Earth's Energy Budget

The Earth's climate is a solar powered system. Over the course of a year, the Earth absorbs solar energy, using it to drive photosynthesis, melt snow and ice, and warm the Earth.

The Sun doesn't heat the Earth evenly. Because the Earth is a sphere, the Sun heats equatorial regions more than polar regions. The atmosphere and oceans work non-stop to even out the Earth's temperature by moving heat around the planet in the form of air and ocean currents.

In addition to absorbing energy from the Sun, Earth must also radiate energy back into space. Otherwise, Earth would endlessly heat up. The net flow of energy into and out of the Earth system is known as **Earth's energy budget**.

When the flow of incoming solar energy is balanced by an equal flow of heat into space, Earth is said to be in **thermal equilibrium**. While in equilibrium, average global temperature remains stable. Anything that increases or decreases the amount of incoming or outgoing energy disturbs this equilibrium, causing global temperatures to rise of fall in response.

Incoming Energy

The amount of solar energy entering the Earth's atmosphere is estimated at 174 quadrillion watts. This energy consists of:

- solar radiation
- geothermal energy
- tidal energy
- waste heat

Outgoing Energy

Approximately 30% of the incoming solar energy is reflected directly back into space:

- 6% is reflected from the atmosphere
- 20% is reflected from clouds
- 4% is reflected from the surface of the Earth (land, water, and ice)

The remaining 70% of the incoming solar energy is absorbed:

- 51% is absorbed by land and water, and then is radiated back into space in the following ways:
    - 23% is transferred to the atmosphere by evaporating water
    - 7% is transferred to the atmosphere by warm air as it rises
    - 6% is radiated directly back into space
    - 15% is transferred to the atmosphere by radiation

- 19% is absorbed by the atmosphere and clouds
    - 16% is absorbed by the atmosphere
    - 3% is absorbed by the clouds

When the Earth is in thermal equilibrium, the same 70% that is absorbed is also reradiated back into space:

- 64% is radiated back into space by the atmosphere and clouds
- 6% is radiated back into space by the surface

The diagram below illustrates the reflection, absorption, and radiation of solar energy as it moves into and out of the Earth system.

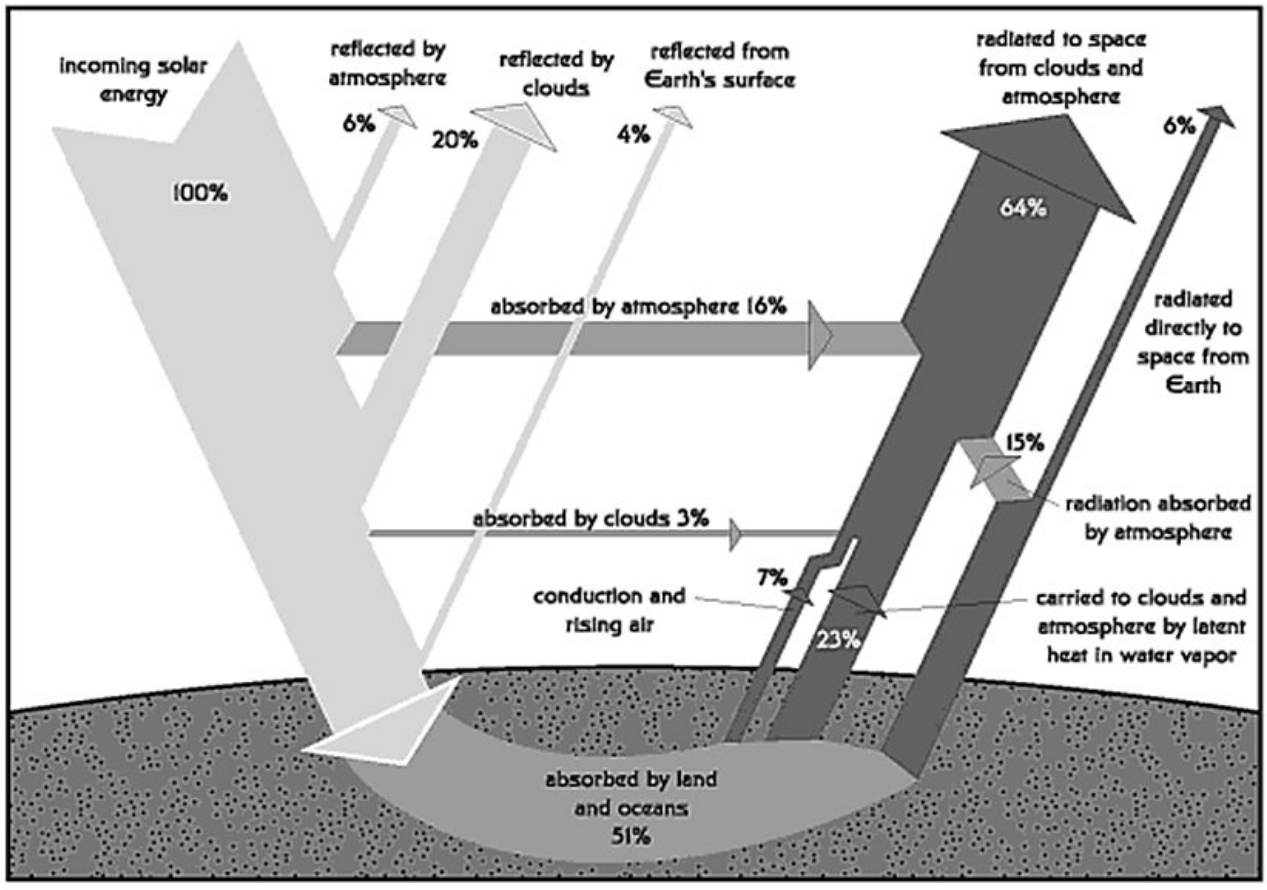


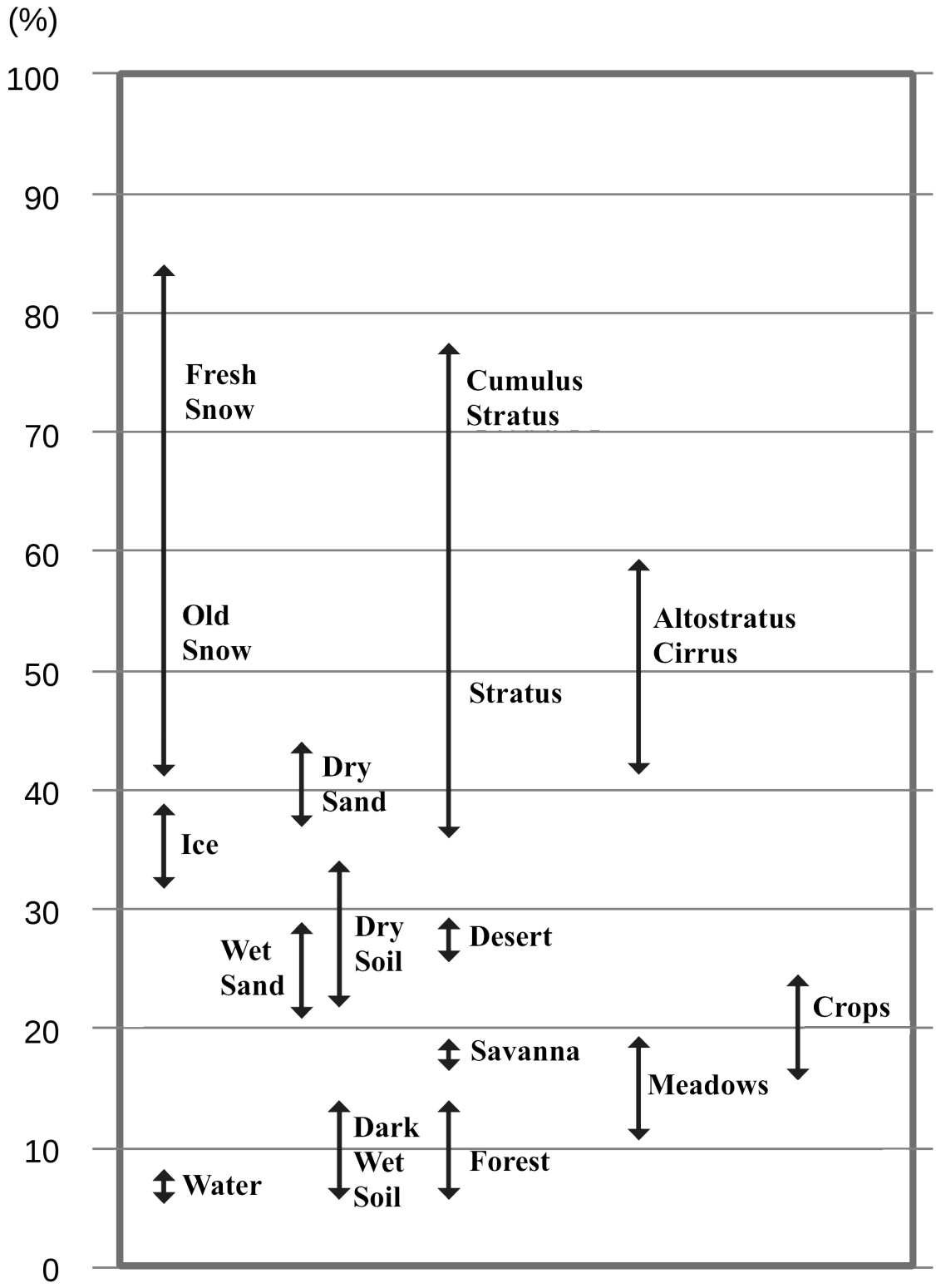
Figure 5.1
Partitioning of the incoming solar radiation. Based on Smil (1999a).

Notice that the amount of energy entering the system (100%) and the amount leaving the system (6 + 20 + 4 + 64 + 6 = 100%) are the same. Thus, the Earth is in thermal equilibrium, and global temperature remains stable.

Albedo

As we have seen above, a portion of the incoming solar energy is reflected (from the atmosphere, the clouds, and the surface). The **albedo** of a material is the percent of incoming solar radiation that is reflected from that material. For example, the average albedo of the Earth is 30%.

The diagram below illustrates the albedo of various materials.



Greenhouse Gases

The energy that gets radiated back to space from Earth's surface encounters atmospheric gases and clouds on the way up. These bounce some of this energy back to Earth. Depending on the type of gases and the amount of clouds, the amount of energy that gets bounced back to Earth may increase or decrease.

This "trapping" of energy between the surface and the clouds is known as the **greenhouse effect**. Because it results in less energy being radiated out into space, the greenhouse effect results in an increase in average global temperature.

Greenhouse gases are naturally occurring or man-made gases that have a significant impact on the heat-trapping properties of the atmosphere. An increase in these gases causes a corresponding increase in average global temperature.

The main greenhouse gases are water vapor, carbon dioxide, methane, and chlorofluorocarbons (CFCs). Fossil fuel consumption and forest fires are the top sources of carbon dioxide, while agriculture is the top source of methane.

Worksheet

1. What percentage of the incoming solar energy is reflected by the atmosphere and the clouds?

2. What percentage of the incoming solar energy is absorbed by the atmosphere and the clouds?

3. What percentage of the incoming solar energy is absorbed by Earth's surface (land and oceans)?

4. What percentage of the incoming solar energy ends up being reflected/radiated back into space?

5. What would happen if less solar energy was reflected/radiated back into space?

6. What would happen if more solar energy was reflected/radiated back into space?

7. What has a higher albedo, ice or open ocean?

8. If an increase of one degree in global temperatures causes the Arctic Ocean to remain ice free for two additional weeks each year, how will it affect the ocean's albedo? Why?

9. If the ocean's albedo decreases, how will this affect ocean temperatures and ice formation in the winter? Explain.

10. When forests are cleared, the soil exposed often has a smaller albedo than the trees that were there. What effect does that have on the local temperature?

11. What is the effect of wearing dark clothes in strong sunlight rather than lighter colored clothing?

12. What effect do clouds have on the albedo of the earth?

13. What effect does dust in the atmosphere have on the albedo of the earth?

14. What effect does a large volcanic eruption have on the albedo of the earth?

15. Cities commonly have low albedos. Why?