Introduction to Meteorology

31 Thunderstorms (2)

Introduction

There are many extreme weather events that cause disasters in a short period.
A typical example is thunderstorms. A thunderstorm producing heavy rain, hail, gust and lightning results in loss of lives and massive property damages.
The thunderstorm is a storm with heavy rain and thunder. This phenomenon occurs when the atmosphere is unstable, and moist air rises locally so that it releases latent heat. Air in the cloud warmed by the latent heat release further increases the upward buoyant force and triggers strong convection. Thus more low-level moisture condensation occurs by a strong updraft. Because the air that is rapidly raised by convection cannot go over the tropopause, it spreads out horizontally resulting in an anvil cloud. Convection develops vertically to the tropopause by strong updraft. A convective cloud with an anvil is called a cumulonimbus (or cumulus).
In the mature cumulus, heavy rain develops as warm and humid air rises rapidly and condenses. Also, the ice process plays an important role as cloud reaches the tropopause.

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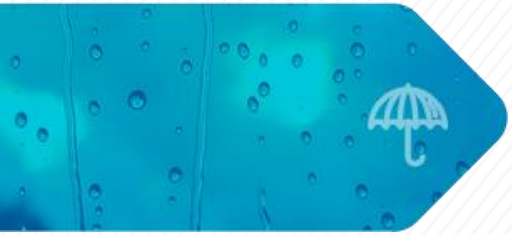


1. Life cycle of thunderstorms and associated phenomena

Learning objectives

1. Describe the causes of thunderstorms.
2. Explain the life cycle of thunderstorms.

Learning Activities

1. Life cycle of thunderstorms and associated phenomena

1) Forcing mechanism

The forcing mechanism of thunderstorms can be: unequal heating at the surface during a warm and humid summer afternoon, uplift along mountain barriers, warm air rising along a frontal zone, and converging surface winds and ascending air in a low-pressure zone.

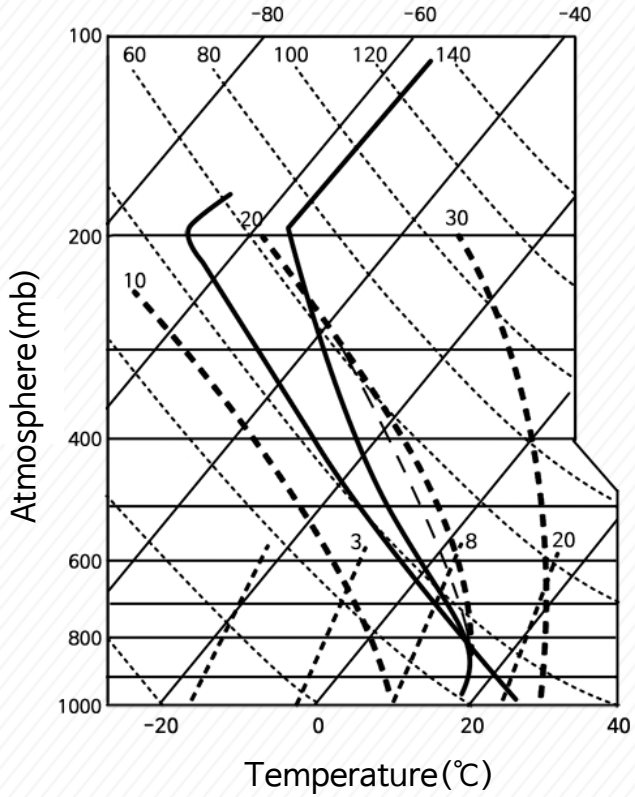
Learning Activities

1. Life cycle of thunderstorms and associated phenomena

2) Development conditions of thunderstorms

The most important conditions that determine the development of thunderstorms are the atmospheric static stability and vertical wind structure. Most of the cases, the conditionally unstable state is required.

In other words, an air parcel in the developing thunderstorm becomes buoyant and rises to the tropopause, because its temperature is warmer than the surroundings. Lifted Index (LI) is an index used to assess the degree of (in)stability of a parcel.



Learning Activities

1. Life cycle of thunderstorms and associated phenomena

LI is used for assessing thunderstorm and tornado development. The larger the positive (negative) value, the more stable (unstable) the atmosphere. For example, if the LI is lower than −6, a strong thunderstorm can develop. The thermodynamic structure of the atmosphere determines the intensity of the thunderstorm.

Meanwhile, the most important factor that affects the type of thunderstorm is the vertical wind shear.
The stronger the vertical wind shear, the more sustainable thunderstorm develops. When the wind is weak, or the vertical shear is weak, the thunderstorm has a short life span because of a self−destructive structure with strong downdraft over a broad region.

On the other hand, when the vertical wind shear is strong, thunderstorms are separated from warm and wet air rising zone and precipitation zone. This induces a self−sustaining structure that can maintain a strong updraft.

Learning Activities

1. Life cycle of thunderstorms and associated phenomena

3) Life cycle

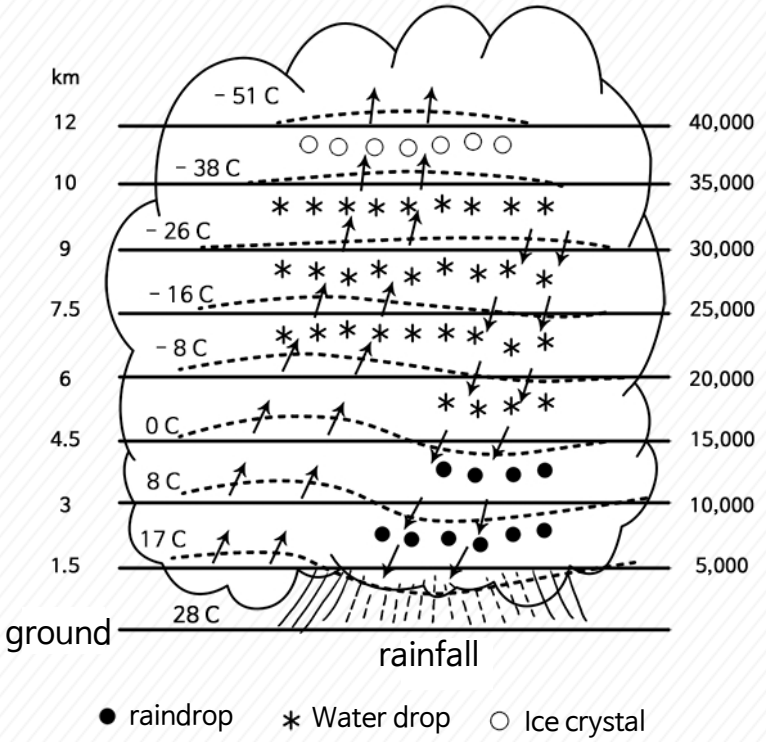
Thunderstorms are made up of several cells, and in some cases, new cells gradually develop over time. The development of one cell can be divided into a development stage, mature stage, and dissipation stage. Strong updraft within the cumulus cloud can reach 20m/s. Because of the condensation heat, the temperature within the cumulus cloud is higher than the ambient temperature. It develops to 1~10km in diameter in about 15 minutes and reaches the height of about 10km.

Learning Activities

1. Life cycle of thunderstorms and associated phenomena

Entrainment suppresses the development of the cloud by the lateral mixing of environmental air into a preexisting cloud. Cloud droplet gradually increases in the cloud.
In the upper-level of cloud (above 0 ℃), ice crystals and water droplets exist. In the mature phase, as shown in the picture, the low-level clouds consist of water droplets, the mid-level clouds consist of water droplets and ice crystals, and the upper-level is composed of ice crystal clouds. When the upper-level cloud becomes ice crystal, the precipitation starts, and downdraft zone with 10m/s spreads around.

The updraft also increases, reaching more than 30m/s instantaneously. The precipitation continues until the downdraft is spread throughout (14~20 minutes). In the dissipating stage, clouds still develop in the tropopause and become anvil clouds.



Entrainment suppresses the development of the cloud by the lateral mixing of environmental air

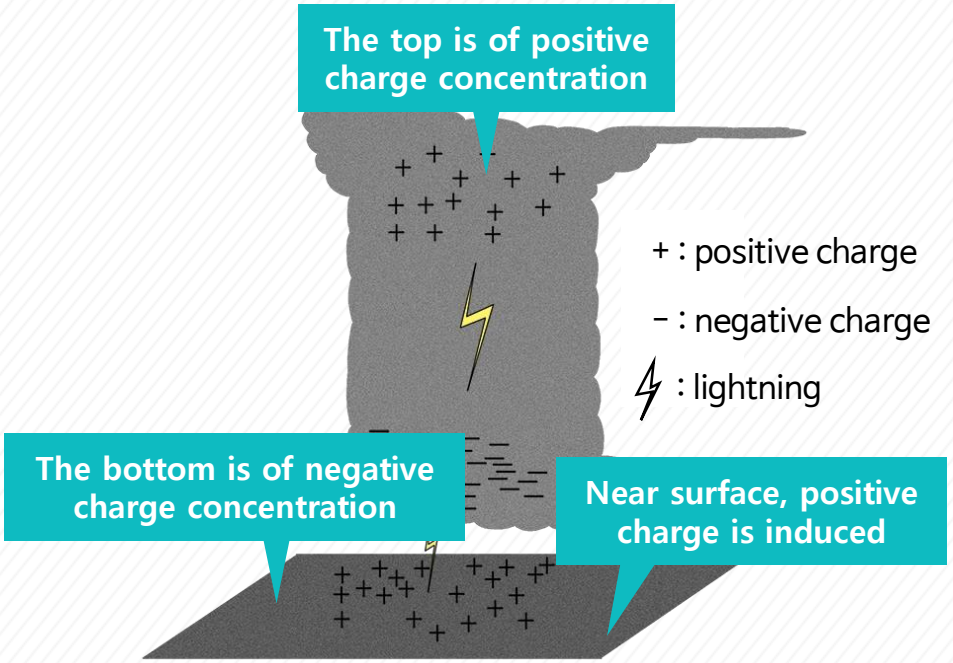
Learning Activities

1. Life cycle of thunderstorms and associated phenomena

4) Lightning and thunder

A thunderstorm is a storm accompanied by thunder and lightning. Because thunder is induced by lightning, two phenomena occur together. Lightning is a discharge of electricity. It is a giant spark between negatively and positively charged particles, which usually occurs in a mature thunderstorm.

According to observations, the top of the cloud is a region of positive charge concentration, and the bottom is a region of negative charge concentration. Because opposite charges attract one another, the negative charge at the bottom causes a region of the ground beneath it to become positively charged.



Learning Activities

1. Life cycle of thunderstorms and associated phenomena

Because the atmosphere is not a good conductor, the charge separation lasts until the electric potential becomes sufficiently large (on the order of one million to hundred million volts per meter). The lightning discharge takes place through a channel of air with a diameter of several centimeters. It warms the air in the narrow path and instantly raises the temperature to 8,000 ~ 33,000K. This extreme heating causes the air to expand explosively, thus initiating a wave that becomes a booming sound wave – called thunder. Light travels so fast that we see the light instantly after a lightning flash. However, the sound of thunder takes much longer to reach the ear. We can determine how far away the stroke is by counting seconds from the moment we see the lightning until we hear the thunder.

Let's see how charge separation in the clouds occurs. Because cumulonimbus develops up to the tropopause, much of the cloud is made up of ice particles. Below the condensation level, water droplets are formed, and on top of that, ice crystals or supercooled water droplets form clouds.

There is a considerable temperature gradient between the surface and inside of the ice crystal. When there is a temperature difference, due to the thermoelectric effect, the positive charge moves to the lower temperature side. Therefore, positive charge accumulates on the surface of the ice crystal, and negative charge accumulates inside.

As the temperature of the ice crystals becomes lower, the surface of the ice crystals breaks and creates a large number of small ice crystals with a positive charge. These positively charged small ice crystals are transported to the top of the clouds by the updraft. Large negatively charged ice crystals fall to the bottom of the cloud, resulting in charge separation between the top and bottom of the cloud.

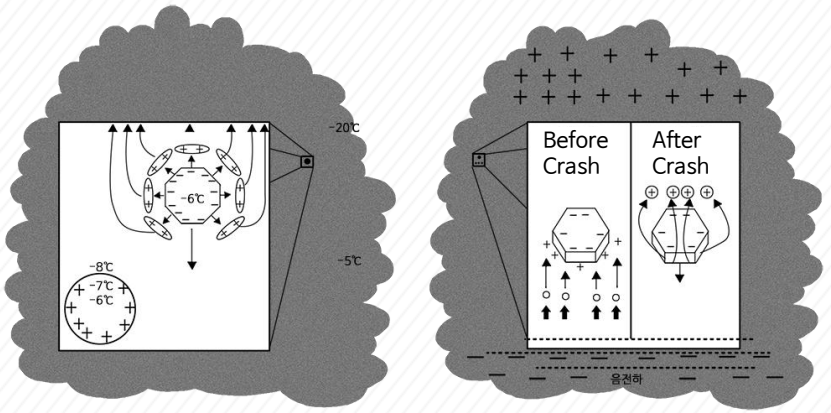
Learning Activities

1. Life cycle of thunderstorms and associated phenomena

However, according to the experiment, an additional mechanism is needed to explain the charge separation. Let's say that there exist positive charges at the top of the cloud and negative charges at the bottom of the cloud. The isolated charge distribution induces charge separation in the ice crystals and supercooled droplets in the middle layer of the cloud.

The negative charge is at the top of the ice crystal, and positive charge is located at the bottom. In this situation, small ascending particles collide with the lower part of the ice crystal, takes a positive charge, and then rises continuously to increase the positive charge at the top of the cloud. The large water droplets and ice crystals with negative charge fall to the bottom and increase the negative charge at the lower part of the cloud.

Through such processes, charge separation occurs and a considerable amount of electric potential is formed in the cloud. Meanwhile, a positive charge is induced near the ground because the bottom part of the cloud is negatively charged.



〈Charge separation in ice crystals and supercooled water droplets〉

Summary

1. Life cycle of thunderstorms and associated phenomena

- Thunderstorms can be caused by – local heating, topography, fronts and lows.
- Thunderstorms can be enhanced depending on the atmospheric static stability and vertical structure of the wind.
- A thunderstorm is a storm accompanied by thunder and lightning.