Introduction to Meteorology

13 Precipitation process

Introduction

The cloud particles vary in phase depending on the temperature. Clouds that have above-freezing temperature at all levels are called warm clouds. The mixed clouds are the clouds in which the top is below 0˚C and is composed of supercooled clouds and ice-crystals. Because of the different phases of cloud particles, the development process of precipitation is different in warm and mixed clouds.

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1. Collision-coalescence process
2. Drop velocity of cloud particles
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5. Mixed cloud precipitation

Learning objectives

1. Describe the processes of condensation and collision-coalescence of cloud droplets in warm clouds.
2. Explain the Bergeron, riming and aggregation processes in mixed clouds.

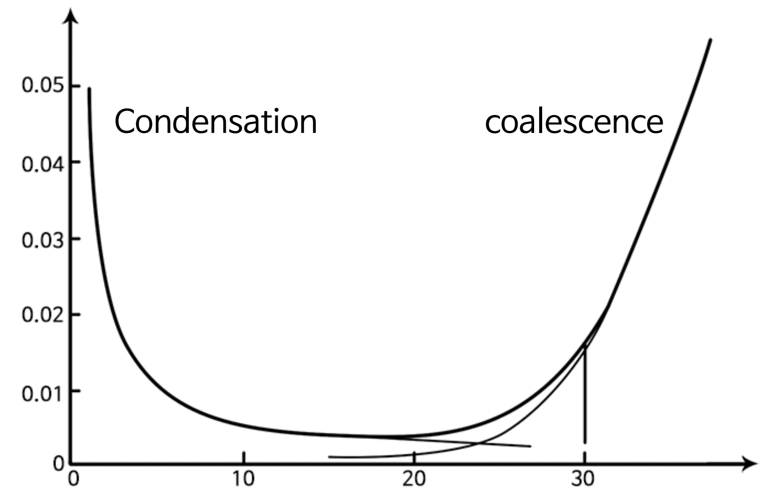
Learning Activities

1. Collision-coalescence process

Growth of cloud droplets takes place in two stages - by condensation, and by collision- coalescence. The growth of cloud droplet by condensation occurs efficiently only when the droplet radius is smaller than 20㎛. If the radius is larger than 20㎛, the growth by condensation is not effective.

For example, in order for droplets to grow to 1mm in size only by condensation it takes longer than normal and is almost impossible. Therefore, for larger droplets, growth by collision-coalescence process occurs efficiently than growth by condensation.

Collision and coalescence process works efficiently if the size of the droplets varies. This is because larger droplets fall faster than smaller droplets, thus larger droplets fall and collide with smaller droplets in their path.



〈Growth rate of droplet by condensation, collision, coalescence〉

Learning Activities

2. Drop velocity of cloud particles

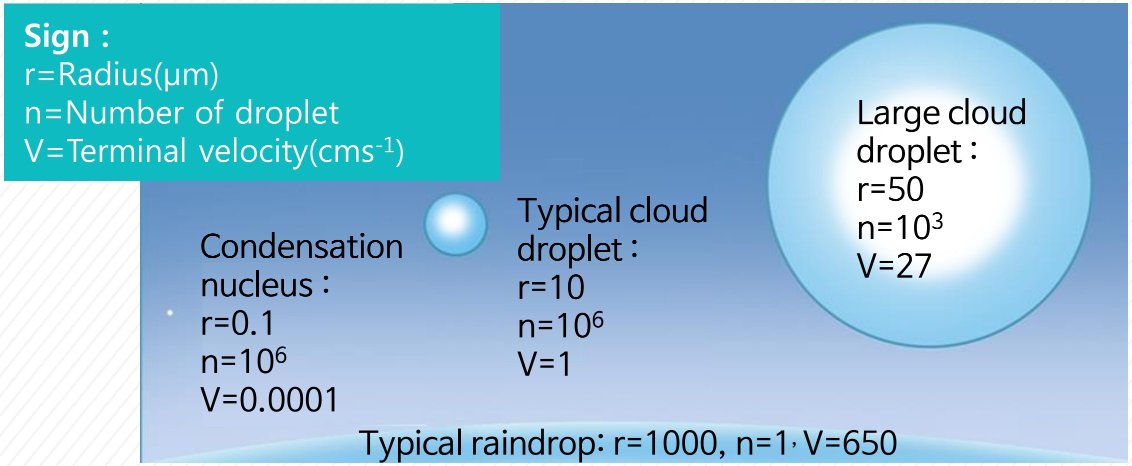
Assuming that the atmosphere is stationary, there are three types of forces acting on the cloud droplet: buoyancy, gravity, and frictional forces. If we assume the droplet density as 10kgm^{-3} and density of air as a 1kgm^{-3}, the buoyancy is 1/1000 of gravity. Therefore, we might have to primarily take into account the gravity and friction (or drag). The frictional force depends on the size, shape and speed of a droplet. The larger the droplet size or the faster the falling speed of the droplet, the greater the frictional force.

Learning Activities

2. Drop velocity of cloud particles

1) Terminal velocity

The speed at which the frictional force and gravity are balanced is called the terminal velocity. That is, if the atmosphere is at rest, the droplets fall at the terminal velocity.



〈Size of cloud particles〉

※ Source: Environmental atmospheric science (Kim, Kyung-Eak et al., Donghwa Technology)

It is interesting to compare the terminal velocity among different sized cloud droplets. The condensation nuclei that form the droplets have the slowest terminal velocity. The nucleus is so small, that its falling speed is not detectable. Terminal velocity of larger cloud droplets (with a radius of about 10~50μm) is approximately 1~25 cm s^{-1} . The terminal velocity of rain droplet is about 650 cm s^{-1}, which is 25 times faster than that of cloud droplet.

Learning Activities

2. Drop velocity of cloud particles

1) Terminal velocity

What if there is updraft in the atmosphere? The updraft acts in the opposite direction to the descent of the droplets, so the fall velocity of the droplet can be expressed as follows.

$$V_f = V_t - w_a$$

where V_f is the fall velocity in the presence of an upward flow, V_t is the terminal velocity of the droplet, w_a is the speed of the droplet by updraft. If the velocity of the updraft is greater than the terminal velocity, the droplet will rise, and if it is small, the droplet will fall. This implies that there is always an updraft when cloud exits.

Large droplets colliding with smaller droplets become even larger drops. This merging of cloud droplets by collision is called coalescence. The growth rate of large droplets satisfies the following relationship.

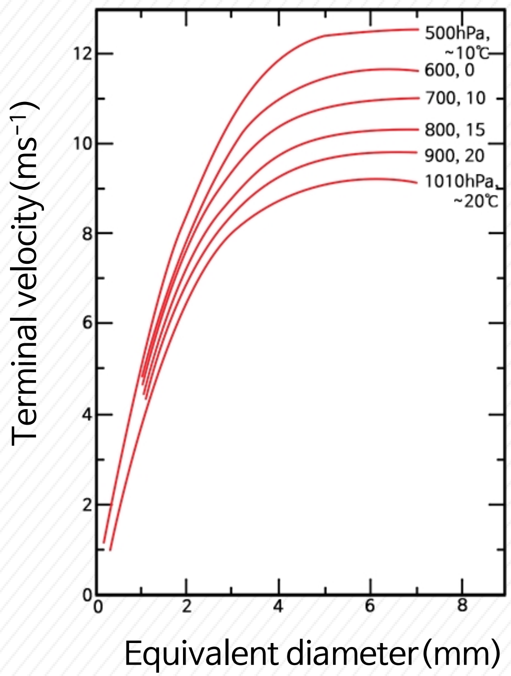
$$\frac{drz}{dt} \propto \mathrm{A}(U_2 - U_1) \qquad (\mathrm{A} = \pi(r_1 + r_2)^2)$$

where U_2 and r_2 (U_1 and r_1) represent the drop velocity and radius of the large (small) droplets, respectively. A is the area of collision between the large and small droplets.

Learning Activities

2. Drop velocity of cloud particles

1) Terminal velocity



⟨Terminal velocity as a function of diameter of droplet⟩

※ Source: Environmental atmospheric science
(Kim, Kyung-Eak et al., Donghwa Technology)

Figure shows that the larger the diameter of the droplet, the larger the terminal velocity.

$$\frac{drz}{dt} \propto \mathrm{A}(U_2 - U_1)$$

If $U_2 - U_1$ gets larger, $\frac{drz}{dt}$ becomes larger.
That is, the larger the difference in size of the droplet, the better the droplet grows.

Learning Activities

3. Warm cloud precipitation

Clouds that have above-freezing temperature at all levels are called warm clouds. Thus, all cloud particles are droplets. The growing process of droplets can be classified into two stages: condensation and collision. At each stage, the growth rate of droplet is closely related to its size.

If the radius of droplet is smaller than 20㎛, the growth of cloud droplet by condensation exceeds the growth by collision-coalescence. If the radius is larger than 20㎛, the growth by collision-coalescence dominates. Therefore, in order to form a raindrop in warm clouds, a radius of the droplet should be larger than 20㎛.

As shown earlier, if the droplet size increases, the drop velocity increases. The growth rate can be expressed as

$$\frac{drz}{dt} \propto \mathrm{A}(U_2 - U_1)$$

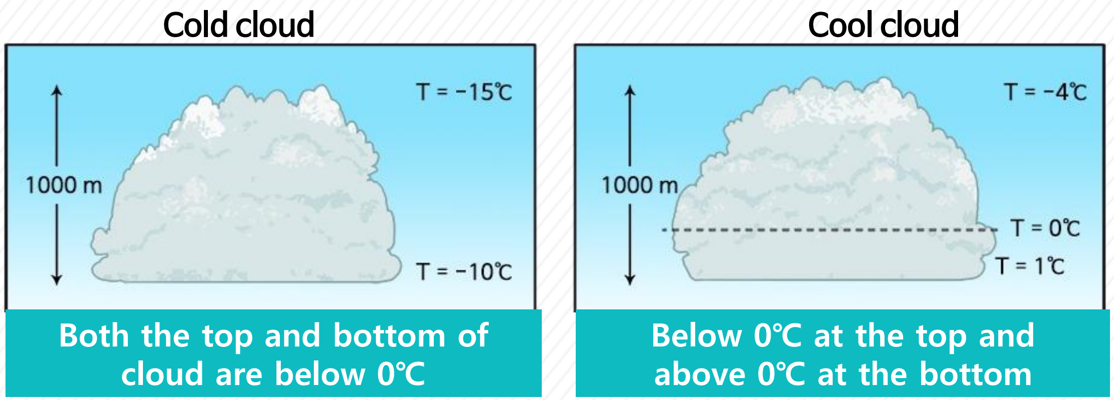
In order to effectively form raindrops in clouds within a short period of time, the range of the droplet size distribution must be wide. Warm clouds over the ocean often start to precipitate within 30 minutes due to the wider range of the droplet size over ocean than over land.

Learning Activities

4. Cold cloud precipitation

1) Ice growth

When the temperature of clouds is below 0℃, supercooled droplets and ice crystals are in present. These clouds are called mixed clouds. Mixed clouds can be observed in mid and high latitudes. Mixed cloud can be divided into two types.



〈Types of mixed cloud〉

※ Source: Environmental atmospheric science (Kim, Kyung-Eak et al., Donghwa Technology)

Cold cloud consists of supercooled droplets and ice crystals. The precipitation development process in cold clouds can be divided into the ice crystal (Bergeron) process and collision-coalescence process.

The precipitation in cold clouds necessitates high concentration of ice particles. Therefore, ice multiplication without freezing of supercooled droplets or growth of ice nuclei is required to increase the number of ice crystals in clouds. There are three types of ice multiplication process. Ice crystals formed by the ice multiplication are called secondary ices.

Learning Activities

4. Cold cloud precipitation

2) Accretion and aggregation

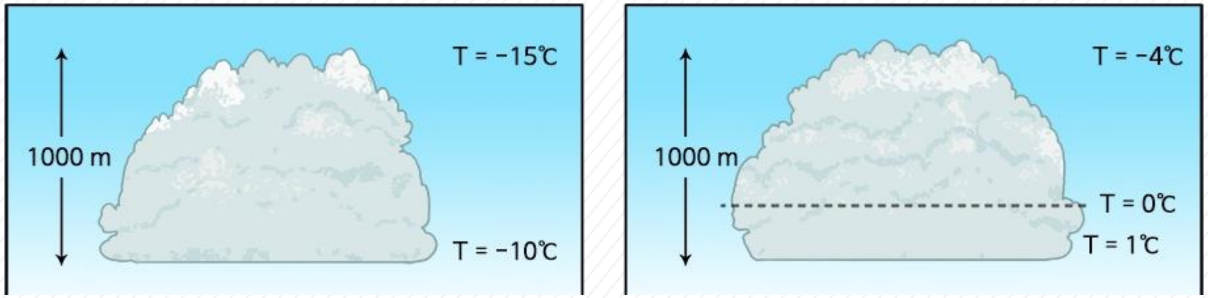
In cold clouds, ice crystals might collide with supercooled liquid droplets. Upon contact, the droplets freeze into ice and stick together. This process of ice crystals is called accretion.

Aggregation happens when ice crystals collide to form larger ice crystals. Aggregation occurs easily when the surface of the ice crystal is covered with water rather than when it is dry. Such water coating is most likely to occur when the temperature of the cloud is not lower than 0˚C. If the cloud is below the altitude of 0˚C level, the aggregation plays a very important role in the development of precipitation. It is therefore likely that large snowflakes will occur more often when it is warm, such as early winter.

Learning Activities

5. Mixed cloud precipitation

In the lower part of mixed clouds (cool clouds), the temperature is higher than 0 ℃, so the cloud particles exist as liquid.
In the case of a layer below 0 ℃, ice crystals and supercooled droplets co-exist, so clouds grow differently comparing to warm clouds.



⟨Cold cloud and cool cloud⟩

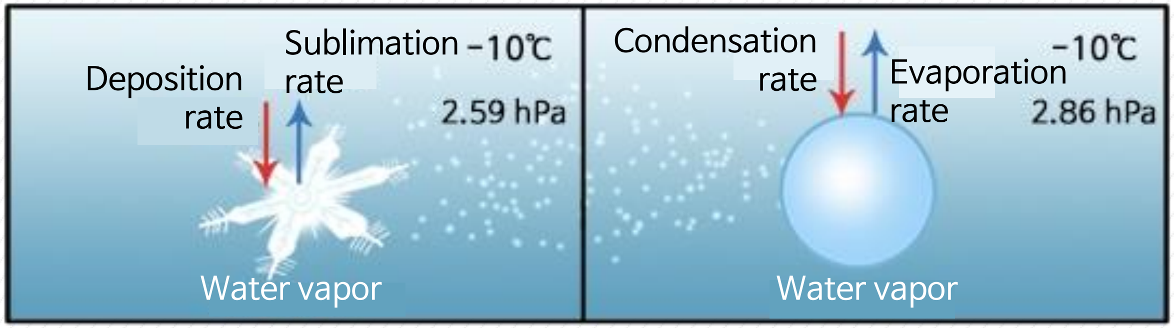
※ Source: Environmental atmospheric science (Kim, Kyung-Eak et al., Donghwa Technology)

Learning Activities

5. Mixed cloud precipitation

1) Bergeron process

The Bergeron process, which is used to describe the process of precipitation in mixed clouds, is also known as the ice crystal process. To understand the ice crystal process, let's first consider the following experiment.



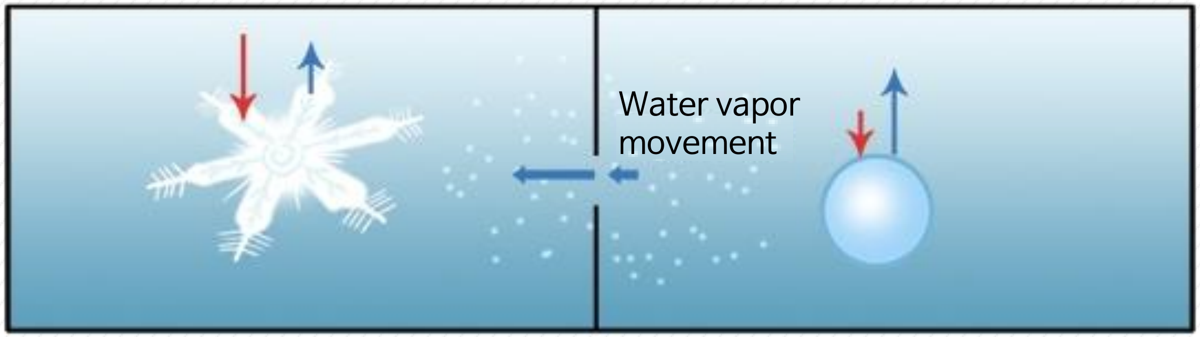
(a)

Assume that a box is divided in half by a partition, and the air in both sides does not communicate with each other.
Supercooled water vapor at −10 ˚C occupies right half of the box and ice crystals at −10 ˚C occupies other left half.
The saturation water vapor pressure in the right half of the box is 2.86 hPa and in the left half of the box is about 2.59 hPa.

Learning Activities

5. Mixed cloud precipitation

1) Bergeron process



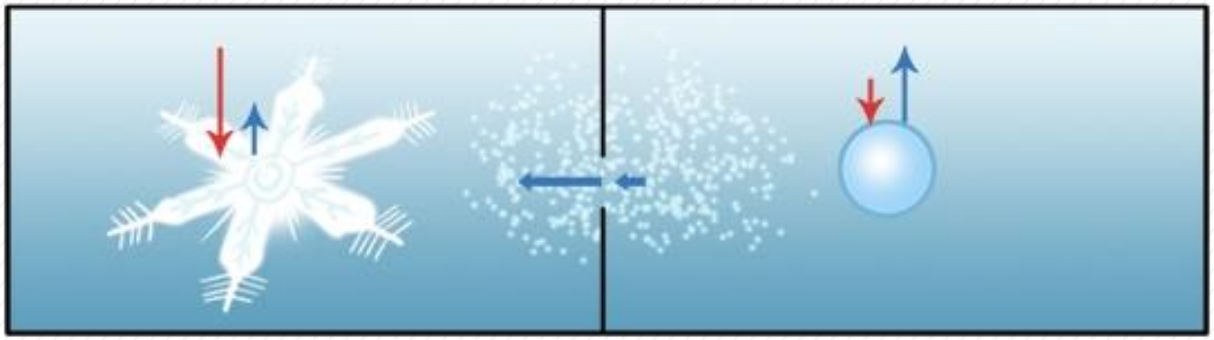
(b)

If a small hole is made in the partition to allow air in both parts to communicate with each other, the water vapor will move from high to low saturated water vapor pressure, i.e. from the supercooled water to the ice crystal. As a result, the ice crystal in the left half of the box becomes supersaturated by the water vapor deposition on the ice surface, while the supercooled water in the right half of the box becomes unsaturated due to the loss of water vapor. The supercooled water continues to evaporate resulting in decrease in water.

Learning Activities

5. Mixed cloud precipitation

1) Bergeron process



(c)

If this process is applied to clouds where supercooled water and ice crystals co-exist, the supercooled water droplets will gradually decrease in size due to the evaporation, while ice crystals will continue to grow due to the deposition.

The growth of ice crystals due to the deposition usually causes weak precipitation. As the ice crystals grow, their mass increases which causes the ice crystals to collide with droplets or other ice crystals as they fall. Two important processes that rapidly accelerate the growth rate of ice crystals are riming and aggregation.

Summary

1. Collision-coalescence process

- Collision-coalescence process works efficiently if the size of the droplets varies.

Summary

2. Drop velocity of cloud particles

- The velocity when the friction force and the gravity are balanced is called the terminal velocity.
- Drop velocity in the presence of updrafts can be expressed as

$$V_f = V_t - w_a$$

- The growth rate of large droplets satisfies the following relationship.

$$\frac{drz}{dt} \propto \mathrm{A}(U_2 - U_1)$$

Summary

3. Warm cloud precipitation

- Clouds that have above-freezing temperature at all levels are called warm clouds. Warm clouds develop in tropical region or in mid latitudes during summer.
- The growing process of the droplet can be classified into two stages: condensation and collision.
- If the radius of droplet is smaller than 20㎛, the growth of cloud droplet by condensation dominates. If the radius is larger than 20㎛, the growth by collision-coalescence dominates.
- For raindrops to effectively form in warm clouds, the range of the size distribution of droplet must be wide.

Summary

4. Cold cloud precipitation

- Ice multiplication without freezing of supercooled droplets or growth of ice nuclei is required to increase the number of ice crystals in clouds. Ice crystals formed by the ice multiplication are called secondary ices.
- There are three types of ice multiplication process.
- Two important processes that rapidly accelerate the growth rate of ice crystals are riming and aggregation.