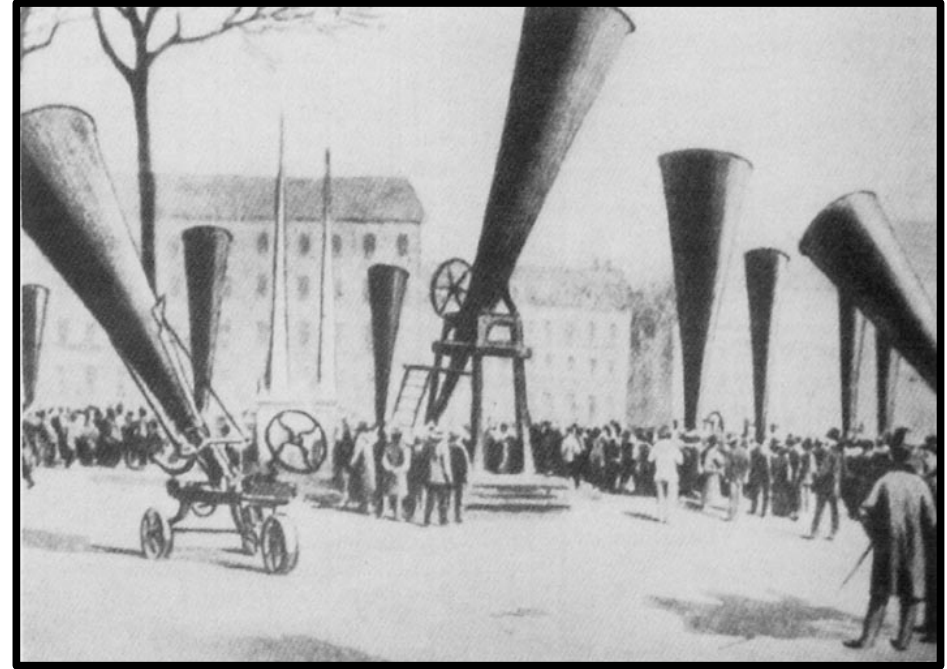


History of Weather Modification

- Many early attempts at modification of the weather.
- Generally, no scientific basis until 1940's.
- Work done at General Electric Research Labs in New York.



[Hail cannons](#) at an international congress on hail shooting held in 1901.

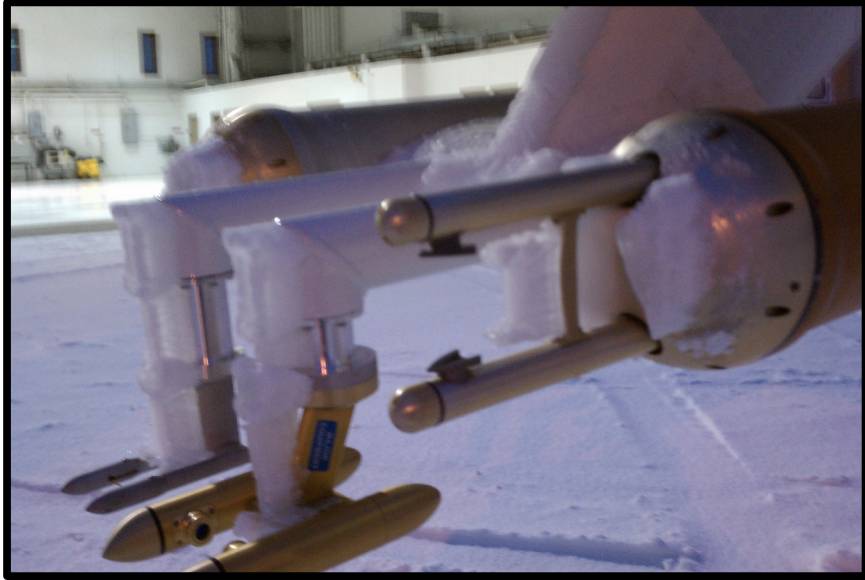
General Electric Research

- Experiments during World War II were conducted dealing with aircraft icing.
- Aircraft icing experiments directed by Irving Langmuir.
- Additional group involved Vincent Schaefer and Bernard Vonnegut.



Wilson Hunter, the Head of the Icing Research Section is shown demonstrating the dangerous icing of the propellers of a P-39 after a wind tunnel test. General Arnold (left) and George Lewis (far left).

Aircraft Icing: Still a Research Topic



Icing of Cloud Probes on the Citation Research Aircraft after November 24, 2010 flight.



Rosemount Icing Detector probes on the fuselage and on hot-wire boom under the left wing of P-3 aircraft for NASA IMPACTS 2023 field project.

Important Early Results for Weather Modification

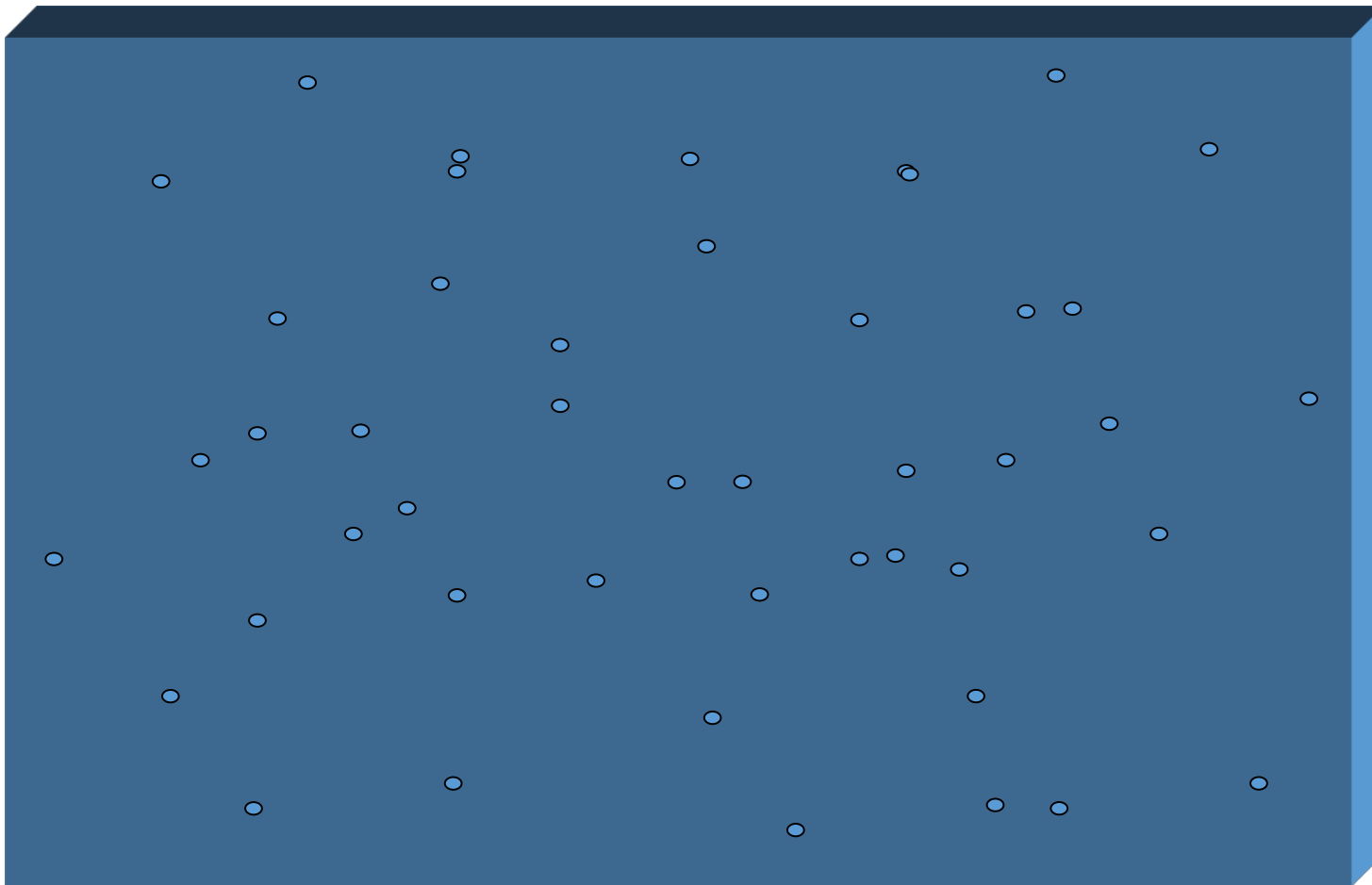
- Concept of Supercooled Liquid Water (important as for aircraft icing)
- Cold Box Experiments

How cold can supercooled liquid droplets be in the atmosphere?

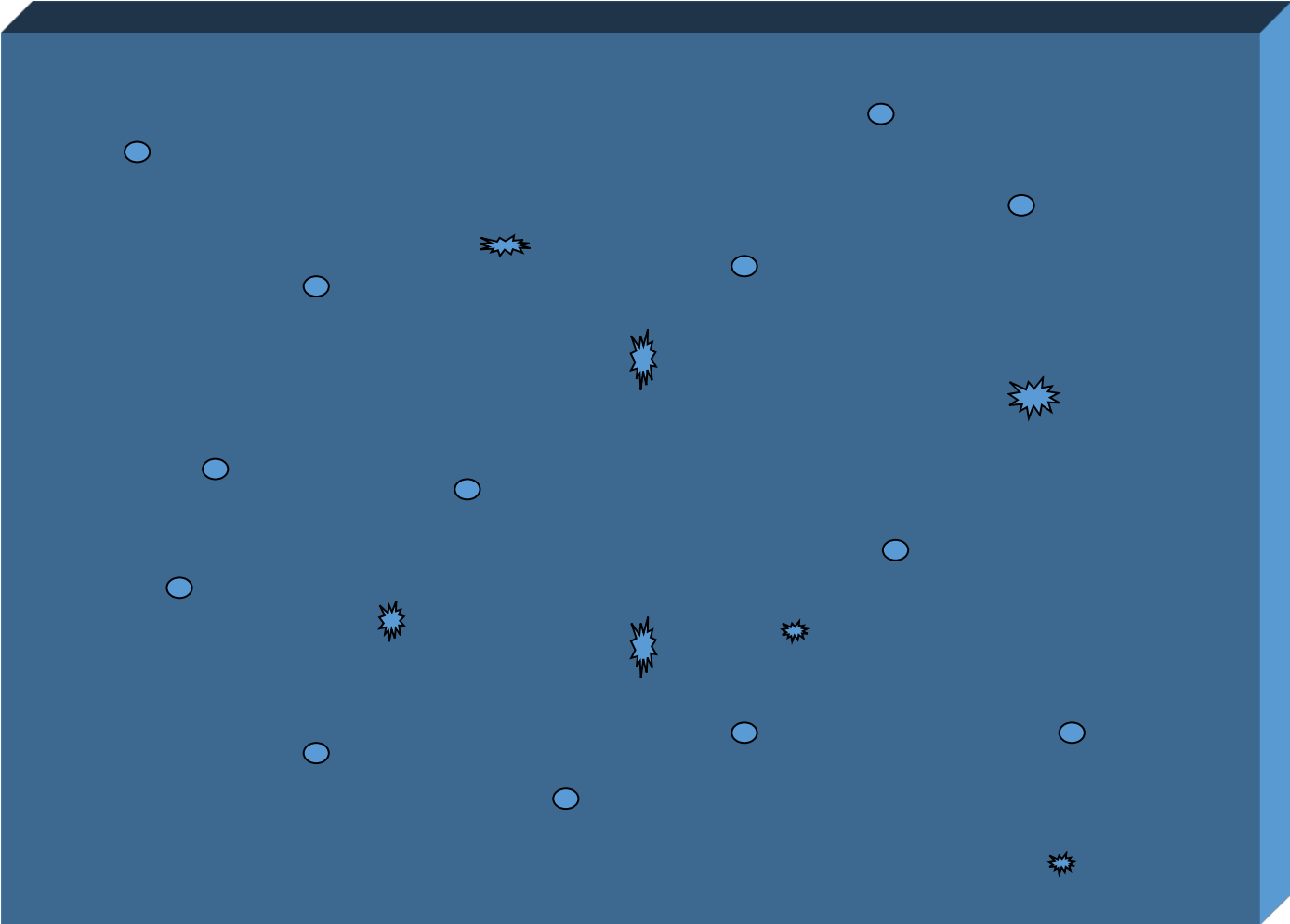


Photo of a hole punch cloud and the associated fall streaks, taken on the east side of Madison, WI, at 11:20 AM CST on Sunday, November 7th. By Tim Wagner

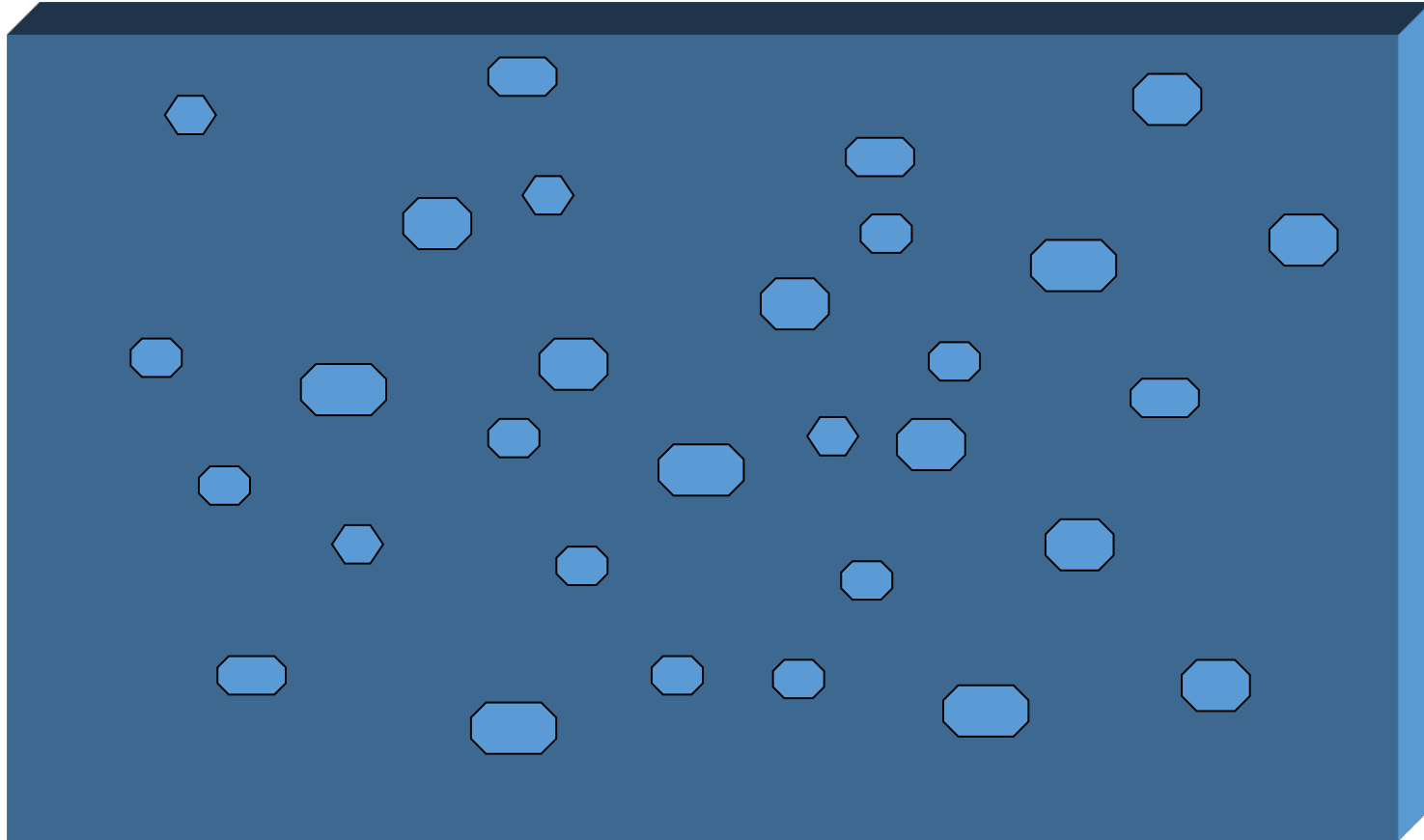
Supercooled Cloud Formed in Chest Freezer



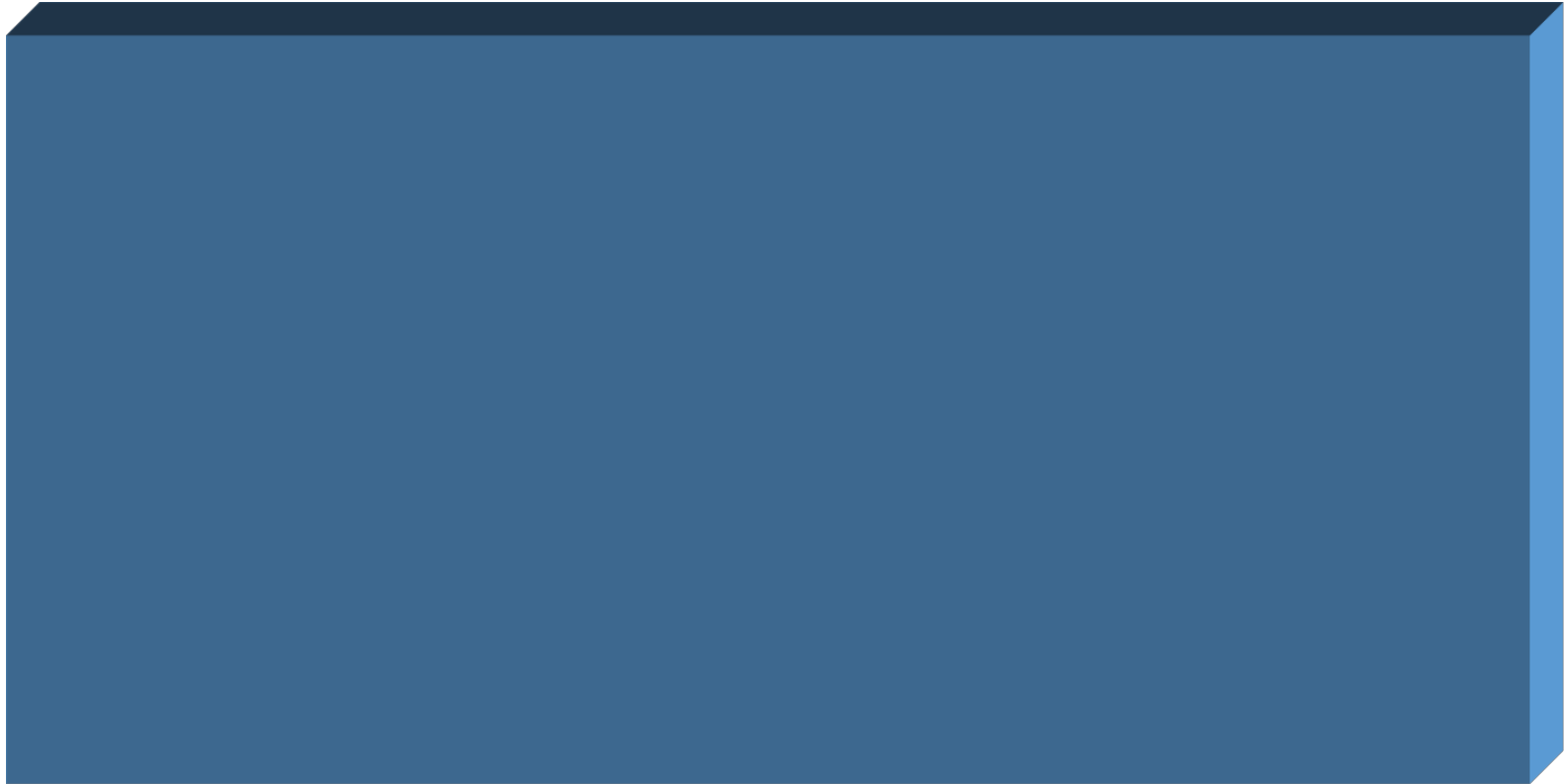
Dry Ice Introduced to the Supercooled Cloud



In time, the water droplets disappeared and the ice crystals grew large.



As time continued, the large ice crystals fell out, leaving only the ice at the bottom of the box and no cloud.



Chamber Observational Window Videos

http://aerosol.atmos.und.edu/CloudChamberVideos_2018.html

June 21, 2018 - 3:14

0:23 - Injection starts.

1:14 - Start to see some ice.

2:16 - More turbulent eddies.

2:33 - Ice is becoming more prevalent.

3:52 - In the upper right corner, a large dark area.

5:22 - Ice continue to increase.

7:00 - Water drops depleting as more dark spots apparent

8:37 - Very little super cooled drops left.

9:06 - Lot of the ice particles apparent.

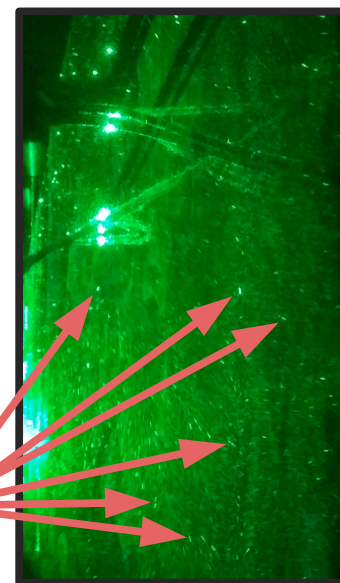
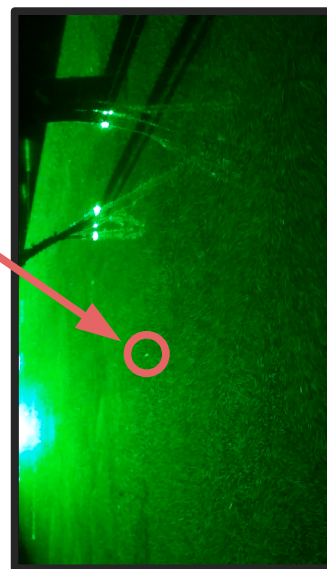
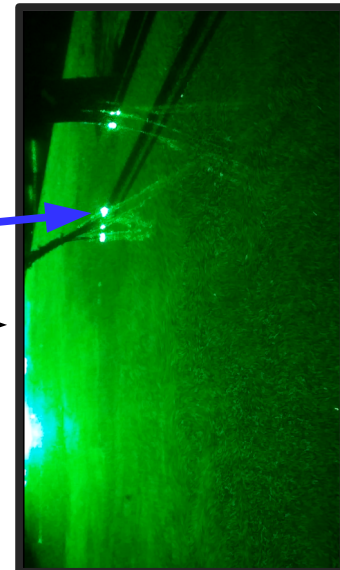
9:33 - Water drops increasing.

10:15 - Chamber mainly ice particles.

Injection Tubes

Ice

Lots of Ice



Would this happen in a real cloud?

- This question was addressed and finally tried November 13, 1946.
- Vincent Schaefer dropped about 1.5 kg of dry ice into stratiform cloud in western Massachusetts.



What likely is the cause the whole observed in the image above?

What was the result of putting dry ice into stratiform cloud in western Massachusetts?

- A hole appeared in the cloud
- Ice crystals fell from the base of the cloud
- Ice crystals fell about 600 m below cloud base before sublimating in the dry air below cloud base.

Meanwhile, back at in the laboratory

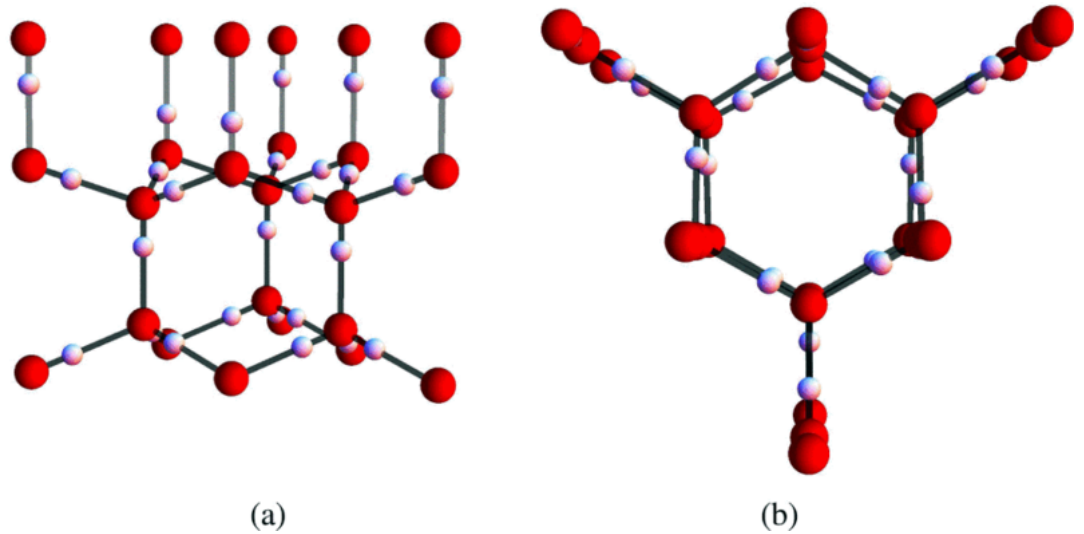
- The mechanism causing this phase change was being investigated.
- Bernard Vonnegut proposed a different method to achieve the same results.

Summary of the Concept

- Once an ice crystal formed, it would continue to grow.
- If a crystal is introduced that looks like an ice crystal, ice would continue to grow on that “seed” crystal.

Are there any substances that have a crystal structure similar to that of ice?

- Silver Iodide (AgI) is very close.
- AgI has a hexagonal crystal lattice structure.
- The spacing between molecules in AgI is very close to the spacing between molecule in ice.

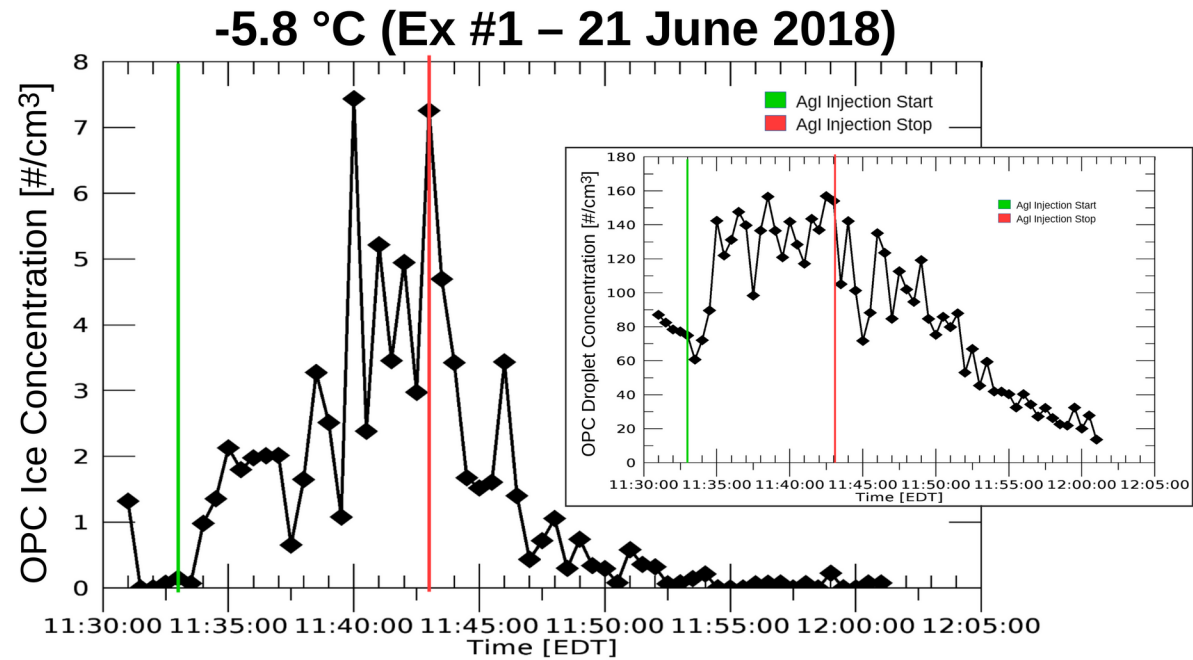


Crystal structure of hexagonal (Ih) water ice. Water ice can be viewed as a frozen configuration of water molecules, satisfying the Bernal-Fowler “ice rules” [1, 2], in which each oxygen (red sphere) forms two short, covalent bonds, and two long, hydrogen bonds with neighboring protons (white spheres). Oxygen atoms form an ordered lattice, belonging to the hexagonal space group P63/mmc, with a four-site primitive unit cell. Protons do not show any long-range order. (a) Structure viewed perpendicular to the hexagonal symmetry axis (the crystallographic c axis). (b) Structure viewed along the hexagonal symmetry axis.

Benton, Owen & Sikora, Olga & Shannon, Nic. (2015). Electromagnetism on ice: classical and quantum theories of proton disorder in hexagonal water ice. Physical Review B. 93. 10.1103/PhysRevB.93.125143.

Does it Work?

- AgI turned out to be quite effective as a nucleating agent.
- AgI would form ice crystals in the cloud at temperatures as warm as -5 degrees Celsius.



Results from an experiment designed to test ice nucleation of Silver Iodide cloud seeding flares using the Pi Cloud Chamber.

Delene, David J., Kyle Pederson, Bruce Boe, and Charlie Harper, An Experiment Designed to Test Ice Nucleation of Silver Iodide Cloud Seeding Flares using the Pi Cloud Chamber, Presentation given (2:00 pm on Wednesday 24 April 2019) at the 2019 Weather Modification Association Annual Meeting in Phoenix, Arizona.

The “Big Three”

- Foreground: Vincent Schaefer
- Left: Irving Langmuir
- Right: Bernard Vonnegut



Summary of the Early Results

Can We Make Rain?

Certainly, but it may not be cost-effective.

Can We Make Rain Cost-Effectively?

This is a lot more difficult.

It can be done if there is a weak link in the process that we can change with a small amount of effort.

The Weakest Link for Precipitation Formation?

- The early Schaefer experiments identified a potential weak link in the rain-making process.
- The existence of supercooled liquid water in clouds could be changed to precipitation with the addition of a small amount of “seeding material”.

The Answer to Water Shortages

- The development of AgI as a seeding agent made it possible to release material from the ground and influence large volumes of air.
- Hence, seeding could be done economically on a large scale.

Off to the Races

- Everyone (almost) started getting into the cloud seeding business.
- By 1950, about 10 % of the land area of the U.S. was under contract to cloud seeding firms.
- Great claims were being made about the effectiveness of the operations.

The Periodic Seeding Experiment

- Project Cirrus, a research project at GE Research Labs.
- Seeding from the ground in New Mexico several days each week.
- Analysis of rainfall patterns across the U.S. indicated a seven-day periodicity in various weather elements.

The Skeptics

- How do we know that these alleged seeding effects would not have happened naturally?
- Do we know that Schaefer's original cloud experiment was the result of the dry ice or something different?

<https://factsanddetails.com/world/cat56/sub401/entry-6219.html>



The Skeptic Carneades

The Answer → Great Racetrack Demonstration



Quasi-believers

- Generally, even the most skeptical came to believe that the microphysical properties of the clouds could be changed by seeding.
- However, the question of additional precipitation at the ground had not been clearly demonstrated.



Experiments, and More Experiments

- The periodicity experiment was brought into question since seven-day periodicities in weather elements had been observed with data prior to this experiment.
- The claims of additional precipitation in seeded areas were not regarded as proof due to the high rainfall variability.
- Needed to demonstrate the effects clearly.

Delene, David J., Kyle Pederson, Bruce Boe, and Charlie Harper, An Experiment Designed to Test Ice Nucleation of Silver Iodide Cloud Seeding Flares using the Pi Cloud Chamber, Presentation given (2:00 pm on Wednesday 24 April 2019) at the 2019 Weather Modification Association Annual Meeting in Phoenix, Arizona.



The Hydro-illogical Cycle

“Interest in weather modification is soluble in water.”
(Archie Kahan)

Drought Response

