Tentative Training Programme

Understanding of cloud nature and weather modification for water resources management in ASEAN

Hua Hin, Thailand, July 2019 **Lecture at 10:30-12:00, 24 July**

Hail Suppression Technology

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Outline

- Goal and purpose
- Theory for hail formation in severe storms
- Hypotheses and conceptual model for hail suppression
- Monitoring and seeding technologies relevant to hail suppression
- Uncertainties and future focus

Goal and purpose

- Understanding the natural hail formation mechanism
- Finding the appropriate method for hail suppression
- Reducing the damage from hailstorm

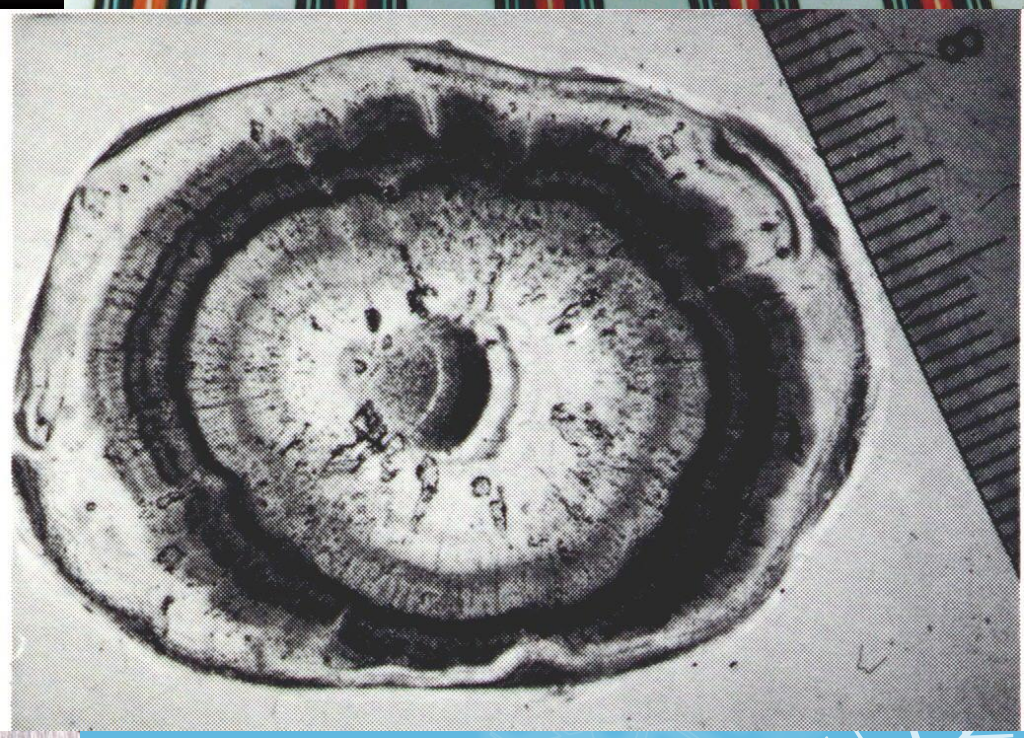
a. Theory for hail formation in severe storms

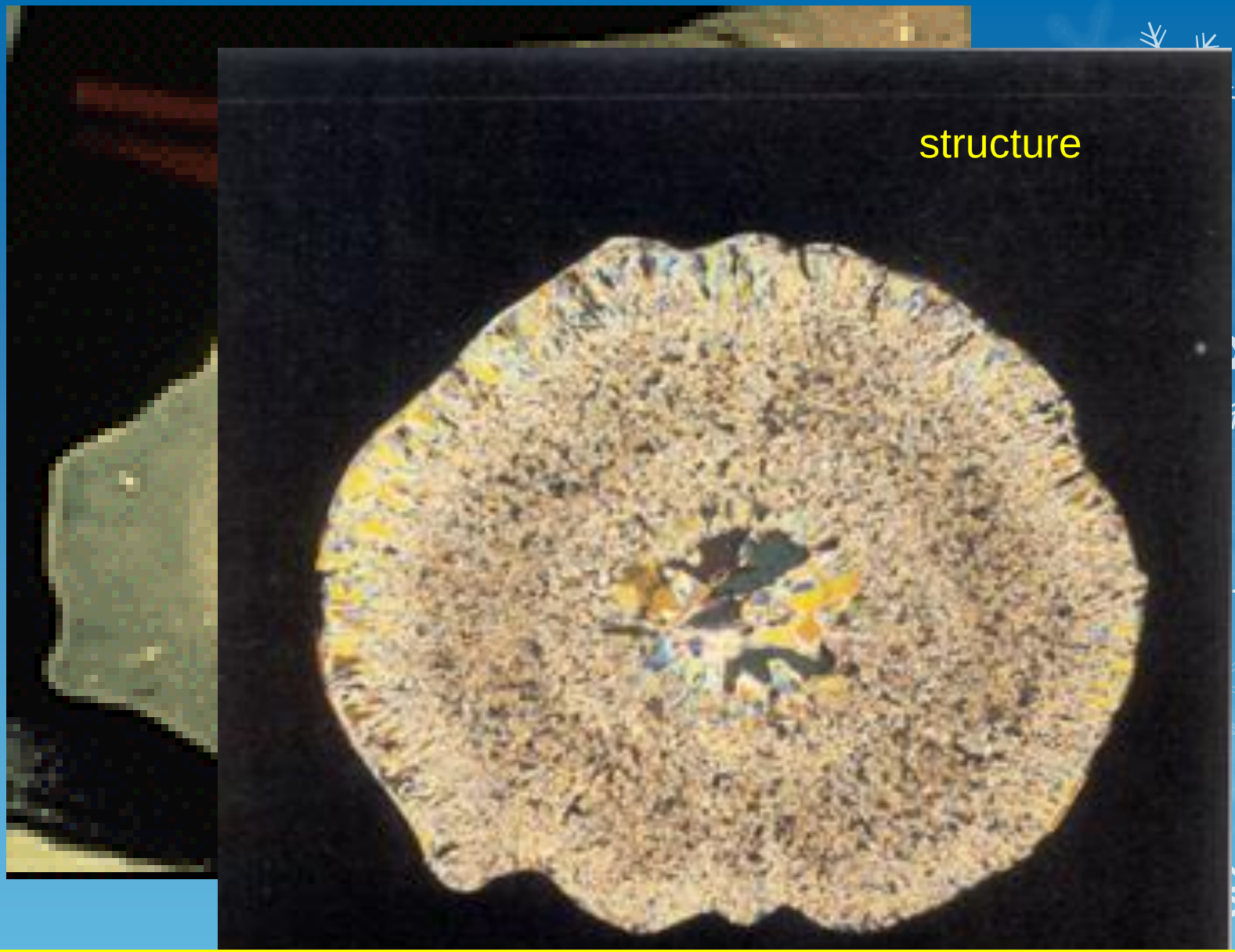
Basis of hail suppression!

hailstone


JULY 6 , 1975 6:30 p.m.
BYEMOOR , ALTA
(20 miles S.E. of STETTLER)
Slazenger

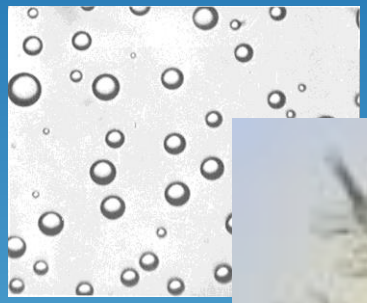

FIBER-GLASS
NO APTO PARA USO COMERCIAL
MADE IN JAPAN
BUTTERFLY





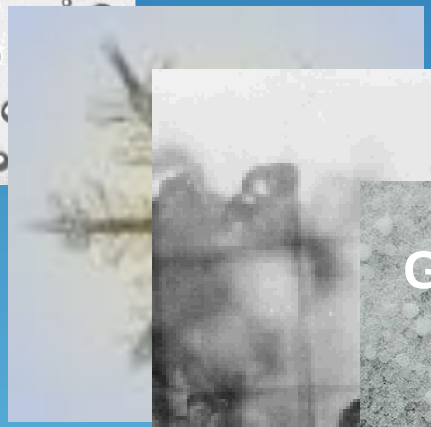
During 1950-1960s，we understand the sever storm by investigating the hailstone, and now we understand the hail formation by probing hailstorm

supercooled drops



further riming growth

Freezing



Riming

Graupel

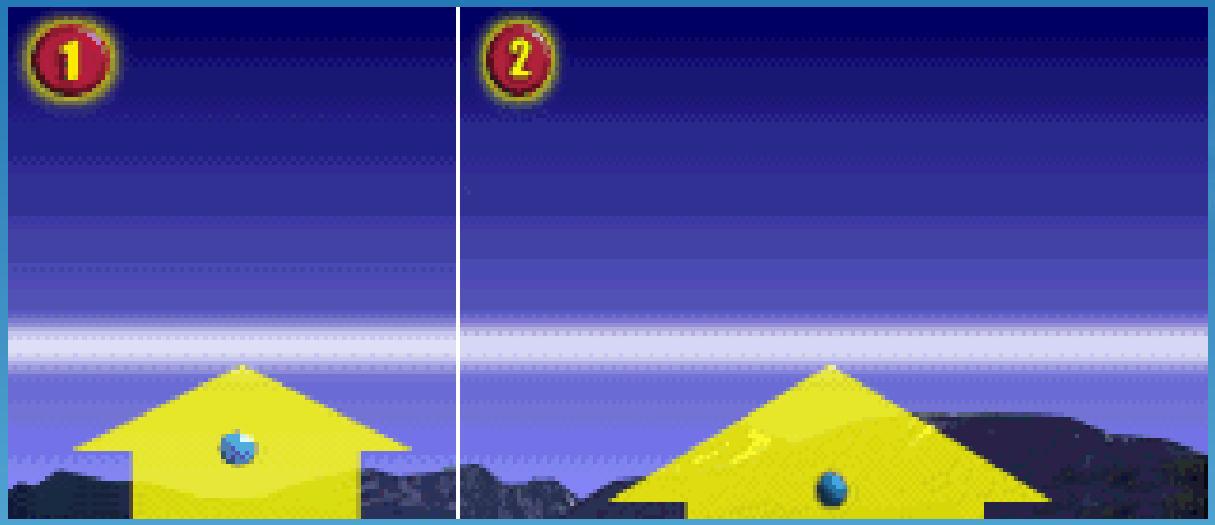
melting as rain

Simple formation process for hailstone

Conceptual model for hail formation

1. Up-down growth

melting level



small-size hail corresponds weak updraft

large hail corresponds high updraft

small drops freezing → collision with supercooled drops

to form hailstones

Suitable Conditions for large hailstone formation

- **Time condition**: enough staying time in the suitable growth region
- **Dynamic condition**: updraft should equal or largee the terminal velocity of hailstone in order to maintain continuous growth of hailstone.
- **Microphysical condition**: enough supercooled water

Terminal velocty of hailstone:

$$V_t = \left(\frac{2g^*}{\rho_a C_d}\right)^{1/2} (\rho_p R)^{1/2}$$

其中：$g^* = g\left[1 - \left(\rho_a / \rho_p\right)\right]$，$g$，重力加速度；

ρ_a，空气密度；ρ_p，冰雹容积密度，C_D，拖曳系数；

R，是冰雹粒子半径

e.g. for 2 cm-radius hailstone, density is 0.2 g/cm3, Vt is about 10 m/s;

for 2 cm-radius: density is 0.9g/cm3, Vt is about 40 m/s

- Fitschfield and Douglas,(1965)
- Sulakvelidze et al.,(1967)

2. Accumulation zone of supercooled rain drops

They proposed that there is a high accumulation zone of supercooled rain drops in hailstorms, and this may realize the rapid growth of hailstone, and greatly reduce the limitation dynamics needed for larg hailstone.

Problem: the hailstone formed by this propose has high water content, containing about 60-90%, which is not fully

3. Low-density growth

- **Pflaum et al., (1978, 1980) proposed microphysical recycling growth mechanism for hailstone by low-density growth of riming and wet growth, depending on perturbation of terminal velocity of hailstones.**

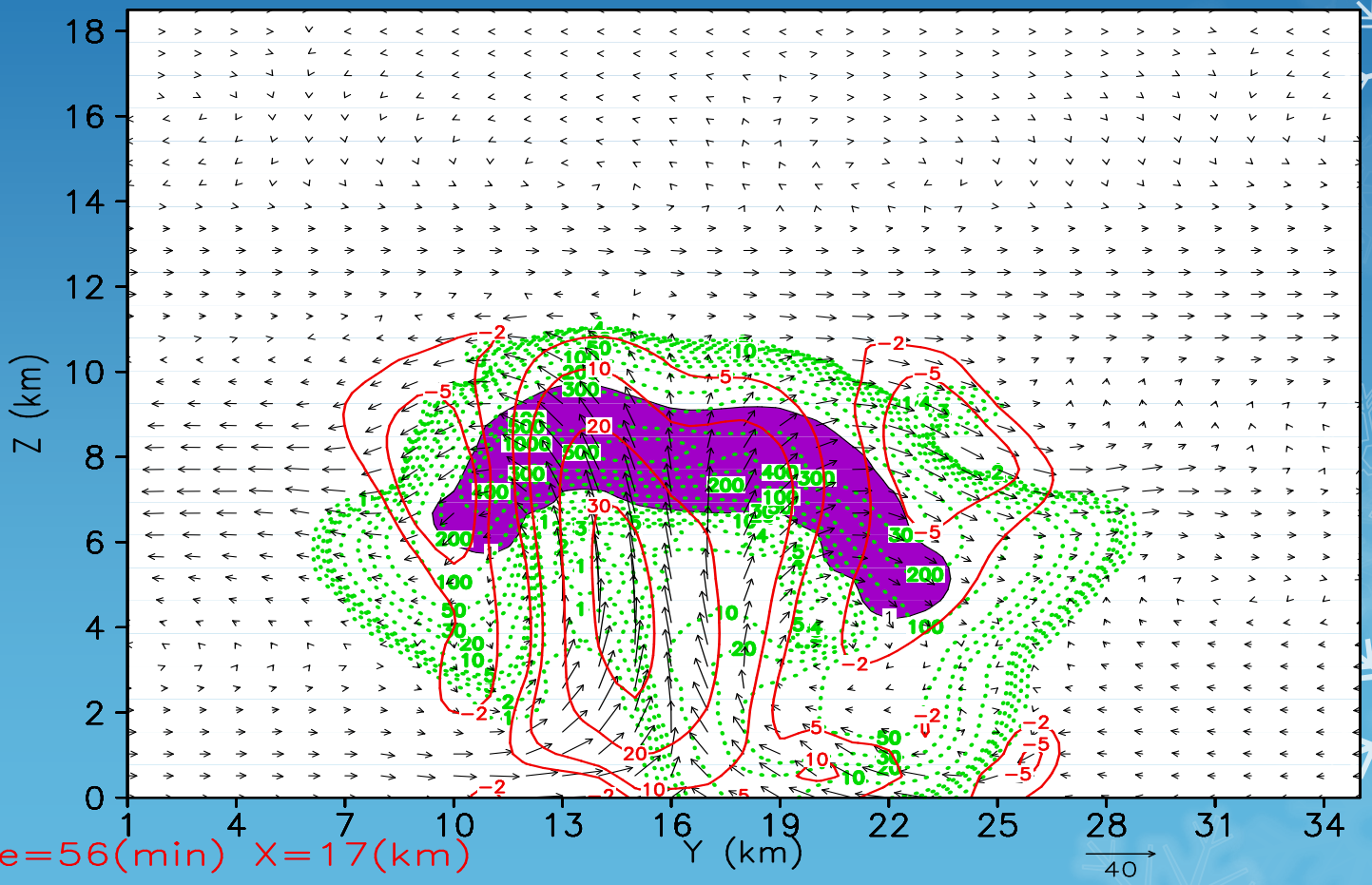
This hypothesis decreas the reqirement for dynamics of hail growth.

4. Recycling growth mechanism

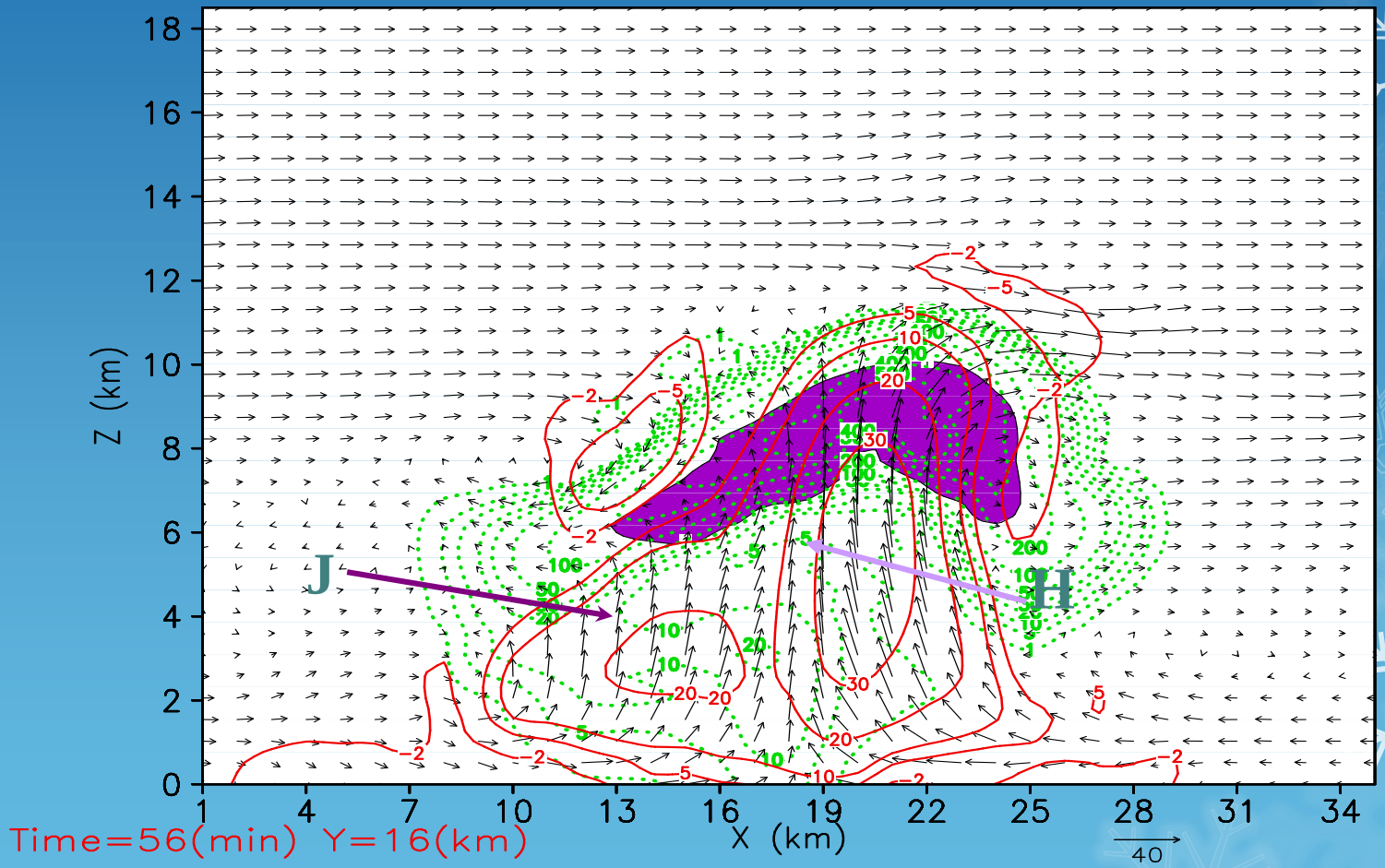
- Browning and Foote（1978）proposed that the hailtone falling in front of tilting storm may reenter updraft. This mechanism may extend the growth time of hailstone.
- Heymsfield et al.,(1980) proposed “particle injection” mechamism for multicullular hailstorm.

Guo and Huang （1997，2002）modeled this process by hail-bin model.《Atmospheric Research》63，2002，59-99

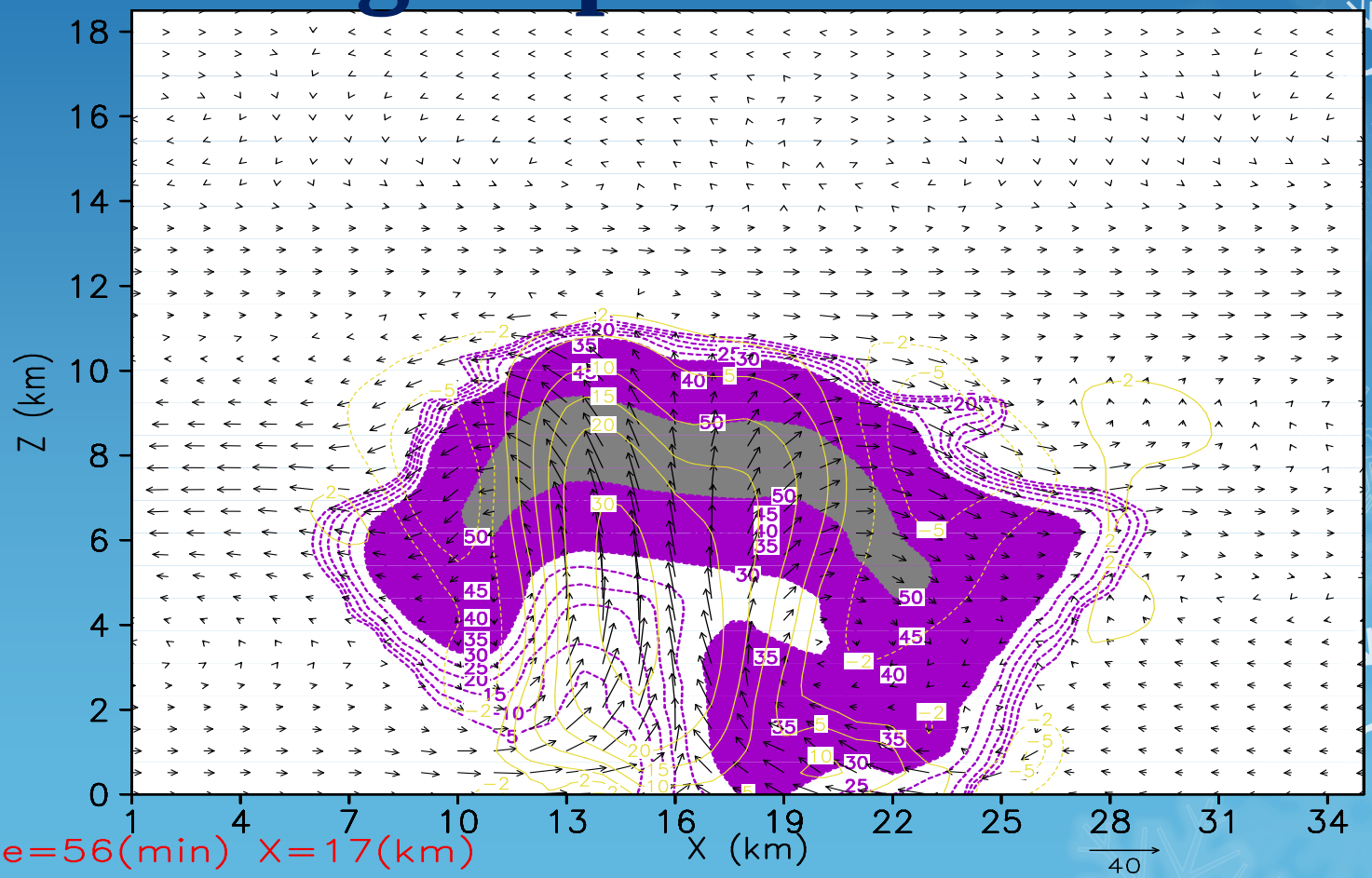
Vertical distribution of hail and graupel modeled



Vertical distribution of hail and graupel modeled



Vertical distribution of hail and graupel modeled



b. Hypotheses and conceptual model for hail suppression

(1) **Beneficial competition (over-seeding);**

(2) Early rainout

(ice particles are up to 10^{10}-10^{11} m^{-3} by rocket seeding);

(3) Trajectory lowering of hailstones;

(4) Glaciation of supercooled water of potential hail cloud;

(5) Dynamic effect on updraft by explosion;

(6) Enhance the rain process in hail cloud with warm cloud base.

How to protect it?

Three key parameters for hail suppression:

- Seeding time: when?
- Seeding location: where?
- Seeding amount: what?

Many types of hailstorm in nature!

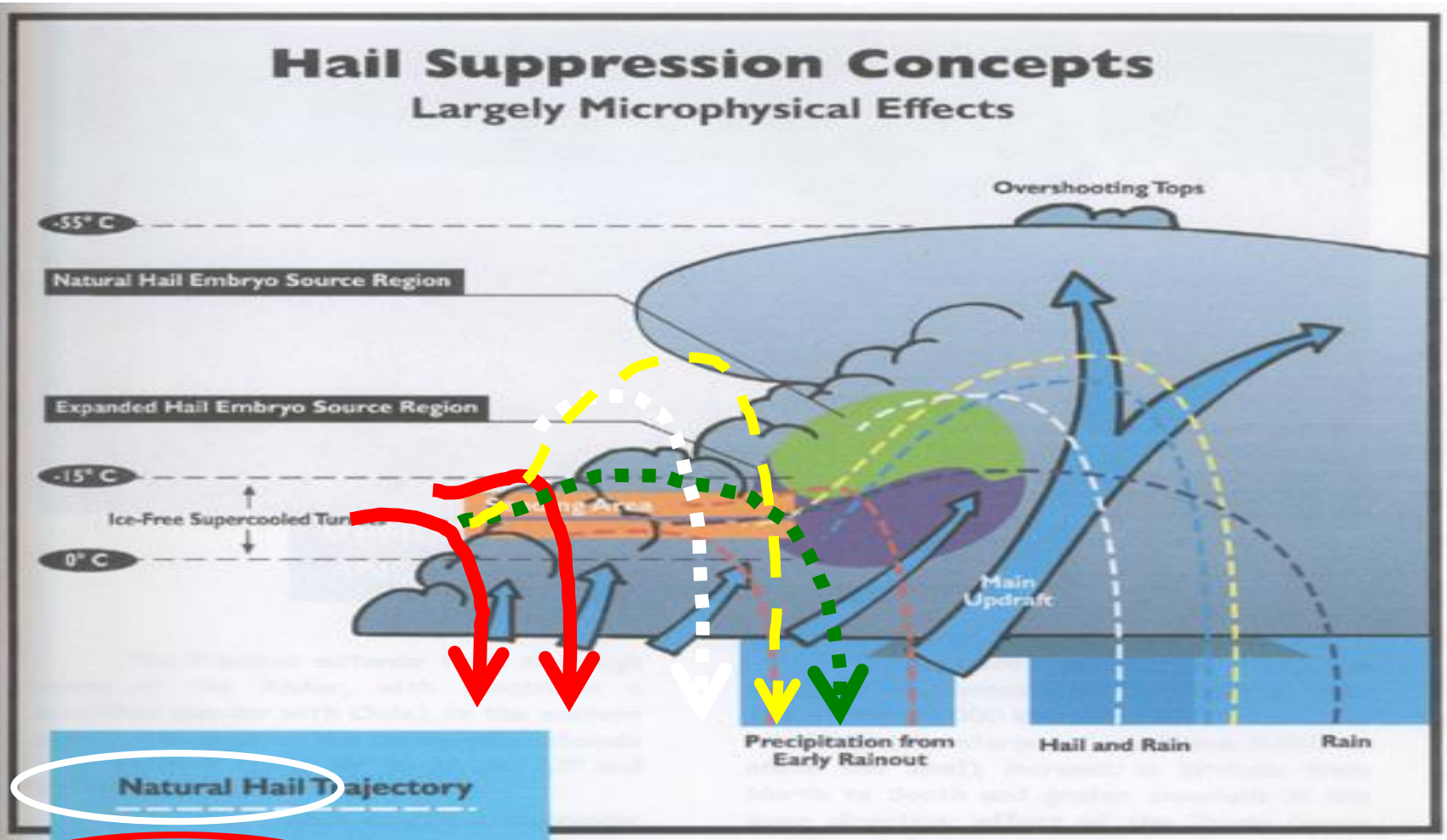
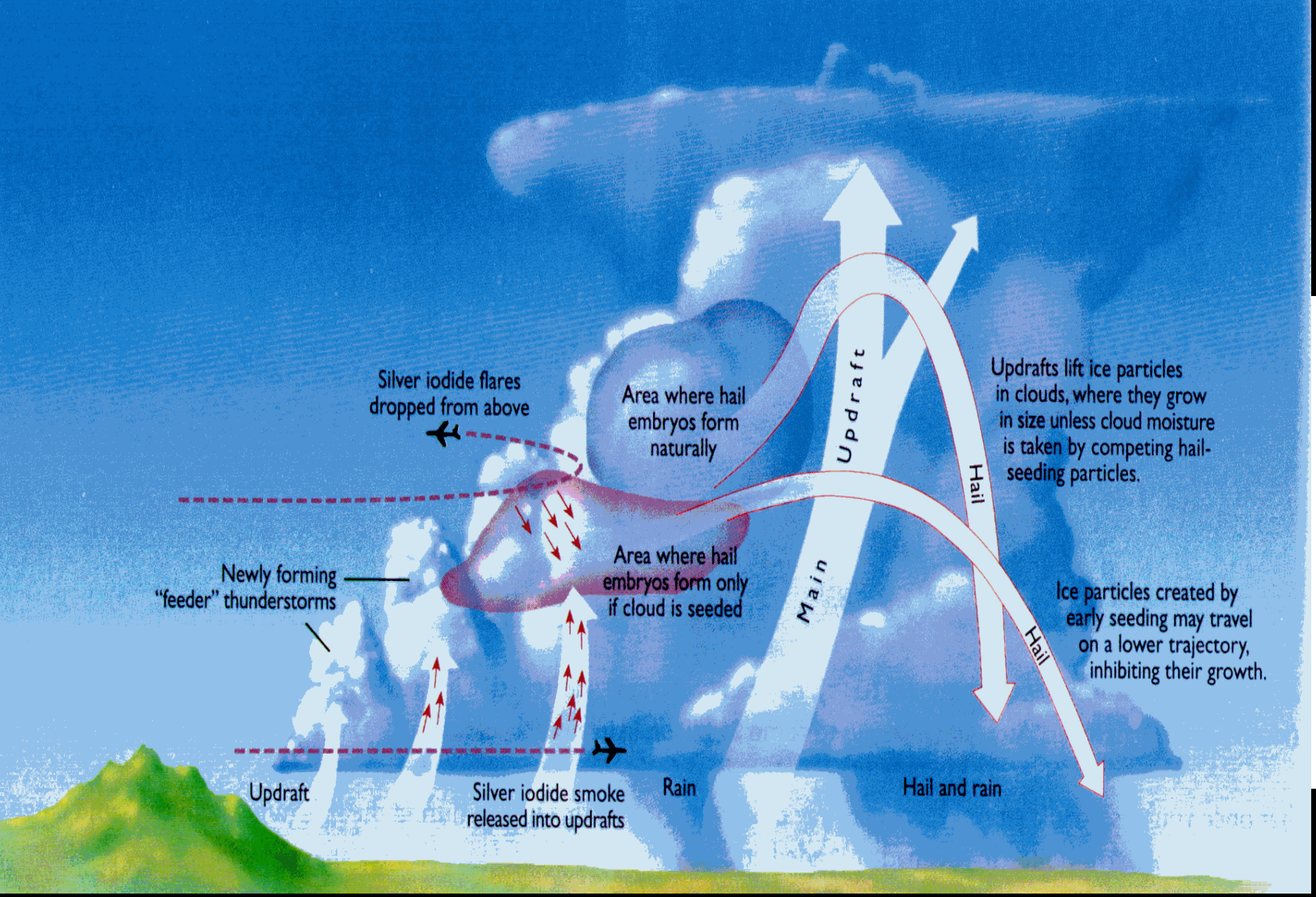


Figure Nº

Seeding area showed on an illustration taken from the WMP Report Nº 26 (Courtesy of Dr. Bruce Boe)


Silver iodide flares dropped from above
Area where hail embryos form naturally
Updrafts lift ice particles in clouds, where they grow in size unless cloud moisture is taken by competing hail-seeding particles.
Main Updraft
Hail
Newly forming "feeder" thunderstorms
Area where hail embryos form only if cloud is seeded
Ice particles created by early seeding may travel on a lower trajectory, inhibiting their growth.
Hail
Updraft
Silver iodide smoke released into updrafts
Rain
Hail and rain

c. Monitoring and seeding technologies relevant to hail suppression

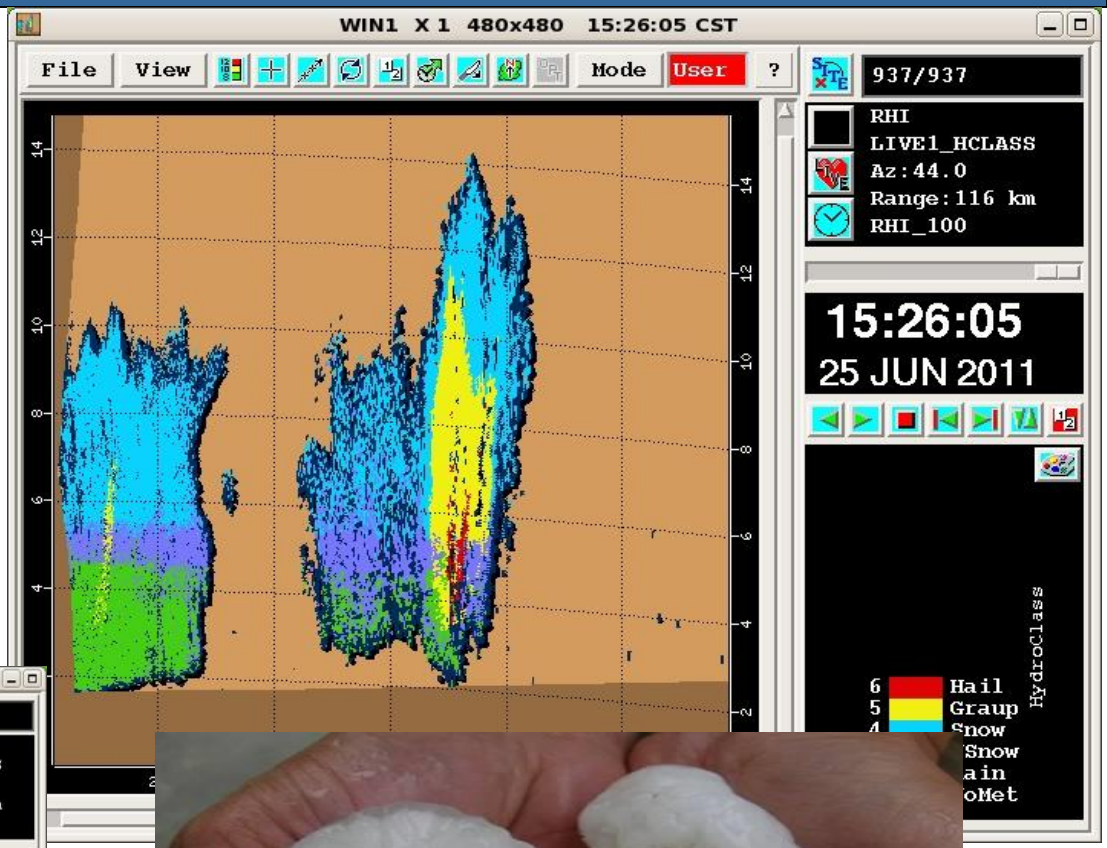
Key for hail suppression!

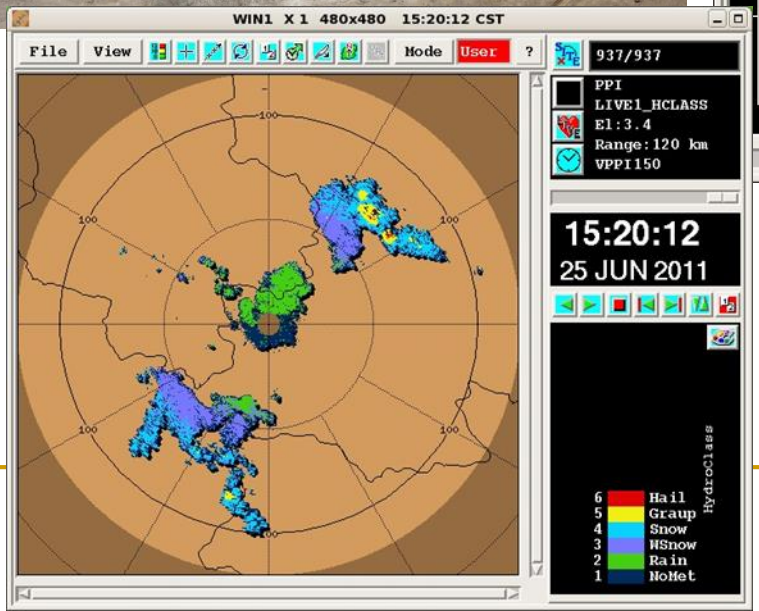
How to identify rain cloud and hail cloud?

- Weather forecasting?
- Radar monitoring?
- Mostly using method is to depend on the radar echo intensity and its location. such as Ref.>45 dBZ at upper cloud level.
- Advanced technology is polarized radar!

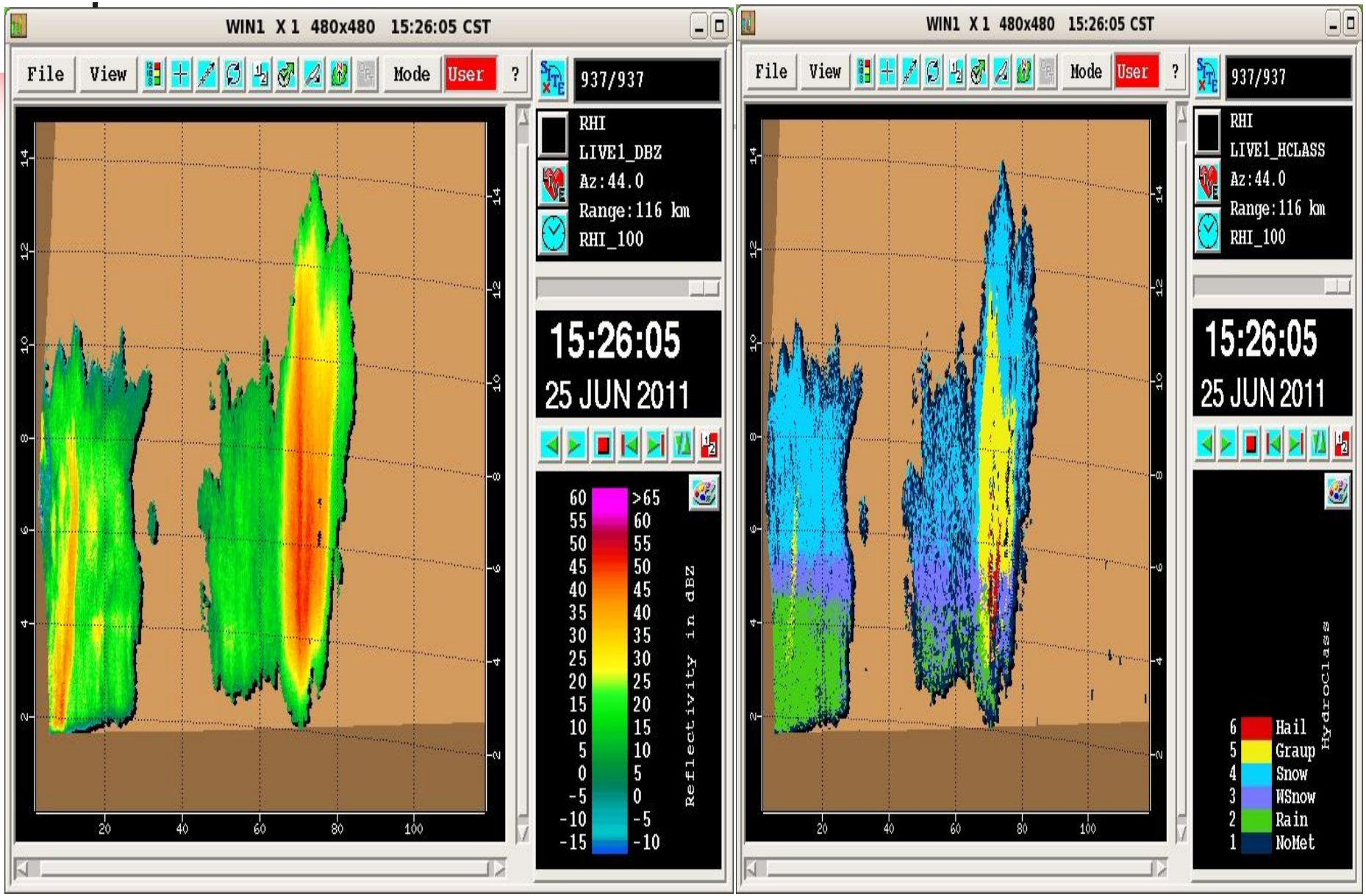
Polarized Doppler radar system

Advanced polarized radar

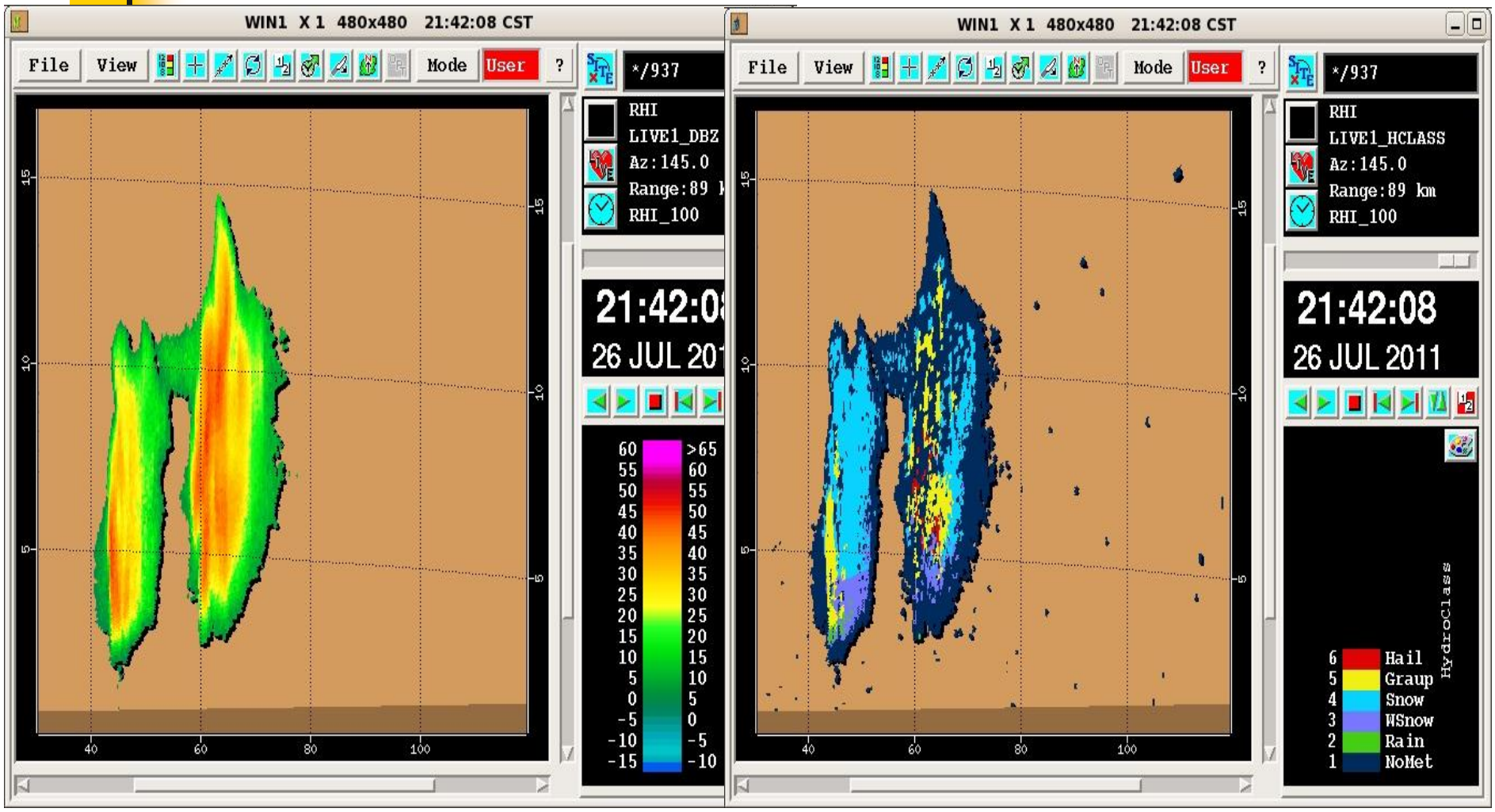




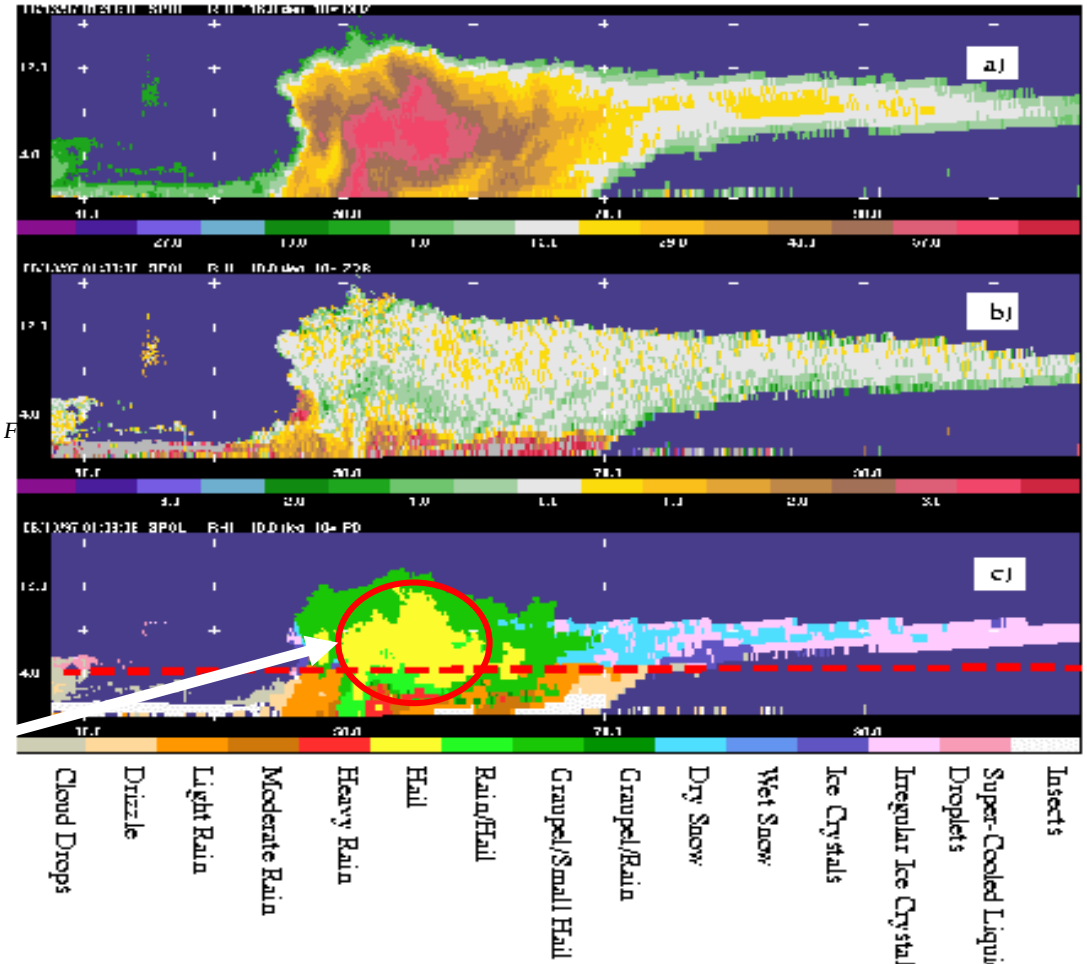
Hailstorm on June 25, 2011, Gansu Province



Hail cloud on July 26, 2011, Beijing



polarized radar



hailstone

RHI scans of (a) Z_{HH}, (b) Z_{DR} and (c) the corresponding particle classification results (the dashed line denotes the freezing level).

Seeding technology for hail suppression?

Mostly used technologies:

- **Aircraft-based: ejectable flares**
- **Anti-aircraft gun or artillery**
- **Rochet system**

...

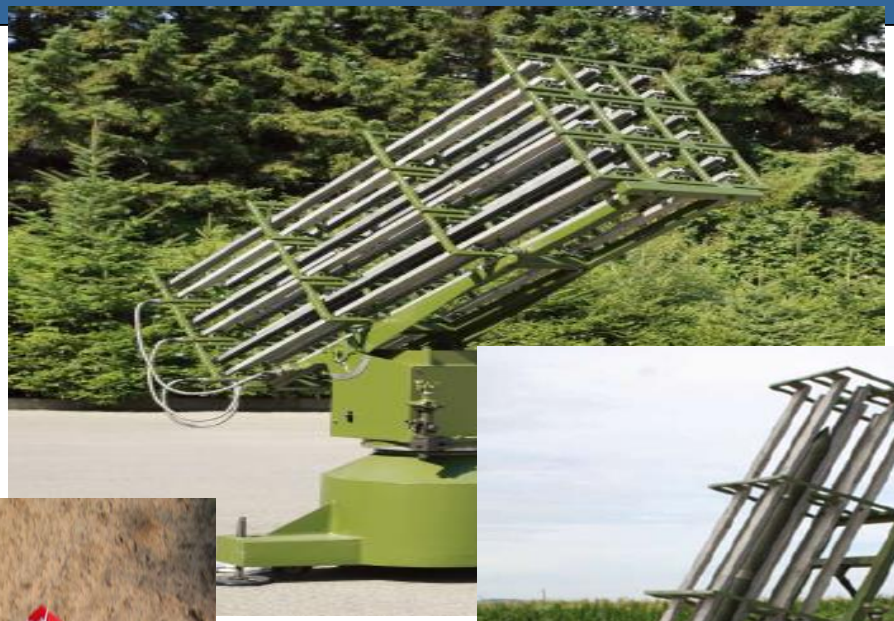
Seeding cloud tops (-10 C) with ejectable flares

Hail suppression

- The artillery shoots a shell to reach a maximum height of 6,000 meters.
- Each shell contains 1 or 4 grams of AgI, which would produce 10^{10}—4×10^{10} ice nuclei.

Advanced cloud-seeding rocket

- High Reliability
- High Safety
- High efficiency



Horizontal parachute-opening structure

- The rocket reach a maximum height of 7000-10000 meters.
- Each rochet contains 10 or 20,even more, grams of AgI, which would produce more ice nuclei.

Requirements for rocket seeding

- Hail cloud (hailstorm) forecast :
  depend on weather forecast and hail cloud models…
- Identification of hail clouds:

depend on radar and criterion

- High reliable seeding rockets

Advanced technical requirements for rockets used in hail suppression operation

- **High automatic and reliable techniques:**

  such as high precise seeding technique, to ensure the rockets into the desired seeding location

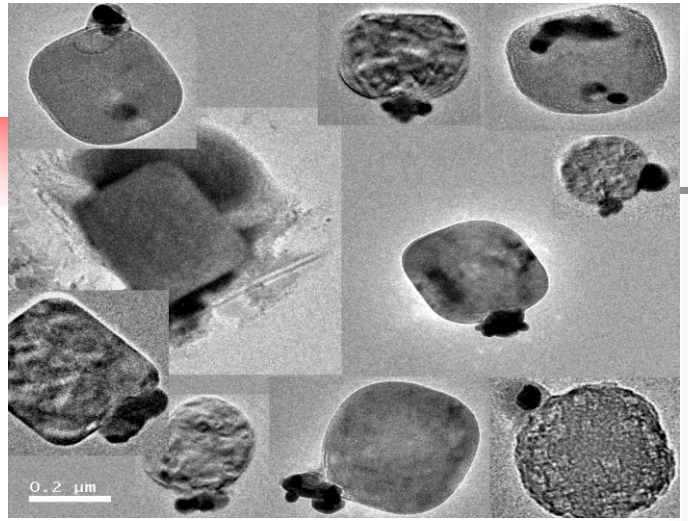
- **High efficiency of seeding:**

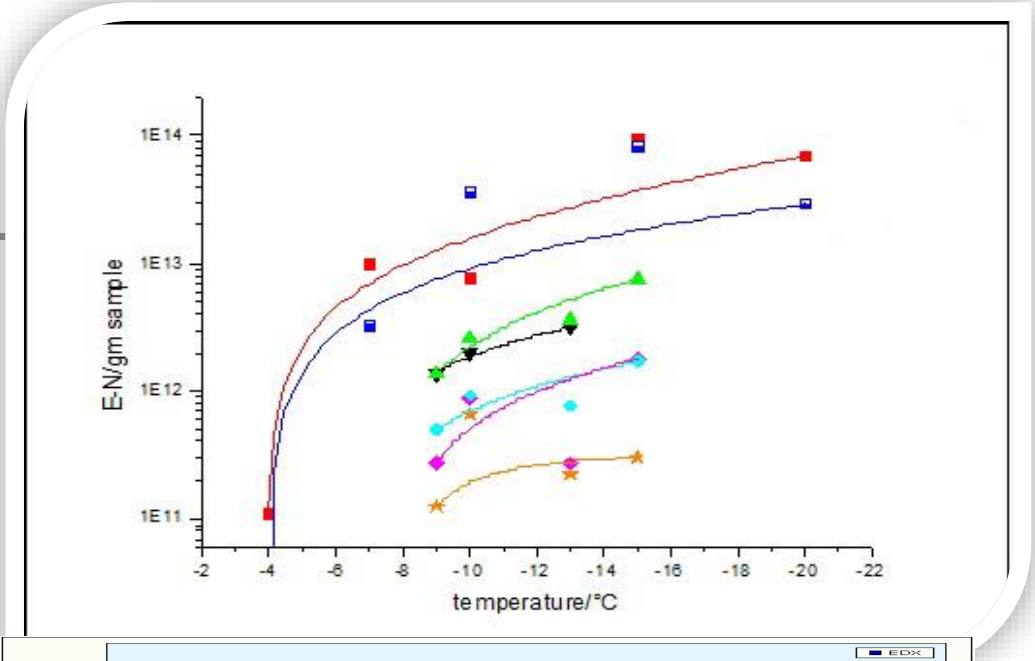
  such as volume seeding technique and high-efficiency of seeding agent contained in rockets

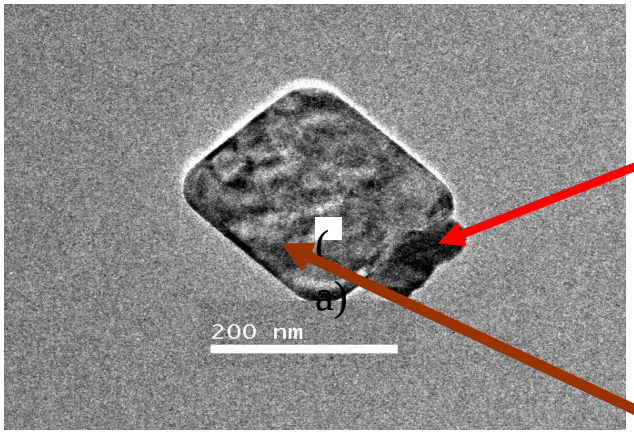
- **High safety:**

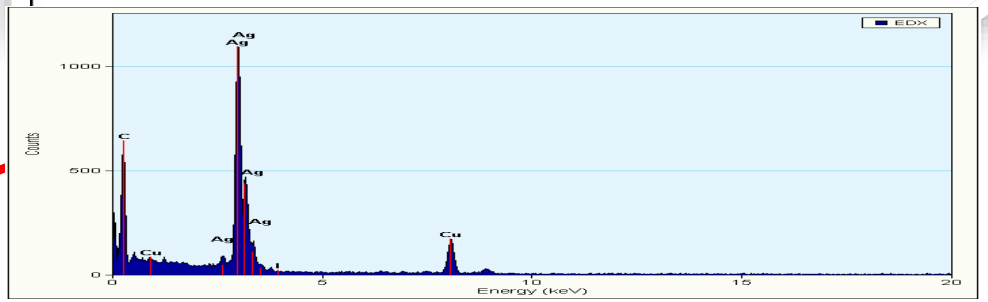
such as rocket wreckage treatment etc.

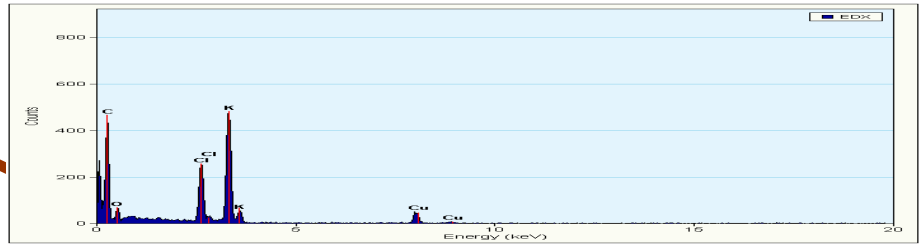
High efficiency of Seeding agent





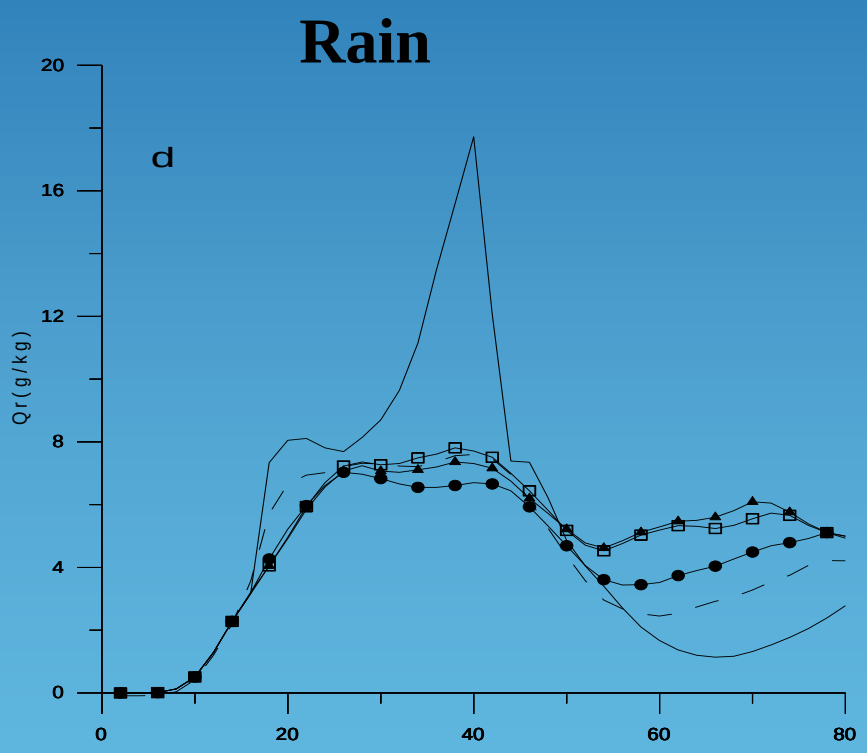


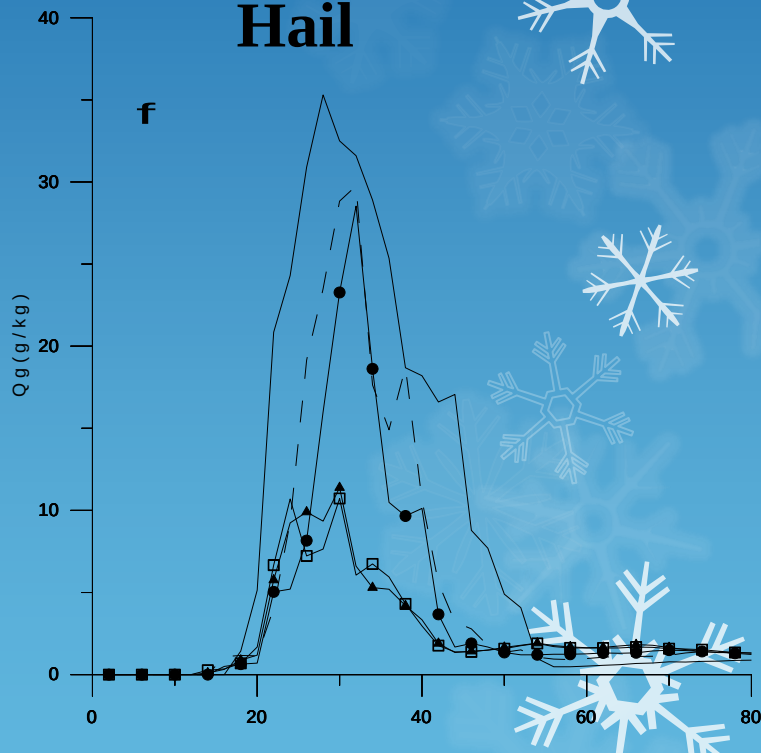




Hailstorm on 31 May 2005,Beijing city, more than 8787 cars were damaged.

Convective cloud seeding for rain enhancement and hail suppression

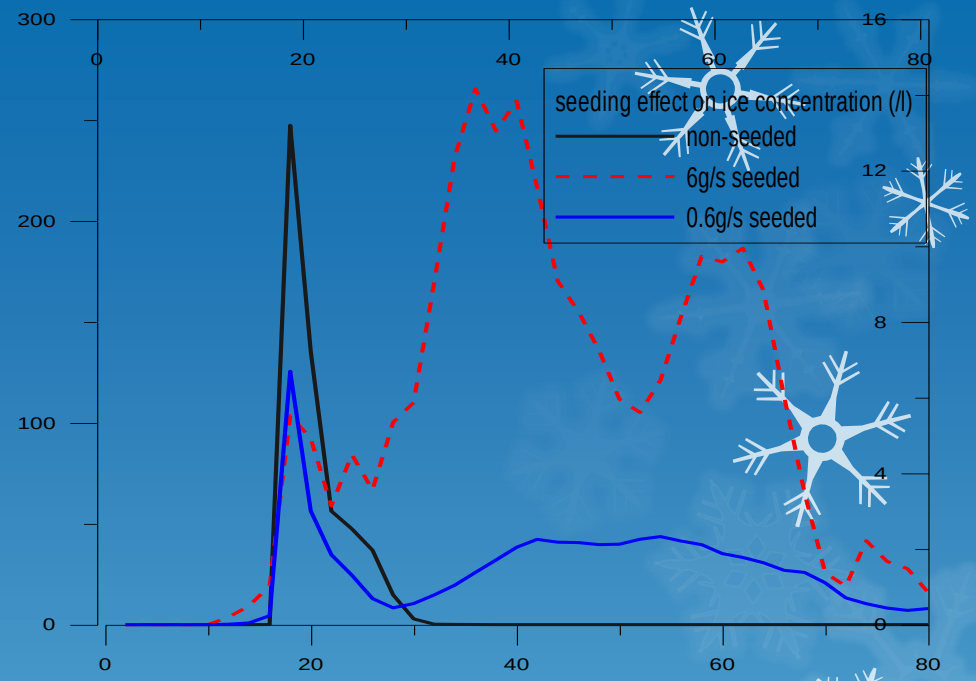


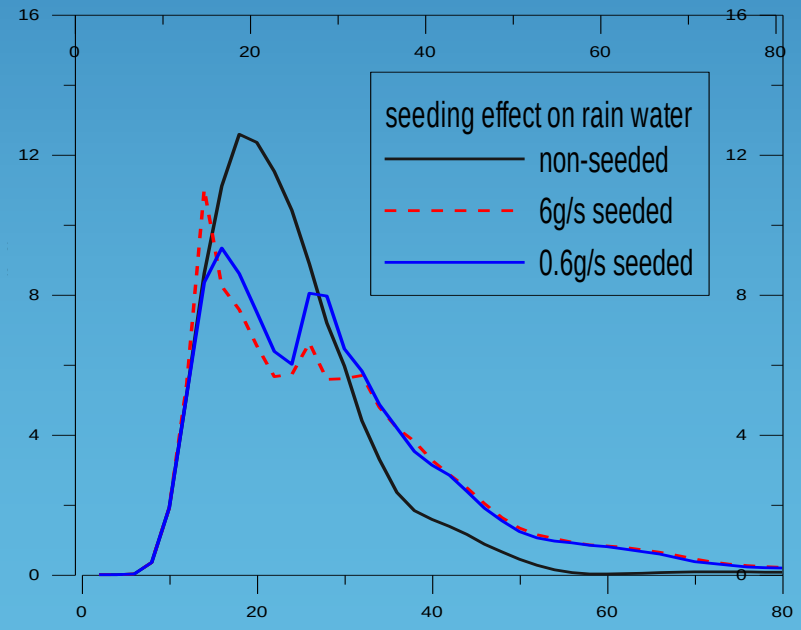


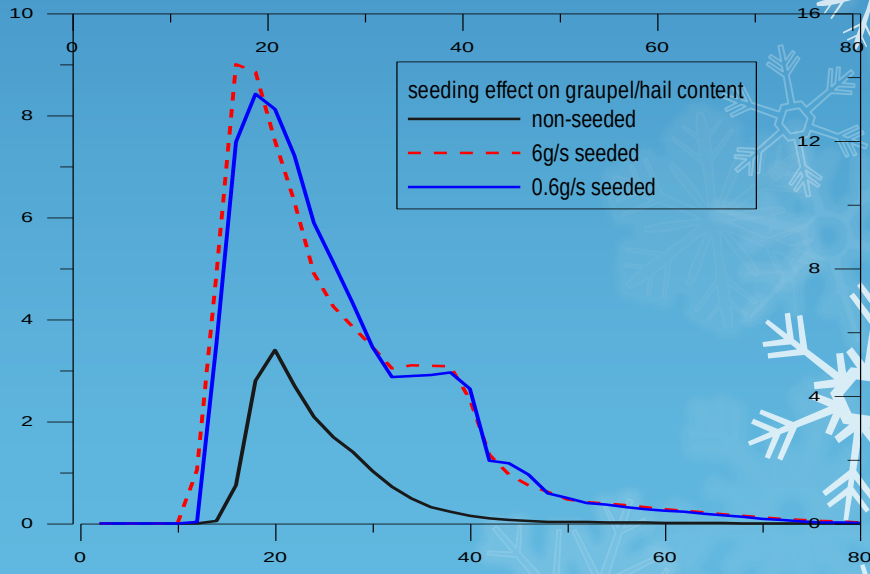
Hail suppression and rain-making for severe storm,Solid line：unseeded，dashed line：seeded

d. Uncertainties and future focus

We know a little about nature!


seeding effect on ice concentration (/l)
non-seeded
6g/s seeded
0.6g/s seeded


seeding effect on rain water
non-seeded
6g/s seeded
0.6g/s seeded


seeding effect on graupel/hail content
non-seeded
6g/s seeded
0.6g/s seeded

Future focus

Improve the effectiveness of hail suppression:

- **Obtain operation-related conditions and criterions**
- **Identify adequate time and location in clouds for seeding**
- **Need more complete understanding of physical processes responsible for hail formation in different hailstorms**

Thank you!

Share experience in weather modification