Introduction to Meteorology

11 Air uplift

Introduction

Uplift of air is important in the process of forming clouds. In order for a cloud to form, air should rise and must expand adiabatically. A variety of meteorological phenomena occur on the surface depending on the processes for air uplift. The following mechanisms are responsible for the development of the majority of clouds: surface heating and convection, horizontal convergence of air, forced lifting by orography, and uplift along weather fronts.

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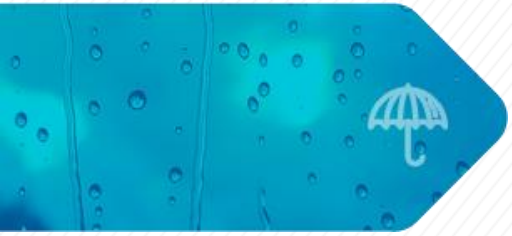


1. Convection
2. Convergence
3. Uplift by orography
4. Uplift by weather fronts

Learning objectives

1. Describe the four mechanisms that cause the air to rise
2. Understand the weather phenomenon caused by uplift mechanisms.

Learning Activities

1. Convection

1) Convection

Clouds are formed in most cases as a result of convection and forced lifting process. The convection is the vertical movement of the air driven by the buoyancy due to the density difference between the air and the surrounding air. To understand the buoyancy, consider an unsaturated air parcel within the atmosphere of density ρ_e, and temperature T_e. If gravitational acceleration is g, and volume is V, the gravitational force acting on the air parcel which has density ρ_p would be $\rho_p Vg$. At the same time, the upward buoyant force of the air parcel, following the Archimedes' principle, is $\rho_e Vg$. Therefore, if the friction is ignored, the vertical motion of the air parcel can be given as follows:

$$ma_b = \rho_e Vg - \rho_p Vg$$

where m is the mass of the air parcel, a_b is the vertical acceleration of the air. As the mass of air parcel is $m=\rho_p V$, the vertical acceleration of the air parcel is given as follows:

$$a_b = \frac{\rho_e - \rho_p}{\rho_p} g$$

Learning Activities

1. Convection

If $\rho_e \rangle \rho_p$, then air parcel is subjected to positive buoyancy ($a_b \rangle 0$), and if $\rho_e \langle \rho_p$ then the air has negative buoyancy ($a_b \langle 0$). Observations, in general, measure air pressure, temperature, and humidity rather than the density, thus the vertical motion is expressed in terms of temperature. Applying the equation of state with air parcel temperature T_p and surrounding temperature as T_e, the vertical acceleration can be expressed as:

$$a_b = \left(\frac{T_e - T_p}{T_p}\right) g$$

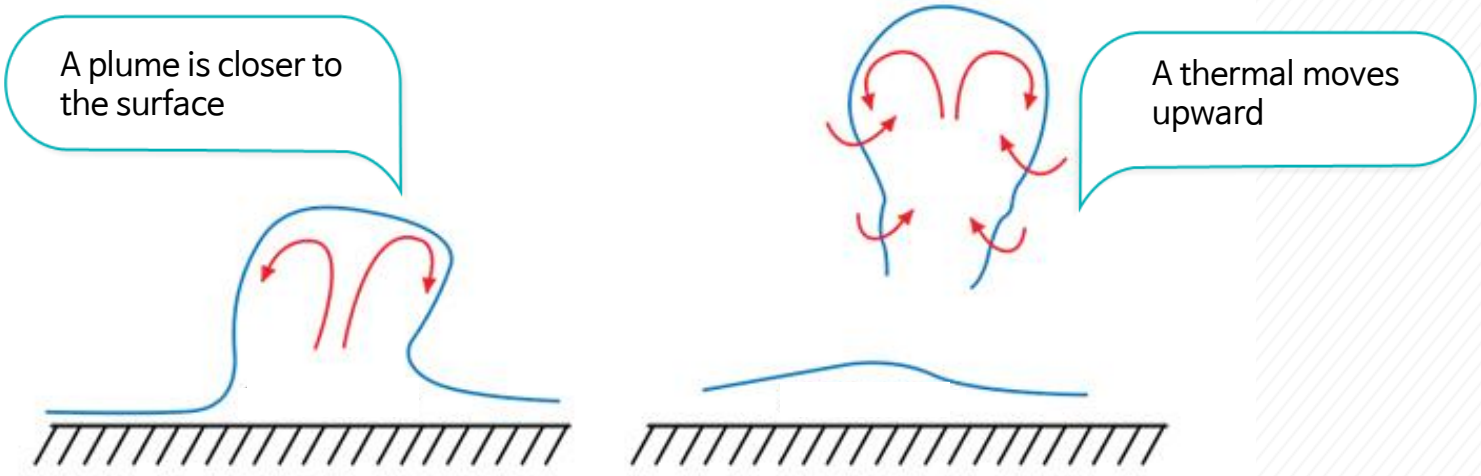
If $T_p \rangle T_e$, then air parcel is subjected to positive buoyancy ($a_b \rangle 0$), and if $T_p \langle T_e$, then it has negative buoyancy ($a_b \langle 0$). The ascending motion of the air by buoyancy is fast enough to approximate its temperature change as an adiabatic process. Therefore, the air initially unsaturated can reach the saturation forming clouds due to the condensation of the water vapor when the air is adiabatically cooled as it ascends.

Learning Activities

1. Convection

2) Local convection

Local convection refers to the convection that occurs because of differences in the density of the atmospheres where the surface is heated unevenly. Convection caused by density difference of fluid is called free convection. The fluid heated unevenly becomes less dense and rises in the form of a plume or a thermal. A plume seems attached to the surface, whereas a thermal is separated from the surface.



〈Plume and Thermal〉

※ Source: Environmental atmospheric science (Kim, Kyung-Eak et al., Donghwa Technology) p99

Learning Activities

2. Convergence

Convergence is the accumulation of air at one point as a result of atmospheric motion. Air can either converge horizontally or vertically, but only horizontal convergence, which is related to cloud formation, will be considered here. Horizontal convergence can be roughly divided into two cases.

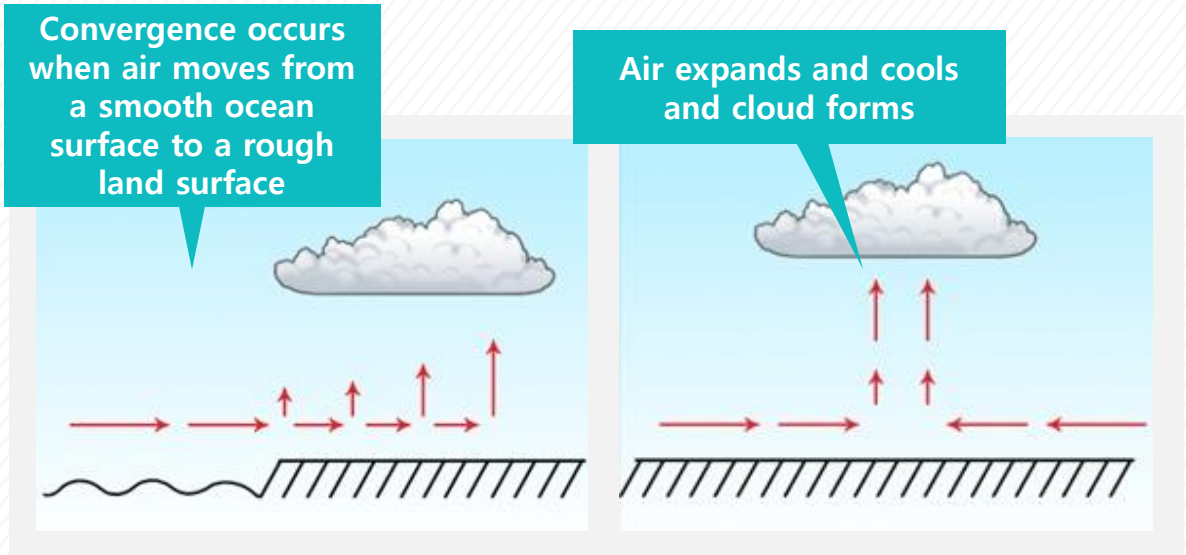
Learning Activities

2. Convergence

1) Horizontal convergence

The first is the convergence by the low pressure. As the air moves from high to low pressure, horizontal convergence occurs at the center of the low pressure. Secondly, convergence occurs when the speed of air movement decreases due to topographical factors.

Convergence occurs, for example, when air moves from a relatively smooth ocean surface to a rough land surface. Also, as the air meets the mountains, the horizontal flow slows down and convergence occurs. One can imagine that the density increases as the air converges horizontally, but the density does not change much. Instead, the air will rise up, since the air cannot go into the ground.
As a result, air expands and cools, and cloud can be formed.



〈Convergence of the air〉

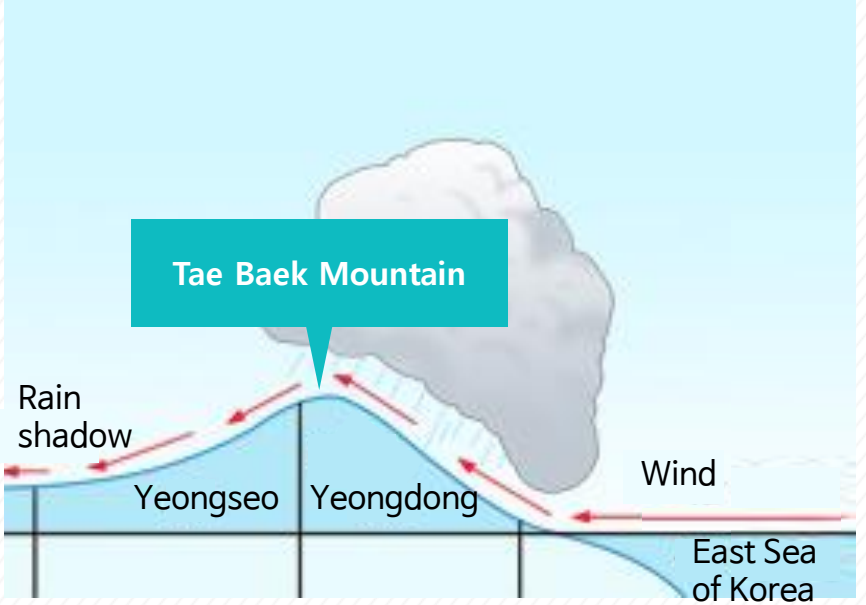
※ Source: Environmental atmospheric science
(Kim, Kyung-Eak et al., Donghwa Technology) p100

Learning Activities

3. Uplift by orography

Orographic uplift is a phenomenon in which horizontally moving air is forced to rise over a slope when it approaches a mountain range or a hill, which is also called an orographic effect. Also, the cloud formed by this effect is called the orographic cloud. The orographic cloud is formed by orographic uplift, but the clouds height is not limited to the terrain or hill. Some clouds stretch to the bottom of the stratosphere.

In addition, the orographic cloud causes unusual weather phenomena such as rain shadow effects. The relatively humid and cold air rises and releases water in the form of precipitation in the windward side and changes to dry and warm air in the leeward side.



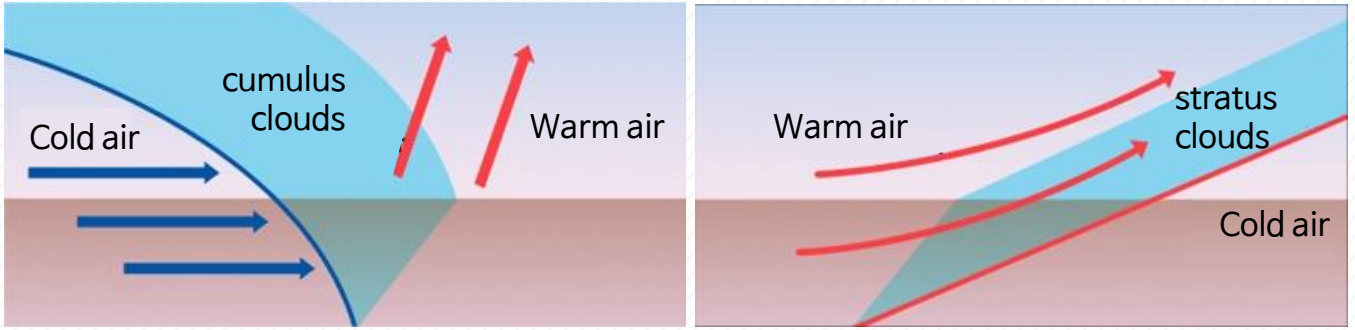
〈Rain shadow effect〉

※ Source: Environmental atmospheric science (Kim, Kyung-Eak et al., Donghwa Technology) p101

Learning Activities

4. Uplift by weather fronts

In general, the temperature of the atmosphere changes gradually rather than rapidly. However, as the properties of air mass change, the temperature can change rapidly. This is called the transition zone, a front. There are cold front, warm front, occluded front, stationary front, etc.



〈Uplift by cold front and warm front〉

※ Source: Environmental atmospheric science (Kim, Kyung-Eak et al., Donghwa Technology) p101

In cold front, the heavier cold air pushes under the lighter warm air. Therefore, in general, the cold front leads to a steeper front boundary resulting in a narrower region of ascending air. In warm front, air rises above cold air covering a broad area.
As a result, cumulus clouds form well on the cold front and stratus clouds form on the warm front.

Summary

1. Convection

- The convection is the vertical movement of the air generated by the buoyancy resulted from the density difference between the air and the surrounding air.
- The fluid heated unevenly becomes less dense and rises in the form of a plume or a thermal.

Summary

2. Convergence

- Convergence is the accumulation of air at one point as a result of atmospheric motion.
- Horizontal convergence occurs by low pressure and orographic effect.
- the density does not change much when air converges.

Summary

3. Uplift by orography

- Orographic uplift is a phenomenon in which horizontally moving air is forced to rise over a slope when it meets a mountain range or a hill, which is also called an orographic effect.
- The height of the orographic cloud is not limited to the height of terrain or hill.
- The orographic cloud causes unusual weather phenomena such as rain shadow effects.

Summary

4. Uplift by weather fronts

- Front is the region where the temperature of the atmosphere changes rapidly as the properties of air mass changes.
- In cold front, the heavier cold air pushes under the lighter warm air. In warm front, air rises above cold air.
- Cumulus clouds form well on the cold front and stratus clouds form on the warm front.