Introduction to Meteorology

40 Climate system feedback and interaction (2)

Introduction

The Earth climate system is in a delicate balance between incoming and outgoing energy. If this balance is broken, even slightly, climate can undergo a series of complicated changes. A remakable disturbance is the global warming attributed to the emission of carbon dioxide by human activity. The radiative forcing due to an increase in greenhouse gases may cause a temperature increase of less than 0.5 degree for 100 years. However, the actual global temperature has risen more than 0.5 degree. This is due to the feedback within the climate systems. The water vapor-temperature positive feedback is a typical example. Increase in atmospheric temperature allows more water vapor to evaporate into the atmosphere and again strengthens the greenhouse effect.

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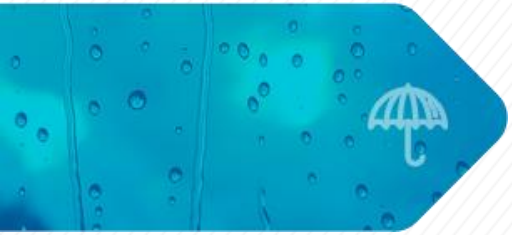

1. The role of climate system feedbacks and interactions in global warming

Learning objectives

1. Describe the impacts of major climate system feedbacks and interactions in the global warming process.

Learning Activities

1. The role of climate system feedbacks and interactions in global warming

What are the climate system feedbacks in the global warming process? Positive feedbacks include ice-albedo feedback, water vapor feedback, cloud feedback, and carbon cycle feedback. Negative feedbacks include the Plank feedback and the role of the ocean.

Learning Activities

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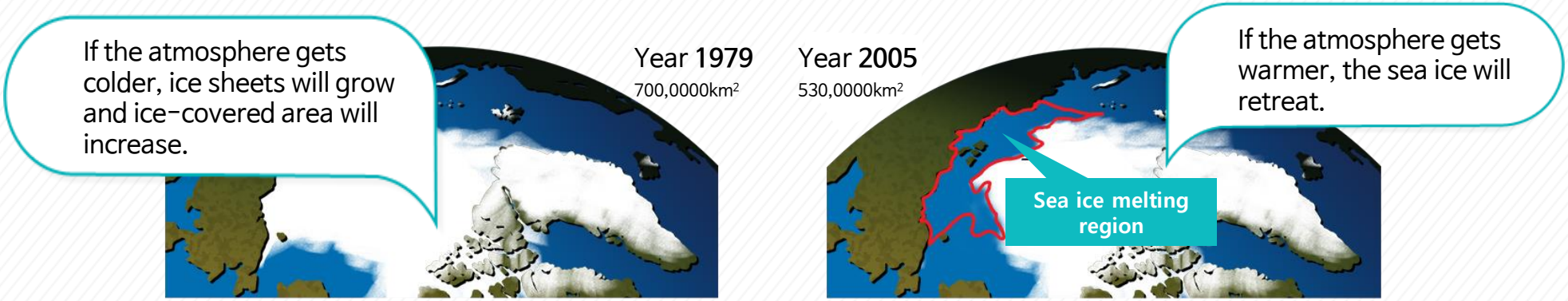
1) Positive feedback

First, let's look at the ice-albedo positive feedback. In the following figure, the surface is covered by huge continental ice sheets and the sea ice. If the atmosphere becomes cold enough, ice sheets will grow, and the area covered by ice will be extended. If the atmosphere is warm, the sea-ice will retreat.



〈Sea-ice distribution in 1979〉
※ Source: www.yonhapnews.co.kr

〈Sea-ice distribution in 2005〉
※ Source: www.yonhapnews.co.kr

Ice has high albedo. As the ice sheet extends, it will reduce the solar energy that the surface can absorb. On the other hand, warm climate loses ice and thus makes the climate warmer. This is why the change is more striking in the middle or high latitude than the low latitude. In regions without ice, such as the tropics, the feedback does not occur.

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The water vapor feedback is a typical positive feedback. Water vapor is a natural greenhouse gas. When the atmosphere warms, more water vapor is evaporated from the ocean. This increases the water vapor in the atmosphere which absorbs and re-emits the Earth's radiation, and further increases the surface temperature. According to climate model simulations, the water vapor feedback contributes to about half of global warming.

Next is the cloud feedback. Rising global temperature increases atmospheric water vapor, and warming near the surface decreases atmospheric stability, leading to increase in the amount of cloud.

Cloud is a very powerful reflector for solar radiation and absorber of earth radiation. Especially, high clouds are fairly transparent to solar radiation, but they efficiently absorb the earth radiation and can amplify the greenhouse effect. However, if low clouds increase, the cloud feedback can be a negative feedback because low clouds reflect the sunlight efficiently. However, the cloud feedback mechanism is so complex that the future climate change projection can be uncertain.

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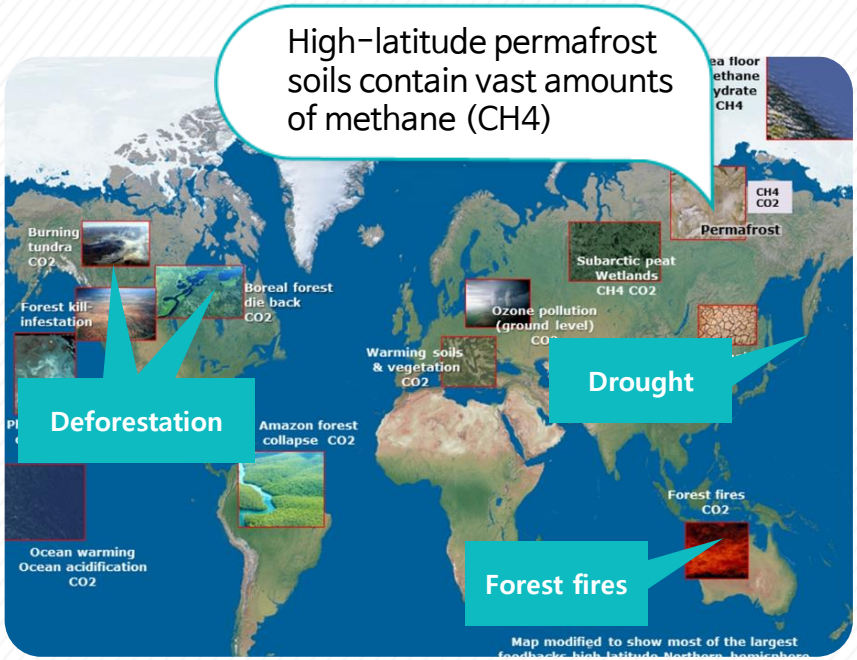
Next is the carbon cycle feedback. The increase in atmospheric temperature helps to release the greenhouse gases from the ocean and land to the atmosphere.

In the ocean, a tremendous amount of carbon dioxide is dissolved. As the temperature of the ocean rises, more carbon dioxide can be released into the atmosphere. This may amplify the warming.

The following figure illustrates the processes related to the carbon cycle positive feedback.
For example, high-latitude permafrost soils contain vast amounts of methane. If the permafrost thaws due to the warming, methane can escape into the atmosphere rapidly. Because methane is a very powerful greenhouse gas, it can contribute to the positive feedback of global warming.

In addition, deforestation, drought, and wildfire increase atmospheric CO_2.



〈Carbon feedback sources〉

※ Source: http://www.onlyzerocarbon.org/arctic_feedback.html

Learning Activities

1. The role of climate system feedbacks and interactions in global warming

2) Negative feedback

The climate system has a strong negative feedback mechanism as well. The typical one is the Plank feedback. All objects emit radiation proportional to the fourth power of the temperature. As the global temperature increases, more radiation will be emitted, and the temperature can be effectively declined. Nevertheless, we are experiencing global warming because other feedbacks are stronger.

Climate change is greatly influenced by the interaction between the atmosphere and ocean. In fact, the most powerful negative feedback is the carbon dioxide absorption by the ocean.

It is known that about half of the carbon dioxide emitted since the Industrial Revolution was absorbed by the ocean. Eventually, the ocean has played a role in mitigating the greenhouse effect.

However, the ocean temperature has gradually increased, and the absorption efficiency of carbon dioxide in the ocean is declining. If the ocean temperature rises significantly in the future, carbon dioxide can be released into the atmosphere, which can induce a strong positive feedback on global warming.

Learning Activities

1. The role of climate system feedbacks and interactions in global warming

In the North Atlantic Ocean, the oceanic thermohaline circulation has a negative feedback on global warming. If the Greenland ice melts, more fresh water flows into the North Atlantic, which is less dense than the surrounding water. It weakens the convection of sinking water into the deep ocean. This weakening of the thermohaline circulation reduces the intensity of the Gulf Stream. As a result, the temperature in the European side can be lowered if the warming of the Gulf of Mexico is weakened.

One of the important feedback effects of global warming is the effect of carbon dioxide concentration on the photosynthetic rate. When the content of carbon dioxide in the atmosphere increases, some plants can rapidly through active photosynthesis. When the temperature rises, especially in high latitudes, the growth of several plants is stimulated. Plants play a role in adjusting carbon dioxide in the atmosphere, which is a negative feedback effect.

Learning Activities

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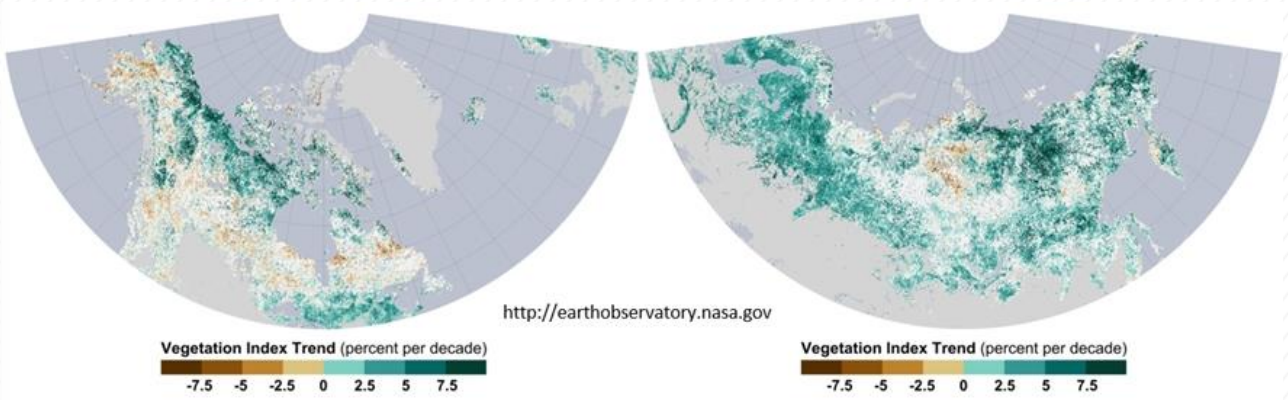
Such "carbon fertilizing effect" is already occurring between 45~70N. This figure shows a trend of the vegetation index in the northern hemisphere during the period 1982-2011 observed by satellite. Green indicates that vegetation growth has increased. It can be seen that vegetation growth has increased in many regions where the amount of CO_2 and temperature increased.



〈Linear trend of vegetation index for the period 1982-2011〉

Summary

1. The role of climate system feedbacks and interactions in global warming

- Ice-albedo feedbacks
  - The increase in ice sheets leads to solar energy reduction due to the high albedo of ice.
  - Warm weather accelerates ice melting and causes warmer climate.
- Evaporation of water vapor
  - If the climate becomes warmer, it accelerates surface evaporation, and the atmosphere will eventually contain more water vapor.
  - The atmosphere absorbs more infrared radiation amplifying the initial warming.
- Ocean-atmosphere interaction
  - Climate change can have an impact on ocean circulation which in turn can affect the global climate.
- Atmosphere-biosphere interaction
  - Vegetation influences the atmospheric water vapor through the transpiration process.
  - Plant clusters change the surface albedo and modify the heat exchange efficiency at the surface.
  - When the carbon dioxide concentration in the atmosphere increases, some plants can grow rapidly by active photosynthesis. Plants play a role in adjusting carbon dioxide in the atmosphere which is a negative feedback effect.