Earth System Climate (ESS200A)

- Course Time

  Lectures: Tu, Th 9:30-10:20
  Discussion: 3315 Croul Hall

- Text Book

  The Earth System, Kump, Kasting, and Crane, Prentice-Hall

  Global Physical Climatology, Hartmann; Academic Press

- Grade

  Homework (40%), Final (60%)

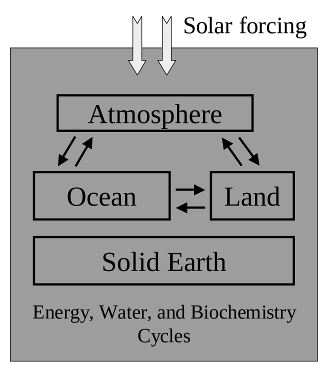
- Homework

  Issued and due every Thursday

Course Description

A general description of the Earth climate system and its subcomponents: the atmosphere, ocean, land surface, ice, and solid earth.

Course Outline: Climate System



Syllabus

Week 1-2: Atmosphere (Chapters 3 and 4)
Global Energy Cycle
Basic Structure and Dynamics
General Circulation in the Troposphere
General Circulation in the Stratosphere

Week 3: Ocean (Chapter 5)
Basic Structure and Dynamics
Surface Ocean Circulation: Wind-Driven
Deep Ocean Circulation: Density-Driven

Week 4: land surface and Cryosphere (Handout)
Land Surface Properties (Soil and Vegetation)
Surface Energy and Water Balance
Sea Ice and Land Ice
Climate Roles of Land Surface and Ice

Week 4: Solid Earth (Chapter 6)
Internal Structure of the Solid Earth
Theory of Plate Tectonics
History of Plate Tectonics

Week 5 – Climate Change and Variation (Chapters 8, 12, and 14)
Past Climate Change
El Nino Southern Oscillation
Ozone Hole

***** FINAL *****

ATMOSPHERE (Outline)

- ❑ Global Energy Balance
- ❑ Basic Dynamics
- ❑ General Circulation in the Troposphere
- ❑ General Circulation in the Stratosphere
- ❑ Climate Variability in the Troposphere and Stratosphere
- ❑ Climate Feedback Processes in the Atmosphere

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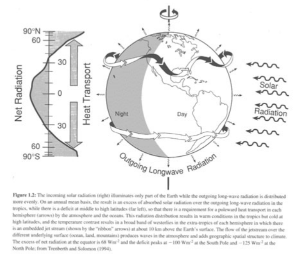
Global Energy Cycle



(from *Climate Change 1995*)

- **Planetary energy balance**

  Energy absorbed by Earth = Energy emitted by Earth
- **Role of the atmosphere**

  Greenhouse effect
- **Role of oceans**

  Polarward energy transport
- **Role of land surface**

  not significant due to its low heat capacity

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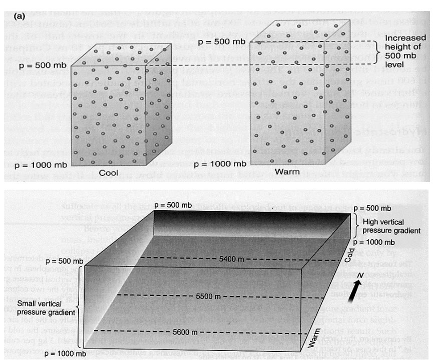
Temperature and Pressure



(from *Weather & Climate*)

- Hydrostatic balance tells us that the pressure decrease with height is determined by the temperature inside the vertical column.
- Pressure decreases faster in the cold-air column and slower in the warm-air column.
- Pressure drops more rapidly with height at high latitudes and lowers the height of the pressure surface.

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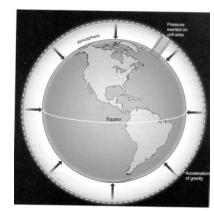
Thermal Energy to Kinetic Energy



cold

warm

H (high pressure)

pressure gradient force

L (low pressure)

(on a horizontal surface)

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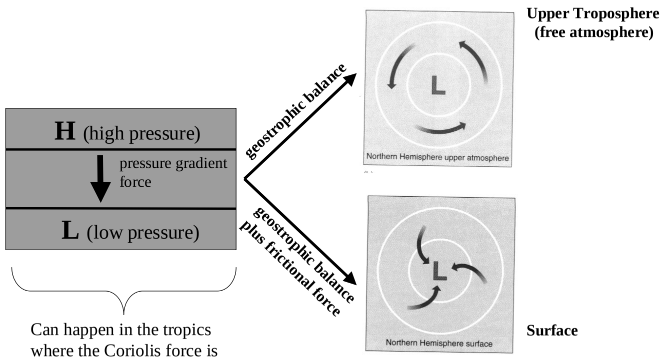
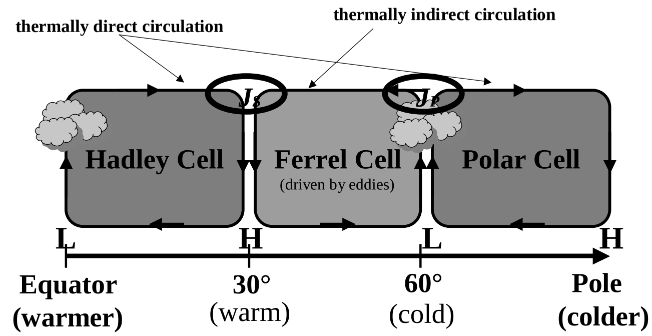
Balance of Force in the Horizontal



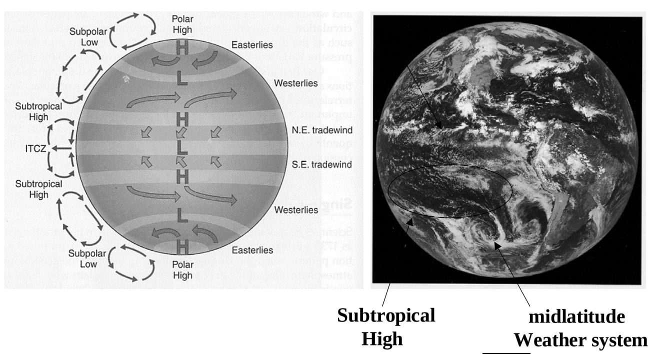
Can happen in the tropics where the Coriolis force is small.

(from *Weather & Climate*)

Properties of the Three Cells

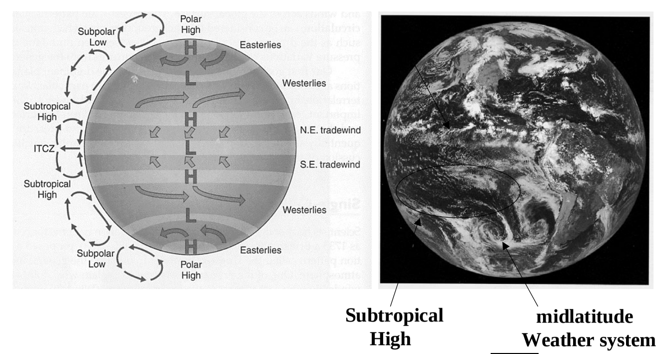


The Three Cells



(Figures from *Understanding Weather & Climate* and *The Earth System*)

The Three Cells



(Figures from *Understanding Weather & Climate* and *The Earth System*)

Global Distribution of Deserts

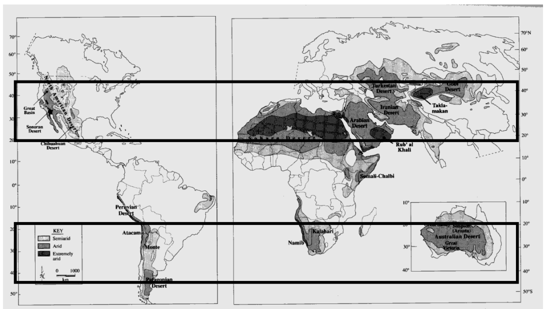


Fig. 6.21 Map showing arid lands around the world. Meigs classification taken from *Mosaic* magazine (Vol. 8, Jan/Feb 1977). [See McGinnies *et al.*, eds., (1968). Permission granted by the Office of Arid Lands Studies.]

(from *Global Physical Climatology*)

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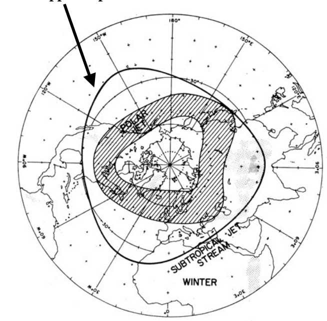
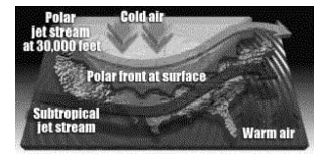
Jet Streams Near the Western US

Pineapple Express





- ❑ Both the polar and subtropical jet streams can affect weather and climate in the western US (such as California).
- ❑ El Nino can affect western US climate by changing the locations and strengths of these two jet streams.

(from *Riehl (1962), Palmen and Newton (1969)*)

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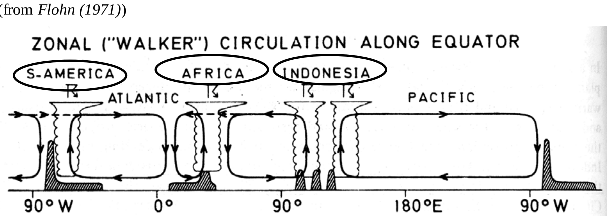
East-West Circulation

(from *Flohn (1971)*)



❑ The east-west circulation in the atmosphere is related to the sea/land distribution on the Earth.

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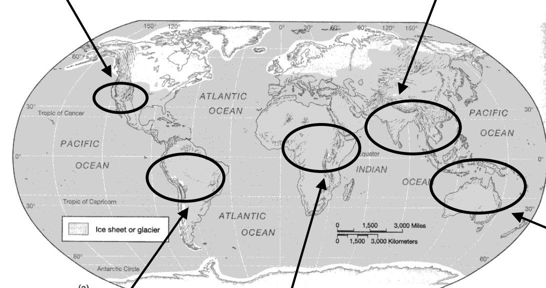
How Many Monsoons Worldwide?

North America Monsoon

Asian Monsoon



Australian Monsoon

South America Monsoon

East Africa Monsoon

(figure from *Weather & Climate*)

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Stratosphere: Circulation and Temperature

Zonal Wind

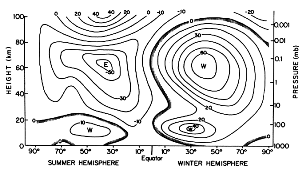


Fig. 1.4. Schematic latitude-height section of zonal mean zonal wind ($m\,s^{-1}$) for solstice conditions; W and E designate centers of westerly (from the west) and easterly (from the east) winds, respectively. (Courtesy of R. J. Reed.)

Temperature

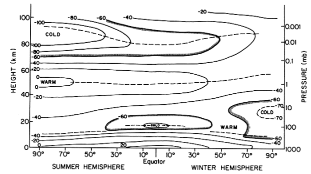
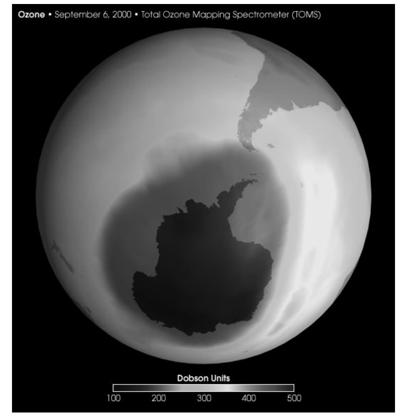


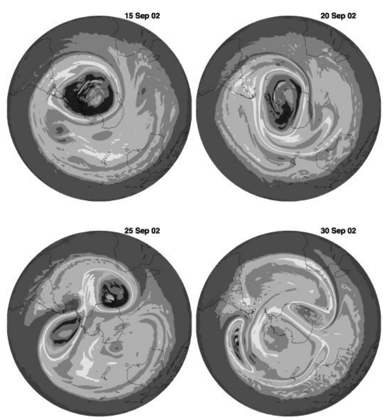
Fig. 1.3. Schematic latitude-height section of zonal mean temperatures (°C) for solstice conditions. Dashed lines indicate tropopause, stratopause, and mesopause levels. (Courtesy of R. J. Reed.)

Satellite View of the Ozone Hole



September 6, 2000

Stratospheric Sudden Warming

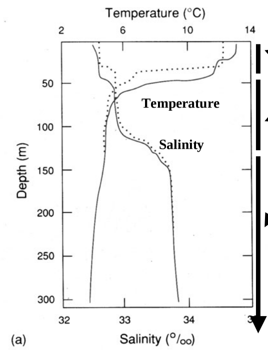


- ❑ Every other year or so the normal winter pattern of a cold polar stratosphere with a westerly vortex is interrupted in the middle winter.
- ❑ The polar vortex can completely disappear for a period of a few weeks.
- ❑ During the sudden warming period, the stratospheric temperatures can rise as much as 40°K in a few days!

Oceans - Outline

- ❑ Basic Dynamics
  - From atmospheric winds to oceanic currents
  - Ekman transport
  - Geostrophic Currents
- ❑ Surface Ocean Circulation: Wind-Driven
  - Subtropicl gyre
  - Boundary current
- ❑ Deep Ocean Circulation: Density-Driven
  - Thermohaline conveyor belt

Subcomponent: Global Oceans



Mixed Layer: T and S well mixed by winds

Thermocline: large gradient of T and S

Deep Ocean: T and S independent of height

(from Climate System Modeling)

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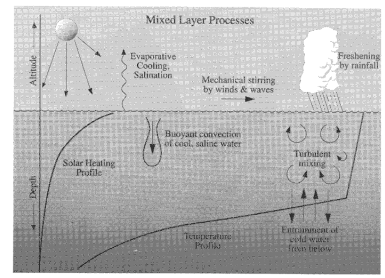
Mixed Layer Processes



(from *Global Physical Climatology*)

- ❑ The depth of the mixed layer is determined by (1) the rate of buoyancy generation and (2) the rate kinetic energy supply.

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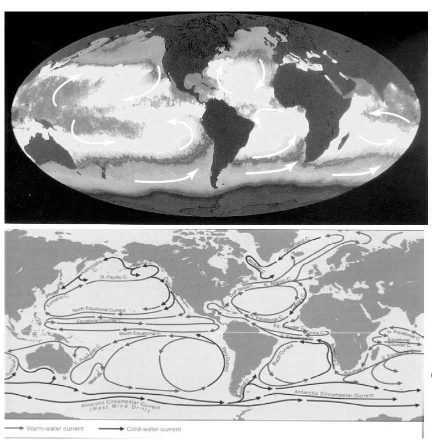
Six Great Current Circuits in the World Ocean



- ❑ **5 of them are geostrophic gyres:**
  - North Pacific Gyre
  - South Pacific Gyre
  - North Atlantic Gyre
  - South Atlantic Gyre
  - Indian Ocean Gyre
- ❑ **The 6th and the largest current:**
  - Antarctic Circumpolr Current
  - (also called West Wind Drift)

(Figure from *Oceanography* by Tom Garrison)

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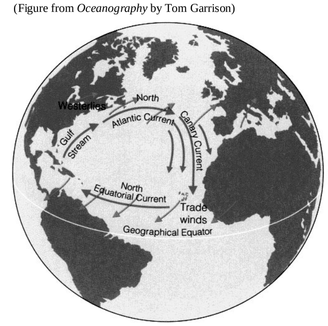
Characteristics of the Gyres

(Figure from *Oceanography* by Tom Garrison)



Volume transport unit:
1 sv = 1 Sverdrup = 1 million m^3/sec
(the Amazon river has a transport of ~0.17 Sv)

- ❑ **Currents are in geostropic balance**
- ❑ **Each gyre includes 4 current components:**
  - two boundary currents: western and eastern
  - two transverse currents: easteward and westward

Western boundary current (jet stream of ocean)
the fast, deep, and narrow current moves **warm** water polarward (transport ~50 Sv or greater)

Eastern boundary current
the slow, shallow, and broad current moves cold water equatorward (transport ~ 10-15 Sv)

Trade wind-driven current
the moderately shallow and broad westward current (transport ~ 30 Sv)

Westerly-driven current
the wider and slower (than the trade wind-driven current) eastward current

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Step 1: Surface Winds

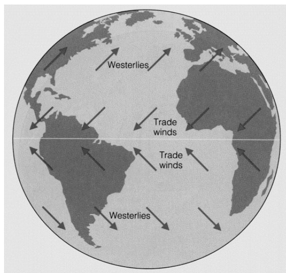


Figure 9.1 Winds, driven by uneven solar heating and Earth's spin, drive the movement of the ocean's surface currents. The prime movers are the powerful westerlies and the persistent trade winds (easterlies).

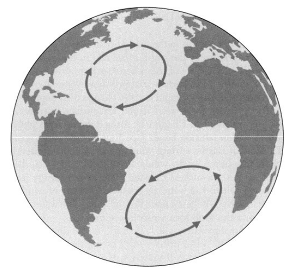
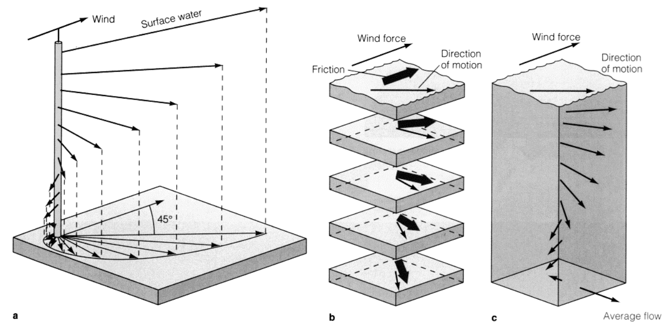


Figure 9.2 A combination of four forces—surface winds, the sun's heat, the Coriolis effect, and gravity—circulates the ocean surface clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere, forming gyres.

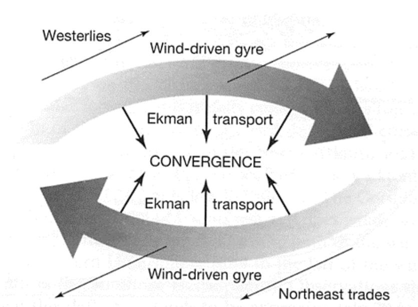
(Figure from *Oceanography* by Tom Garrison)

Step 2: Ekman Layer
(frictional force + Coriolis Force)



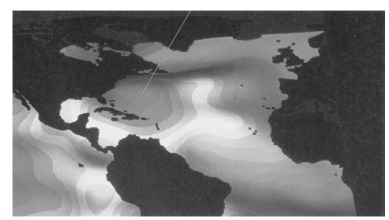
(Figure from *Oceanography* by Tom Garrison)

Ekman Transport

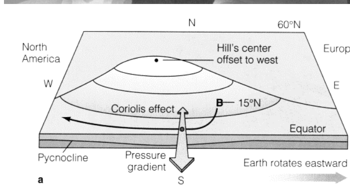


(Figure from *The Earth System*)

Step 3: Geostrophic Current
(Pressure Gradient Force + Corioils Foce)

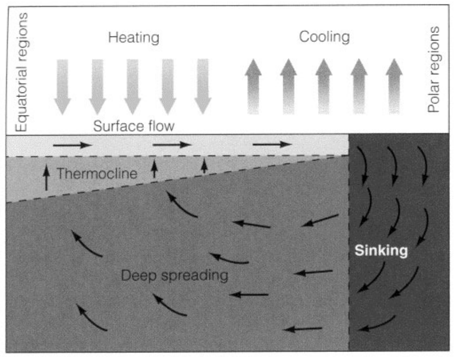


NASA-TOPEX Observations of Sea-Level Hight



(from *Oceanography* by Tom Garrison)

Thermohaline Circulation



(Figure from *Oceanography* by Tom Garrison)

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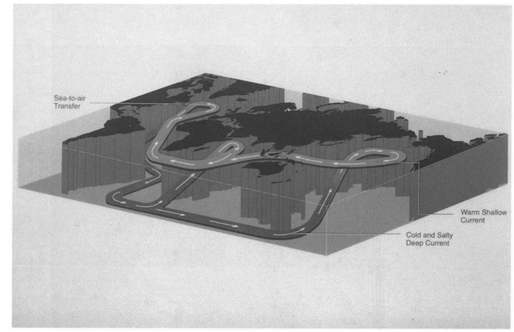
Thermohaline Conveyor Belt



(Figure from *Climate System Modeling*)

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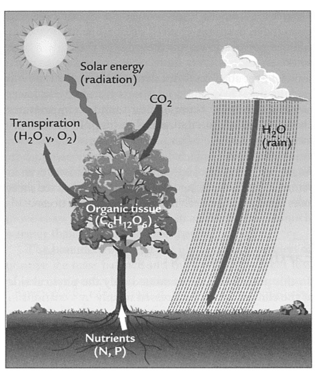
Land Surface - Outline



(from *Our Changing Planet*)

- ❑ Climate Role
- ❑ Surface Energy Balance
- ❑ Surface Water Balance
- ❑ Vegetation (Canopy)
- ❑ Soil (moisture)

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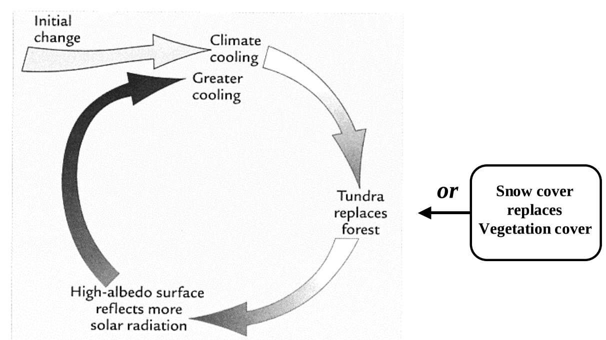
Climate Role 1: Albedo ➔ Energy Cycle



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

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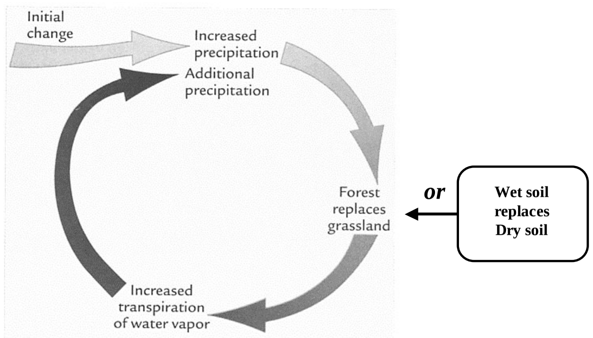
Climate Role 2: Transpiration ➔ Water Cycle



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

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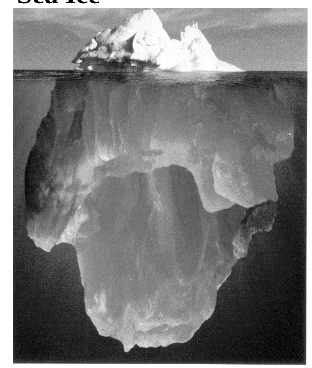
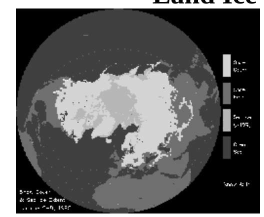
Cryosphere – Outline

Sea Ice



(from *The Blue Planet*)

Land Ice



- ❑ The cryosphere is referred to all the ice near the surface of Earth: including sea ice and land ice.
- ❑ For climate, it is the surface (rather than the mass) of ice that is of primary importance.

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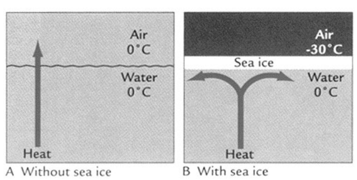
Why is Ice Important to Climate?



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

- ❑ Surface ice of any depth is a much more effective reflector of solar radiation than the underlying surface.
- ❑ Sea ice is a good insulator and allows air temperature to be very different from that of the seawater under the ice.
- ❑ At present, year-round ice covers 11% of the land area and 7% of the world ocean.

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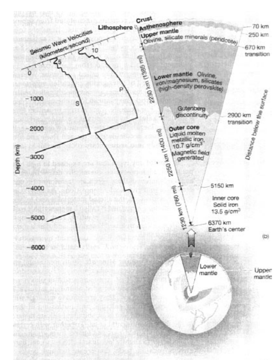
Solid Earth - Outline



(from *The Earth System*)

- ❑ Internal Structure of the Solid Earth
- ❑ Theory of Plate Tectonics
- ❑ History of Plate Tectonics

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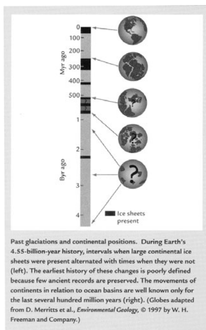
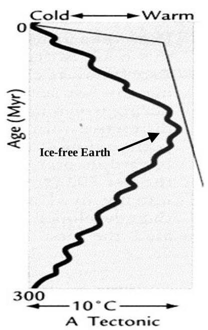
Tectonic-Scale Climate Change





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

- The faint young Sun paradox and its possible explanation.
- Why was Earth ice-free even at the poles 100 Myr ago (the Mesozoic Era)?
- What are the causes and climate effects of changes in sea level through time?
- What caused Earth's climate to cool over the last 55 Myr (the Cenozoic Era)?

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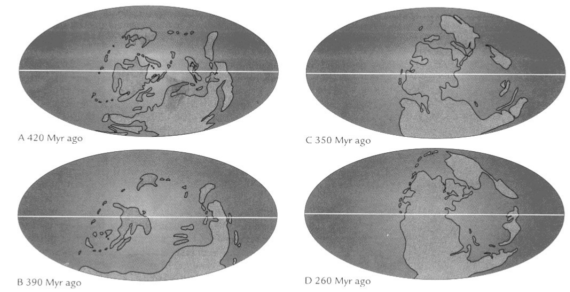
History of Plate Tectonics



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

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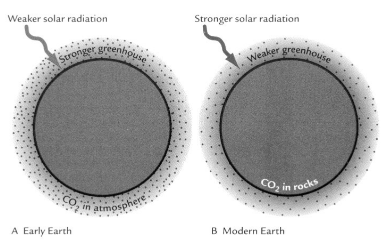
Earth's Thermostat – Chemical Weathering



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

- Chemical weathering acts as Earth's thermostat and regulate its long-term climate.
- This thermostat mechanism lies in two facts:
  (1) the average global rate of chemical weathering depends on the state of Earth's climate,
  (2) weathering also has the capacity to alter that state by regulating the rate which CO_2 is removed from the atmosphere.

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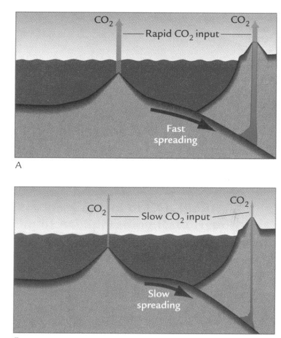
Tectonic Control of CO_2 *Input* – The Seafloor Spreading Rate Hypothesis



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

- During active plate tectonic processes, carbon cycles constantly between Earth's interior and its surface.
- The carbon moves from deep rock reservoirs to the surface mainly as CO_2 gas associated with volcanic activity along the margins of Earth's tectonic plates.
- The centerpiece of the seafloor spreading hypothesis is the concept that changes in the rate of seafloor spreading over millions of years control the rate of delivery of CO_2 to the atmosphere from the large rock reservoir of carbon, with the resulting changes in atmospheric CO_2 concentrations controlling Earth's climate.

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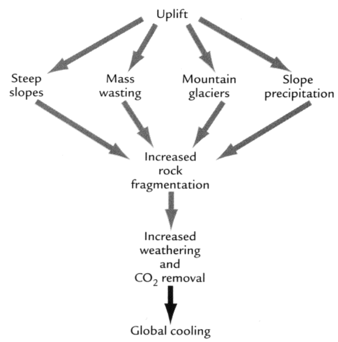
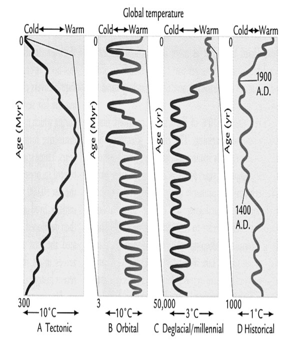
Tectonic Control of CO_2 *Removal* – The Uplift Weathering Hypothesis



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

- The uplifting weathering hypothesis asserts that the global mean rate of chemical weathering is heavily affected by the availability of fresh rock and mineral surfaces that the weathering process can attack.
- This hypothesis suggests that tectonic uplifting enhances the exposure of freshly fragmented rock which is an important factor in the intensity of chemical weathering.
- This hypothesis looks at chemical weathering as the active driver of climate change, rather than as a negative feedback that moderates climate changes.

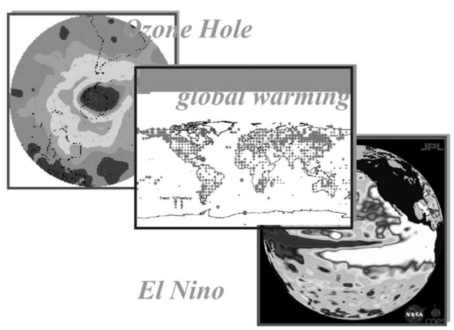
Climate Change and Variation - Outline



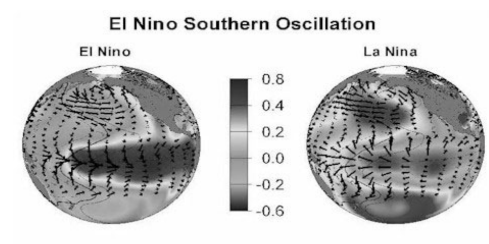
(from *Earth's Climate: Past and Future*)

- Climate Sensitivity and Feedback
- Past Climate Change
- El Nino-Southern Oscillation
- Ozone Depletion

CONCERN ON THE EARTH

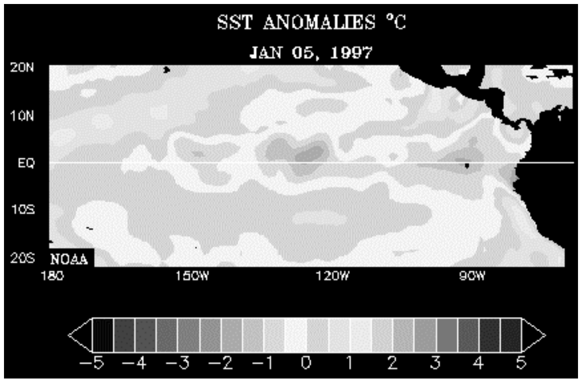


El Nino-Southern Oscillation (ENSO)



- ENSO is a interannual (year-to-year) climate variability in the eastern tropical Pacific Ocean.
- ENSO is found to have profound impacts on global climate.

1997-98 El Nino



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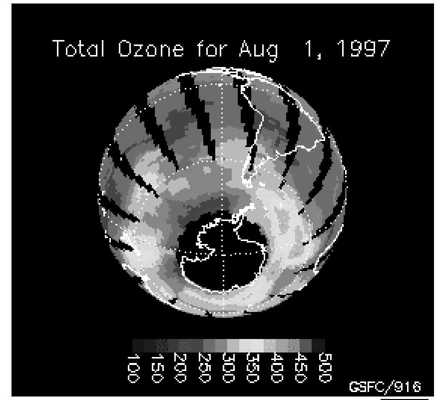
The 1997 Ozone Hole



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