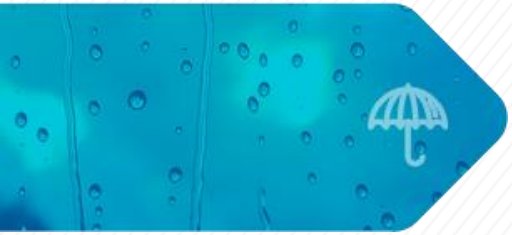
Introduction to Meteorology

12 Cloud formation and growth

Introduction

Clouds consist of raindrops formed by condensation or ice-crystals formed by freezing. The formation, development, and dissipation of clouds change the weather, which not only affects our everyday life, but also plays an important role in various atmospheric processes such as atmospheric dynamics and thermodynamics, atmospheric radiation, and hydrology.

Contents



1. Formation and growth of cloud
2. Cloud formation

Learning objectives

1. Understand the formation of cloud and ice-crystals, and explain the concepts of condensation nucleus and ice nucleus.
2. Understand the causes of air uplift and cloud formation processes.

Learning Activities

1. Formation and growth of cloud droplets

Clouds are a collection of floating cloud droplets or ice crystals in the air or a mixture of both. Therefore, the first step of cloud formation is the formation of droplets and ice crystals.

Learning Activities

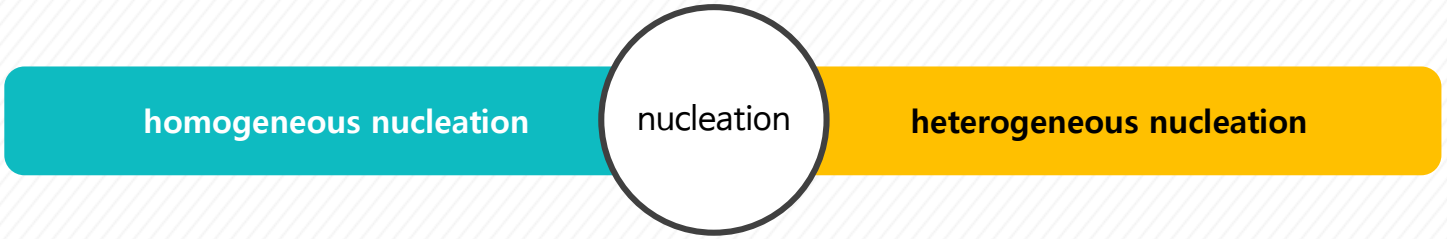
1. Formation and growth of cloud droplets

1) Nucleation

Cloud droplets are formed by condensation of water vapor, and ice crystals are formed by sublimation of water vapor or freezing of subcooled droplets. When relative humidity reaches 100%, condensation of water vapor occurs in the presence of condensation nuclei in the atmosphere. This is because the condensation nucleus provides a surface on which water vapor can condense.

If pure water vapor is condensed with supersaturated vapor without condensation nuclei, the relative humidity must be at least 400%. Likewise, formation of ice crystals by deposition of water vapor is also difficult without the help of ice nuclei. Supercooled water droplets formed in the absence of ice nuclei can exist as subcooled droplets without phase lower than −40˚C.

Nucleation is the process in which water vapor or supercooled droplets transform to cloud droplet or ice crystals through phase changes.



Nucleation can be classified to homogeneous nucleation consisting of only pure water molecules and heterogeneous nucleation by condensation nuclei or ice nuclei

Learning Activities

1. Formation and growth of cloud droplets

2) Aerosol

Solid or liquid particles floating in the atmosphere, besides cloud droplet or rain droplet, is called aerosol.

Aerosols are generally 0.01 to 10 μm in radius, and act as condensation nuclei or ice nuclei contributing to cloud formation. Types of aerosols can be classified according to their size as follows.

〈Types of aerosol〉

Aitken nucleus Radius < 0.1μm	Large nucleus Radius 0.1~1μm	Giant nucleus Radius > 1μm

Aerosols play an important role in the cloud and precipitation processes. The most important contributor to the formation of droplets in the atmosphere is the giant nucleus.

Learning Activities

1. Formation and growth of cloud droplets

Aerosols can be divided into those occur by natural, man-made, and chemical reaction.

Natural	Solid particles, pollen, bacteria, etc.
Man-made	Smoke, organic aerosol, etc.
Chemical reaction	Sulfur, nitrogen, hydrocarbon compound particles, etc.

Particles with hygroscopicity (moisture absorbing properties), such as sea salt particles, become condensation nuclei, while aerosols such as soil, pollen and bacteria with non-hygroscopic or hydrophobic properties become ice nuclei. But the number of ice nuclei is small compared to the condensation nuclei.

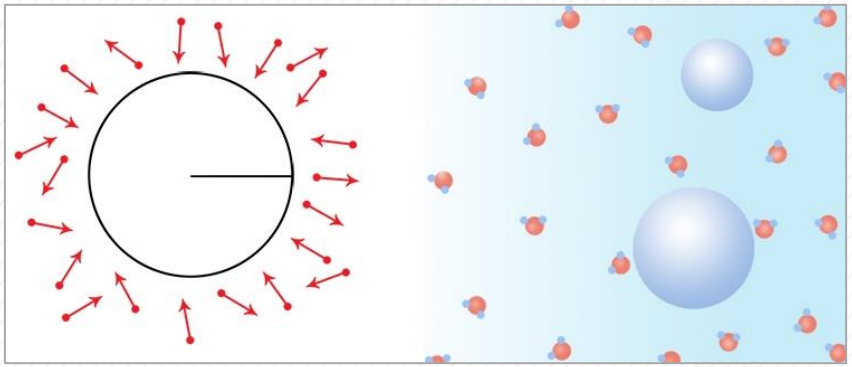
The distribution of aerosols varies spatially and temporally. It exists in the lower part of the troposphere and near the source. Aerosols in the troposphere are the condensation nuclei of water vapor, and last over a few days in the atmosphere.

Learning Activities

1. Formation and growth of cloud droplets

3) Growth of cloud droplets and ice crystals

Air parcel lifted to the upper air expands and cools adiabatically. The ascending air is cooled to the dew point temperature at the lifting condensation level. When the air saturates by further uplift or by cooling, the water vapor is condensed on the surface of the condensation nuclei.



〈Growth of droplets by condensation of water vapor〉

Water vapor molecules diffuse from high to low density. If the water vapor density around the droplet surface is larger than that of the droplet, ~~and~~ the droplet grows as condensation occurs. As the growth rate of the droplet is inversely proportional to the radius of the droplet, ~~so~~ it grows quickly in the earlier stage of droplet formation. Over time, even if the interior of the cloud is supersaturated, the growth rate of droplets decreases rapidly. Growth rate of cloud droplets with radius smaller than 20μm is fast, while the growth rate of bigger cloud droplet is slow.

Learning Activities

1. Formation and growth of cloud droplets

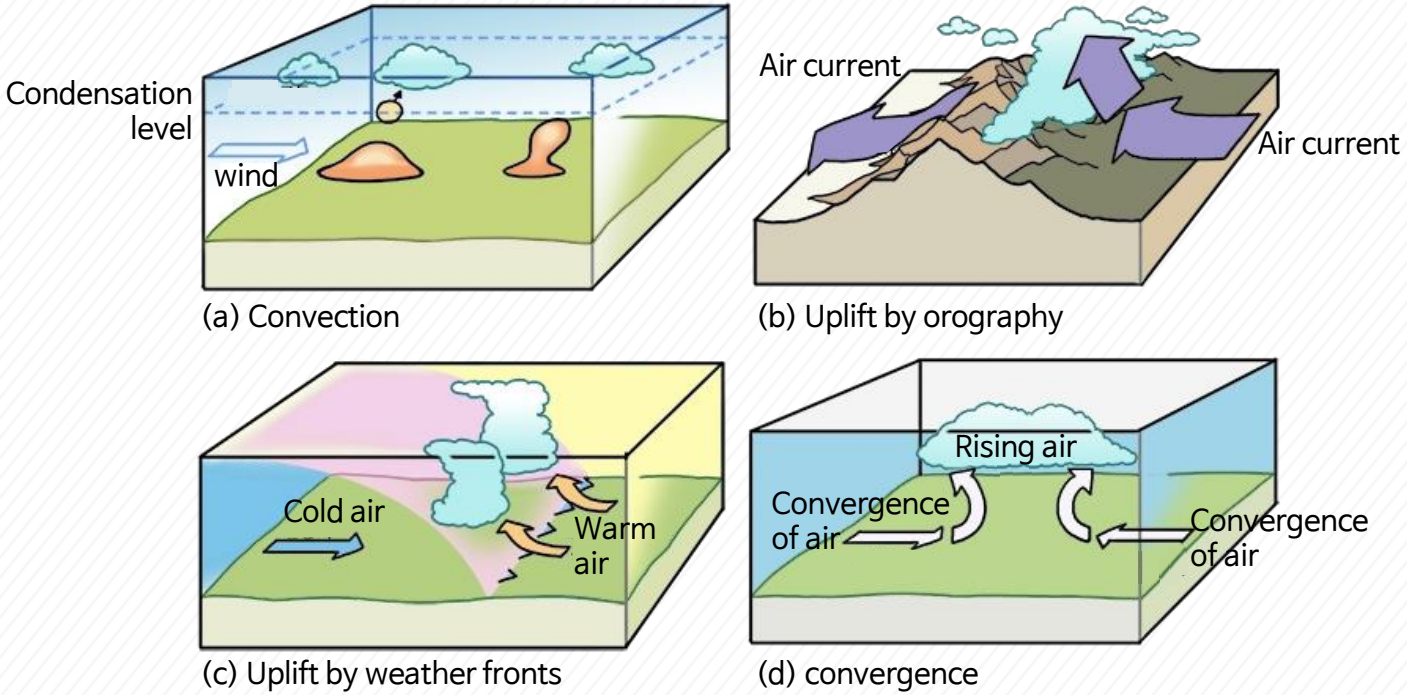
Generally having hexagonal structure, ice-crystals are formed by the deposition of water vapor in the supersaturated state when the temperature is below 0 ° C. The shape of the ice crystals, however, varies depending on the environment in which the ice crystal grows. Ice crystals grow when the density of water vapor around a droplet is higher than the density of water vapor on the surface of ice crystals.

The shapes of ice crystals are affected by ambient temperature and humidity at the time of growth. It is determined by the temperature whether a crystal grows into a plate or column shape. The humidity around is also related to the complexity of the ice-crystal shape. If the humidity is low, the ice crystals appear to be simple shapes, but as humidity increases, the shapes of ice crystals become complex.

Learning Activities

2. Cloud formation

Most of the clouds are formed by condensation of water vapor and freezing when rising air parcel cools adiabatically and reaches to saturation. The uplift of air can occur, through convection, orographic lifting, frontal lifting, and convergence of air.



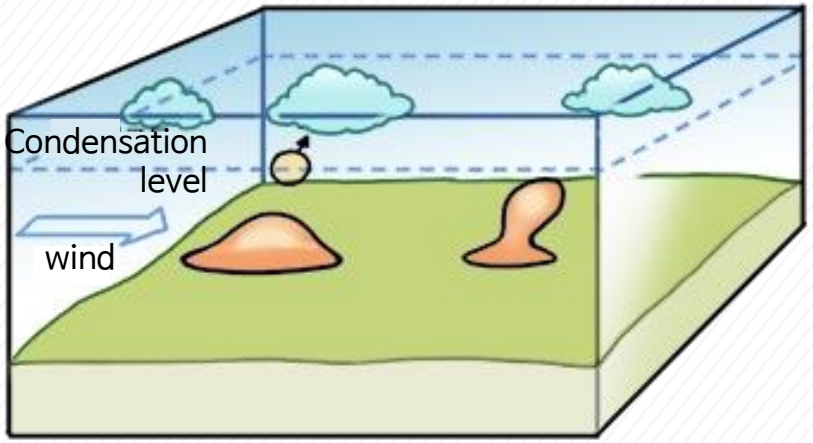
〈Air uplift processes〉

※ Source: Introduction to Atmospheric Science (Korea Meteorological Society, Sigma press) p76

Learning Activities

2. Cloud formation

1) Convection



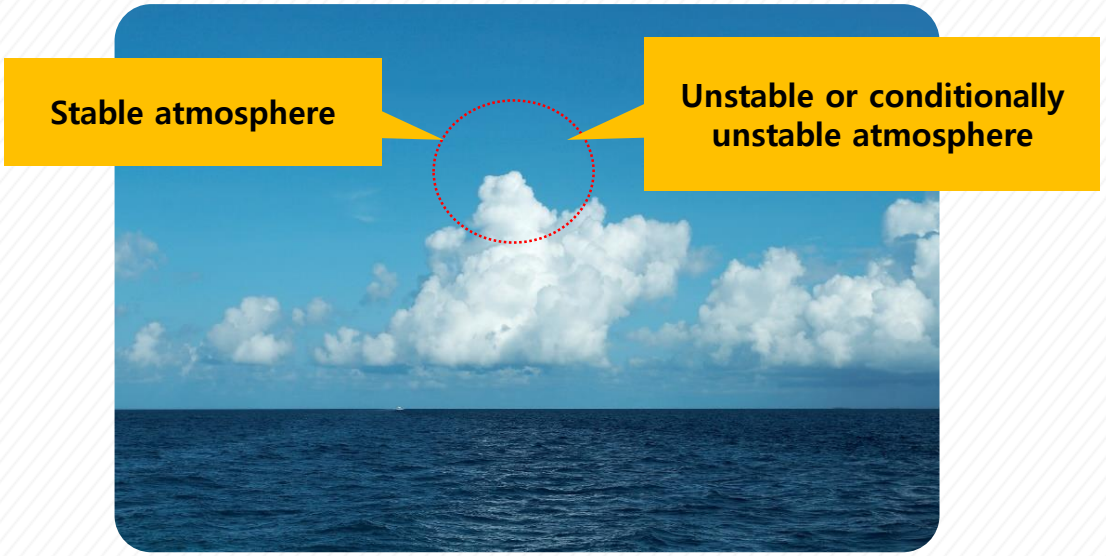
(a) Convection

Some areas absorb sunlight more than others. As a result, the area heats faster than its surroundings. A thermal (heated air parcel) rises and cools. As it rises, it mixes with the cooler and dryer ambient air, which gradually slows the rising motion. When the rising air is cooled to the saturation point, condensation occurs to form a cloud, where the altitude is referred to as the lifting condensation level. The thermals appear in the form of cumulus clouds.

Learning Activities

2. Cloud formation

Atmospheric stability has an important influence on the vertical development of the cumulus. For example, if the atmosphere is stable near the top of cumulus, the cloud can no longer grow vertically. In contrast, if there exists an unstable or conditionally unstable atmosphere above the clouds, clouds will develop more vertically.

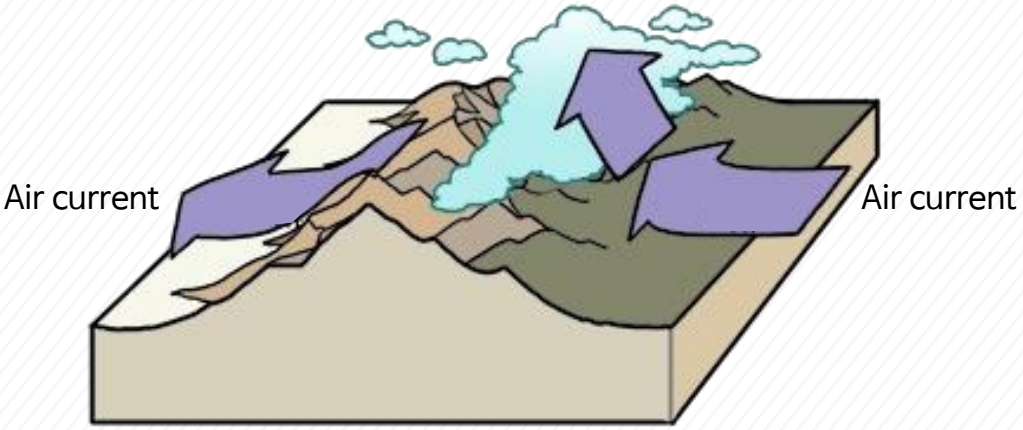


〈Atmospheric stability〉

Learning Activities

2. Cloud formation

2) Uplift by orography



(b) Uplift by orography

Because the air moves horizontally, it will force air to rise when it encounters an obstacle such as a mountain. When the air rises along the slope of the mountain on the windward side due to the elevation of the terrain, the air expands and cools adiabatically.

When the air continues to rise and reaches the condensation level, clouds begin to form. It rains in the windward side and changes to dry and warm air in the leeward side. The conversion of sensible heat to latent heat during the condensation process warms the air. The air that descends is already dry ~~air~~ as much water vapor is removed from the windward side, forming a rain shadow on the leeward side.

Learning Activities

2. Cloud formation

Generally, you can see more clouds on the windward side of the mountain, but clouds can also form on the leeward side under certain conditions. For example, stable air over mountains often travels leeward side over hundreds of kilometers, causing waves. Clouds are formed at the peak of such waves, and such clouds are called lenticular clouds because they resemble lenses.

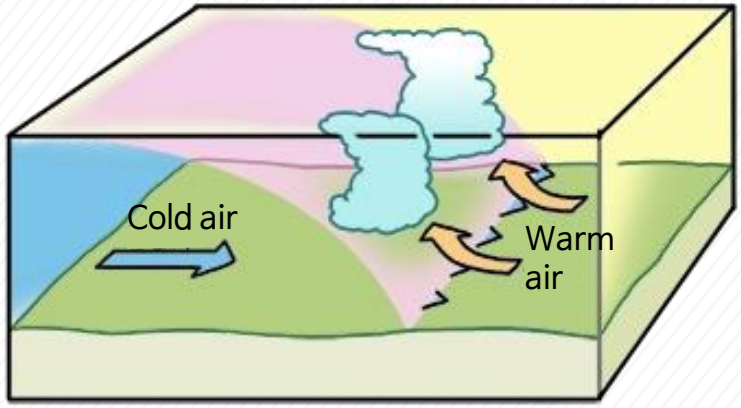
〈Lenticular clouds〉

※ Source: Weather Photo Exhibition, KMA

Learning Activities

2. Cloud formation

3) Uplift by weather fronts



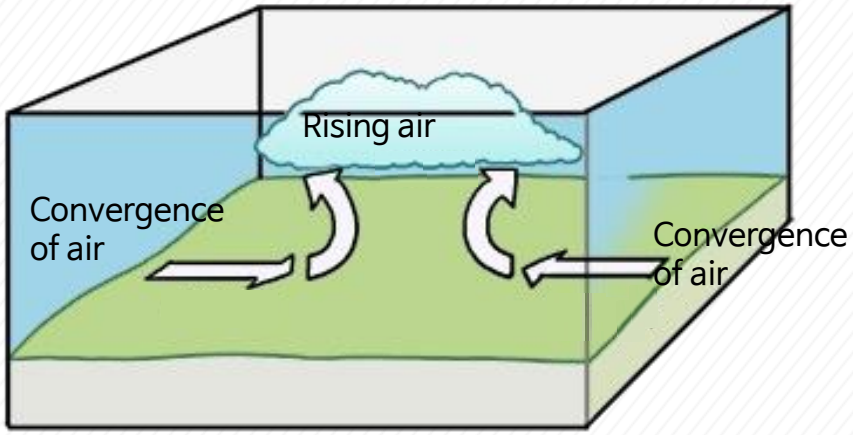
(c) Uplift by weather fronts

Clouds can form when air is lifted by a front. When two air parcels with different densities are encountered, an interface is created, which is called a front. In cold fronts, the heavier cold air pushes under the lighter warm air. In warm fronts, air rises above cold air covering a wide area. When air rises, condensation occurs, and clouds form.

Learning Activities

2. Cloud formation

4) Convergence



(d) convergence

Convergence is caused by pressure gradient or by topographical factors. When the converged air rises, clouds form by adiabatic expansion, cooling, and condensation.

Summary

1. Formation and growth of cloud

- Nucleation is the process in which water vapor or supercooled droplets transform to cloud droplet or ice crystals through phase changes.
- Aerosols are solid or liquid particles floating in the atmosphere and act as cloud condensation nuclei.
- Particles with hygroscopicity become condensation nuclei, while aerosols with non-hygroscopic properties become ice nuclei.

Summary

2. Cloud formation

- Clouds are formed by condensation of water vapor and freezing when rising air parcel cools adiabatically and reaches to saturation.
- The uplift of air occurs through convection, orographic lifting, frontal lifting, and convergence of air.