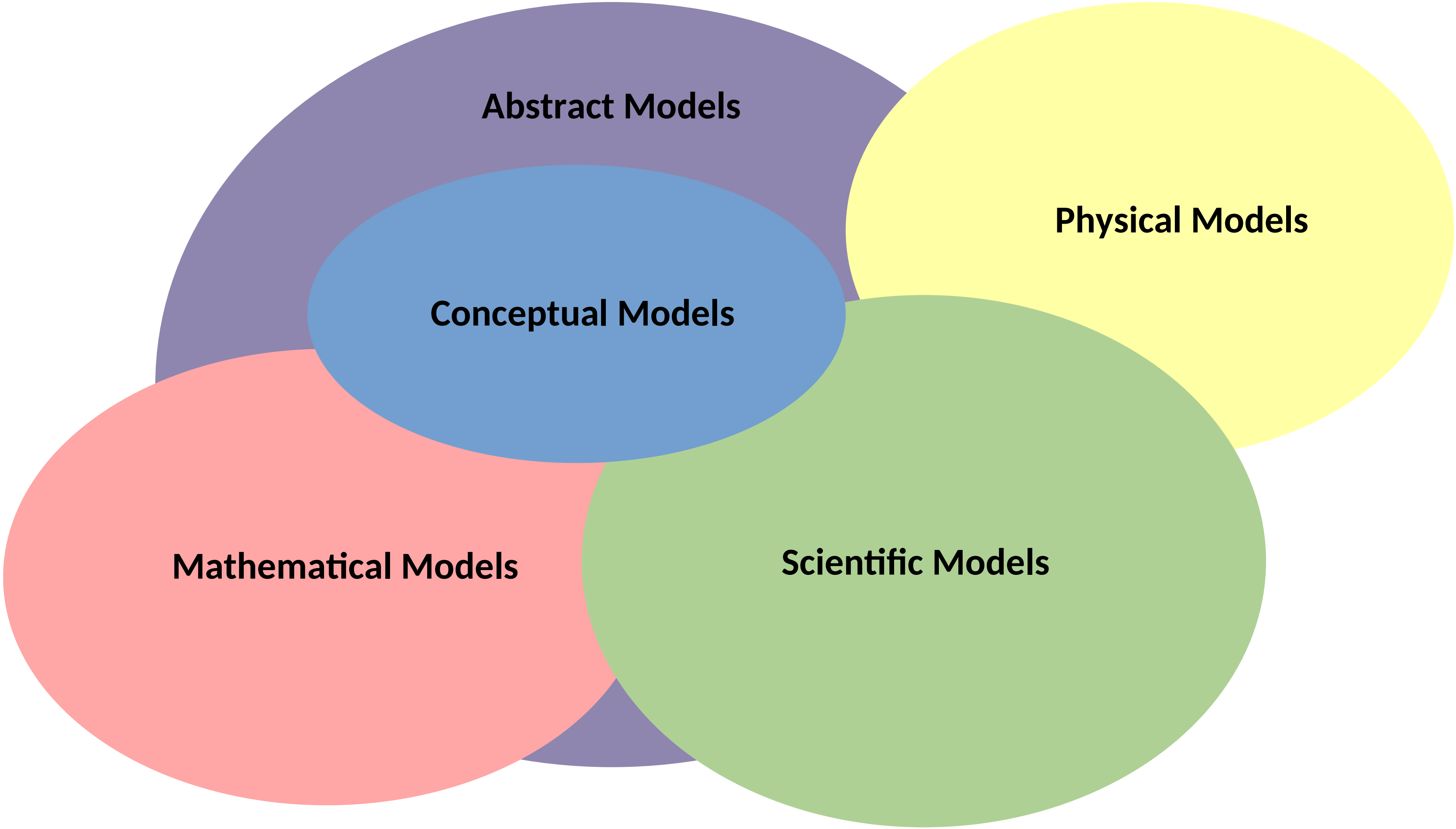
Precipitation Augmentation Models



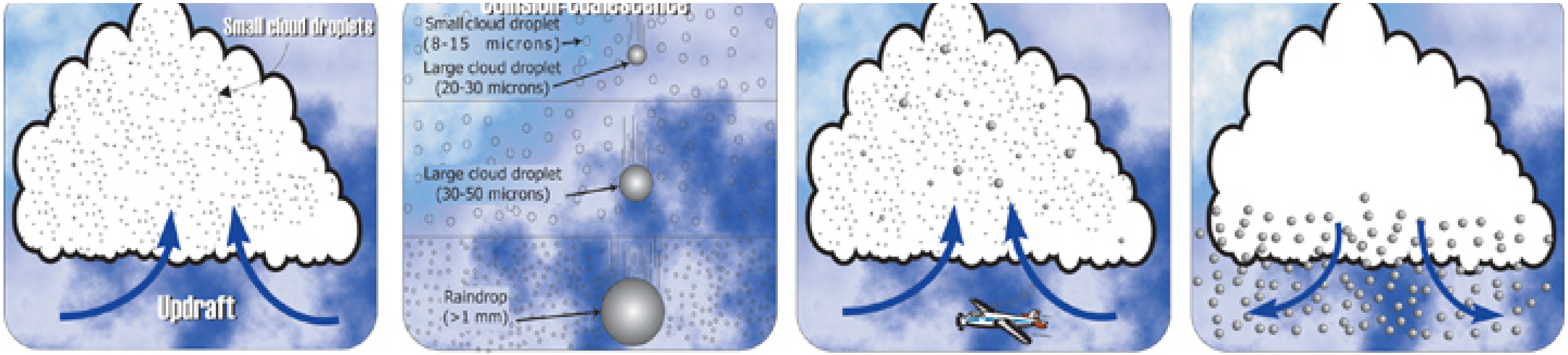
Seeding Models

- 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.

Microphyscial Effects – Rain Increase

- Goal is to make the cloud more efficient
- Efficiency = fraction of inflow water vapor that fall out as precipitation
  - 0% - No Rain
  - 100% - All Rain (no vapor/liquid/ice left behind)

Warm Cloud Rain Increase (Hygroscopic Seeding)



1

Rain formation begins when water molecules in a cloud condense on naturally occurring nuclei (i.e., dust particles) to produce small cloud droplets, around 8-15 microns in diameter.

2

Cloud droplets may grow by a collision-coalescence process; that is, by colliding with other droplets and coalescing into a larger droplet.

However, this doesn't occur until the droplets are about 20-30 microns in diameter.

3

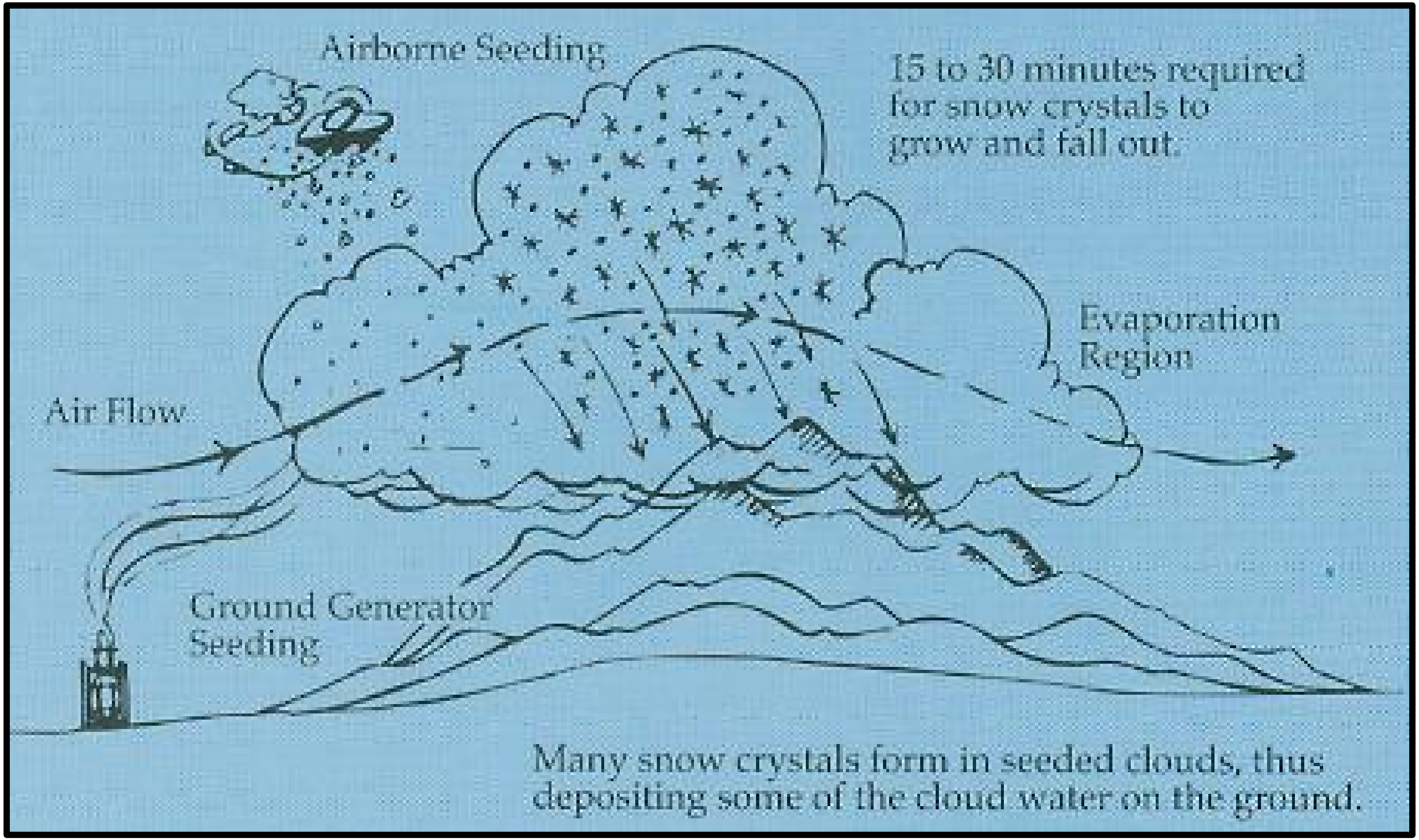
Hygroscopic seeding accelerates the collision-coalescence process to produce rain.

Hygroscopic flares are burned at the base of a cloud into an updraft. This releases hygro-scopic nuclei into the cloud and starts the collision-coalescence process. The hygroscopic nuclei produce larger cloud droplets than would occur naturally (30-50 microns in size). Through collision-coalescence, the droplets grow rapidly.

4

Once the droplets reach more than approximately one millimeter in diameter, their terminal velocity is large enough for them to fall from the cloud as rain.

Snowfall Increase (Orographic Clouds)



Snowfall Increase (MedEd)

- Check Out MetEd Module
  - How Cloud Seeding Works

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).

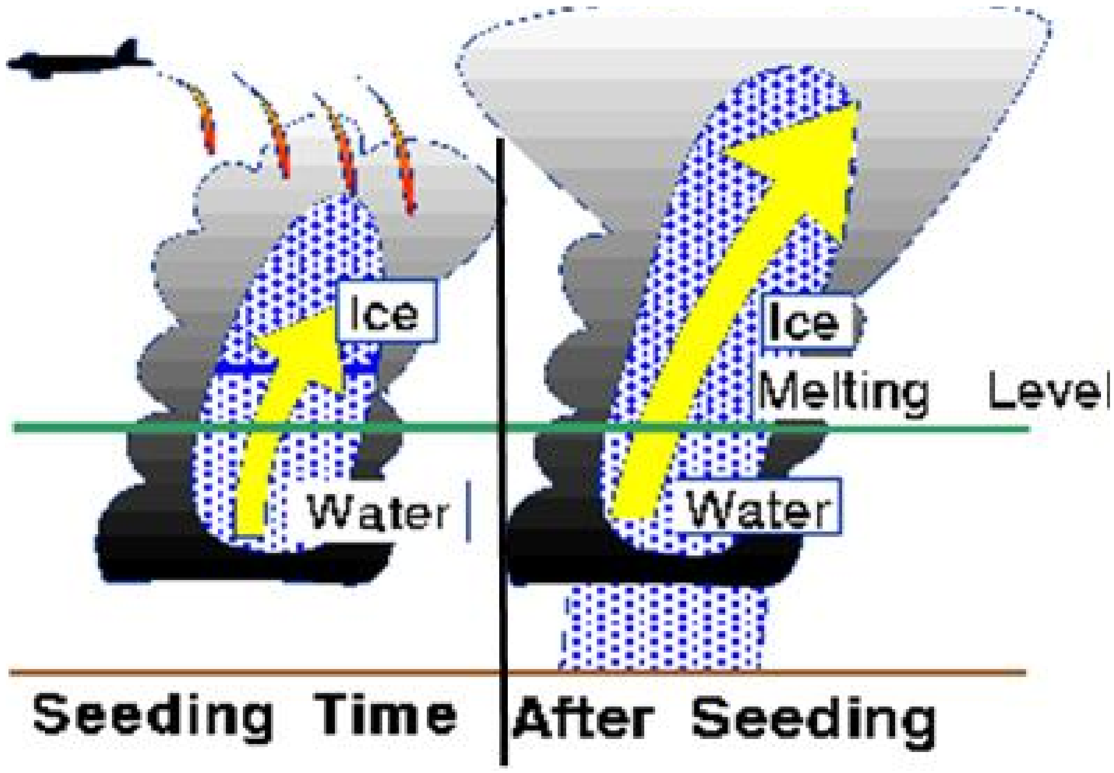


Diagram of the seeding of the upper part of a cloud by airplane, after which more rain is hoped to develop (graphic: NOAA Hurricane Research Division).

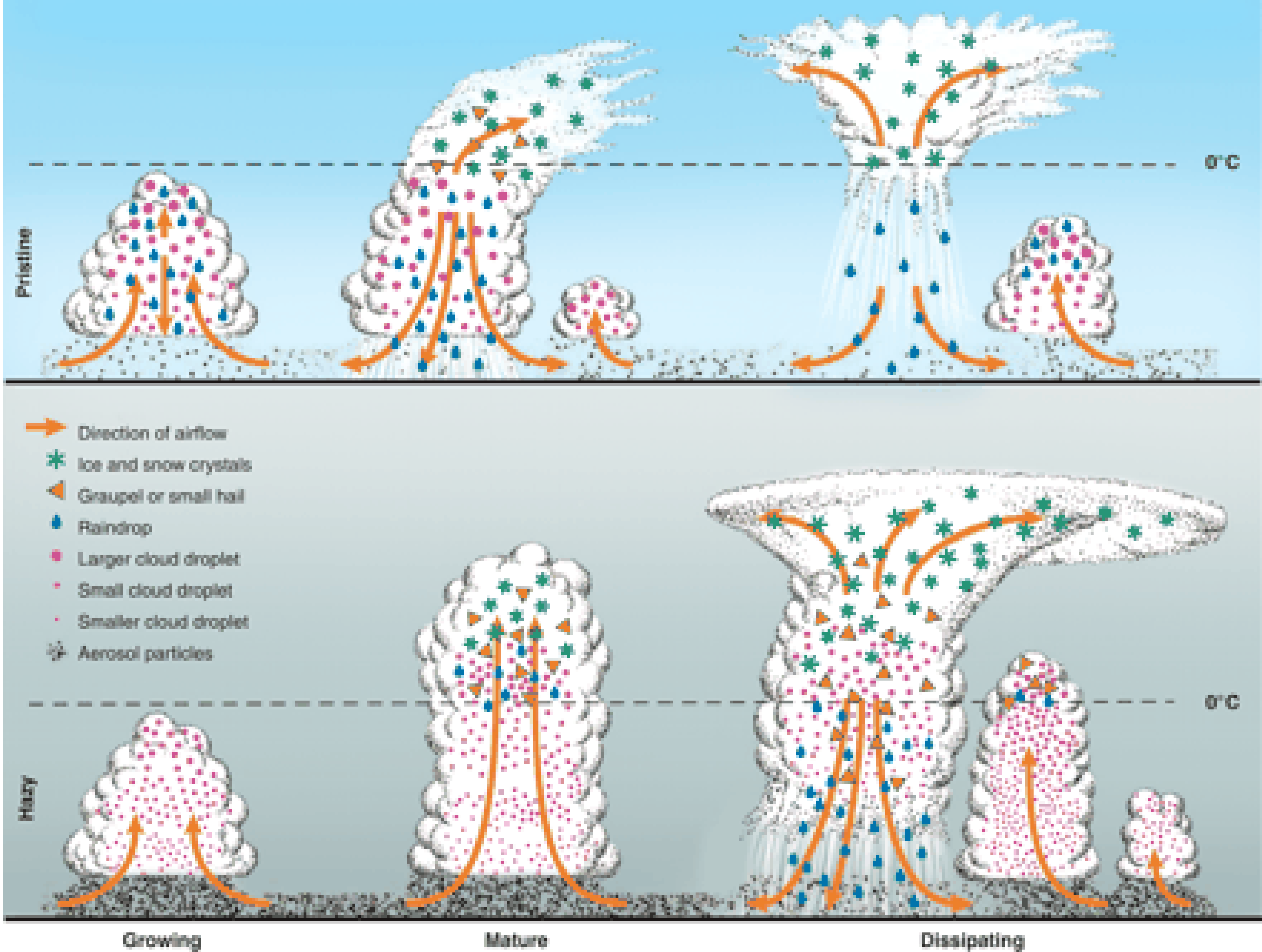
FACE - Project

- 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



Overseeding Models - CCN

- Attempt to transform a maritime cloud into a continental cloud.
- To get 100 nuclei cm^{-3}, we must add NaCl particles of radius 2μm.
- Each particle would have a mass of $(4/3)\pi r^3\rho = 6.7\times10^{-14}$ kg.
- Each cm^3 of cloud must have 6.7×10^{-12} kg of NaCl.

Overseeding Models - CCN

- 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 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.
- ABOUT 8 TONS!
- Obviously, this would not be very practical.

Overseeding Models - 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 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 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.

Covariates

- Numerical models require other inputs, such as soundings, winds, etc. These are referred to as covariates.
- Some of the models might be quite simple, such as
  - P = a x LI +b,
  - Where a and b are constants and P is the precipitation and LI is the Lifted Index.