12.335/12.835 – Special Topics : Aerosol and Cloud Section

Special Topic :

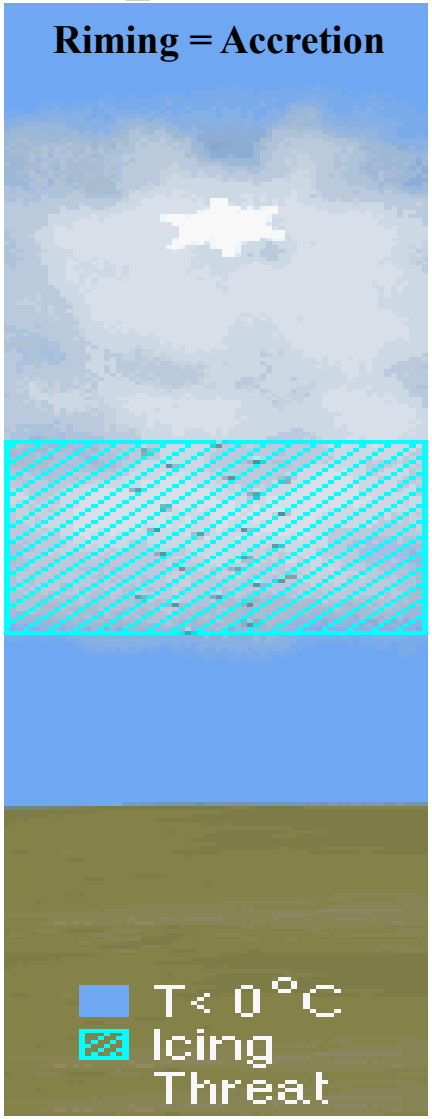
Weather Modification

Thursday, Dec 4, 2014

Rain

Snow

Graupe & Hail



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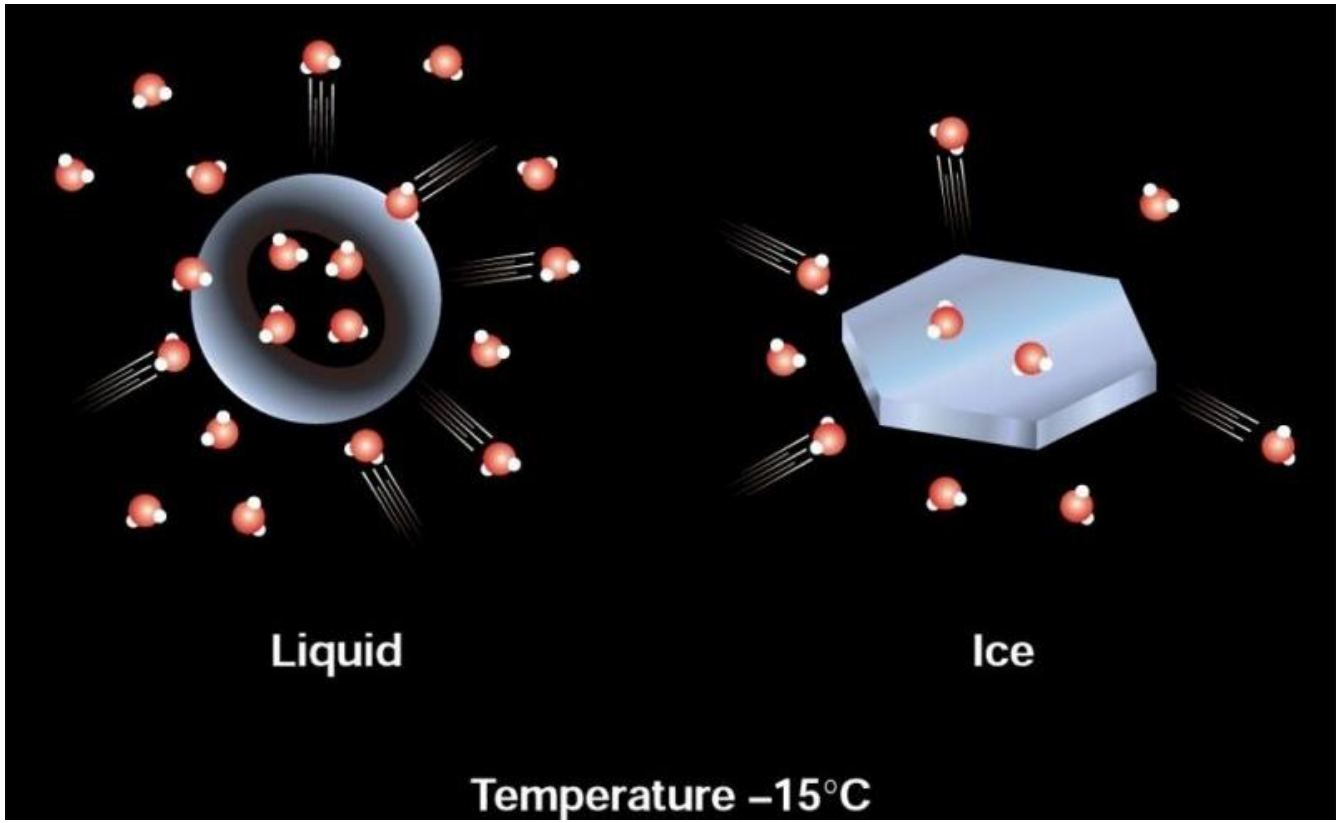
Please see: http://www.ems.psu.edu/~lno/Meteo437/Riming.jpg.

Graupel Diameter < 5mm

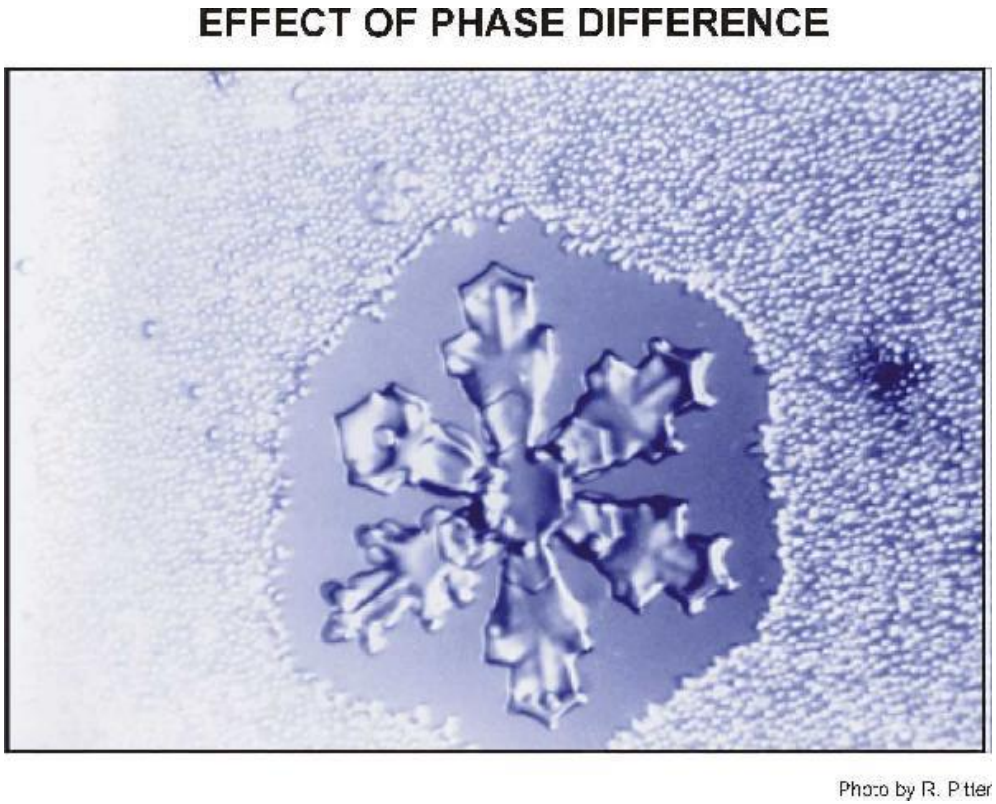
Hail Diameter > 5mm

Vapor pressure above water is higher than the vapor pressure above ice, this mean that more water molecules will be around the water drop.



Due to the fact that the Ice crystal is supersaturated and the water drop is just saturated, the ice crystal will grow on the account of the water drop growth.

Bergeron-Findeisen Process



Ice particles grow at the expense of water droplets

Weather Modification:

Deliberate human intervention to influence atmospheric processes that constitute the weather.

Artificial Weather Modification Goals:

1) Precipitation Enhancement
2) Hail Suppression
3) Hurricane Modification
4) Fog Dissipation
5) Cloud Dissipation

Cloud Seeding - Act of **adding foreign objects** to change the type and amount of precipitation that a cloud will release.

Church bells and Hail cannons

During the Middle Ages, people in Europe used to ring church bells and fire cannons to try to prevent hail, and the subsequent damage to crops.

Albert Stiger 1896
Austrian winegrower

Hail cannon market at 3rd International Congress on Hail Shooting, Lyon 1901 (Changon and Ivens, 1981).

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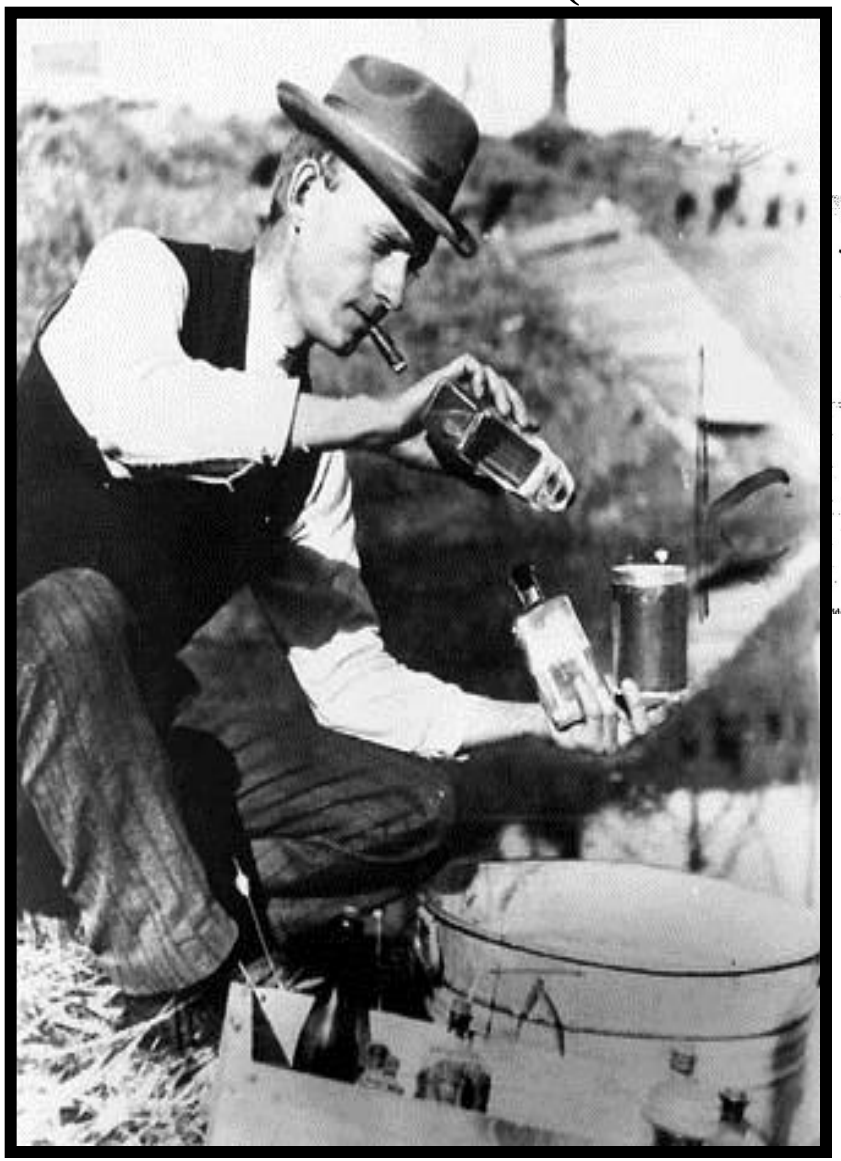
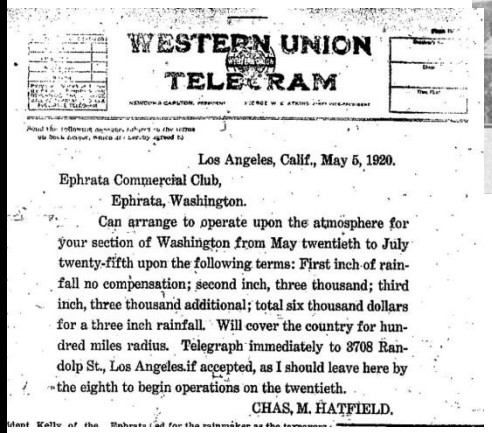
The Moisture Accelerator - The Rainmaker

Charles M. Hatfield (*1876-1958*)





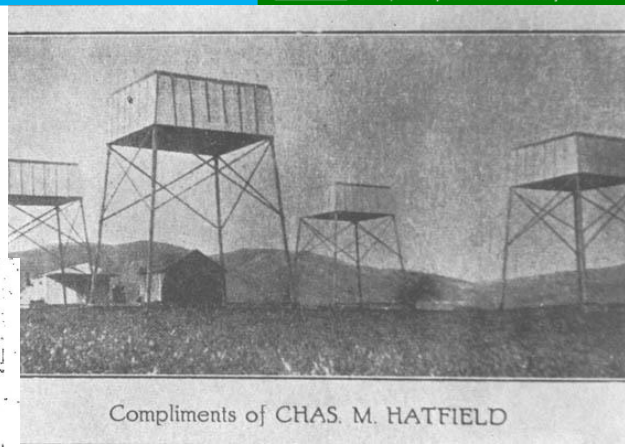
WESTERN UNION
TELEGRAM

Los Angeles, Calif., May 5, 1920.

Ephrata Commercial Club,
Ephrata, Washington.

Can arrange to operate upon the atmosphere for your section of Washington from May twentieth to July twenty-fifth upon the following terms: First inch of rainfall no compensation; second inch, three thousand; third inch, three thousand additional; total six thousand dollars for a three inch rainfall. Will cover the country for hundred miles radius. Telegraph immediately to 3708 Randolp St., Los Angeles.if accepted, as I should leave here by the eighth to begin operations on the twentieth.

CHAS, M. HATFIELD.



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Images courtesy of Washington Secretary of State, from http://blogs.sos.wa.gov/library/index.php/2012/11/a-rainmaker-meets-his-match-in-ephrata.

1946 Vincent Schaefer discovered by accident that supercooled water can be transformed into ice using dry ice (solid CO_2);

1947 Bernard Vonnegut while working for the General Electric Corporation in New York found that silver iodide (AgI) aerosols were excellent ice-nuclei.

The Nucleation of Ice Formation by Silver Iodide

B. VONNEGUT
General Electric Research Laboratory, Schenectady, New York

(Received March 17, 1947)
J. Appl. Phys. 18, 593 (1947)

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Houghton, 1985

Substance	Crystal lattice dimension		Temperature to nucleate ice (°C)
	a axis (Å)	*c* axis (Å)	
Pure substances			
Ice	4.52	7.36	0
AgI	4.58	7.49	−4

Irving Langmuir (top left), Bernard Vonnegut (top right) and Vince Schaefer.

On Nov 13, 1946, Shaeffer dropped 1.4 kg of dry ice (solid CO_2) pellets from an airplane into a supercooled stratus cloud at 14,000ft (-20ºC), flying in a race-track pattern near Schenectady, New York.

And snow fell!

Broad scale seeding -Seeding below cloud base along a predetermined line. Often ground generators are used.

Target seeding -Seeding individual clouds based on their development stage. Cannons or airplanes are often used.

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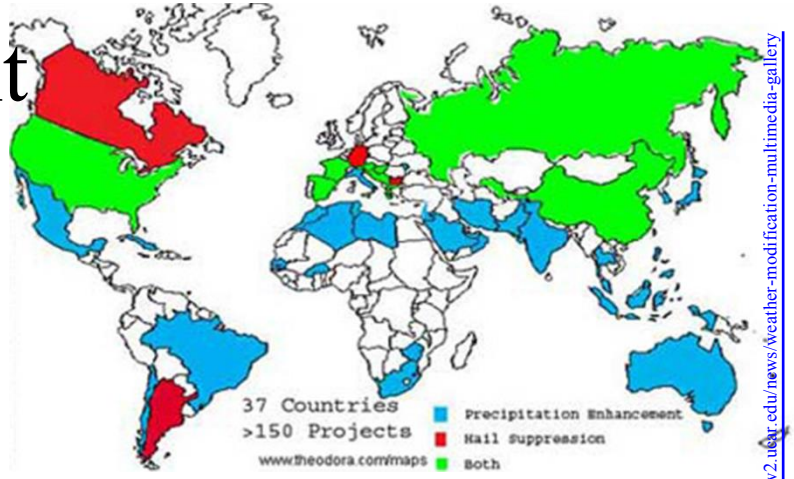
Artificial Weather Modification Goals:

1) Precipitation Enhancement
2) Hail Suppression
3) Hurricane Modification
4) Fog Dissipation
5) Cloud Dissipation



150 weather modification programs operating in 37 countries worldwide

https://www2.ucar.edu/news/weather-modification-multimedia-gallery

WMO criteria for successful experiments

1) The experiments have to be **randomized** and **evaluated by statistical methods**.
2) Success has to be judged on the basis of the **rain obtained at the ground.**
3) Statistical success of an experiment has to be **supported by physical insights and understanding**.
4) Success has to be **repeated in other areas of the world (transferability).**

National Academy of Science, 2003 : Last comprehensive report on weather modification (http://www.nap.edu/catalog.php?record_id=10829)

Both physical and statistical evaluations

Even a well designed statistical experiment will not be accepted by scientific community as being credible unless that experiment is supported by physical evidence:

1. Seeding material actually entered the cloud.
2. Seeded cloud exhibit broader droplet spectra than unseeded clouds.
3. Seeded cloud have higher drop concentrations than unseeded clouds.
4. Large amount of rainfall actually reach the ground.

Cotton and Pielke, 2007

Precipitation Enhancement - seeking to increase rainfall amount

*1.Glaciated seeding-**cold cloud seeding***

a. Static Seeding - Alter the microphysical properties of clouds by adding ice crystals (AgI or dry ice)

b. Dynamic Seeding - Attempt to modify the air motion in clouds. enhancing vertical air currents and thereby vertically process more water through the clouds

2.Hygroscopic Seeding- ***warm cloud seeding***

Adding hygroscopic material (GCCN e.g. Salt, Ammonium Nitrate, Sodium chloride) to obtain the intended result of Static or Dynamic.

Low concentration of ice crystals

Can we increase it artificially and produce more rain?

Assumption: Ice will grow faster than water drops, leading to more efficient rain formation.

Optimal for Cumulus & Winter Orographic clouds

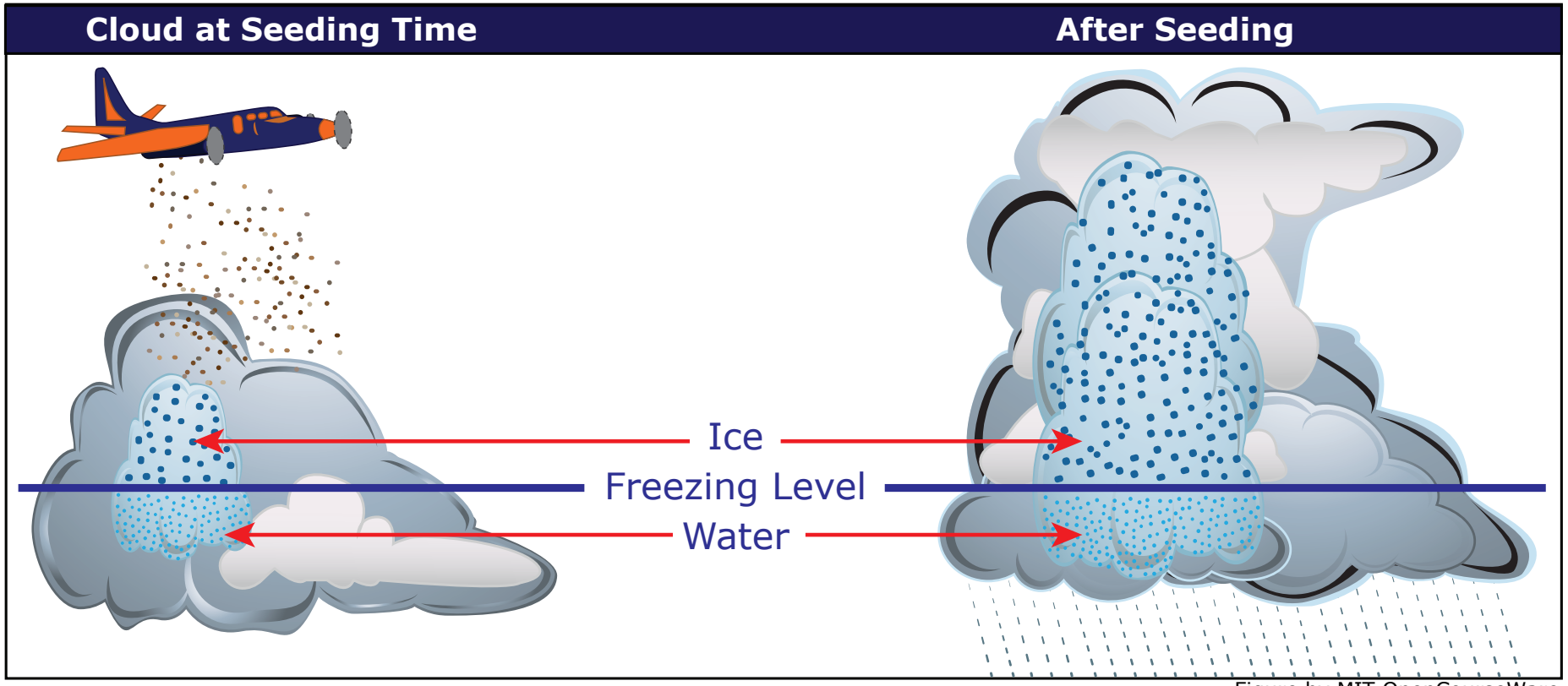


Figure by MIT OpenCourseWare.

window of opportunity :

Not all clouds may be amenable to seeding and there exists a certain window of opportunity.

For the static seeding concept this opportunity appears to be limited to:

- Clouds are relatively cold-based and *continental* type.
- Clouds top temperatures approximately -10 to -20 C.
- limited to the time when significant amounts of supercooled liquid water is available for growth by riming of the seeded produced ice crystals.

Project Cirrus - The five year experiment was born in February of 1947 at Fort Monmouth, New Jersey. It was a joint effort of the Army, Navy, Air Force, and GE

Cloud seeding did not always produce the expected results

Israel Rain Enhancement Experiments

Israel I 1961- 1968
Israel II 1969-1975
Israel III 1975-1994

Re-analysis of the cloud seeding experiment and operations in Israel shows that seeding has not produced the expected enhancement in rainfall. **seeding had little or no effect on total precipitation on the ground.**

Levin et al. 2010

The focus of the dynamic seeding of cloud seeding is to enhance the vertical air currents in clouds and thereby vertically process more water through the clouds resulting in increased precipitation.

Over Seeding

Dynamic Seeding steps

1. Supercooled liquid water converted into ice particles
2. Releasing latent heat
3. Increasing buoyancy and motivate Cloud updrafts.
4. Cloud grow larger
5. Process more water vapor
6. Yield more precipitation

The main difference between the static and dynamic seeding is in the amounts of seeding material that introduced into clouds.

static mode

dynamic mode

seeding target at temperatures warmer than -15ºC

Over Seeding

1 - 10 IC/L

100 - 1000 IC/L

200-1000g of AgI in flares dropped directly into the high supercooled liquid water content updrafts of cumuli.

Hygroscopic seeding - GCCN (Ammonium Nitrate, Sodium chloride) are released into a cloud. These particles grow until they are large enough to cause precipitation to form. Usually done on individual clouds.

Kraft paper mill in South Africa

Mather, 1991

Hygroscopic seeding for maritime cloud will have no effect, since coalescence is already very efficient in such clouds. Reisin et al. (1996) and Cooper et al. (1997)

Experiments in S. Africa, Mexico and Thailand, hygroscopic seeding seems promising under specific circumstances. Though promising, it is not well understood (National Research Council , 2003).

Seeding with Snomax

Snomax Snow Inducer is an ice-nucleating protein derived from the naturally occurring bacteria, *Pseudomonas syringae*.

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http://www.snomax.com/

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http://www.snomax.com/english/environment.html

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Rain enhancement by cloud ionization

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Please see: http://climateviewer.com/wp-content/uploads/2014/03/desert-rain-110104c-02.jpg.

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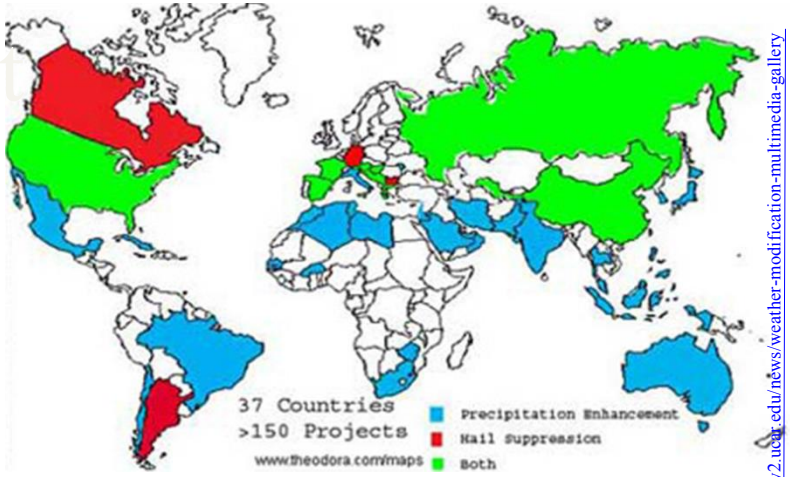
According to WMO report weather-modification technologies such as "ionization methods" **had no sound scientific basis and "should be treated with suspicion"**

Artificial Weather Modification Goals:

1) Precipitation Enhancement
2) **Hail Suppression**
3) Hurricane Modification
4) Fog Dissipation
5) Cloud Dissipation



150 weather modification programs operating in 37 countries worldwide

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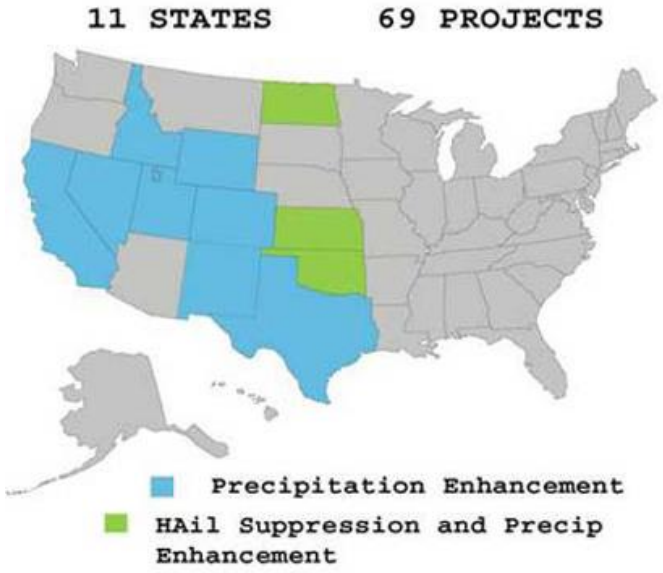
2. Hail Suppression

Summary of 2010 Weather Events, Fatalities, Injuries, and Damage Costs

Weather Event	Fatalities	Injuries	Property Damage (million $)	Crop Damage (million $)	Total Damage (million $)
Convection					
Lightning	29	182	71.13	0.45	71.58
Tornado	45	699	1,106.92	27.64	1,134.57
Thunderstorm Wind	15	325	214.04	10.56	224.61
Hail	0	42	924.11	99.82	1,023.93



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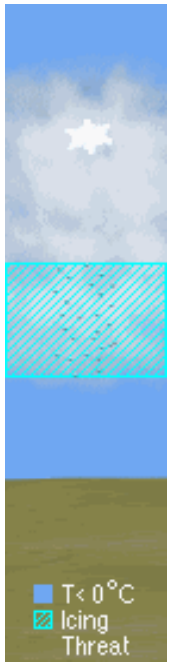

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Major hail risk area in Europe (Berz and Siebert, 2000)

Over seeding

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The idea is to reduce the average size of the hailstones and to increases the number of small ice particles competing for the available supercooled droplets.

Switzerland project "**Grossversuch IV**" (1977-1981)

research groups from Switzerland, Italy and France

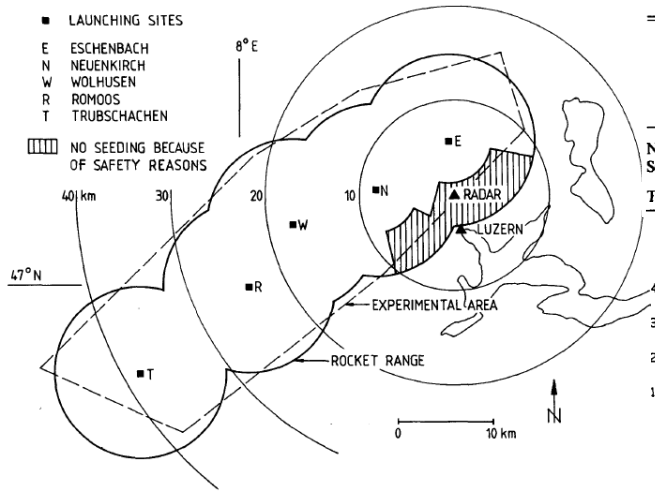
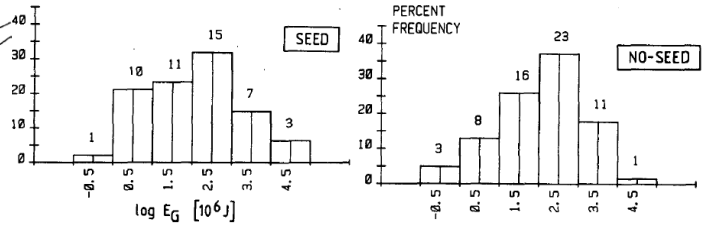


TABLE 3. Number of hail days and experimental cells (derived from radar) for each operational year, the total for each year, the total for the period 1977–81 (confirmatory analyses) and for the period 1977–82 (future exploratory analyses).

Random-ization	1977		1978		1979		1980		1981		Total 1977–81		1982		Total 1977–82	
	Days	Cells	Days	Cells	Days	Cells	Days	Cells	Days	Cells	Days	Cells	Days	Cells	Days	Cells
No-seed (*N*)	7	18	12	31	11	34	4	18	9	21	43	122	3	18	46	140
Seed (*S*)	9	26	8	16	4	12	4	11	8	29	33	94	4	19	37	113
Total	16	44	20	47	15	46	8	29	17	50	76	216	7	37	83	253



"The main result is that there is no statistically significant difference between seeded and unseeded hail cells".

According the American Meteorological Society (AMS):

- The ***efficacy*** of projects intended to mitigate the severity of hailstorms remains ***indeterminate***.
- Statistical assessments of certain operational projects indicate ***successful reduction of crop hail damage***.
- ***Scientific*** establishment of ***cause and effect are incomplete.***
- Results of various operational and experimental projects provide a range of outcomes. Some suggest ***decreases*** in hailfall (reduction of 20-50%), while others have produced inconclusive results, and some suggest ***increases***.

Our understanding of hailstorms is not yet sufficient to allow confident prediction of the effects of seeding individual storms, and the most appropriate seeding methodology has not been determined.

People who do not know history are doomed to repeat it (Wieringa and Holleman, 2006)

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Please see: http://www.hailcannon.com.

Spain
Canada
Belgium
Italy
France
Austria
Tibet
Australia
New Zealand
The Netherlands
United States

Hail cannons

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Please see:http://www2.ljworld.com/photos/2008/sep/23/155789/ and http://realneo.us/content/hail-cannon.

There is neither a scientific basis nor a credible hypothesis to support the use of cannons (WMO, 2001).

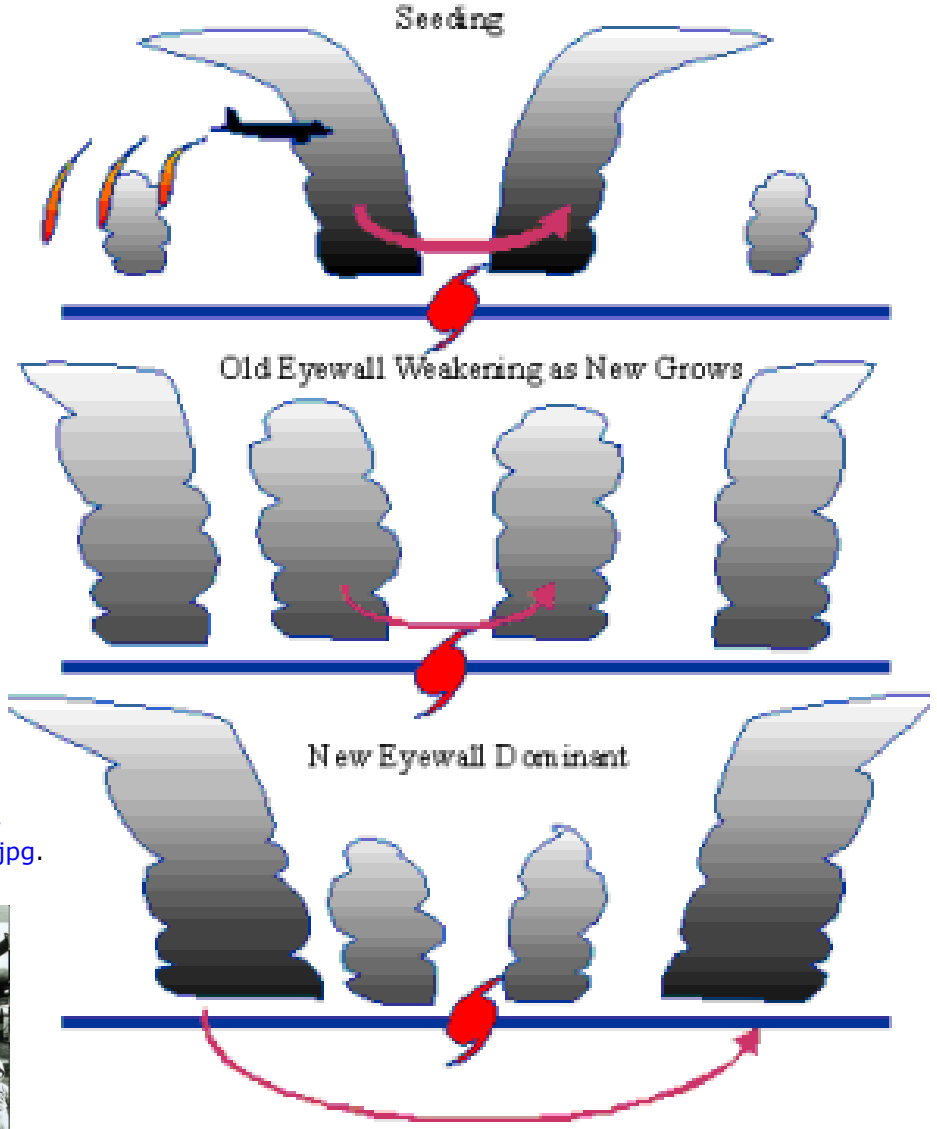
These images have been removed due to copyright restrictions.
Please see: http://cloud-seeding.eu/images/slides/generators/ground_generator_start.jpg and http://cloud-seeding.eu/documents_pic/88/small-rocket-big.jpg.

Hail cannons or ionization devices, have no physical basis and are not recommended for Hail suppression (WMO, 2007).

Artificial Weather Modification Goals:

1) Precipitation Enhancement
2) Hail Suppression
3) Hurricane Modification
4) Fog Dissipation
5) Cloud Dissipation

The general strategy is to reduce the intensity of the storm by seeding the outside the eye wall. This will lead to form a new eye wall that would surround the existing eye wall and therefore reduce the intensity of the hurricane.



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Project Cirrus
(1947)

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Project STORMFURY
(1962 – 1983)

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Since a hurricane's destructive potential increases rapidly as its strongest winds become stronger, a reduction as small as 10% would have been worthwhile.

- There is **no generally accepted conceptual model** for modifying tropical disturbances.
- Hurricane modification experiments of the 1950s and 1960s **were inconclusive**.
- **No sound physical hypotheses** exist for the modification of tornadoes, or of damaging winds in general, and **no scientific experimentation has been conducted.**

Artificial Weather Modification Goals:

1) Precipitation Enhancement
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4. Fog Dissipation

Salt Lake City

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Heathrow Airport

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Please see: http://pandawhale.com/post/11343/fog-before-amp-after.

Heathrow, 2006. About 350 flights cancelled (50%) during Christmas holiday. 40,000 people affected

Tenerife, 1977
Collision in heavy fog
583 people killed.

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Please see Figures 9 and 10. Vardiman, L, E. D. Figgins, and H. S. Appleman, 1971: Operational Dissipation of Supercooled Fog using Liquid Propane. Journal of Applied Meteorology and Climatology 10: 515–25.

Seeding from the ground
Mainly with dry ice

5. Cloud Dissipation

”Russian government spent 64 million rubles ($20 million) to “dissipate” clouds in Moscow in preparation for Moscow’s “birthday” celebration.

“it never rains during the May Day parade”

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CO_2 (in the form of dry ice), liquid nitrogen and a powdered cement reagent called “cement m-500.”

2008 Olympics open ceremony in Beijing, no rain by breaking up clouds headed towards Beijing and forcing them to drop rain on outlying areas instead.

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Operation and Maintenance

This is an expensive technology to operate, requiring sophisticated equipment, control and monitoring procedures, and materials, including:

- cloud-seeding airplane
- measurement and monitoring plane
- communications plane for experimental and monitoring purposes
- aircraft maintenance
- hanger facilities
- meteorological radar
- air sounding equipment
- computer system and data analysis software
- rain gauge network and automatic weather stations
- suitable cloud formations.

Estimated $1 billion spent world-wide per year on some type of modification

Costs - The cost of water produced is about $1.50/m^3/season/ha (United Nations, 1985).

This cost is made up of scientific equipment and hardware costs; flying costs for cloud seeding (capital and operational, including maintenance or hire charges); salaries for scientists and pilots; the cost of seeding agents and flares; and, software costs (for experimental and monitoring purposes).

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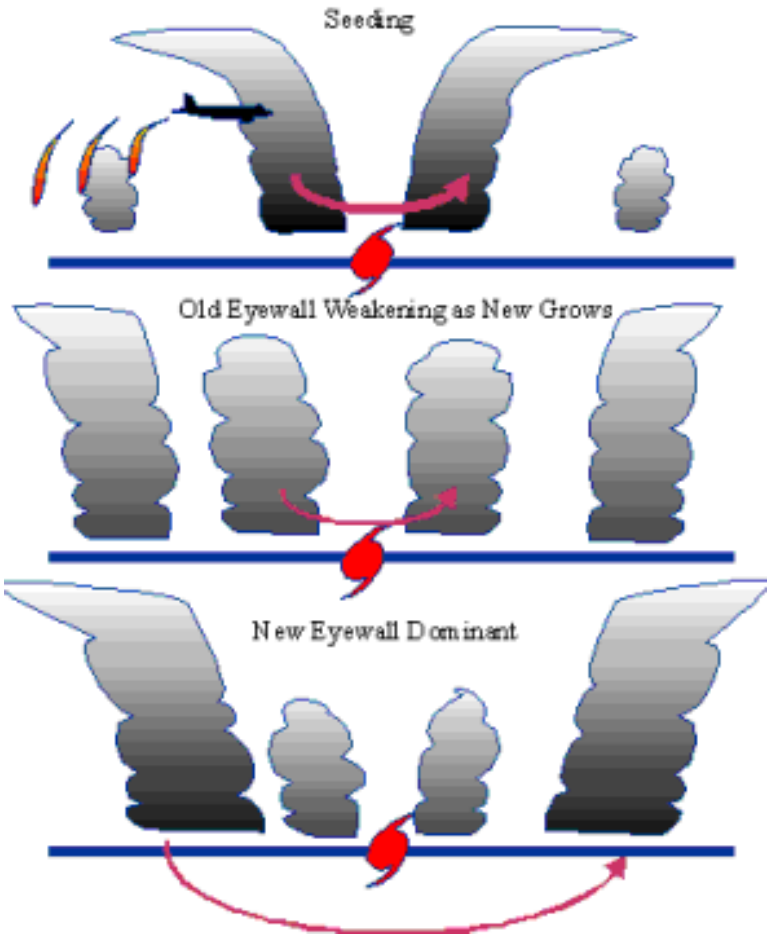

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This image has been removed due to copyright restrictions. It's about how to measure hail.
Please see: http://www.cocorahs.org/Media/images/hailpad_large_md.jpg.

12.335/12.835 Experimental Atmospheric Chemistry

Fall 2014