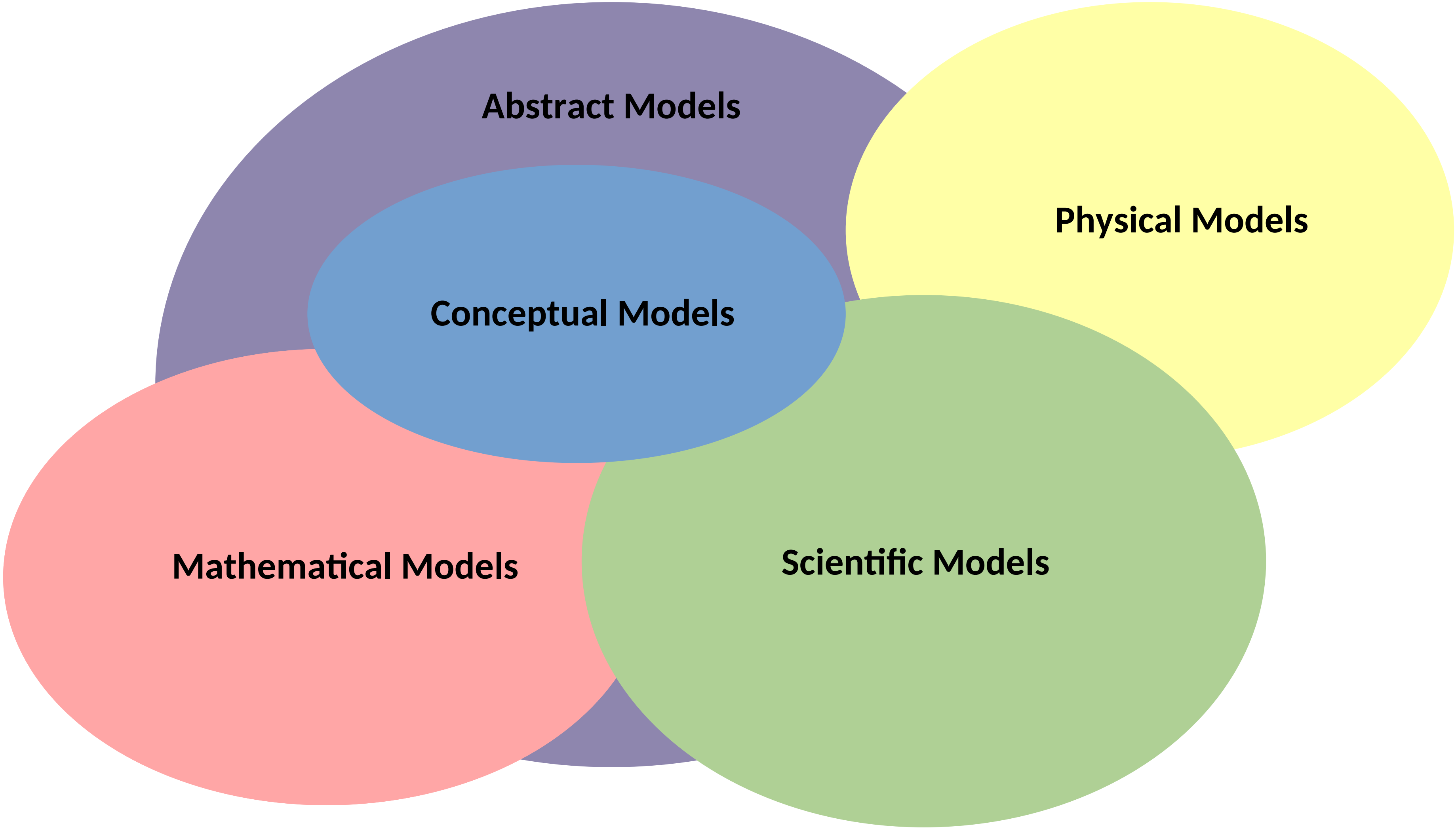
Precipitation Augmentation Conceptual Models



Cloud Seeding Conceptual Models

- Enhancing the cold rain process through addition of ice particles.
- Enhancing the warm rain process by addition of giant Cloud Condensation Nuclei (CCN).
- Increasing the cloud depth through release of latent heat of fusion.
- Promoting the merger of small clouds into larger clouds through release of latent heat of fusion.

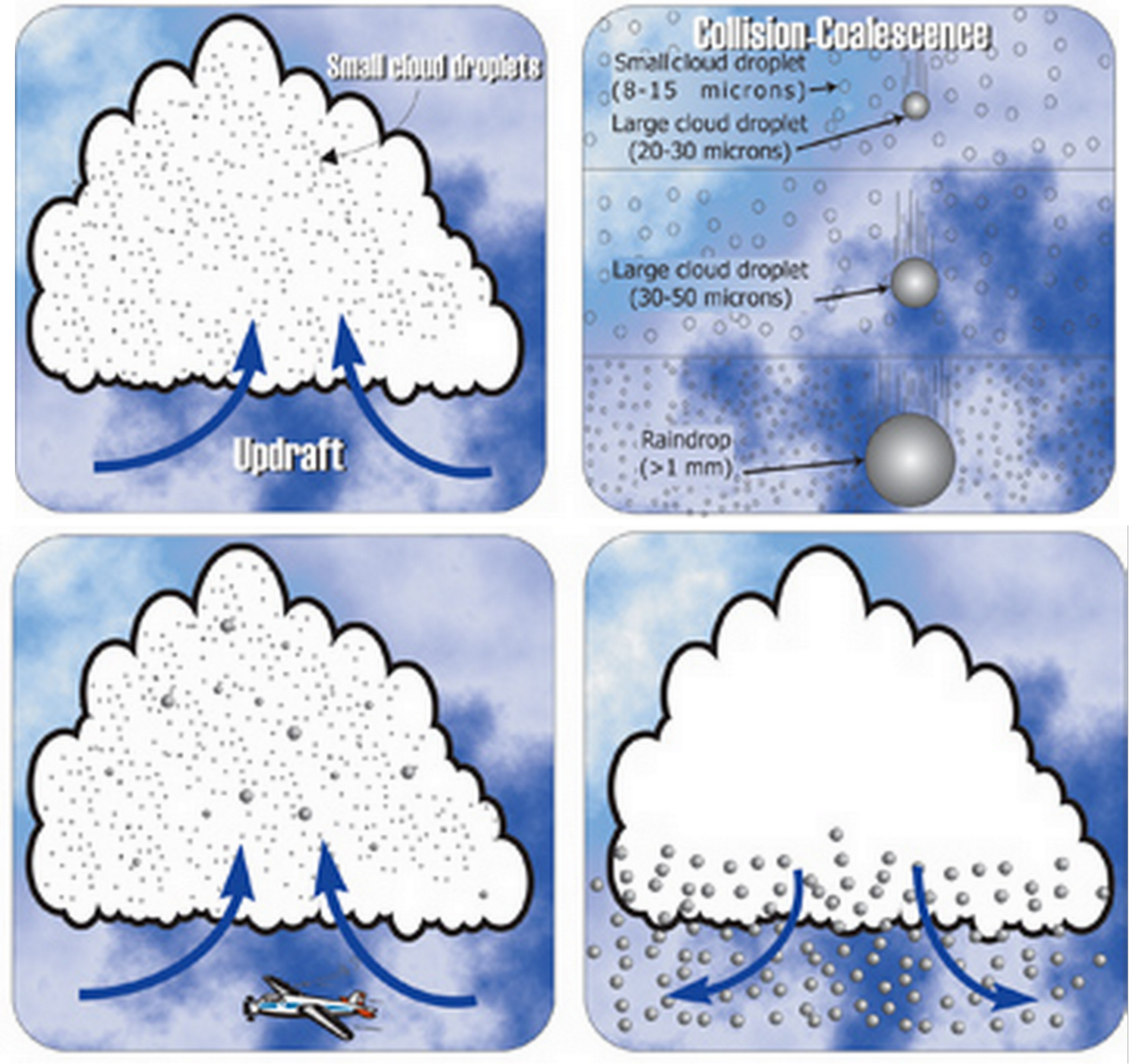
Micro-physical Effects to Increase Rainfall

- The goal is to make the cloud more efficient.
- Efficiency is equal to the fraction of inflow water vapor that fall out as precipitation.
  - 0 % efficiency mean there is no rainfall.
  - 100 % efficiency means all water vapor is converted to rainfall with no vapor/liquid/ice left behind.

Warm Cloud Rain Increase (Hygroscopic Seeding)

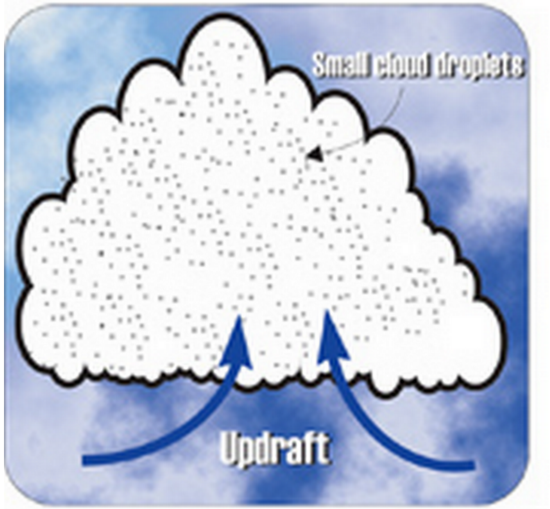
Natural Warm Precipitation

Cloud Seeding Precipitation

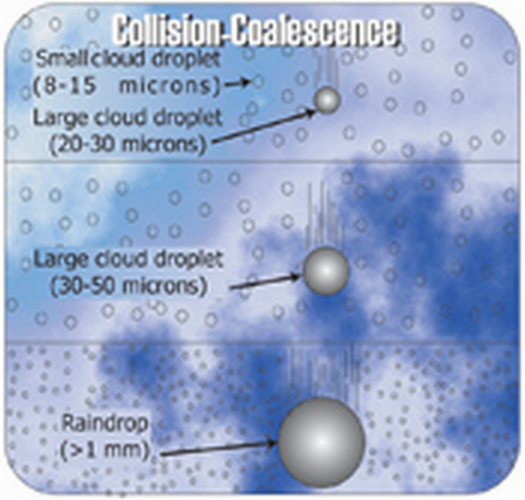


Natural Warm Precipitation Process

- Rain formation begins when water molecules in a cloud condense on naturally occurring nuclei to produce small cloud droplets.



- Cloud droplets grow by collision-coalescence process once droplets are about 20-30 um in diameter.



Cloud Seeding Precipitation Process

- Hygroscopic Seeding accelerates the collision-coalescence process.
  - Hrgroscopic flares are burned at cloud base to release nuclei into the cloud.
  - The hygroscopic nuclei produce larger cloud droplets enhancing the collision-coalescence process.
  - Once drops are large enough, their terminal velocity cause them to fall.

Cloud Seeding for Dynamic Effects

- Under some conditions, the additional buoyancy due to the release of latent heat of fusion could be significant.
- This was the conceptual model used in the Florida Area Cumulus Experiment (FACE).

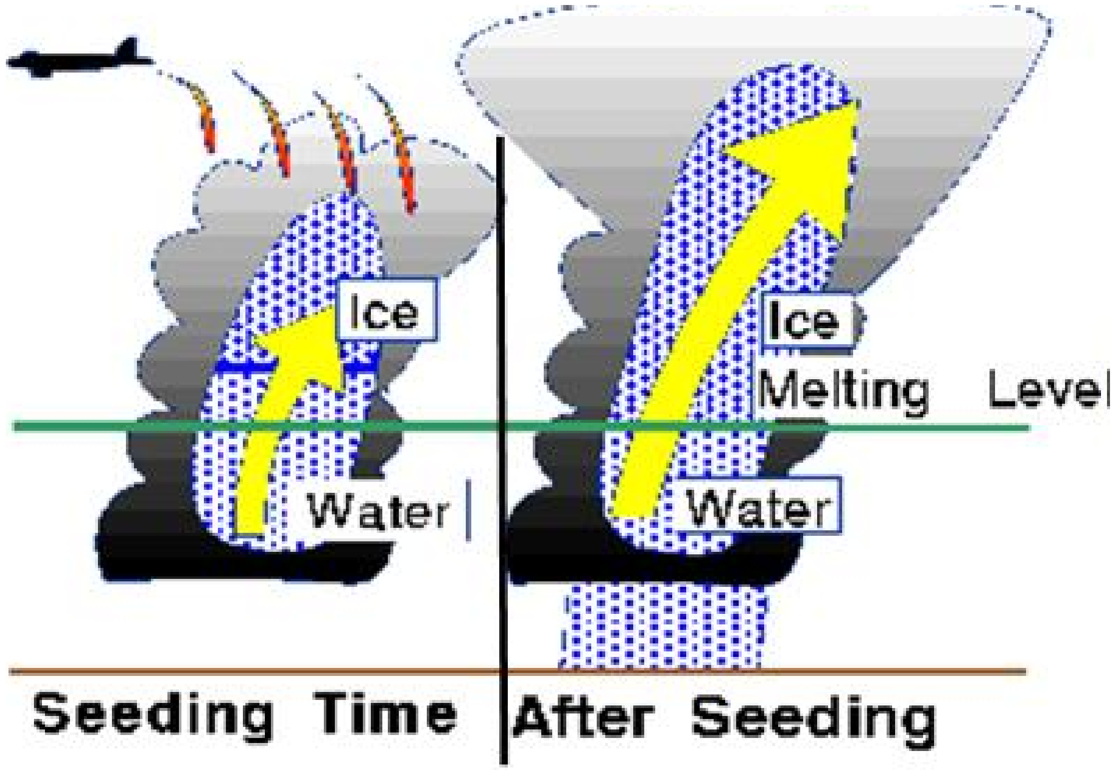


Diagram of the seeding of the upper part of a cloud by airplane, after which more rain is hoped to develop (graphic: NOAA Hurricane Research Division).

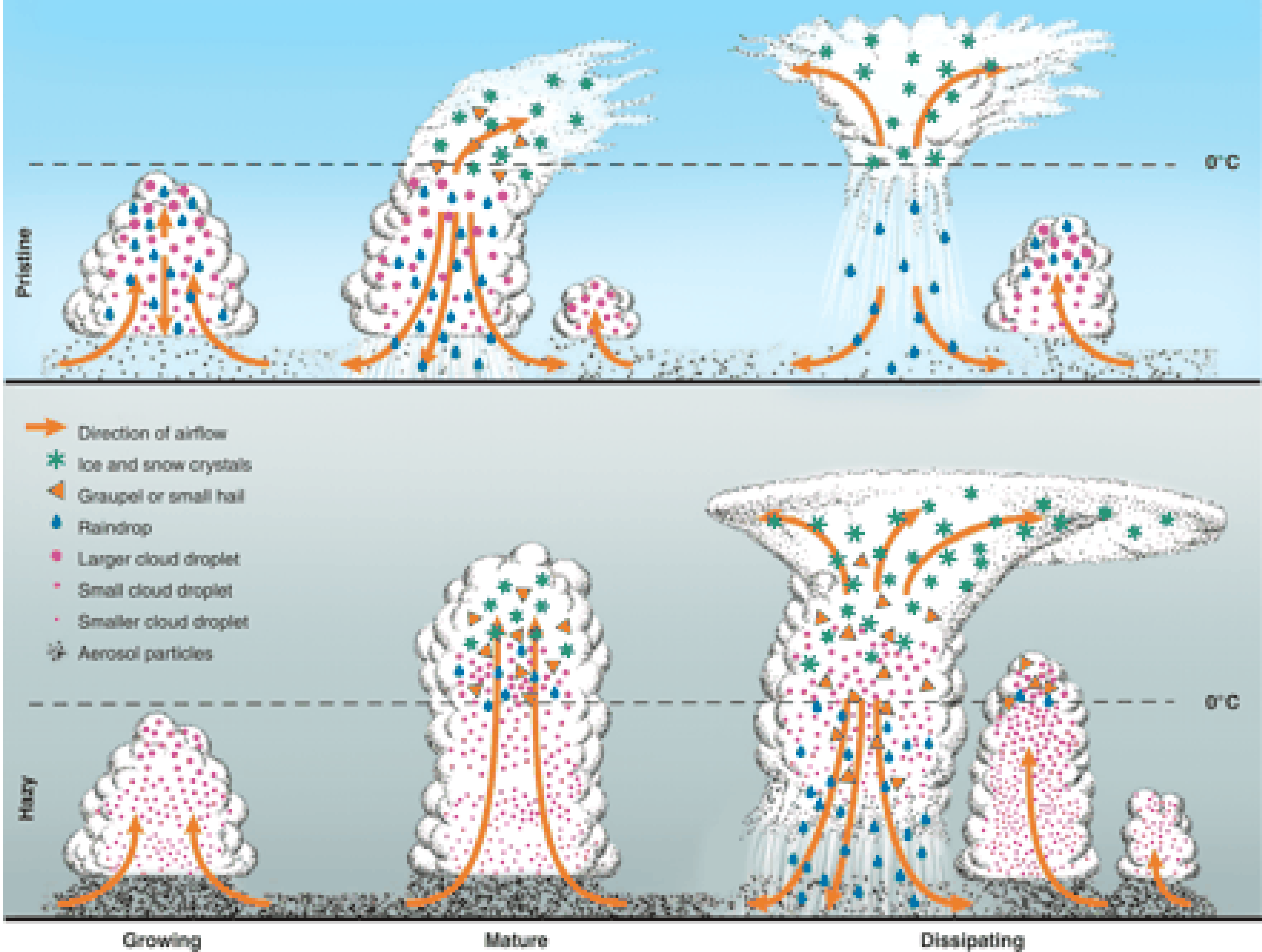
Florida Area Cumulus Experiment
FACE - Project

- Many times there was a weak Trade-wind inversion that kept clouds from growing.
- Tried to seed clouds with enough seeding material such that the updrafts would break through the inversion and grow to much greater heights.
- Early results appeared to be successful.

Dynamic Effects with Hygroscopic Seeding

- By introducing hygroscopic nuclei below cloud base,
  - Earlier release of the latent heat of vaporization.
  - This might result in a more organized and stronger updraft.
  - This has not been documented.
- May also change water loading dynamics.

Dynamic Effects of CCN



Over-seeding: Cloud Condensation Nuclei

- Attempt to transform a maritime cloud into a continental cloud.
- To get 100 nuclei per cm^{-3}, need to add NaCl particles of radius 2 μm.
- Each particle would have a mass of $(4/3)\pi r^3\rho = 6.7\text{x}10^{-14}$ kg.
- Each volume (cm^3) of cloud must have $6.7\text{x}10^{-12}$ kg of NaCl.

Cloud Condensation Nuclei (CCN) Required

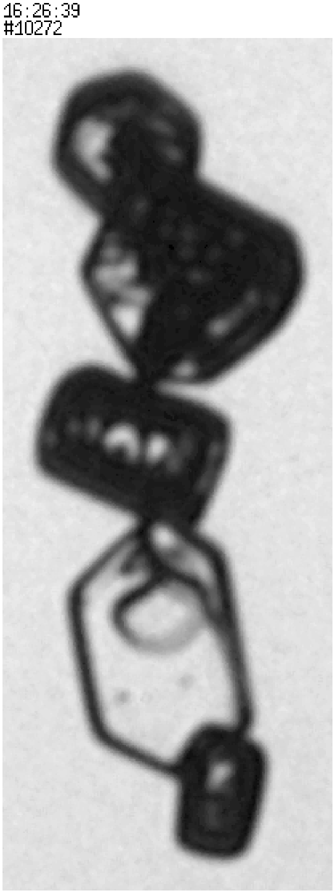
- Take a moderate-sized cumulus cloud that is 3 km tall and 2 km on a side.
- This would have a volume of approximately 3x2x2 = 12 $km^3 = 1.2 \times 10^9\ m^3 = 1.2 \times 10^{15}\ cm^3$.
- Since each volume (cm^3) of cloud needed 6.7×10^{-12} kg of NaCl, the cloud would need.
  - $(6.7 \times 10^{-12}) \times (1.2 \times 10^{15}) = 8.4 \times 10^3$ kg.
    - Approximately 8 tons!!
  - Obviously, this amount would not be very practical.

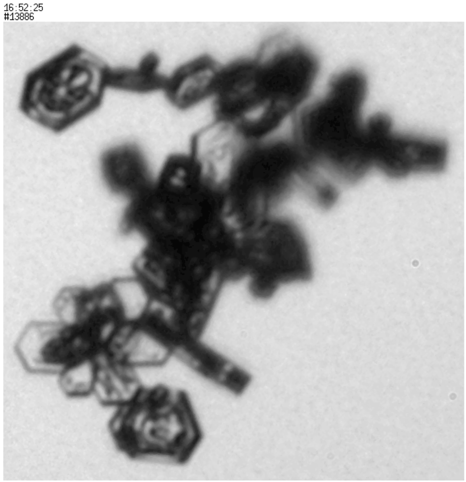
Over-seeding: Ice Nuclei (IN)

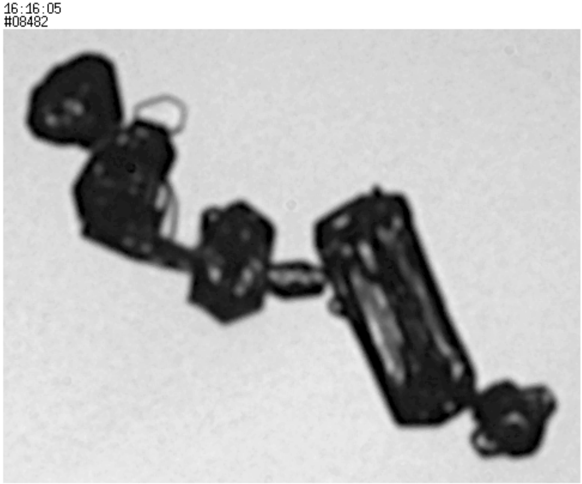
- Attempt to get thousands of ice crystals per liter.
  - Ice crystals will grow, but will be small.
  - Terminal velocities will be small so that they will not fall out as rapidly.
  - Resulting precipitation will fall out farther downwind of original precipitation location.

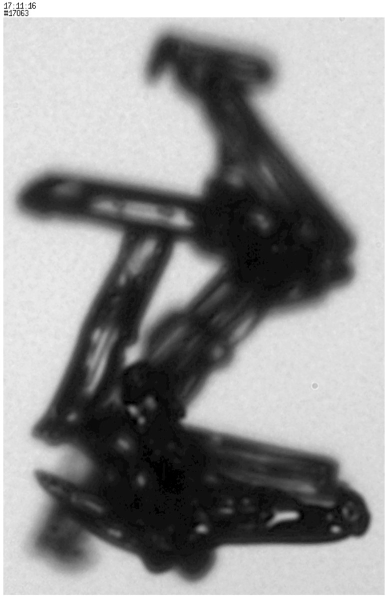
Overseeding Attempts in Lee of Lake Erie

- Few experimental cases were seeded.
  - Appeared to be successful in that the desired numbers of ice crystals were formed.
  - Not successful in that the crystals formed large aggregates and fell rapidly.









Numerical Cloud Seeding Models

- Outgrowth of conceptual models.
- Can be used to better understand what the seeding effects might be.
- Can also be used to predict what the natural precipitation would be.

Uses of Numerical Cloud Seeding Models

- The main difficulty in trying to evaluate a weather modification program is the extreme variability of the precipitation events (primary response variable).
- Once a cloud has been seeded, there is no way of knowing what the cloud would have done had it not been seeded (or vice versa).

Uses of Numerical Models

- If a large fraction of the variance in the natural precipitation can be accounted for by a model, the response variable can be redefined as the (actual precipitation) - (model-predicted precipitation).
- This new response variable will have (hopefully) a smaller variance and any differences due to seeding will be easier to demonstrate.

Use of Co-variates

- Numerical models require other inputs, such as soundings, winds, etc.
  - The inputs are referred to as co-variates.
- Some of the models might be quite simple, such as

  $$P = a \times LI + b,$$

  Where a and b are constants and P is the precipitation and LI is the Lifted Index.