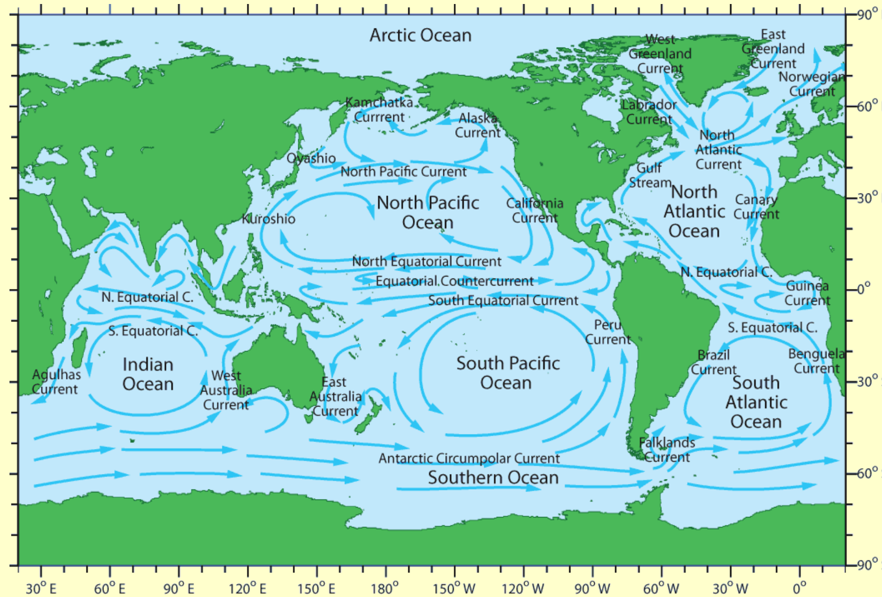
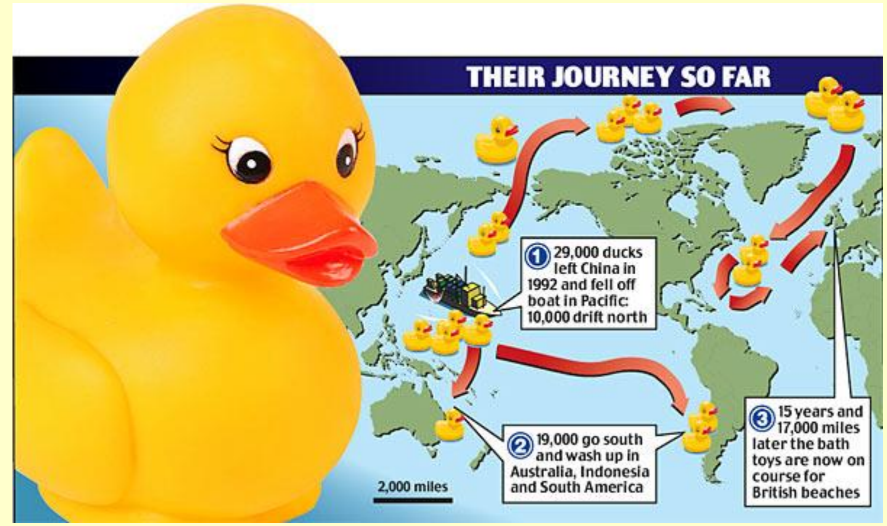
Lecture 2: Ocean Basins & Circulation

- Introduction:
  - Ocean is BIG
  - Heterogeneous
  - Multiple forces

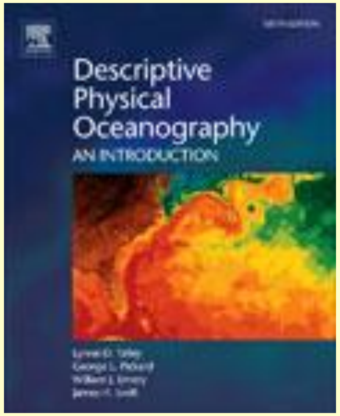


- Review ocean physical features



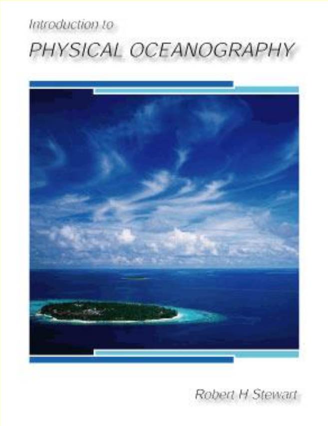
Goals for Lecture 2

- Introduce course format and content
- Review ocean basin physical features
- Review ocean / atmospheric circulation



(DPO)

Ch 1 and 2



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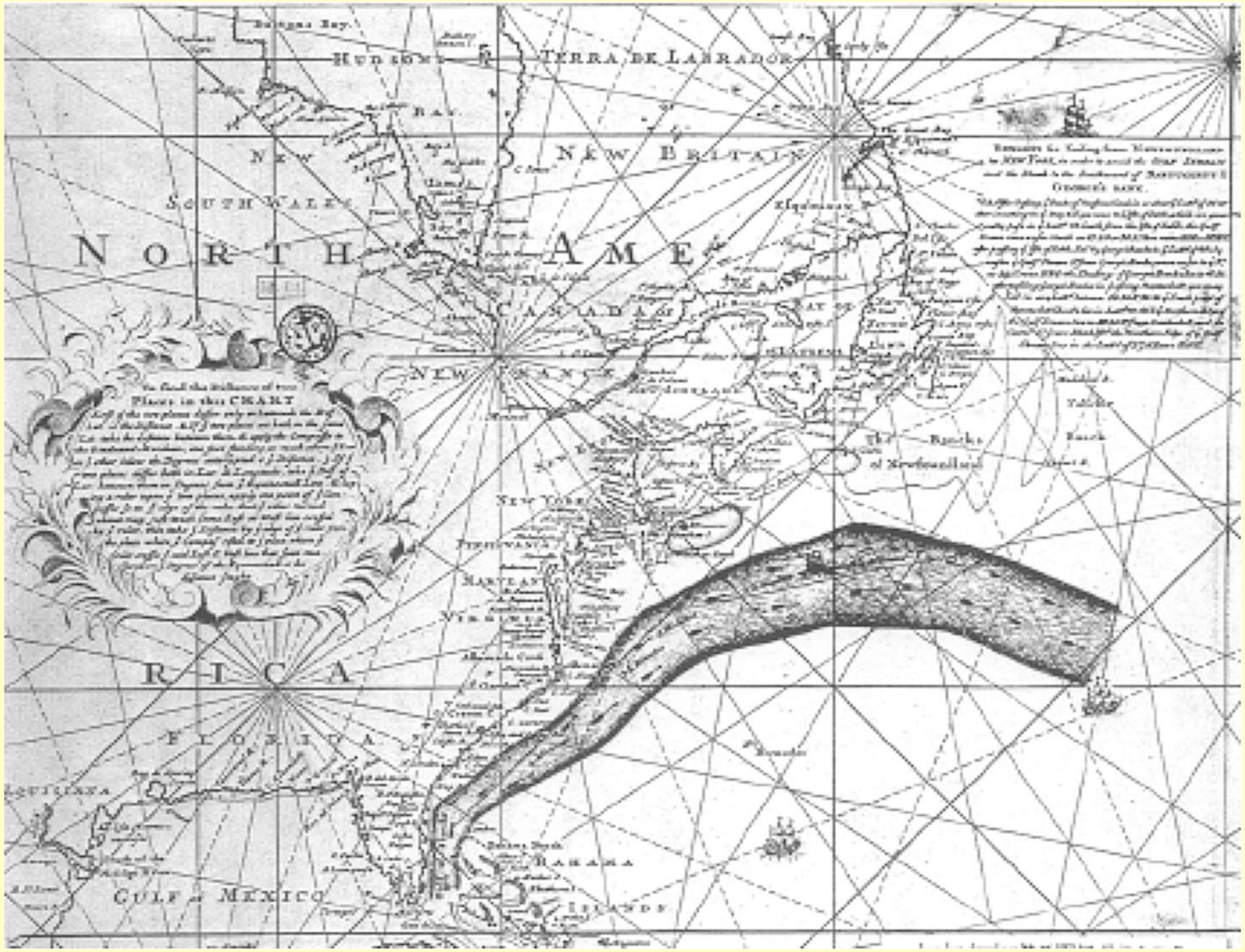
Ch 3

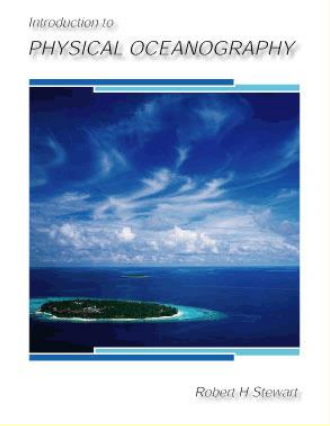
Historical Perspective

Currents as Rivers in the Sea



Franklin-Folger map of the Gulf Stream.

Source: Richardson (1980).

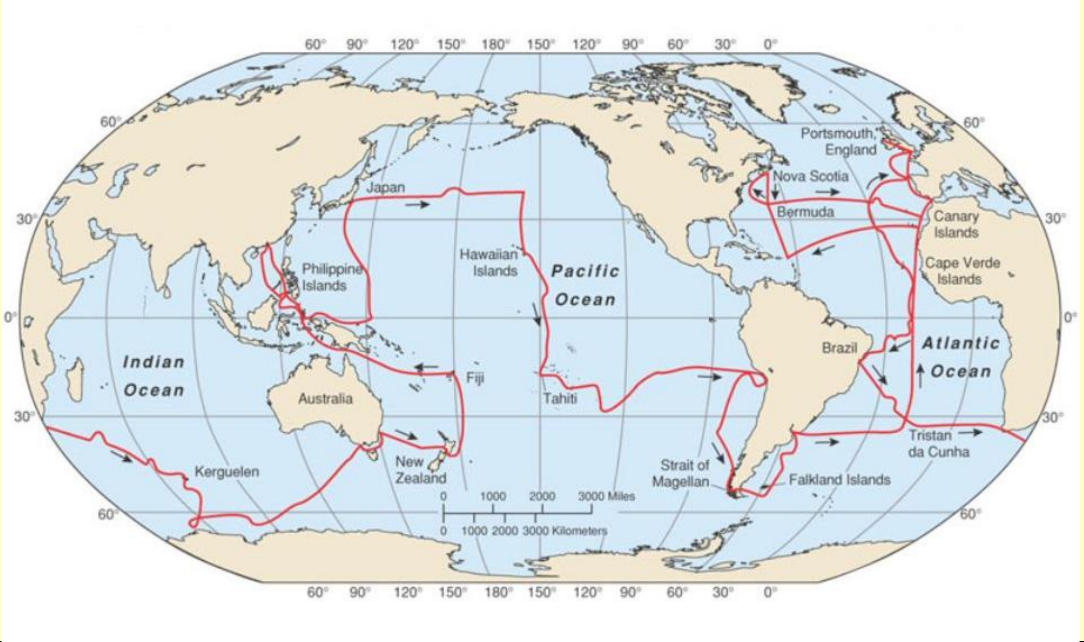


Ch 2

Historical Perspective

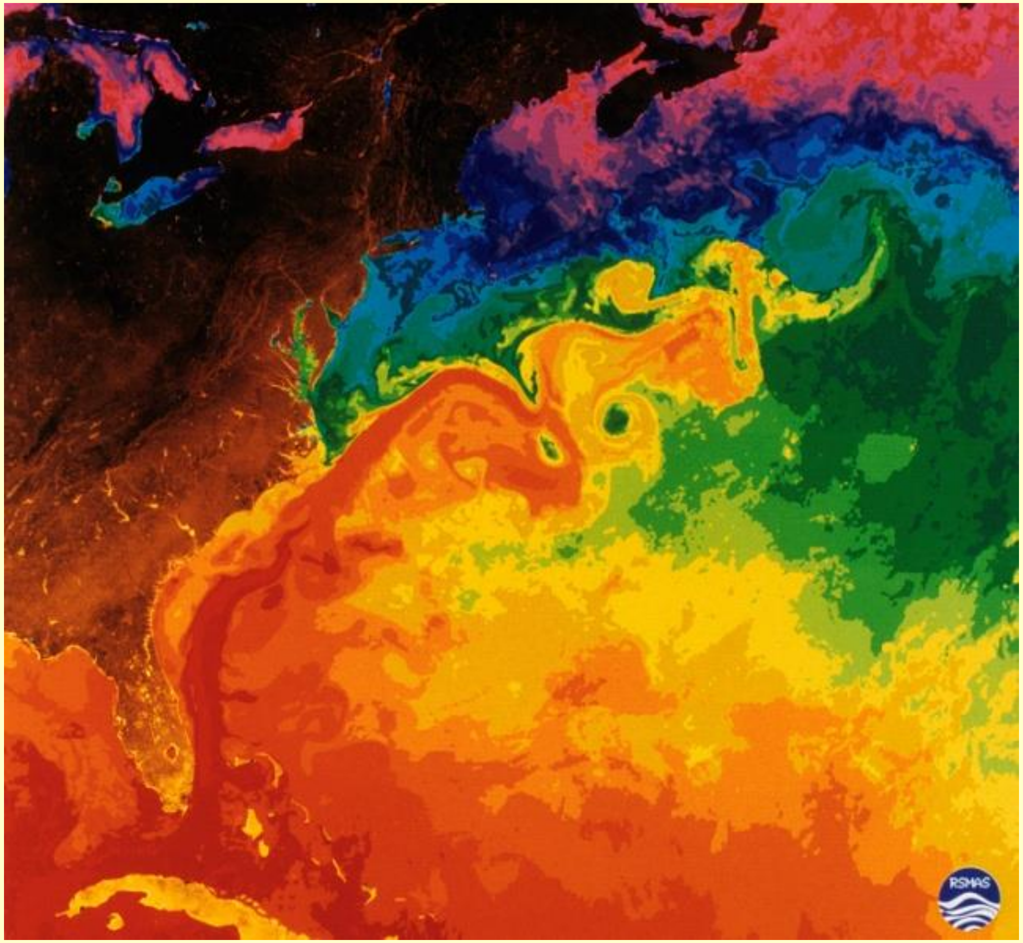
Challenger expedition, under the direction of the Scottish professor Charles Wyville Thompson and the British naturalist Sir John Murray.

Took place **from 1872** to **1876** and opened the era of descriptive oceanography.



Current Perspective

Mesoscale Dynamics



Sea surface temperature map from satellites: the advanced very high resolution radiometer (AVHRR) instrument

Current Perspective

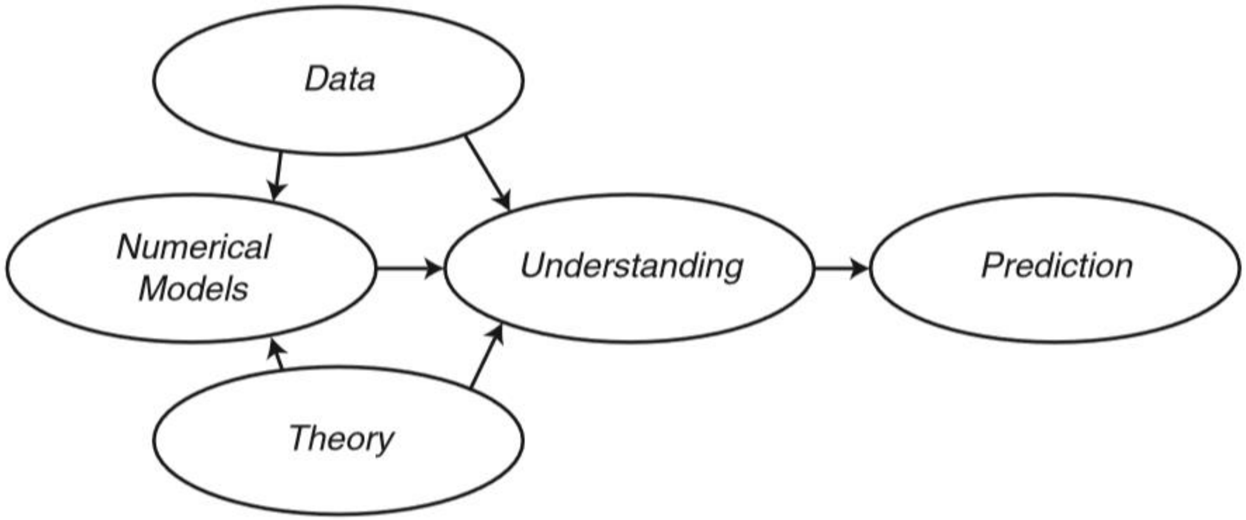


Figure 1.1 Data, numerical models, and theory are all necessary to understand the ocean. Eventually, an understanding of the ocean-atmosphere-land system will lead to predictions of future states of the system.

By combining theory and observations in numerical models we avoid some of the difficulties associated with each approach used separately.

The ultimate goal is to know the ocean well enough to predict the future changes in the environment.

Current Perspective

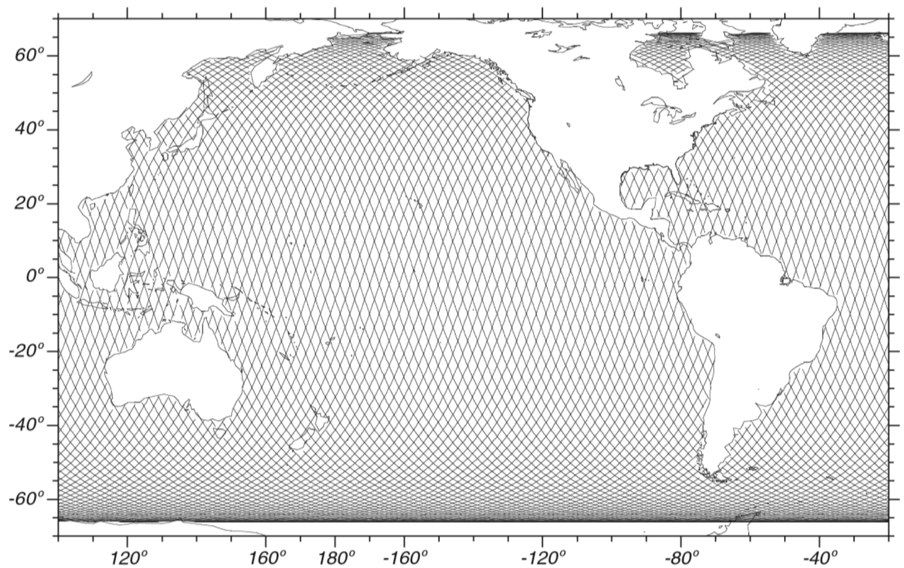


Figure 2.6 Example from the era of satellites. Topex/Poseidon tracks in the Pacific Ocean during a 10-day repeat of the orbit. From Topex/Poseidon Project.

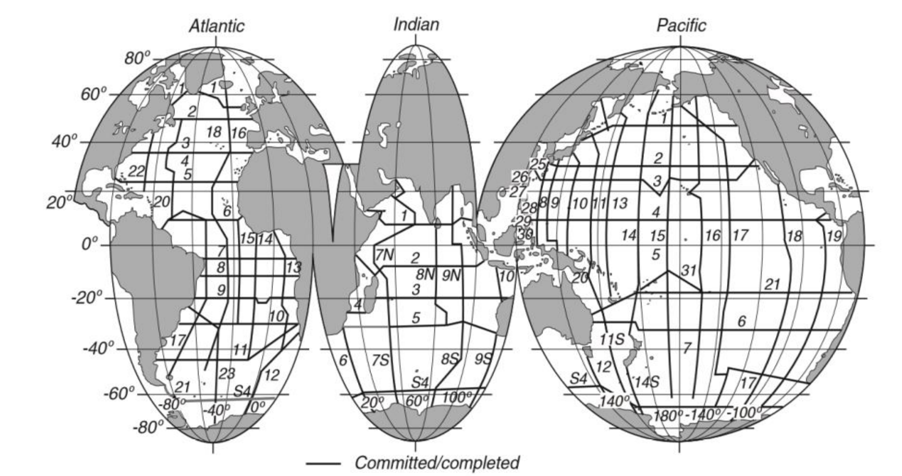


Figure 2.5 World Ocean Circulation Experiment: Tracks of research ships making a one-time global survey of the ocean of the world. From World Ocean Circulation Experiment.

"The more one is able to observe the ocean, the more the complexity and subtlety that appears"

Wunsch (2002).

Designing experiments:

1. What accuracy is required in the measurements ?

2. What resolution in time and space is required ?

Learning objectives

Understand distribution of solar heat flux versus latitude and its consequences

Understand the Coriolis effect and its consequences

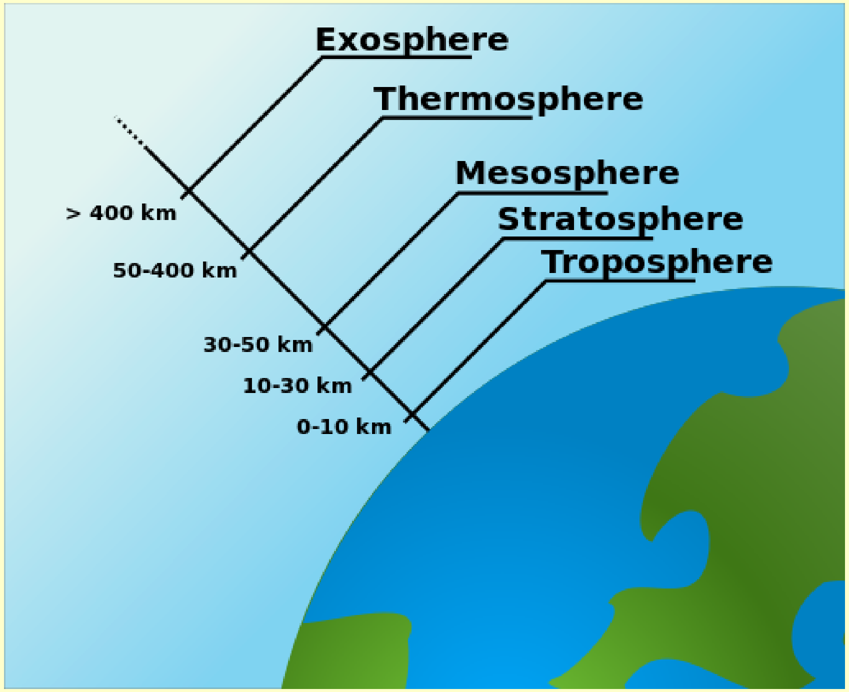
Understand the wind circulation patterns and the climatic impacts of this flow

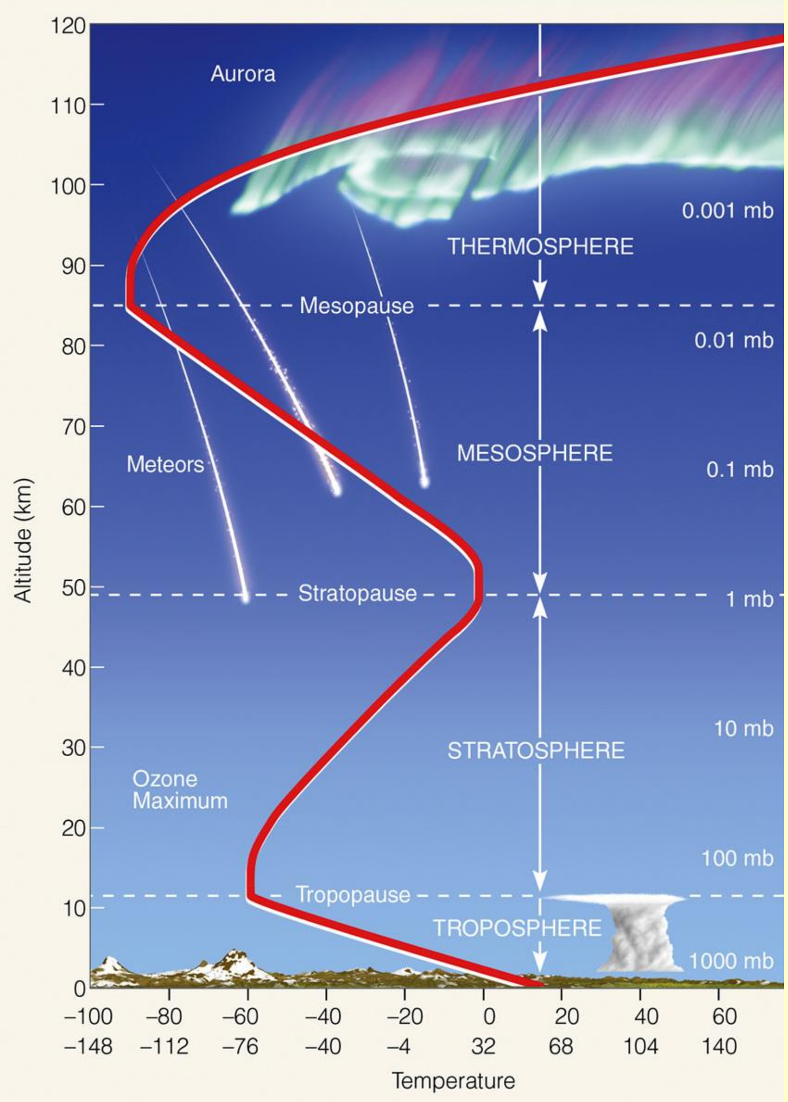
Understand the following concepts and conventions:

- Know how currents and winds are named / described
- Know basic terminology for surface ocean circulation and major ocean surface flow patterns
- Understand concept of thermohaline circulation

The Atmosphere

Height of the Troposphere: ~ 10 km





Heat Input to Earth's surface

Greatest at the equator

Least (seasonally: zero) at poles

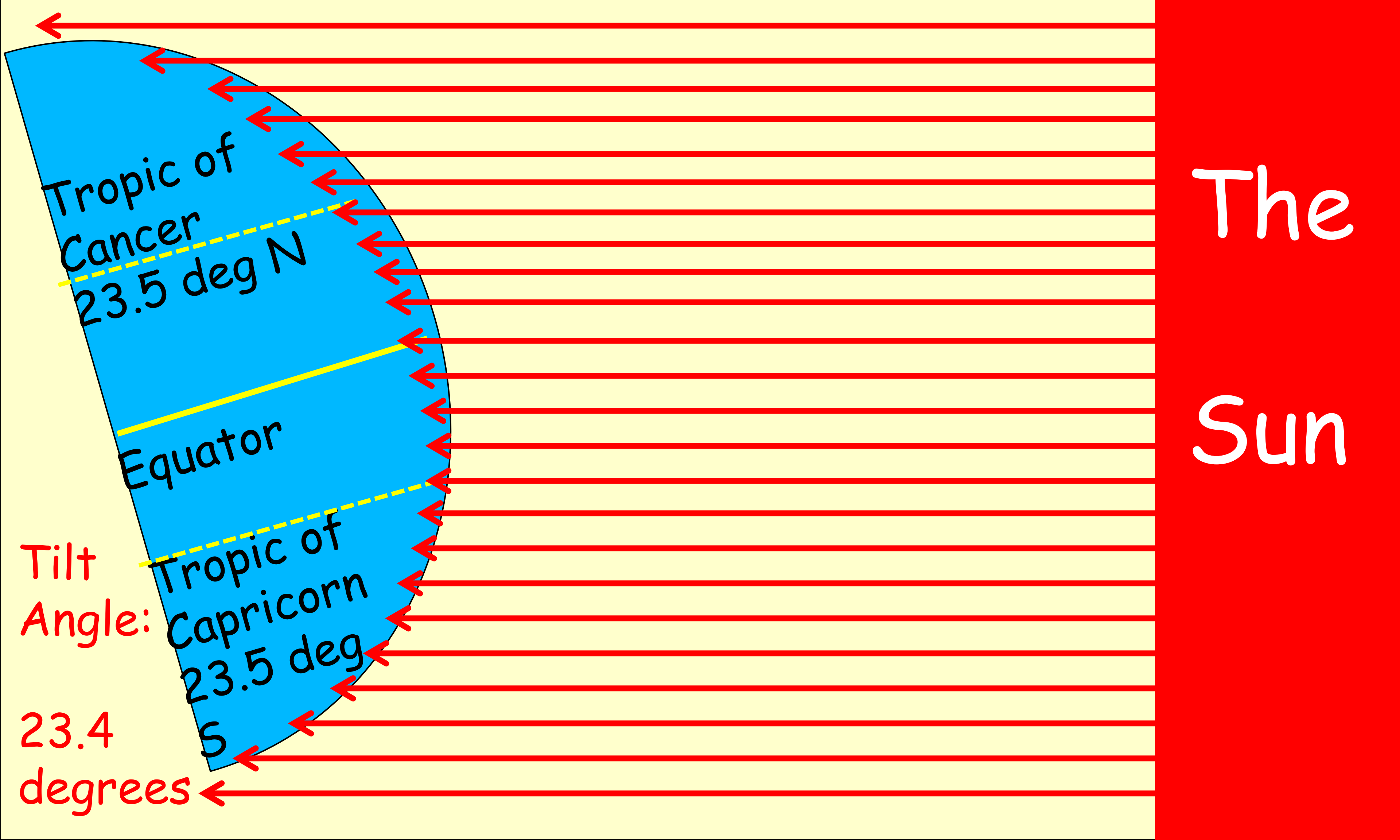
- Reasons:
  - Incident angle
  - Reflection

Net heat loss at poles

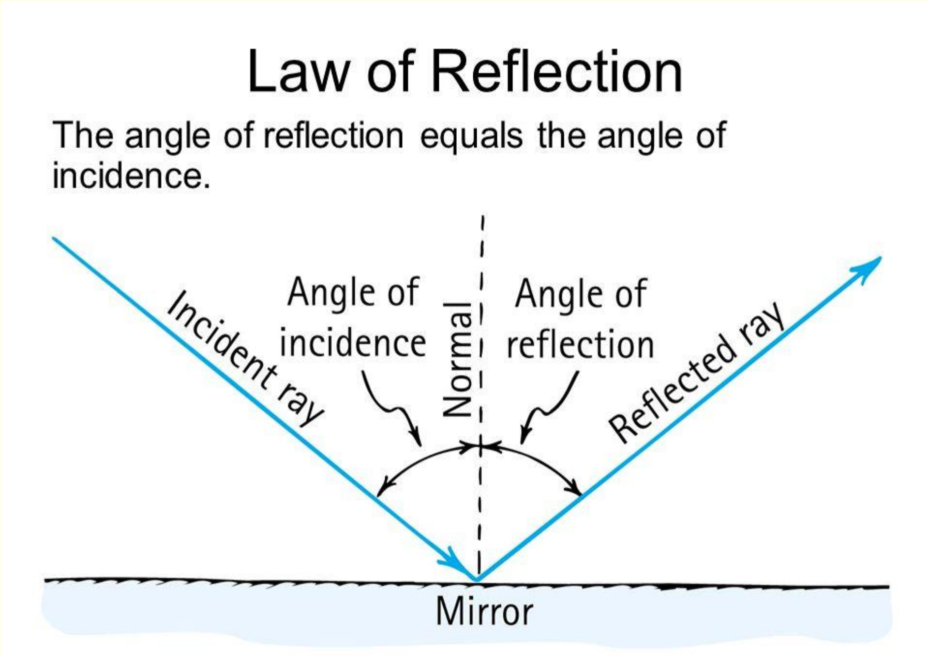
Net heat gain at equator

Uneven Heating

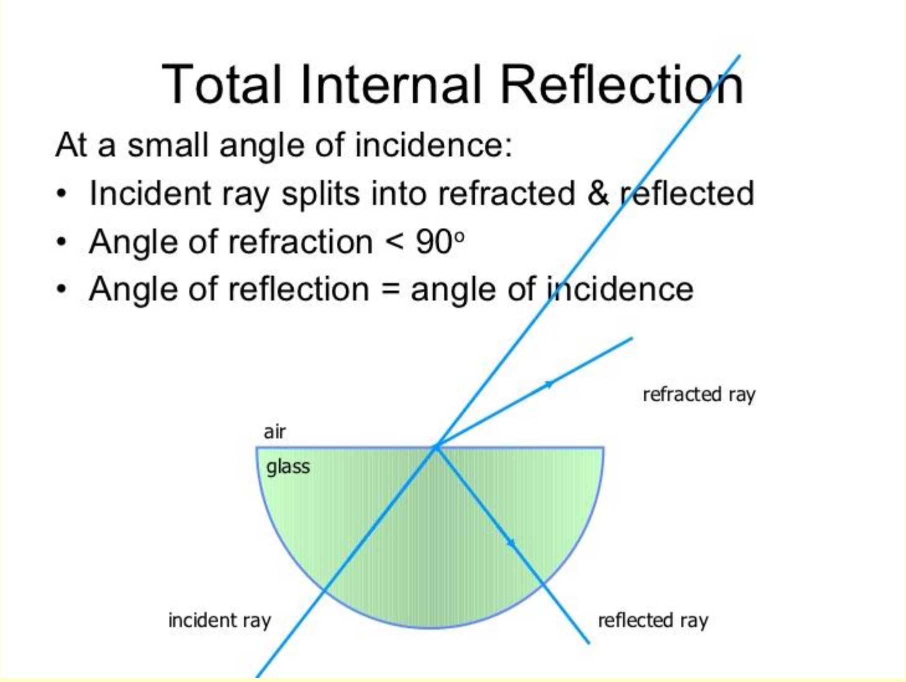
Earth's surface heated unevenly by the Sun



Reflection is the change in direction of a wave at an interface between two media so that the wave returns into the medium from which it originated.

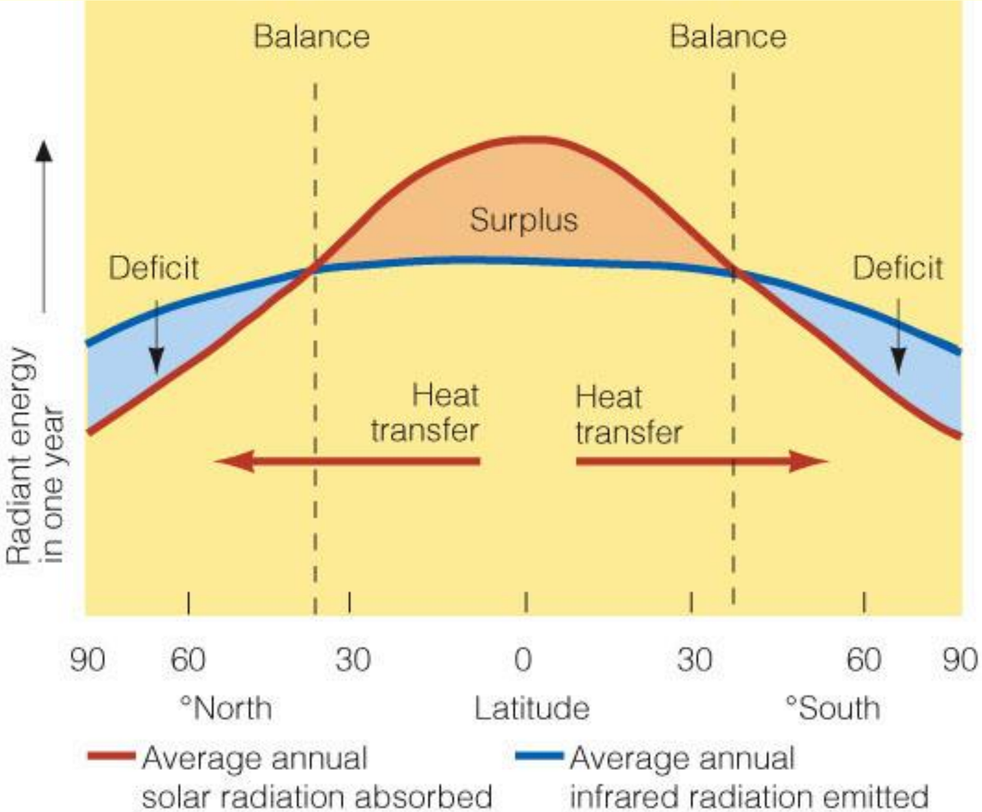


At a small incidence angle, the incident ray splits into a reflected and refracted rays.

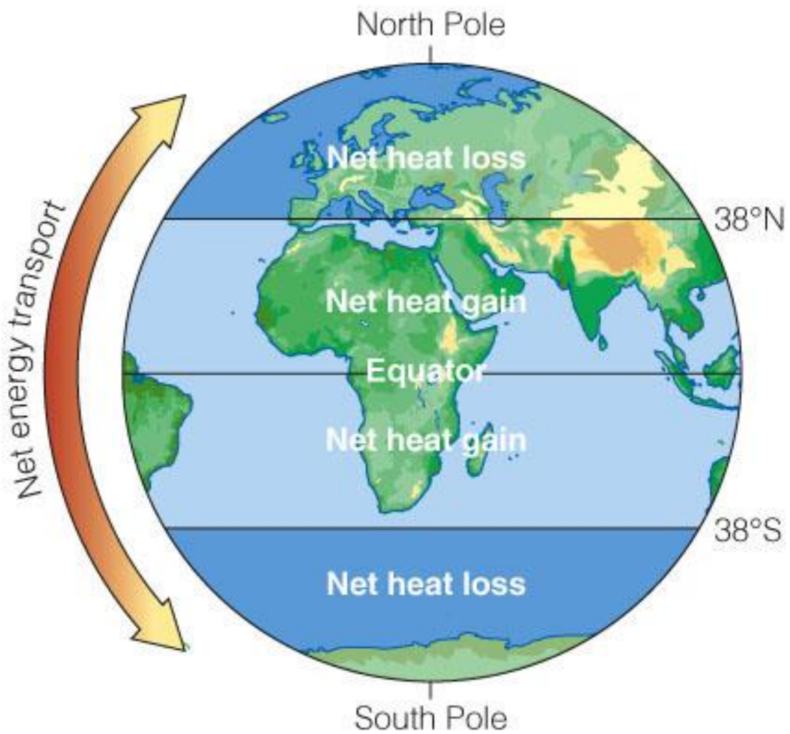


More scattering at smaller incidence angle.

Heat Budget on Earth

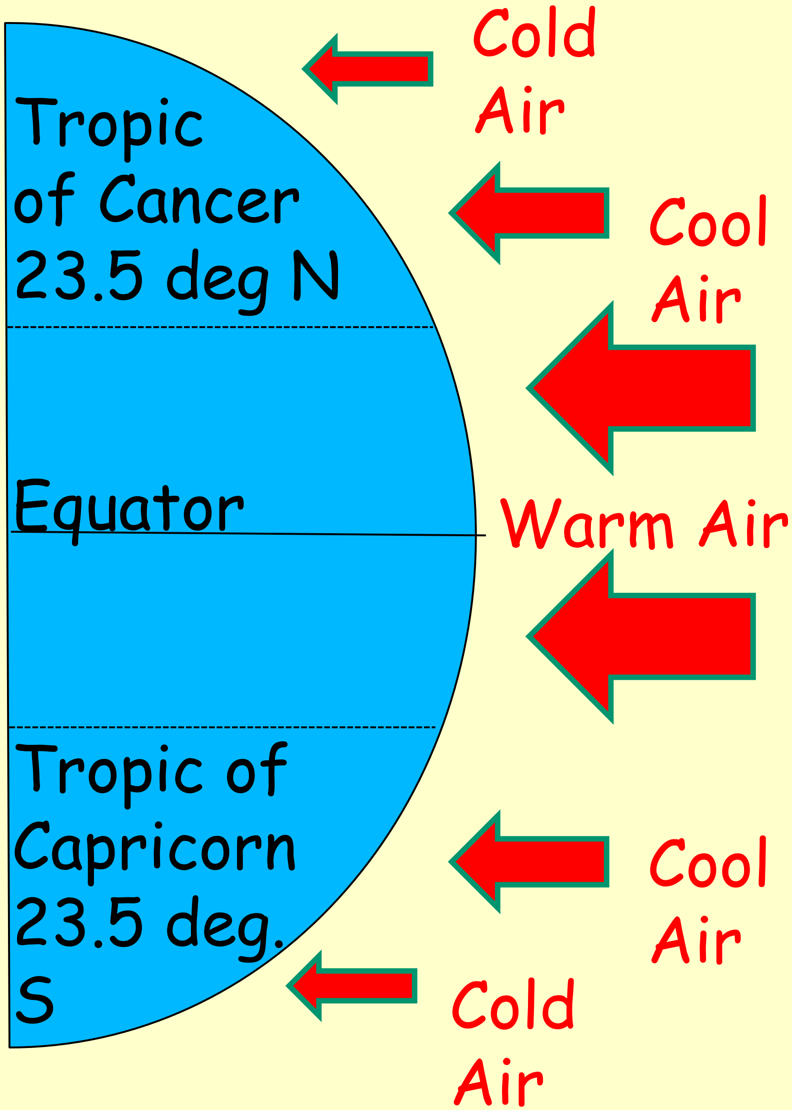


(a) The average annual incoming solar radiation (red line) *absorbed* by Earth is shown along with the average annual infrared radiation (blue line) *emitted* by Earth. Note that polar latitudes lose more heat to space than they gain, and tropical latitudes gain more heat than they lose. Only at about 38°N and 38°S latitudes does the amount of radiation received equal the amount lost. Because the area of heat gained (orange area) equals the area of heat lost (blue areas), Earth's total heat budget is balanced.

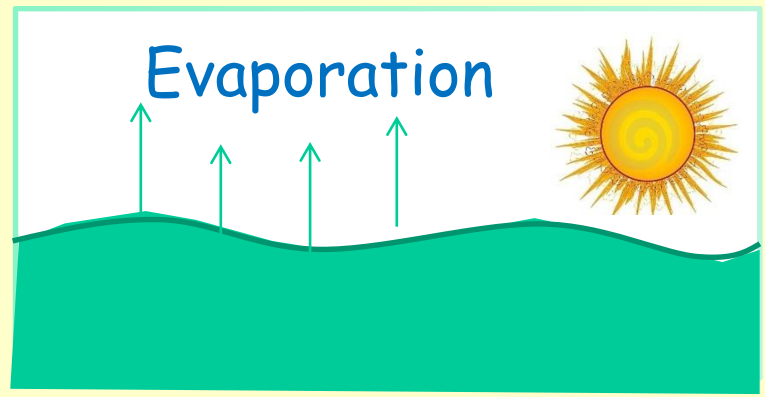


(b) The ocean does not boil away near the equator or freeze solid near the poles because heat is transferred by winds and ocean currents from equatorial to polar regions.

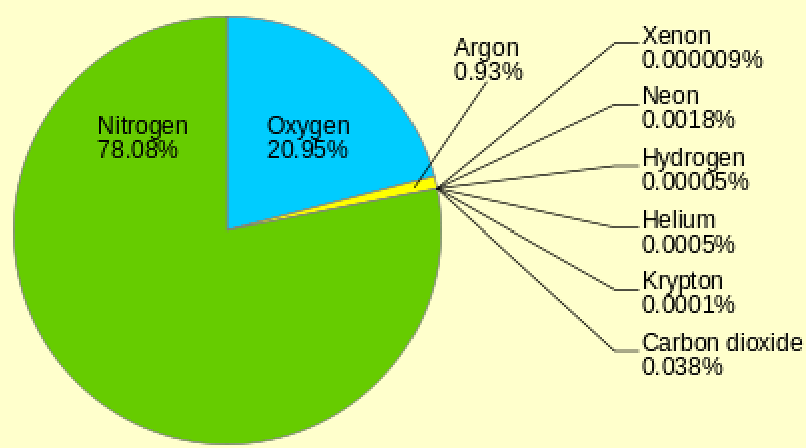
Winds Redistribute Uneven Heat



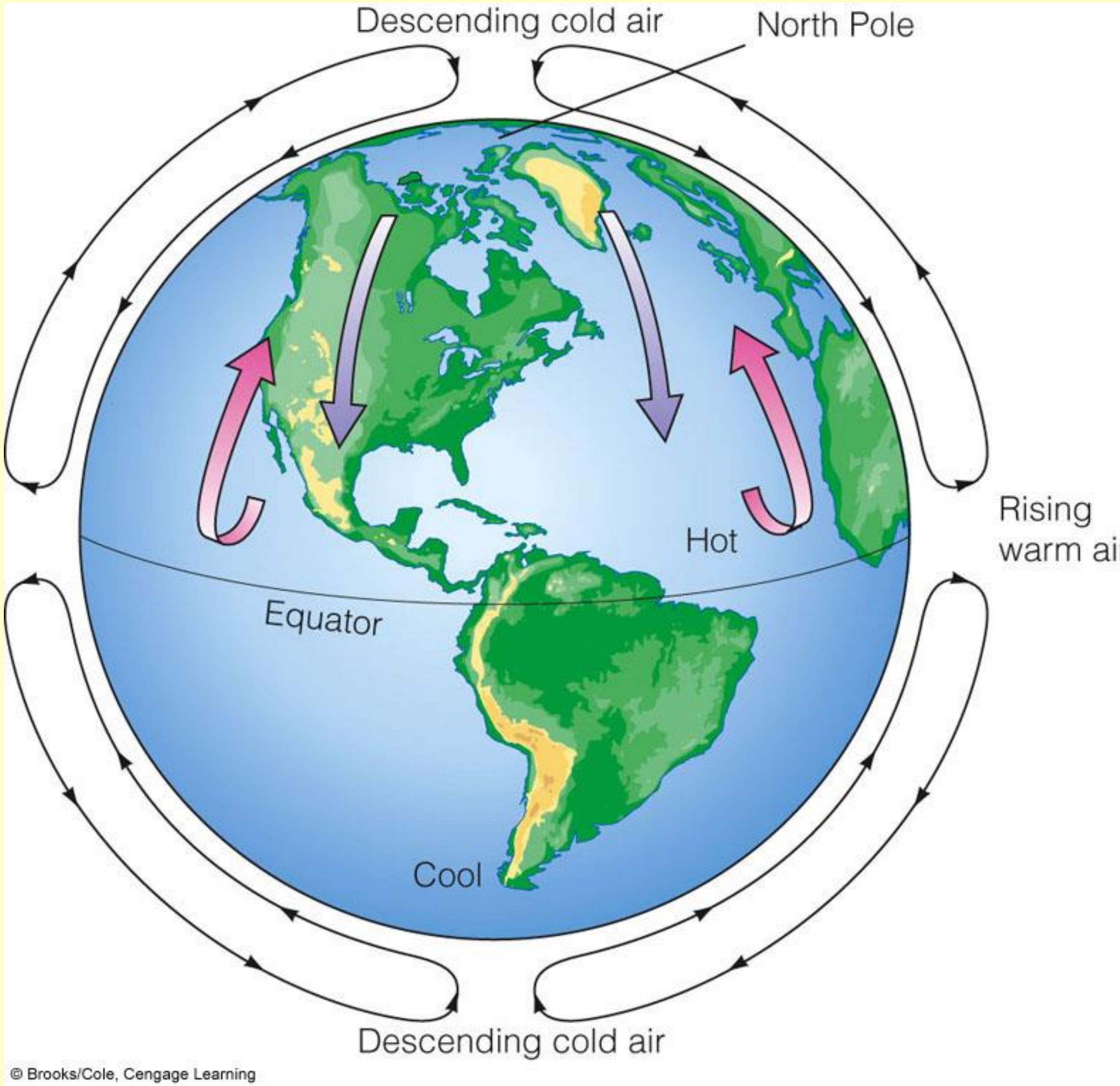
Heating of the Earth's surface leads to seawater evaporation



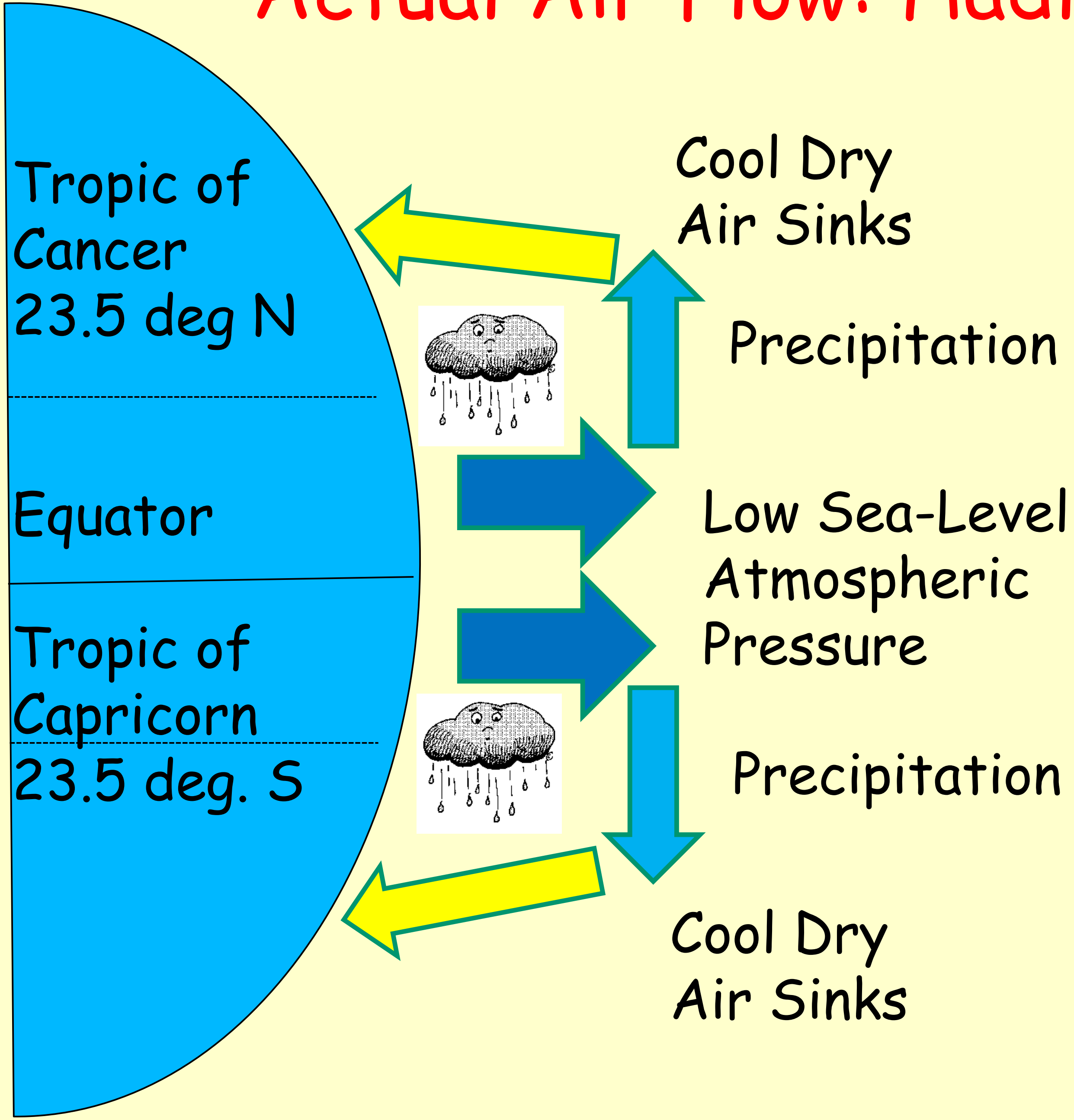
Evaporation leads to lower sea-level atmospheric pressure



Theoretical Air Flow: Atmospheric Cells



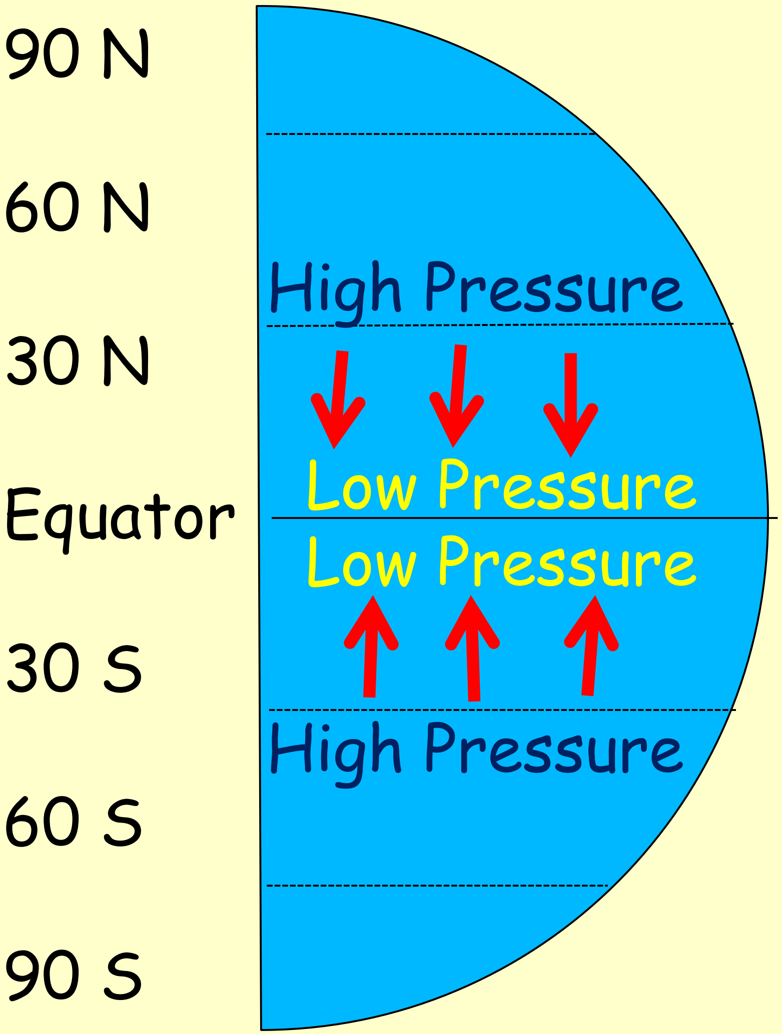
Actual Air Flow: Hadley Cells

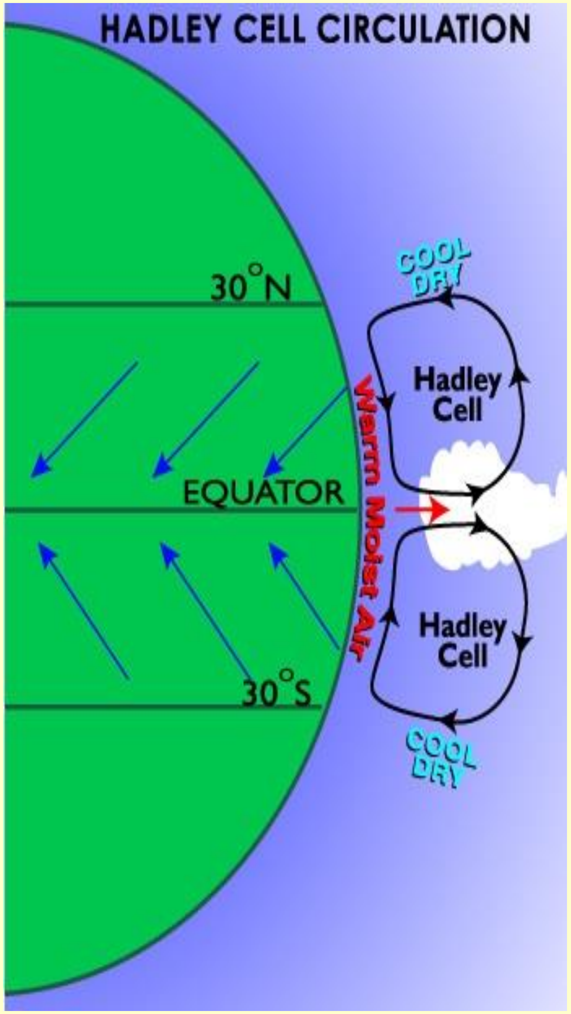


Remember:

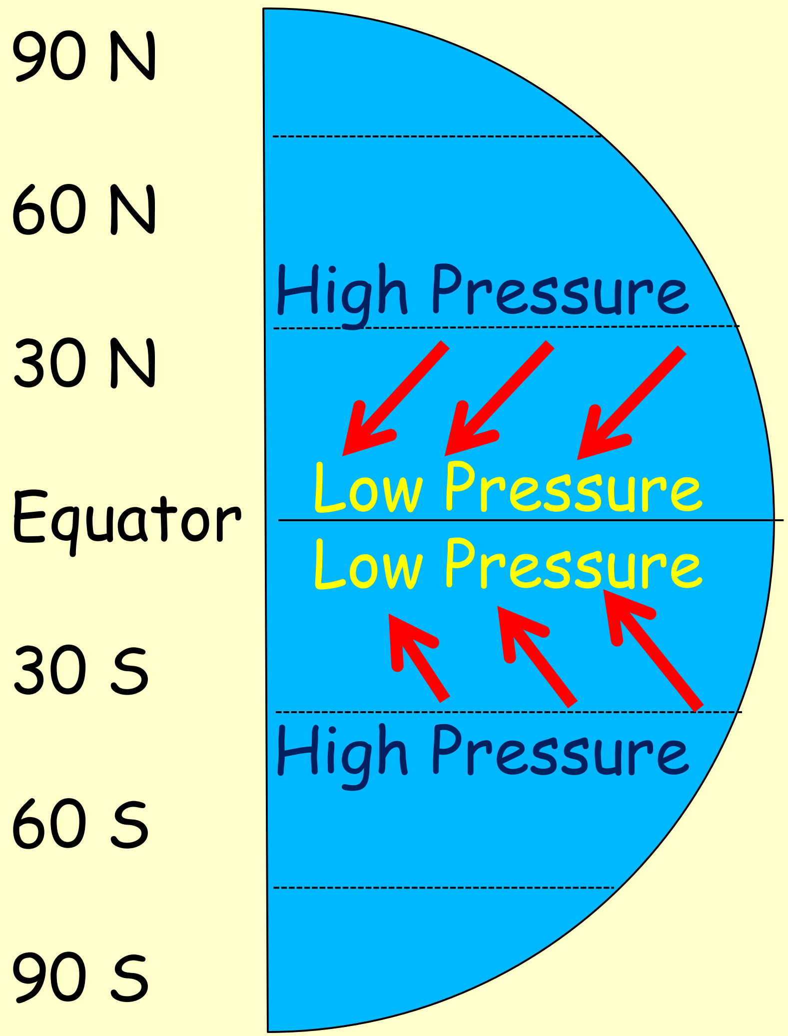
At Earth's surface, winds flow from areas of high to low sea-level atmospheric pressure

Surface Winds



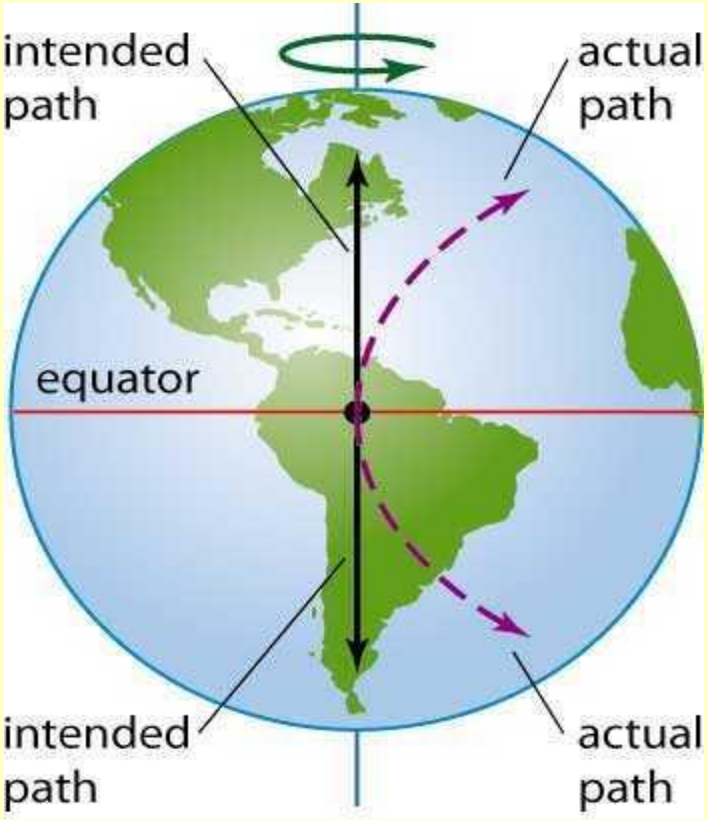


Surface Winds



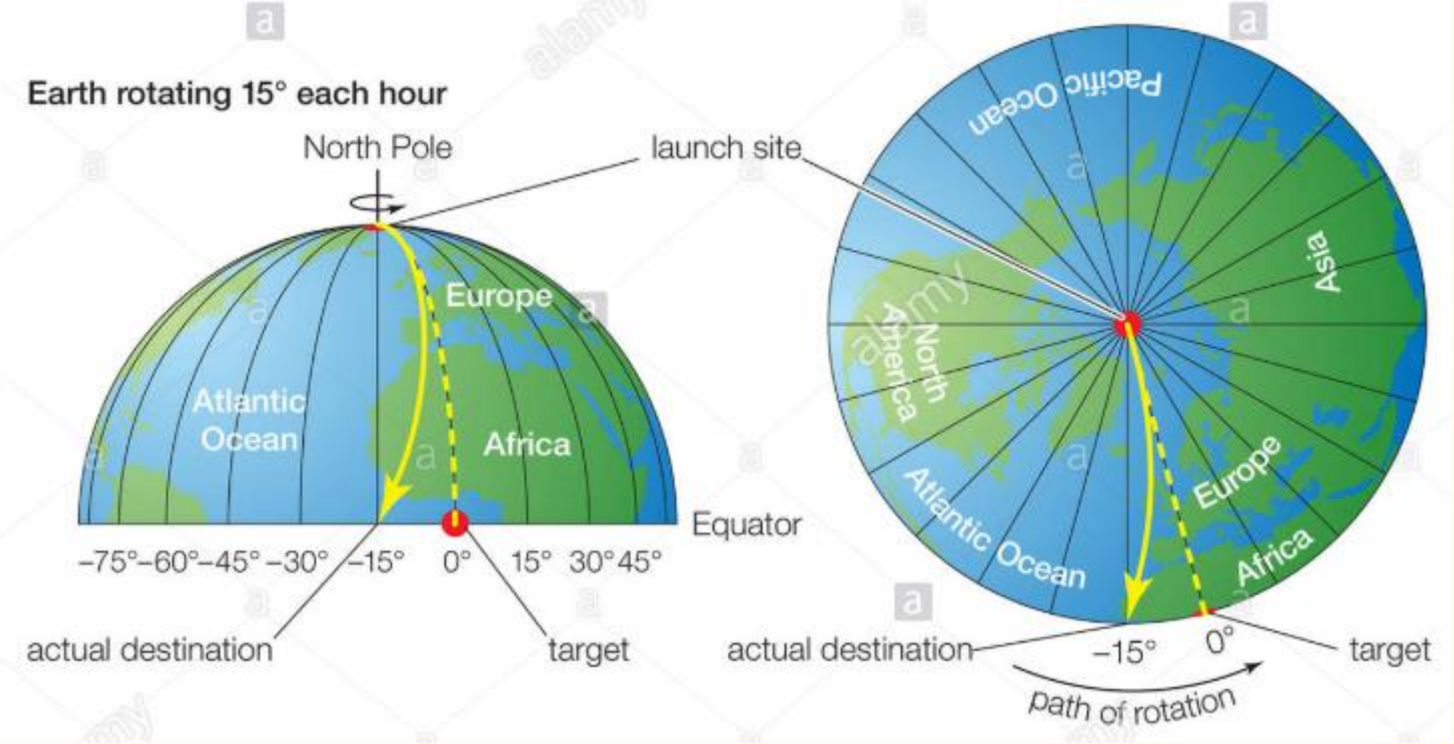
Remember:
The Earth rotates to the East

Coriolis Effect



- Consequence of rotation
- Deflects object's motion to right in N hemisphere and left in S hemisphere
- Empirical Example:
  Draw straight line along a rotating disc
- Theoretical Explanation:
  Conservation of angular momentum

Coriolis Effect Videos

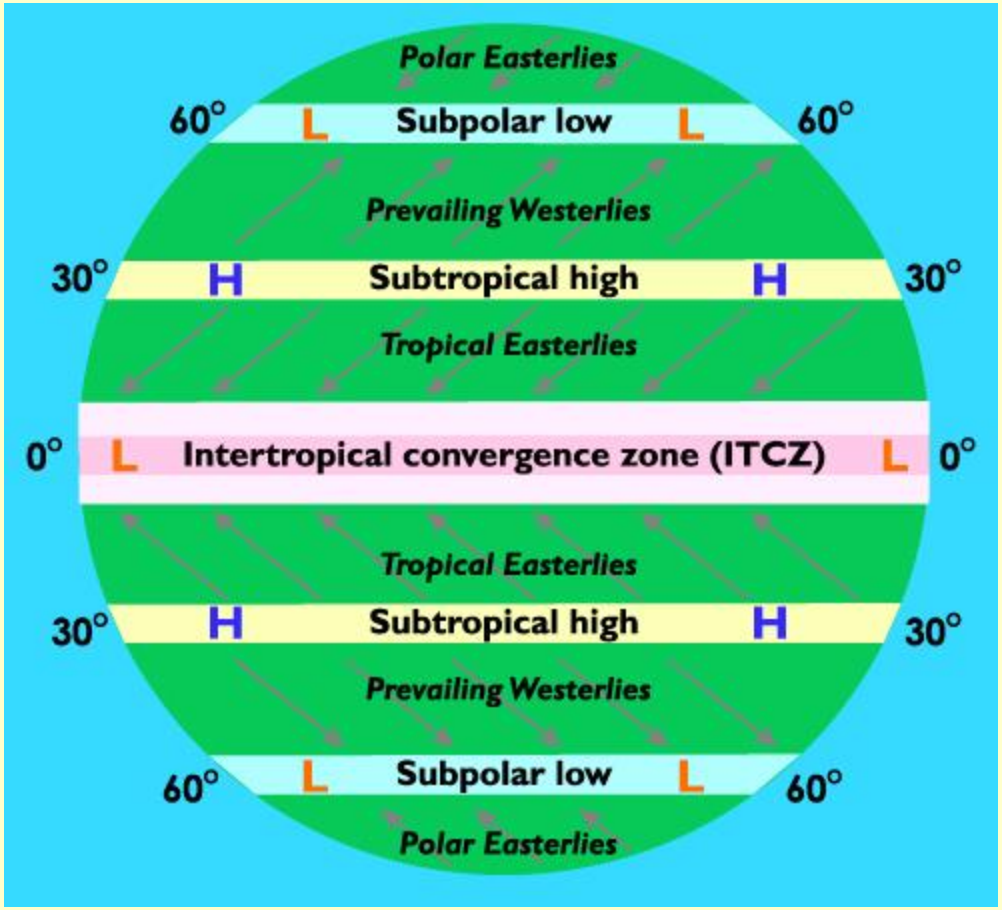


https://www.youtube.com/watch?v=6L5UD240mCQ

https://www.youtube.com/watch?v=aeY9tY9vKgs

https://www.youtube.com/watch?v=UEPThmlk9As

Surface Winds



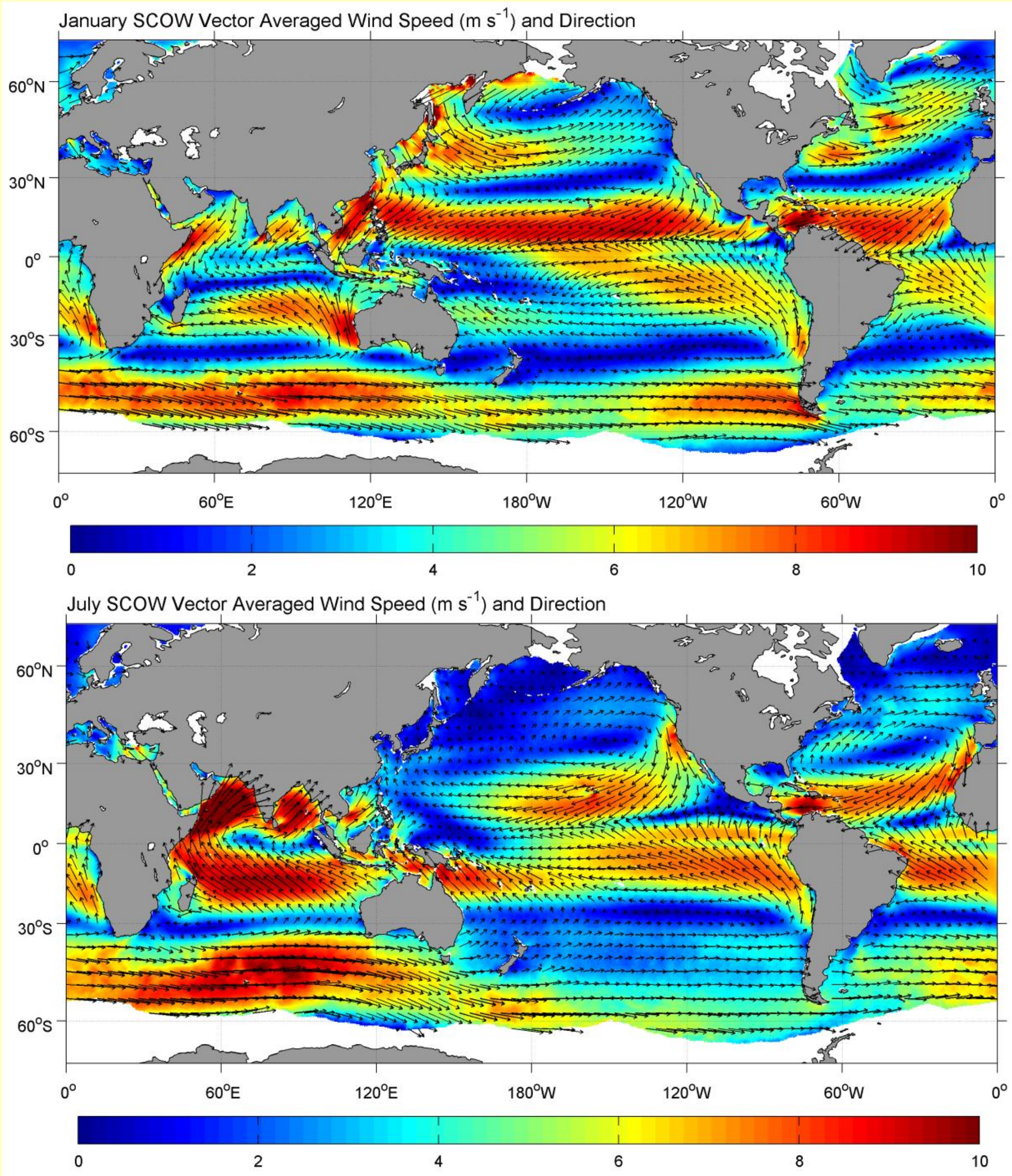
High

Low

High

Remember: At the Earth's surface, winds flow from areas of high to low sea-level atmospheric pressure

Seasonal Climatology Wind Maps



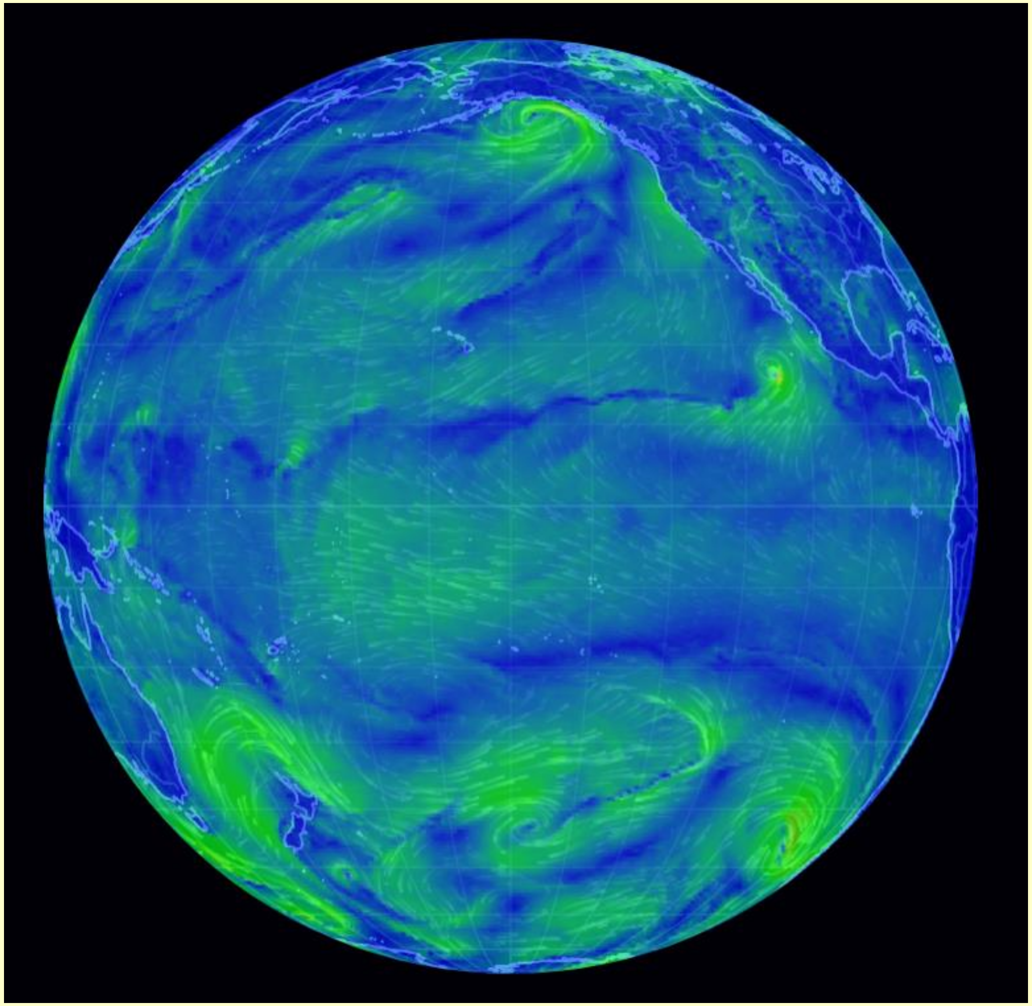
January:

July:

QuikSCAT Scatterometer Climatology of Ocean Winds (SCOW) (1999 – 2007)

Instantaneous Wind Maps

Actual depiction of surface winds



Atmospheric Cells

High

Low

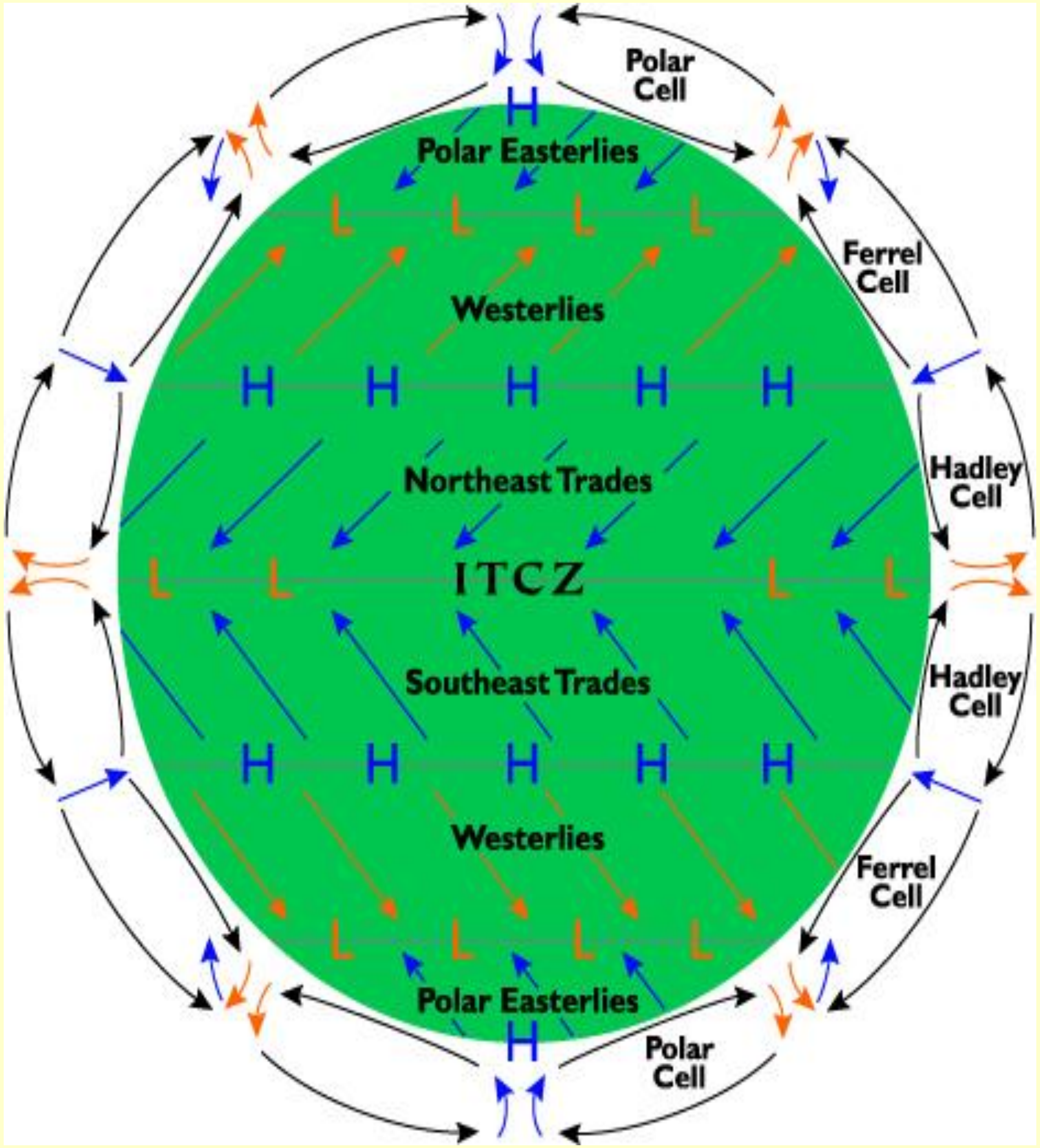
High

Low

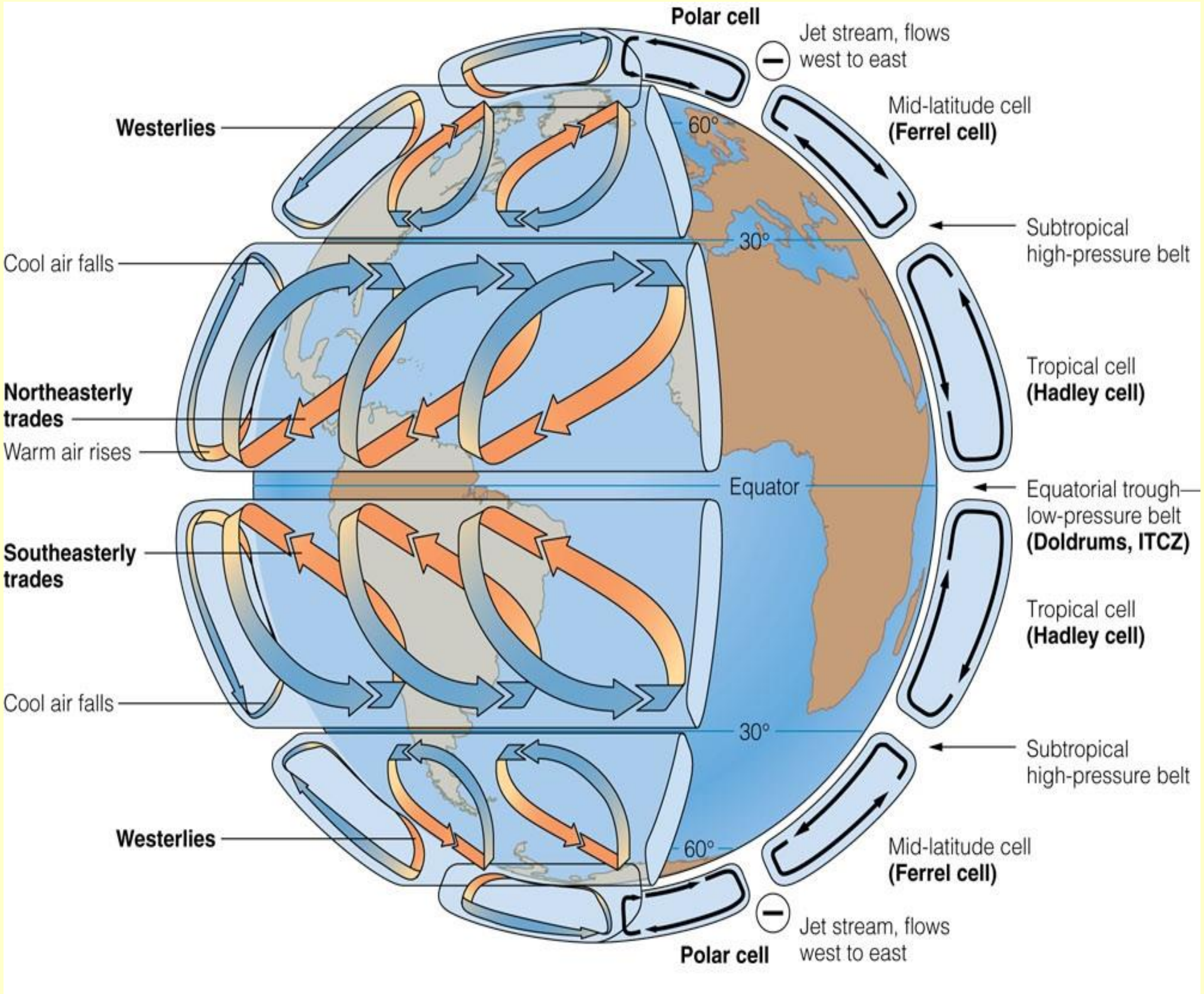
High

Low

High



Atmospheric Pressure - Terminology



Subpolar Low

Mid-lat Cell (Ferrell)

Subtropical High

Tropical Cell (Hadley)

Equatorial Trough

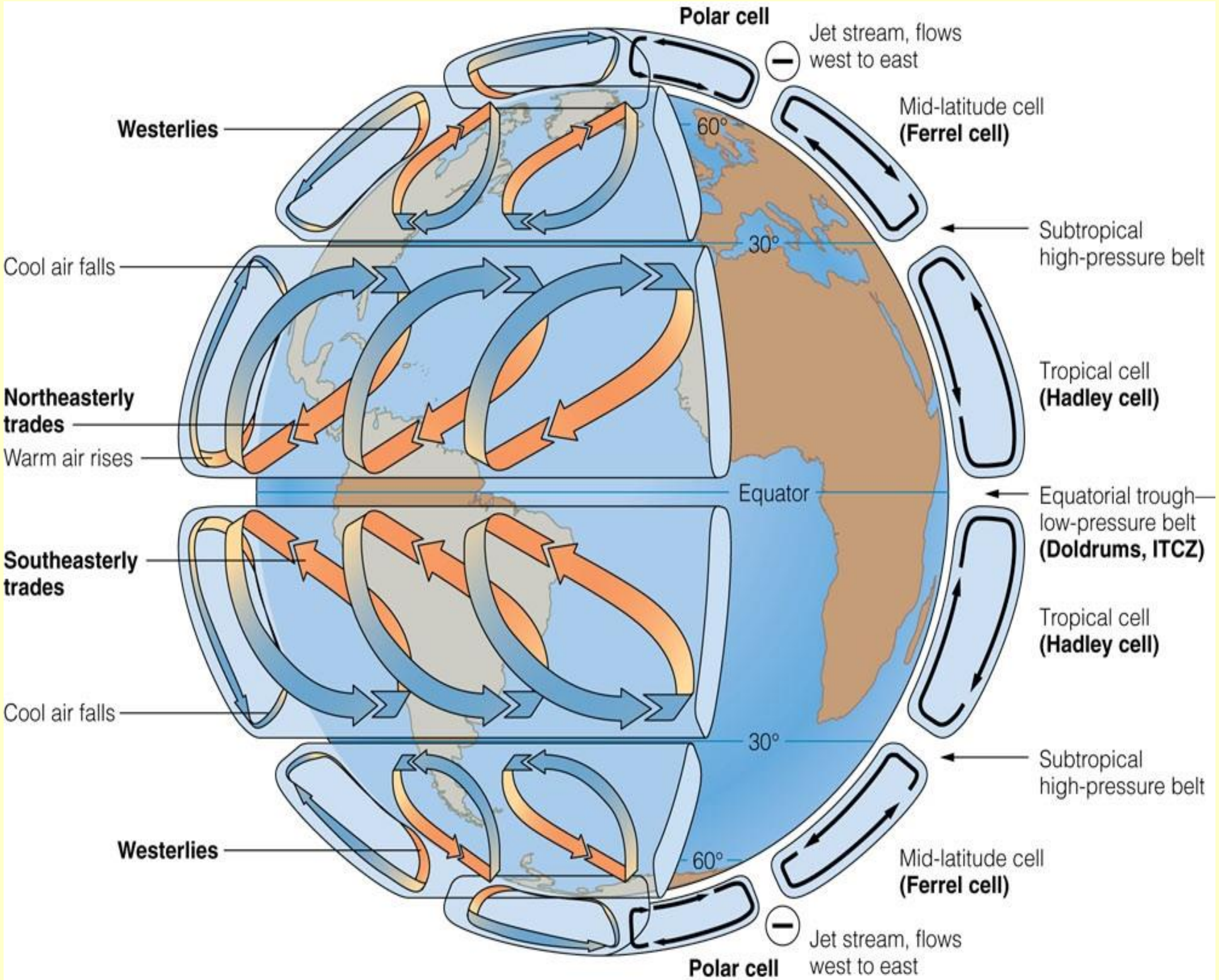
Tropical Cell (Hadley)

Subtropical High

Mid-lat Cell (Ferrell)

Subpolar Low

Winds - Terminology



Westerlies

Northeasterly Trades

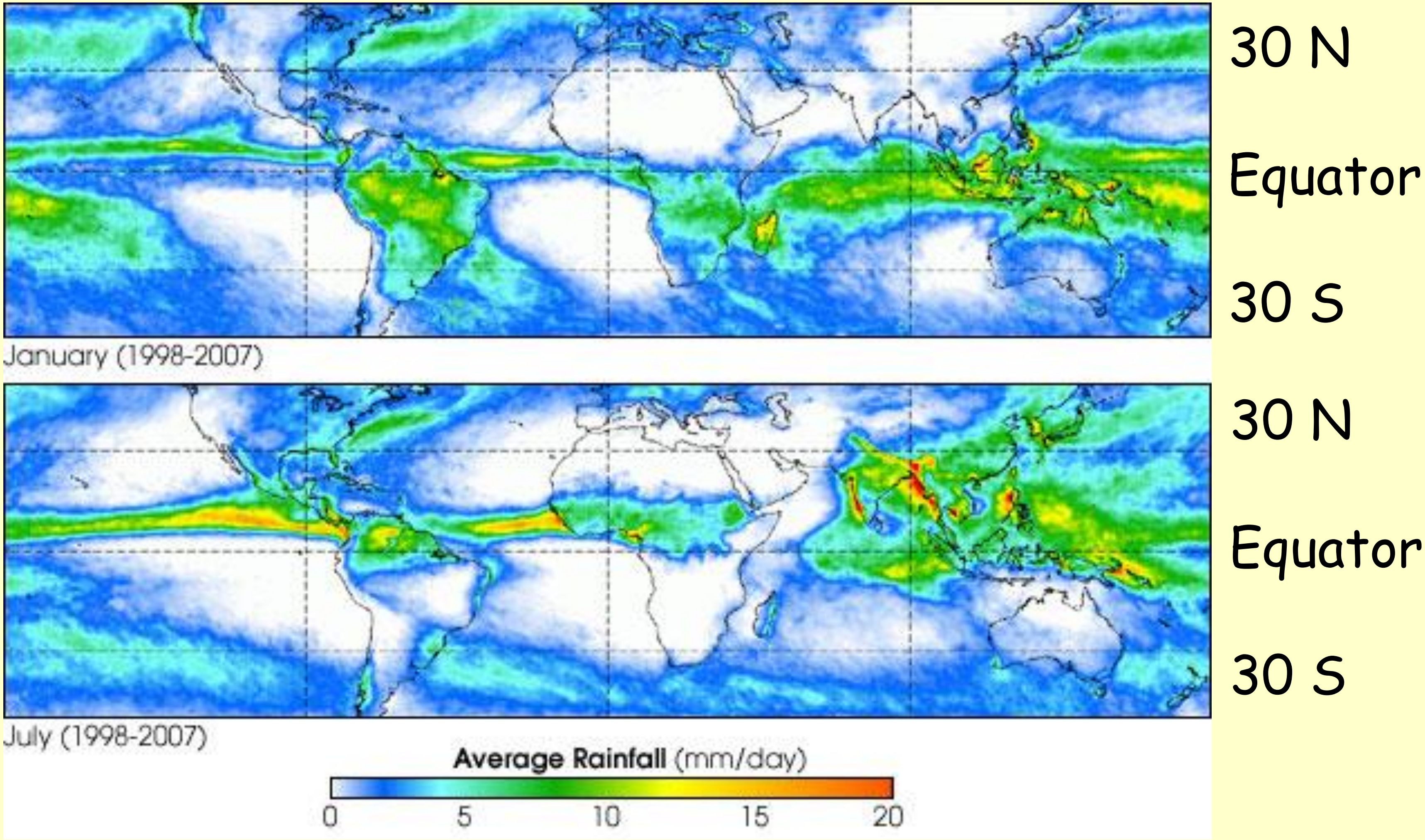
Equatorial Trough

Southeasterly Trades

Westerlies

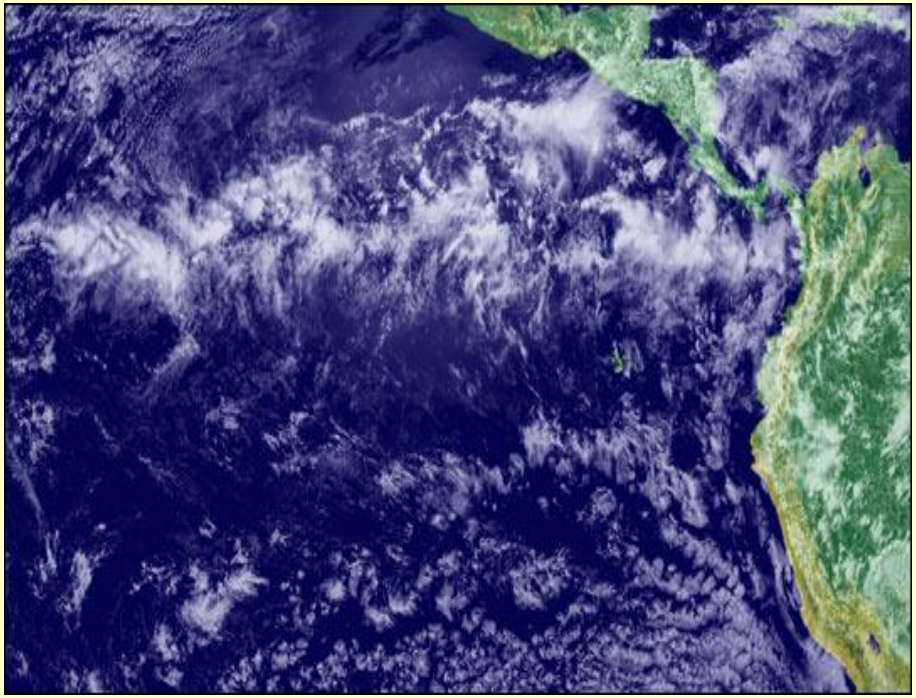
Remember: Winds named by the direction they blow from

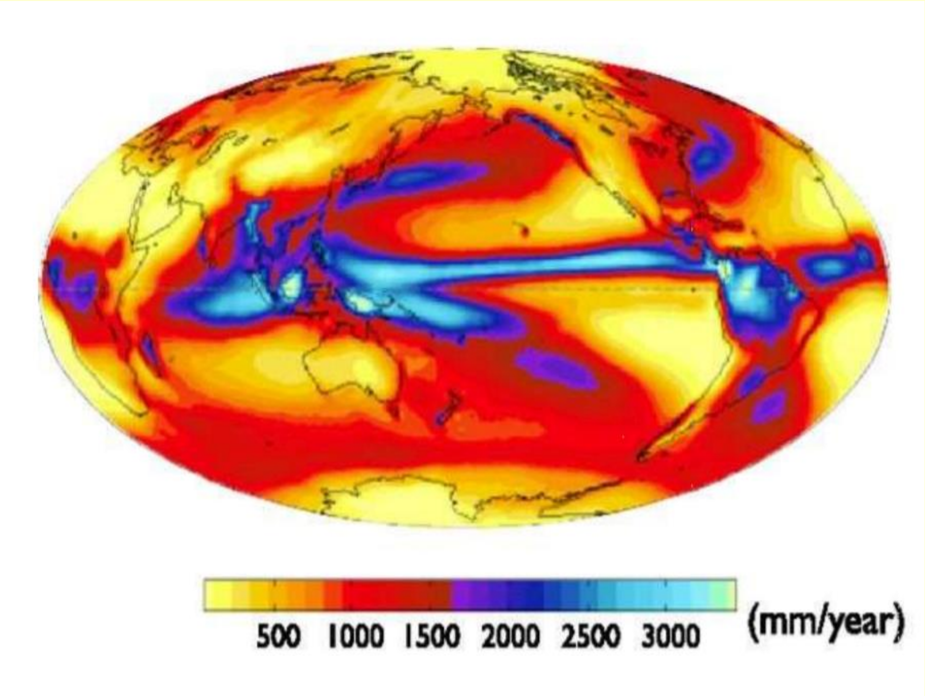
Precipitation Maps



Tropical Precipitation Band (Equator)
Low Rainfall (15 - 45 degrees)

Cloudiness and Precipitation along ITCZ



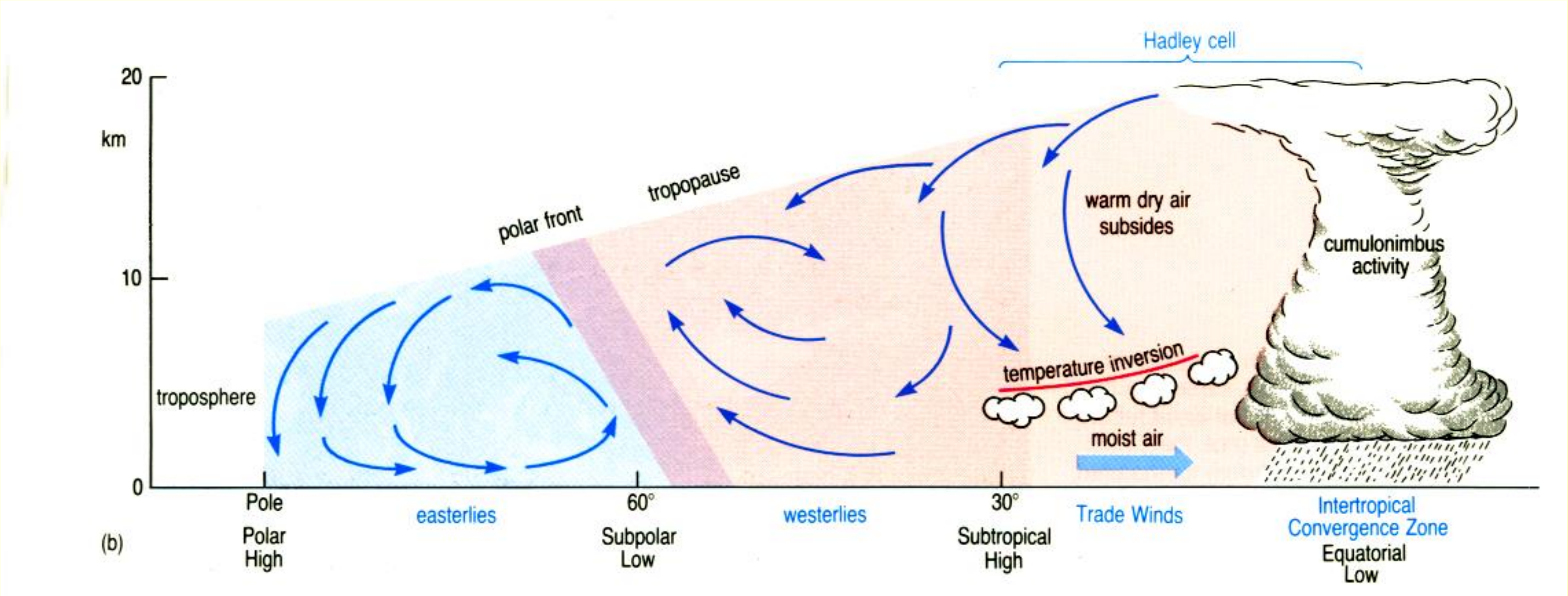


ITCZ characterized by enhanced cloud cover:

Cumulus clouds and convection (NASA)

ITCZ characterized by enhanced precipitation: (Global Precipitation Climatology Project)

Hadley Cells

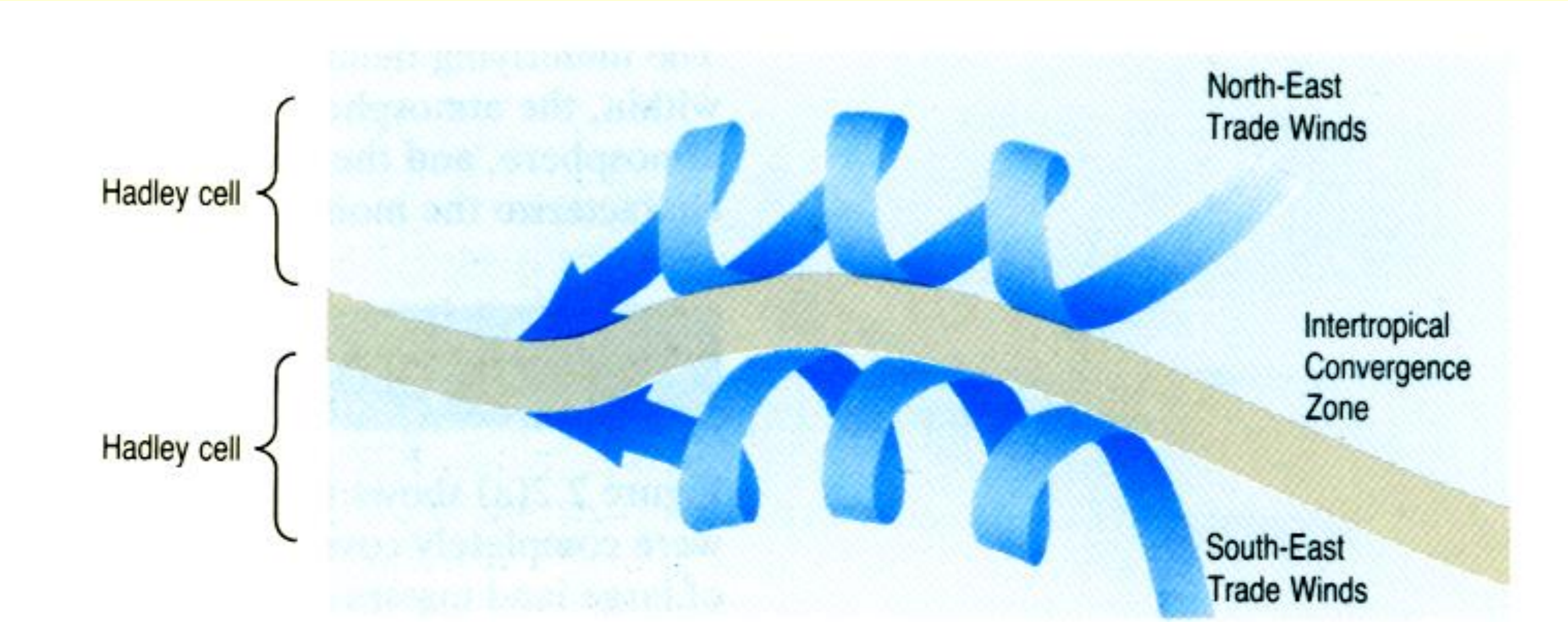


- North – South Gradient:

  Varying thickness of troposphere

  Showing three main atmospheric cells

ITCZ

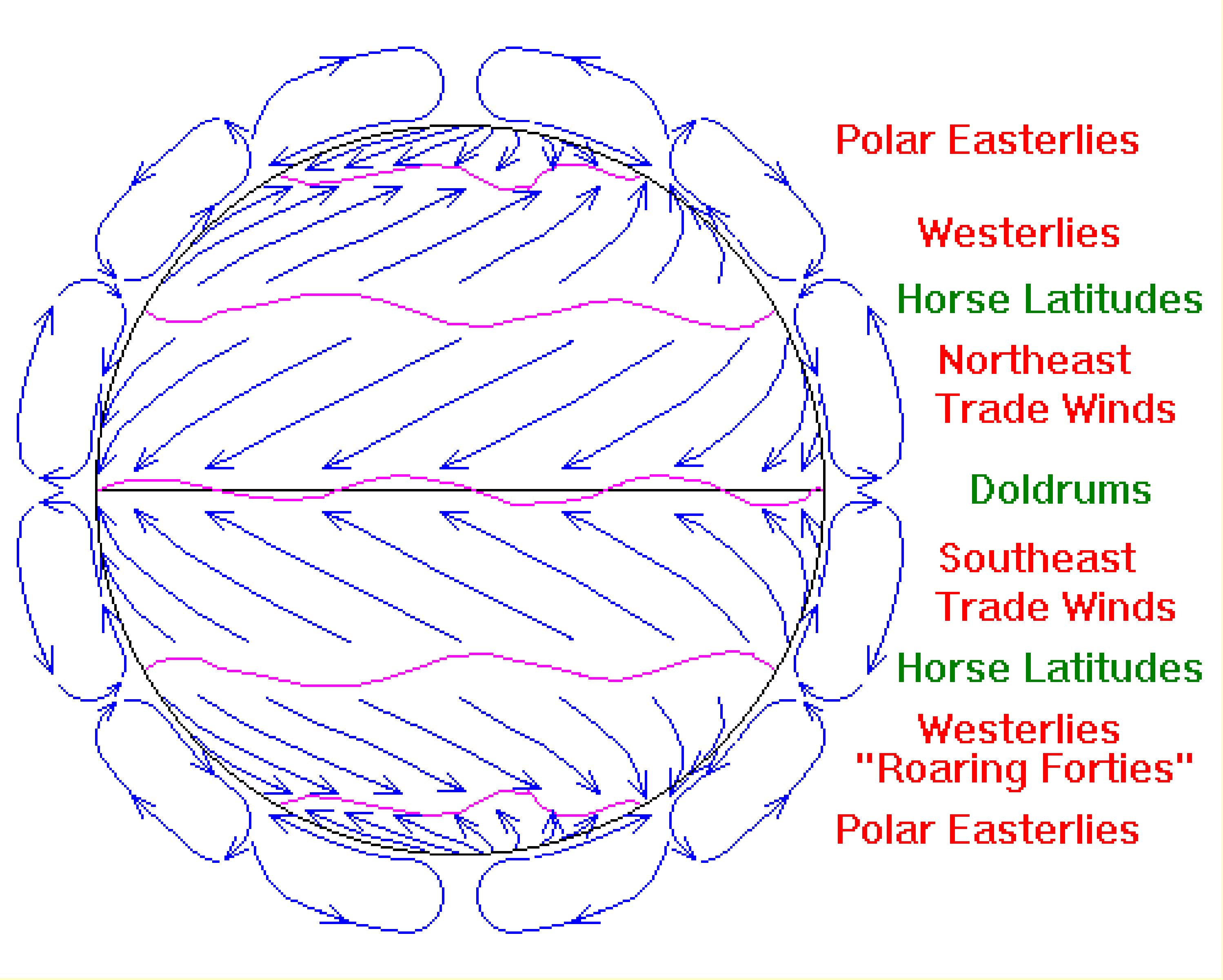


- East – West Variability in ITCZ position:

  Spatial oscillations north and south

  Seasonal shifts north and south

Climatic Zones



Wind and Atmospheric Pressure

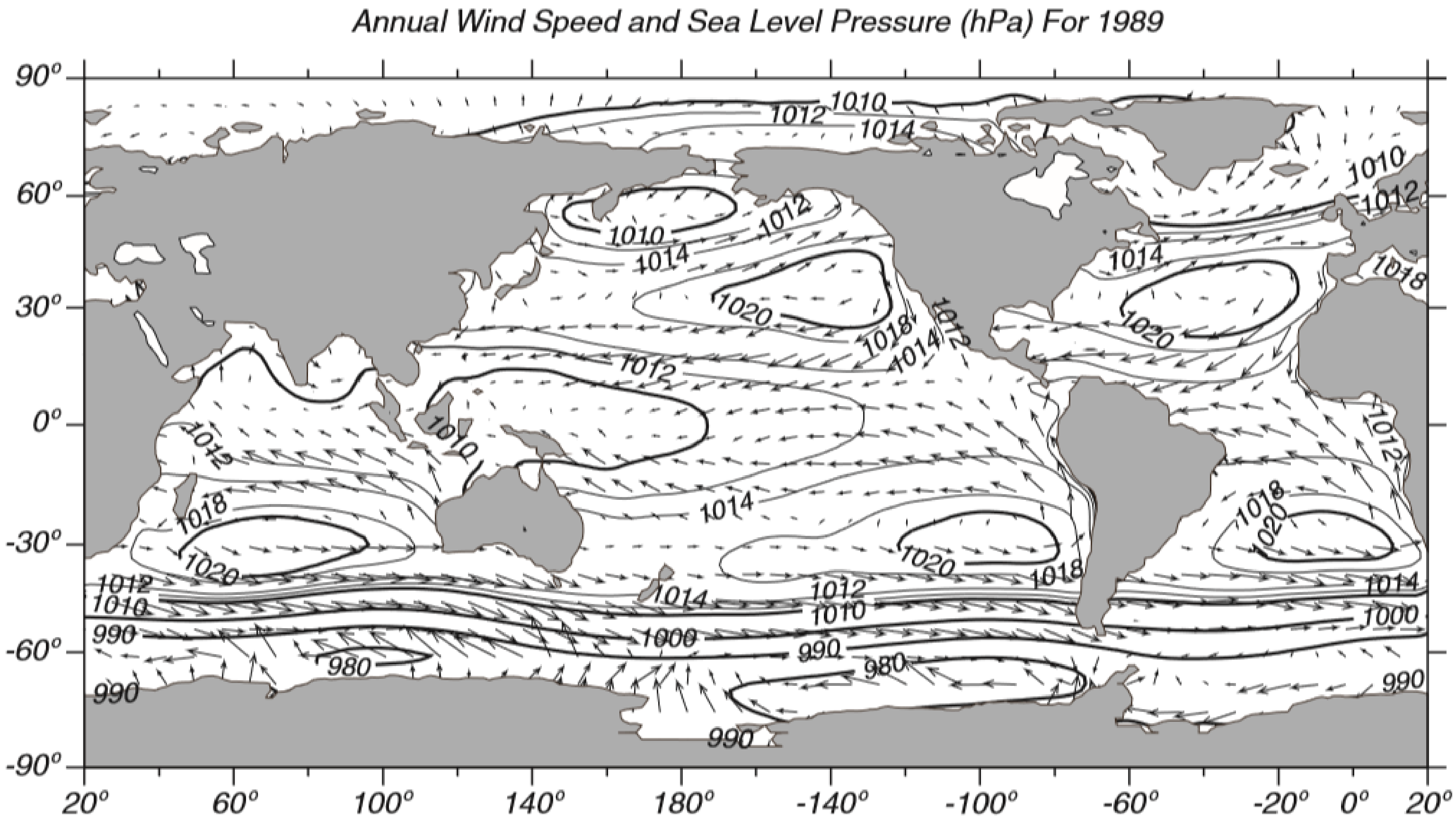
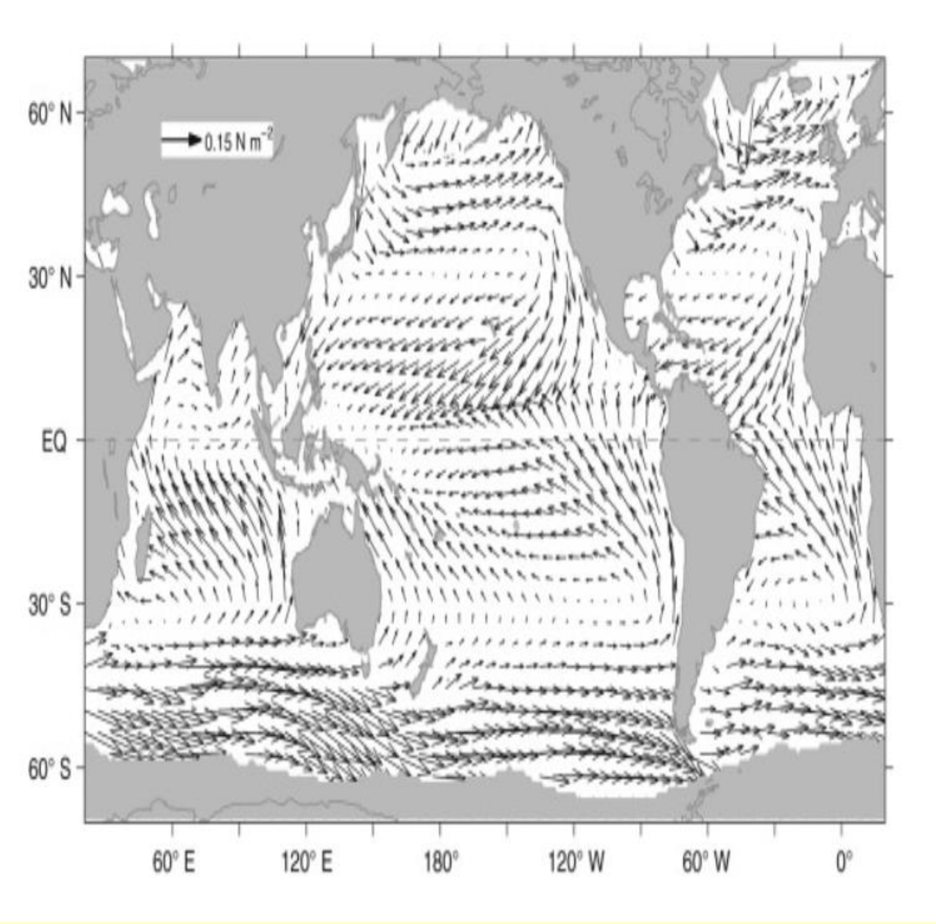


Figure 4.2 Map of mean annual wind velocity calculated from Trenberth et al. (1990) and sea-level pressure for 1989 from the NASA Goddard Space Flight Center's Data Assimilation Office (Schubert et al. 1993). The winds near 140°W in the equatorial Pacific are about 8 m/s.

Wind Stress

- The force of the wind (the work done by wind)

- Wind Stress = T
  - Horizontal force of wind on the sea surface.
  - It is the vertical transfer of horizontal momentum from the atmosphere to ocean.



(Units: N m^{-2})

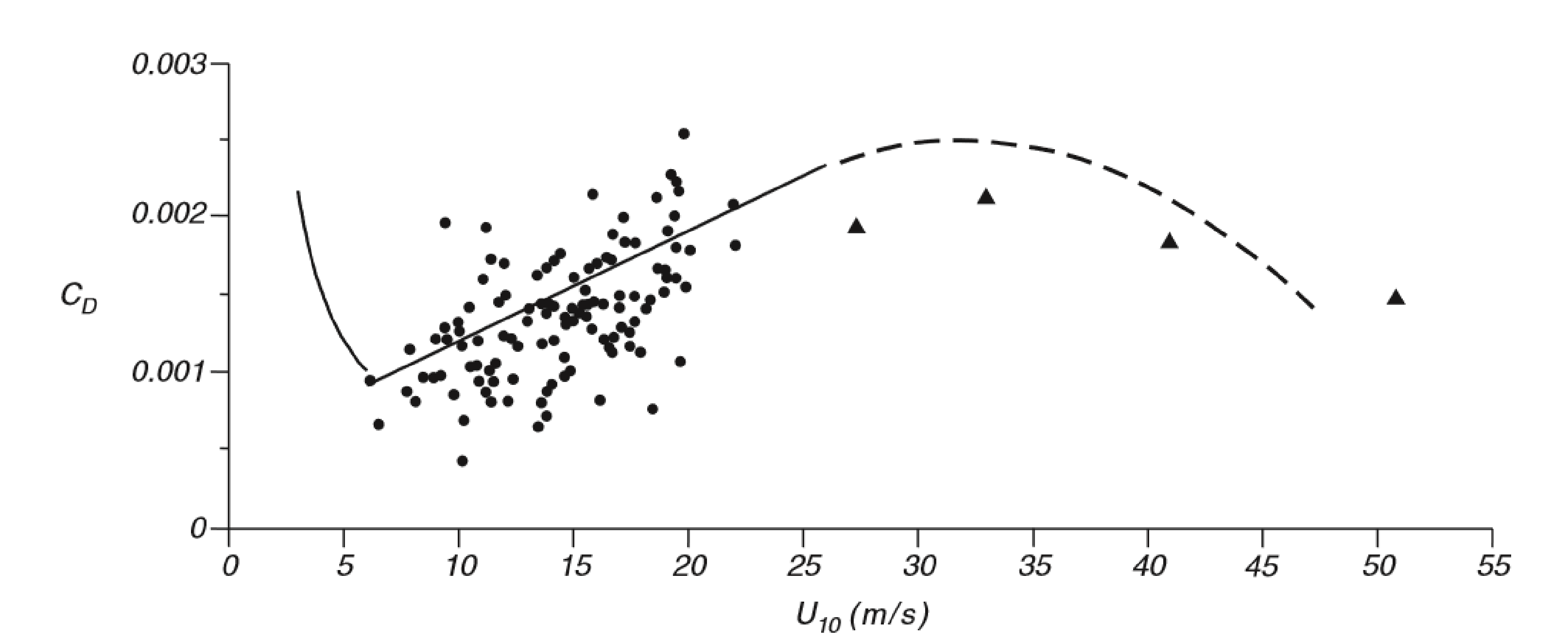
Wind Stress

$\boxed{T = \rho_a * C_D * U_{10}^2}$ where:

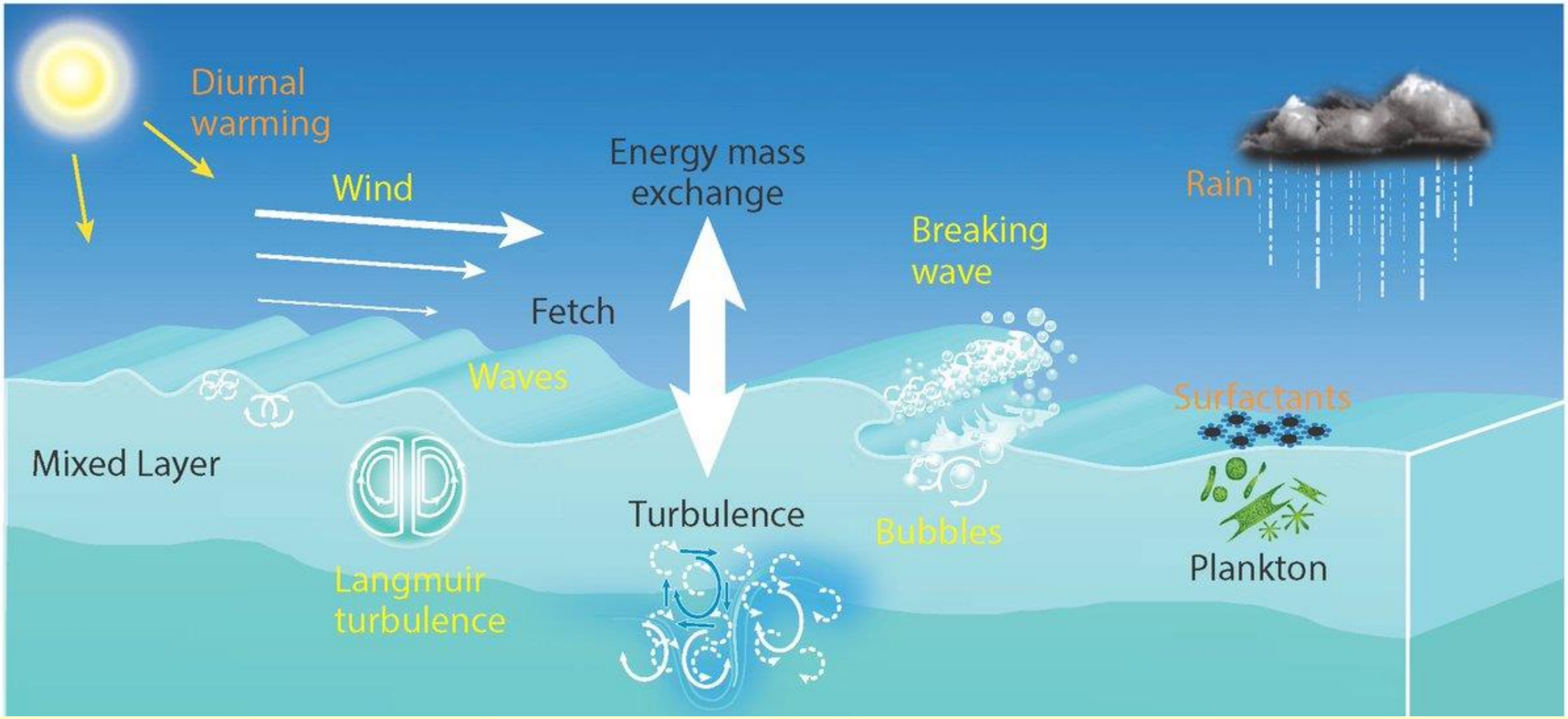
ρ_a is the density of air (1.3 kg m^{-3})

U_{10} is wind speed at 10 meters

C_D is the drag coefficient



Boundary (Transition) Layer



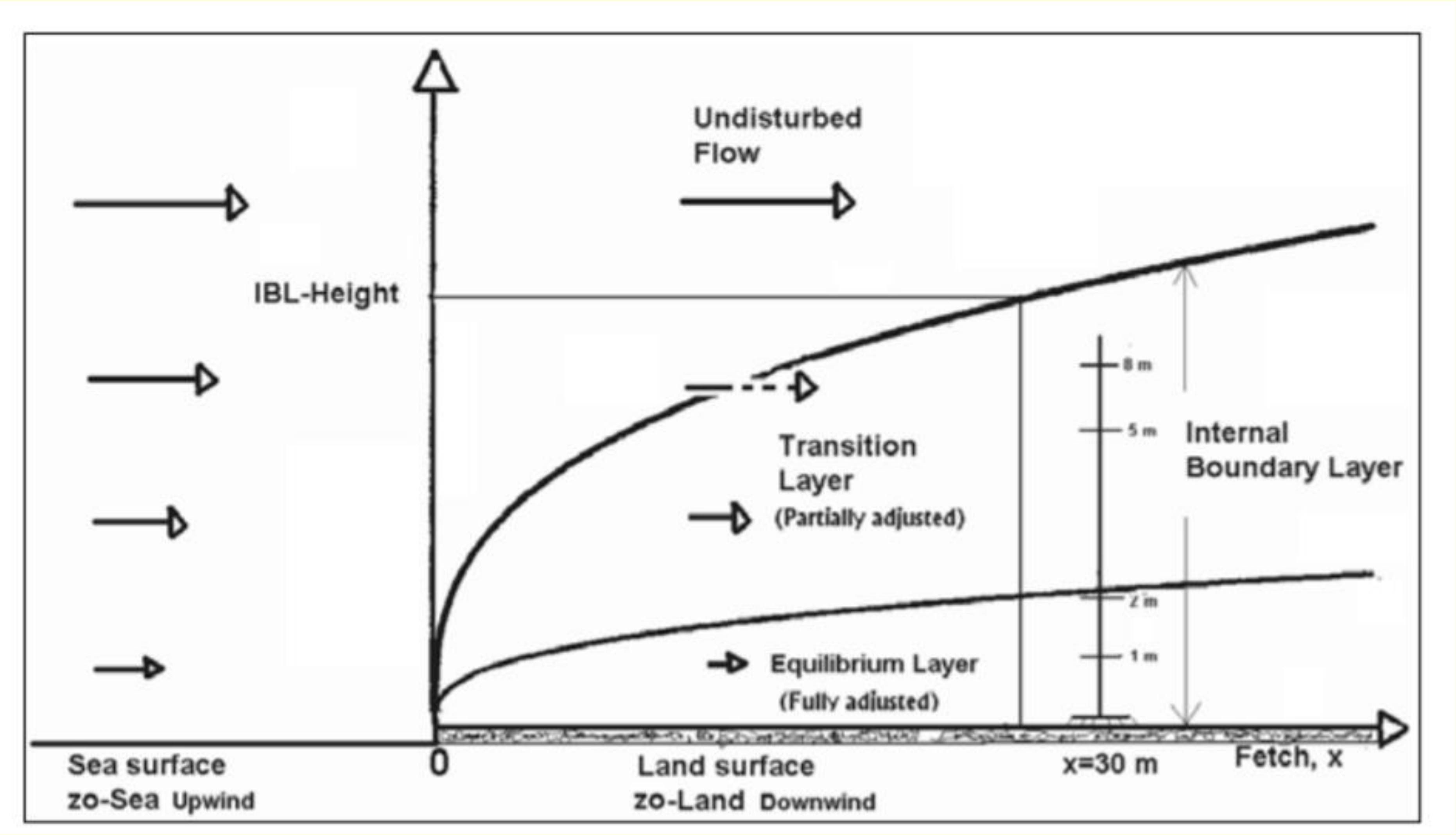
$C_D \approx 10^{-3}$ is the empirical drag coefficient. It is not a constant; it varies with wind speed. The formula is based on *in-situ* measurements; however, it needs to be improved, especially for strong winds.

- As wind speed increases, turbulence increases:

$\boxed{\text{Turbulence} \sim U_0^3}$

- Mixing increases and deepens
- Surface convergence and divergence

Ocean Influence on the Atmosphere



Air – Sea Interface

The atmospheric boundary (or transition) layer is defined as the lowest part of the troposphere that is directly influenced by the presence of the earth's surface.

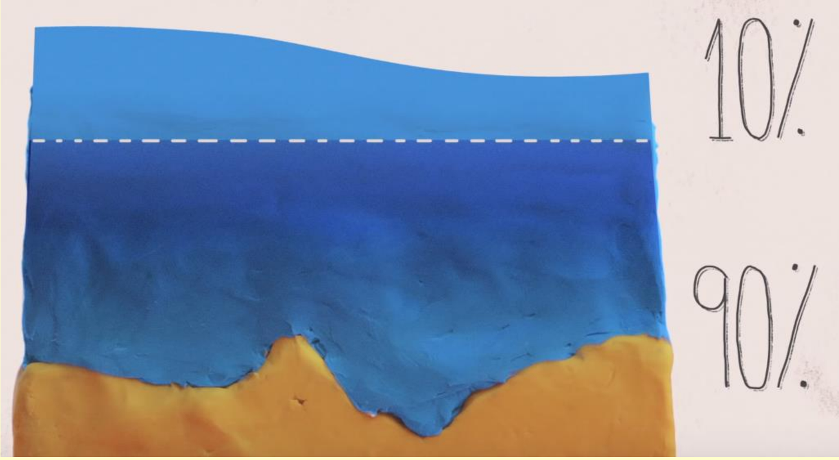
Over the ocean, it is influenced by the turbulent drag of the wind on the sea and the fluxes of heat.

Its thickness (Zi) varies from 10s of m for weak winds blowing over water colder than the air to 1000 m for stronger winds blowing over water warmer than the air.

The surface (or equilibrium) layer is the lowest part of the atmospheric boundary layer, closest to the ocean surface. Within this layer, of thickness ~ 0.1 Zi, vertical fluxes of heat and momentum are nearly constant.

Overview of Ocean Circulation

Ocean divided into two layers:



Surface circulation: Wind-driven

Largely east-west (Zonal)

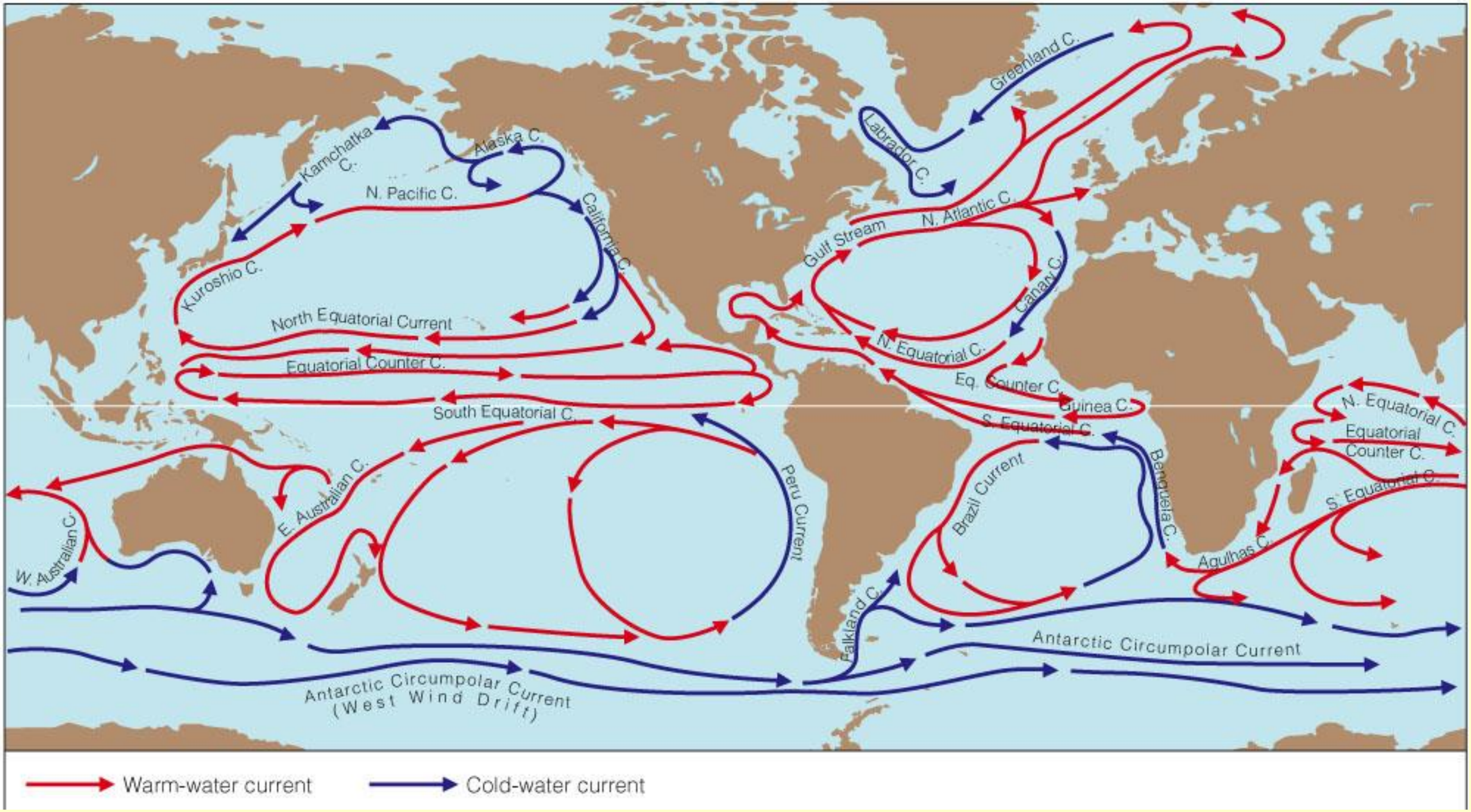
~ Top 10% of water column

Deep circulation: Thermohaline (density-driven)

Largely north-south (Meridional) and Overturning

~ Remaining 90% of water column

Surface Ocean Currents



World ocean's major surface currents. The powerful western boundary currents flow along the western boundaries of ocean basins in *both* hemispheres.

Boundary Currents

Western Boundary

- Kuroshio
- Gulf Stream
- Agulhas
- East Australian
- Brazil

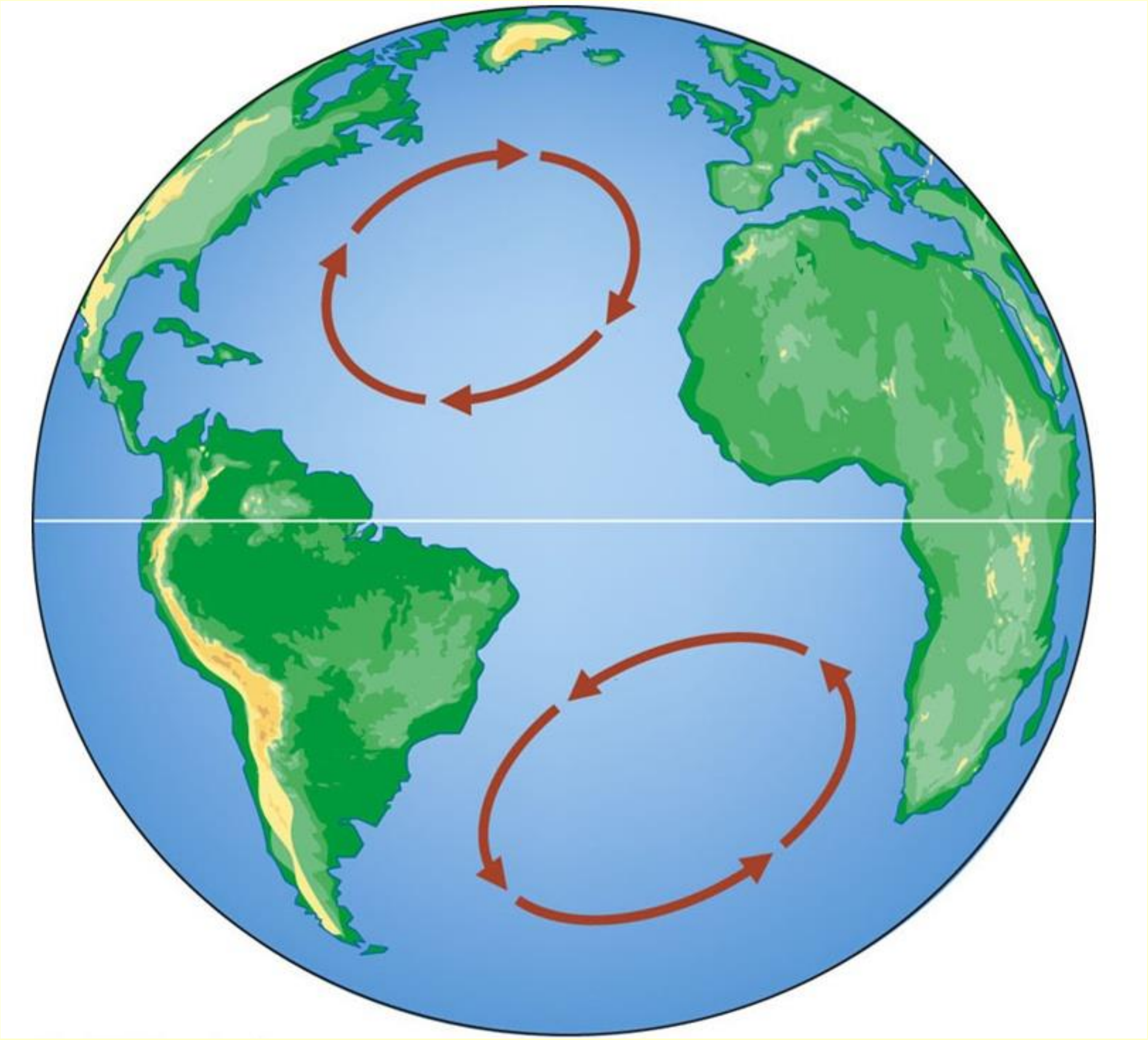
- These are fast, narrow and deep

Eastern Boundary

- Peru/Chile
- Benguela
- Canary
- California
- Oyashio
- Labrador

- These are slow, broad and shallow

Gyres = large systems of rotating ocean currents



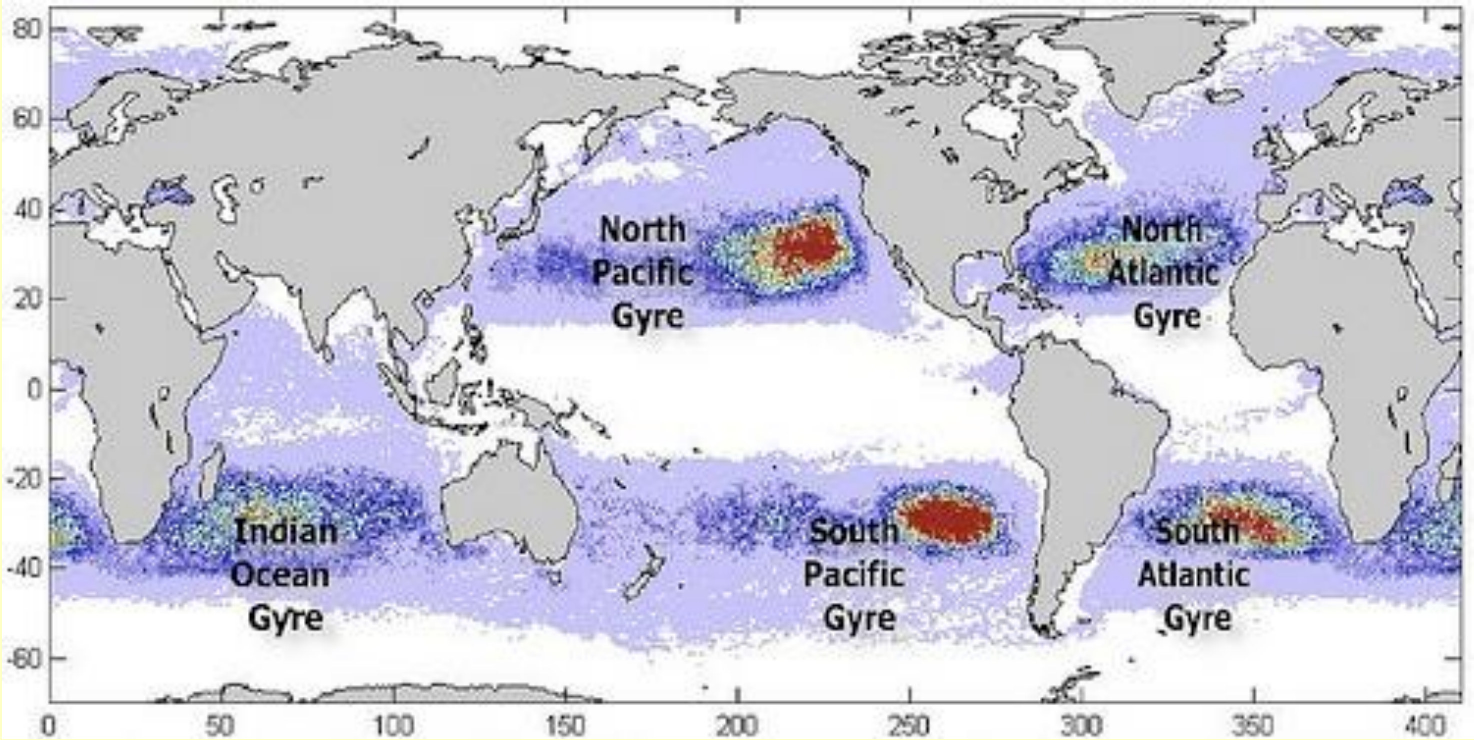
Anti-cyclonic: leads to higher pressure in the center

Cyclonic: leads to lower pressure in the center

Major Gyre Systems

Subtropical Gyres (5 of these)

- Clockwise in the Northern Hemisphere
- Counterclockwise in the Southern Hemisphere
- Influenced by the Trades and the Westerlies
- Flow intensifies to the West



Major Gyre Systems

Subpolar Gyres (2 of these)

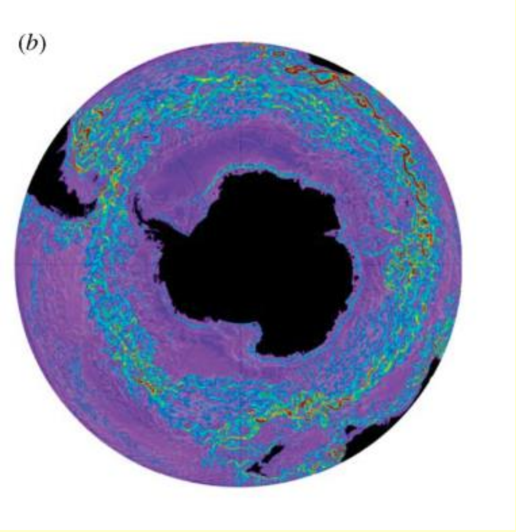
Opposite circulation to the subtropical gyres

Best developed in the North Pacific and North Atlantic because of the enclosed basins

Although most motion is East-West there is some North-South motion due to boundary currents

Absent in Northern Indian Ocean
- due to seasonal monsoon

Absent in Southern Ocean due to Antarctic Circumpolar Current



Gyre Nomenclature

Pacific

- North Pacific and South Pacific Subtropical Gyres
- North Pacific Subpolar Gyre

Atlantic

- North Atlantic and South Atlantic Subtropical Gyres
- North Atlantic Subpolar Gyre

Indian Ocean

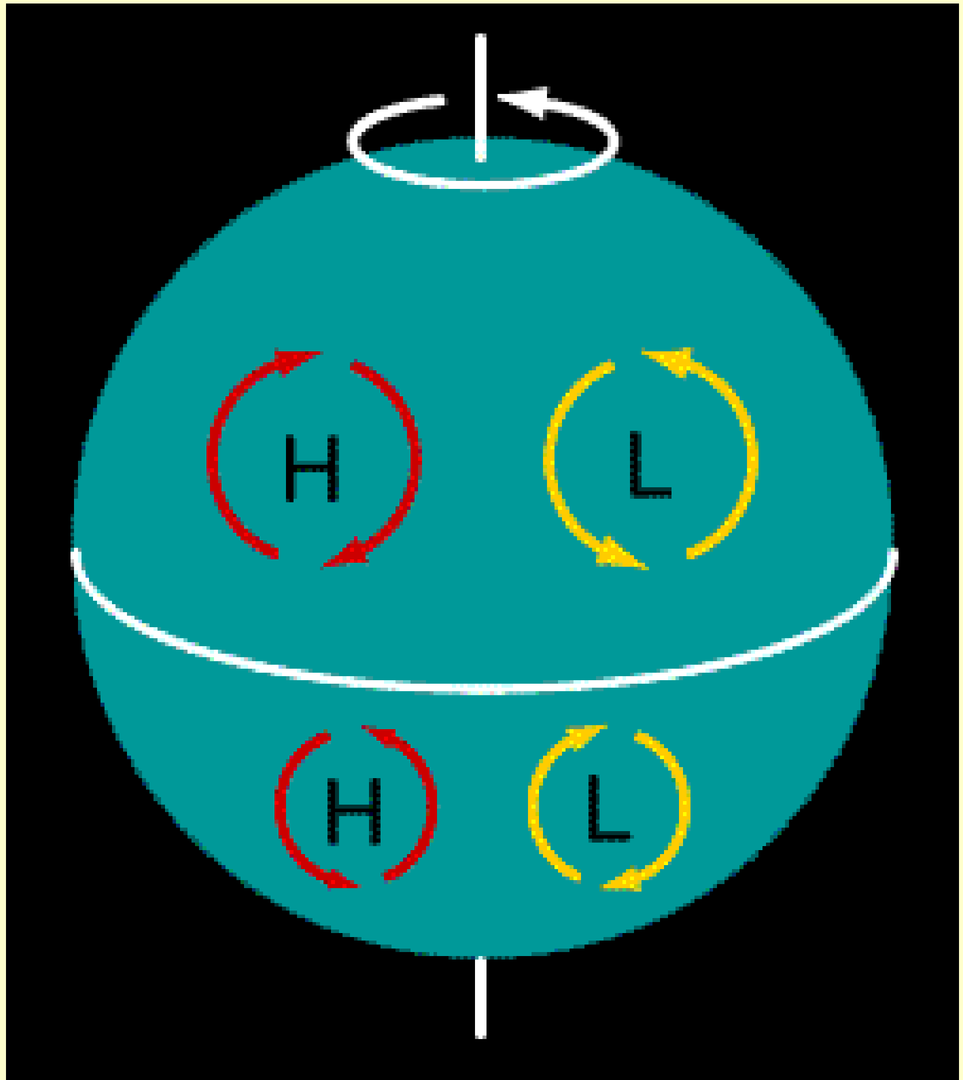
- South Indian Subtropical Gyre

Clockwise

Anticyclonic

Anticlockwise

Cyclonic



Anticlockwise

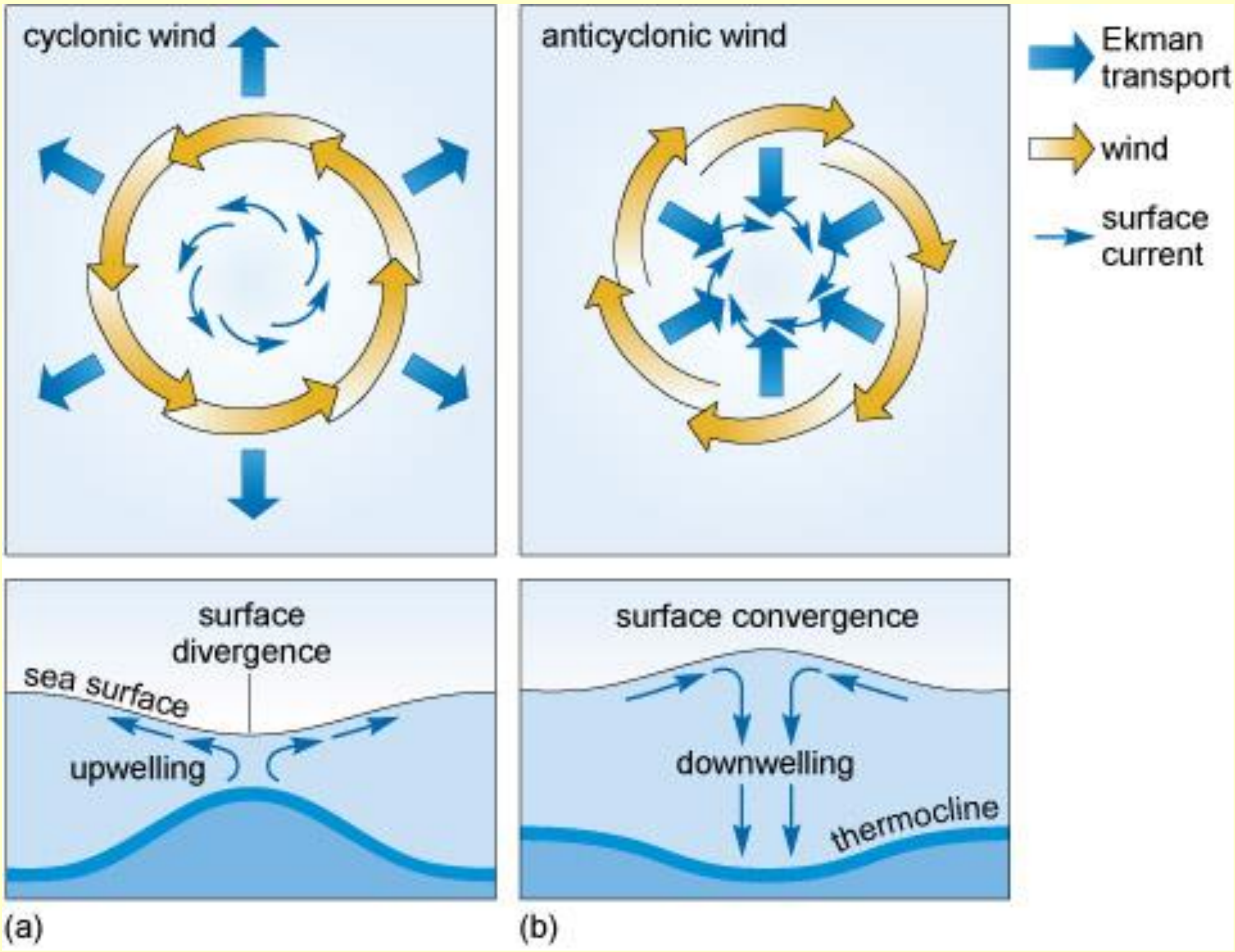
Anticyclonic

Clockwise

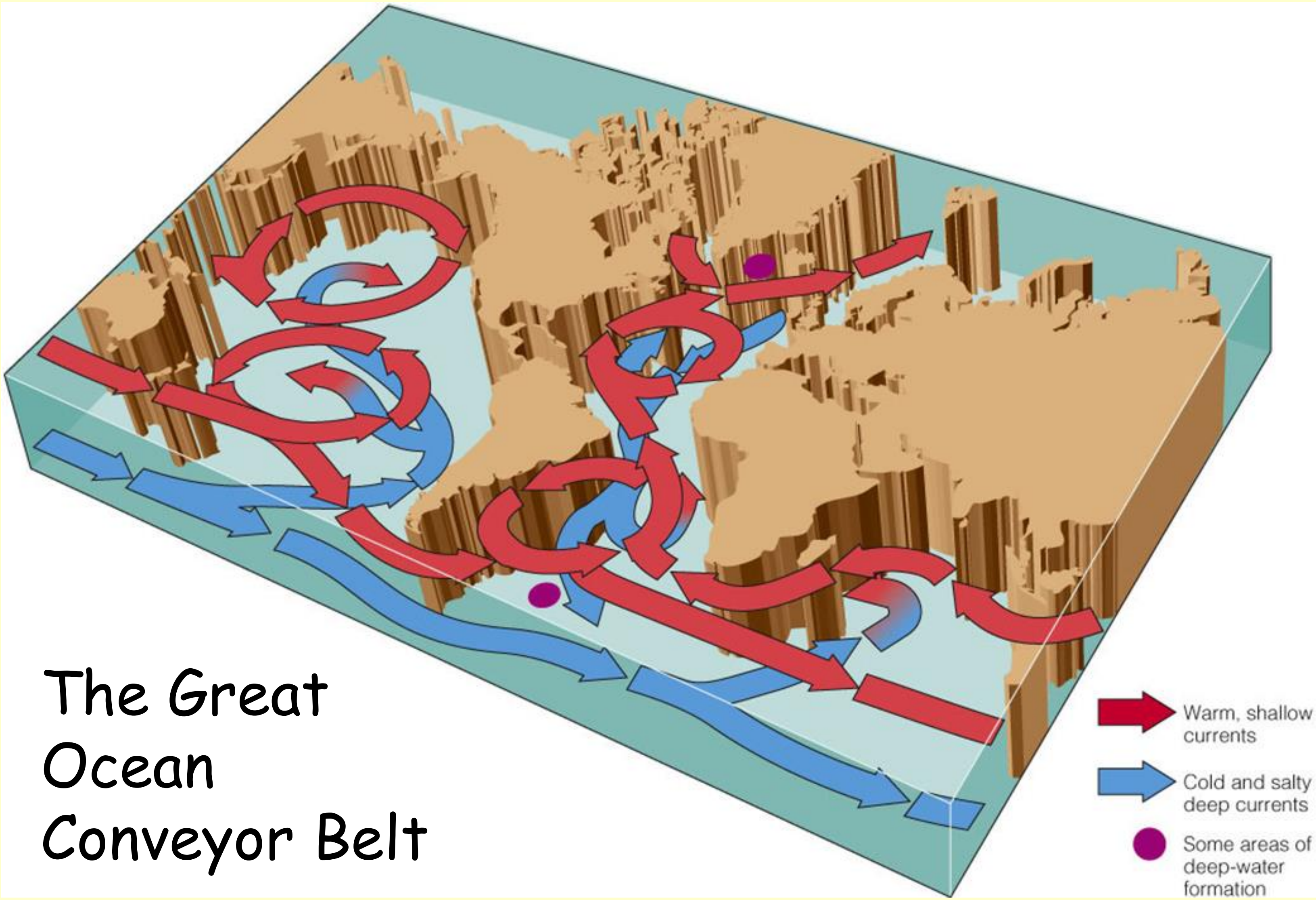
Cyclonic

Gyres Influence the Water Column

Surface Convergence / Divergence



Simplified Thermohaline Circulation



Take-Home Ideas

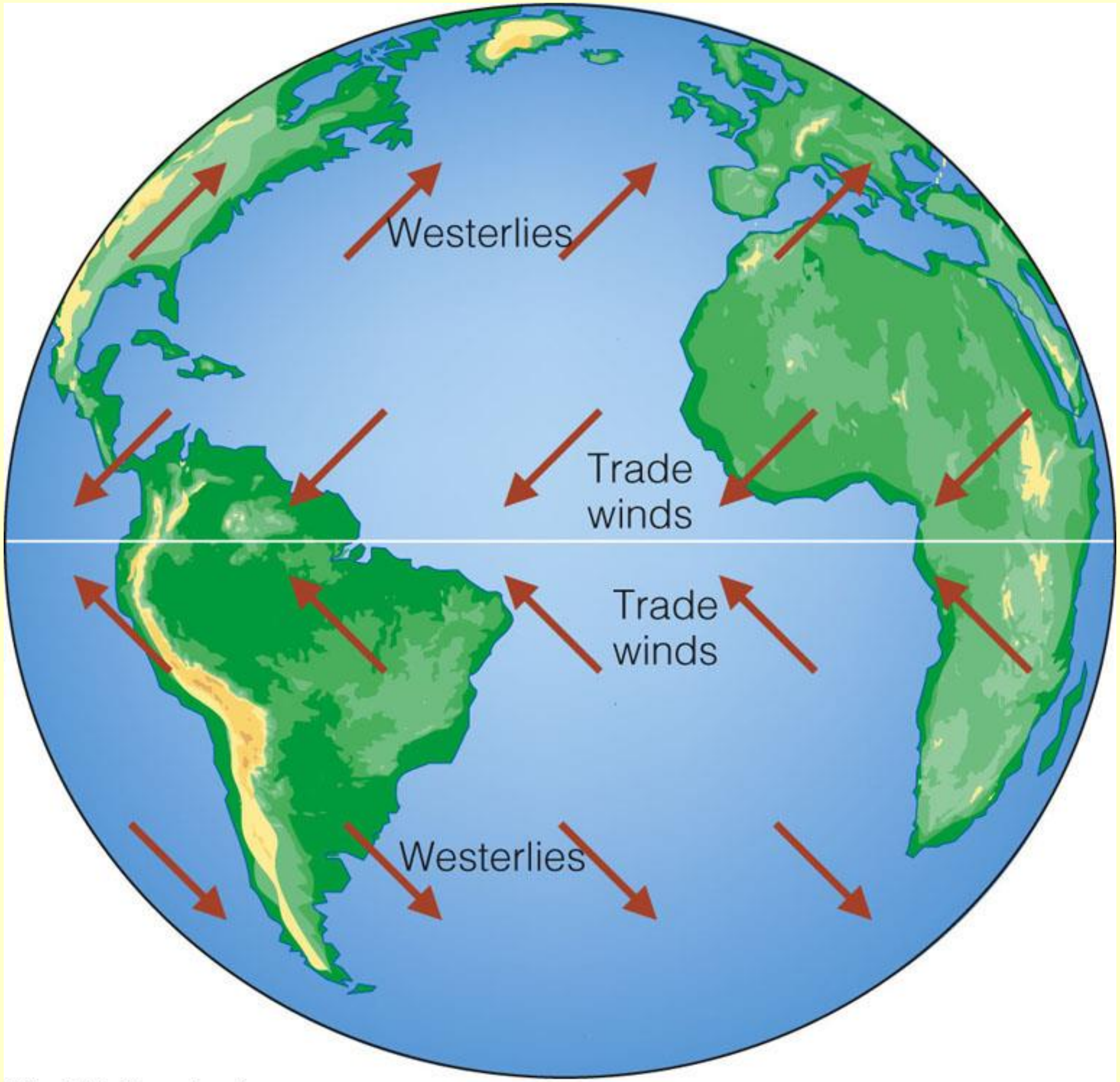
Wind driven circulation is mostly east-west (also called zonal)

Can influence the structure of the water column via upwelling / downwelling

Thermohaline circulation is generally north south (also called meridional)

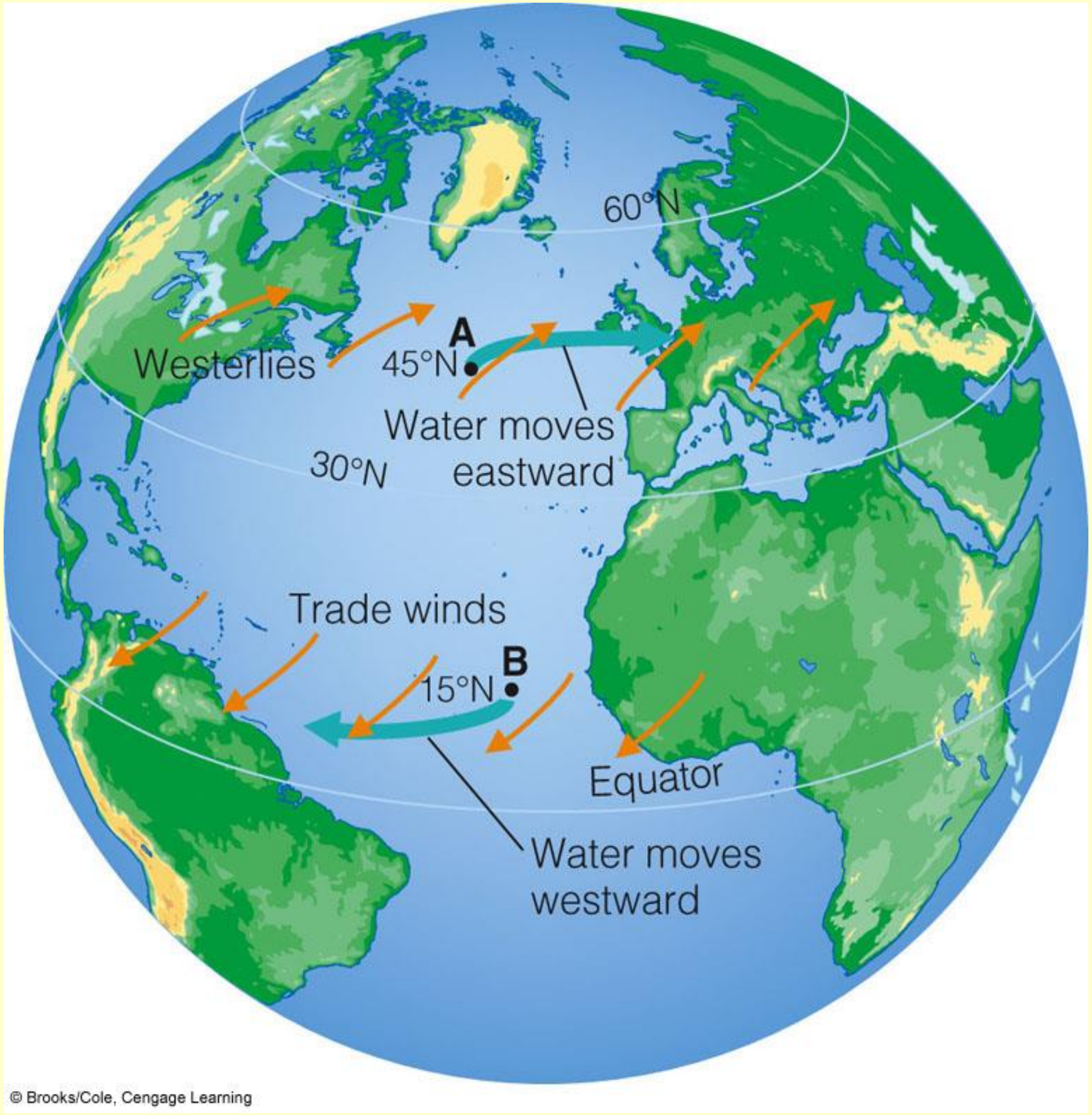
Thermohaline circulation also called meridional overturn (within context of ocean climate)

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

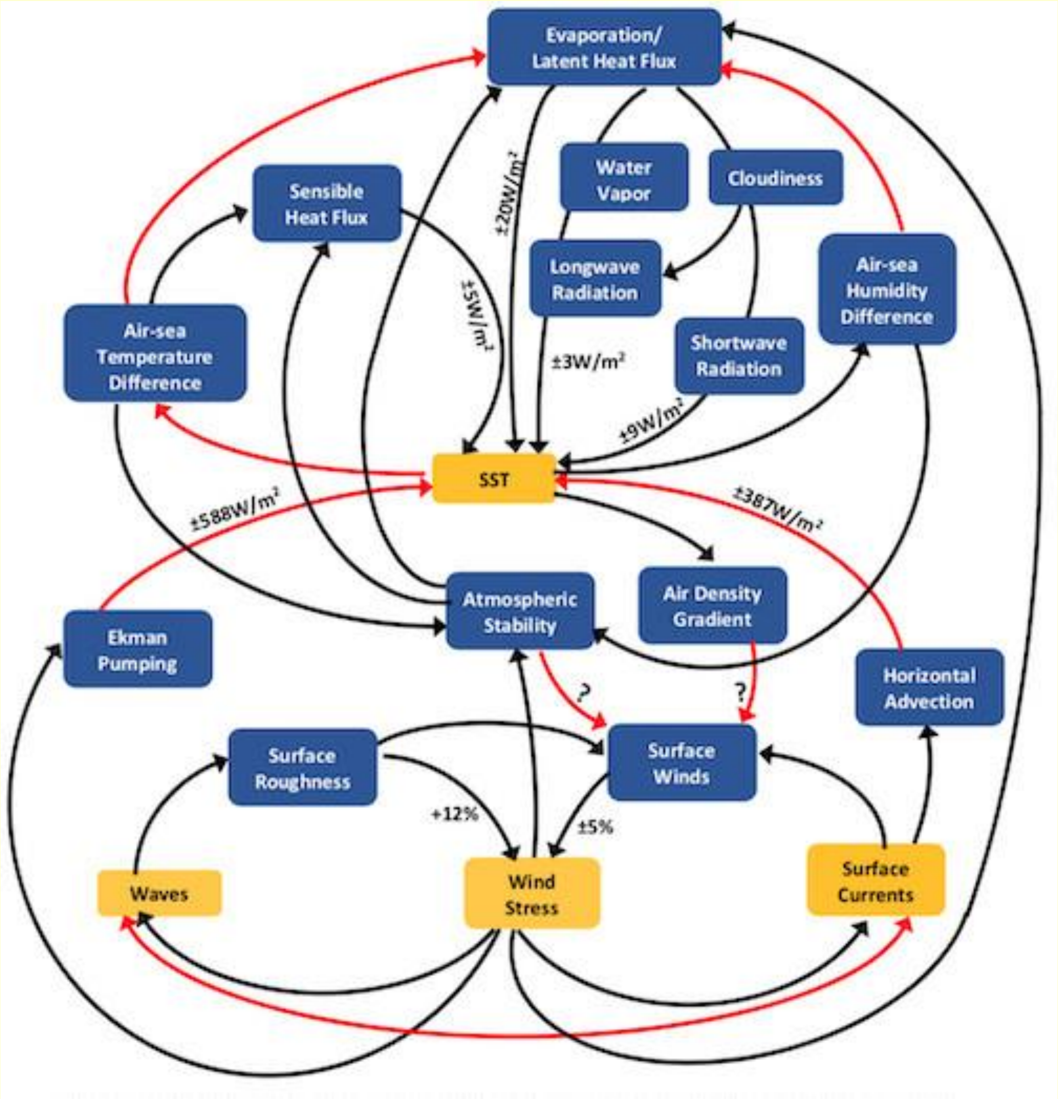


Surface water blown by the winds at point **A** veers to the right of its initial path and continues eastward.

Water at point **B** veers to the right and continues westward.



Feedback Mechanisms Coupling Ocean Currents, Waves and Wind Stress



Concepts to Know

- Atmospheric cells
- Surface winds
  - Trades
  - Westerlies
  - Polar easterlies
- Climatic zones
  - Doldrums
  - Horse latitudes
  - Polar front

REMEMBER:

Winds named for where they are come from

North-east Trades from the north east

Currents named for where they are going

Westward current moves toward the west