



Introduction to Meteorology

15 Atmospheric pressure

Introduction



The Earth we live on is covered by air, and the thickness of the atmosphere is about 1,000 km. The gas molecules that make up the Earth's atmosphere are also influenced by the gravitational force. Because of Earth's gravity, the gas molecules cannot escape the Earth and have surrounded Earth's surface for 4.6 billion years. Due to these gas molecules we live under the pressure of the motion of gas molecules. However, in everyday life, we hardly feel the atmospheric pressure, and sometimes forget about its existence. The atmospheric pressure is the source of many weather phenomena, such as wind, cloud, precipitation, which are caused by horizontal and vertical pressure gradient.

Contents



1. Atmospheric pressure
2. The ideal gas law (equation of state) and hypsometric equation
3. Measuring air pressure

Learning objectives



1. Understand the definitions of pressure and atmospheric pressure.
2. Understand the ideal gas law and use it to measure the atmospheric pressure.
3. Explain how to measure pressure and explain the principles of each measurements.

Learning Activities

1. Atmospheric pressure

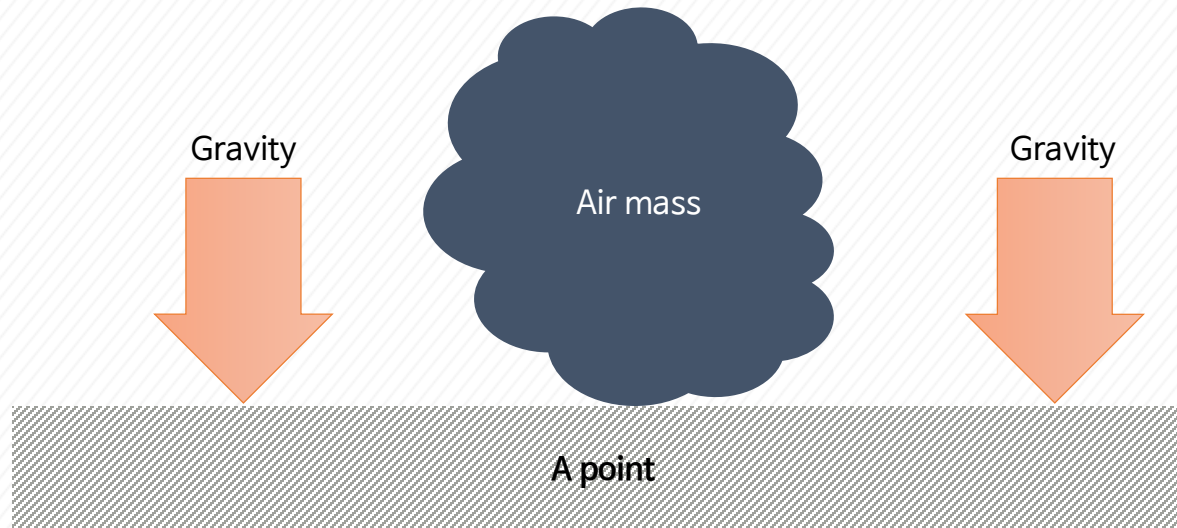
The gas molecules that compose the atmosphere seem to be at rest, but in fact they are not in a static state. Not all gas molecules are moving at the same speed, and all molecules are constantly moving very fast. A collision occurs with the surface when the moving gas molecules come into contact with a surface, and the force acts in this process. The force acting on a unit area is the pressure. In other words, air pressure is the force exerted by the air molecules over a given area.

Learning Activities

1. Atmospheric pressure

1) Atmospheric pressure

The atmospheric pressure at any point is the force due to the weight of column of air above a unit area. In other words, it is the pressure acting by the air mass being pulled down by gravity. Note that pressure is always the same in all directions.



Learning Activities

1. Atmospheric pressure

2) Air pressure

Air pressure is the pressure acting by the gas molecule motion. In other words, pressure and air pressure are physically the same concept.



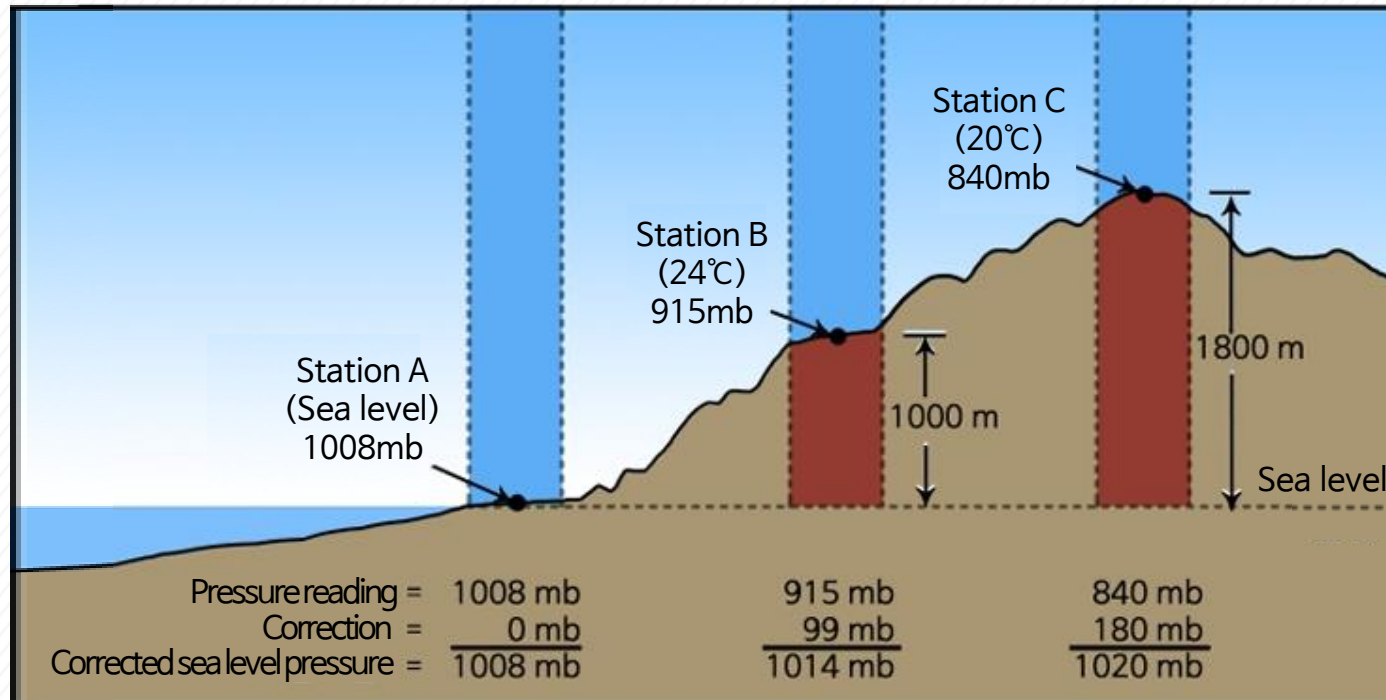
Therefore, Pascal (Pa), which is the unit of pressure, can be used as the unit of air pressure. However, the magnitude of the atmospheric pressure near the surface is usually too large to represent in Pascal. Therefore, meteorologists use the milibar(mb) or hectopascals (hPa) as the basic unit for air pressure. Hectopascals are equivalent to milibars, and the relationship is as follows.

$$\begin{aligned} 1 \text{ hPa} \\ &= 100 \text{ Pa} \\ 1 \text{ hPa} \\ &= 1 \text{ mb} \end{aligned}$$

Learning Activities

1. Atmospheric pressure

Because atmospheric pressure depends on the altitude of the observer, the altitude effect should be excluded. The concept introduced for this is sea level pressure



〈Air pressure corrections〉

※ Source: Figure 6.6 in The Atmosphere, 8th edition, Lutgens and Tarbuck, 8th edition, 2001

Learning Activities

1. Atmospheric pressure

The atmospheric pressure we usually measure is the surface pressure, which is actually the pressure observed in a specific area. On the other hand, the sea level pressure is the air pressure when the observation point is at the mean sea level. Since most of the land surface is higher than the mean sea level, most of the surface pressure is less than the sea level pressure. Horizontal atmospheric pressure differences can be calculated even if there are differences in altitude between two different stations. For this, it is necessary to assume that the rate of vertical change of the atmospheric pressure is consistent in any station. Under this assumption, the surface pressure can be converted to the pressure at the mean sea level.

In particular, for areas with low altitudes, it is reasonable to assume that the decrease in atmospheric pressure with increasing height is constant. The atmospheric pressure decreases by 100 hPa per 1 km of altitude near the surface, but this assumption is not valid at higher altitude due to the increase in error. Note that the averaged atmospheric pressure on the mean sea level is 1013.25 hPa. The horizontal variation of atmospheric pressure is not that large compared to the vertical variation of atmospheric pressure.

North America

The sea level pressure difference between the highest and lowest region is only about 25 hPa

Korea

Even in the case of strong typhoon, the center pressure is about 950 hPa

Learning Activities

2. The ideal gas law (equation of state) and hypsometric equation

The Earth 's atmosphere is made up of gases. In order to understand the nature of the Earth's atmosphere, it is necessary to understand how gases are characterized by various environmental conditions.

Learning Activities

2. The ideal gas law (equation of state) and hypsometric equation

1) The ideal gas law (equation of state)

The equation of state of gas is the relationship between gas pressure, temperature and density. It shows how density changes when certain gas pressure and temperature conditions change. In many cases, the Earth's gas is treated as an ideal gas.

$$p = \rho RT$$

Therefore, the equation given is called the ideal gas equation. p is the pressure (Pa), ρ is the density (kg m^{-3}), T is absolute temperature (K), and R is the gas constant of the dry air (specific gas constant) $287 \text{ J kg}^{-1} \text{ K}^{-1}$.

The state equation of the gas can be understood very intuitively. As the pressure is the pressure generated by the collision with the adjacent surface while the gas molecules are moving, there are two major factors influencing the pressure: the density of the gas molecule and the velocity of the gas molecule.

It can be expected that the higher the density, the greater the number of molecules impacting the surface per time, and the greater the pressure. This can be understood as an extension of Avogadro's law. The higher the temperature of the gas molecules, the faster the average speed of motion. Therefore, if temperature is higher, the speed of gas molecules and atmospheric pressure will increase. This is an extension of Charles's law.

Earth's atmosphere has little movement in the vertical direction, except in a case such as a strong low-pressure center. The atmosphere is much more active in the horizontal direction than in the vertical direction. Therefore, it can be assumed that the Earth's atmosphere has almost no net force in the vertical direction.

Learning Activities

2. The ideal gas law (equation of state) and hypsometric equation

The force acting on the atmosphere is mainly the gravitational and pressure gradient forces.

Gravitational force

- Vector sum of universal gravitation and centrifugal force
- Positive downward

Pressure gradient force

- The force acting on high to low pressure
- Positive upward

The gravitational force and pressure gradient force are in balance, called hydrostatic equilibrium. This can be expressed by the following equation.

$$\frac{Dw}{Dt} = -\frac{1}{\rho} \frac{\partial p}{\partial z} - g = 0$$

In this equation, z means altitude and g is gravitational force.

Learning Activities

2. The ideal gas law (equation of state) and hypsometric equation

2) Hypsometric equation

Taking into account the hydrostatic equation and the equation of state, the following equations yield a hypsometric equation, which is the relation between altitude and pressure.

$$\frac{Dw}{Dt} = -\frac{1}{\rho} \frac{\partial p}{\partial z} - g = 0$$

$$p = \rho RT$$

The derivation of the Hypsometric equation is as follows.

$$\frac{RT}{t} \frac{\partial p}{\partial z} (= RT \frac{\partial \ln(p)}{\partial z}) = -g$$

$$\partial \ln(P) = -\frac{g}{RT} \partial z$$

$$\int_{p_1}^{p_2} \partial \ln(p) = -\frac{1}{RT_{(const)}} \int_{z_2}^{z_1} g \partial z$$

$$\ln \left(\frac{p_2}{p_1} \right) = -\frac{g}{RT} (Z_1 - Z_2)$$

The equation is derived under assumptions of constant gravity and temperature. This equation can be used to quantitatively calculate the pressure change by altitude.

Learning Activities

3. Measuring air pressure

The instrument that measures pressure is called a barometer. There are many kinds of barometers. The most popular barometers are the mercury barometer and the aneroid barometer.

Learning Activities

3. Measuring air pressure

1) Mercury barometer



〈Fortin barometer〉

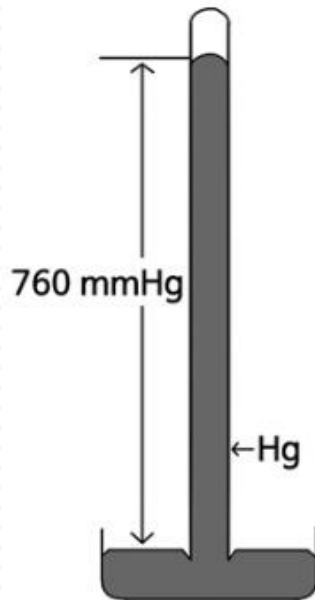
※ Source : http://williamsugghistory.co.uk/?page_id=173

Mercury barometers are the most standard instrument of measuring atmospheric pressure. The mercury barometer was designed by Torricelli in 1643. It measures the pressure through the height of the mercury column, which applies the same amount of pressure as atmospheric pressure. Therefore, the height of mercury becomes higher as the pressure increases.

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Learning Activities

3. Measuring air pressure



〈The mercury barometer〉

※ Source : <http://www.gcestudybuddy.com/using-word-documents/pressure>

The mercury barometer is shaped like an inverted tube with mercury with a vacuum space.

The average atmospheric pressure measured at mean sea level using a mercury barometer corresponds to a mercury 760 mm height. This means that the pressure of 760 mm in mercury barometer equals to 1013.25 hPa. The unit of pressure, mmHg, is also used by measuring the height of the mercury bar.

Why do we use mercury barometer? First, the density of mercury is so large, 13.6 times larger than that of water, that it is advantageous to use mercury to make the instrument precise and easy to handle. Second, mercury is not temperature sensitive. All materials vary in volume with temperature, and such volume change reduces the accuracy of air pressure measurements. Since mercury is a liquid with little change in volume with temperature, it is suitable for use in barometers. To increase accuracy when measuring atmospheric pressure, a thermometer is always attached to the mercury barometer. Thus, it is necessary to record the current temperature to obtain more precise data when reading the atmospheric pressure value.

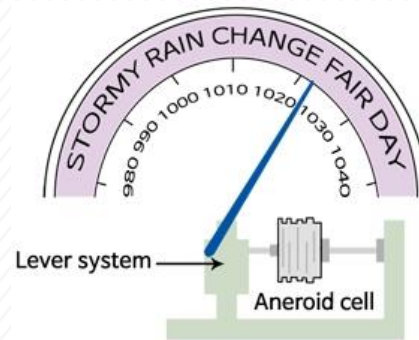
Third, mercury is a gas with very low vapor pressure. It is difficult to keep the tube in a vacuum state when using a gas with large vapor pressure.

Learning Activities

3. Measuring air pressure

2) Aneroid barometer

The mercury barometer is a standard instrument for measuring atmospheric pressure. However, in general it is very expensive and difficult to manage, maintain and move. The aneroid barometer is designed to measure pressure more easily at various places.



〈The aneroid barometer〉

※ Source : http://apollo.lsc.vsc.edu/classes/met130/notes/chapter8/aneroid_bar.html

The aneroid barometer is cheaper than the mercury barometer, but it can still measure the pressure very accurately. The aneroid barometer has a chamber that contracts and expands as the pressure changes. The chamber displays the pressure as the chamber compresses in proportion to the pressure. The aneroid barometer does not require any temperature adjustment, and it can be conveniently designed to continuously record changes in pressure over time. A barometer designed to automatically record pressure is called a barograph

Summary

1. Atmospheric pressure

- Air pressure is the force exerted by the air molecules over a given area.
- Atmospheric pressure is the pressure acting by the air mass being pulled down by gravity. Atmospheric pressure is acting in all directions.
- Atmospheric pressure varies by location and decreases as altitude increases.
- The horizontal variation of atmospheric pressure is smaller than the vertical variation of atmospheric pressure.

Summary

2. The ideal gas law (equation of state) and hypsometric equation

- The equation of state of gas is the relationship between gas pressure, temperature and density.
- The atmosphere can be assumed to be in hydrostatic equilibrium because the vertical movement is negligible.
- Taking into account the hydrostatic equation and the equation of state, the hypsometric equations can be derived. Hypsometric equation can be used to quantitatively calculate the pressure change by altitude.

Summary

3. Measuring air pressure

- Barometer is used to measure the atmospheric pressure. The most popular barometers are the mercury barometer and the aneroid barometer.
- Although the mercury barometer is a standard instrument for measuring atmospheric pressure, it is very expensive and difficult to manage, maintain and move.
- Aneroid barometer is relatively cheap, but accurate and portable, and does not require temperature adjustment.