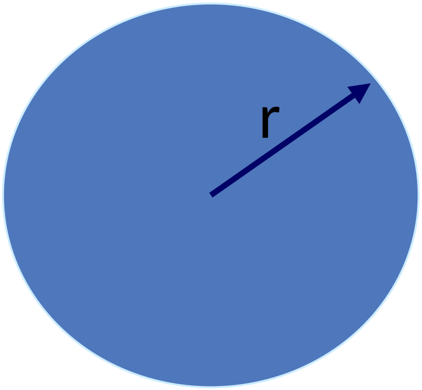
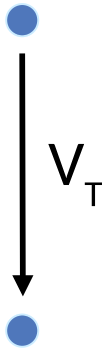
Precipitation Processes

July 8, 2012 – North Dakota (POLCAST4 Field Project)

Water Droplets Growth by Condensation

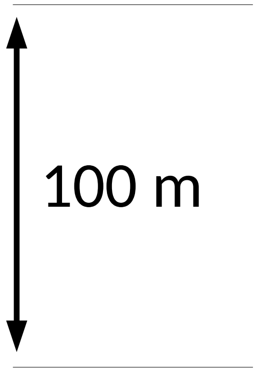
Droplet Radius (r)	Terminal Velocity (V_T)	Time (t) to Fall 100 m	Growth Time (τ)
1.0 µm	0.028 cm s^{-1}	4.13 days	1 s
10 µm	**2.8 cm s^{-1}**	**1.0 hour**	**30 min**
100 µm	70 cm s^{-1}	2.3 min	8 days

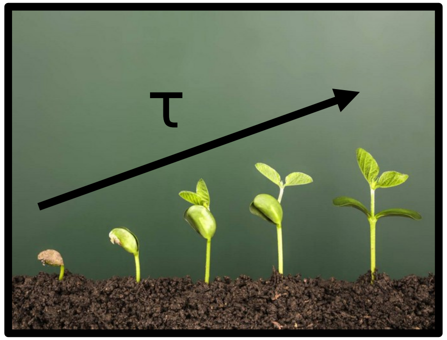




$t = 100 \text{ m} / V_T$

t = (100 m / 0.00028 m/s) / (60*60*24) = 4.13 days

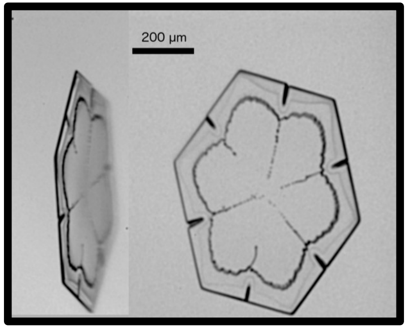




Condensation Growth is Insufficient for Precipitation Formation

- It clearly takes too long (> 8 days) to grow water drops by condensation alone in order to get precipitation sized particles.

- Need larger fall speed, which requires larger drops and ice crystals.



Cloud Drop Size (r) and Fall Speed (V_T)

r – Radius (µm)

N – Number Conc. (# L^{-1})

V_T - Terminal Velocity (cm s^{-1})

1000 # L^{-1} = 1 # cm^{-3}

10^6 # L^{-1} = 10^3 # cm^{-3}

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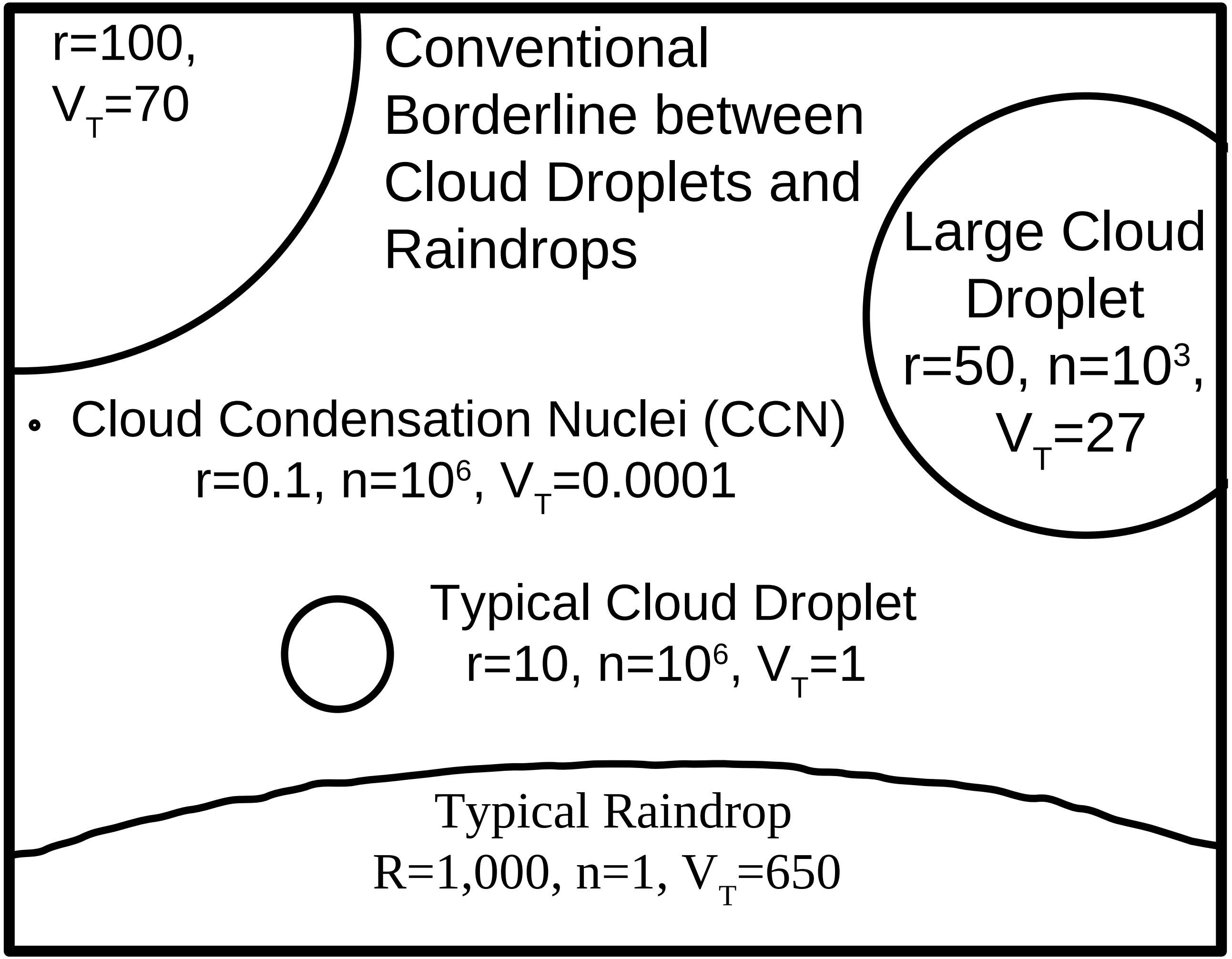


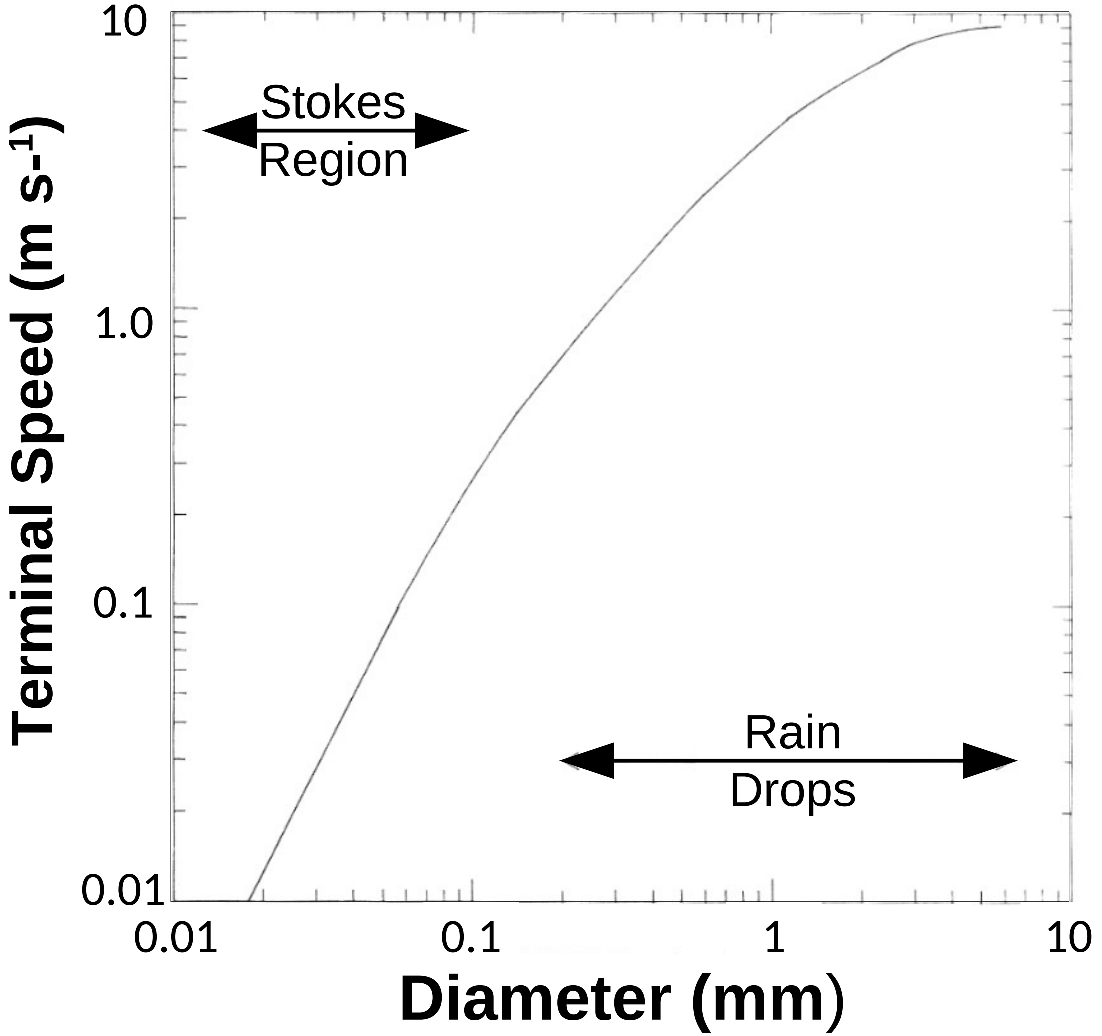
Terminal Velocities of Water Drops

101.325 kPa (1001.325 mbars)

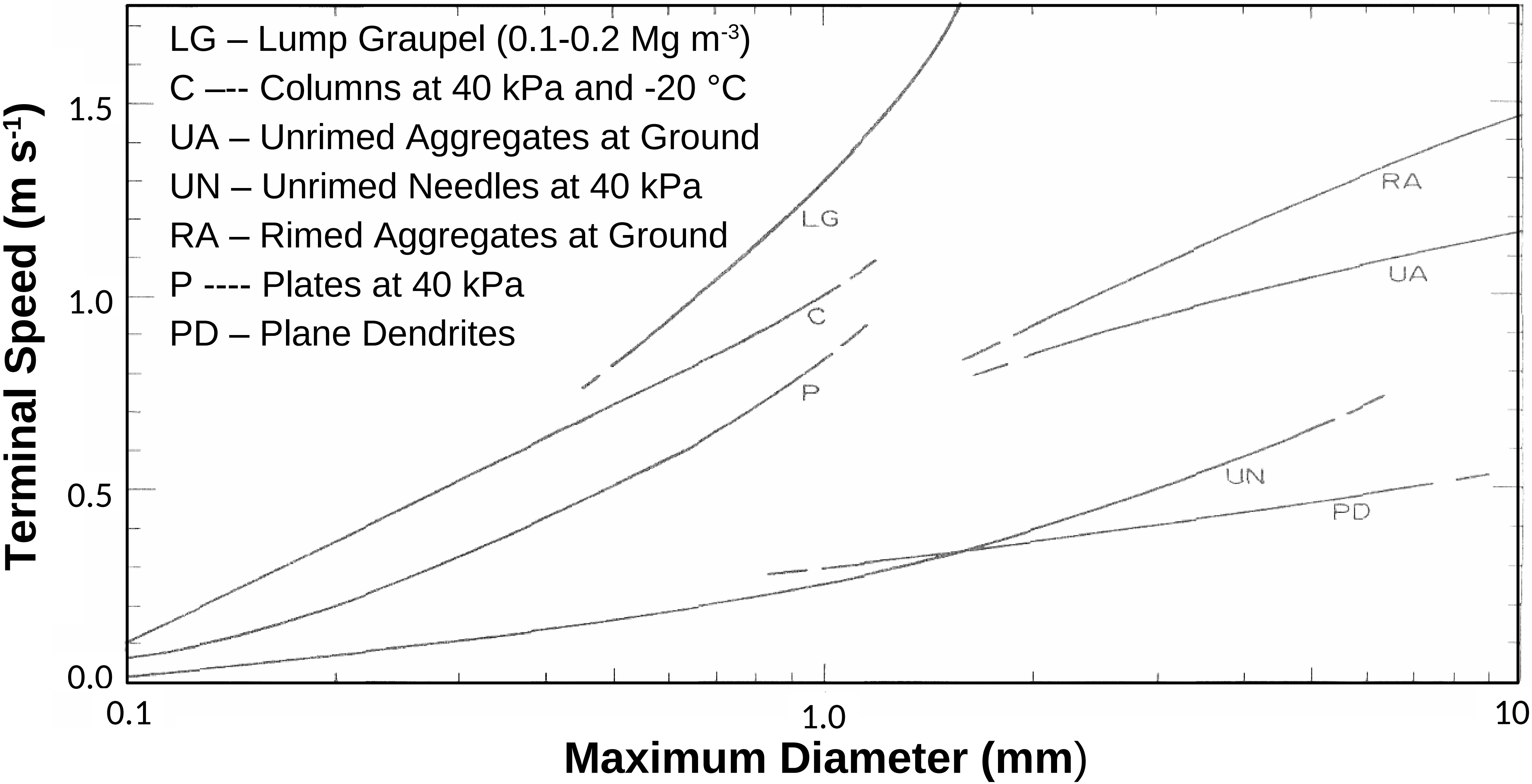
20 °C

0.1 m/s = 0.22 mph
1.0 m/s = 2.24 mph
10 m/s = 22.4 mph

Reproduced Based On
List, R. Kennzeichen atmosphärischer Eispartikeln. Journal of Applied Mathematics and Physics (ZAMP) 9, 180–192 (1958). https://doi.org/10.1007/BF01600631



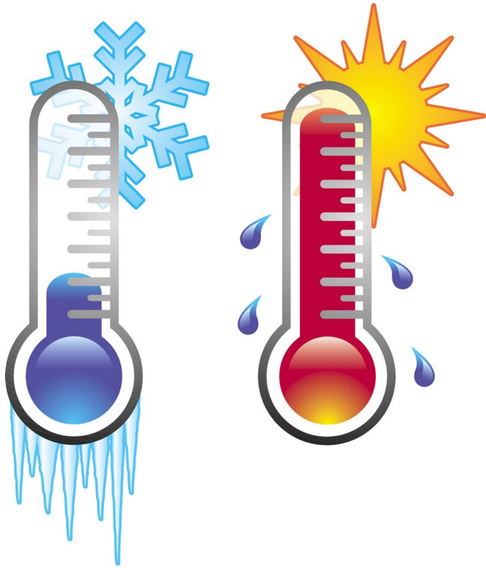
Terminal Velocities of Ice Particles



Precipitation Formation Processes

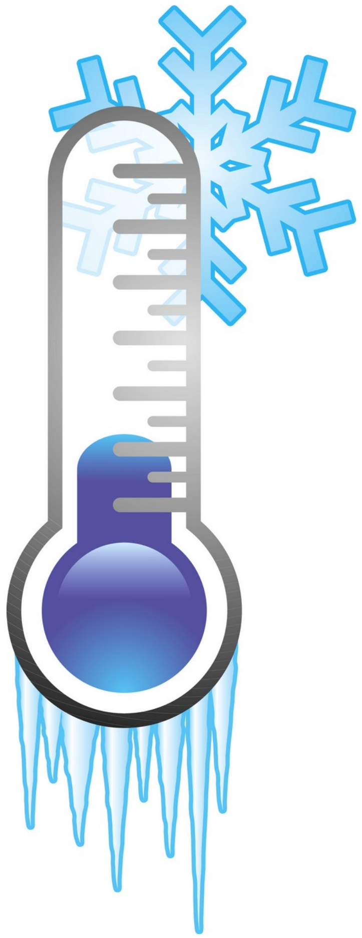
- Condensation growth process takes too long to get precipitation sized particles.
- There are two other processes that go on to develop precipitation:
  - Cold Rain Process

    (Bergeron-Findeisen)
  - Warm Rain Process

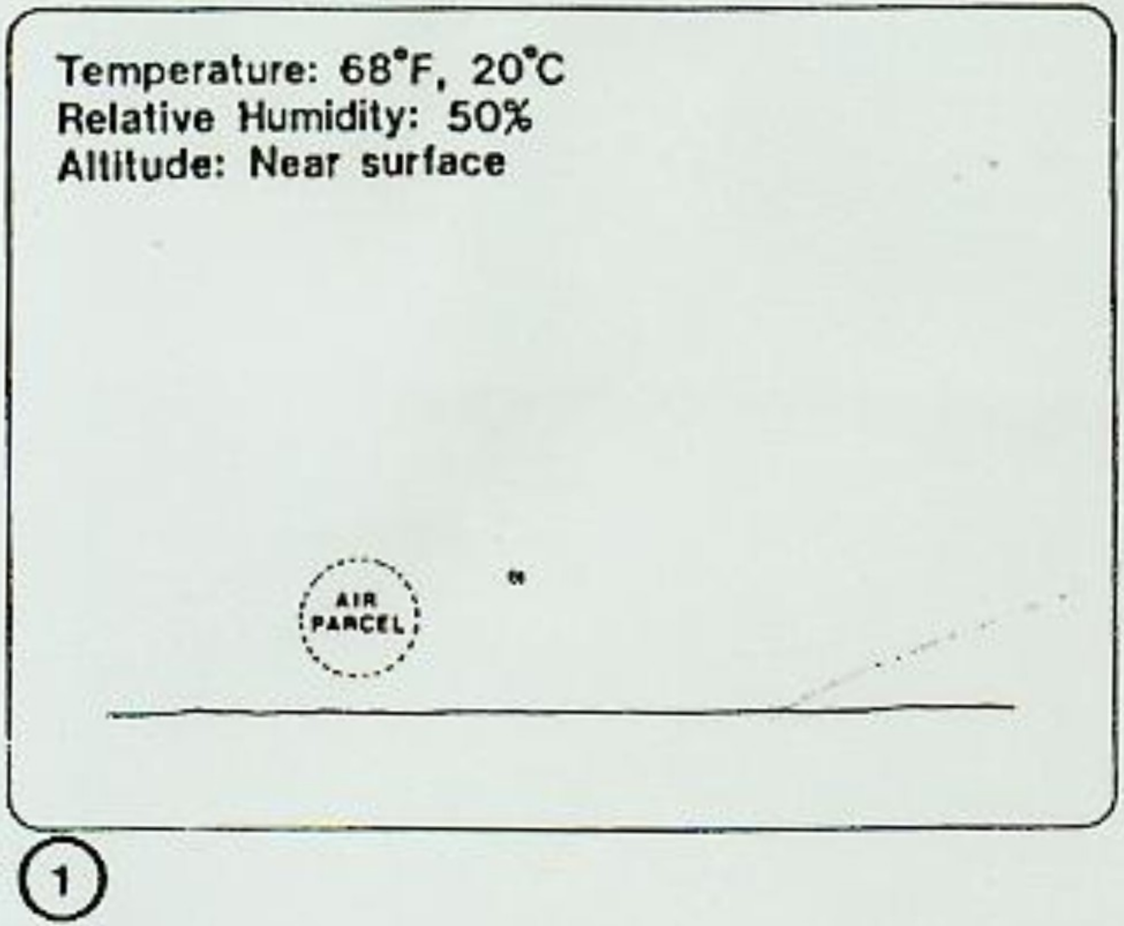


Cold Rain Process

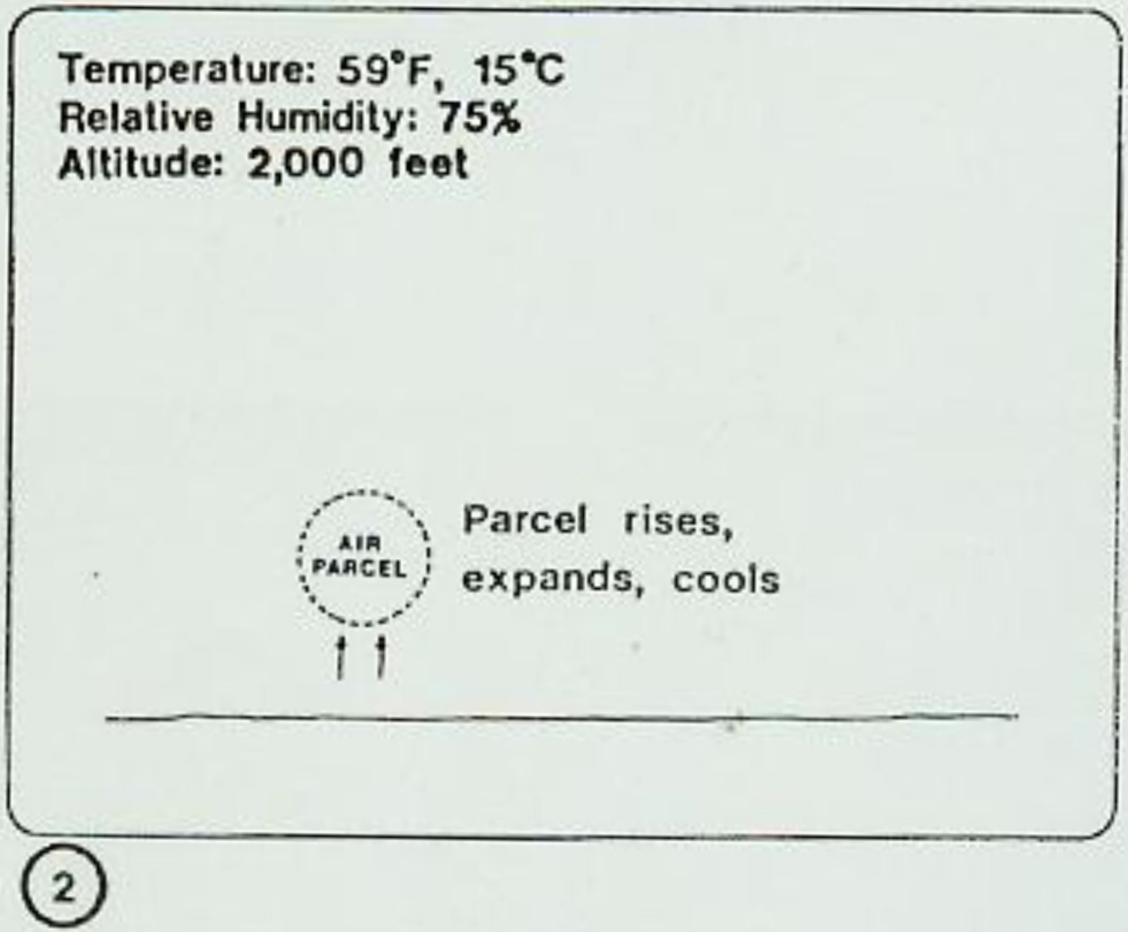
- Requires the presence of a mixed phase cloud (i.e., both supercooled liquid water and ice).
- Ice crystals grow rapidly while the water droplets evaporate.
- Once ice crystals reach a large enough size, they fall through the liquid water, collecting the cloud droplets as they fall.



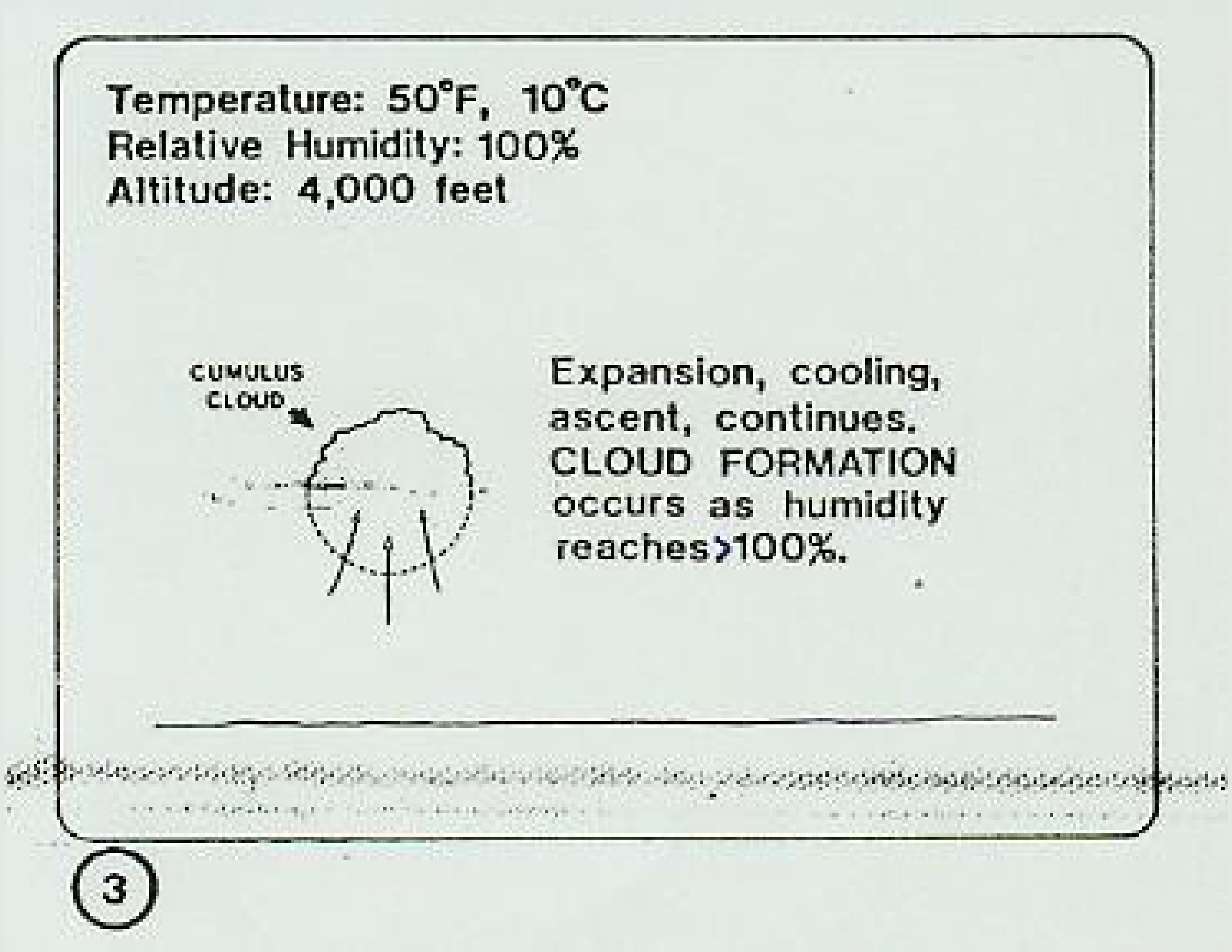
Cold Rain Process



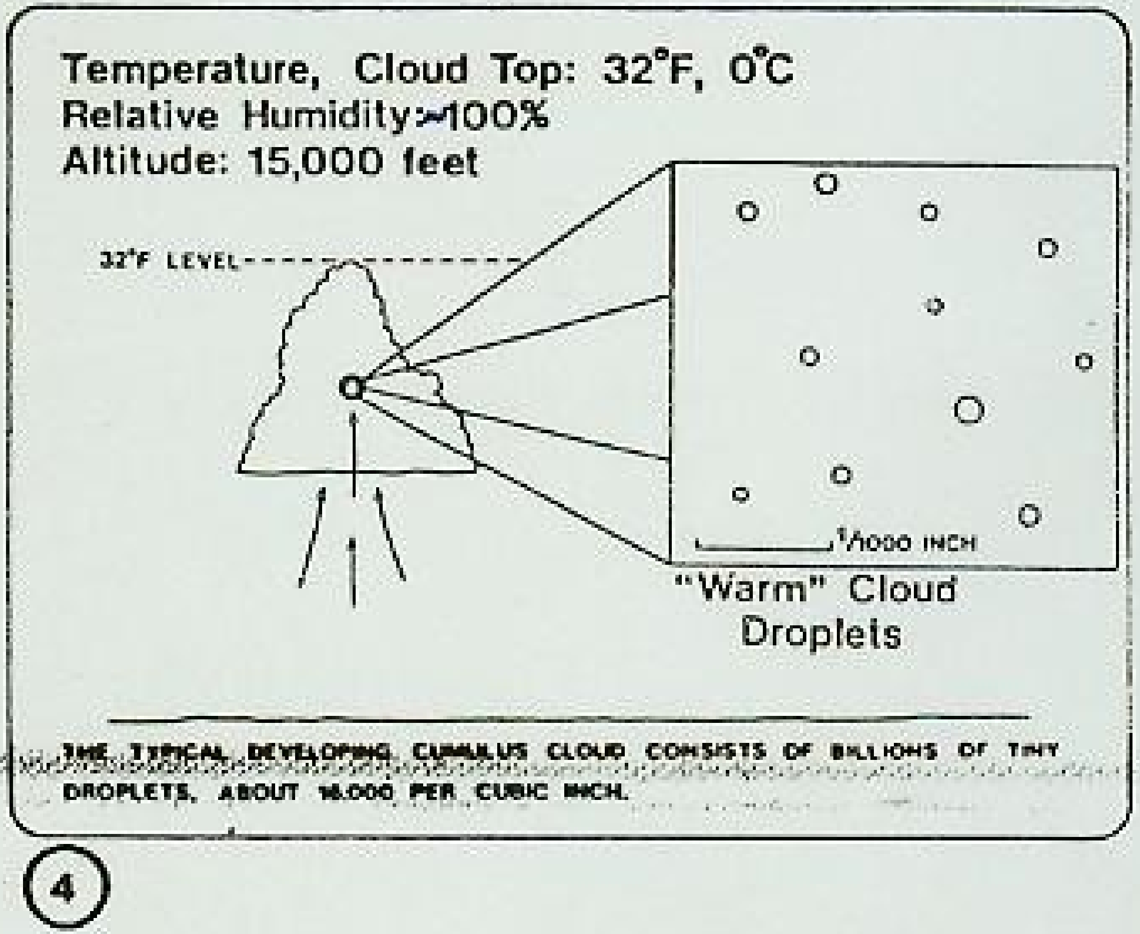
Cold Rain Process



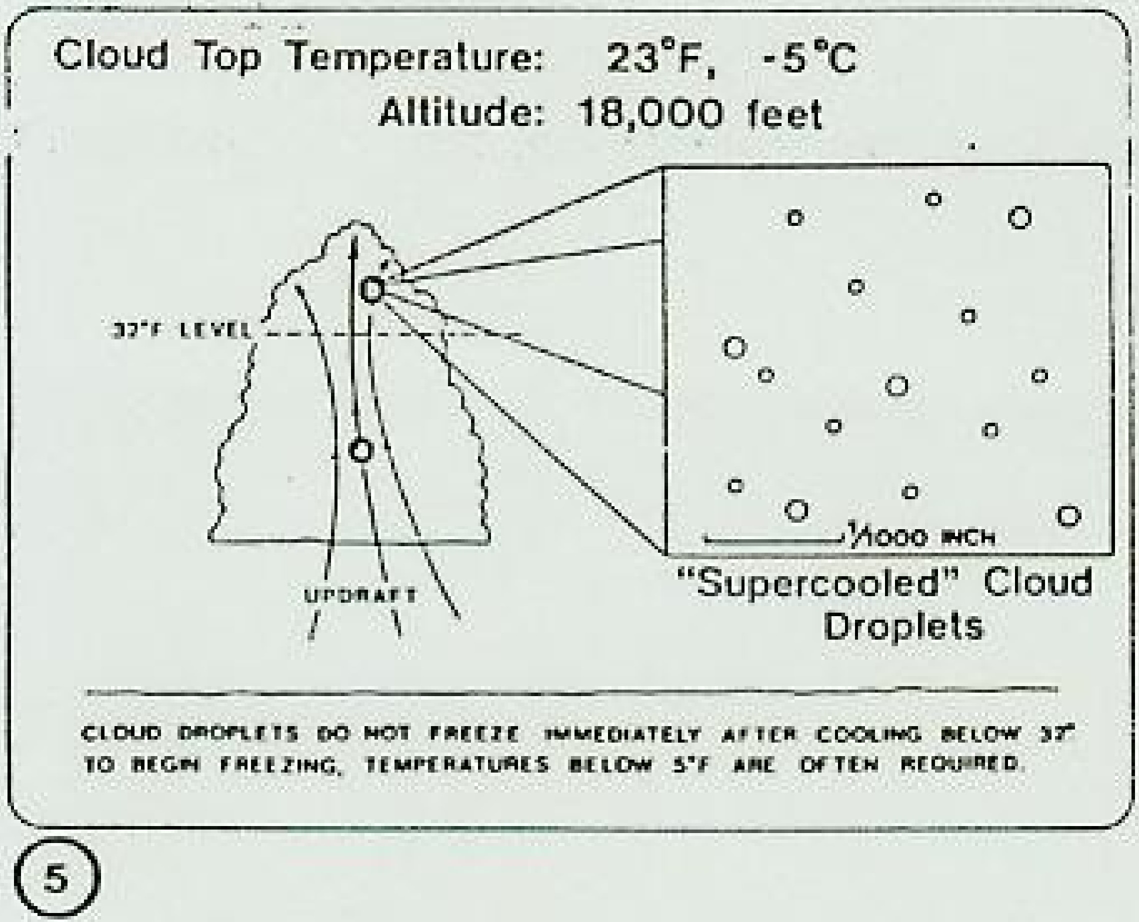
Cold Rain Process



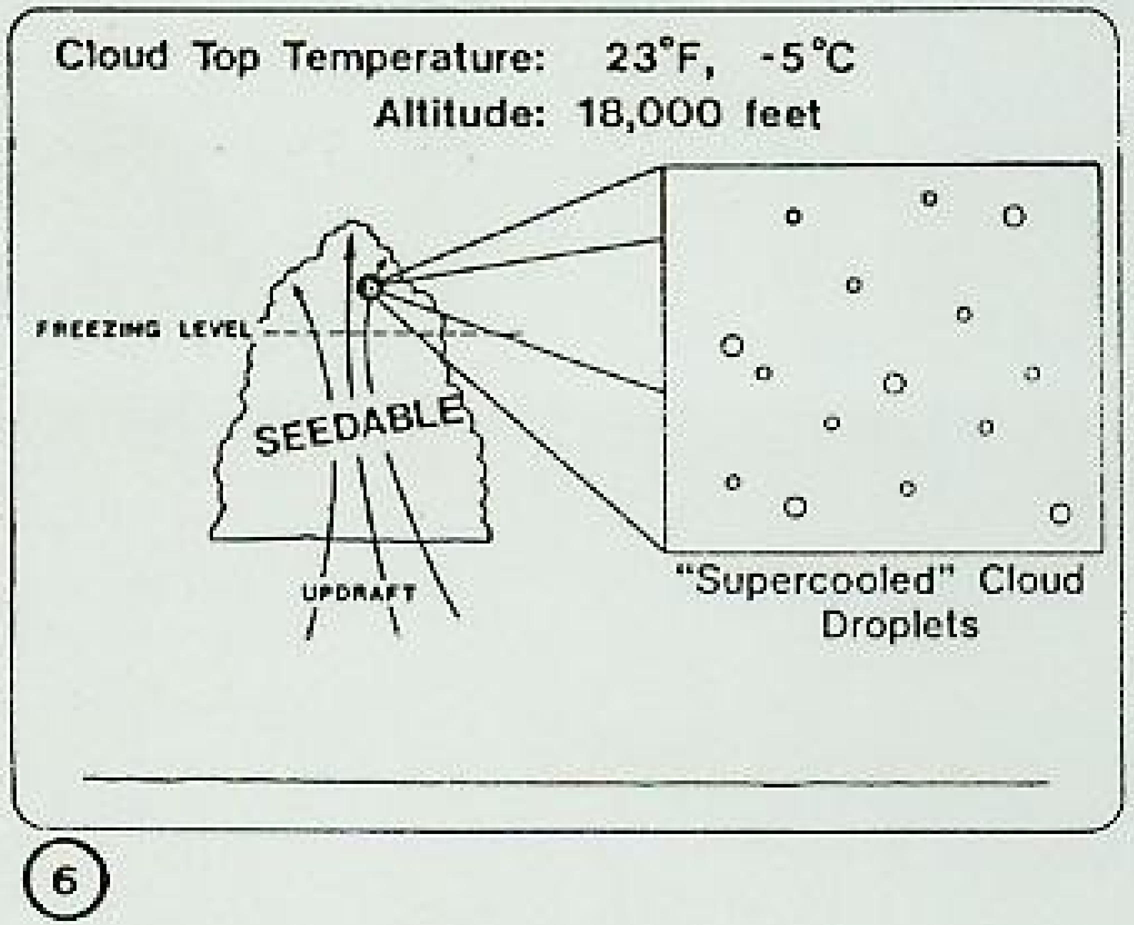
Cold Rain Process



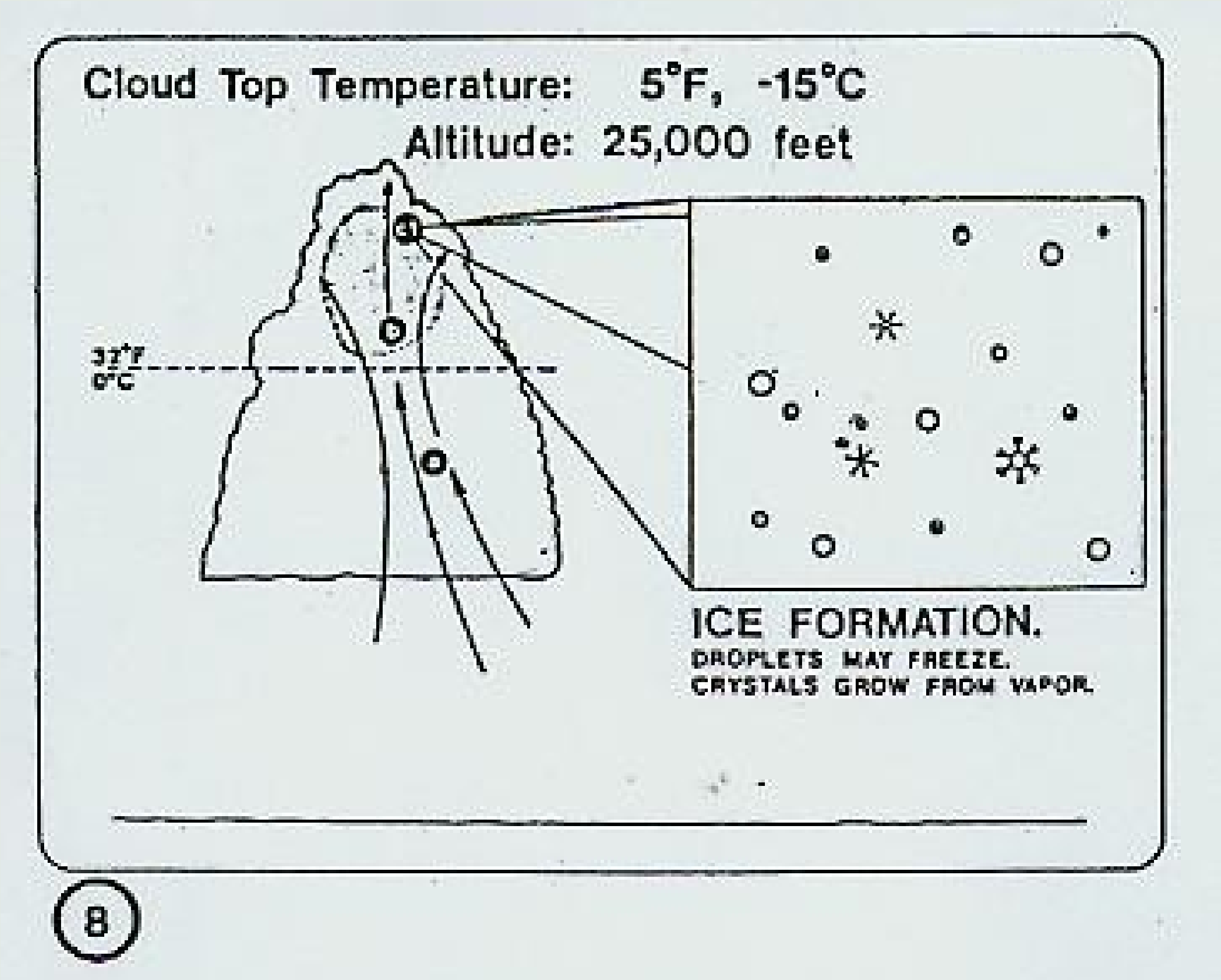
Cold Rain Process



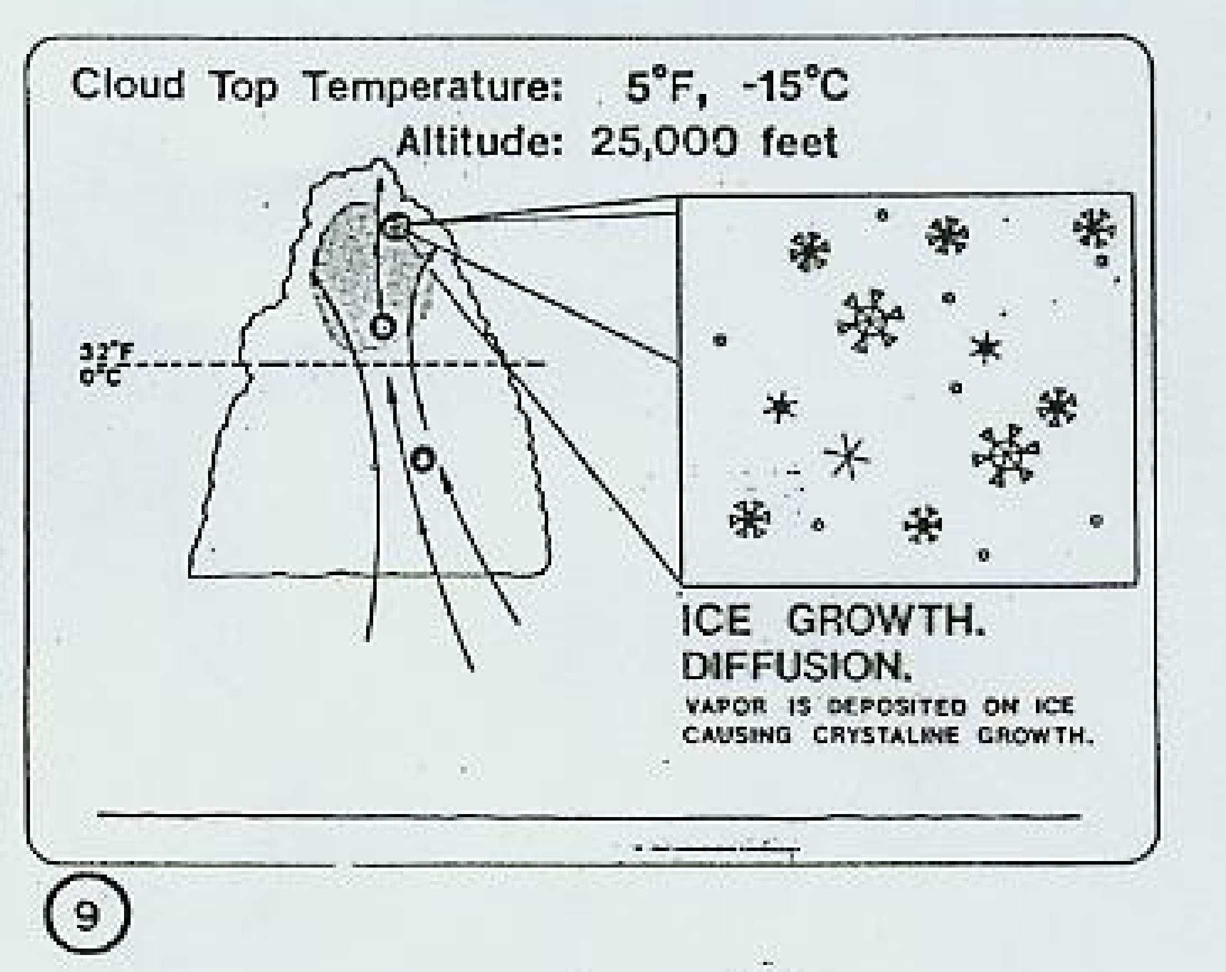
Cold Rain Process



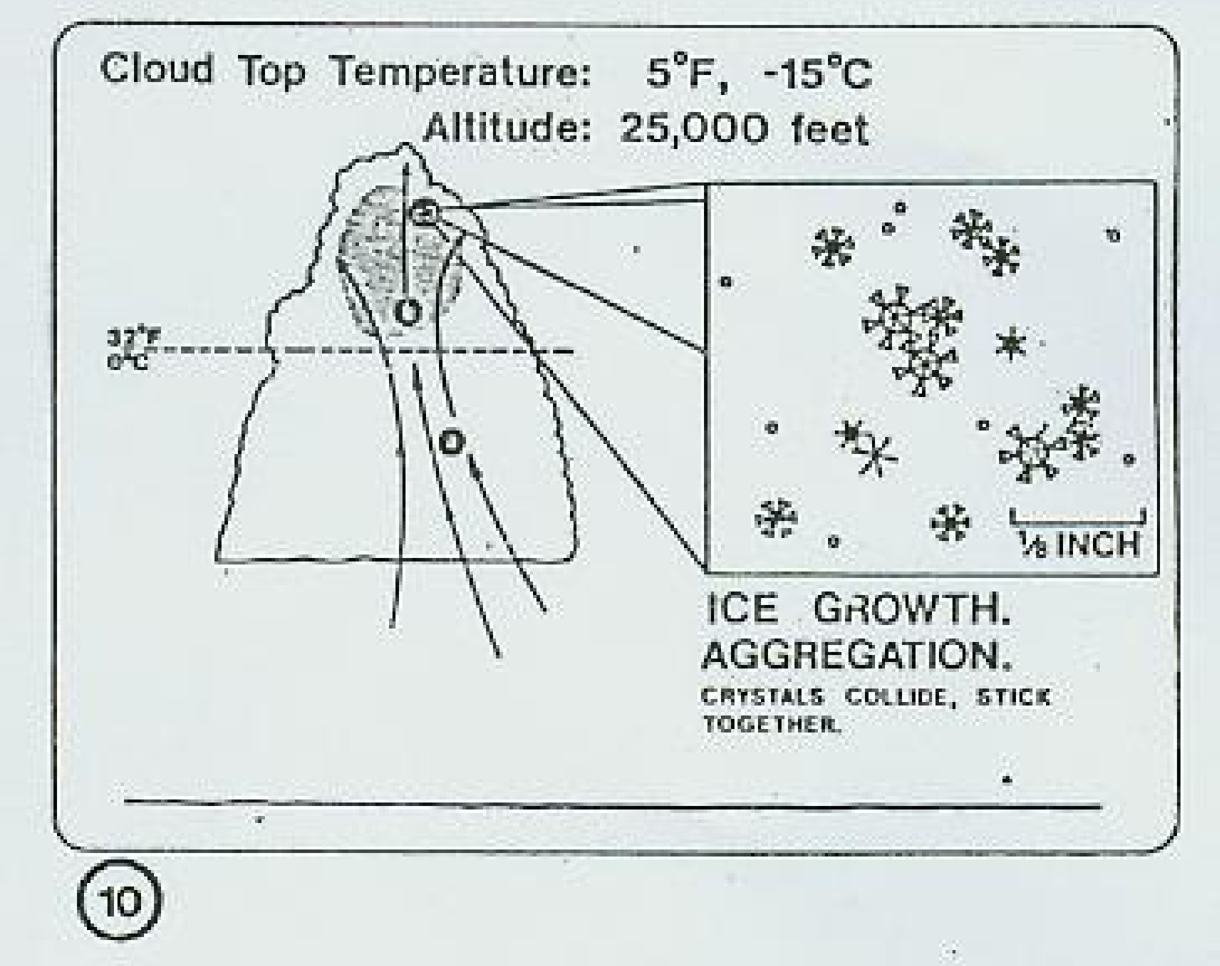
Cold Rain Process



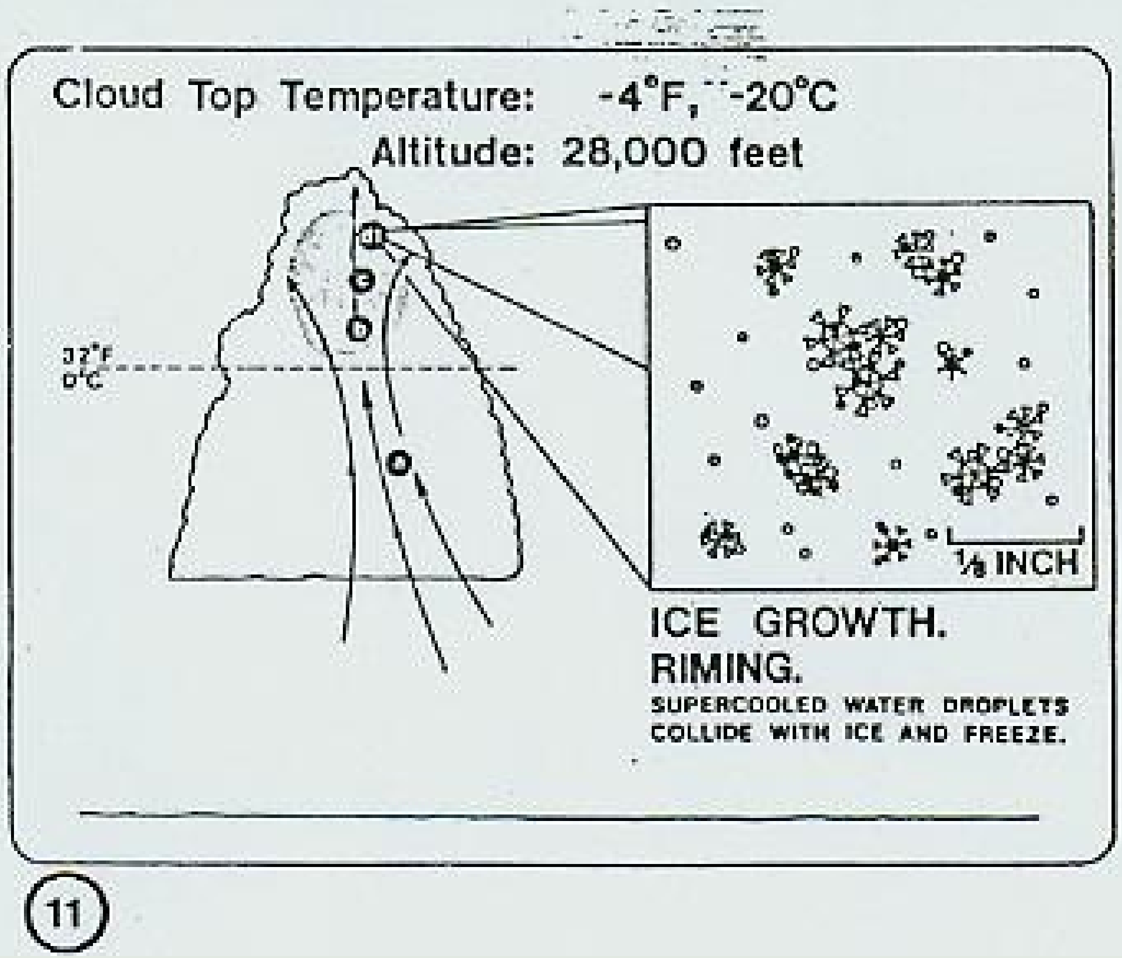
Cold Rain Process



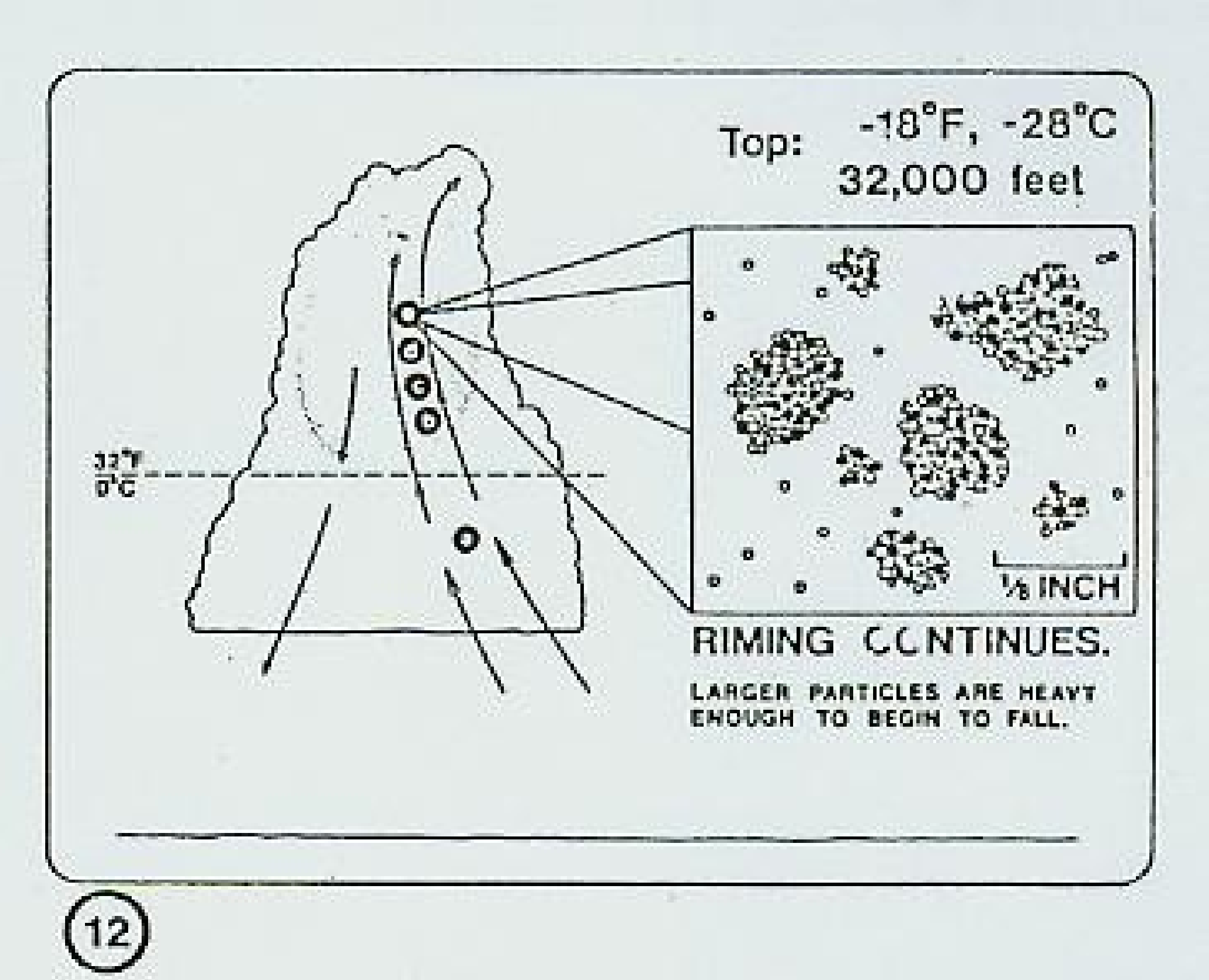
Cold Rain Process



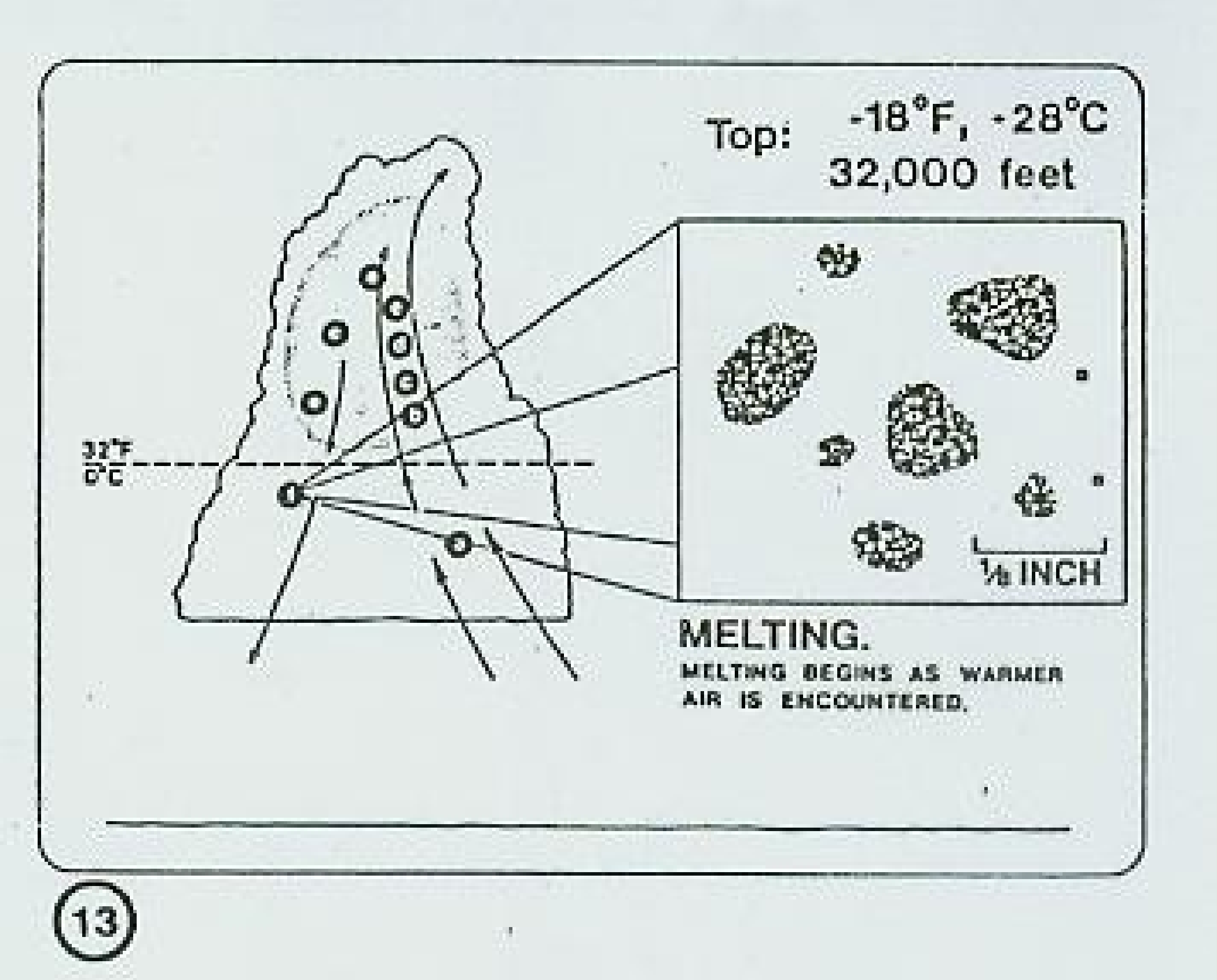
Cold Rain Process



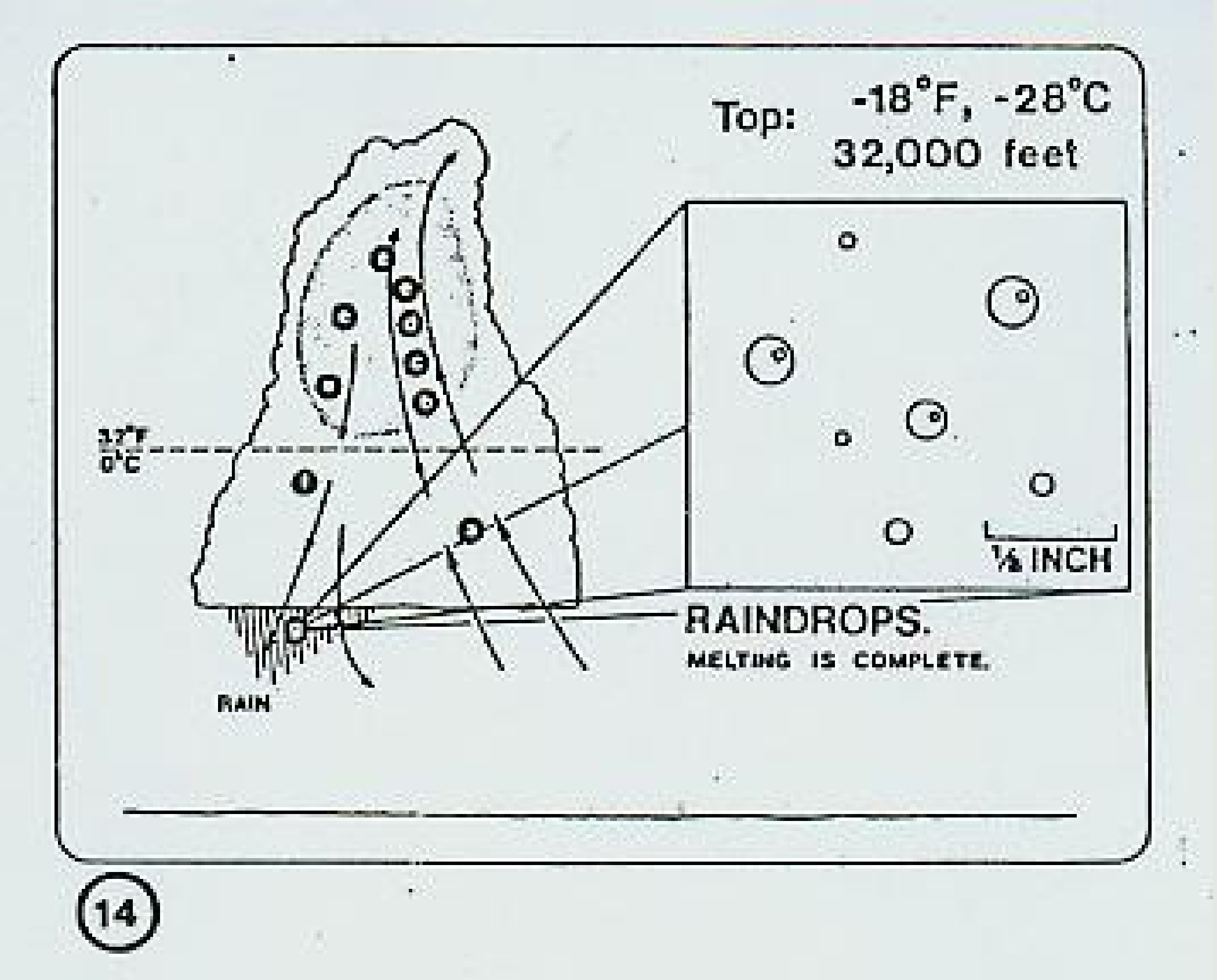
Cold Rain Process



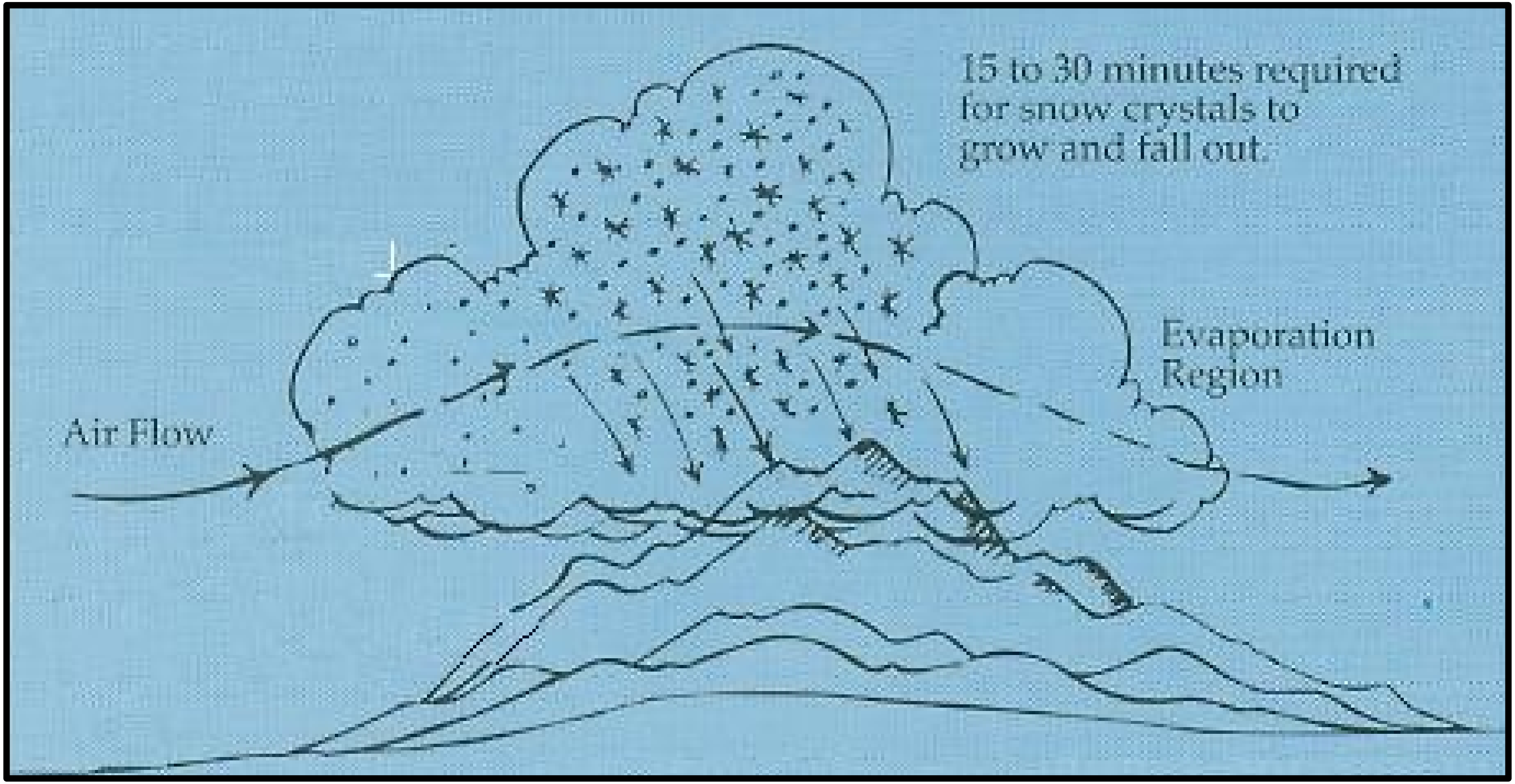
Cold Rain Process



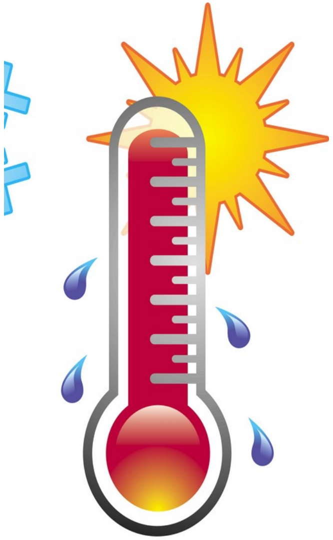
Cold Rain Process



Orographic Precipitation
Mountain Cloud



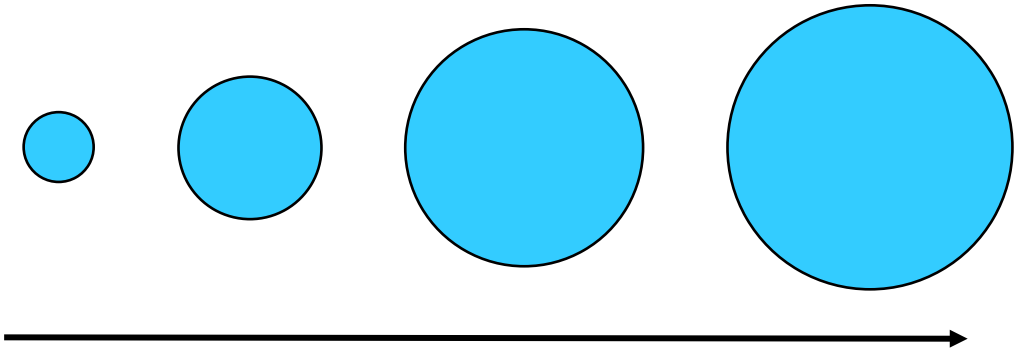
Warm Rain Process



Condensation growth depends on particle size.

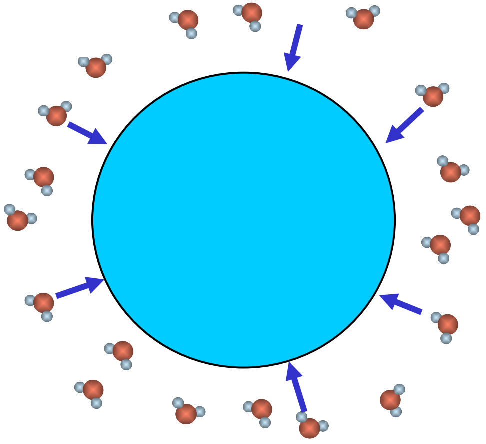
Much Slower as Droplet Grows

Initially Fast



Time

Condensation Growth

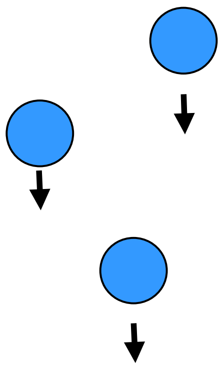


Condensation Produces Drops too Small to Precipitate

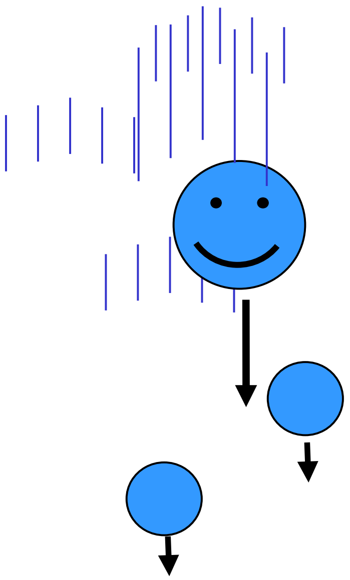
Warm Rain Process

Some other process is needed to produce precipitation:

Collision / Coalescence Growth

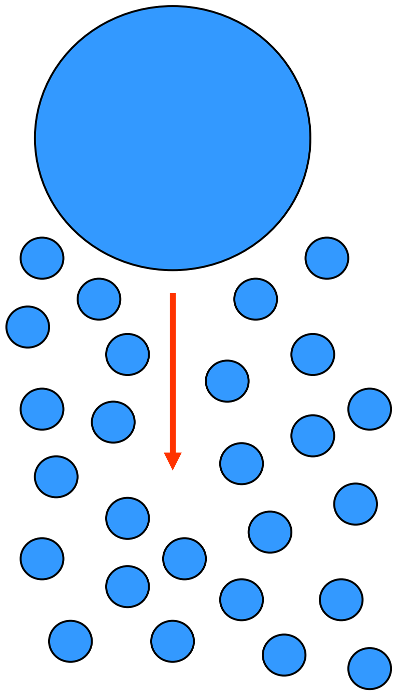


Larger Drops Fall Faster



Collision / Coalescence Process

Large drops run into (collide) with small drops that stick to (coalesce with) the larger drop.



Rain Drop Shape Video

Water Drop Collisions, Coalescence & Breakup

→ Need some large drops.

Warm Rain Process

- The large drops are called "Precipitation Embryos"
- Where do large drops come from?
  - Very Large Cloud Condensation Nuclei (CCN)
  - Hygroscopic Cloud Condensation Nuclei (CCN)
  - Random Collisions of Small Droplets
  - Shattering of Large Rain Drops

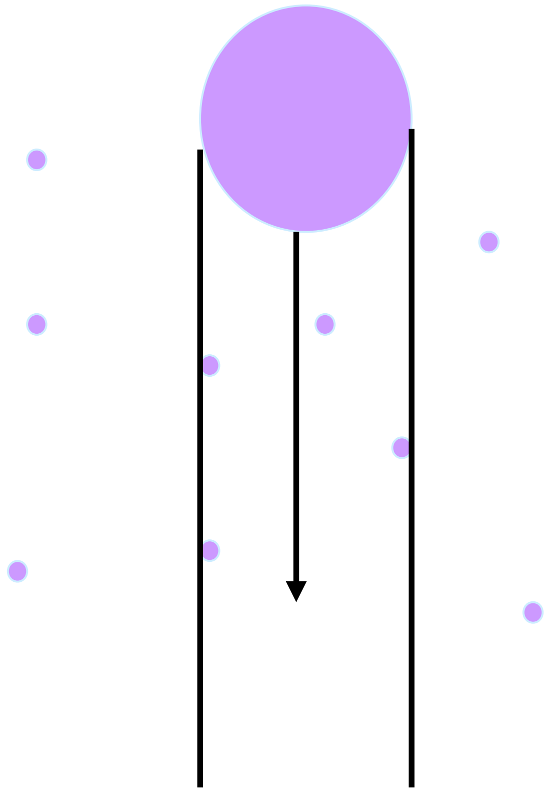
Where do we find favorable CCN?

What conditions would then be favorable for the Warm Rain Process to occur?

Warm Rain Process

- Does not require the presence of ice in the cloud.
- Does require the presence of some large drops that can fall through the cloud of smaller droplets.
- The larger, falling drops collide with and coalesce with the smaller cloud droplets, making them grow faster as they fall.

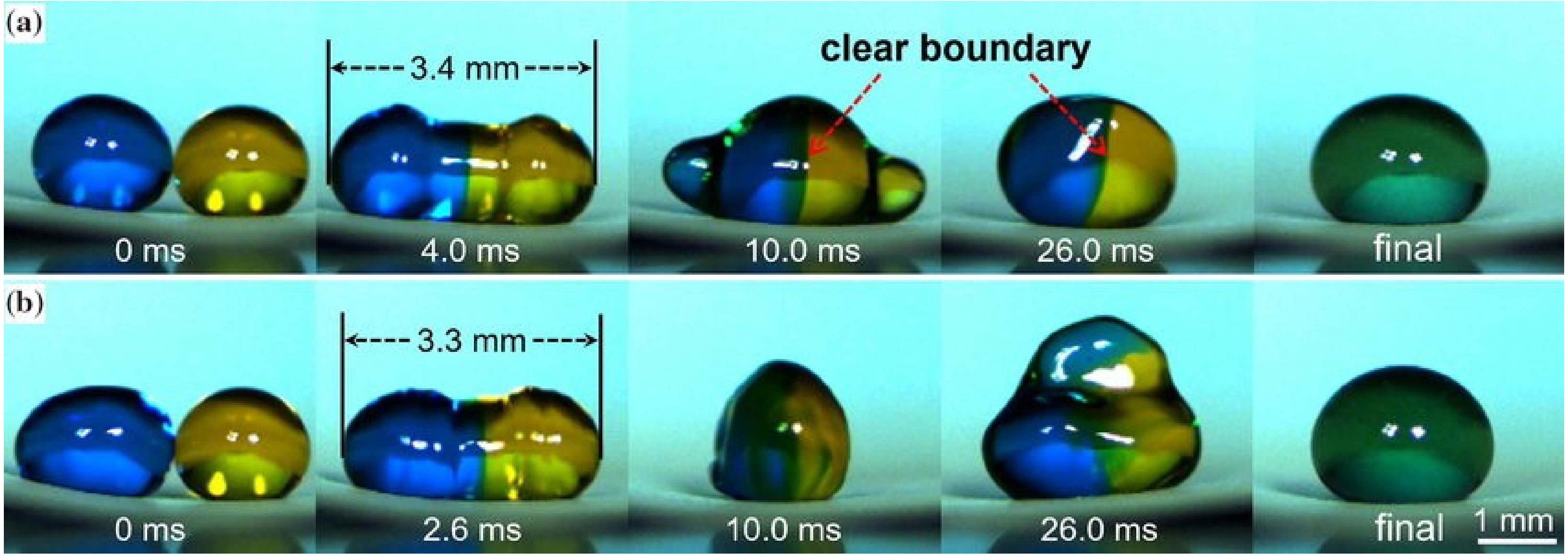
Collision Efficiency



- Defined as the number of droplets in swept-out volume that actually collide with the falling drop divided by the total number of droplets in the swept-out volume.
- Collision efficiency of 1.0 would imply that all the droplets in the volume were colliding with the falling drop.

Coalescence Efficiency

- Defined as the the fraction of the droplets that collide with the falling drop that actually merge with the falling drop.
- A coalescence efficiency of 1.0 implies that all the droplets that strike the falling drop merge with the falling drop.



Collection Efficiency

Defined as the product of the Collision Efficiency and the Coalescence Efficiency.

Collision Efficiency * Coalescence Efficiency