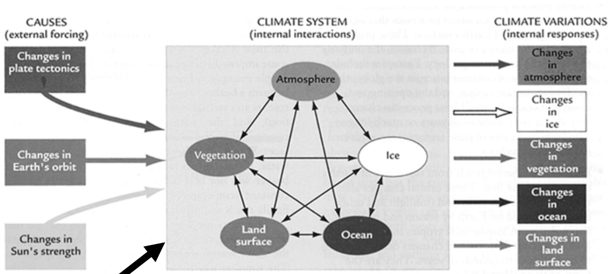
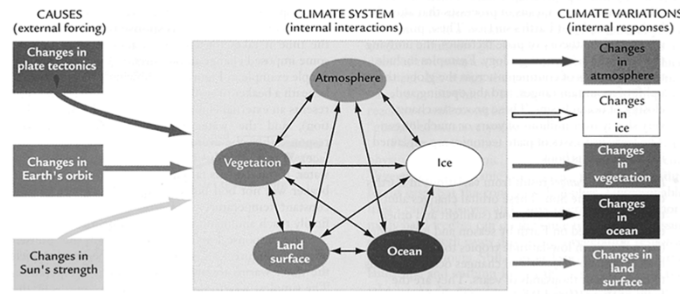
Lecture 10: Climate Sensitivity and Feedback



Human Activities

- ❑ Climate Sensitivity
- ❑ Climate Feedback

Climate Sensitivity and Feedback



(from *Earth's Climate: Past and Future*)

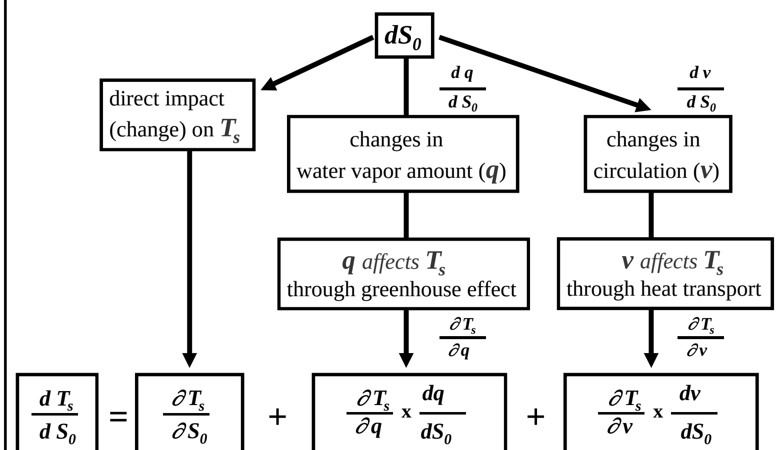
Definition and Mathematic Form

direct impact

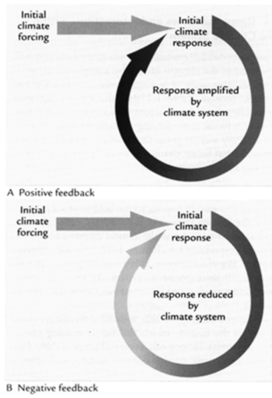
$$\frac{dT_s}{dS_0} = \frac{\partial T_s}{\partial S_0} + \sum_{j=1}^{N} \frac{\partial T_s}{\partial y_j}\frac{dy_j}{dS_0}$$

- ❑ Climate Sensitivity: the relationship between the measure of forcing and the magnitude of the climate change response.
- ❑ Feedback Mechanism: a process that changes the sensitivity of the climate response.

Direct Impact and Feedback Process



Major Climate Feedback Processes



- **Water Vapor Feedback** - Positive
- **Snow/Ice Albedo Feedback** - Positive
- **Longwave Radiation Feedback** - Negative
- **Vegetation-Climate Feedback** - Positive
- **Cloud Feedback** - Uncertain

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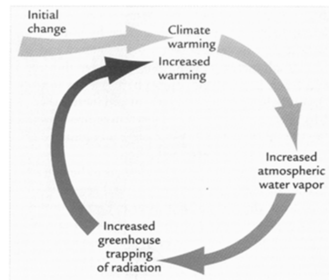
Water Vapor Feedback



- **Mixing Ratio** = the dimensionless ratio of the mass of water vapor to the mass of dry air.
- **Saturated Mixing Ratio** tells you the maximum amount of water vapor an air parcel can carry.
- The saturated mixing ratio is a function of air temperature: the warmer the temperature the larger the saturated mixing ration.
  - ➔ a warmer atmosphere can carry more water vapor
  - ➔ stronger greenhouse effect
  - ➔ amplify the initial warming
  - ➔ one of the most powerful positive feedback

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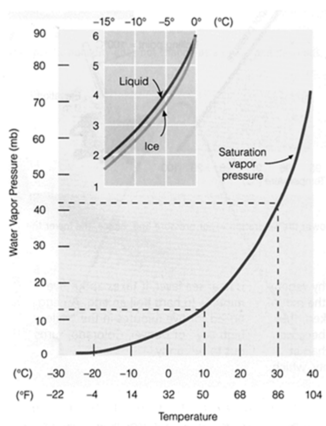
Saturation Vapor Pressure



- Saturation vapor pressure describes how much water vapor is needed to make the air saturated at any given temperature.
- Saturation vapor pressure depends primarily on the air temperature in the following way:

$$\frac{de_s}{dT} = \frac{L}{T(\alpha_v - \alpha_l)}$$

The Clausius-Clapeyron Equation

➔ $$e_s \cong 6.11 \bullet \exp\left\{\frac{L}{R_v}\left(\frac{1}{273} - \frac{1}{T}\right)\right\}$$

- Saturation pressure increases exponentially with air temperature.

L: latent heat of evaporation; α: specific volume of vapor and liquid

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Snow/Ice Albedo Feedback

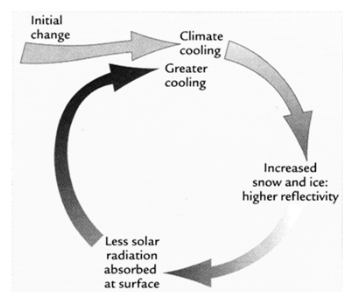

TABLE 2-1 Average Albedo Range of Earth's Surfaces

Surface	Albedo range (percent)
Fresh snow or ice	60–90%
Old, melting snow	40–70
Clouds	40–90
Desert sand	30–50
Soil	5–30
Tundra	15–35
Grasslands	18–25
Forest	5–20
Water	5–10

Adapted from W. D. Sellers, Physical Climatology *(Chicago: University of Chicago Press, 1965), and from R. G. Barry and R. J. Chorley,* Atmosphere, Weather, and Climate, *4th ed. (New York: Methuen, 1982).*

- The snow/ice albedo feedback is associated with the higher albedo of ice and snow than all other surface covering.
- This positive feedback has often been offered as one possible explanation for how the very different conditions of the ice ages could have been maintained.

(from *Earth's Climate: Past and Future*)

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Temperature Changes due to Anthropogenic Warming

associated with a decline in the moist adiabatic lapse rate of temperature in the tropics as the climate warms

1. enhanced warming in tropical troposphere

Warming in the troposphere and cooling in the stratosphere

→ due to the absorption of longwave radiation by CO_2 in the troposphere such that it is no longer available to the stratosphere.

colder stratosphere → increases PSC → deplete ozone

associated with polar ozone depletion

2. enhanced cooling in polar stratosphere

associated with snow-ice-albedo feedback in the Arctic

3. enhanced warming at polar surface

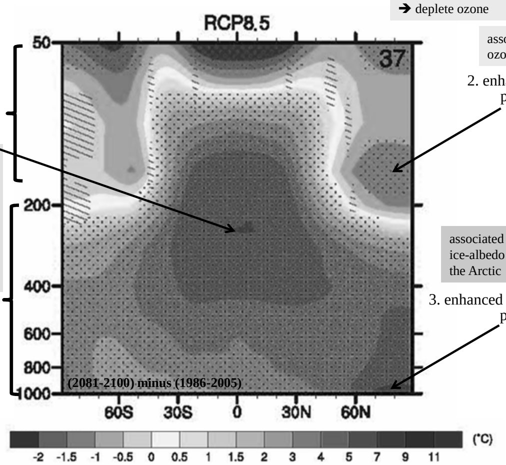
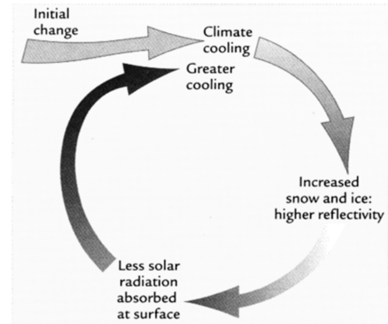


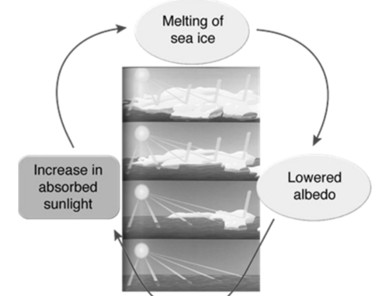
Figure 12.12 | CMIP5 multi-model changes in annual mean zonal mean temperature in the atmosphere and ocean relative to 1986–2005 for 2081–2100 under the RCP2.6 (left), RCP4.5 (centre) and RCP8.5 (right) forcing scenarios. Hatching indicates regions where the multi-model mean change is less than one standard deviation of internal variability. Stippling indicates regions where the multi-model change mean is greater than two standard deviations of internal variability and where at least 90% of the models agree on the sign of change (see Box 12.1).

(from IPCC AR5)

Snow/Ice-Albedo Feedback

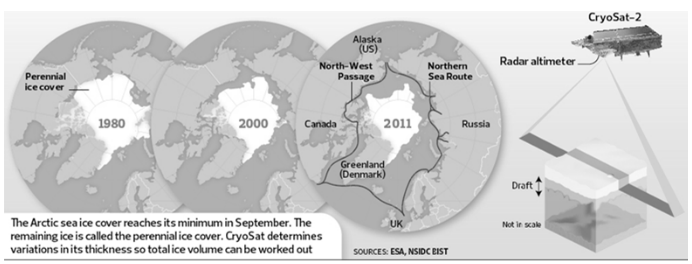


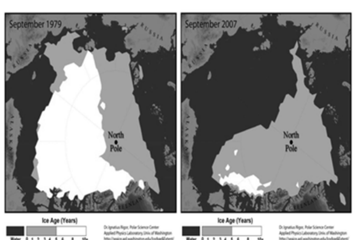
(from *Earth's Climate: Past and Future*)



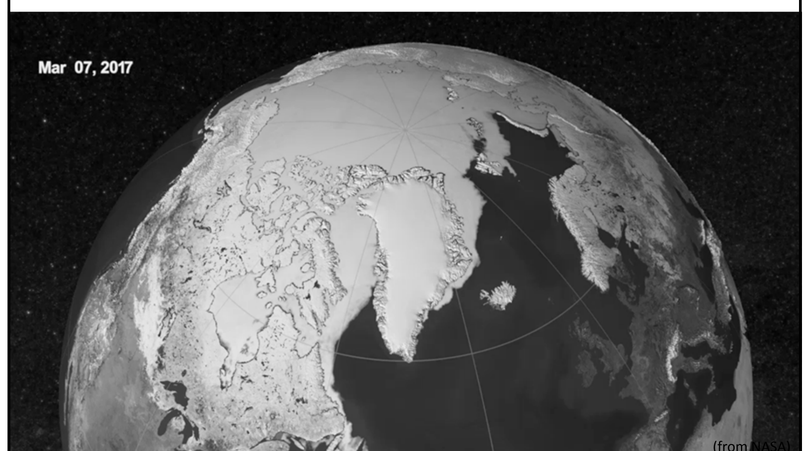
(from *http://www.onlyonesolution.org*)

Accelerated Sea Ice Lost in Arctic



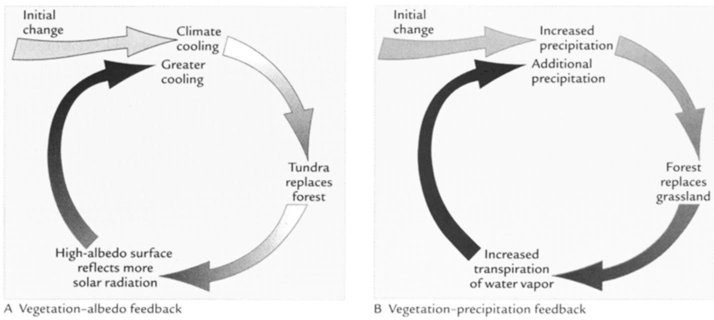


Arctic Sea Ice from March to September 2017



(from NASA)

Vegetation-Climate Feedbacks



(from *Earth' Climate: Past and Future*)

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Albedo

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(from *Earth's Climate: Past and Future*)

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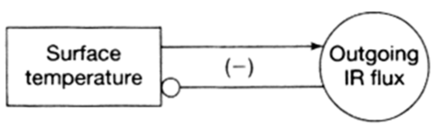
Longwave Radiation Feedback



- The outgoing longwave radiation emitted by the Earth depends on surface temperature, due to the Stefan-Boltzmann Law: $F = \sigma(T_s)^4$.

  ➔ warmer the global temperature
  ➔ larger outgoing longwave radiation been emitted by the Earth
  ➔ reduces net energy heating to the Earth system
  ➔ cools down the global temperature
  ➔ a negative feedback

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Cloud Feedback

Cloud Radiative Forcing as Estimated from Satellite Measurements

	Average	Cloud-free	Cloud forcing
OLR	234	266	+31
Absorbed solar radiation	239	288	−48
Net radiation	+5	+22	−17
Albedo	30%	15%	+15%

Radiative flux densities are given in W m^{-2} and albedo in percent. [From Harrison *et al*. (1990), © American Geophysical Union.]

- Clouds affect both solar radiation and terrestrial (longwave) radiation.
- Typically, clouds increase albedo ➔ a cooling effect (negative feedback)
  clouds reduce outgoing longwave radiation ➔ a heating effect (positive feedback)
- The net effect of clouds on climate depends cloud types and their optical properties, the insolation, and the characteristics of the underlying surface.
- In general, high clouds tend to produce a heating (positive) feedback. Low clouds tend to produce a cooling (negative) feedback.

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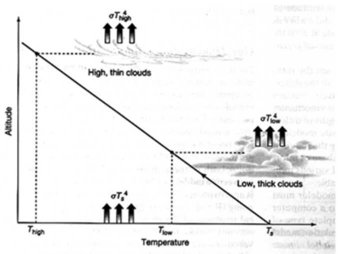
Important Roles of Clouds In Global Climate



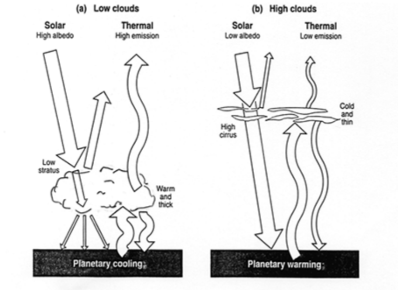


Figure 11.13 The effects of clouds on the flow of radiation and energy in the lower atmosphere and at the surface. Two cases are shown: (a) low clouds, with a high solar albedo and high thermal emission temperature; and (b) high clouds, with a low solar albedo and low thermal emission temperature. The solar components are shown as straight arrows, and the infrared components, as curved arrows. The relative thicknesses of the arrows indicate the relative radiation intensities. The expected impact on surface temperature in each situation is noted along the bottom strip.

- ❑ Longwave radiation feedback is ______ feedback.

(a) Positive (b) negative