12.335/12.835 – Special Topics: Aerosol and Cloud Section

Special Topic:

Weather Modification

Thursday, Dec 4, 2014
Graupe & Hail

Rain

Snow

Graupe & Hail

Riming = Accretion

Aggregation

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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

EFFECT OF PHASE DIFFERENCE

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Weather Modification:

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


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1946 Vincent Schaefer discovered by accident that supercooled water can be transformed into ice using dry ice (solid CO₂);

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

<table>
<thead>
<tr>
<th>Substance</th>
<th>a axis (Å)</th>
<th>c axis (Å)</th>
<th>Temperature to nucleate ice (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ice</td>
<td>4.52</td>
<td>7.36</td>
<td>0</td>
</tr>
<tr>
<td>AgI</td>
<td>4.58</td>
<td>7.49</td>
<td>-4</td>
</tr>
</tbody>
</table>

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 14,000 ft (-20ºC), flying in a race-track pattern near Schenectady, New York. And snow fell!
Definitions for cloud seeding

**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.
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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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).

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.
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.

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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
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.
Examples for Cold-cloud seeding- Static seeding

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

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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**
- Seeding target at temperatures warmer than -15°C
- 1 - 10 IC/L

**dynamic mode**
- Over Seeding
- 100 - 1000 IC/L
- 200-1000g of AgI in flares dropped directly into the high supercooled liquid water content updrafts of cumuli.
1. Precipitation Enhancement - *Warm-cloud seeding*

**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*.

http://www.snomax.com/
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:

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### 2. Hail Suppression

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

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

**11 STATES 69 PROJECTS**

- Precipitation Enhancement
- Hail Suppression and Precipitation Enhancement

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

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2. Hail Suppression

Over seeding

The idea is to reduce the average size of the hailstones and to increase 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

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</thead>
<tbody>
<tr>
<td>No-seed (N)</td>
<td>7</td>
<td>18</td>
<td>12</td>
<td>31</td>
<td>11</td>
<td>34</td>
<td>4</td>
<td>18</td>
<td>9</td>
<td>21</td>
<td>43</td>
<td>122</td>
<td>3</td>
<td>18</td>
<td>46</td>
<td>140</td>
</tr>
<tr>
<td>Seed (S)</td>
<td>9</td>
<td>26</td>
<td>8</td>
<td>16</td>
<td>4</td>
<td>12</td>
<td>4</td>
<td>11</td>
<td>8</td>
<td>29</td>
<td>33</td>
<td>94</td>
<td>4</td>
<td>19</td>
<td>37</td>
<td>113</td>
</tr>
<tr>
<td>Total</td>
<td>16</td>
<td>44</td>
<td>20</td>
<td>47</td>
<td>15</td>
<td>46</td>
<td>8</td>
<td>29</td>
<td>17</td>
<td>50</td>
<td>76</td>
<td>216</td>
<td>7</td>
<td>37</td>
<td>83</td>
<td>253</td>
</tr>
</tbody>
</table>

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

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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**.
Hail Suppression

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

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

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
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3. Hurricane Modification

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.

Project Cirrus
(1947)

Project STORMFURY
(1962 – 1983)
Hurricane Modification – does it work?

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:

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4. Fog Dissipation

Heathrow Airport

Salt Lake City

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

Tenerife, 1977
Collision in heavy fog
583 people killed.

Seeding from the ground
Mainly with dry ice

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Please see: http://photos1.blogger.com/blogger/2067/3930/400/Imagem2.0.png.

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5. Cloud Dissipation

“it never rains during the May Day parade”

It never rains during the May Day parade.

CO₂ (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.
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.

Costs - The cost of water produced is about $1.50/m³/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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