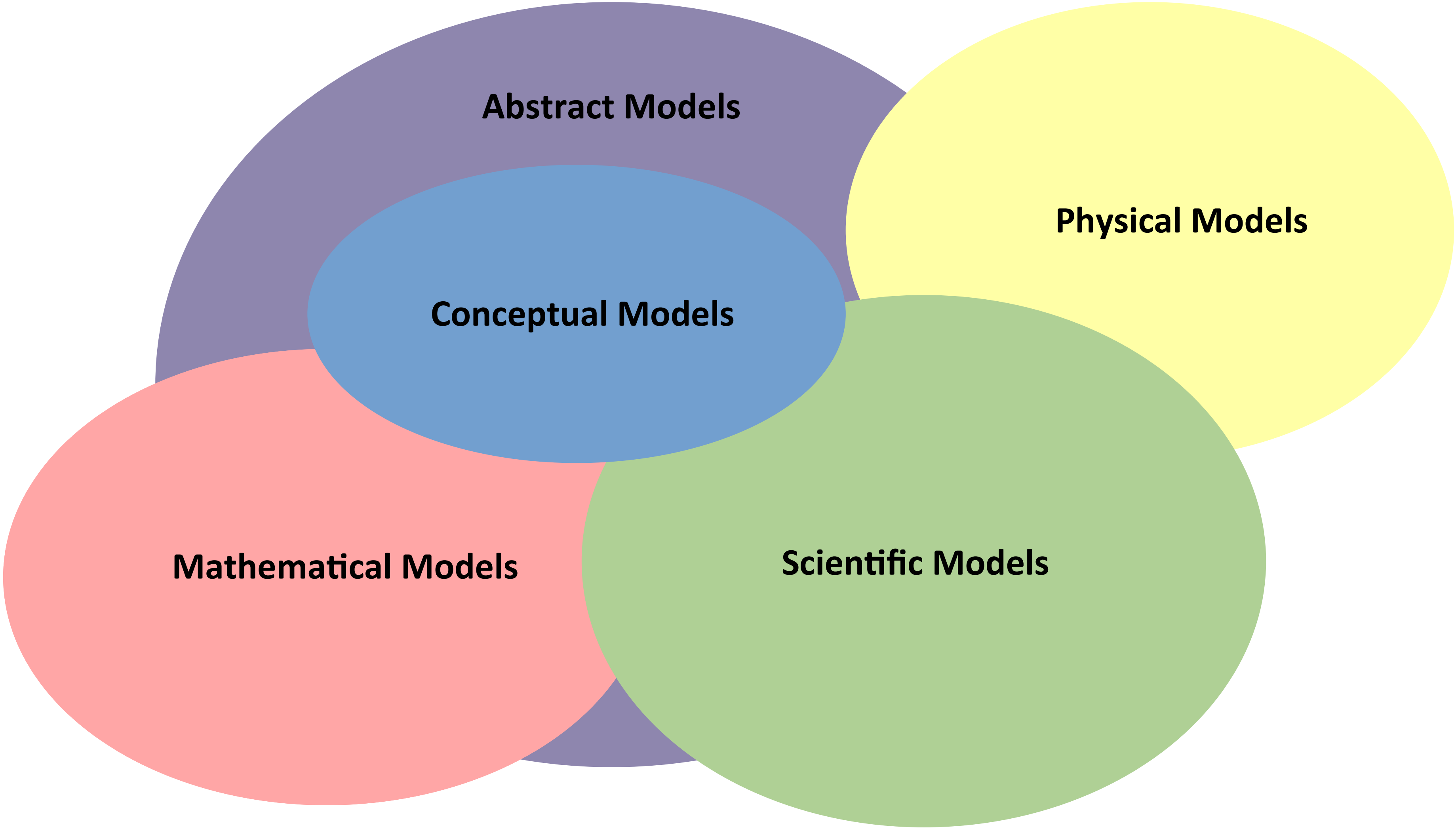
Precipitation Augmentation Conceptual Models

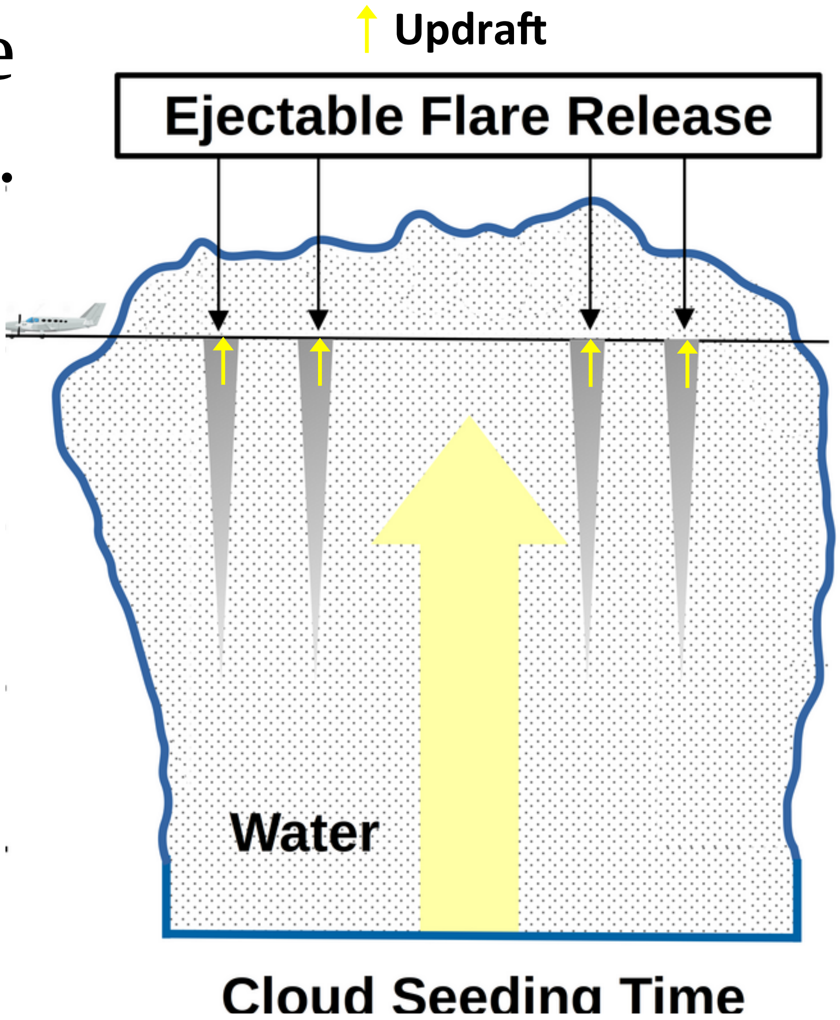


Cloud Seeding Conceptual Models

- 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).

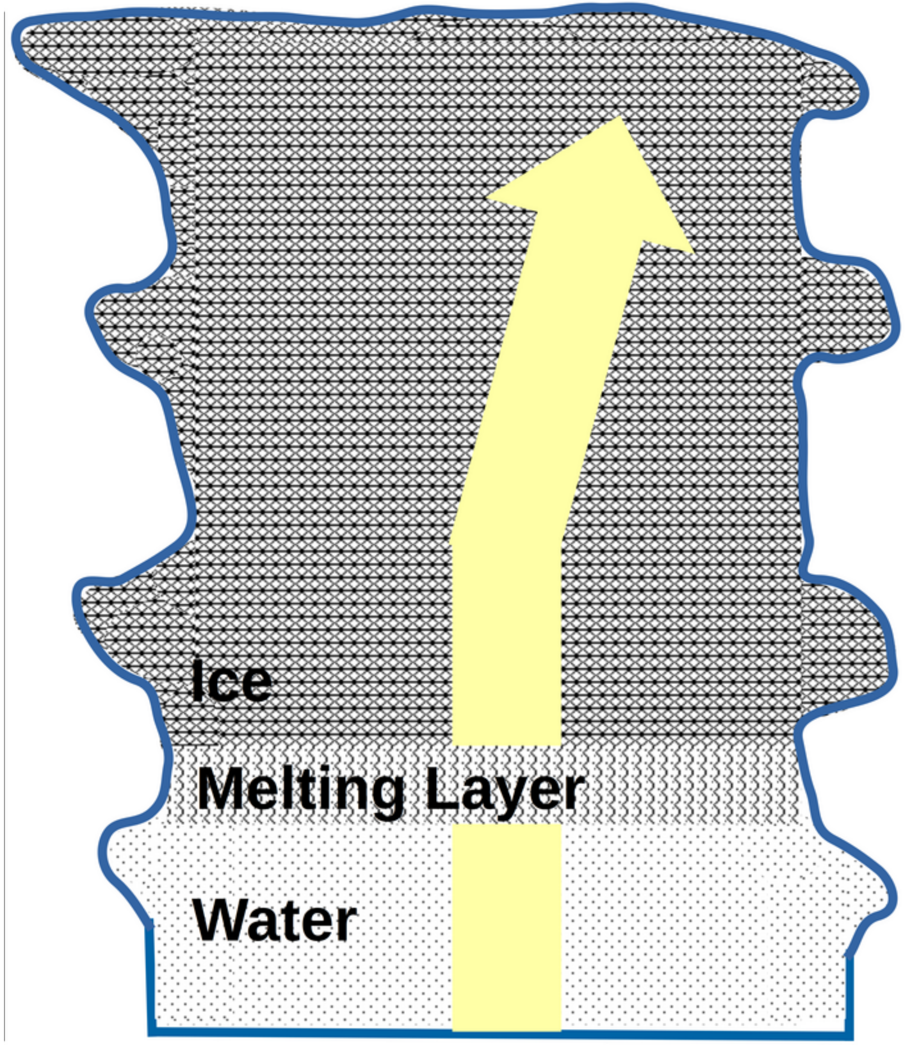
Micro-physical Effects to Increase Rainfall

- The goal is to make the cloud more efficient at producing precipitation.
- Precipitation 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.



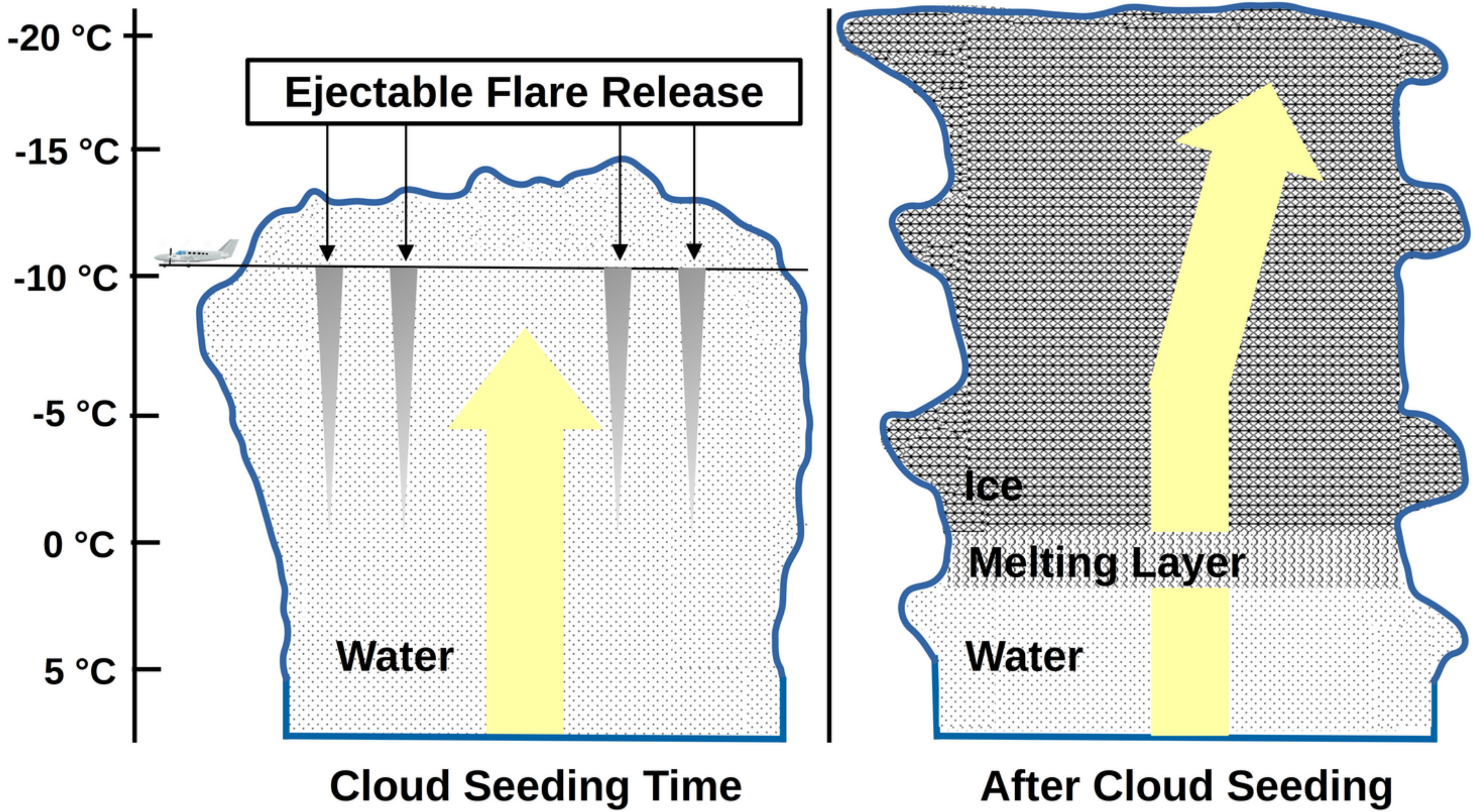
Dynamic Effect to Increase Rainfall

- 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).



After Cloud Seeding

Seeding to Increase Rainfall



Warm Cloud Rain Increase (Hygroscopic Seeding)

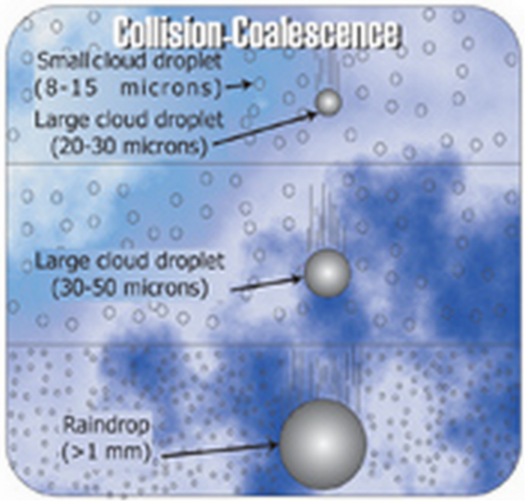
Natural Warm Precipitation

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.
  - 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.

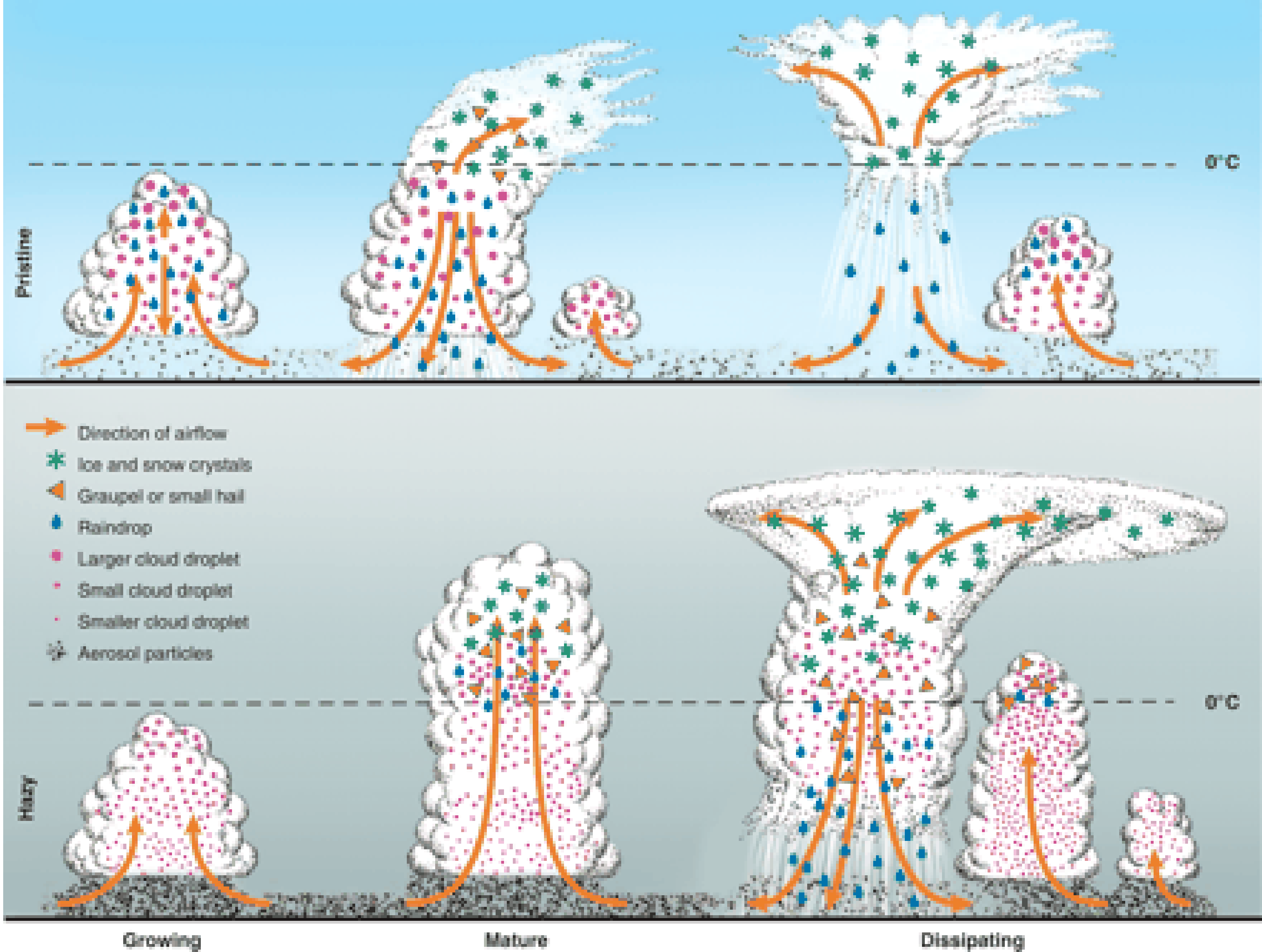
Florida Area Cumulus Experiment FACE - Project

- 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 µm.**
- Each particle would have a mass of $(4/3)\pi r^3 \rho = 6.7\times10^{-14}$ kg.
- Each volume (cm^3) of cloud must have 6.7×10^{-12} kg of NaCl.

Cloud Condensation Nuclei (CCN) Required

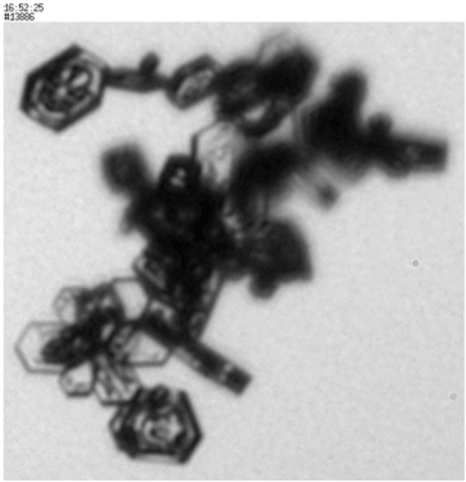
- Take a moderate-sized cumulus cloud that is 3 km tall and 2 km on a side.
- This would have a volume of approximately 3x2x2 = 12 km^3 = $1.2x10^9$ m^3 = $1.2x10^{15}$ cm^3.
- Since each volume (cm^3) of cloud needed $6.7x10^{-12}$ kg of NaCl, the cloud would need.
  - ($6.7x10^{-12}$) x ($1.2x10^{15}$) = $8.4x10^3$ kg.
    - Approximately 8 tons!!
  - Obviously, this amount would not be very practical.

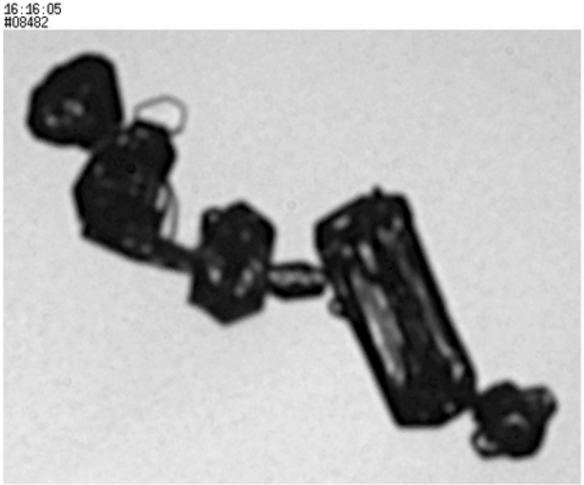
Over-seeding: Ice Nuclei (IN)

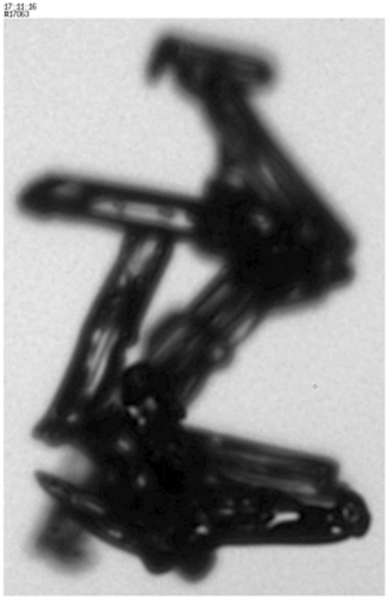
- Attempt to get thousands of ice crystals per liter.
  - Ice crystals will grow, but will be small.
  - Terminal velocities will be small so that they will not fall out as rapidly.
  - Resulting precipitation will fall out farther downwind of original precipitation location.

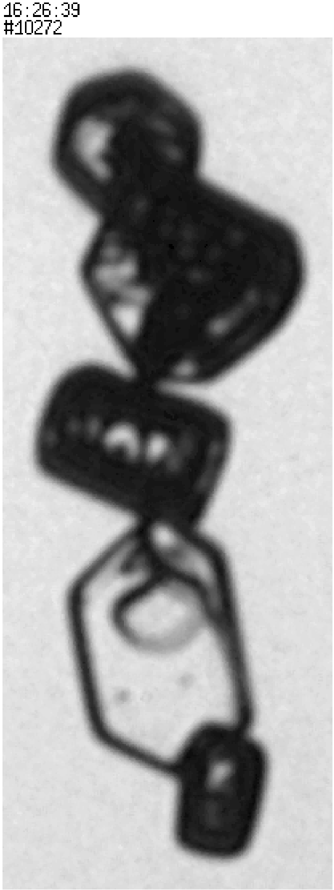
Over-seeding Attempts in Lee of Lake Erie

- 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.