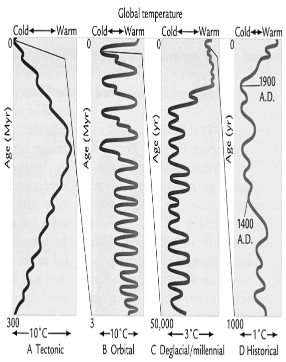
Climate System Change - Outline



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

- ❑ Climate Sensitivity and Feedback
- ❑ Tectonic-Scale Climate Changes
- ❑ Orbital-Scale Climate Changes
- ❑ Deglacial and Millennial Climate Changes
- ❑ Historical Climate Change
- ❑ Anthropogenic Climate Changes

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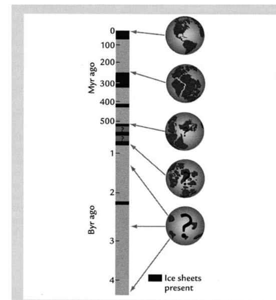
Tectonic Scale



Past glaciations and continental positions. During Earth's 4.55-billion-year history, intervals when large continental ice sheets were present alternated with times when they were not (left). The earliest history of these changes is poorly defined because few ancient records are preserved. The movements of continents in relation to ocean basins are well known only for the last several hundred million years (right). (Globes adapted from D. Merritts et al., *Environmental Geology*, © 1997 by W. H. Freeman and Company.)

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

- ❑ Tectonic Scale: the longest time scale of climate change on Earth, which encompasses most of Earth's 4.55-billion years of history.
- ❑ Tectonic processes driven by Earth's internal heat alter Earth's geography and affect climate over intervals of millions of years.
- ❑ On this time scale, Earth's climate has oscillated between times when ice sheets were presented somewhere on Earth (such as today) and times when no ice sheets were presented.

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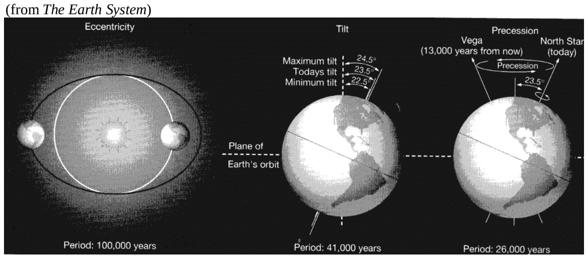
Orbital Scale

(from *The Earth System*)



- ❑ Orbital-scale climate changes are caused by subtle shifts in Earth's orbit.
- ❑ Three features of Earth's orbit around the Sun have changed over time:
  (1) the tilt of Earth's axis,
  (2) the shape of its yearly path of revolution around the Sun
  (3) the changing positions of the seasons along the path.
- ❑ Orbital-scale climate changes have typical cycles from 20,000 to 400,000 years.

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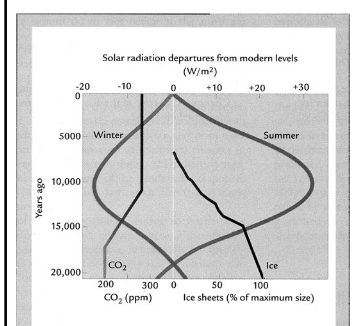
Deglacial and Millenial Scales



Deglacial climatic forcing For the past 21,000 years, model experiments based on known climatic forcing (insolation, ice sheets, and CO_2) can be compared with observations from the geologic record. (Adapted from J. E. Kutzbach et al., "Climate and Biome Simulations for the Past 21,000 Years," *Quaternary Science Reviews* 17 [1998]: 473–506.)

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

- ❑ Climate changes of these scales in the past several tens of thousands of years occurred within the time span of recorded human civilization.
- ❑ These change can be resolved by ^{14}C-dated records.
- ❑ The major boundary conditions that have driven climate changes during the last 21,000 years have been the changes in:
  (1) size of ice sheet
  (2) seasonal insolation
  (3) level of greenhouse gases in the atmosphere.

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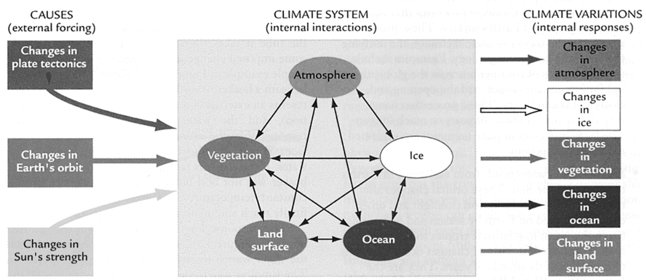
Climate Sensitivity and Feedback



(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.

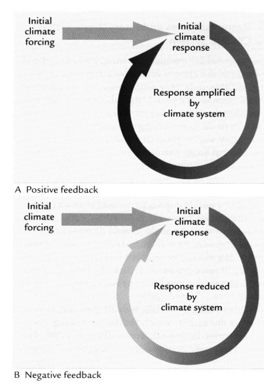
Direct Impact and Feedback Process

dS_0

- direct impact (change) on T_s → $\frac{\partial T_s}{\partial S_0}$
- $\frac{dq}{dS_0}$: changes in water vapor amount (q) → q *affects* T_s through greenhouse effect → $\frac{\partial T_s}{\partial q}$
- $\frac{dv}{dS_0}$: changes in circulation (v) → v *affects* T_s through heat transport → $\frac{\partial T_s}{\partial v}$

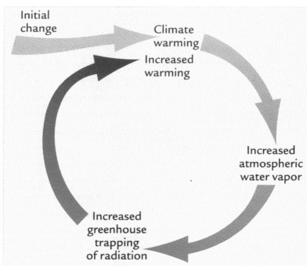
$$\frac{dT_s}{dS_0} = \frac{\partial T_s}{\partial S_0} + \frac{\partial T_s}{\partial q} \times \frac{dq}{dS_0} + \frac{\partial T_s}{\partial v} \times \frac{dv}{dS_0}$$

Major Climate Feedback Processes



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

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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Snow/Ice Albedo Feedback

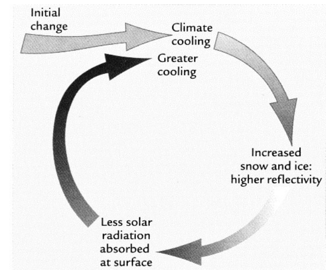

TABLE 2-1 Average Albedo Range of Earth's Surfaces

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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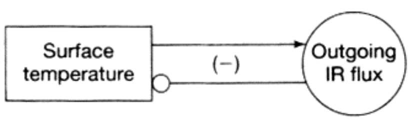
Longwave Radiation Feedback



- ❑ 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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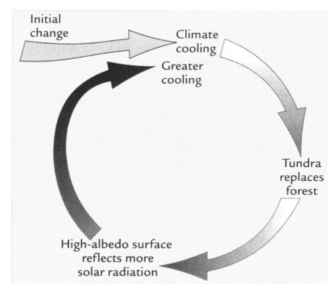
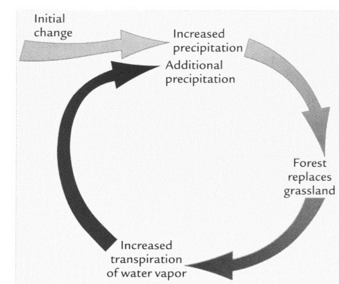
Vegetation-Climate Feedbacks



A Vegetation–albedo feedback



B Vegetation–precipitation feedback

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

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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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