Earth System Climatology (ESS200A)

- ## Course Time

  Lectures: Tu, Th 9:00-10:20

  Discussion: 3315 Croul Hall

- ## Text Book

  The Earth System, 2^{nd} Edition, Kump, Kasting, and Crane, Prentice-Hall

  Global Physical Climatology, Hartmann; Academic Press

  Meteorology Today, 7^{th} Edition, Ahrens, Brooks Cool.

- ## Grade

  Homework (40%), Final (60%)

- ## Homework

  Issued and due every Thursday

ESS 200A: Earth System Climatology (Fall 2005)

Lecture: Tuesday & Thursday 9:00-10:20, Croul Hall 1103
Discussion: 3315 Croul Hall

INSTRUCTOR

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DESCRIPTION

An introduction to the earth climate system and its subsystems. Understanding factors influencing climate including interactions among the atmosphere, oceans, and land surface processes. Sensitivity and feedback mechanisms of climate system.

TEXTBOOKS

- Lee R. Kump, James F. Kasting, Robert G. Crane, **"The Earth System"**, Prentice Hall
- Hartmann, Dennis L., **"Global Physical Climatology"**, Academic Press, 1994.
- **C. Donald Ahrens, "Meteorology Today", Seventh Edition, Brooks Cole, 2003.**

SYLLABUS

Week 1: Global Energy Balance

- Atmosphere Composition
- Planetary Energy Balance
- Greenhouse Effect
- Role of Cloud

[OVERVIEW] (powerpoint) (handout) ***Updated on 9/27/2005***
[CLASSNOTE #1] (powerpoint) (handout) ***Updated on 9/27/2005***

Suggested Reading:
The Earth System (Ch3);
Meteorology Today (Ch2); and
Global Physical Climatology (Ch2)

Week 2: Atmospheric General Circulation

Course Description

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

Syllabus

Week 1 - Global Energy Balance
Planetary Energy Balance
Greenhouse Effect
Atmospheric Composition and Structure
Role of Cloud

Week 2 - Atmospheric General Circulation
Hydrostatic Balance
General Circulation in the Troposphere
General Circulation in the Stratosphere
Jetstreams
Regional Circulation Systems

Week 2-3 - Weather
Air Masses and Fronts
Mid-Latitude Cyclones
Tropical Hurricane

Week 3-4: Ocean
Basic Structure and Dynamics
Surface Ocean Circulation: Wind-Driven
Deep Ocean Circulation: Density-Driven

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

Week 5 – Climate Change and Variation
Past Climate Change
Short-term Climate variation (ENSO, NAO)
Ozone Hole

***** FINAL (October 27, Thursday) *****

Global Energy Cycle

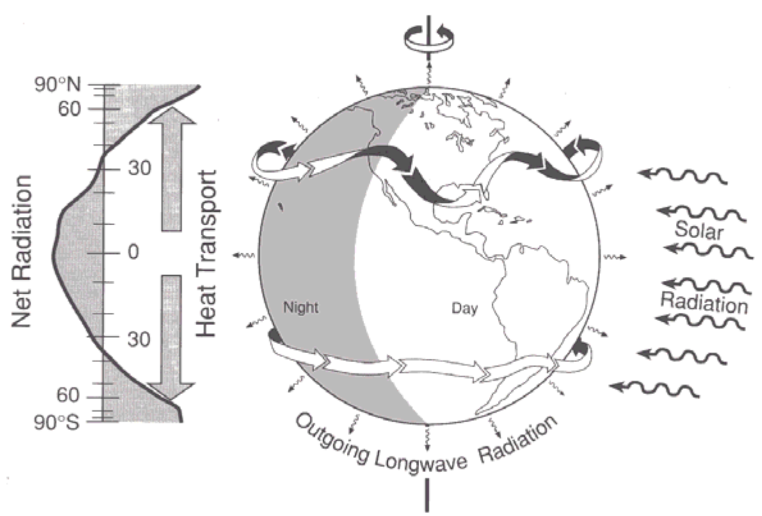


Figure 1.2: The incoming solar radiation (right) illuminates only part of the Earth while the outgoing long-wave radiation is distributed more evenly. On an annual mean basis, the result is an excess of absorbed solar radiation over the outgoing long-wave radiation in the tropics, while there is a deficit at middle to high latitudes (far left), so that there is a requirement for a poleward heat transport in each hemisphere (arrows) by the atmosphere and the oceans. This radiation distribution results in warm conditions in the tropics but cold at high latitudes, and the temperature contrast results in a broad band of westerlies in the extra-tropics of each hemisphere in which there is an embedded jet stream (shown by the "ribbon" arrows) at about 10 km above the Earth's surface. The flow of the jetstream over the different underlying surface (ocean, land, mountains) produces waves in the atmosphere and adds geographic spatial structure to climate. The excess of net radiation at the equator is 68 Wm^{-2} and the deficit peaks at −100 Wm^{-2} at the South Pole and −125 Wm^{-2} at the North Pole; from Trenberth and Solomon (1994).

(from *Climate Change 1995*)

- **Planetary energy balance**

  Energy absorbed by Earth = Energy emitted by Earth

- **Role of the atmosphere**

  Greenhouse effect

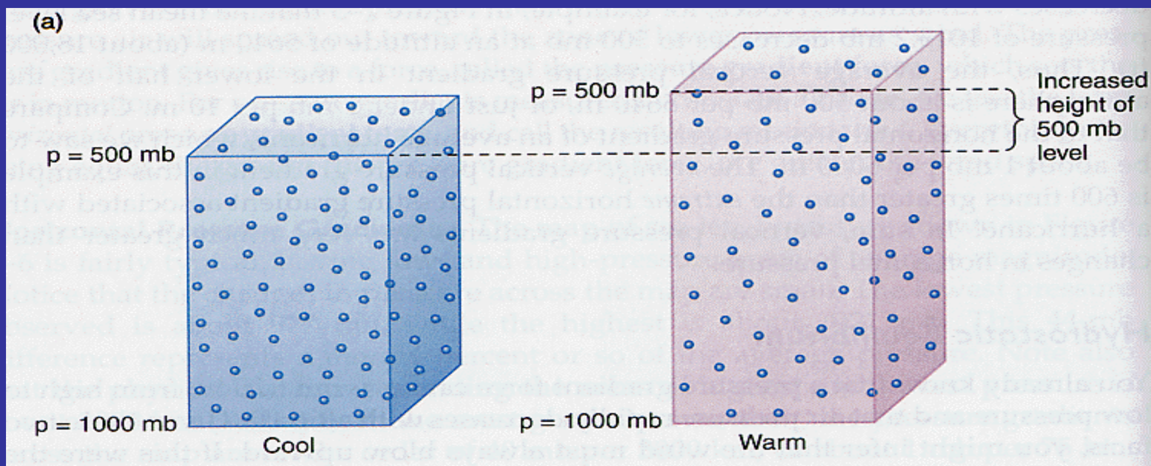
- **Role of oceans**

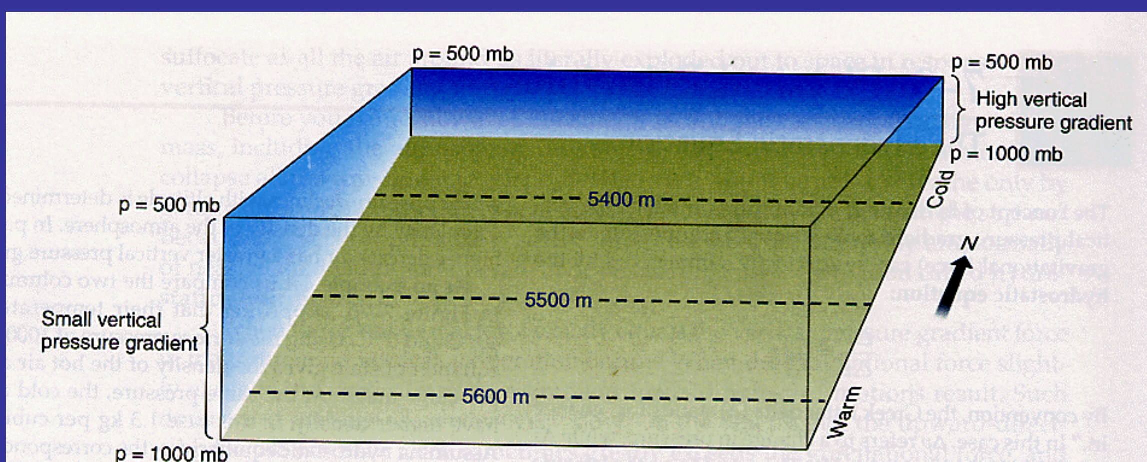
  Polarward energy transport

- **Role of land surface**

  not significant due to its low heat capacity

Hydrostatic Balance: Temperature and Pressure

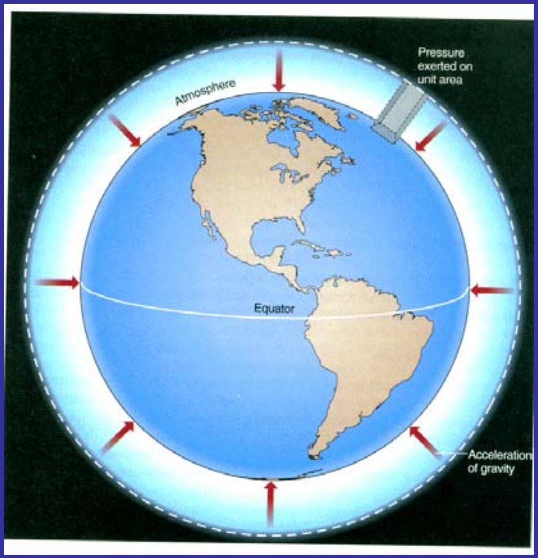




(from *Weather & Climate*)

- 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.

Thermal Energy to Kinetic Energy



cold

warm

H (high pressure)

pressure gradient force

L (low pressure)

(on a horizontal surface)

Balance of Force in the Horizontal

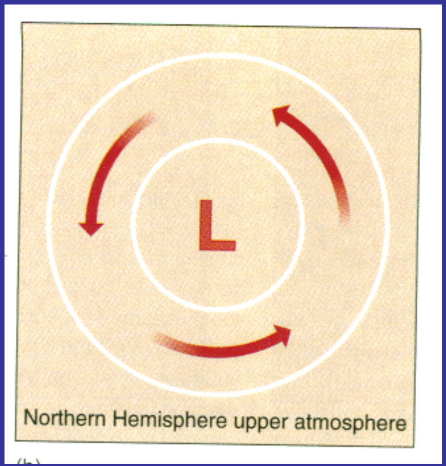
H (high pressure)

pressure gradient force

L (low pressure)

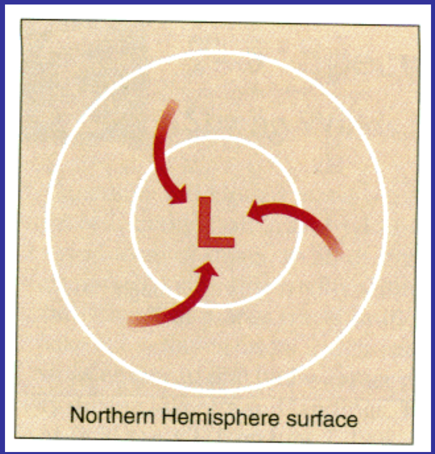
Can happen in the tropics where the Coriolis force is small.

geostrophic balance



Upper Troposphere (free atmosphere)

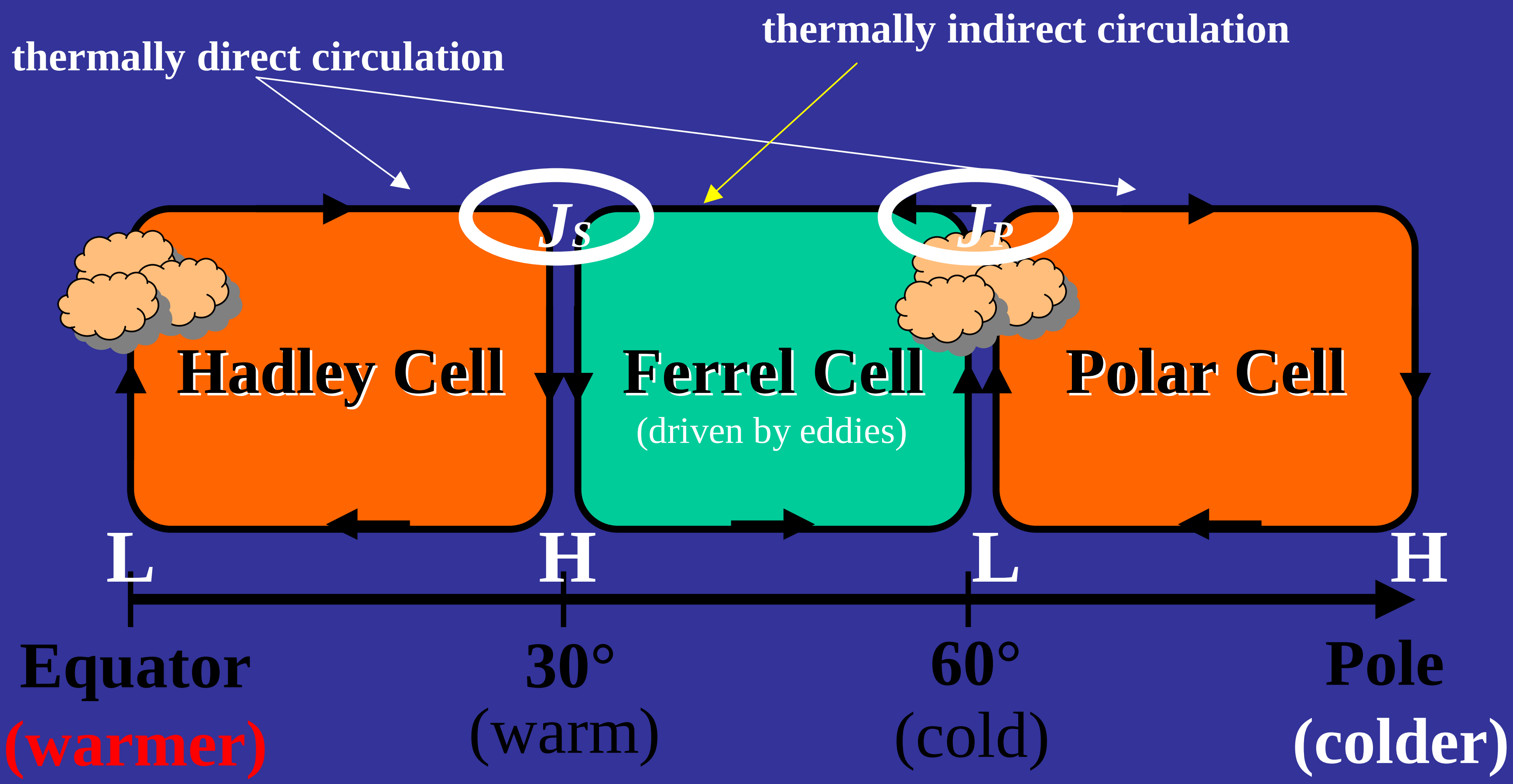
geostrophic balance plus frictional force



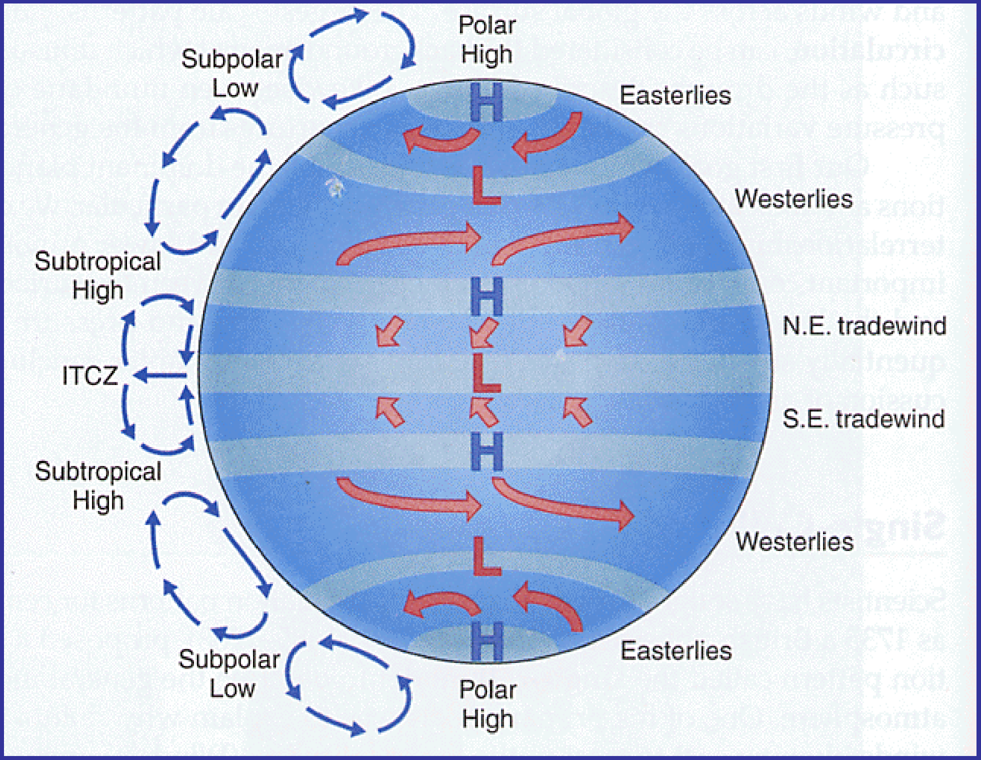
Surface

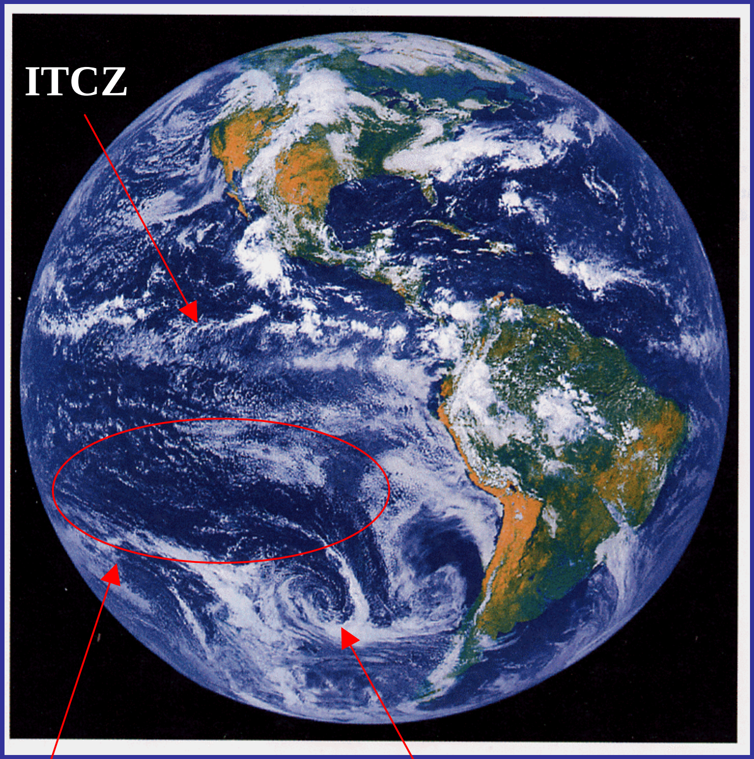
(from *Weather & Climate*)

Properties of the Three Cells



The Three Cells



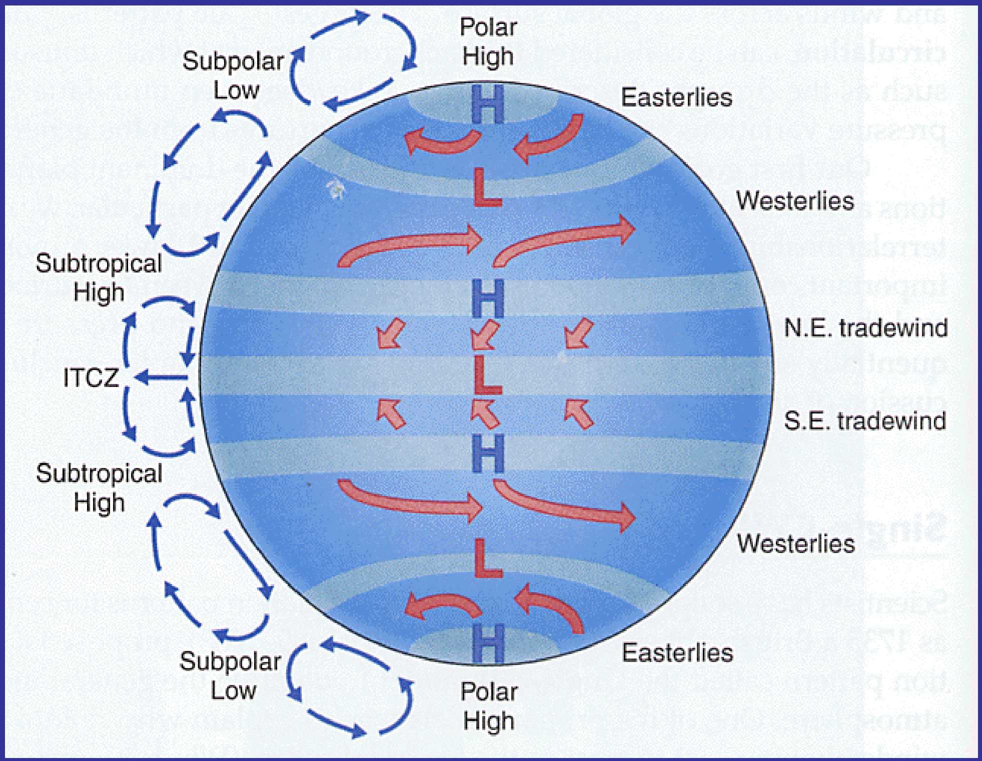


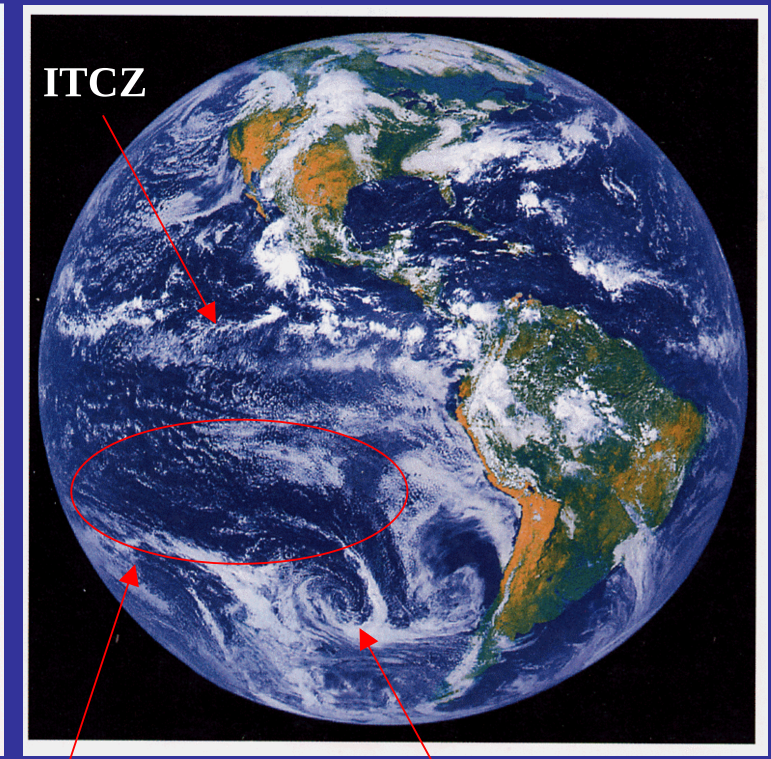
Subtropical High

midlatitude Weather system

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

The Three Cells





Subtropical High

midlatitude Weather system

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

Global Distribution of Deserts

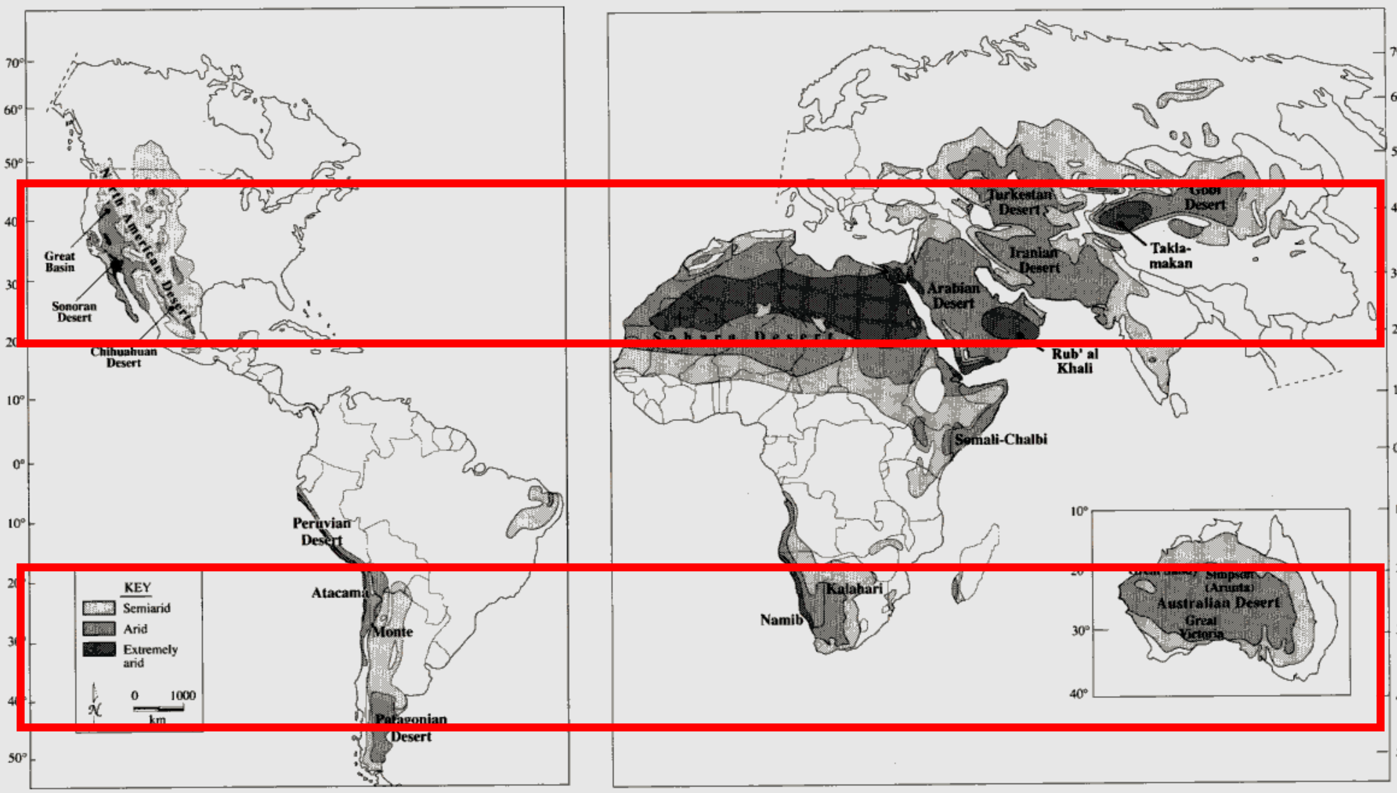
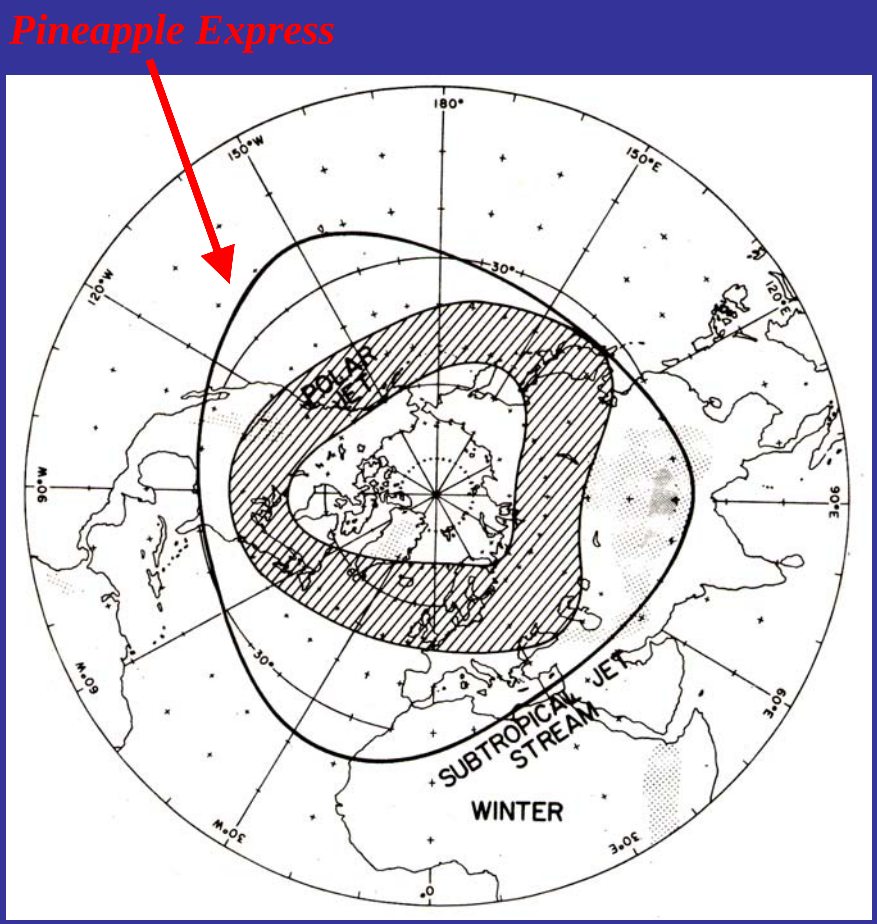


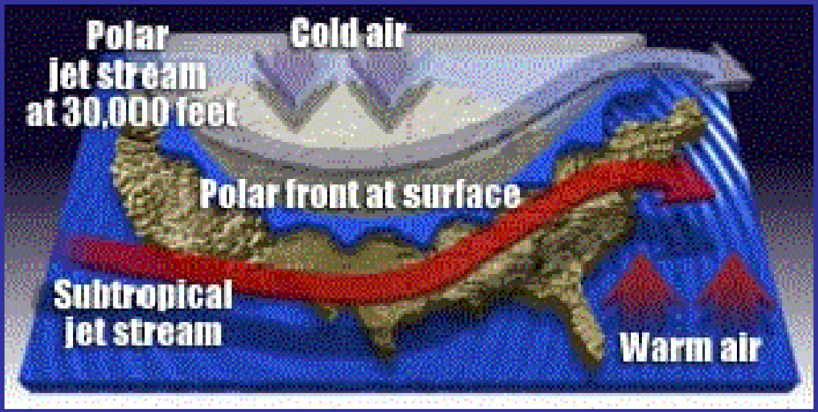
Fig. 6.21 Map showing arid lands around the world. Meigs classification taken from *Mosaic* magazine (Vol. 8, Jan/Feb 1977). [See McGinnies *et al.*, eds., (1968). Permission granted by the Office of Arid Lands Studies.]

(from *Global Physical Climatology*)

Jet Streams Near the Western US



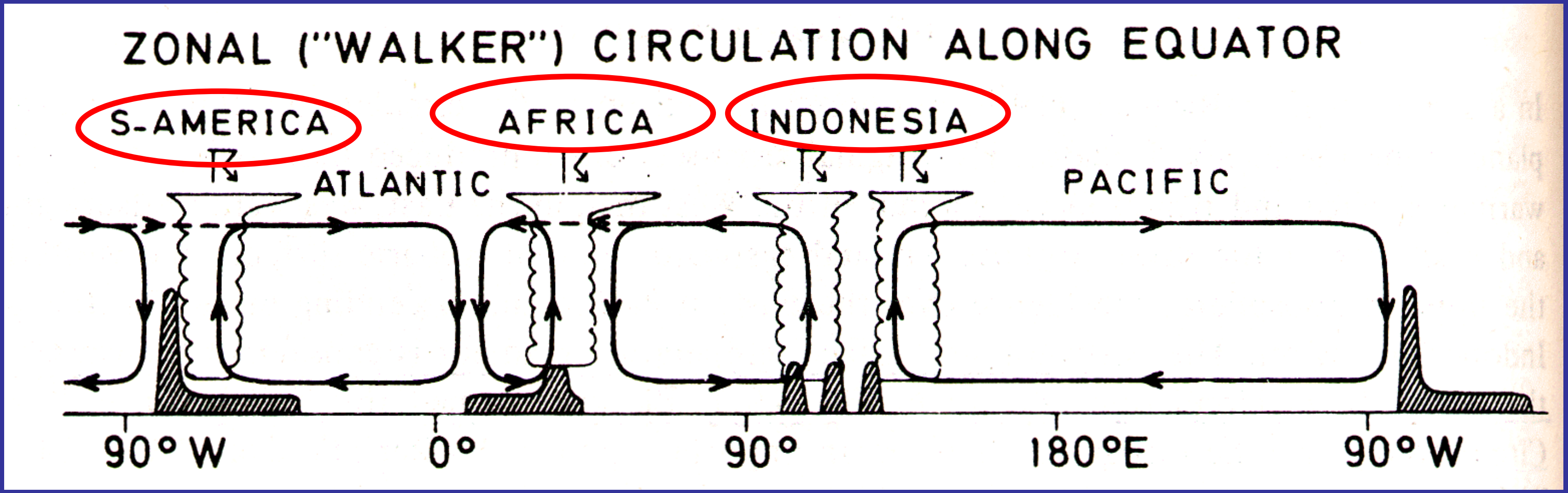
(from *Riehl (1962), Palmen and Newton (1969)*)



- ❑ 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.

East-West Circulation

(from *Flohn (1971)*)

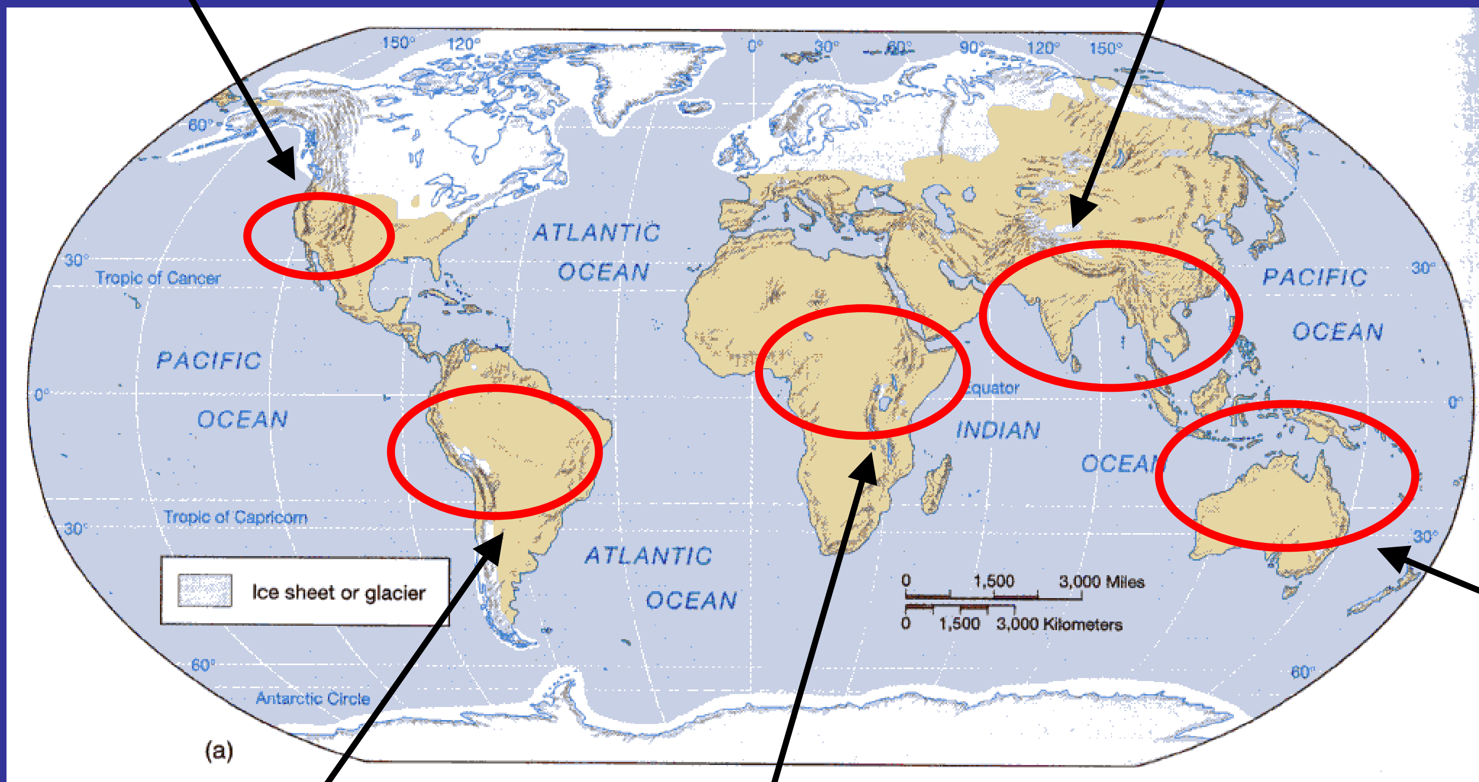


- The east-west circulation in the atmosphere is related to the sea/land distribution on the Earth.

How Many Monsoons Worldwide?

North America Monsoon

Asian Monsoon



Australian Monsoon

South America Monsoon

East Africa Monsoon

(figure from *Weather & Climate*)

Stratosphere: Circulation and Temperature

Zonal Wind

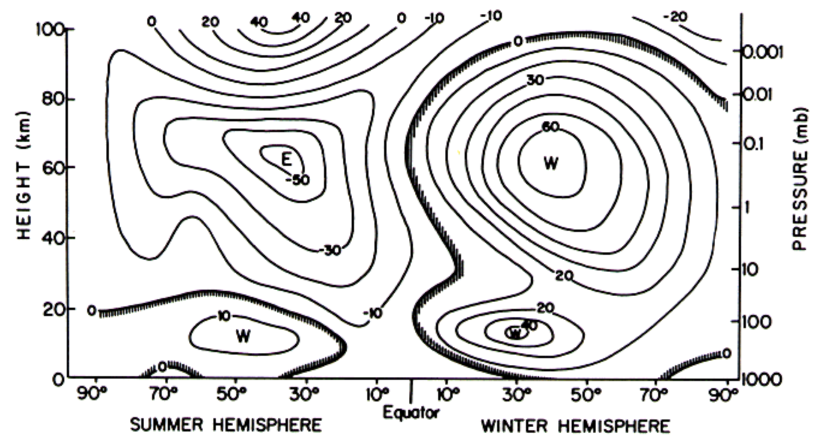


Fig. 1.4. Schematic latitude-height section of zonal mean zonal wind (m s^{-1}) for solstice conditions; W and E designate centers of westerly (from the west) and easterly (from the east) winds, respectively. (Courtesy of R. J. Reed.)

Temperature

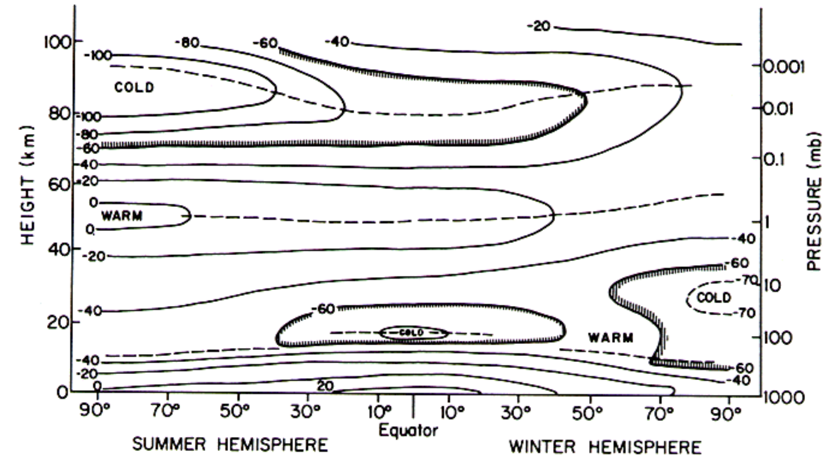
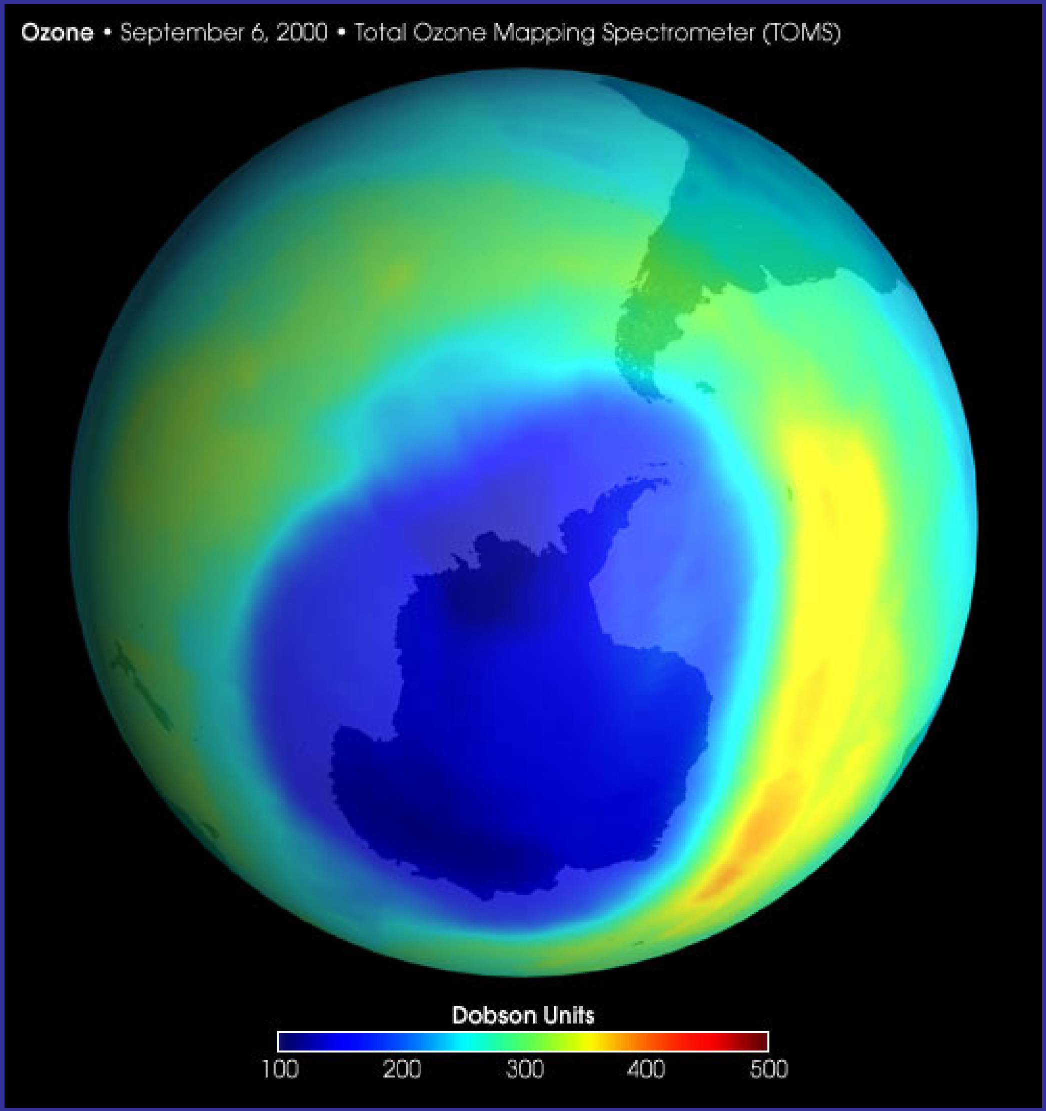


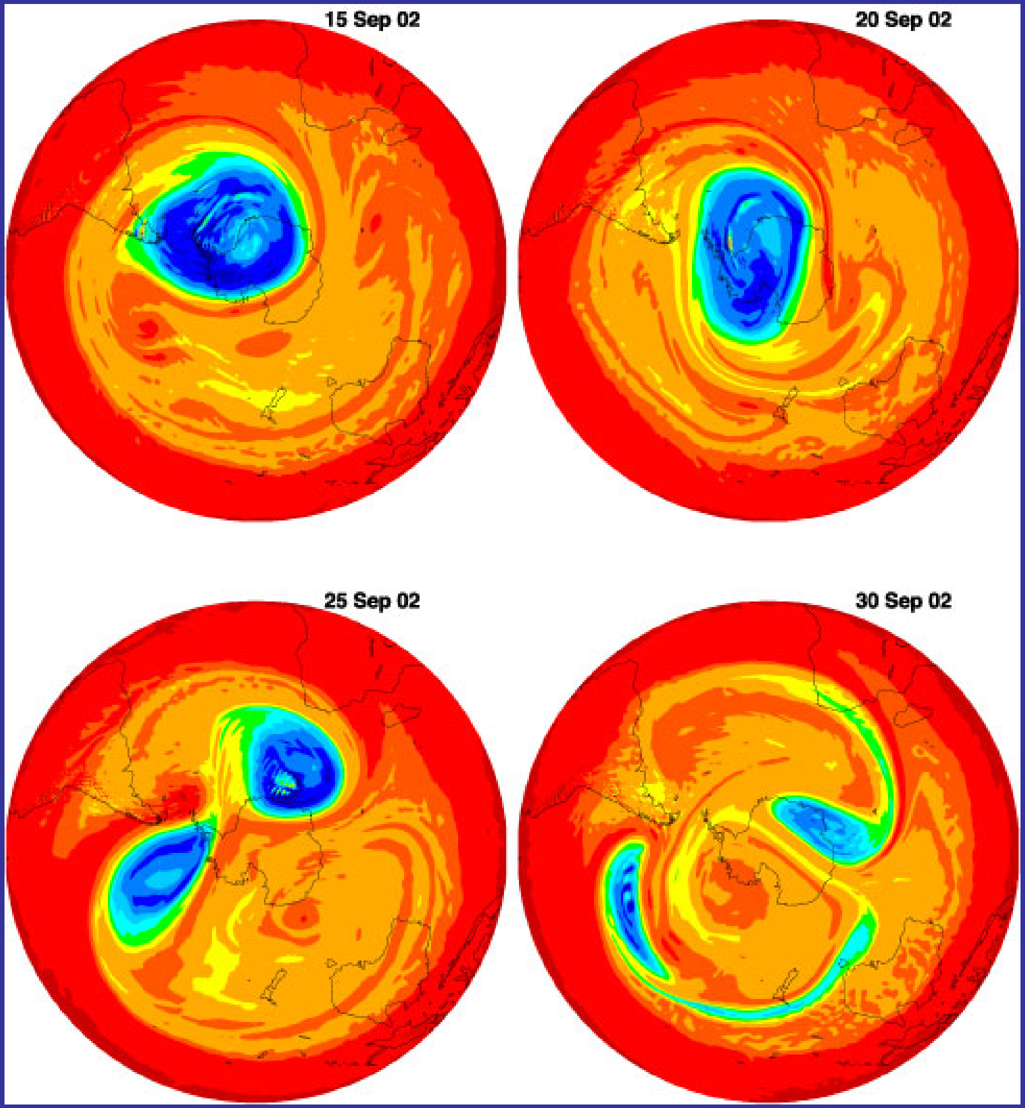
Fig. 1.3. Schematic latitude-height section of zonal mean temperatures (°C) for solstice conditions. Dashed lines indicate tropopause, stratopause, and mesopause levels. (Courtesy of R. J. Reed.)

Satellite View of the Ozone Hole



September 6, 2000

Stratospheric Sudden Warming

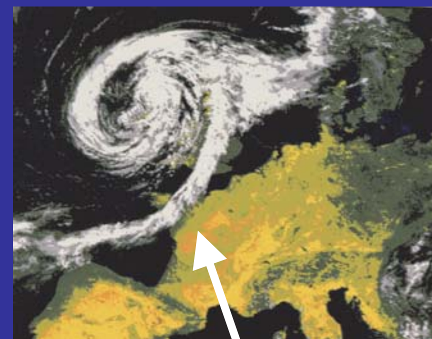


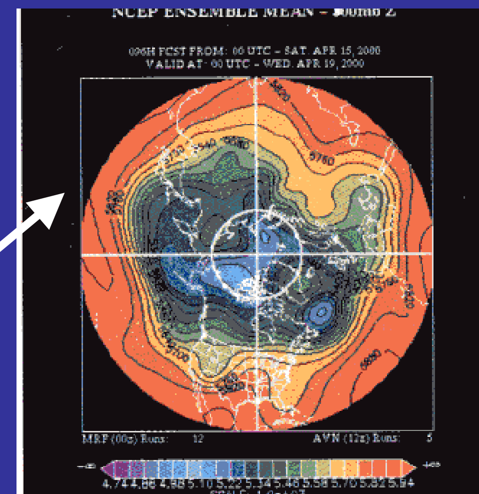
- Every other year or so the normal winter pattern of a cold polar stratosphere with a westerly vortex is interrupted in the middle winter.
- The polar vortex can completely disappear for a period of a few weeks.
- During the sudden warming period, the stratospheric temperatures can rise as much as 40°K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

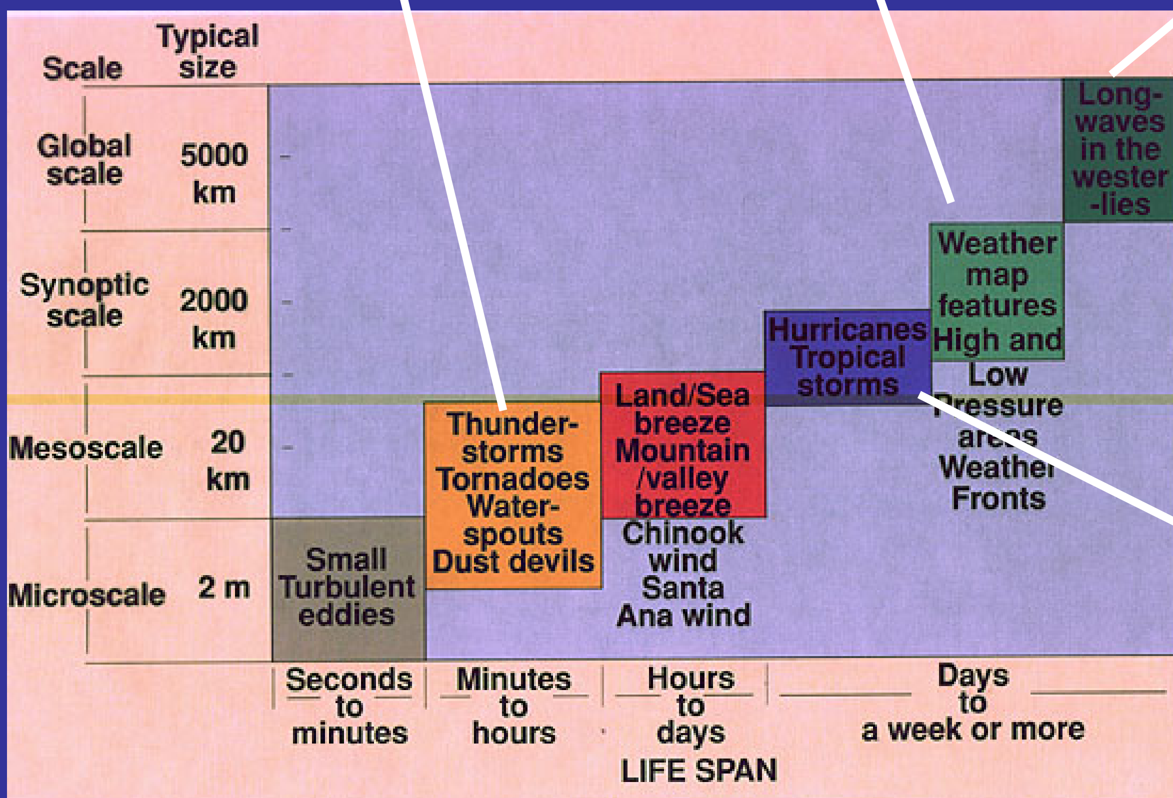
0 %

Loading

Scales of Motions in the Atmosphere





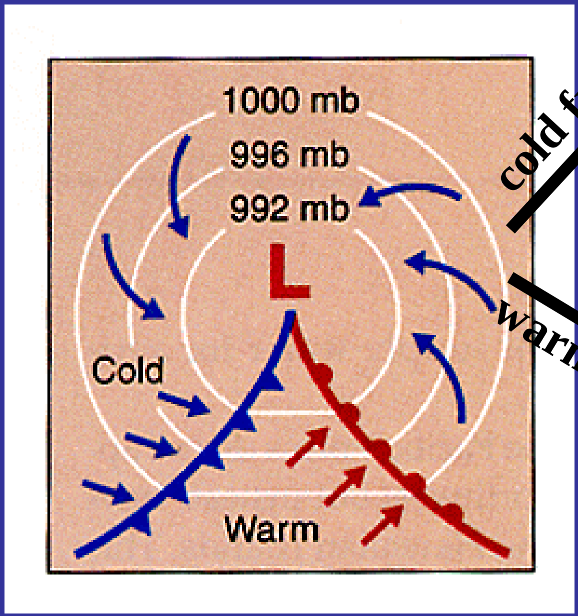


(from Meteorology Today by C. Donald Ahrens © 1994 West Publishing Company)

ESS200A
Prof. Jin-Yi Yu

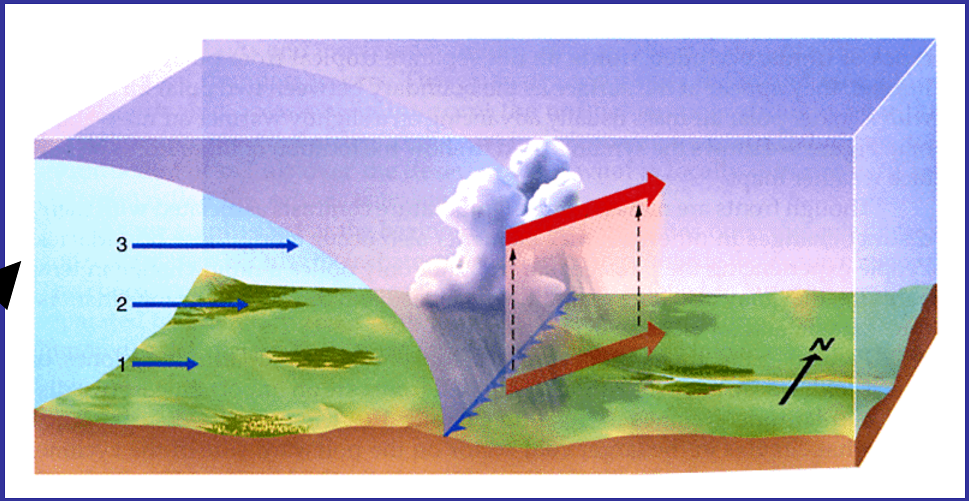
Cold and Warm Fronts

Mid-Latitude Cyclone

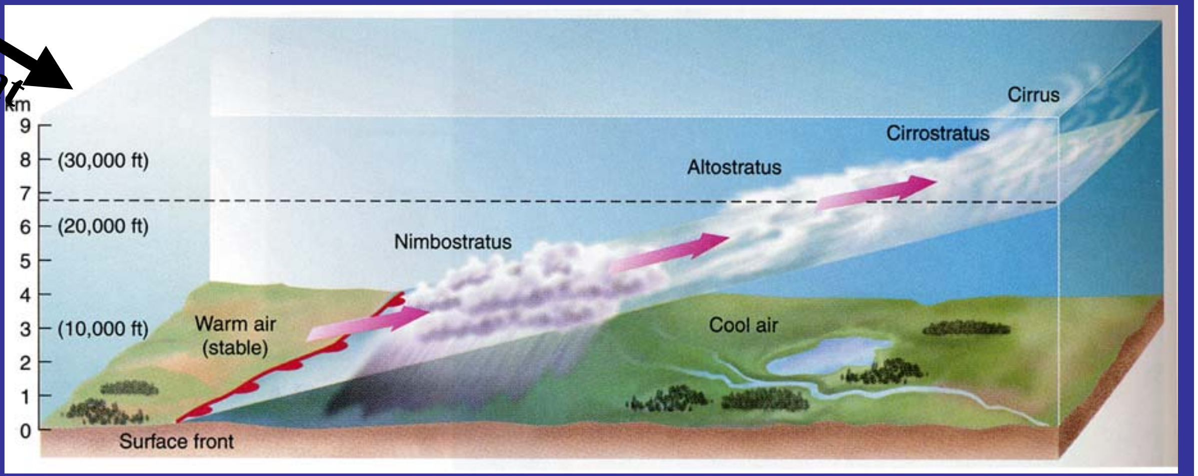


(From *Weather & Climate*)

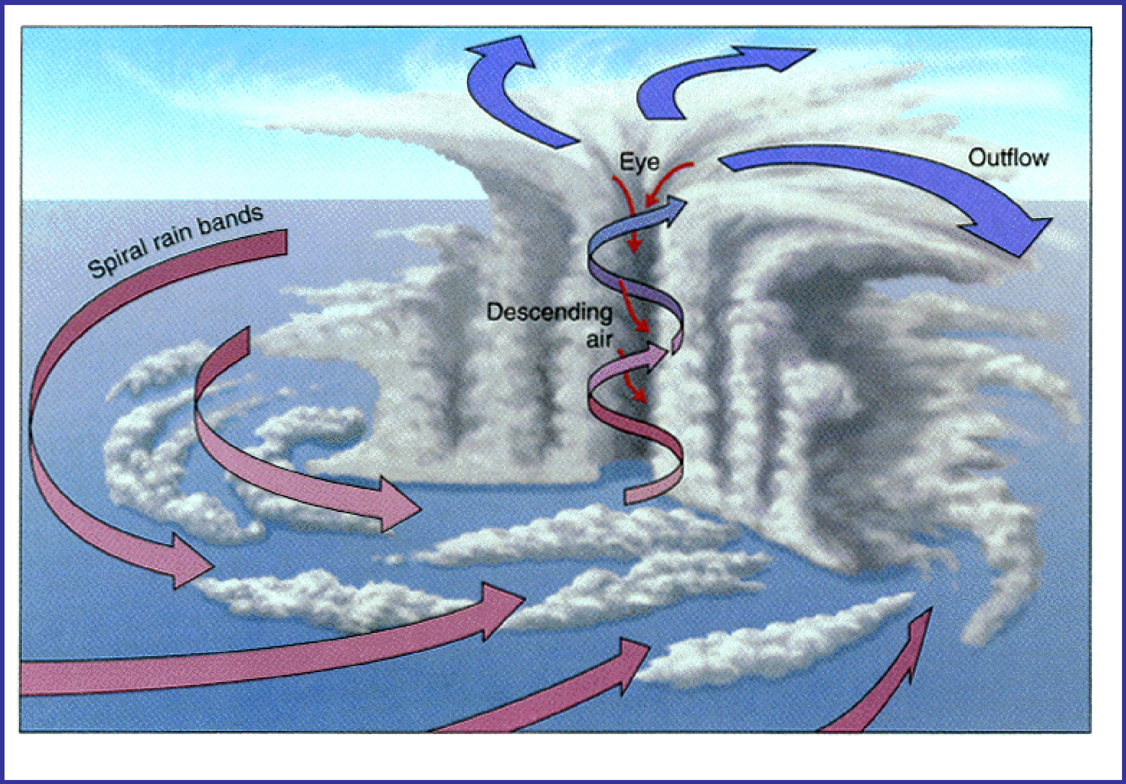
cold front



warm front



Tropical Hurricane



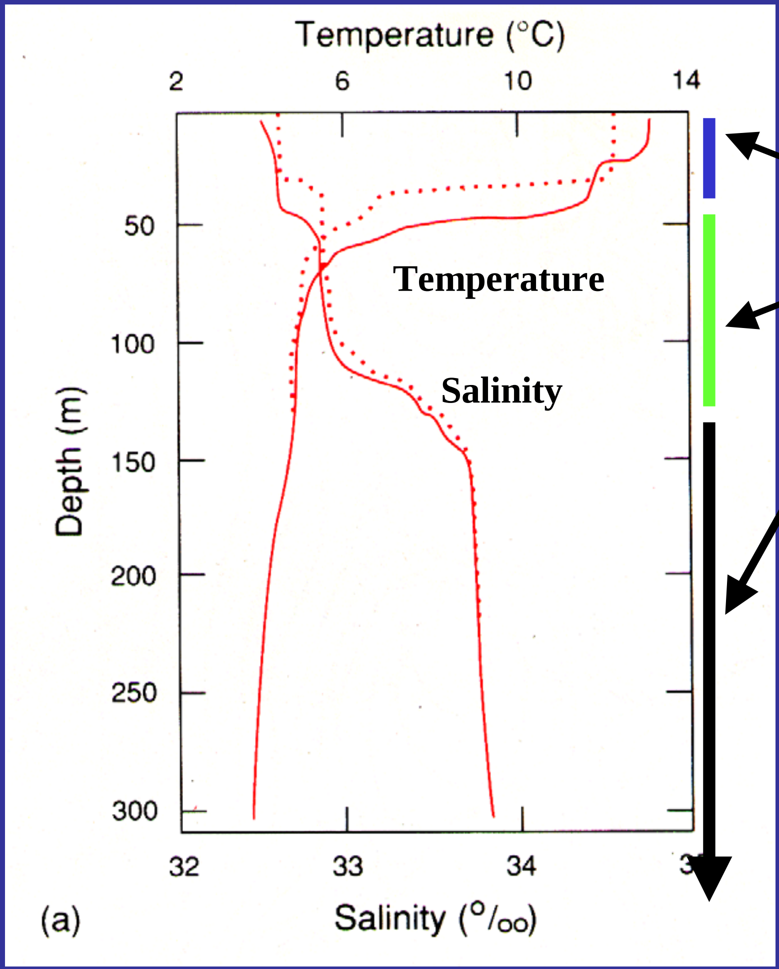
(from Understanding *Weather & Climate*)

- The hurricane is characterized by a strong thermally direct circulation with the rising of warm air near the center of the storm and the sinking of cooler air outside.

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



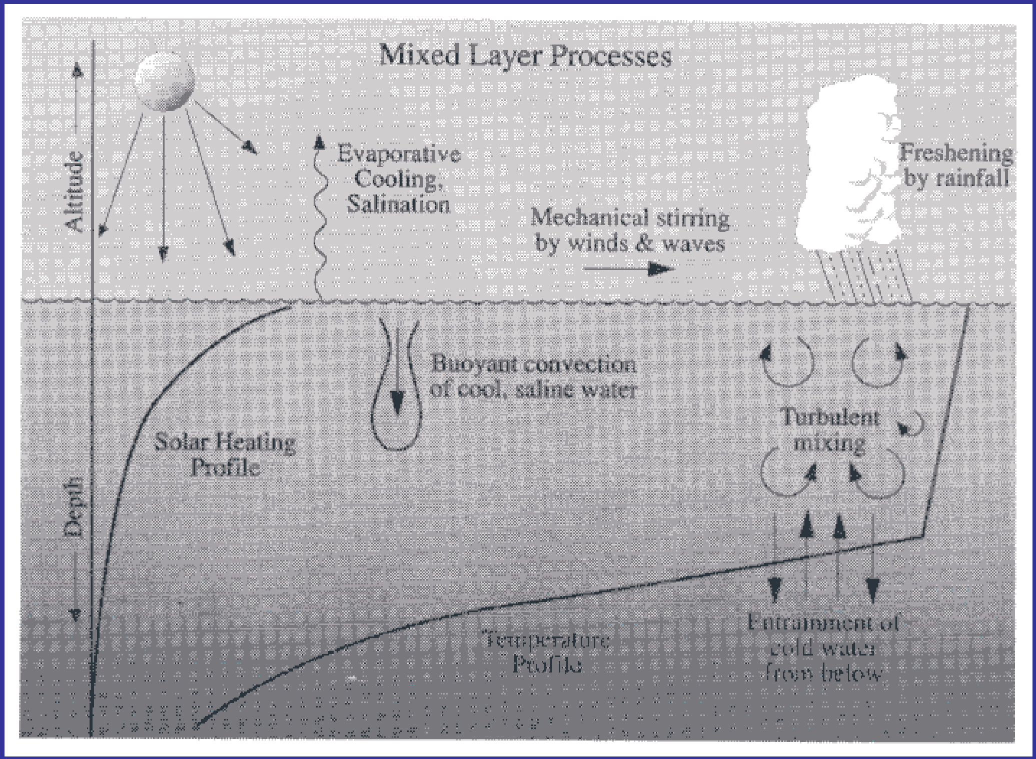
Mixed Layer: T and S well mixed by winds

Thermocline: large gradient of T and S

Deep Ocean: T and S independent of height

(from Climate System Modeling)

Mixed Layer Processes



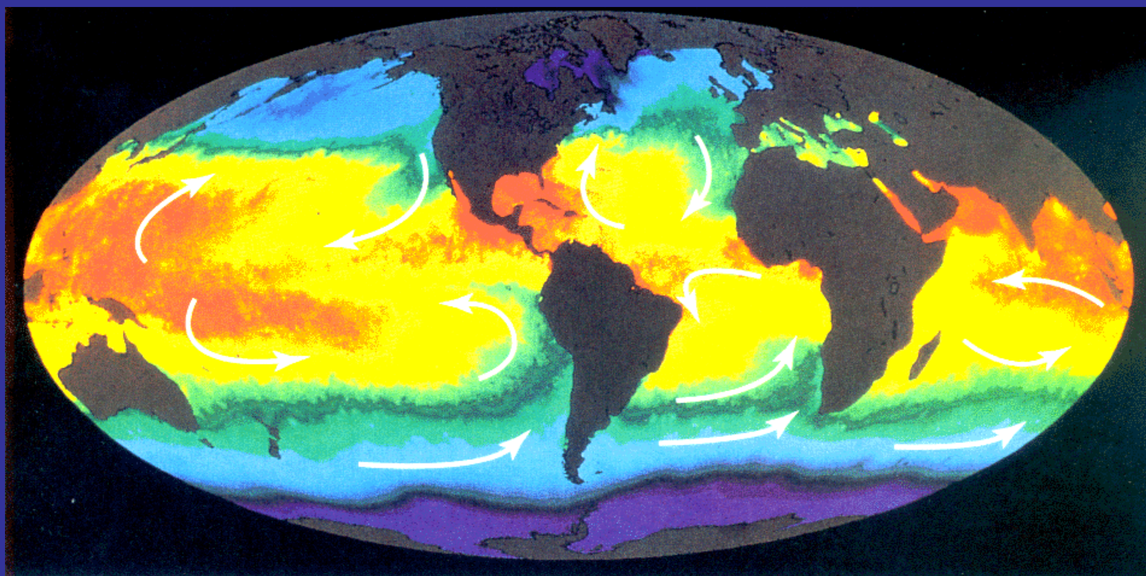
(from *Global Physical Climatology*)

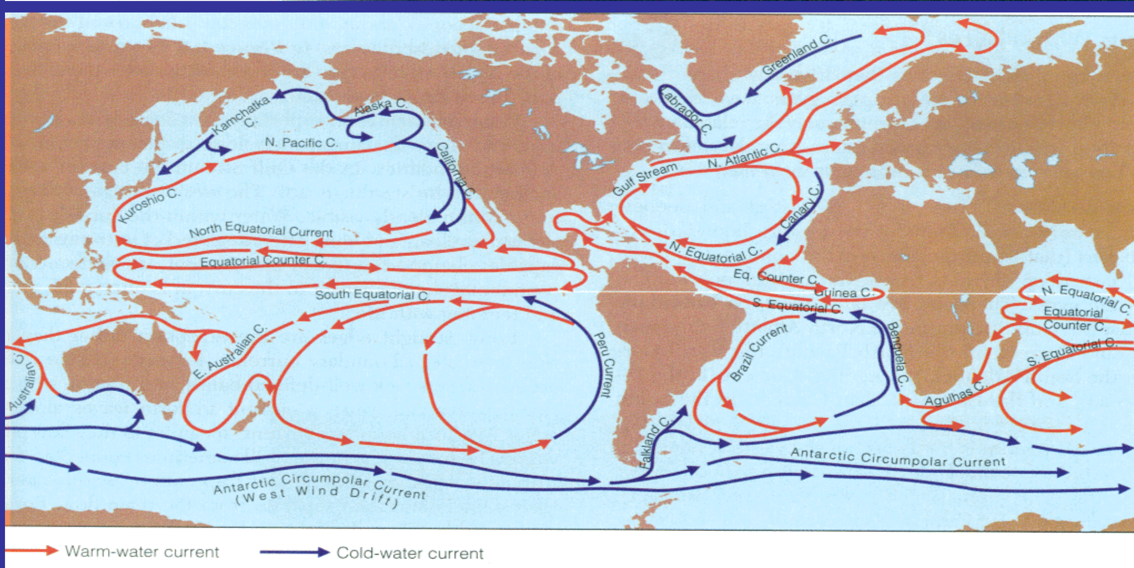
❑ The depth of the mixed layer is determined by (1) the rate of buoyancy generation and (2) the rate kinetic energy supply.

0 %

Loading

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:**

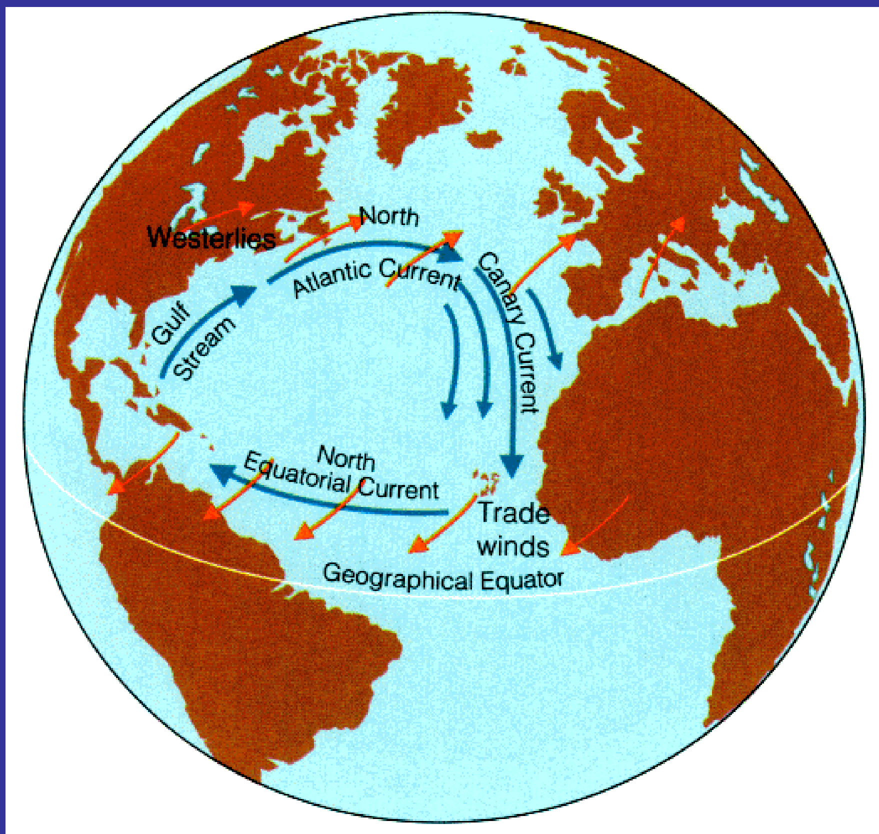
  Antarctic Circumpolr Current

  (also called West Wind Drift)

(Figure from *Oceanography* by Tom Garrison)

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

Step 1: Surface Winds

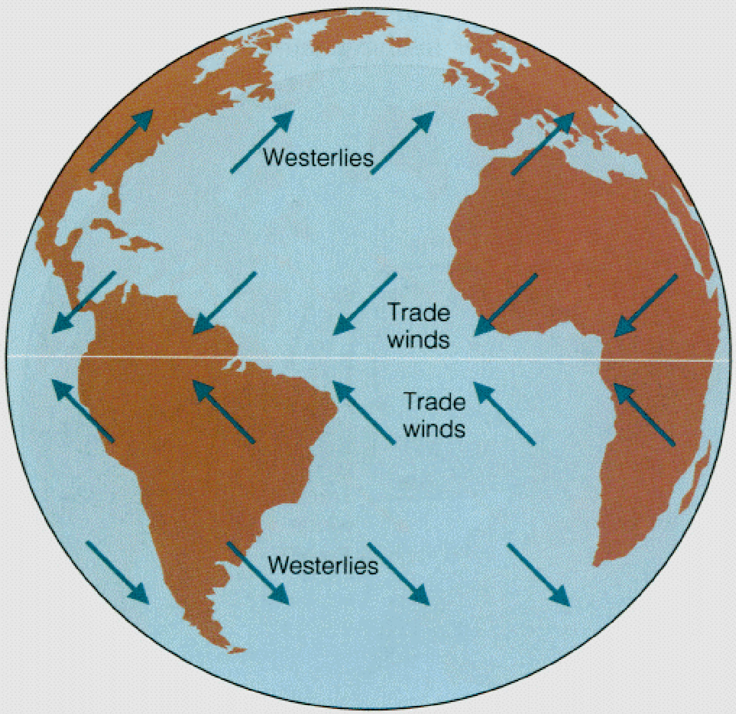


Figure 9.1 Winds, driven by uneven solar heating and Earth's spin, drive the movement of the ocean's surface currents. The prime movers are the powerful westerlies and the persistent trade winds (easterlies).

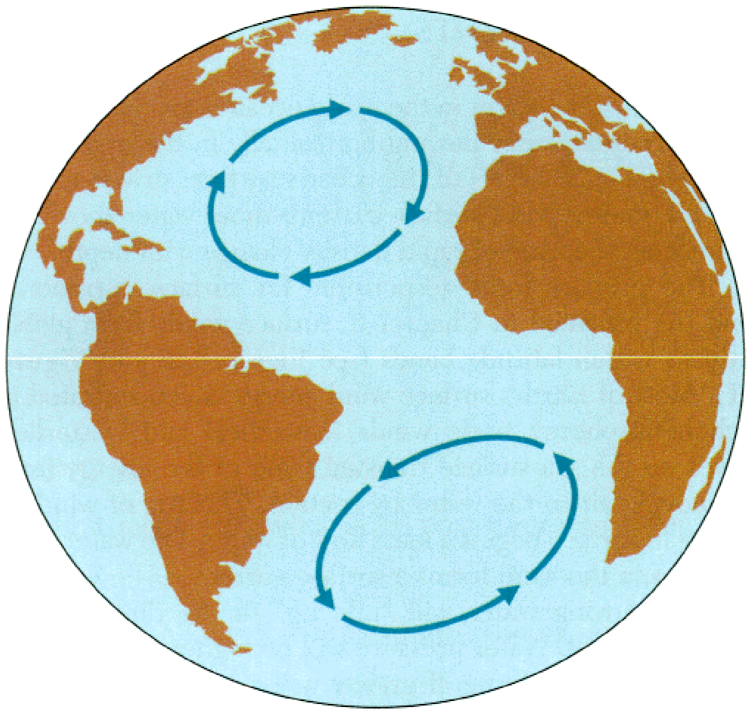
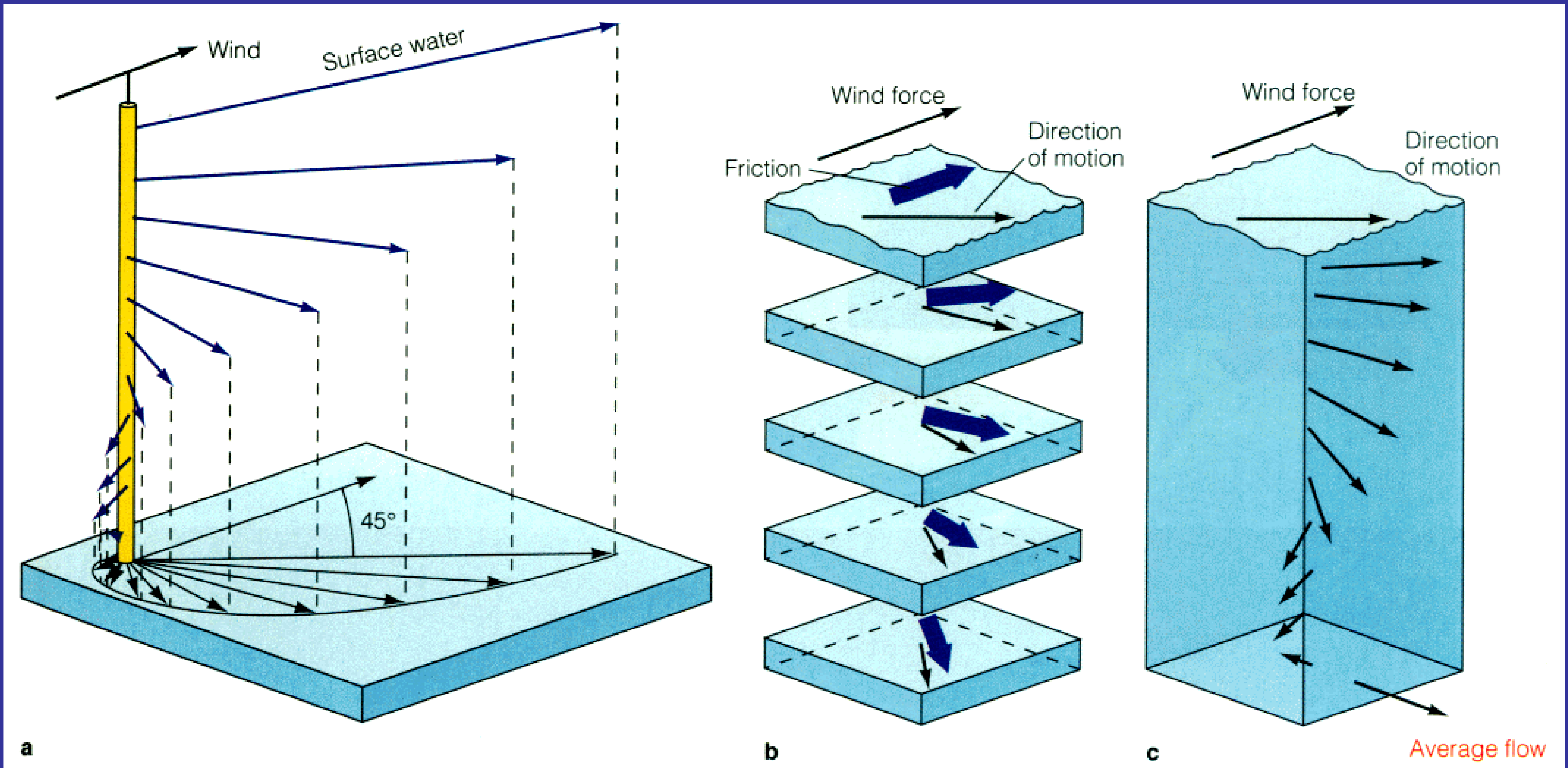


Figure 9.2 A combination of four forces—surface winds, the sun's heat, the Coriolis effect, and gravity—circulates the ocean surface clockwise in the Northern Hemisphere and counterclockwise in the Southern Hemisphere, forming gyres.

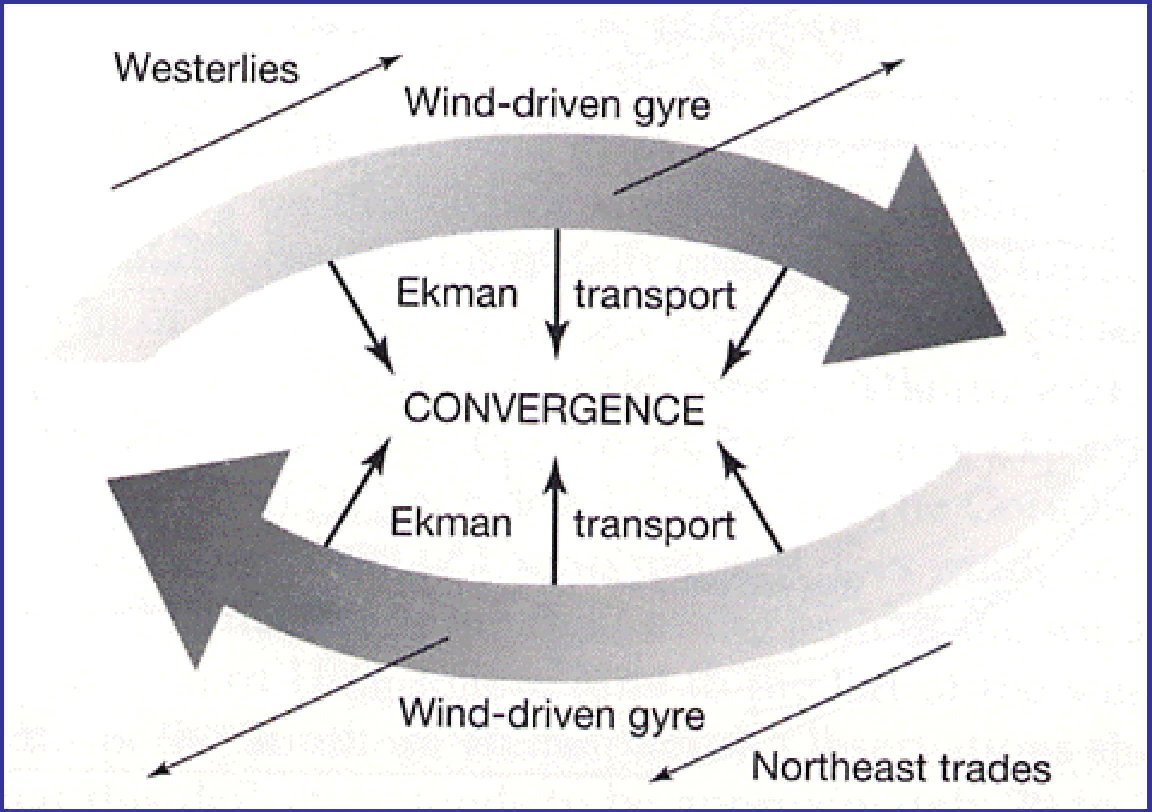
(Figure from *Oceanography* by Tom Garrison)

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



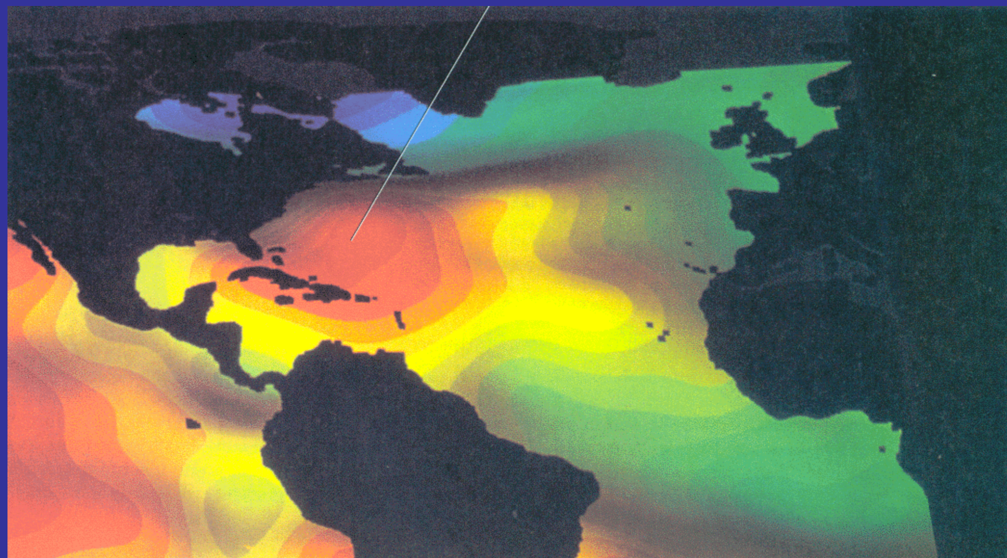
(Figure from *Oceanography* by Tom Garrison)

Ekman Transport

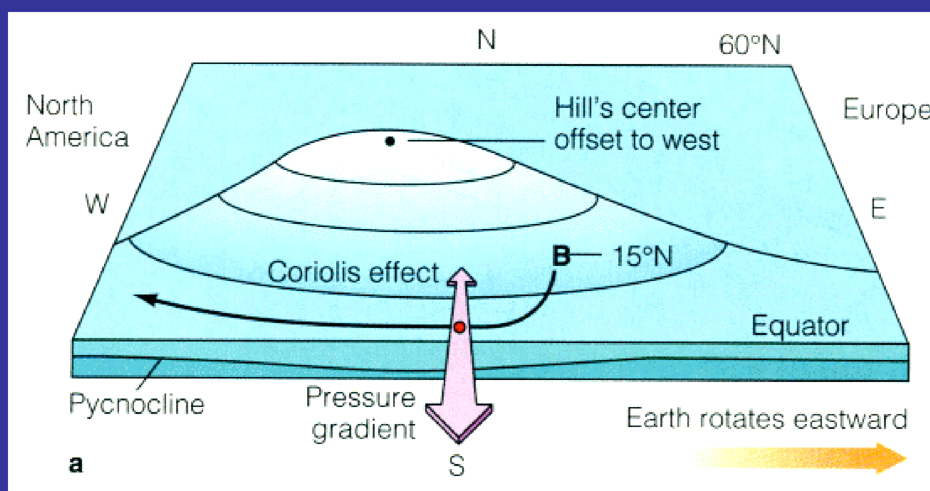


(Figure from *The Earth System*)

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

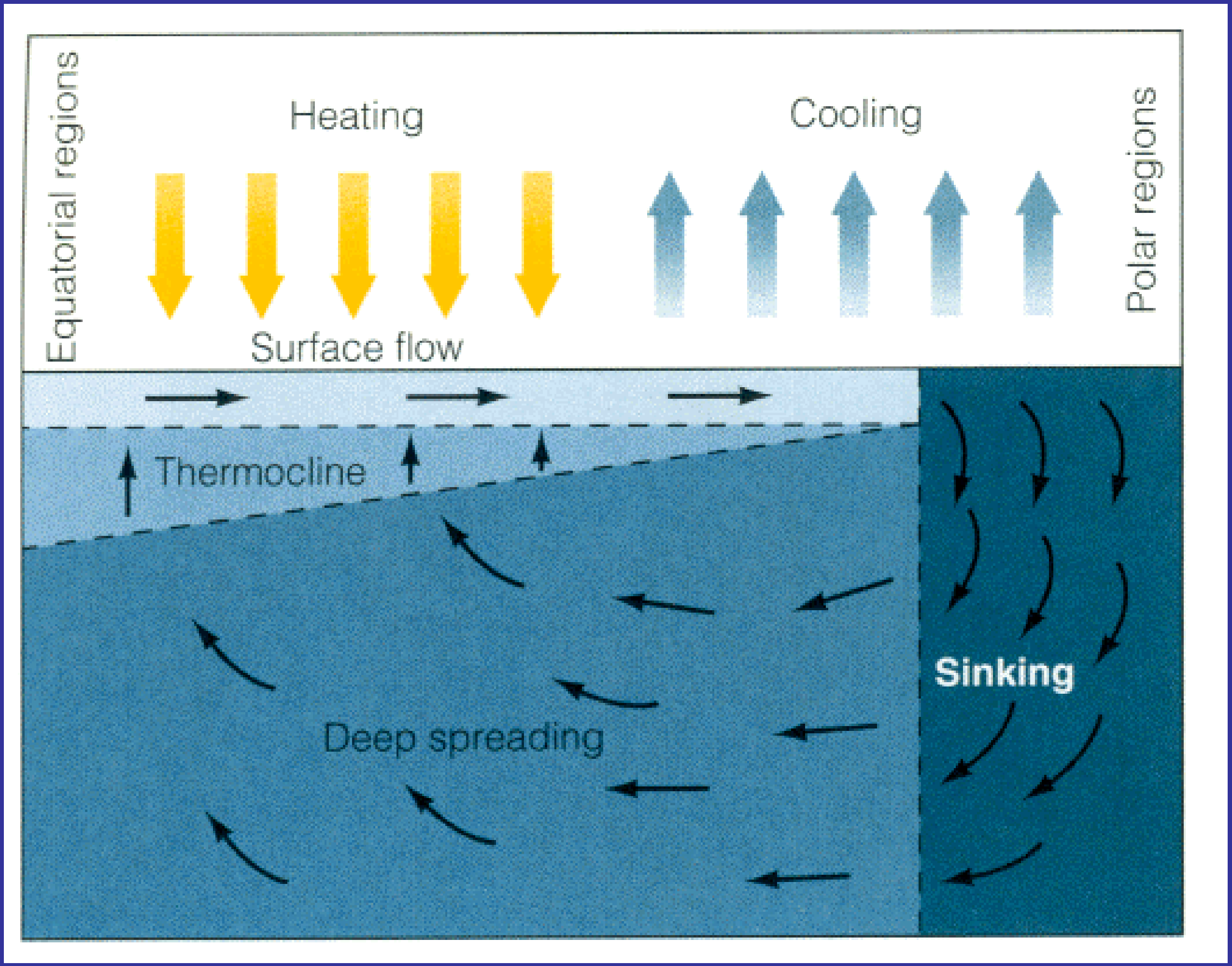


NASA-TOPEX Observations of Sea-Level Hight



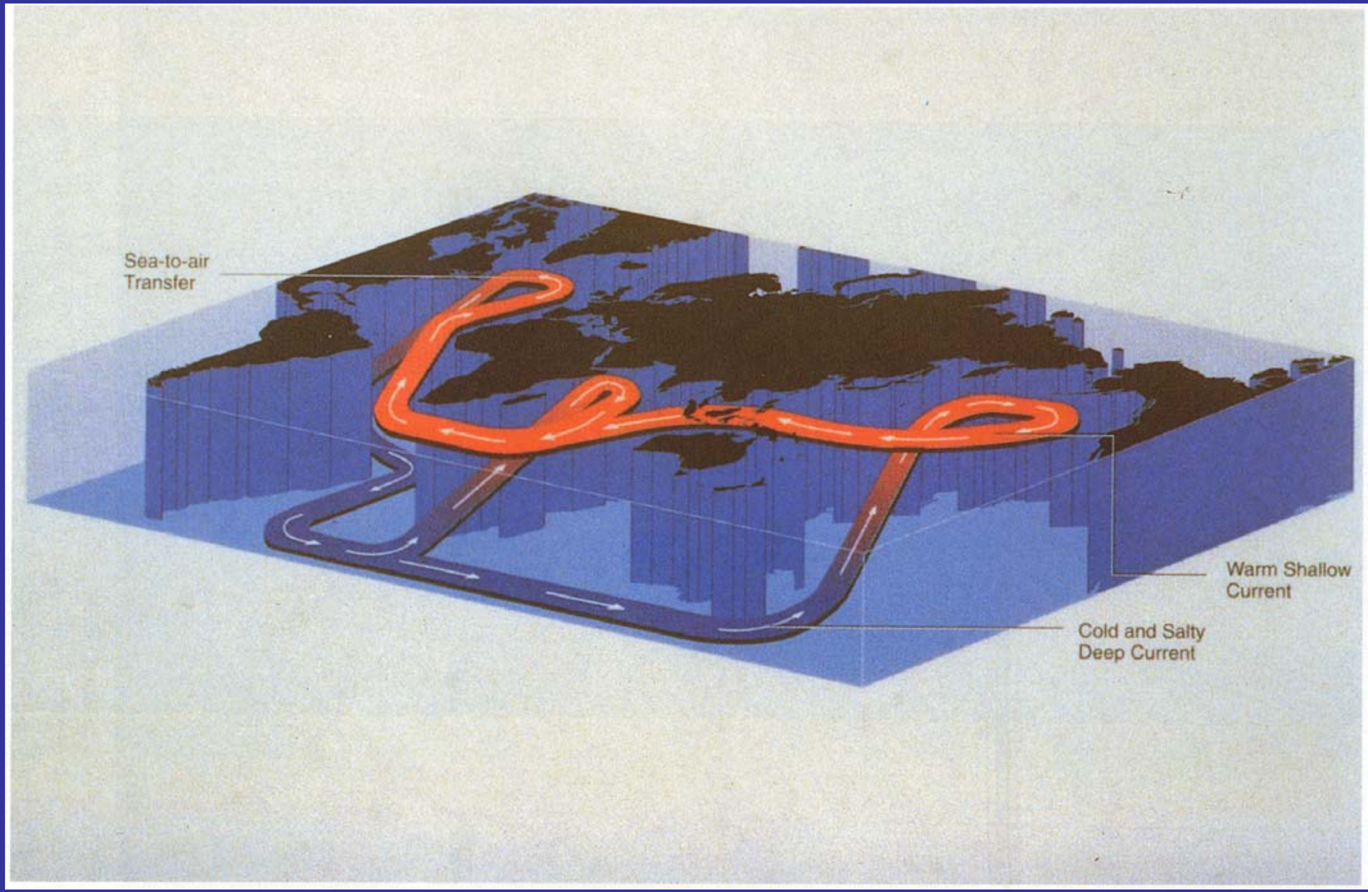
(from *Oceanography* by Tom Garrison)

Thermohaline Circulation



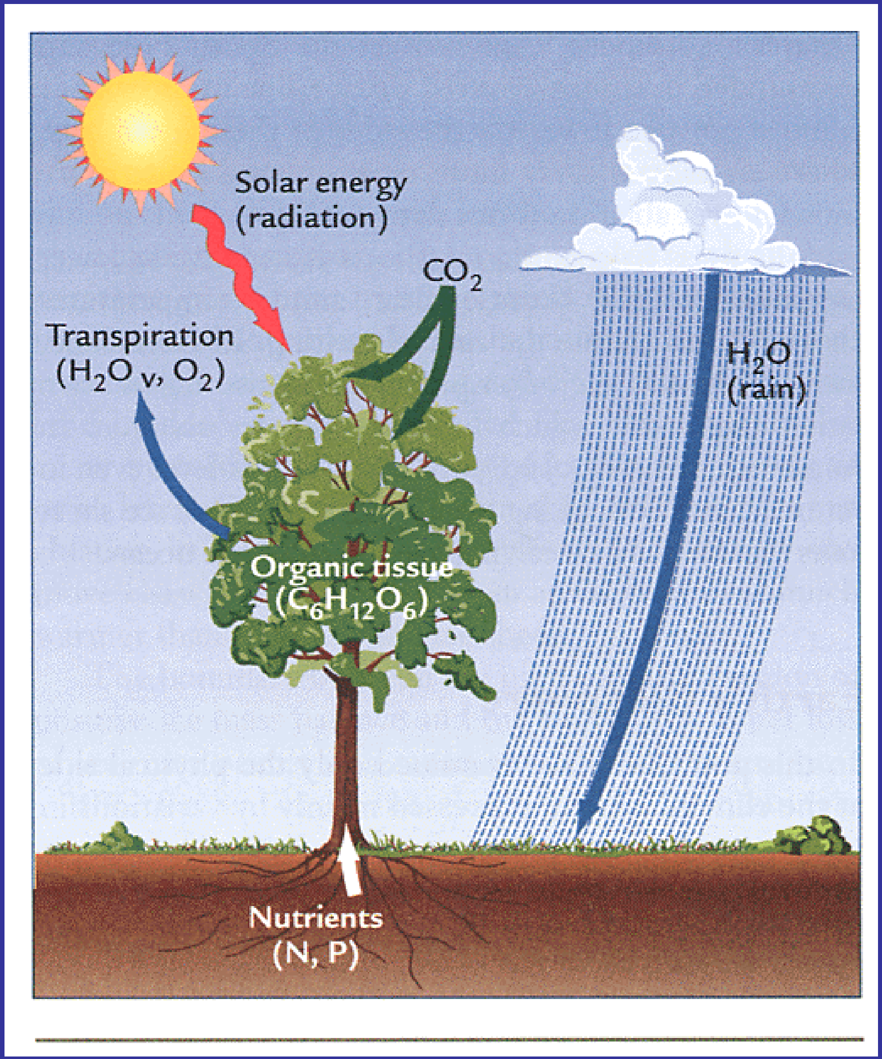
(Figure from *Oceanography* by Tom Garrison)

Thermohaline Conveyor Belt



(Figure from *Climate System Modeling*)

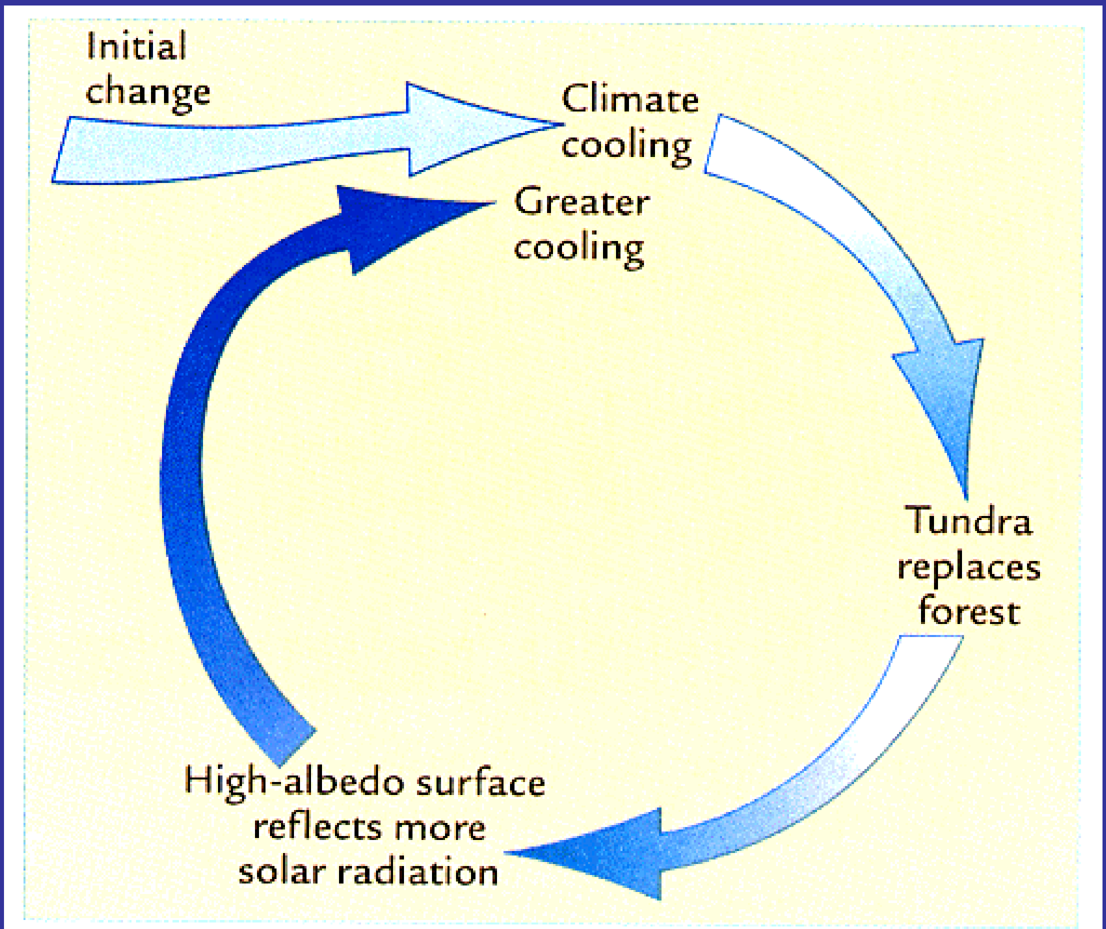
Land Surface - Outline



(from *Our Changing Planet*)

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

Climate Role 1: Albedo → Energy Cycle

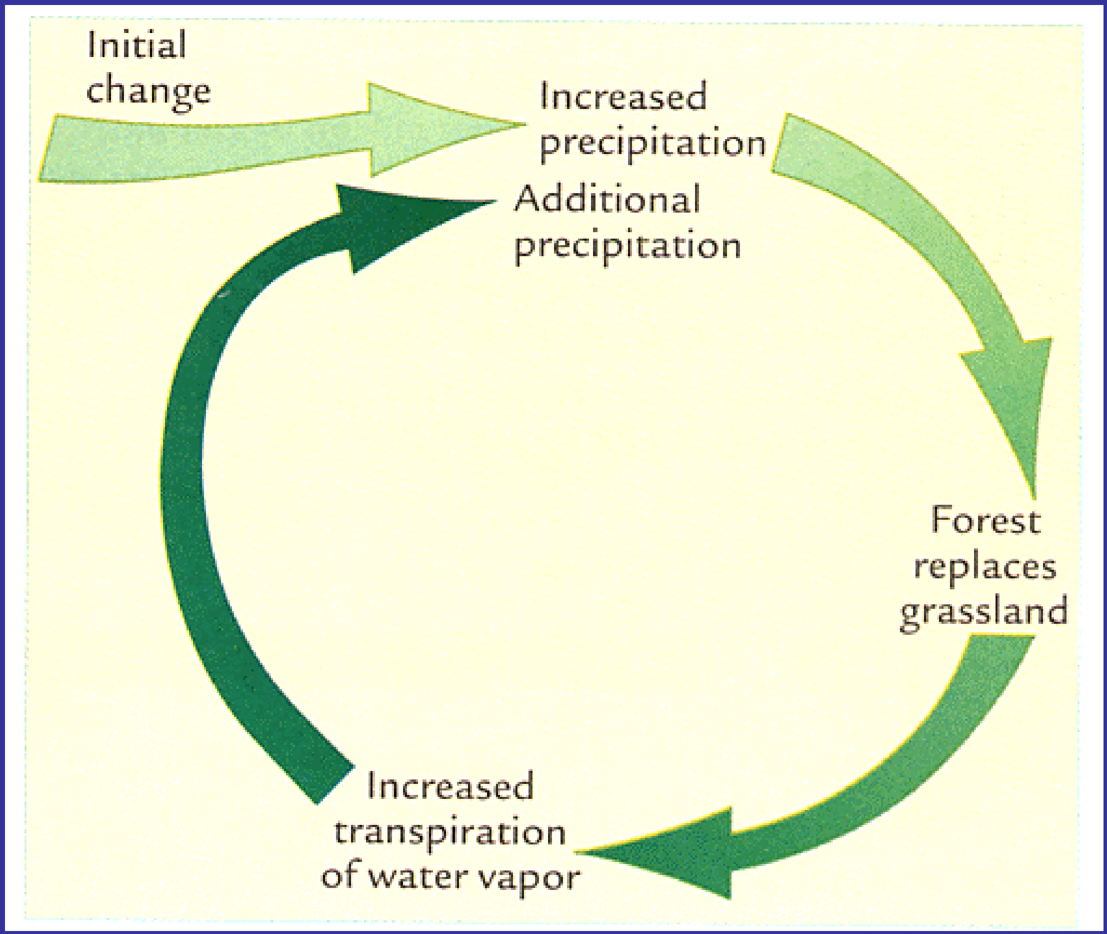


(from *Earth's Climate: Past and Future*)

or

Snow cover replaces Vegetation cover

Climate Role 2: Transpiration → Water Cycle



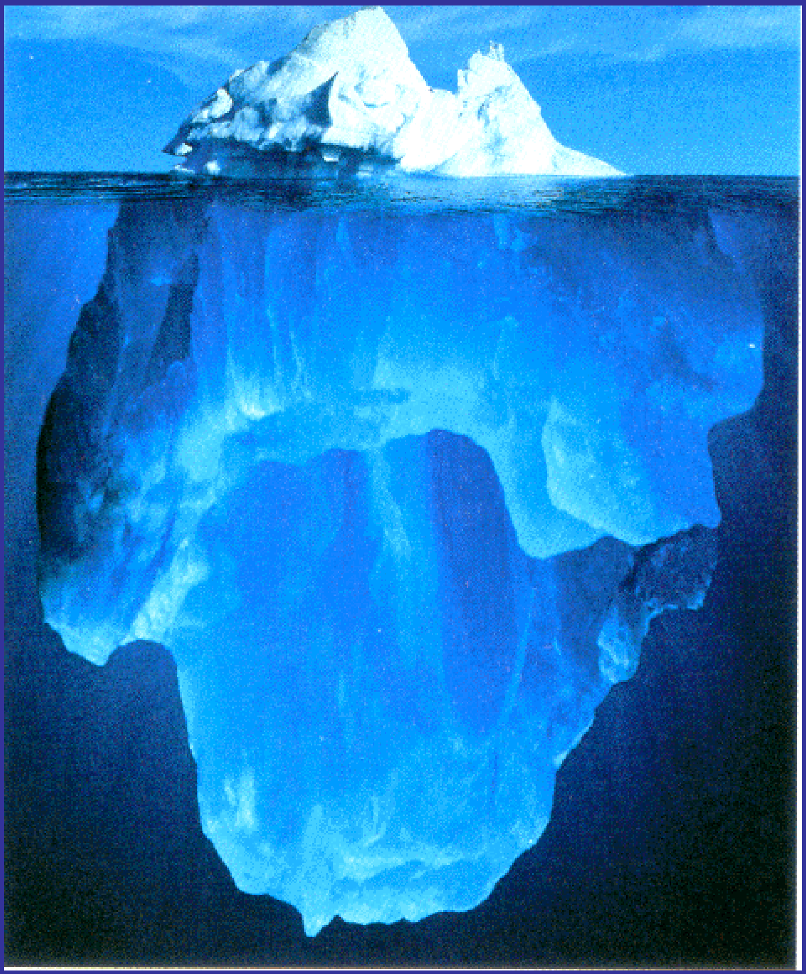
(from *Earth's Climate: Past and Future*)

or

Wet soil replaces Dry soil

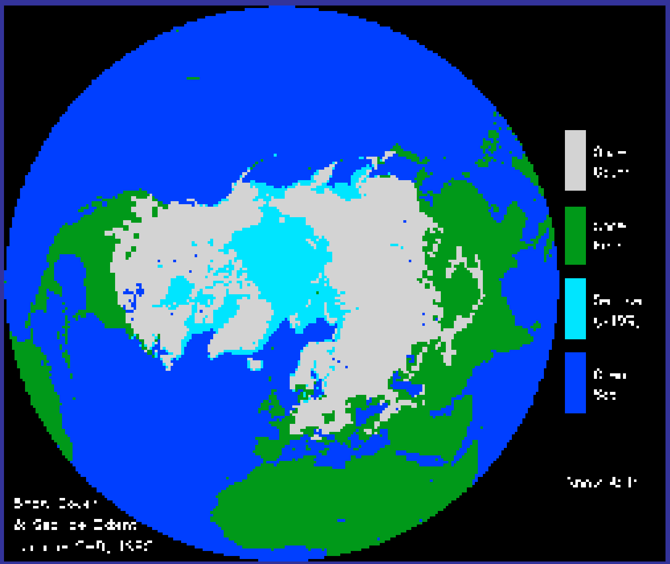
Cryosphere – Outline

Sea Ice



(from *The Blue Planet*)

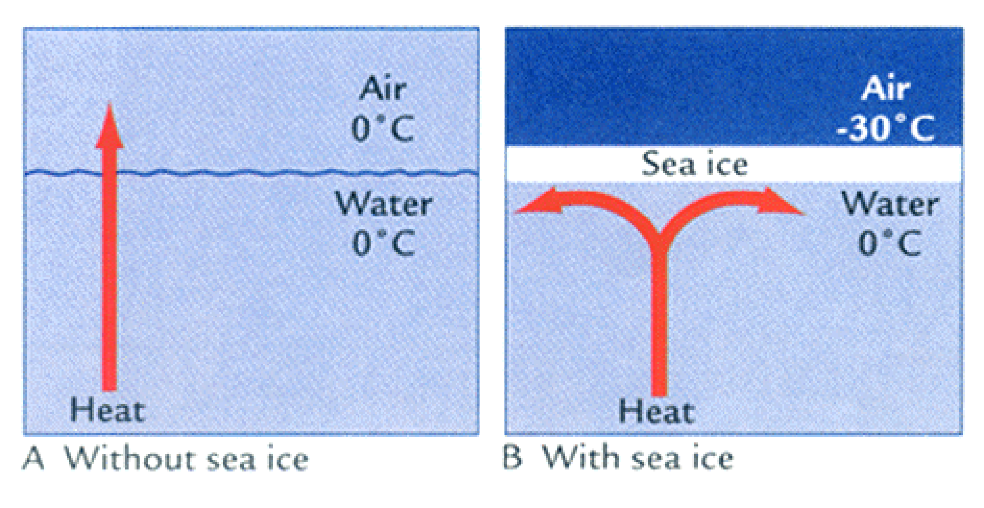
Land Ice



❑ 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.

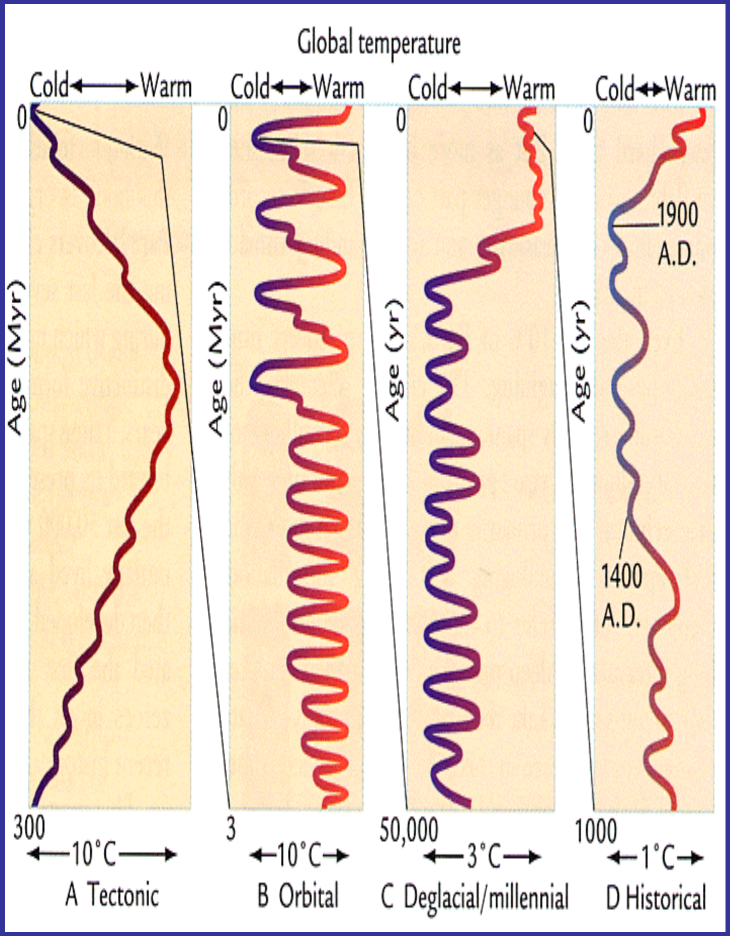
Why is Ice Important to Climate?



(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.

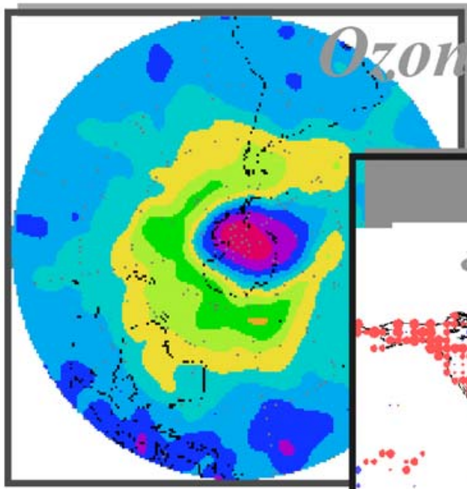
Climate Change and Variation - Outline

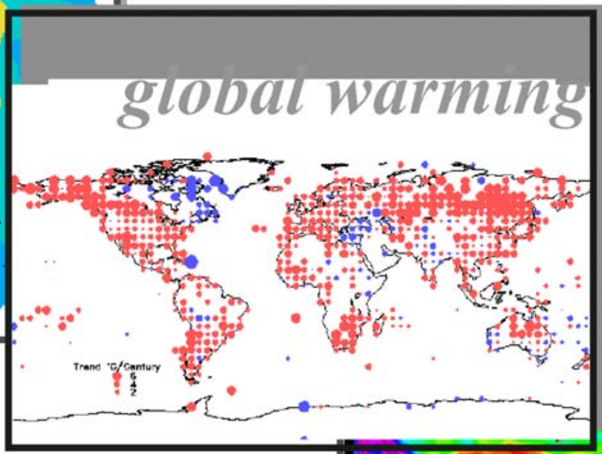


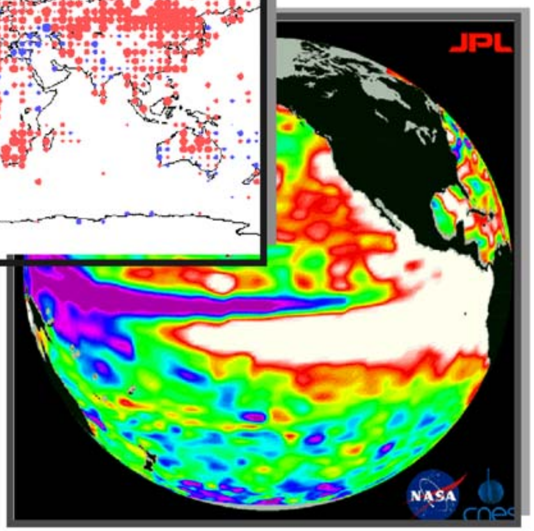
(from *Earth's Climate: Past and Future*)

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

Concern on the Earth

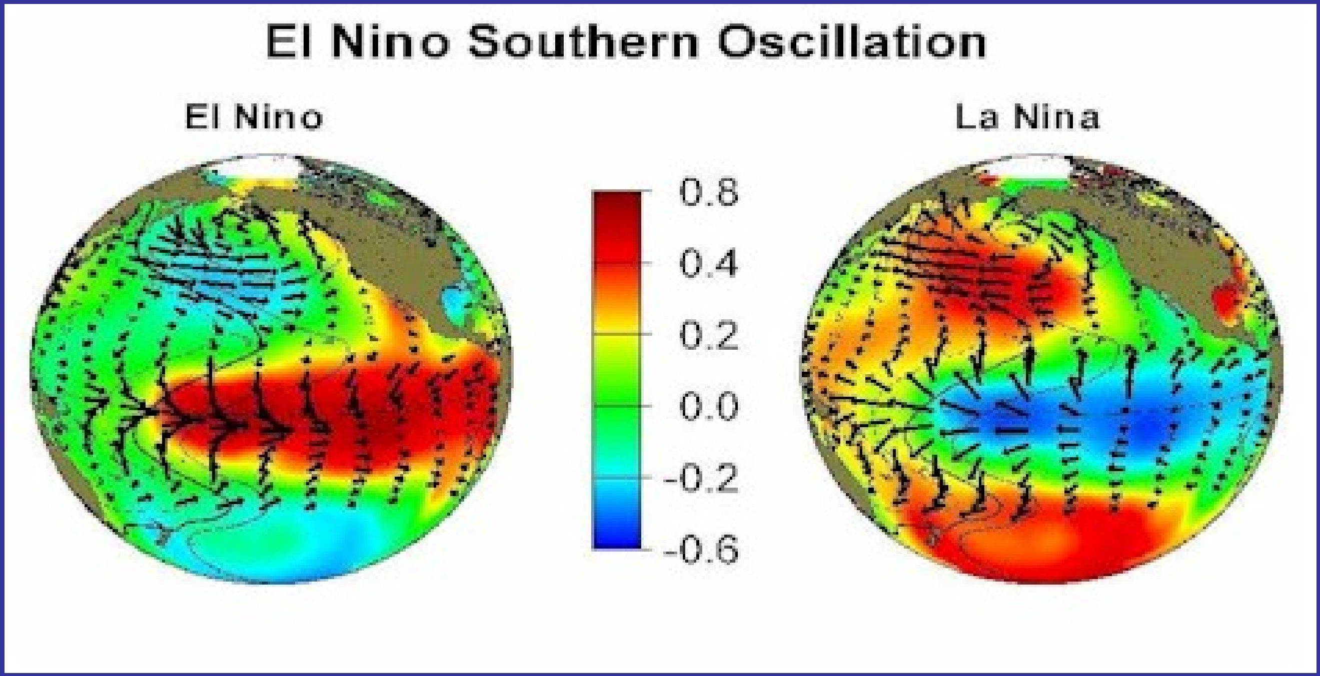






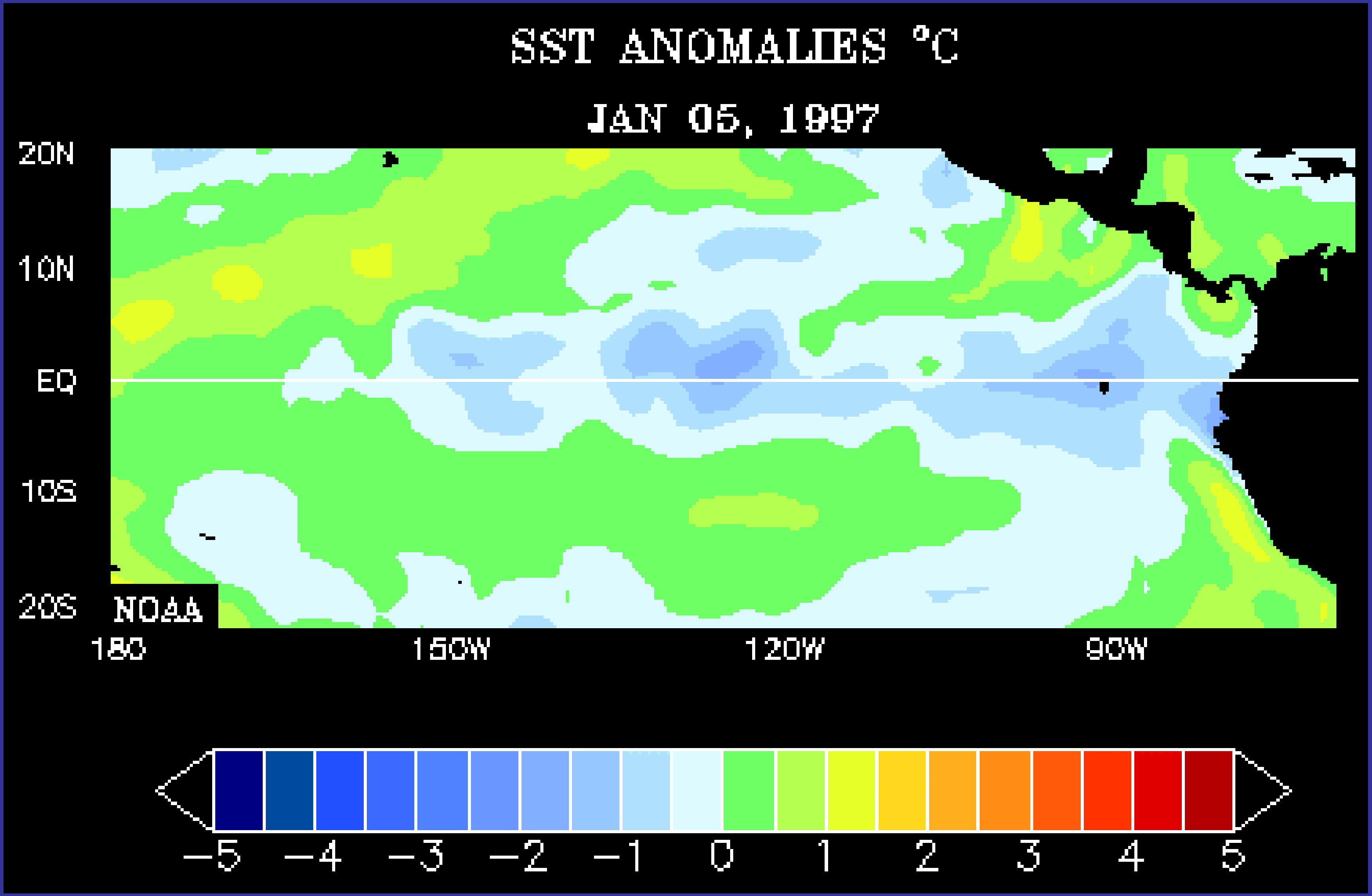
El Nino

El Nino-Southern Oscillation (ENSO)



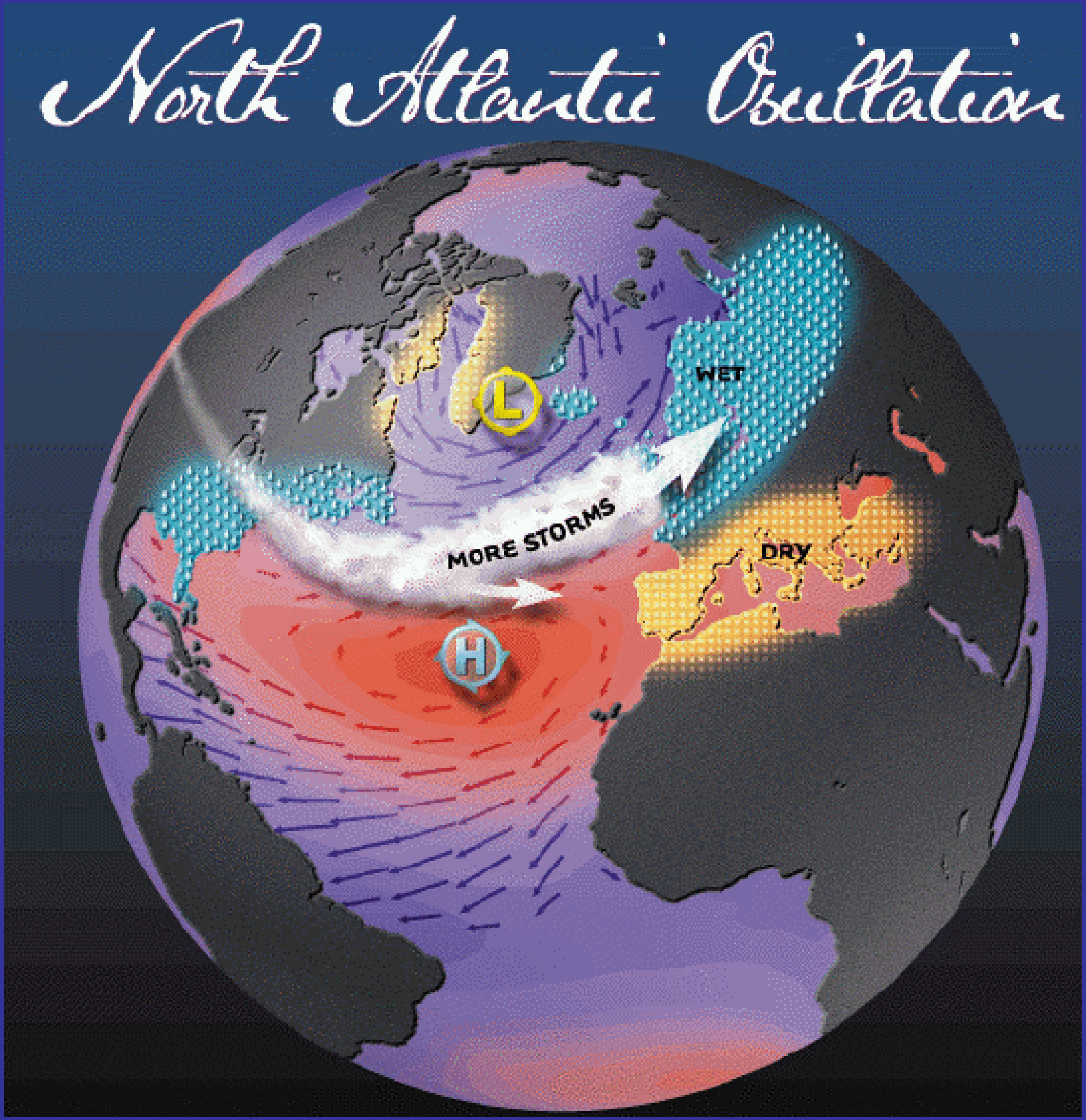
- ENSO is a interannual (year-to-year) climate variability in the eastern tropical Pacific Ocean.
- ENSO is found to have profound impacts on global climate.

1997-98 El Nino



ESS200A
Prof. Jin-Yi Yu

North Atlantic Oscillation



(from http://www.ldeo.columbia.edu/res/pi/NAO/)

- The NAO is the dominant mode of winter climate variability in the North Atlantic region ranging from central North America to Europe and much into Northern Asia.
- The NAO is a large scale seesaw in atmospheric mass between the subtropical high and the polar low.
- The corresponding index varies from year to year, but also exhibits a tendency to remain in one phase for intervals lasting several years.

The 1997 Ozone Hole