

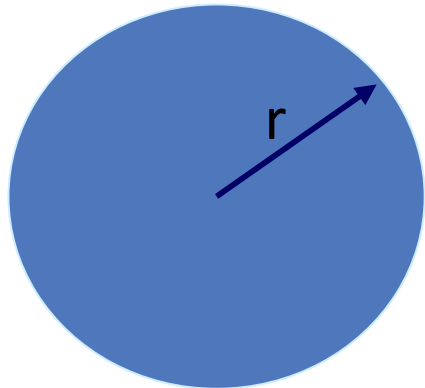
# Precipitation Processes



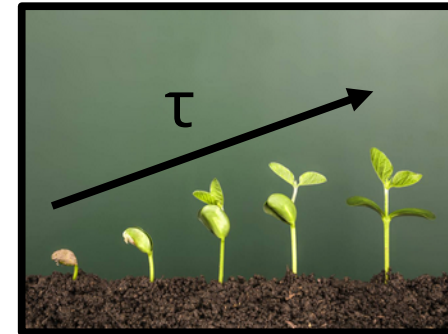
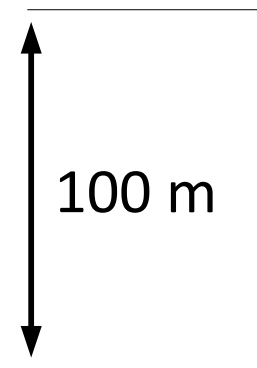
July 8, 2012 – North Dakota (POLCAST4 Field Project)

# Water Droplets Growth by Condensation

Droplet Radius ( $r$ )	Terminal Velocity ( $V_T$ )	Time ( $t$ ) to Fall 100 m	Growth Time ( $\tau$ )
1.0 $\mu\text{m}$	0.028 $\text{cm s}^{-1}$	4.13 days	1 s
<b>10 <math>\mu\text{m}</math></b>	<b>2.8 <math>\text{cm s}^{-1}</math></b>	<b>1.0 hour</b>	<b>30 min</b>
100 $\mu\text{m}$	70 $\text{cm s}^{-1}$	2.3 min	8 days

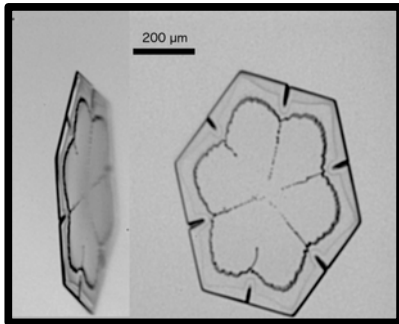


$$t = 100 \text{ m} / V_T$$
$$t = (100 \text{ m} / 0.00028 \text{ m/s}) / (60 * 60 * 24) = 4.13 \text{ days}$$



# 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 ( $\mu\text{m}$ )

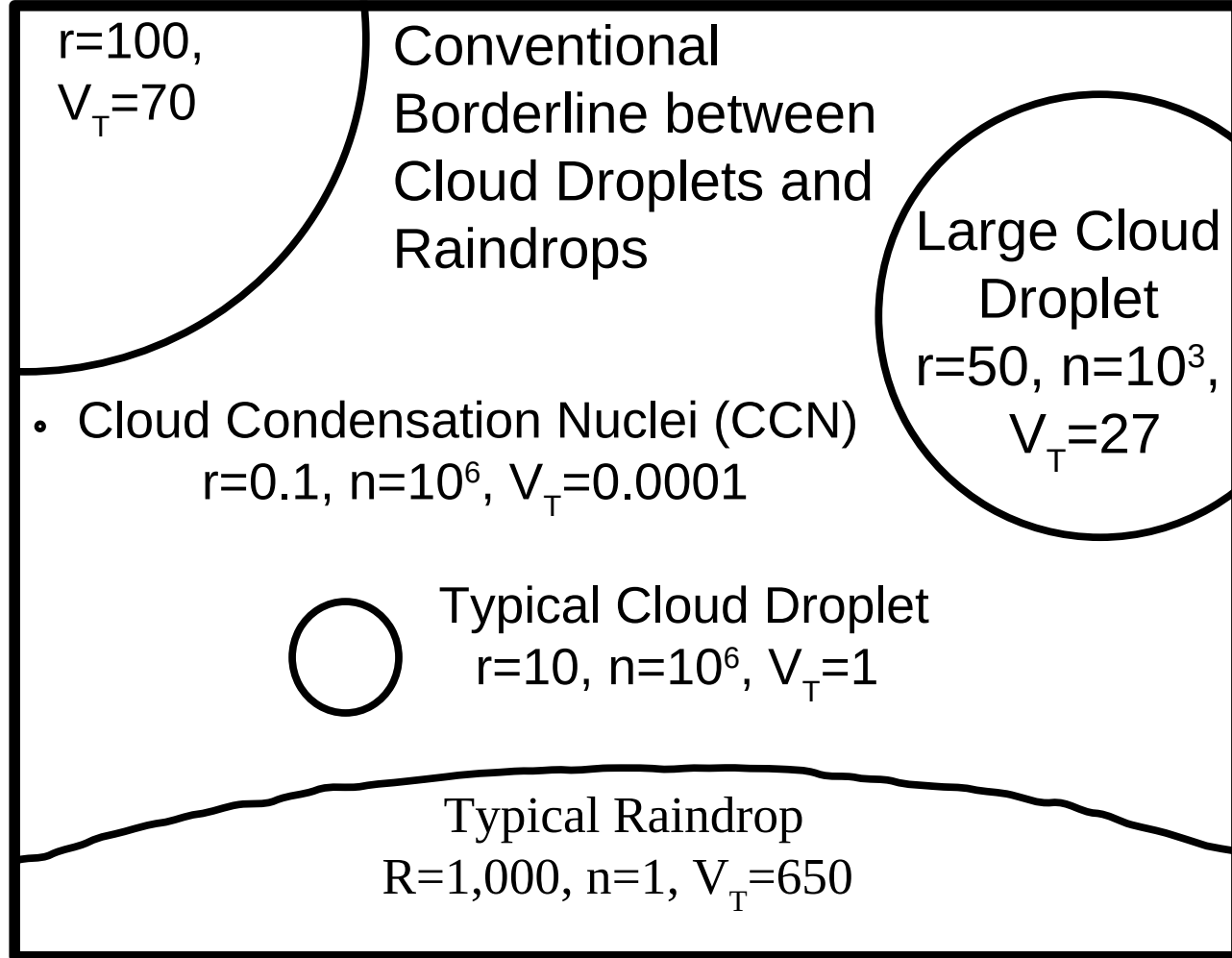
$N$  – Number Conc. ( $\# \text{L}^{-1}$ )

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

$$1000 \# \text{L}^{-1} = 1 \# \text{cm}^{-3}$$

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

Reproduced Based On  
*Advances In Geophysics*  
5, 244 (1958)



# 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

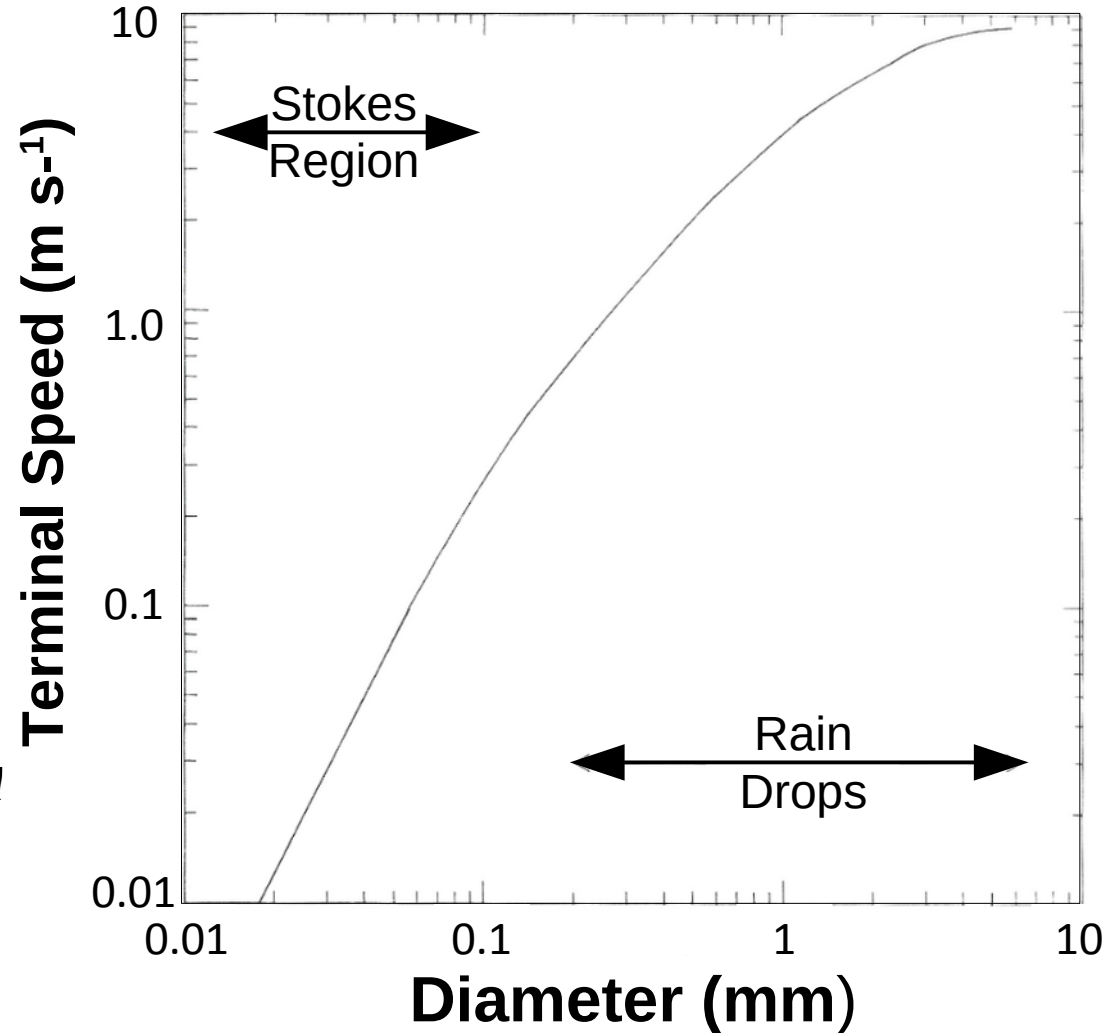
Reproduced Based On

*List, R. Kennzeichen atmosphärischer*

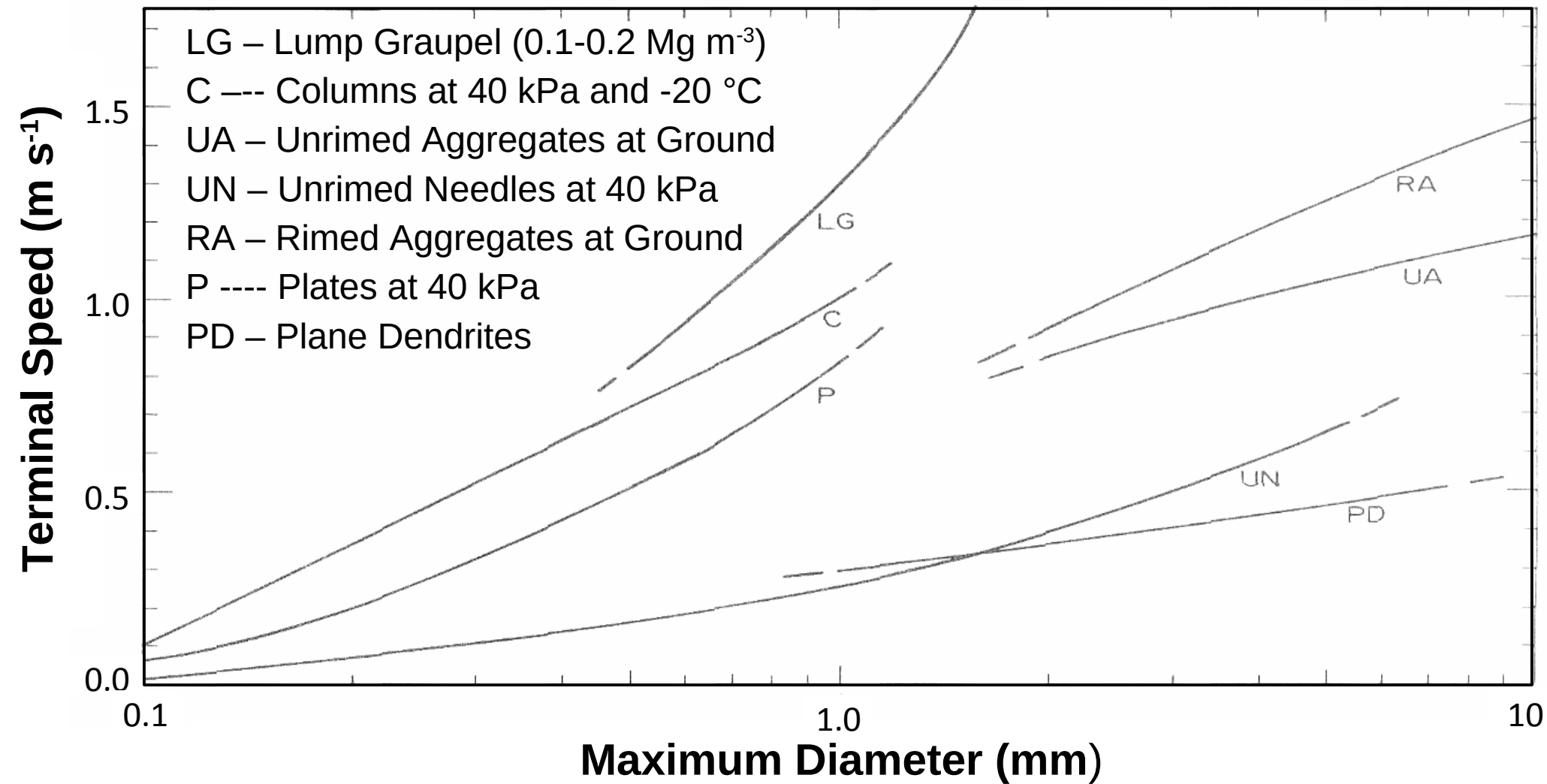
*Eispartikeln. Journal of Applied Mathematics and*

*Physics (ZAMP) 9, 180–192 (1958).*

<https://doi.org/10.1007/BF01600631>

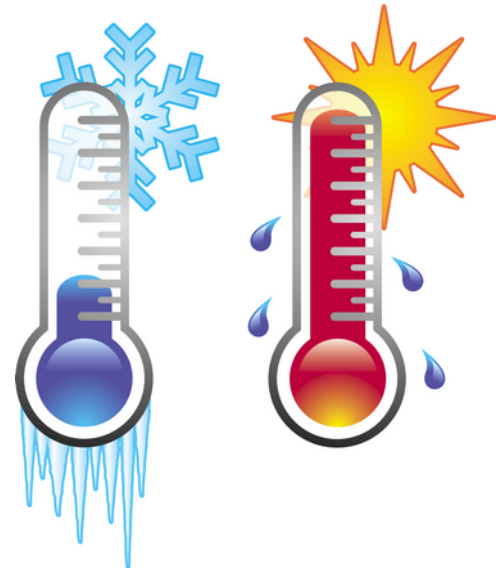


# Terminal Velocities of Ice Particles



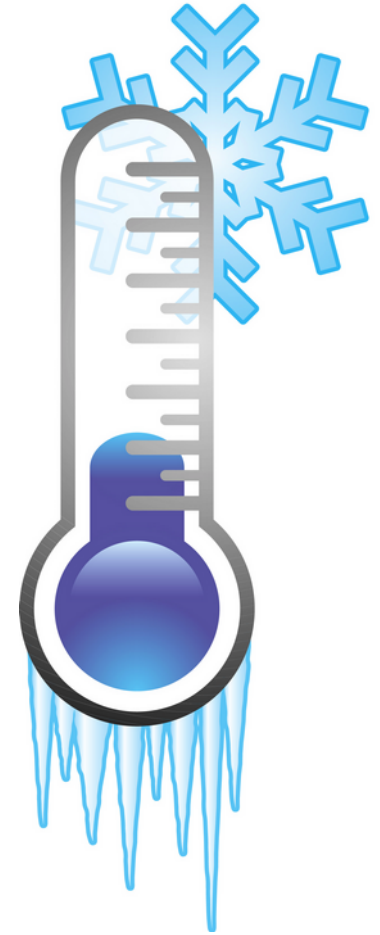
# Precipitation Formation Processes

- 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

Temperature: 68°F, 20°C  
Relative Humidity: 50%  
Altitude: Near surface

AIR  
PARCEL

A diagram showing a dashed circle labeled "AIR PARCEL" near a solid horizontal line representing the ground surface. A dashed line extends from the ground surface upwards and to the right, representing the path of the air parcel.

1

# Cold Rain Process

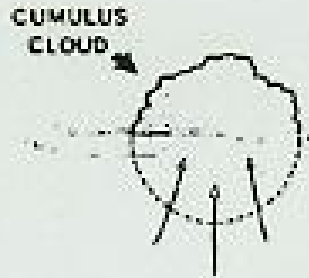
Temperature: 59°F, 15°C  
Relative Humidity: 75%  
Altitude: 2,000 feet



Parcel rises,  
expands, cools

# Cold Rain Process

Temperature: 50°F, 10°C  
Relative Humidity: 100%  
Altitude: 4,000 feet

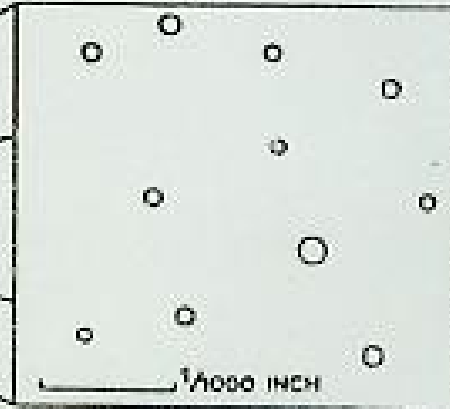
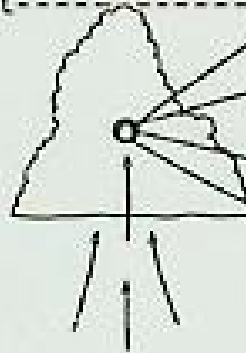


Expansion, cooling,  
ascent, continues.  
CLOUD FORMATION  
occurs as humidity  
reaches >100%.

# Cold Rain Process

Temperature, Cloud Top: 32°F, 0°C  
Relative Humidity: >100%  
Altitude: 15,000 feet

32°F LEVEL

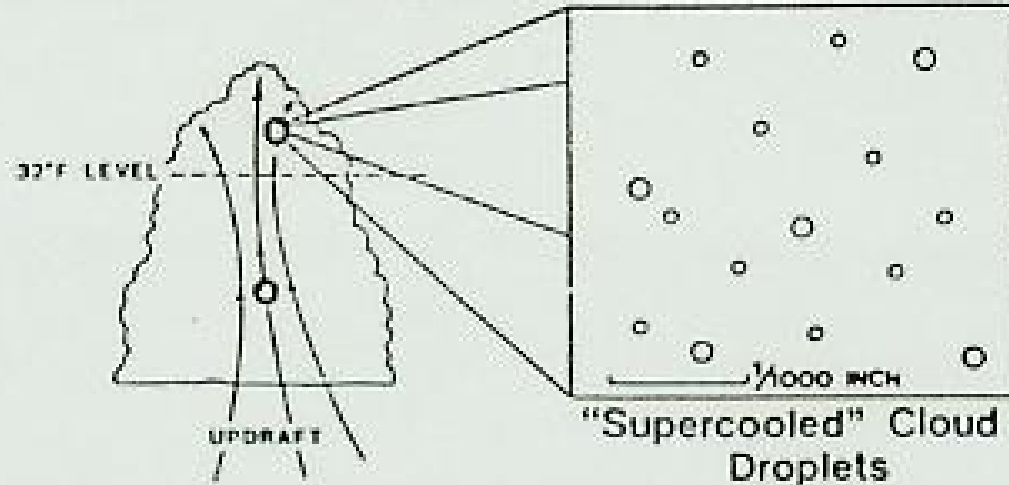


"Warm" Cloud  
Droplets

THE TYPICAL DEVELOPING CUMULUS CLOUD CONSISTS OF BILLIONS OF TINY DROPLETS, ABOUT 10,000 PER CUBIC INCH.

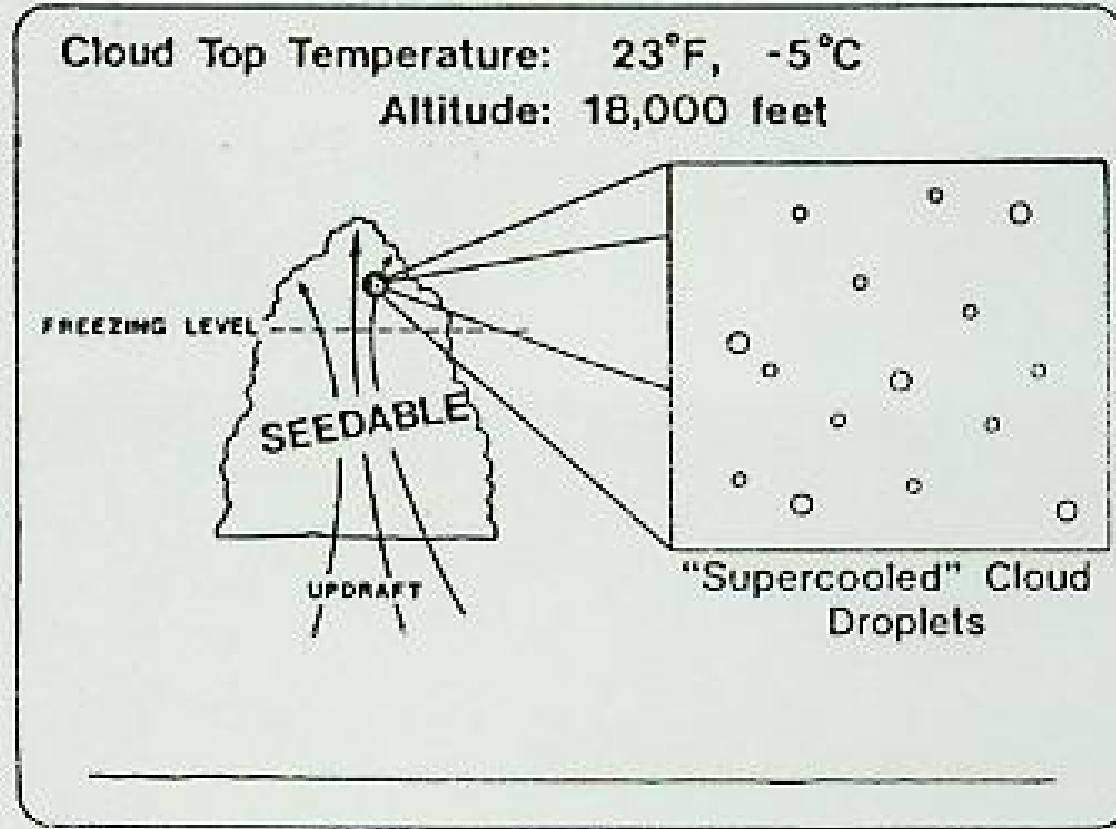
# Cold Rain Process

Cloud Top Temperature: 23°F, -5°C  
Altitude: 18,000 feet



CLOUD DROPLETS DO NOT FREEZE IMMEDIATELY AFTER COOLING BELOW 32°  
TO BEGIN FREEZING, TEMPERATURES BELOW 5°F ARE OFTEN REQUIRED.

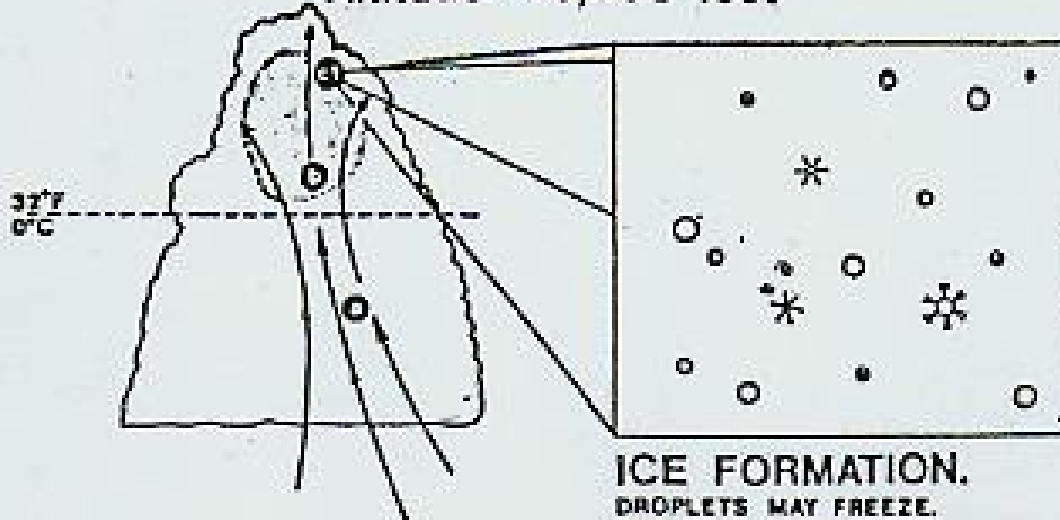
# Cold Rain Process



# Cold Rain Process

Cloud Top Temperature: 5°F, -15°C

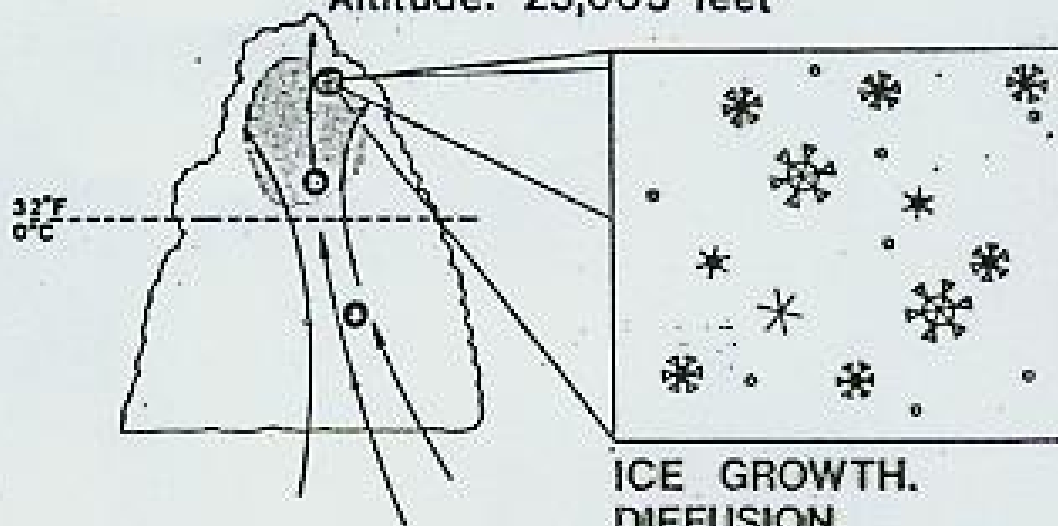
Altitude: 25,000 feet



# Cold Rain Process

Cloud Top Temperature: 5°F, -15°C

Altitude: 25,000 feet



**ICE GROWTH.**

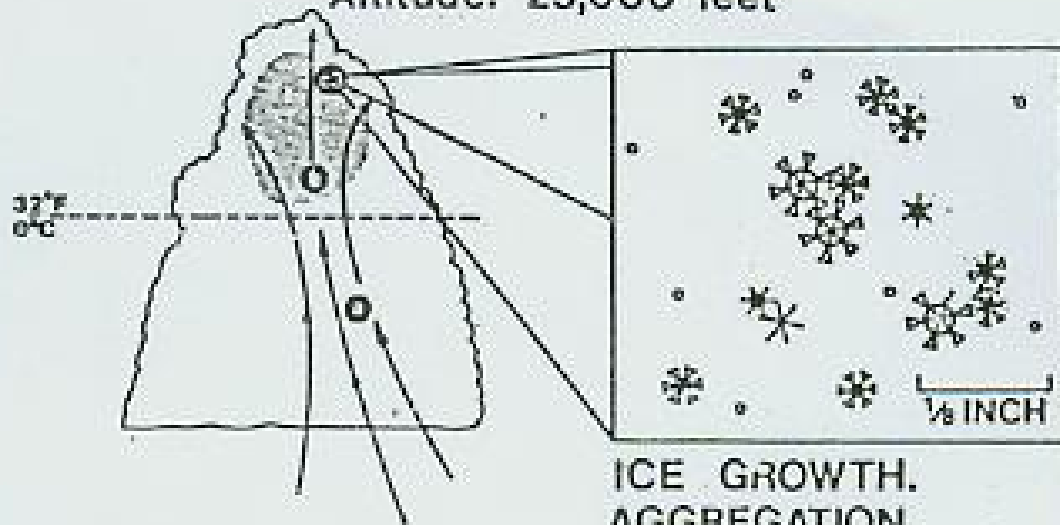
**DIFFUSION.**

VAPOR IS DEPOSITED ON ICE  
CAUSING CRYSTALLINE GROWTH.

# Cold Rain Process

Cloud Top Temperature: 5°F, -15°C

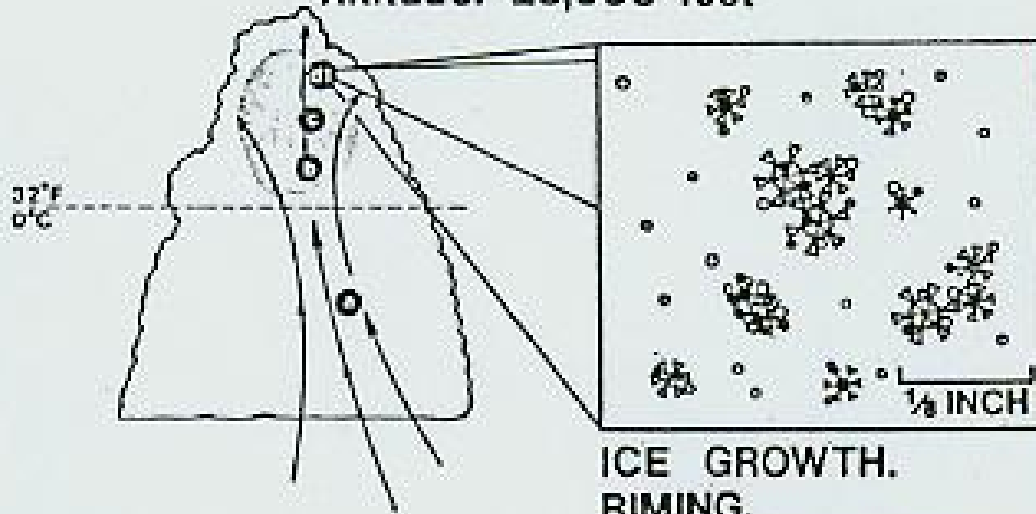
Altitude: 25,000 feet



# Cold Rain Process

Cloud Top Temperature:  $-4^{\circ}\text{F}$ ,  $-20^{\circ}\text{C}$

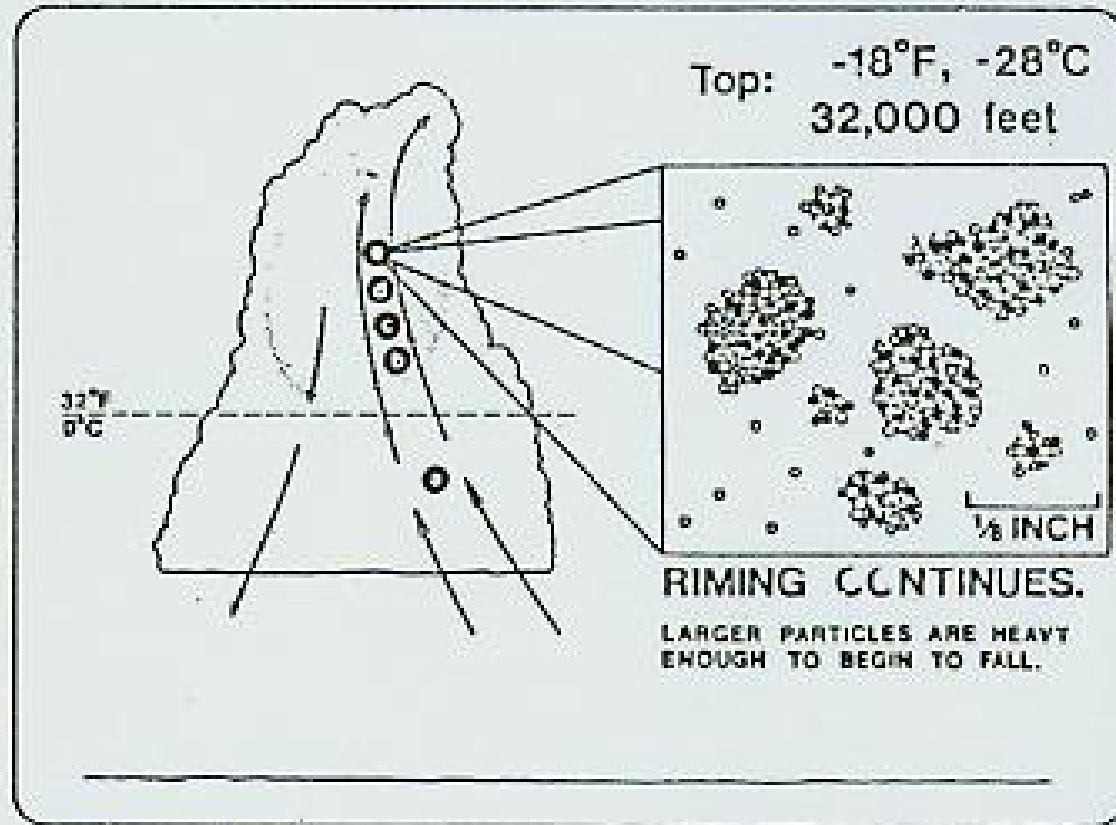
Altitude: 28,000 feet



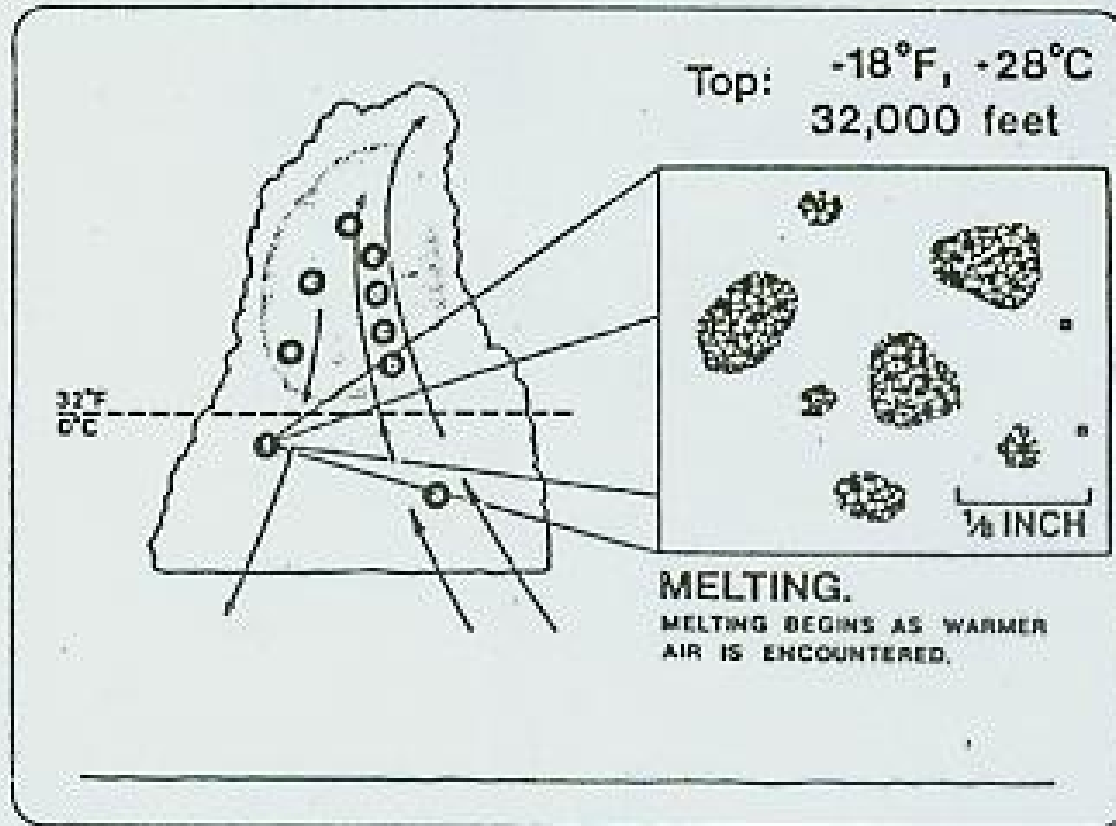
**ICE GROWTH.  
RIMING.**

SUPERCOOLED WATER DROPLETS  
COLLIDE WITH ICE AND FREEZE.

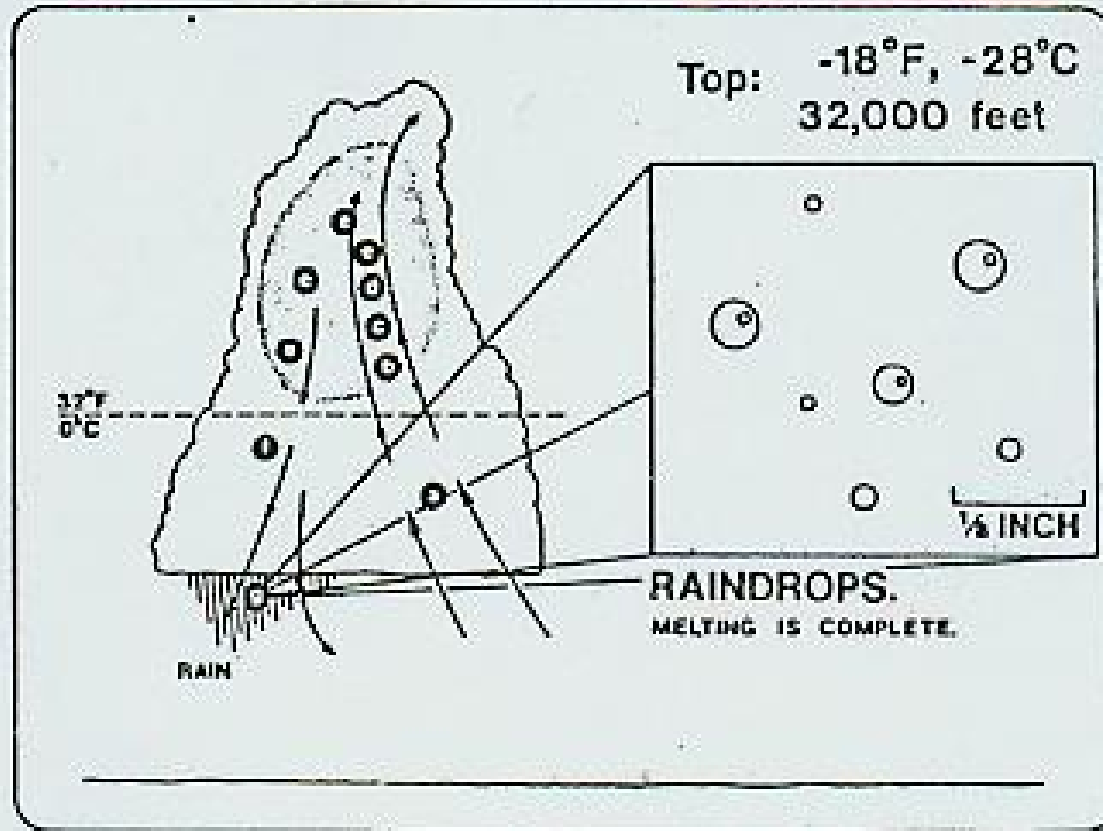
# Cold Rain Process



# Cold Rain Process

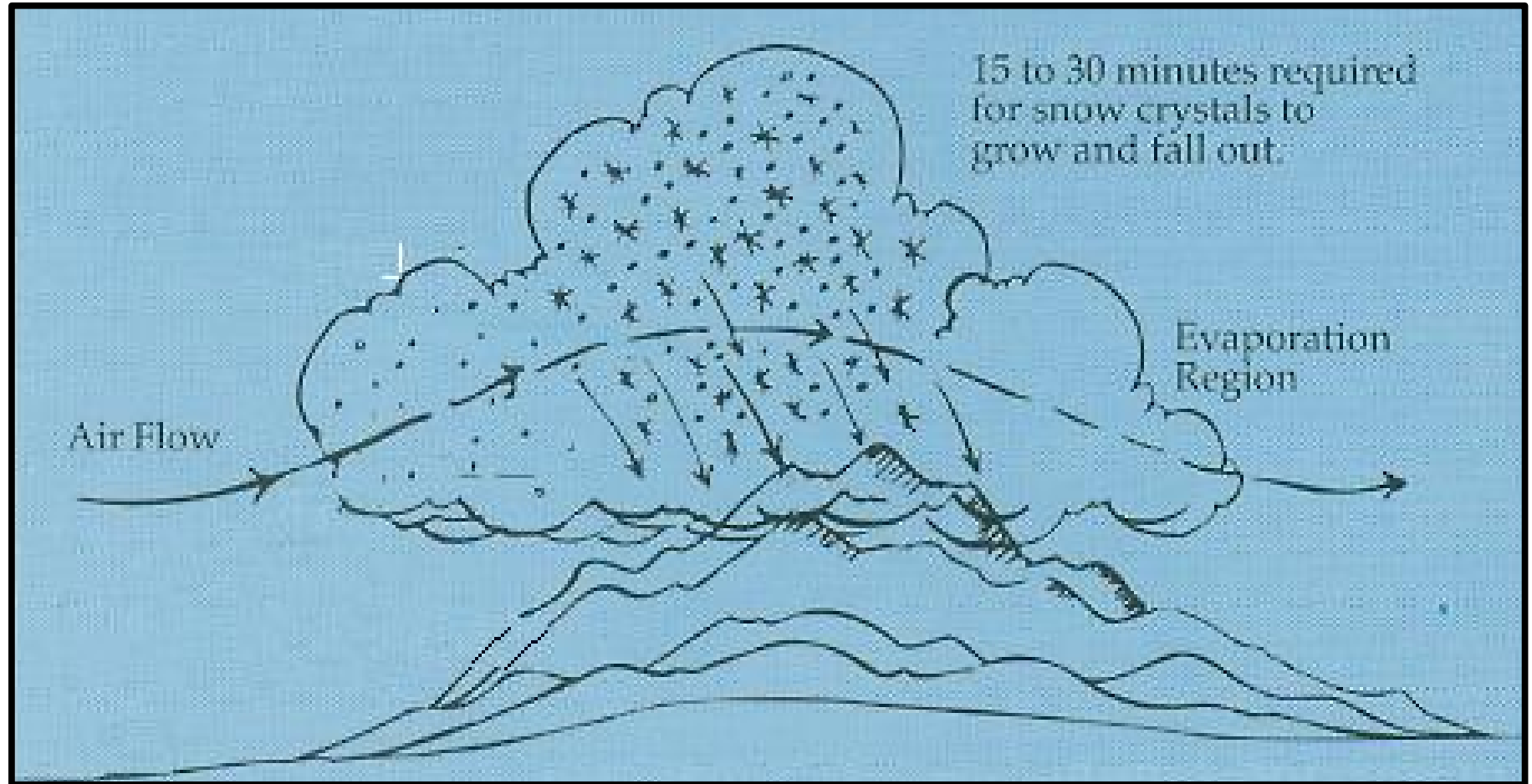


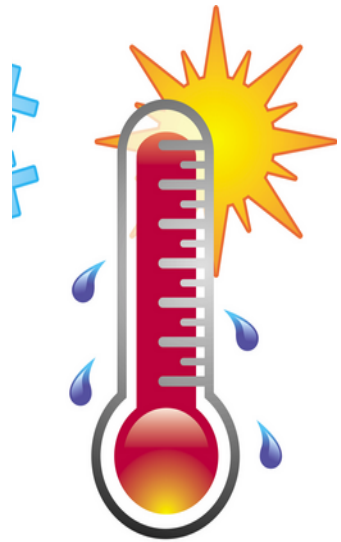
# Cold Rain Process



# Orographic Precipitation

## Mountain Cloud



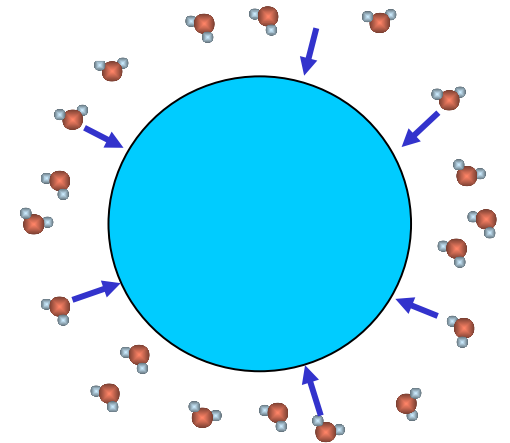


# Warm Rain Process

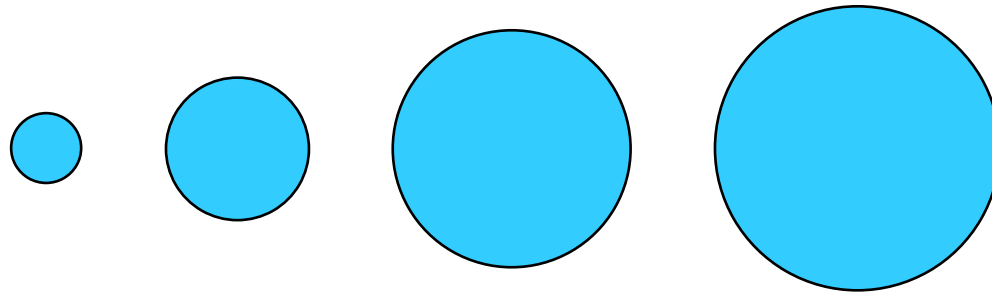
Condensation growth depends on particle size.

Much Slower as Droplet Grows

## Condensation Growth



Initially Fast



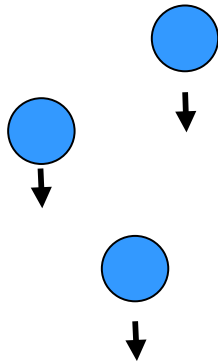
Time 

Condensation Produces Drops too Small to Precipitate

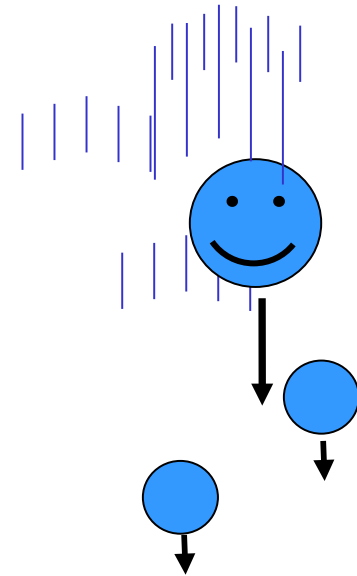
# Warm Rain Process

Some other process is needed to produce precipitation:

**Collision / Coalescence Growth**

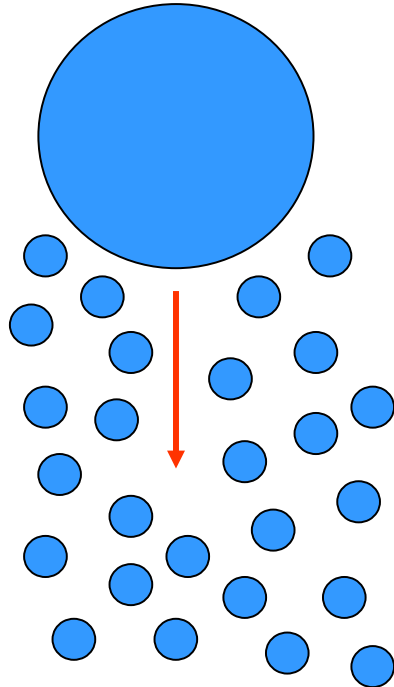


**Larger Drops  
Fall Faster**



# 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?

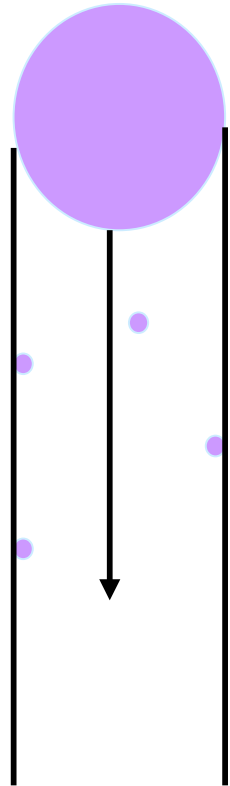
What conditions would then be favorable for the Warm Rain Process to occur?

# 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.



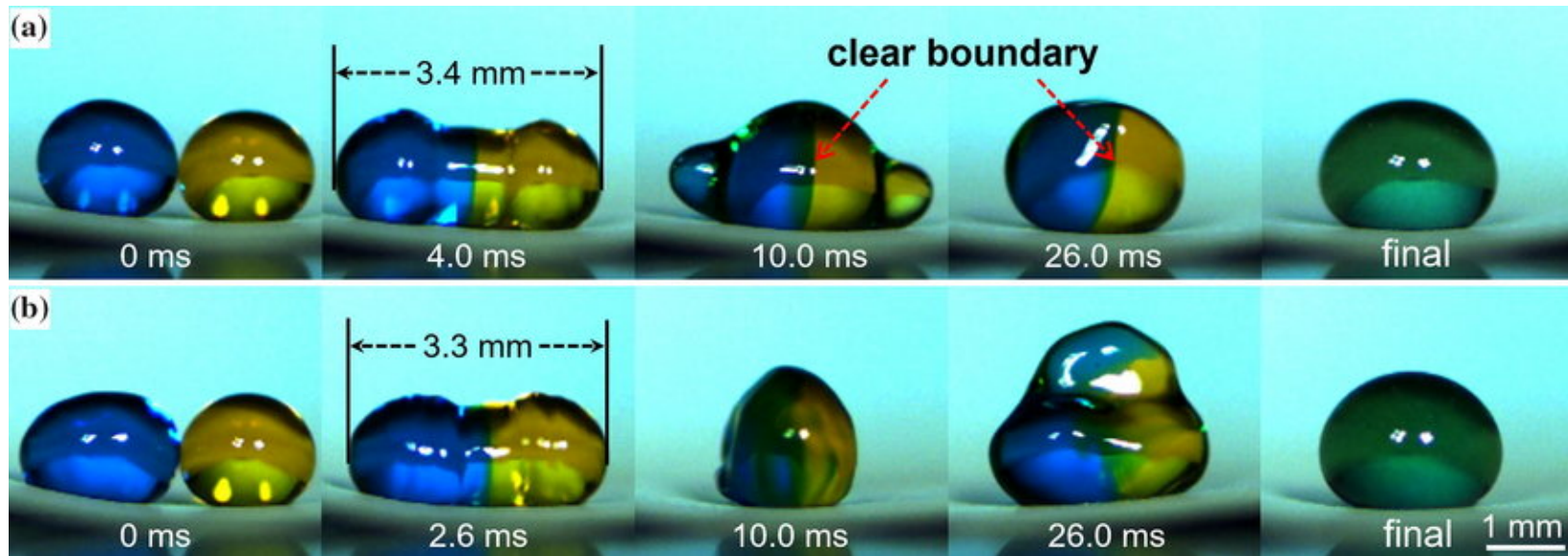
# Collision Efficiency



- 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 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

