

Dry Ice as Cloud Seeding Agent



What is Dry Ice?

- Frozen carbon dioxide, also known as solid CO_2 . Dry ice can sublime, while AgI is a powder that in pure form.
- Does not melt into a liquid, but evaporates directly into a gaseous form by sublimation.
- Liquid carbon dioxide is only found at much higher pressures than exists in the Earth's atmosphere.
- Carbon dioxide is the gas that we exhale during breathing and the gas that plants use in photosynthesis.
- Soda Water = Water + CO_2

History of Dry Ice as Seeding Agent

- Dry Ice has been used as a seeding agent since Schaefer fell upon the idea while trying to lower the chamber temperature.
- Birth of cloud modification started on November 13, 1946.
- Schaefer dumped 3 lbs of dry ice pellets from an aircraft in a racetrack pattern.



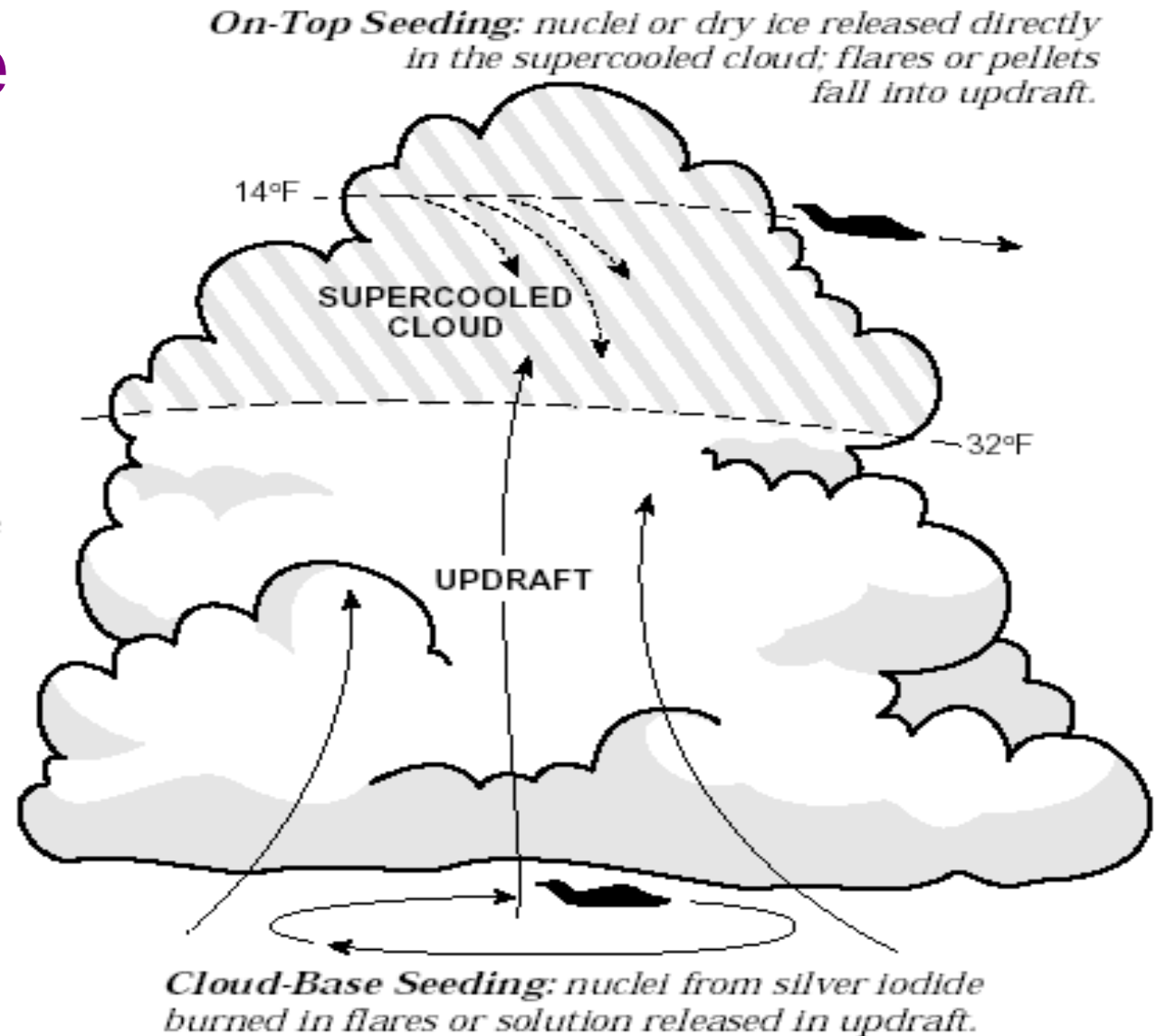
Vincent Schaefer

How does Dry Ice Work?

- Glaciation forms ice crystals by cooling water droplets below -40°C (**Homogeneous Nucleation**).
- Temperature of a falling dry ice pellet is cold enough to super-cool the cloud in its vicinity.
- Freezing cloud droplets, even in the **absence of ice nuclei**.
- CO_2 pellets are not themselves nuclei, but start the rapid development of large numbers of small ice crystals.
- Water droplets evaporate and ice crystals grow larger, until large enough to fall. (cold rain process)

Where is Dry Ice Dispensed?

- Dry Ice pellets are dropped into the upper regions of the clouds.



When to use Dry Ice?

- Direct-injection seeding- aircraft penetrate at or near cloud top.
- Target clouds growing through $-10\text{ }^{\circ}\text{C}$ level.
- Seeding Agents are placed into the supercooled cloud where nucleation is desired.
- Updrafts provide a continuing source or condensate, not used to transport the seeding agent upward from cloud base.

What amount of Dry Ice to use?

- Amount is proportional to liquid water concentration and updraft strength.
- The dry ice hopper can dispense up to a rate of 40 lbs/min, but the preferred rate is approximately **18.75 lbs/min** (5 oz/sec).



What amount of Dry Ice to use?

- Production of ice crystals by dropping dry ice pellets through supercooled clouds is **independent of cloud temperature**, unlike various AgI Compounds.
- Dry ice seeding experiments show an average output between 10^{11} or 10^{12} crystals per gram of dry ice.



Handling of Dry Ice?

- Extremely cold temperature (-78.5 °C or -109.3 °F).
- Ice can cause damage to the skin if handled.
- Use tongs, or insulating gloves, and protective goggles.
- Dry Ice will sublimate at five to ten pounds every 24 hours in a typical ice chest.



Preparing Dry Ice for Cloud Seeding

- Before a launch is called, dry ice pellets should be sifted through $\frac{1}{4}$ inch hardware cloth to remove the water ice (snow) prior to being loaded in the hoppers.
- Don't load hopper until launching.
- Bad insulation and an open bottom in the plane will cause deposition of water
- Ice may freeze the dry ice into clumps. Bad for dispensing.







Storage of Dry Ice During Operations

- Dry Ice is stored on the ground in storage boxes with the lids kept tightly sealed and only opened when necessary.
- Mosquitoes can be an issue with the storage box.



Advantages of Using Dry Ice

- Works immediately.
- Requires less anticipation.
- Creates high concentrations of crystals.
- Works at any temperature colder than 0 °C.
- Smaller (warmer) clouds can be treated more effectively with dry ice than with ejectable flares.



Dry ice dispenser on King Air C90 aircraft (N709EA in 2022).

Experiments Seeding of Supercooled Clouds

- Procedure: Refrigerating chamber (-15 °C).
- Breath into chamber (produces thick, grey, supercooled fog).
- Scratch some dry ice into cloud (dense streaks resembling condensation trails. These contain thousands of tiny ice crystals).
- Ice crystals disperse through chamber. Super cooled water droplets evaporate and vapor will deposit on ice crystals.

Sources of Material

- North Dakota Cloud Modification Project Operations Manual
- <http://www.swc.state.nd.us/arb/ndcmp.html>
- <http://www.weathermod.com>
- Experiments with Dry Ice <http://www.west.net/~science/co2.htm>
- Hanson, B.J., Clouds, Rain & Rainmaking
- Sorbjan, Zbigniew, Hands-on Meteorology
- Bohren, Craig, Clouds in a Glass of Beer