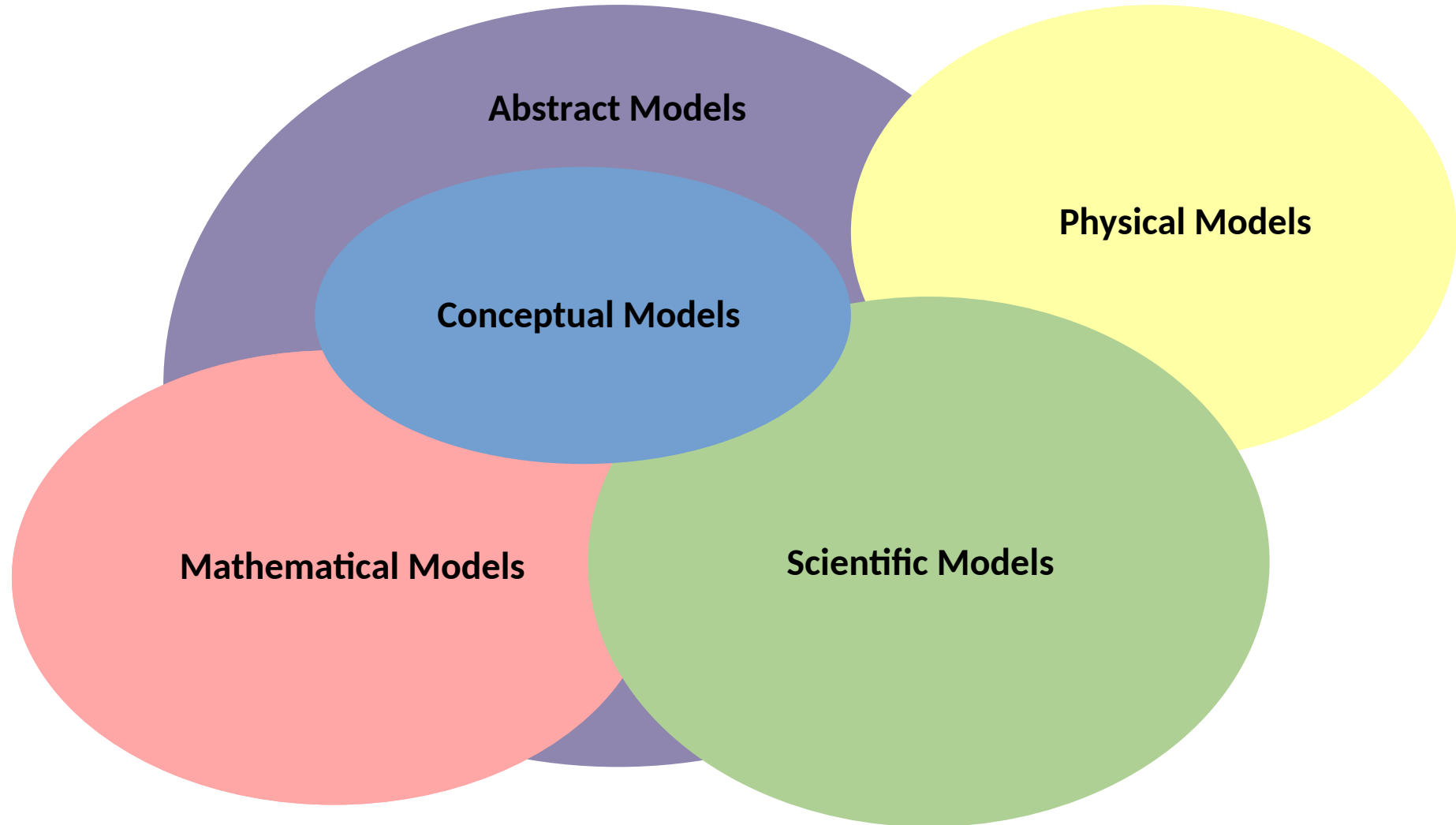


Precipitation Augmentation Conceptual Models

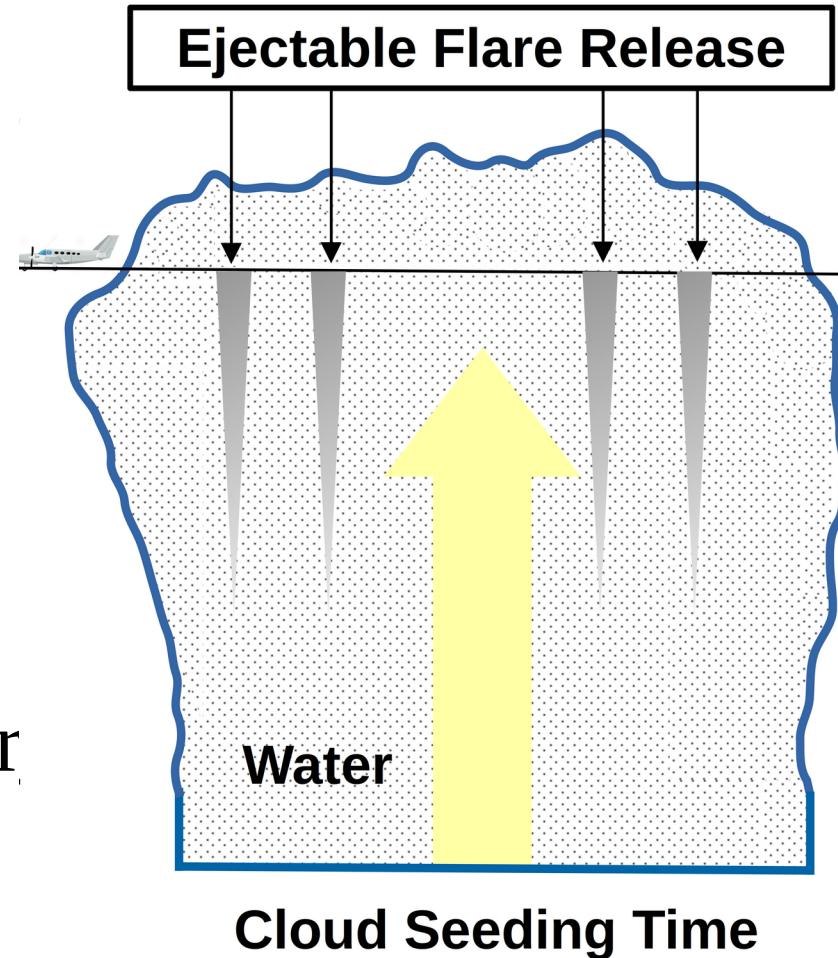


Cloud Seeding Conceptual Models

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

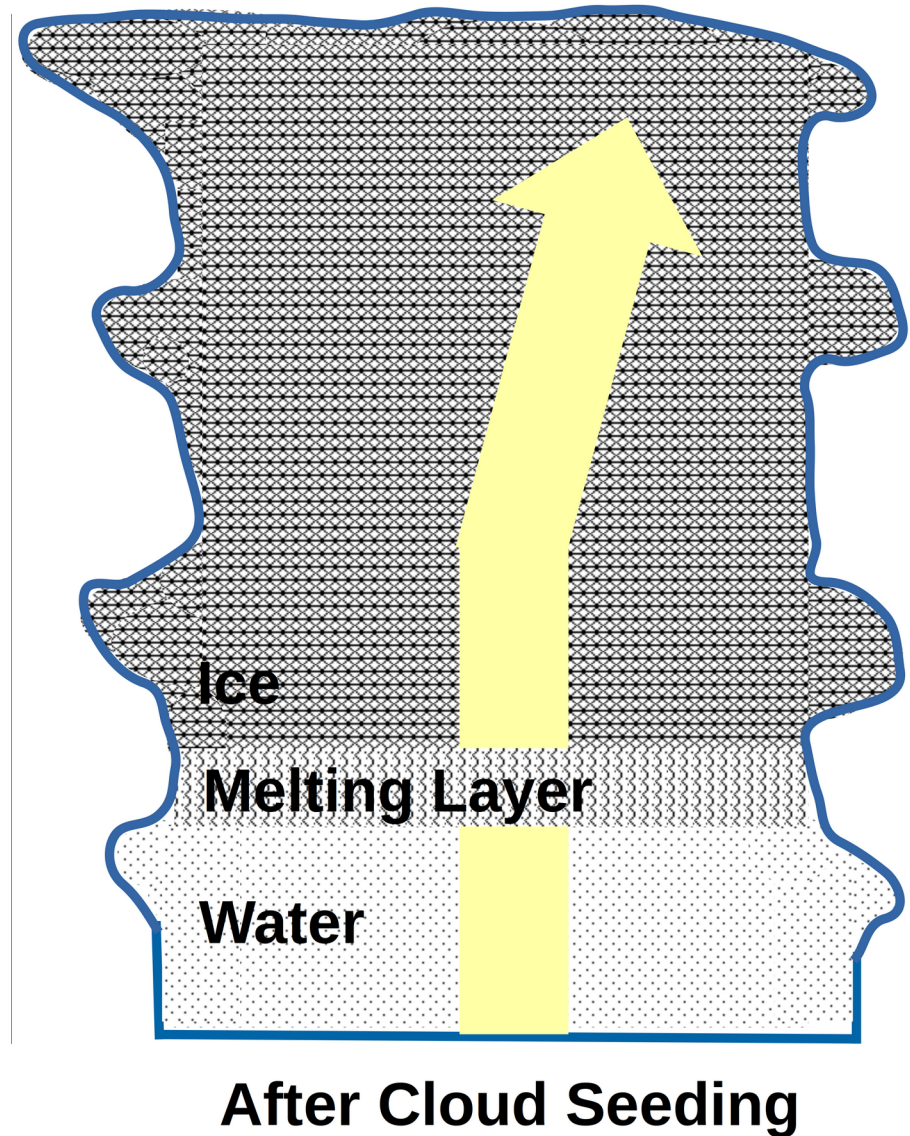
Micro-physical Effects to Increase Rainfall

- 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 vapor is converted to rainfall with no vapor, liquid, or ice left behind.

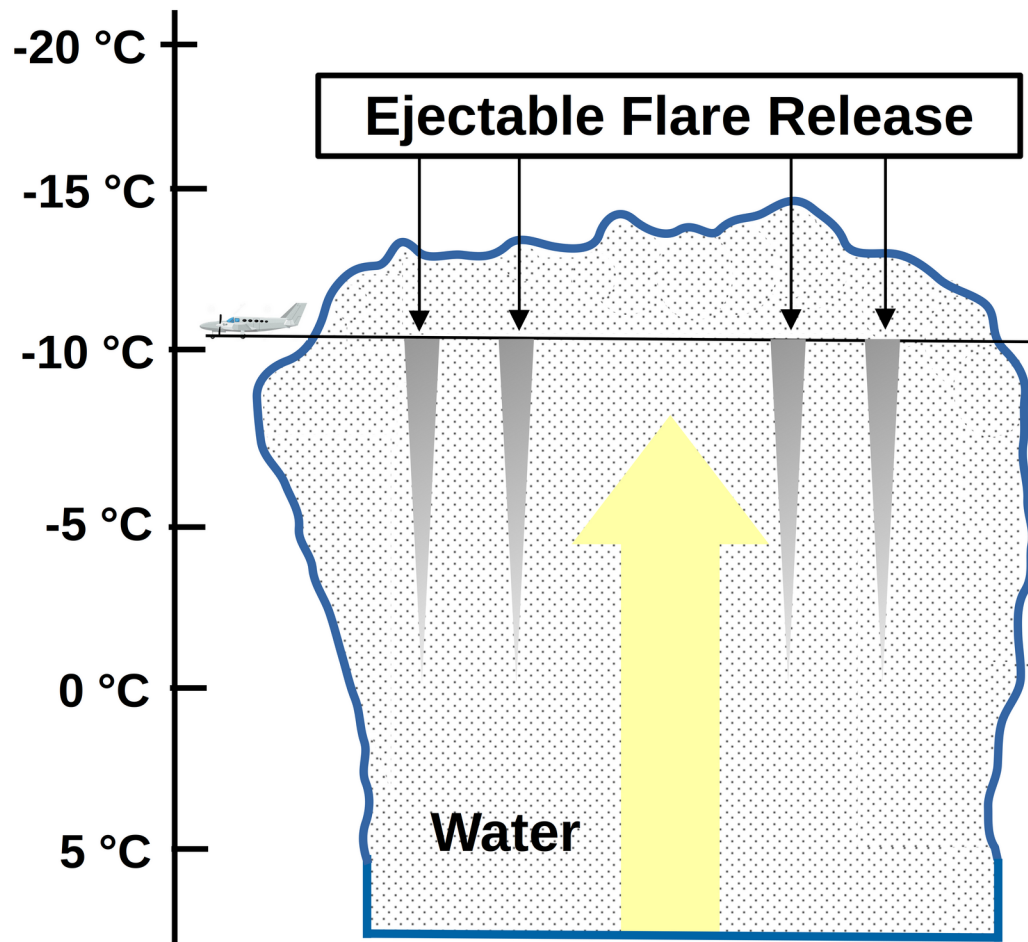


Dynamic Effect to Increase Rainfall

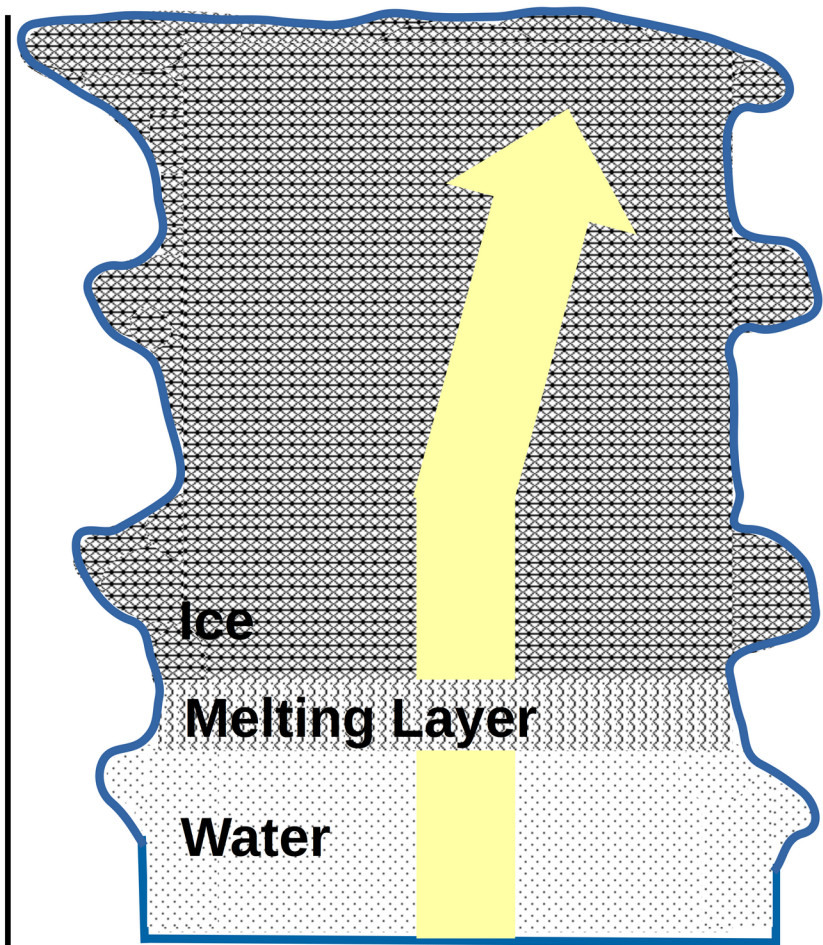
- The additional buoyancy due to the release of latent heat of fusion could be significant.
- This was the conceptual model used for Florida Area Cumulus Experiment (FACE).



Seeding to Increase Rainfall



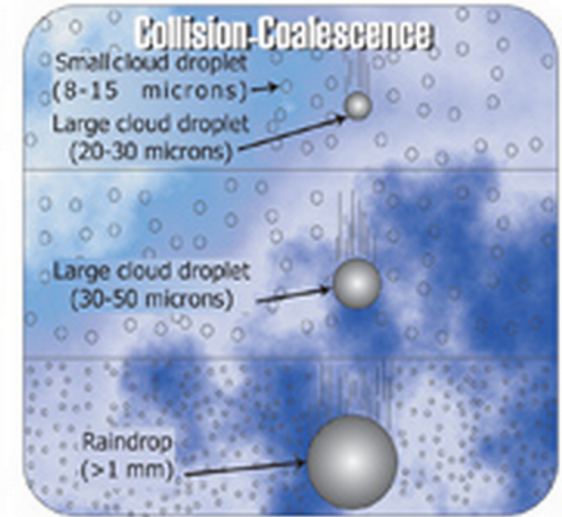
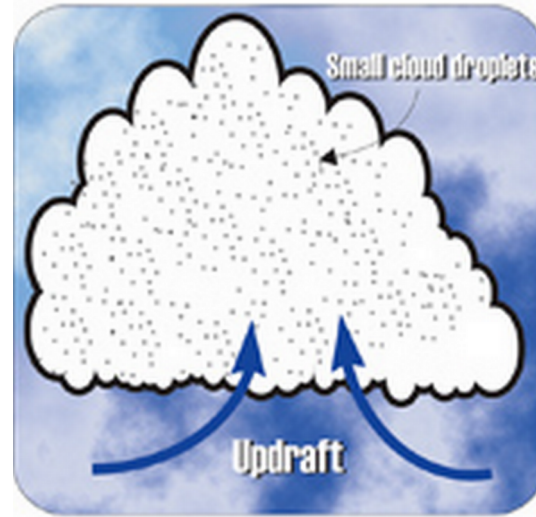
Cloud Seeding Time



After Cloud Seeding

Warm Cloud Rain Increase (Hygroscopic Seeding)

**Natural Warm
Precipitation**

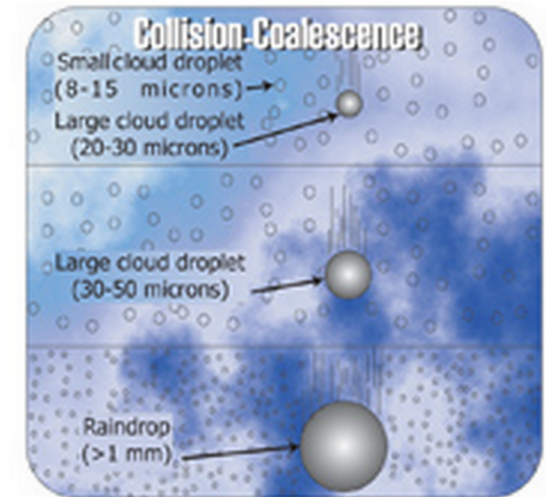
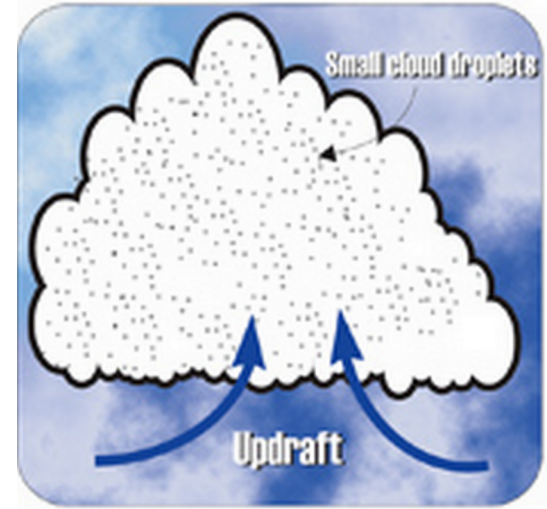


**Cloud Seeding
Precipitation**



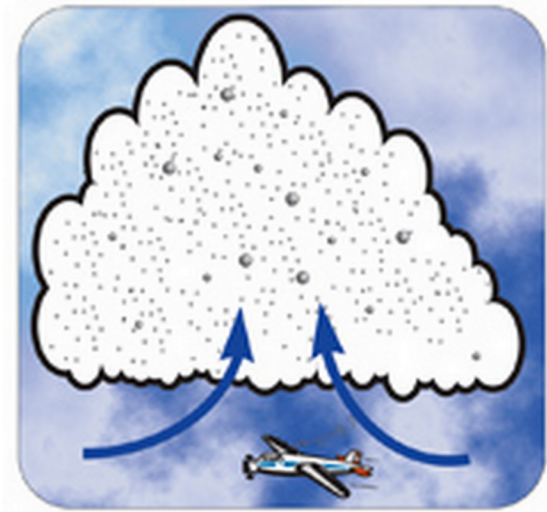
Natural Warm Precipitation Process

- 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 μm in diameter.



Cloud Seeding Precipitation Process

- Hygroscopic Seeding accelerates the collision-coalescence process.
- Hygroscopic 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.



Florida Area Cumulus Experiment

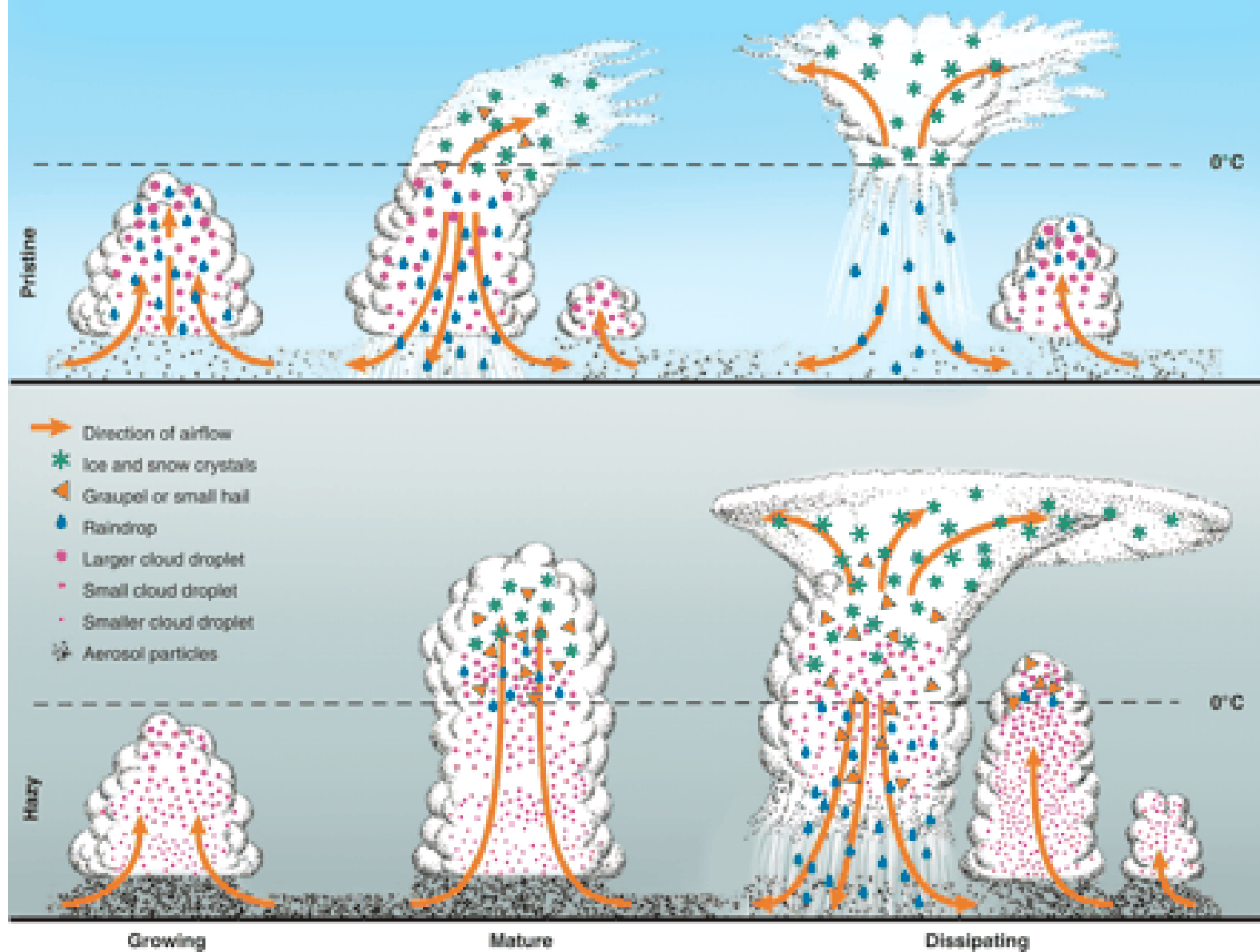
FACE - Project

- 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 $2\text{ }\mu\text{m}$.
- Each particle would have a mass of $(4/3)\pi r^3 \rho = 6.7 \times 10^{-14}\text{ kg}$.
- Each volume (cm^3) of cloud must have $6.7 \times 10^{-12}\text{ kg}$ 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 $3 \times 2 \times 2 = 12 \text{ km}^3 = 1.2 \times 10^9 \text{ m}^3 = 1.2 \times 10^{15} \text{ cm}^3$.
- Since each volume (cm^3) of cloud needed $6.7 \times 10^{-12} \text{ kg}$ of NaCl, the cloud would need.
 - $(6.7 \times 10^{-12}) \times (1.2 \times 10^{15}) = 8.4 \times 10^3 \text{ kg}$.
 - Approximately 8 tons!!
- Obviously, this amount would not be very practical.

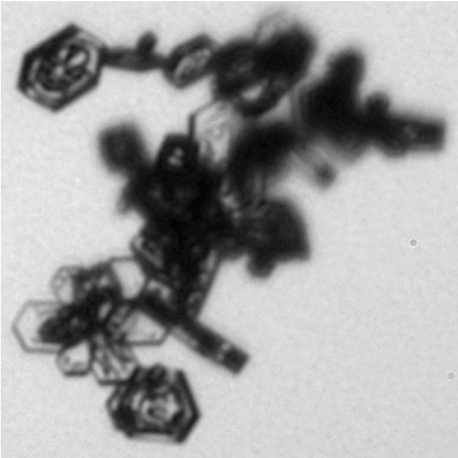
Over-seeding: Ice Nuclei (IN)

- 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.

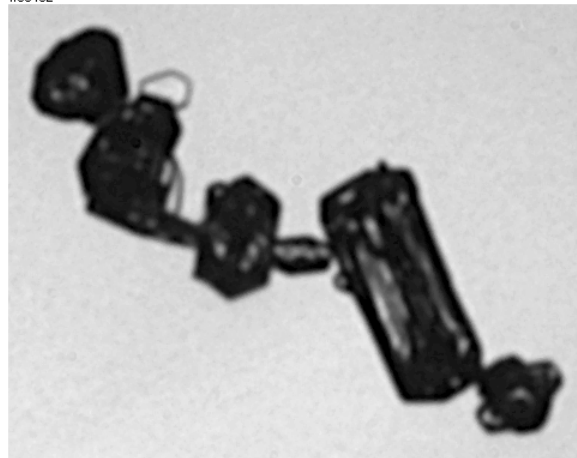
Overseeding Attempts in Lee of Lake Erie

- 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.

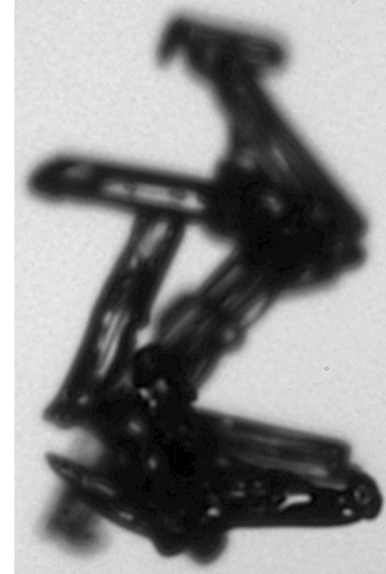
16:52:25
#13886



16:16:05
#08482



17:11:16
#17063



16:26:39
#10272



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.