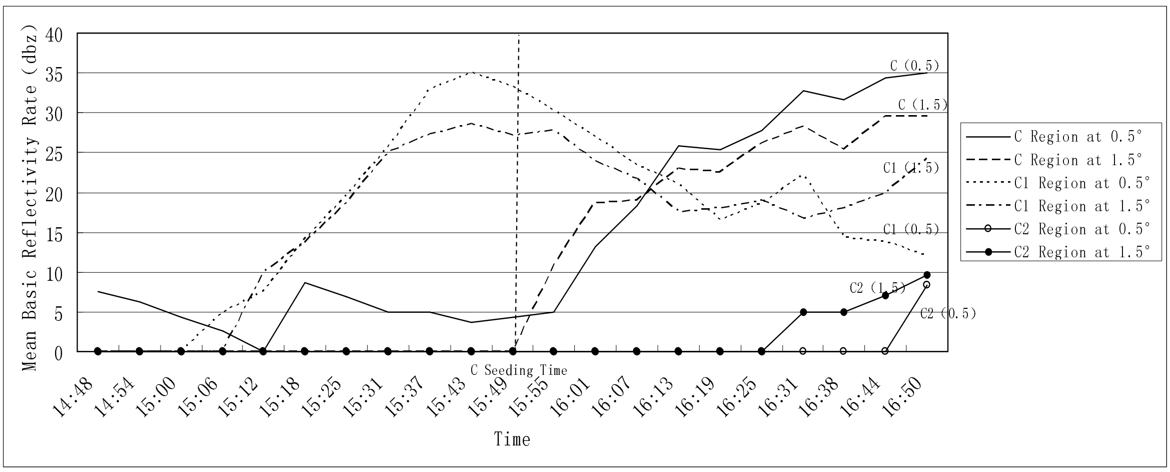

Fig.6 Variation trends of the MBRR over the targeted region C and the controlled region C1,C2

Figure 5 shows the profiles of MBRR over the targeted region B and its controlled region B1 and

B2. We may see that echoes over targeted region B changed more quickly than that over the controlled region B1 and B2, no matter in the supercooled layer or the warm layer. It took 30 minutes for profile B(1.5) to rise from 0 dBz to 25.4 dBz, while it took 35 minutes for profile B(1.5) to rise to the same amplitude. In the warm layer, it took 37 minutes for profile B(0.5) to rise from 0 dBz to 33.8 dBz, while it took 78 minutes for profile B1(0.5) to rise to the same amplitude. There was no echo occurred over B2 region.

Figure 6 shows the profiles of MBRR over the targeted region C and its controlled region C1 and C2. In the supercooled layer, it took 24 minutes for both of profile C(1.5) and C1(1.5) to rise from 0 dBz to 23dBz, but profile C2(1.5) rose only 9.6 dBz at the same time. In the warm layer, It took 22 minutes for the profile C(0.5) to rise from 4.2 dBz to 25.8 dBz, while it took 25 minutes for profile C1(0.5) to rise to the same amplitude, and profile C2(0.5) only increased to 9 dBz.

From the above discussion on MBRR over the targeted regions of A,B,C and the controlled regions of A1,A2,B1,B2,C1,C2, we may see that the CINDAR echoes in both of supercooled layer and warm layer over the targeted region showed a increasingly strengthened trending after seeding, and the amplitude of MBRR over the targeted regions was bigger than that over the controlled regions, and keeping a more longer time that may be over 1 hour, in spite of the MBRR variation at initial time over the targeted region and the controlled region. This fact illustrated that the supercooled water were kept being transformed to ice crystals and grew accelerando, the grown ice and snow crystals melted and turned into raindrops when crossing the layer of 0 ℃ that resulted in the strengthening of CINDAR echo.

4.3 ***Estimation in quantity for MBRR over the targeted region***

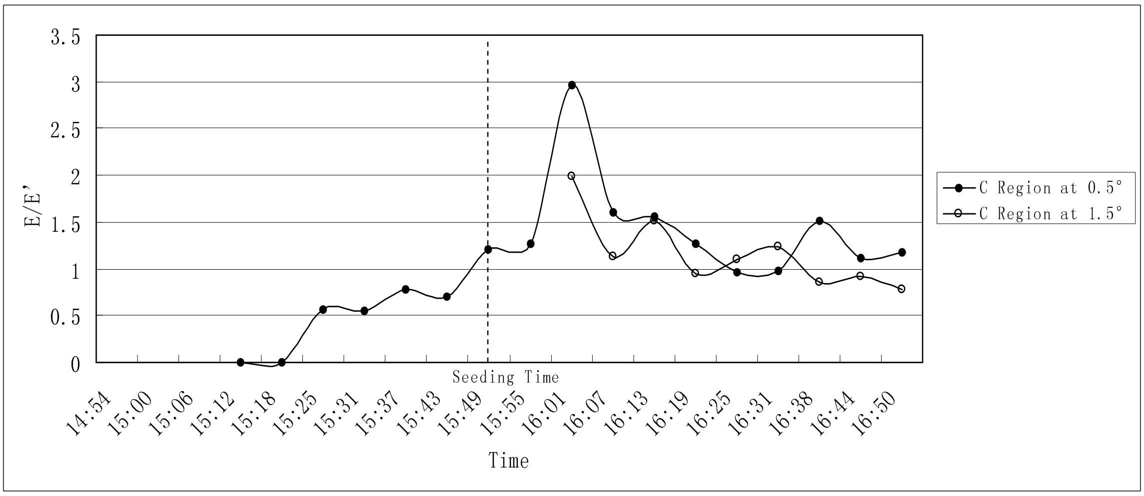

Fig.7 The seeding effects over the targeted region C

Rain suppression experiment was conducted on 7 September 1997 in Russia. In their evaluation of seeding experiment, estimation for precipitation at a certain time after seeding was conducted in Lagrange method, or by the joint use of current rain data over the controlled region and the last rain data over the targeted region. In order to evaluate the seeding conducted on 16 February 2008 in Guangxi, we use the Euler method to estimate the MBRR over the seeded region.

Prediction for MBRR (E'（i）) at a certain time over the targeted region is calculated by,

$$\mathrm{E}'(i) = \mathrm{E}'(i-1) \cdot K(i), \qquad (i = 2 \cdots 7)$$

Where i is the number of time sequence, the number of 2 is at the seeding time, E’（1）is the MBRR before seeding over the targeted region, the predicted factor ***k***(i) is defined as

$$K(i)=\left|E_1(i)/E_1(i-1)+E_2(i)/E_2(i-1)\right|/2 \qquad (i=2\cdots7)$$

Where E_1 and E_2 is the MBRR over the two controlled regions.

Setting E is the real MBRR over the targeted region. If E/E'＞1 , that means the MBRR over the targeted region increase due to the artificial seeding, or if E/E'<1, means the MBRR decline after seeding.

Figure 7 shows the seeding effects over the targeted region C. Since there was no echoes over region A and B at the seeding time, analysis for them were excluded. In Fig.7 we see that E/E' did not equal 1 but showed a vibration before seeding, due to the complicacy and variation of natural cloud. After seeding, E/E' showed a significantly strengthen trend, both in the supercooled layer and the warm layer.

In Fig.7, E/E' reached the summit 12 minutes after seeding, in both of the supercooled layer and the warm layer. Vibration of E/E' in the supercooled layer was bigger than that in the warm layer. The maximum value of E/E' in the supercooled layer was 2.97, in other words, the MBRR might be increased by approximate 200%, The lasting time for E/E' >1.5 might be 18 minutes, and for E/E'> 1 it might be 36 minutes. But in the supercooled layer, it was a liitle difference. The maximum of E/E' was 1.98, or the MBRR might increase by approximate 100%, but the lasting time for E/E'>1.5 was only 3 minutes, while for E/E'>1 it was longer than 30 minutes.

5. PRELIMINARY CONCLUSION

i. Glaciogenic seeding in the supercooled cloud may impact on the CINDAR echoes in both of the supercooled layer and the warm layer, with a significant effect in about 10 to 20 minutes, but the impacting degree will rely on the cloud condition.

ii. After glaciogenic seeding in the supercooled cloud, radar echoes at the seeding altitude will reach the summit more quickly than that in the warm layer with the time difference less than 10 minutes. The facts illustrated that cloud seeding may result in the exhaustion of supercooled water and increase the number of raindrops in the warm layer in a very short time.

iii. After seeding in a systematic cloud, the radar echoes over the targeted region might be more strengthened significantly than over the controlled region, and be more quickly in getting to the summit, and lasting for 1 hour or more.

iv. Cloud seeding will result in the increasing of MBRR in both of the supercooled layer and the warm layer, with the maximum amplitude of 200% and 100%, and last for 30 minutes or more.

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