



# Introduction to Meteorology

06

Energy balance

## Introduction



The earth rotates about the tilted axis of rotation while revolving around the sun. Because of the shape of the Earth, a regional difference of incoming solar energy results in an imbalance of energy. Such imbalance is reduced by atmospheric and ocean circulation. How does the energy budget between the solar and Earth radiation and energy balance by latitude occur?

## Contents



1. Incoming solar radiation absorbed by Earth and the atmosphere
2. Earth-atmosphere energy exchange
3. Energy budget by latitude
4. Season

## Learning objectives



1. Describe the Earth energy balance
2. Describe the Earth albedo.
3. Understand and explain the radiative equilibrium between the sun and earth.
4. Explain the energy budget by latitude and season due to energy imbalance.

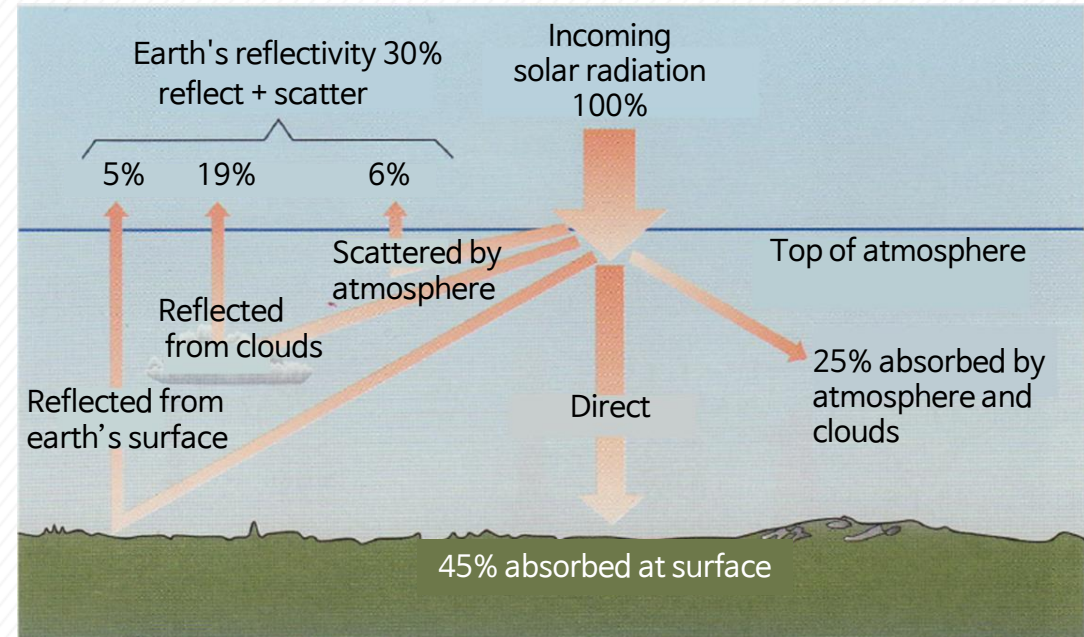
## Learning Activities

### 1. Incoming solar radiation absorbed by Earth and the atmosphere

As the solar radiation reaches the atmosphere or surface, both the atmosphere and the surface emit longwave radiation and maintain the Earth's radiation equilibrium. The annual average of the incoming and outgoing radiation is called the Earth's radiation (energy) budget.

Consider the amount of incoming solar radiation at the top of the atmosphere to be 100 units, then the atmosphere absorbs 25 units. Of the 25, 7 units are ultraviolet radiation absorbed by stratospheric ozone, and the remaining 18 units are near-infrared radiation absorbed by tropospheric gases, including water vapor. Therefore, most of the radiation absorbed by the atmosphere is invisible.

Shortwave radiation is hardly absorbed by clouds. Clouds mainly affect the radiation by scattering and reflections. Cloud particles scatter most of the incoming energy (19 units) back to space. Because of this, highly reflective clouds can be easily identified from the space



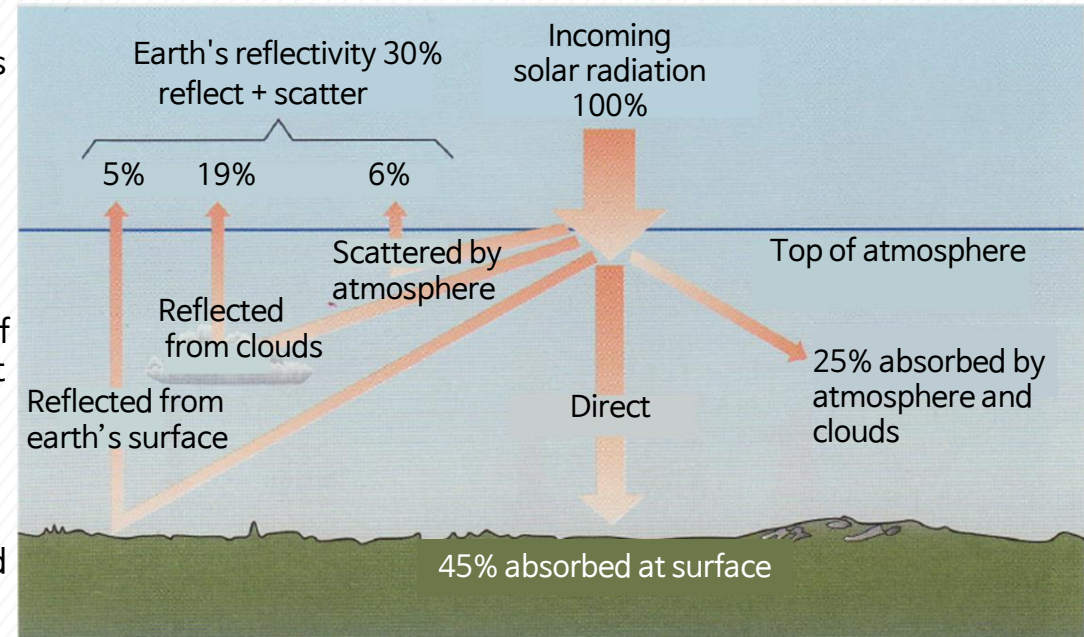
〈Solar energy balance〉

※ Source: Kim, Kyung-Eak et al. (2011),  
Environmental Atmospheric Science, Donghwa Technology

## Learning Activities

### 1. Incoming solar radiation absorbed by Earth and the atmosphere

Radiation backscattered by atmospheric gases or aerosols is 6 units. This is because Rayleigh scattering is larger than Mie scattering which is directed to the surface. The reflection of the cloud and the scattering by the gases and aerosols in the atmosphere add up to 25 units into space, thus the atmospheric reflectivity is 25%. Although 50 units of solar radiation can reach the Earth surface, not all of the radiation that the surface receives is absorbed. Because the surface of the Earth is not a perfect blackbody. Of the 50 units that enter the Earth's surface, 5 units get reflected into space. Consequently, a total of 30 solar radiation units out of 100 units are reflected or scattered back to space. Therefore, the Earth's reflectivity is 30%, which is called Earth's albedo. The amount of solar radiation reflected from the surface is much less than that backscattered by the atmosphere.



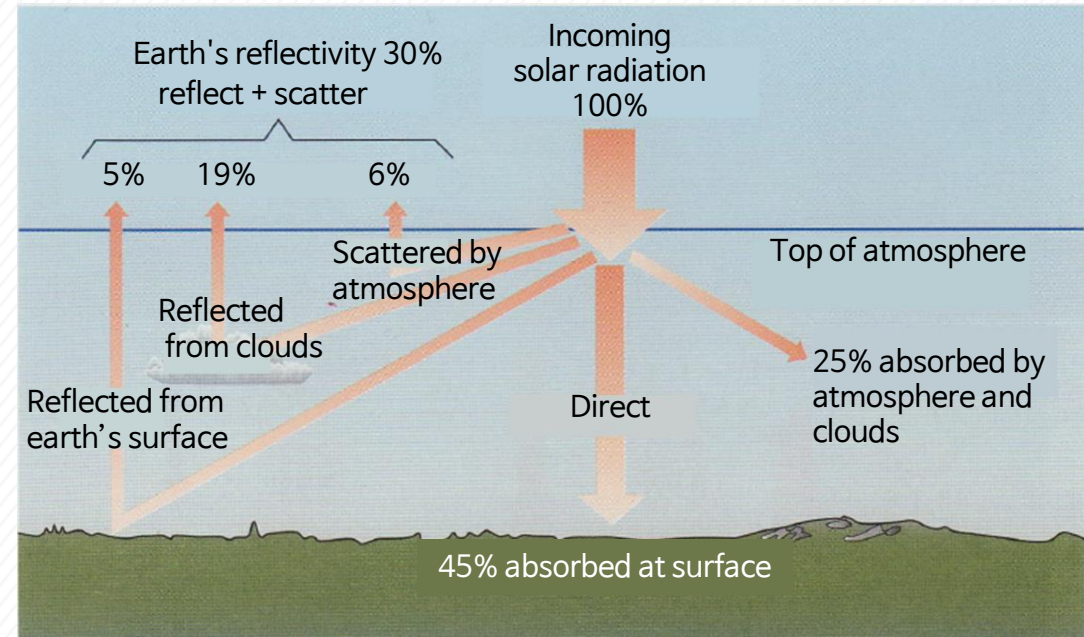
〈Solar energy balance〉

※ Source: Kim, Kyung-Eak et al. (2011),  
Environmental Atmospheric Science, Donghwa Technology

## Learning Activities

### 1. Incoming solar radiation absorbed by Earth and the atmosphere

The atmosphere absorbs 25 units, and the surface absorbs 45 units. If the surface only absorbed 45 units, the surface would heat up continuously. However, the Earth is a blackbody which emits the absorbed energy in various ways keeping Earth's average temperature constant. Also, the surface and atmosphere are constantly exchanging energy.



〈Solar energy balance〉

※ Source: Kim, Kyung-Eak et al. (2011),  
Environmental Atmospheric Science, Donghwa Technology

## Learning Activities

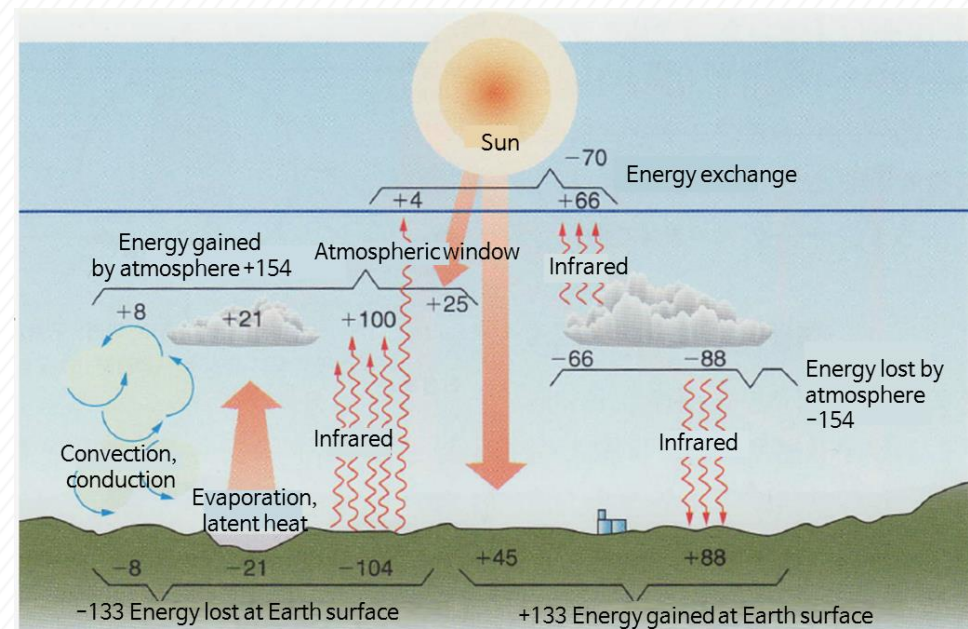
### 2. Earth-atmosphere energy exchange

The surface and the atmosphere mainly emit longwave radiation (infrared). The longwave radiation emitted by the surface is mostly absorbed by the atmosphere. This causes the atmospheric temperature to increase. The atmosphere releases more energy than absorbed in all directions. The surface receives a significant portion of this radiation, heat up more, and emit more longwave radiation, reheating the atmosphere. This energy exchange between the surface and atmosphere occurs repeatedly.

## Learning Activities

### 2. Earth-atmosphere energy exchange

What about the global average longwave radiation energy exchange between the atmosphere and the Earth surface? The longwave radiation emitted from the surface is 104 units, and the amount absorbed by the atmosphere is 100 units. On a clear day, mainly water vapor and carbon dioxide absorb longwave radiation emitted from the surface. Most of the greenhouse gases including water vapor and carbon dioxide absorb longwave radiation, but the  $8 \sim 12 \mu\text{m}$  band (atmospheric window) permeates into space (4 units) without absorption taking place. The total energy emitted by the atmosphere is 154 units, of which 88 units are radiated to the surface and 66 units sent back to space. In this process, the longwave radiation energy lost by the atmosphere is greater than the amount absorbed (100 units) from surface. This difference, which is  $-54$  units, is called net longwave radiation. The surface absorbs 88 units of atmospheric longwave radiation, but emits 104 units, resulting in the net of  $-16$  units. The difference between the emitted and absorbed longwave radiation is called the net longwave radiation, and the net energy between the net longwave radiation and solar radiation (shortwave) is called the net radiation.



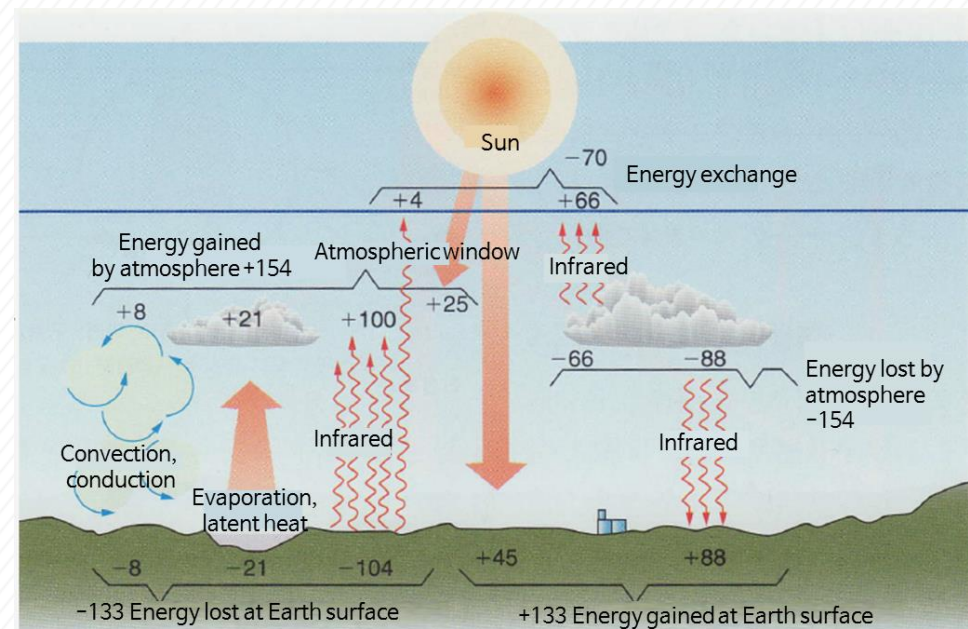
〈Energy exchange between surface-atmosphere-space〉

※ Source: Kim, Kyung-Eak et al. (2011),  
Environmental Atmospheric Science, Donghwa Technology

## Learning Activities

### 2. Earth-atmosphere energy exchange

66 units sent back to space. In this process, the longwave radiation energy lost by the atmosphere is greater than the amount absorbed (100 units) from surface. This difference, which is -54 units, is called net longwave radiation. The surface absorbs 88 units of atmospheric longwave radiation, but emits 104 units, resulting in the net of -16 units. The difference between the emitted and absorbed longwave radiation is called the net longwave radiation, and the net energy between the net longwave radiation and solar radiation (shortwave) is called the net radiation.



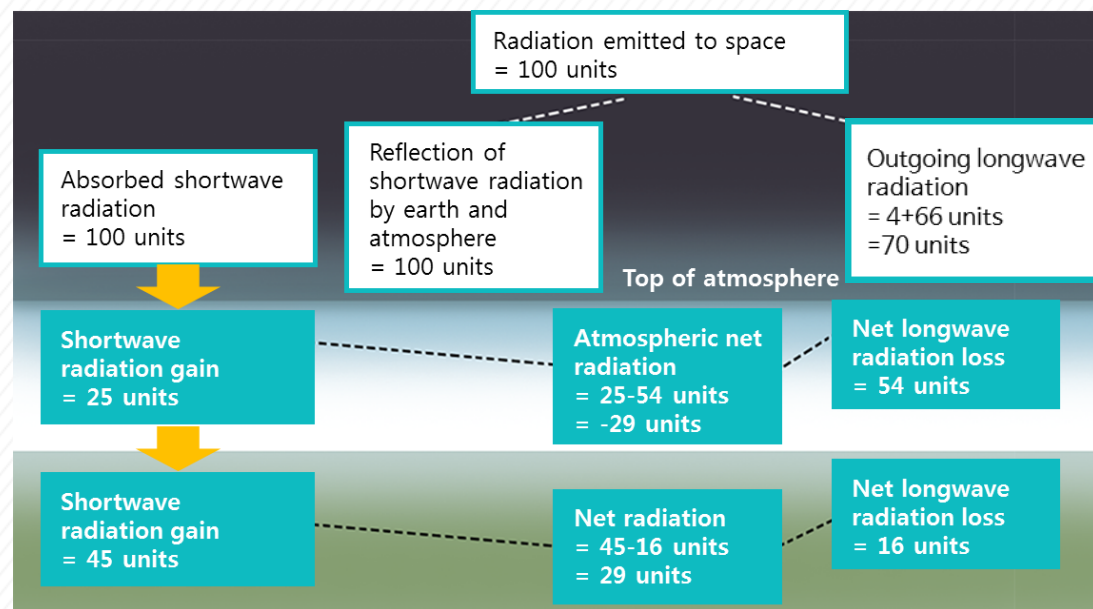
〈Energy exchange between surface-atmosphere-space〉

※ Source: Kim, Kyung-Eak et al. (2011),  
Environmental Atmospheric Science, Donghwa Technology

## Learning Activities

### 2. Earth-atmosphere energy exchange

The atmosphere absorbs 25 units of solar radiation, but it loses 54 units of longwave radiation. Therefore, the atmosphere has deficit of radiation (-29 units). The surface absorbs 45 units of solar radiation but loses 16 units of net longwave radiation, resulting in net surplus (29 units) on the surface. The net radiation deficit in the atmosphere is equal to the net radiation surplus on the surface. If there were no exchange of energy except the radiation, the excess energy absorbed on the surface would continuously heat the Earth and cool the atmosphere. However, energy is exchanged via conduction and convection by which the net radiative surplus is removed from the surface to offset the net radiative loss of the atmosphere.



〈Earth net radiative equilibrium〉

※ Source: Kim, Kyung-Eak et al. (2011),  
Environmental Atmospheric Science, Donghwa Technology

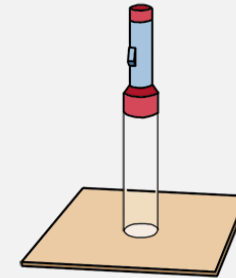
## Learning Activities

### 3. Energy budget by latitude

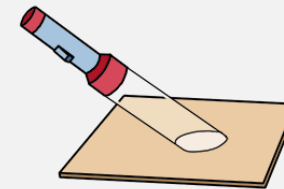
The amount of solar energy entering the Earth varies by latitude.

If the energy of the flashlight coming out per hour is equal, which case shown above will receive more energy?

When the light is coming from directly above (90 degrees), the surface covered by the light rays will receive more energy per unit area than when the beam at an angle less than 90° strikes the surface. Therefore, when the light beam is concentrated in a smaller area, the covered surface can be efficiently warmed. Likewise, the solar energy in low-latitude region more efficiently warms the Earth surface than in the high-latitudes, because solar energy that strikes Earth's surface perpendicularly is more intense than solar energy that strikes the same surface at an angle. Moreover, when solar radiation is incident at an angle, more scattering occurs because it has to pass through a thicker atmosphere.



〈Flashlight strikes a surface directly〉



〈Flashlight strikes a surface at an angle〉

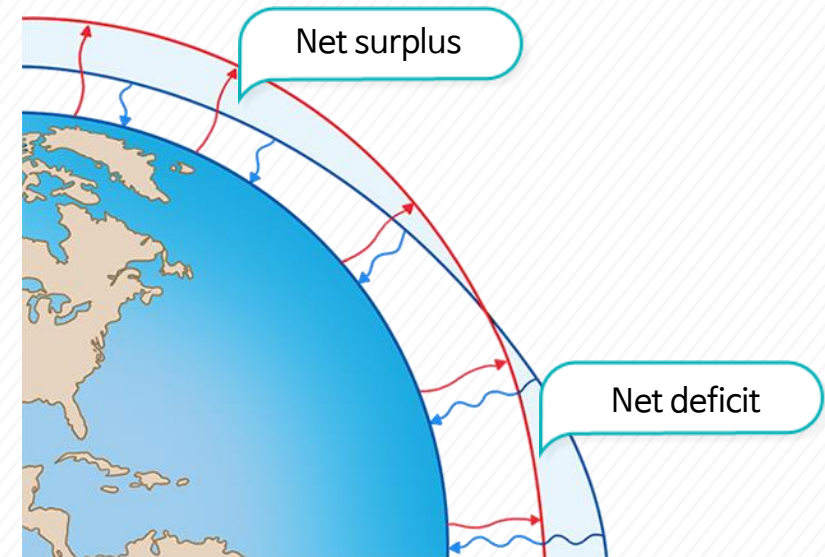
※ Source: Kim, Kyung-Eak et al. (2011),  
Environmental Atmospheric Science, Donghwa Technology

## Learning Activities

### 3. Energy budget by latitude

The figure shows the amount of incoming and outgoing solar radiation depending on latitude. On average, an area between  $38^{\circ}\text{N}$  and  $38^{\circ}\text{S}$ , the incoming energy is higher than the outgoing energy. However, the pattern is reversed to the north of  $38^{\circ}\text{N}$  and south of  $38^{\circ}\text{S}$ .

The boundaries in these energy surplus and deficit areas change by season. During the northern hemisphere summer, more energy is received to the north of  $15^{\circ}\text{S}$ , while more energy is received to the south of  $15^{\circ}\text{N}$  during the winter. Without any other effect, energy surplus would occur in the region between  $38^{\circ}\text{N}$  and  $38^{\circ}\text{S}$  resulting in warmer tropics and subtropics and colder high latitudes. But this cannot happen. It is because the atmosphere and ocean transport the surplus energy to the higher latitudes to supplement the deficit of energy.

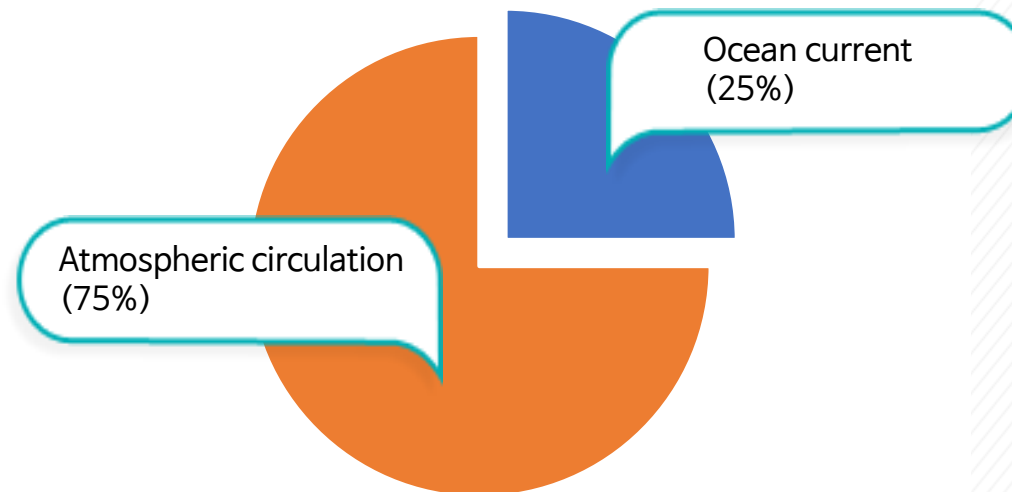


〈Energy balance by latitude〉

※ Source: Kim, Kyung-Eak et al. (2011),  
Environmental Atmospheric Science, Donghwa Technology, 59p

## Learning Activities

### 3. Energy budget by latitude



The energy is transported primarily by atmospheric circulation (75%) and ocean currents (25%). Because of the pressure gradient due to the regional energy imbalance, the atmosphere tends to move from higher to lower pressure area, and it induces horizontal wind. The near surface wind drives ocean currents, and the atmospheric and ocean circulation redistribute the energy globally.

## Learning Activities

### 4. Season

Solar radiation is almost constant, but the energy received over a year on the Earth varies widely in time and space.

The temporal and spatial changes of energy are caused by the earth's revolution and the earth's rotation axis which cause season.

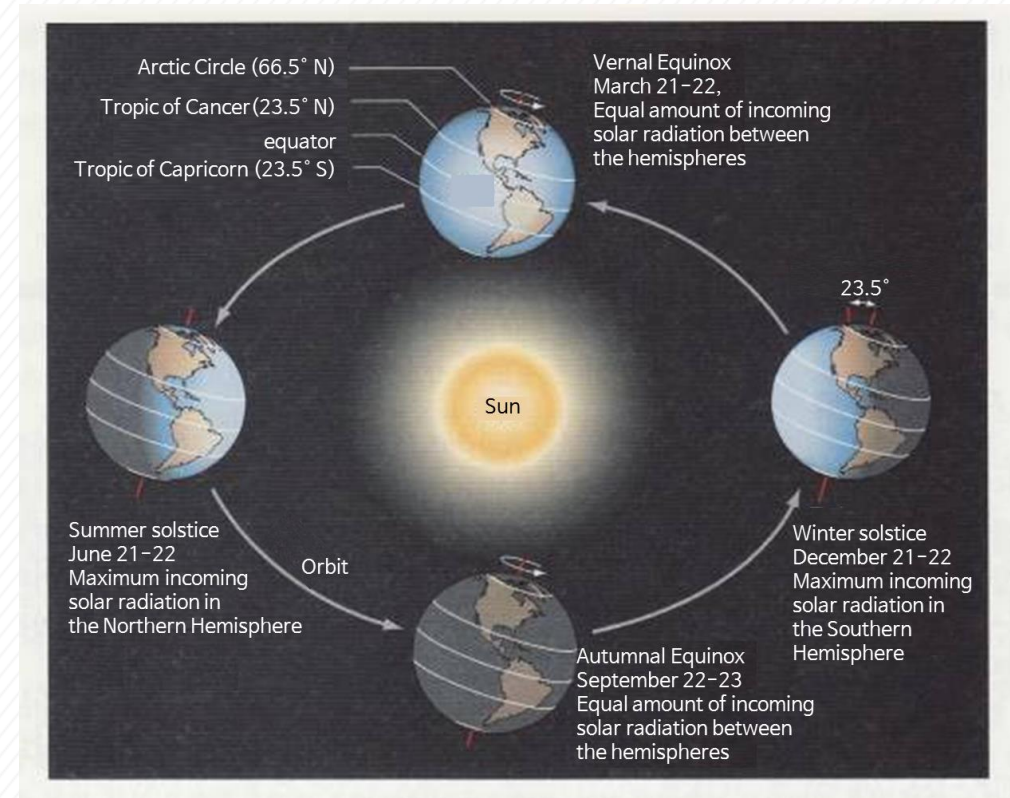
## Learning Activities

### 4. Season

#### 1) Earth rotation and revolution

The Earth revolves around the Sun once every 365.25 days along the orbital plane, and the distance between Earth and the Sun continues to change over the year due to the elliptical orbit

Earth comes closer to the sun in January 3<sup>rd</sup> (Perihelion) than it does in July 3<sup>rd</sup> (Aphelion). The intensity of radiation at the Perihelion is about 7% stronger than that at the Aphelion, but it is too weak to cause seasonal changes. The Earth rotates once every 24 hours around the axis of rotation. The axis of rotation is 23.5° tilted from the Earth's orbit and is tilted toward the sun during half of the year, and tilted away from the sun during the rest. Such changes determine the amount of solar radiation and cause seasonal changes.



〈Earth's Orbit around the Sun〉

※ Source: Kim, Kyung-Eak et al. (2011),  
Environmental Atmospheric Science, Donghwa Technology

## Learning Activities

### 4. Season

#### 2) Solstices and Equinoxes

Looking at the picture showing the seasonal changes along the position of the earth toward the sun, we can see that the northern hemisphere is getting more sunlight during six months of the year and the southern hemisphere in the other six months of the year. In addition, On the summer solstice, the sun at noon would be directly overhead and the declination of sun reaches a maximum. As a result, the northern hemisphere receives maximum radiation and has the longest daytime. It is the opposite during the winter solstice, when the southern hemisphere facing the sun.

Between the summer and winter solstice, when the noonday sun is shining directly over the equator, and when days and nights throughout the world are of equal length (12 hours each), is called the vernal and autumnal equinox. The latitude  $23.5^{\circ}\text{N}$  ( $\text{S}$ ) corresponds to the northernmost (southernmost) declination of the Sun, called the Tropic of Cancer (Tropic of Capricorn).

The change in direction of the Earth toward the sun affects the length of the day, the angle the sunlight, and the distance of incoming solar radiation, which alter the temperature of the atmosphere.

## Learning Activities

### 4. Season

#### 3) Daytime length

Because of the tilted Earth's axis, the length of day and night changes and affects the incoming solar radiation. If the Earth's axis and orbit were tilted at  $90^\circ$ , the northern and southern hemispheres would have equal length of day and night for six months. However, because it is tilted  $23.5^\circ$ , day and night which last for 24 hours only occur in areas higher than  $66.5^\circ$  N or  $66.5^\circ$  S. In the northern part of the Arctic Circle, the daytime lasts for 24 hours (midnight sun) and the daytime length decreases toward the equator. In the southern part of the Antarctic Peninsula, there is a 24-hour night (polar night), and the opposite phenomenon occurs at winter solstice.

## Summary

### 1. Incoming solar radiation absorbed by Earth and the atmosphere

- As the solar radiation reaches the atmosphere or surface, both the atmosphere and the surface emit longwave radiation and maintain the Earth's radiation equilibrium. The annual average of the incoming and outgoing radiation is called the Earth's radiation (energy) budget.
- Solar radiation energy: 100 units of incoming solar radiation
  - Atmosphere: 25 units of absorption (7 units – UV absorbed by the stratospheric ozone, 18 units – absorbed by the troposphere gas including water vapor), and 25 units of reflection (19 units – by clouds, 6 units by gases in the atmosphere, aerosol), consequently the reflectivity of the atmosphere is 25%.
  - Earth surface: 45 units of absorption and 5 units of reflection
- The Earth's albedo : 30 units of reflection (atmosphere + surface) from 100 units of total solar radiation, therefore the earth reflectivity (albedo) is 30%

## Summary

### 2. Earth-atmosphere energy exchange

- The surface and the atmosphere mainly emit longwave radiation (infrared).
  - Longwave radiation emitted by the surface is mostly absorbed by the atmosphere.
  - This causes the atmospheric temperature to rise. The atmosphere releases more energy than it absorbs from all directions, and the surface receives a significant portion of this radiation.
  - The surface heats up more and emits more longwave radiation, reheating the atmosphere. An infinite energy exchange between the surface and atmosphere occurs with constant energy transfer.
- Longwave radiation energy balance
  - Longwave radiation emitted by earth surface= 104 units [absorption by atmosphere = 100 units, amount out of space (atmospheric window) = 4 units]
  - Longwave radiation emitted by atmosphere = 154 units [Surface absorption = 88 units, out of space = 66 units]
  - Net longwave radiation: atmosphere = -54 unit [100-154], surface = -16 unit [88-104]
  - Net radiation: atmosphere = -29 units [25 units (solar radiation) - 54 unit (longwave radiation)], surface = 29 units [45 units (solar radiation) - 16 units (longwave radiation)]

## Summary

### 3. Energy budget by latitude

- The amount of solar energy entering the Earth varies as function of latitude.
  - On average, an area between 38°N and 38°S, the incoming energy is larger than the outgoing energy.
  - An area north of 38°N and south of 38°S, the incoming energy is smaller than the outgoing energy.
  - The boundaries in energy surplus and deficit areas change by season.
  - The energy is transported primarily by atmospheric circulation (75%) and ocean currents (25%).

# Summary

## 4. Season

- Earth rotation and revolution
  - The Earth revolves around the Sun once every 365.25 days along the orbital plane.
  - The earth rotates once every 24 hours around the axis of rotation.
  - The axis of earth rotation is  $23.5^\circ$  tilted facing toward Polaris and it determines the amount of solar radiation and seasonal changes.