# Introduction to Meteorology

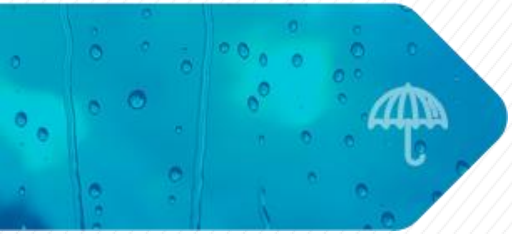
## 01 Overview of the Earth’s Atmosphere

## Introduction

The atmosphere of the Earth is composed of various gases, aerosols, and cloud particles, etc and their distributions differ as the altitude changes. The atmosphere influence the weather and climate of the Earth significantly through the interaction with the sun and earth radiation.

Why is the atmosphere important?  Our atmosphere is a like a blanket that surrounds the fragile earth and influences everything connected to our lives. What if we don't have an atmosphere? There would be no lake and oceans, no sound and cloud, no beautiful sunsets, and no beautiful sky above us. It would be unimaginably cold at night, and hot during the day. All things on the earth would be scorched, dry, and exposed under the merciless heat wave coming directly from the sun. However, humans are adapting to this environment and forgetting how enormous the atmosphere is.

## Contents



1. Origin of the atmosphere
2. Composition of the atmosphere

## Learning objectives

1. Understand and explain the origin of the atmosphere.
2. Understand the composition of the atmosphere and explain its characteristics.
3. Compare and explain permanent gases and variable gases.

# Learning Activities

## 1. The origin of the atmosphere

The atmosphere of the Earth is a thin layer of gas that consists mostly of nitrogen and oxygen, and a small amount of other gases such as water vapor and carbon dioxide.

The thickness of the Earth's atmosphere extends upward for several hundreds of kilometers while almost 99% of the atmosphere lies within 30 km from the surface. This thin layer of air protects the life on Earth, from the Sun's dangerous UV radiation energy and other harmful materials from the outer space.  here is no clear border of the atmosphere but as it goes further up, the air becomes thinner and thinner, eventually ending up a with empty space.

It is generally known that the Earth is about 4.5 billion years old. If the atmosphere was formed with the earth, it would have contained large quantities of gas, including large quantities of hydrogen and helium at the beginning of the formation, because the most abundant gas found in space today is hydrogen and helium. This atmosphere is called primitive atmosphere (or the early atmosphere). However, the present atmosphere is composed mostly of nitrogen and oxygen, and its composition differs greatly from that of the early atmosphere. Through what processes do gases that constitute the primitive atmosphere have turned into the present atmospheric composition?

# Learning Activities

## 1. The origin of the atmosphere

### 1) The early atmosphere

During the first 500 million years, the atmosphere gas was easily dissipated into space. The most likely hypotheses to explain this are hydrogen-helium dissipation hypothesis 1 and hypothesis 2.

According to hydrogen-helium dissipation hypothesis 1, the main elements of the early atmosphere were light-weighted hydrogen and helium which could have traveled at a faster since the temperature was high. Since the gravitational force at that time was not strong enough to hold the atmosphere in place, it is believed that these light-weighted gases dissipated into the space. Since the velocity of these light-weight gases, hydrogen and helium, became fast enough to escape from the atmosphere when these molecules or atoms collide with one another, the gravity of the planet could not hold them, and most of the main elements of the early atmosphere, hydrogen and helium, escaped into the space.

Recently, another hypothesis has been raised. In this theory, it is believed that most of the gases that existed on the planet in its earlier days are considered to have been removed from the earth because of collision between the Earth and another celestial body. That is, a tremendous amount of energy was released as a result of this collision, and much of planetary matters, including the atmosphere, was released and constituted today's atmosphere.

# Learning Activities

## 1. The origin of the atmosphere

### 2) Today's atmosphere

After most of the early atmosphere has almost disappeared, today's atmosphere was formed around the Earth, as dense gases released from the earth by the volcanic eruption constitute the atmosphere.

That is, as the volcano erupts, about 70% of the water vapor, 15% of carbon dioxide, and 5% of nitrogen is emitted, and these gases are very likely to form Today's atmosphere. Hundreds of years after the eruption of the volcano, the atmosphere of the earth gradually cooled down, causing condensation to occur, creating clouds, raining the earth, and forming rivers, lakes, and oceans. Based on this, the removal of water vapor can be easily explained.

The raindrops dissolved the $CO_2$, which existed abundantly in the atmosphere, removing them from the atmosphere. Such rain drops transport carbon dioxide from the atmosphere into the oceans, which erodes the ocean-transported material and sinks into subsea sediments. Through the above process, the water vapor is condensed in a large amount and the density of carbon dioxide is decreased, so that the rate of nitrogen, which is not chemically active, became increased. The composition of the volcanic gas is as follows.

**Volcanic eruptions released 70% of water vapor, 15% of carbon dioxide, and 5% of nitrogen.**

| Volcanic Gas | Ratio (%) |
|---|---|
| Water vapor | 70 |
| Carbon dioxide | 15 |
| Nitrogen | 5 |
| Sulfur dioxide | 5 |
| Others (chloride, hydrogen, argon) | 5 |

〈The composition of the volcanic gas〉

# Learning Activities

## 1. The origin of the atmosphere

### 3) Generation process of Today's atmosphere

Approximately 3.5 billion years ago, atmospheric oxygen ($O_2$) increased, and this change is presumed to be caused primarily by anaerobic bacteria - bacteria that can live without oxygen. These primitive creatures were the first organisms to convert carbon dioxide from the atmosphere to oxygen.

The vegetation and subsequent animal tissues were submerged and organic carbon was trapped within the sediments, and most of the carbon released by the volcanic activity eventually ceased to exist in both the atmosphere and the ocean due to the carbonate formation process. All of these processes gradually increased the atmospheric oxygen while consuming carbon dioxide. But there have been other changes that have enabled the activity of life on the Earth's surface. It's the ozone layer. If there is no ozone layer in the upper atmosphere, ultraviolet light reaches the surface, which can be very fatal to living organisms. In other words, it can be concluded that the ozone layer occurred before the existence of life outside the ocean.

So how does the ozone layer form? In the upper atmosphere, ultraviolet rays separate the binary oxygen molecules to form oxygen atoms, which recombine with oxygen molecules to form ozone and ozone layers. This phenomenon occurs not only under certain conditions, but also under normal conditions, and the ultraviolet rays reaching the surface will be reduced enough for plant growth. As the plant grows and the amount of photosynthesis increases, carbon dioxide in the atmosphere becomes oxygen.

# Learning Activities

## 2. Composition of the atmosphere

The atmosphere consists of invisible gases, numerous small solid particles, water droplets, and so on. Biological processes, such as plant and animal respiration, or physical processes such as volcanic eruptions, cause gas molecules to exchange between the atmosphere and the surface, and are also created or eliminated by chemical reactions between gases.

Let's think about the constantly circulating gas between the atmosphere and the surface. If the amount entering and leaving the atmosphere is the same, the gas concentration in the atmosphere will remain constant. That is, the gas concentration shows a steady state. In this way, even if the gas concentration remains steady in the atmosphere, each molecule will only exist for a certain period of time before the spill occurs and is removed.

The time at which the individual molecules are present in the atmosphere is called the residence time. The residence time can be obtained by dividing the mass in the atmosphere by the flow rate of the material.

Depending on whether they are maintained at a certain concentration, the atmospheric gases can be classified as permanent gases, which maintain a constant concentration in the atmosphere, or as variable gases, in which the concentration of air varies with time and space.

Permanent gas is present in the atmosphere at altitudes below 80 km and accounts for most of the air mass. The atmosphere within 80 km is chemically homogeneous, so it is sometimes called homosphere. The layer above the homosphere layer is called heterosphere, and light gas such as hydrogen or helium distributes in the heterosphere. There is no permanent gas in the heterosphere because the composition changes with altitude. Now, let's take a closer look into each gas.

# Learning Activities

## 2. Composition of the atmosphere

### 1) Permanent gases

First, the permanent gases. The homosphere is composed of nitrogen, oxygen, and a small amount of inert gases, such as argon, neon, and tiny portions of other gases.

| Gas | Symbol | Percent (by Volume) | Molecular weight |
|---|---|---|---|
| Nitrogen | $N_2$ | 78.08 | 28.01 |
| Oxygen | $O_2$ | 20.95 | 32.00 |
| Argon | Ar | 0.93 | 39.95 |
| Neon | Ne | 0.002 | 20.18 |
| Helium | He | 0.0005 | 4.00 |
| Krypton | Kr | 0.0001 | 83.8 |
| Xenon | Xe | 0.00009 | 131.3 |
| Hydrogen | $H_2$ | 0.00005 | 2.02 |

〈Permanent Gases in the Atmosphere of the Earth〉

※ Source: Environmental Meteorology, 3rd edition (Kyoungik Kim, et al, Donghwa Engineering) p13

Nitrogen in the atmosphere consists of one molecule of nitrogen atoms paired. This is a slightly larger value than the molecular weight of a total of 28 protons and neutrons. Generally, nitrogen atoms consist of 7 protons and neutrons, but sometimes have 8 neutrons, so the average molecular weight of the nitrogen molecule is slightly larger than 28.

# Learning Activities

## 2. Composition of the atmosphere

Nitrogen is a stable gas, accounting for about 78% of the total volume of permanent gas and about 75.5% of the total mass. The process of generating and removing nitrogen from the atmosphere is very slow, with a very long residence time of 42 million years.

The second largest gas in permanent gas is oxygen, accounting for about 21% of the total volume of permanent gas and about 23% of total mass. Oxygen is very important in maintaining all life activities. Like nitrogen, atmospheric oxygen molecules are also binary oxygen. The residence time is about 5,000 years.

If 99% of nitrogen and oxygen and permanent gas is occupied, the remaining 1% is occupied by argon. Because the removal process of argon is very slow, the residence time is very long. Nitrogen and oxygen, which make up the largest portion of permanent gases, play a very important role in maintaining life on Earth.

# Learning Activities

## 2. Composition of the atmosphere

### 2) Variable gases

Next, let's look at the variable gas. Variable gases account for a very small portion of the total mass of the atmosphere, but some gases have a very large impact on the characteristics of the atmosphere, including weather and climate change. Water vapor accounts for only 0.25% of the total volume of the atmosphere but is the most abundant in variable gases.

| Composition | Symbol | Percent (by volume) | Molecular weight |
|---|---|---|---|
| Water vapor | $H_2O$ | 0.25 | 18.01 |

〈Variable gases in the atmosphere〉

※ Source: Environmental Meteorology, 3rd Edition (Kyoungik Kim et al., Donghwa Engineering) p14

Atmospheric water vapor is supplied by evaporation from the surface, most of which is within an altitude of 5 km, and the concentration decreases sharply as altitude increases.
Water vapor particles are visible only when they are transformed into larger liquids or solid particles such as cloud droplets or ice crystals. Ice crystals and liquid particles in the atmosphere are removed from the atmosphere in the form of rain, snow, sleet, hail. Evaporation, condensation, and precipitation run at a rapid rate, so the residence time of water vapor is very short, about 10 days.
Since the rate of water vapor in the atmosphere is very low, the change in water vapor is felt even with small changes.
For example, water vapor account for up to up to 4% of the atmospheric gases in warm and steamy tropical regions, but less than 1% in cold polar regions and deserts. This means that among the 100 atmospheric molecules, the water vapor accounts for about four, and the amount of water vapor outside the equator is not more than about 2%.

# Learning Activities

## 2. Composition of the atmosphere

Why is it the water vapor considered to be extremely important though its amount is relatively small? This is because water vapor is not only a source for cloud formation, but also an effective absorber of long-wave radiation emitted from the surface. When the water vapor condenses to form liquid and solid cloud particles, a huge amount of latent heat releases as the phase changes. Latent heat is an important energy source in the atmosphere causing storms such as thunderstorms and typhoons. In addition, water vapor is an important greenhouse gas that strongly absorbs some of the energy emitted by the Earth.
This water vapor plays an extremely important role in the balance of heat and energy on Earth.
It is important that the water vapor is different from the small droplets. Water vapor exists as a molecule of individual gases, unlike liquid or solid molecules, water vapor molecules are not bonded together, and the intermolecular bonding of water vapor is similar to that of nitrogen, oxygen, or other atmospheric gases. However, unlike other gases, there is a big difference in that it can easily be converted to solid or liquid form on the surface or in the atmosphere.
Let’s move on the carbon dioxide in the variable gas. Carbon dioxide accounts for about 0.037% of the total volume of the atmosphere.

| Gas | Symbol | Percent by volume | Molecular weight |
|---|---|---|---|
| Carbon dioxide | $CO_2$ | 0.037 | 44.01 |

〈Variable gases in the atmosphere〉

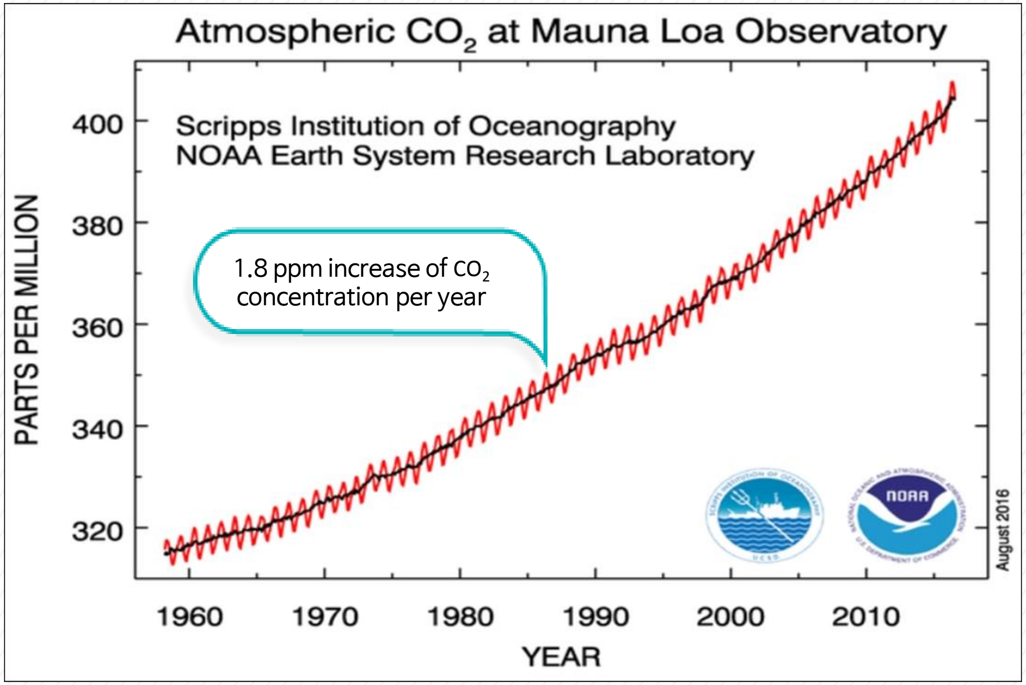
※ Source: Environmental Meteorology, 3rd Edition (Kyoungik Kim et al., Donghwa Engineering) p14

Carbon dioxide is released into the atmosphere by the respiration processes of plants and animals, decay of organic matter, volcanic activity, natural and artificial combustion. Carbon dioxide is removed by the photosynthetic action of plants to convert light energy into chemical energy, and the residence time is 150 years.

# Learning Activities

## 2. Composition of the atmosphere

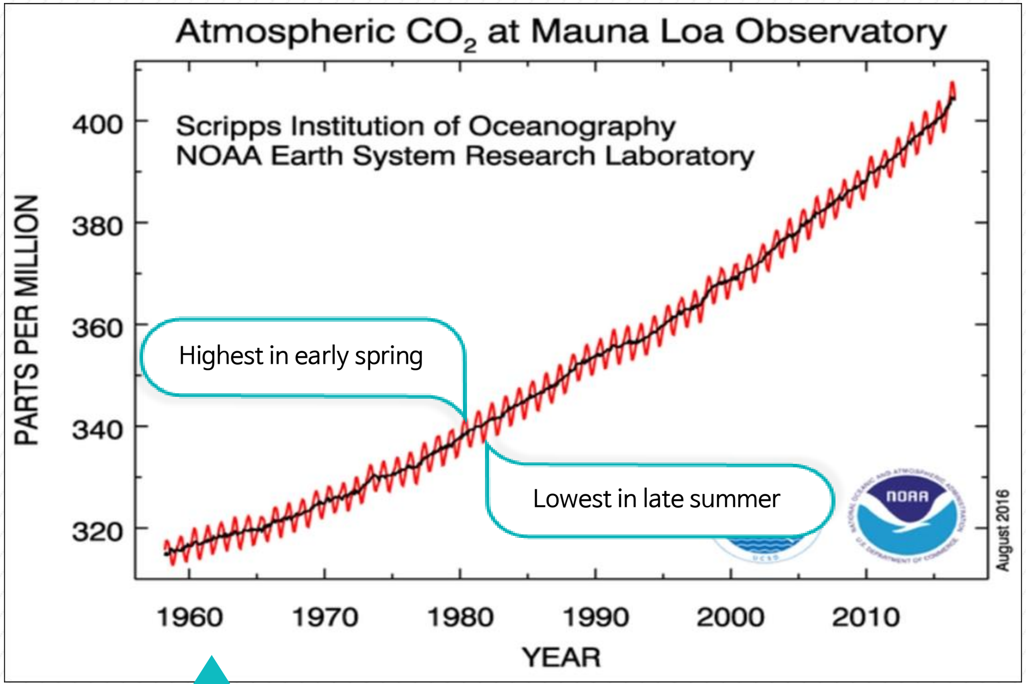
The ocean serves as a reservoir of carbon dioxide, because the phytoplankton of the ocean surface adheres carbon dioxide to organic tissue.
Carbon dioxide, which melts directly onto the surface of the sea, moves deep into the ocean and is believed to contain more than 50 times the total amount of carbon dioxide in the atmosphere.
Prior to the increase in the amount of carbon dioxide due to human activities, the $CO_2$ concentration remained constant at about 280 ppm, but as the industrial revolution began, it has changed.
Since the early 1700's of the Industrial Revolution, 600 billion tons of carbon have been released into the atmosphere by burning of fossil fuels, and such a large amount of $CO_2$ influx has exceeded the amount that can be removed. As a result, the global $CO_2$ concentration has increased by more than 30% from 270 ppm at about 1700 to 400 ppm today.
Looking at the $CO_2$ concentrations observed at the Mauna Loa Observatory in Hawaii, it can be seen that the carbon dioxide concentration has increased by about 1.8 ppm per year since the 1950s.
This increase is mainly due to the burning of fossil fuels and deforestation.



# Learning Activities

## 2. Composition of the atmosphere

Why should we take such increase in carbon dioxide concentration seriously? This is because carbon dioxide traps a portion of the earth's outgoing energy. As the atmospheric $CO_2$ concentration increases, the surface temperature of the Earth's surface increases. If $CO_2$ continue to increase at their present rate, the carbon dioxide will double the current $CO_2$ concentration
in 2100, resulting in serious warming.
The graph also shows seasonal variations in $CO_2$ concentrations. $CO_2$ concentrations are highest in early spring and lowest in late summer. The maximum value in spring is due to slow plant growth and oxidizing leaves during the winter season. On the other hand, during
the summer, as photosynthesis becomes more active, carbon dioxide removal increases and carbon dioxide concentration decreases.




Seasonal variation of carbon dioxide density

# Learning Activities

## 2. Composition of the atmosphere

Photosynthesis removes carbon dioxide and produces oxygen, but atmospheric oxygen levels do not show seasonal fluctuations because the amount of oxygen produced by photosynthesis is much less than the amount of oxygen in the atmosphere. Greenhouse gases do not have only carbon dioxide and water vapor.
Other greenhouse gases that have recently become more dense are methane, nitrous oxide, and chlorofluorocarbons.

Of these, nitrous oxide is also known as laughing gas. Density is increasing at a rate of 0.25% per year. Nitrogen is produced naturally in the soil by chemical action between bacteria and certain microorganisms, and is destroyed by the ultraviolet rays of the sun.
CFCs has been increasing in recent years, and they are widely used as propellants for spray cans. Today, they are mainly used as cleaning agents for microcircuits in refrigerants and electronic products. Although the average density in the atmosphere is very low, it has the potential to increase global temperature, and it also contributes to the destruction of ozone gas.

Next is the Ozone. The small amount of ozone present in the upper atmosphere is an essential element in living life on Earth. But near the surface, it is also a major component of air pollution that causes lung and eye irritation and destroys vegetation. Fortunately, ozone production in the lower troposphere lasts only a few minutes, so even in urban air that is heavily contaminated, the ozone concentration is only about 0.15 ppm. However, the ozone concentration in the stratosphere about 25 km high is about 15 ppm, 50 to 100 times higher than the ground level.
Because ozone absorbs the harmful ultraviolet rays coming from the sun, ozone in the stratosphere is very important in maintaining the earth's life.

# Learning Activities

## 2. Composition of the atmosphere

So why is the majority of ozone in the stratosphere than in the surface? Ozone is generated by the collision of atomic oxygen and molecular oxygen. Ozone is broken down into atomic and molecular oxygen by absorbing UV solar radiation.
Strong UV rays coming into the earth decompose oxygen molecules in the stratosphere into oxygen atoms, and oxygen atoms collide with oxygen molecules, creating ozone. Because stratospheric ozone absorbs most of the UV rays, decomposition of oxygen molecules by UV rays does not occur near the surface. Thus, the ozone concentration near the surface is relatively low compared to the stratosphere.
So how does the stratospheric ozone concentration stay constant? When ozone absorbs UV radiation, it breaks down into oxygen atoms and molecules, and then bonds with other ozone molecules. Through this reaction, ozone has a constant concentration in the ozone layer.

Methane is one of the major variable gases. In recent decades, the atmospheric concentration of methane has increased by about 0.01 ppm per year, and is now around 1.7 ppm.
Methane is released mainly from wetlands, by leaks from natural gas pipelines and oil wells, decomposes vegetable matter by bacteria in rice pods and oxygen-deficient soils, occurs as a biological activity of termites. It also occurs in the process of digesting by livestock, burning waste, burning trees and peat. It is also caused by human activities.
The cause of the rapid increase in methane emissions is currently under study. The main process of methane removal in the atmosphere is through chemical action, and the residence time of methane is about 10 years, shorter than that of carbon dioxide. Because methane is the most powerful absorber of the Earth's radiation despite its low concentration in the atmosphere, atmospheric methane induces the atmospheric warming.

# Learning Activities

## 2. Composition of the atmosphere

### 3) Aerosol

Finally, let's look at aerosols. An aerosol is a term used to refer to all the liquid particles except the solid particles floating in the atmosphere, cloud, and rain. Although sometimes it is associated with air pollution, aerosols arise from human activities and nature.

Aerosols occur naturally by dust, wildfires, and seawater spills, and sometimes volcanic eruptions, such as the Pinatubo volcano in 1991 or the Icelandic volcanic eruption in 2010, which cause large amounts of dust to enter the upper atmosphere. Another type is sulfate and soot from the burning of biomass and fossil fuels. Sulfate particles are particularly important, they form as a result of chemical reactions to sulfur dioxide, and sulfur dioxide is generated in large quantities where it burns coal and oil.

These aerosols are usually small in size, so they drop very slowly and can easily float into the atmosphere even with weak vertical motion. Aerosols are most effectively removed by precipitation and have a residence time of several days to several weeks. Aerosols have strong influence on the atmosphere. Urban smog caused by aerosols worsens visibility. and dust storms also deteriorate visibility. As aerosol floats in the atmosphere, it acts as a condensation nucleus to form cloud particles, absorbing solar radiation and then scattering it back into the atmosphere, affecting the energy balance.

# Summary

## 1. Origin of the atmosphere

The early atmosphere

- It is assumed that a large amount of gas, including a large amount of hydrogen and helium, was contained.
- The hypothesis is that the velocity of the light hydrogen and helium were as fast as the atmospheric escape rate, so most of them either escaped into space or planetary material was released as they collided with planets, providing a basis of the current atmosphere.

Today’s atmosphere

- Dense gases released from within the Earth by volcanic eruptions forms the atmosphere.
- As the volcano erupts, water vapor (about 80%), carbon dioxide (about 10%), nitrogen, etc. are released into the atmosphere which are presumed to have formed the Earth's secondary atmosphere
- Water vapor is mostly removed by condensation, which removes carbon dioxide from the atmosphere by dissolving the abundant carbon dioxide.
- Carbon dioxide dissolved raindrops move carbon dioxide from the atmosphere to the ocean.
- As a result, the proportion of nitrogen in the atmosphere became higher. Oxygen generation by seabed plants and ozone layer formation enabled the survival of land plants. As the oxygen concentration gradually increases, it is assumed that the present atmosphere is formed.

# Summary

## 2. Composition of the atmosphere

- Atmospheric gases can be classified as permanent gases and variable gases depending on whether they are maintained at a constant concentration.
- Permanent gas refers to a gas that maintains a constant concentration in the atmosphere, and variable gas refers to a gas whose concentration varies with time and space.
- Permanent gas consists of nitrogen, oxygen, and small amounts of inert gases such as argon and neon.
  - Nitrogen accounts for about 78% of the total permanent gas volume, about 75.5% of the total mass, and oxygen accounts for about 21% of the total permanent gas volume and about 23% of the total mass
- Variable gases include water vapor, carbon dioxide, ozone, and methane.
  - Water vapor is only 0.25% of the total volume of the atmosphere, but it is the most abundant variable gases, and considered to be important because it is a very effective absorber of long-wave radiation emitted from the Earth surface as well as a source of water necessary for cloud formation.
  - Carbon dioxide is a greenhouse gas that occupies about 0.037% (370 ppm) of the total volume of the atmosphere and absorbs the earth's radiation.
  - If carbon dioxide continues to increase at its present rate, it is predicted that the carbon dioxide will double the current concentration in 2100, resulting in serious warming.
  - Stratospheric ozone absorbs ultraviolet rays and is an essential element for life on earth, although ozone near the surface is a major component of air pollution that causes lung and eye irritation and destroys vegetation growth.
  - The current concentration of methane, one of the major variable gases, is not high, but is continuously increasing.
  - Atmospheric methane concentrations are very low, but it is the most powerful absorber of Earth's radiation.
- Aerosols refers to small solid and liquid particles floating in the atmosphere.
- Aerosols worsen visibility, act as a condensation nucleus to form cloud particles, and absorb and scatter solar radiation, affecting the Earth energy budget.