

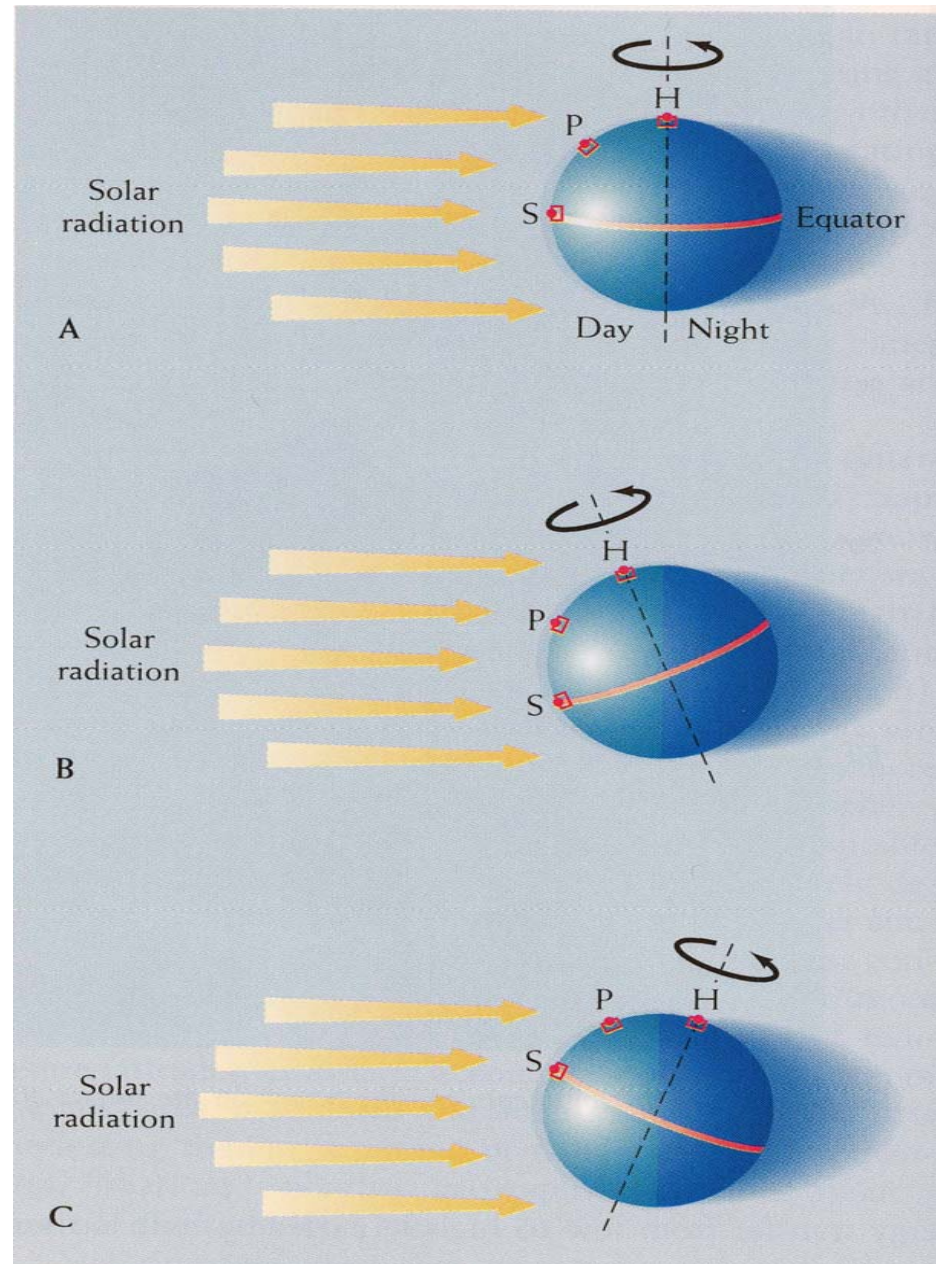


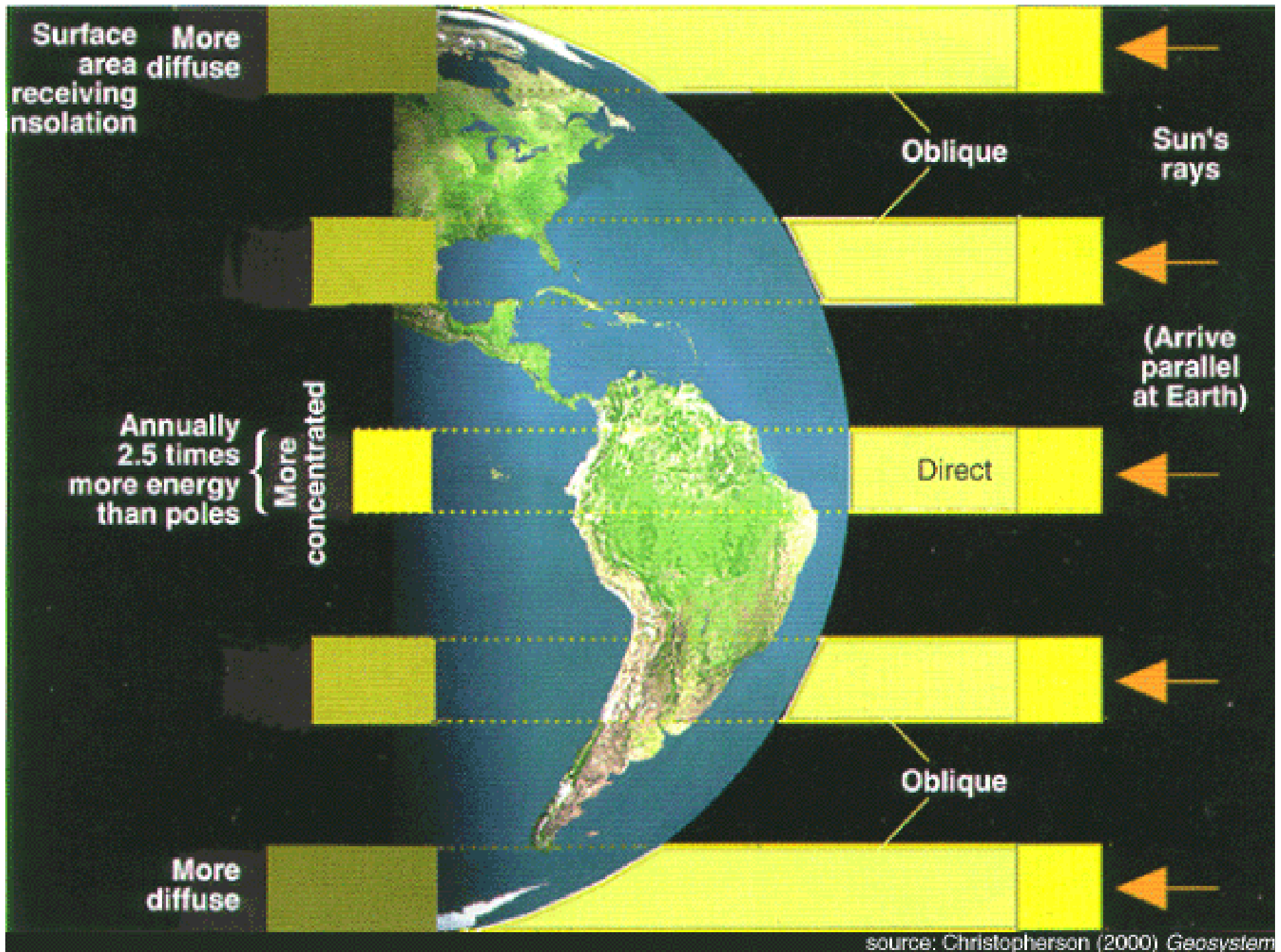
Lecture 6

Winds: Atmosphere and Ocean Circulation

The global atmospheric circulation and its seasonal variability is driven by the uneven solar heating of the Earth's atmosphere and surface.

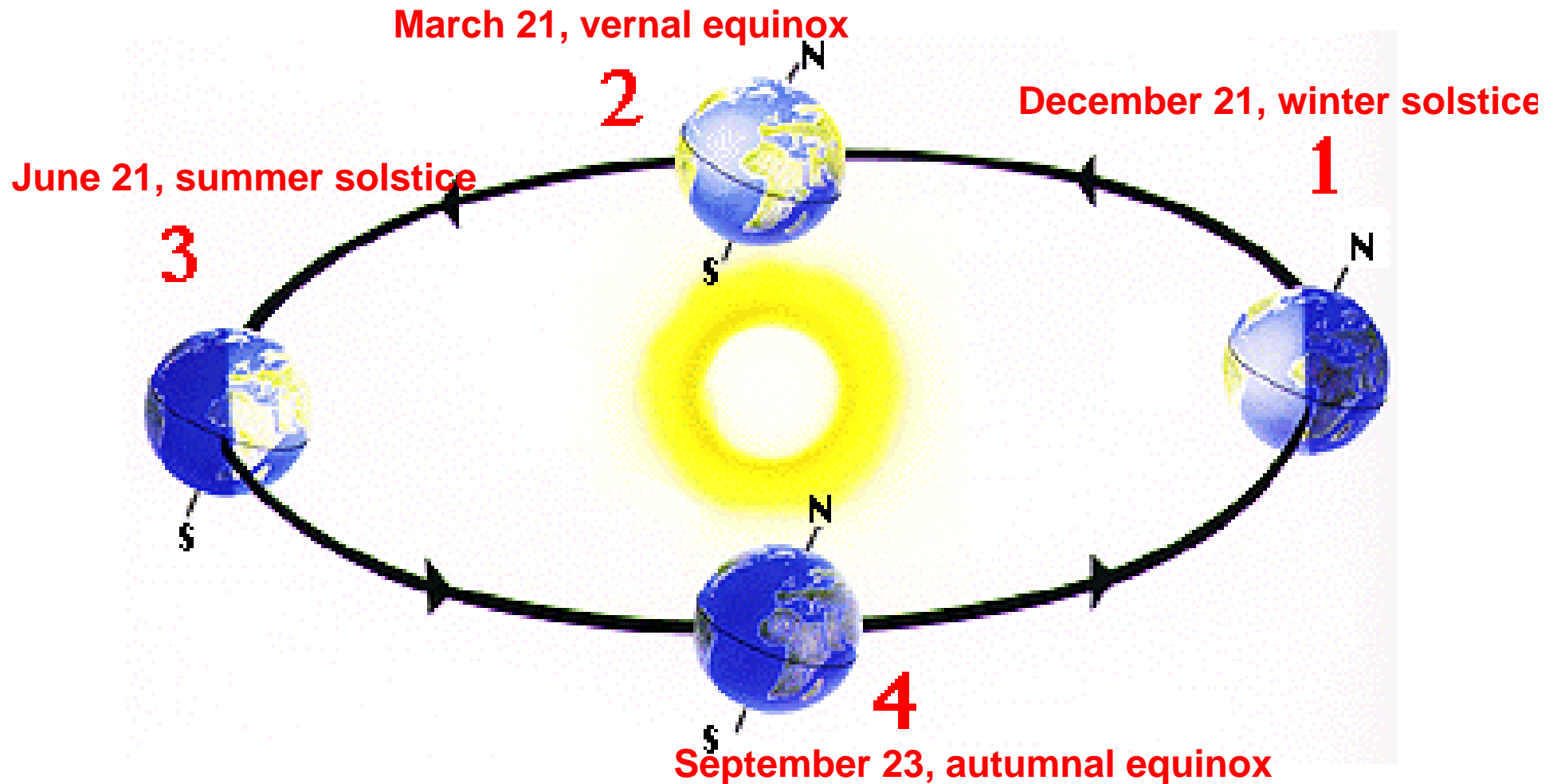
Solar radiation on a planet at different axial inclinations. The concept of flux density ($1/d^2$, energy/time/area) and the cosine law.



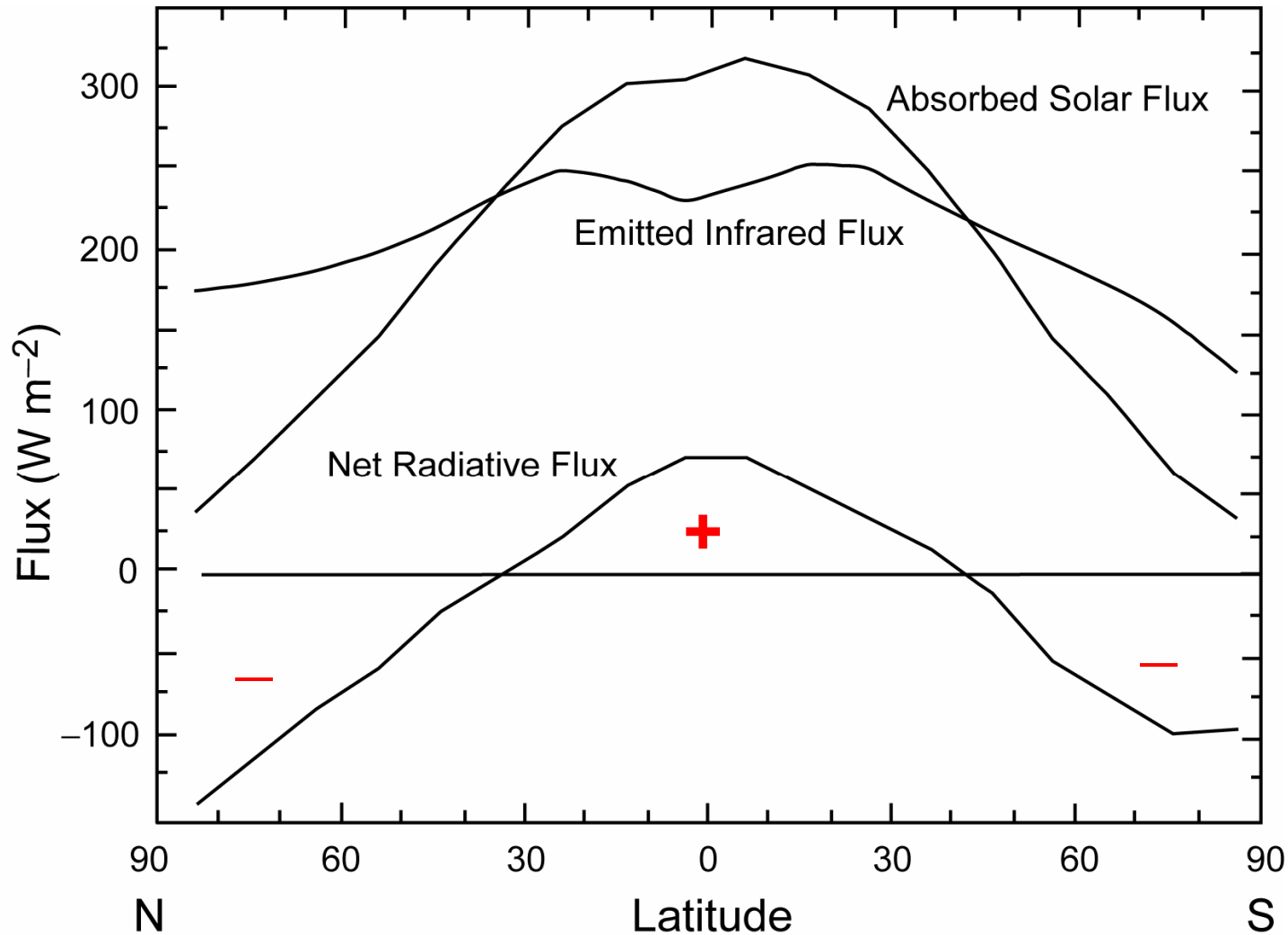


source: Christopherson (2000) *Geosystem*

Because Earth's rotation axis is tilted relative to the plane of its orbit around the sun, there is **seasonal variability** in the geographical distribution of sunshine



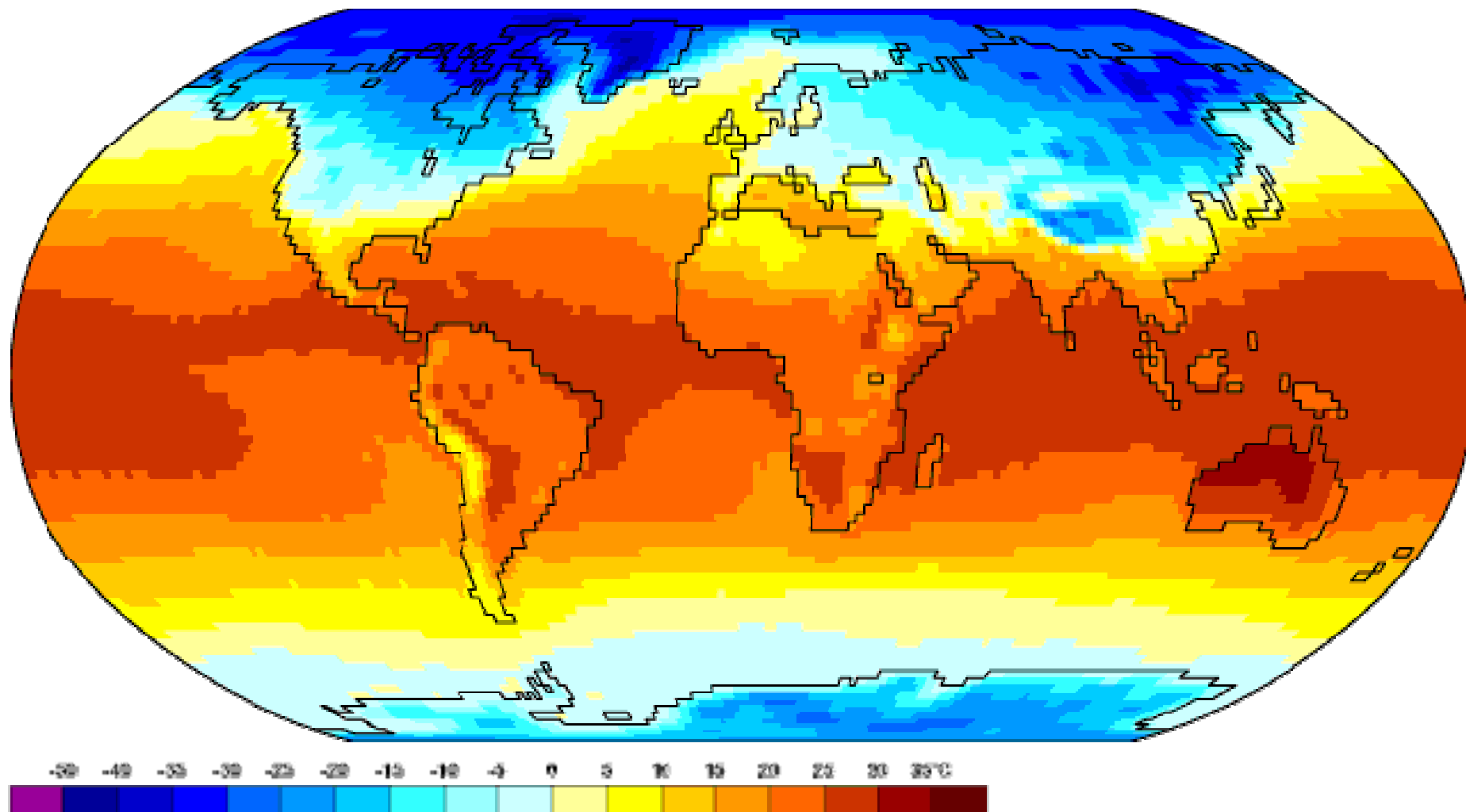
Zonally averaged components of the annual mean absorbed solar flux, emitted Earth's infrared flux, and net radiative flux at the top of the atmosphere, derived from satellite observations.



The geographical distribution of temperature and its seasonal variability closely follows the geographical distribution of sunshine (solar radiation).

Air Temperature

Dec

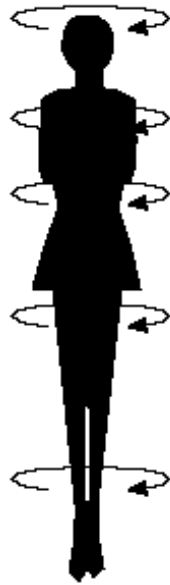


Data: NCEP/NCAR Reanalysis Project, 1958-1997 Climatologies
Animator: Department of Geography, University of Oregon, March 2000

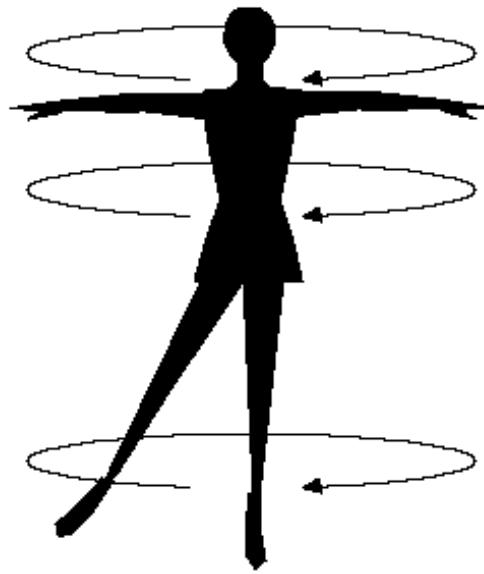
Temperature plays a direct role in determining the climate of every region. Temperature differences are also key in driving the global atmospheric circulation. Warm air tends to rise because it is light, while cold air tends to sink because it is dense, this sets the atmosphere in motion. The tropical circulation is a good example of this.

In addition to understanding how temperature affects the atmospheric circulation, we also need to understand one of the basic forces governing air and water motion on earth: **The Coriolis Force**. But to understand this effect, we first need to review the concept of angular momentum conservation.

Angular momentum conservation means that if a rotating object moves closer to its axis of rotation, it must speed up to conserve angular momentum. Conversely, as a rotating object moves further from its axis of rotation, it must slow down.



Faster



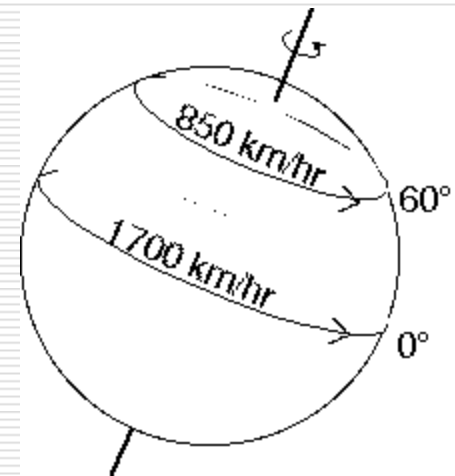
Slower

The earth's curved surface means that objects are moving at very different speeds depending on their latitude:

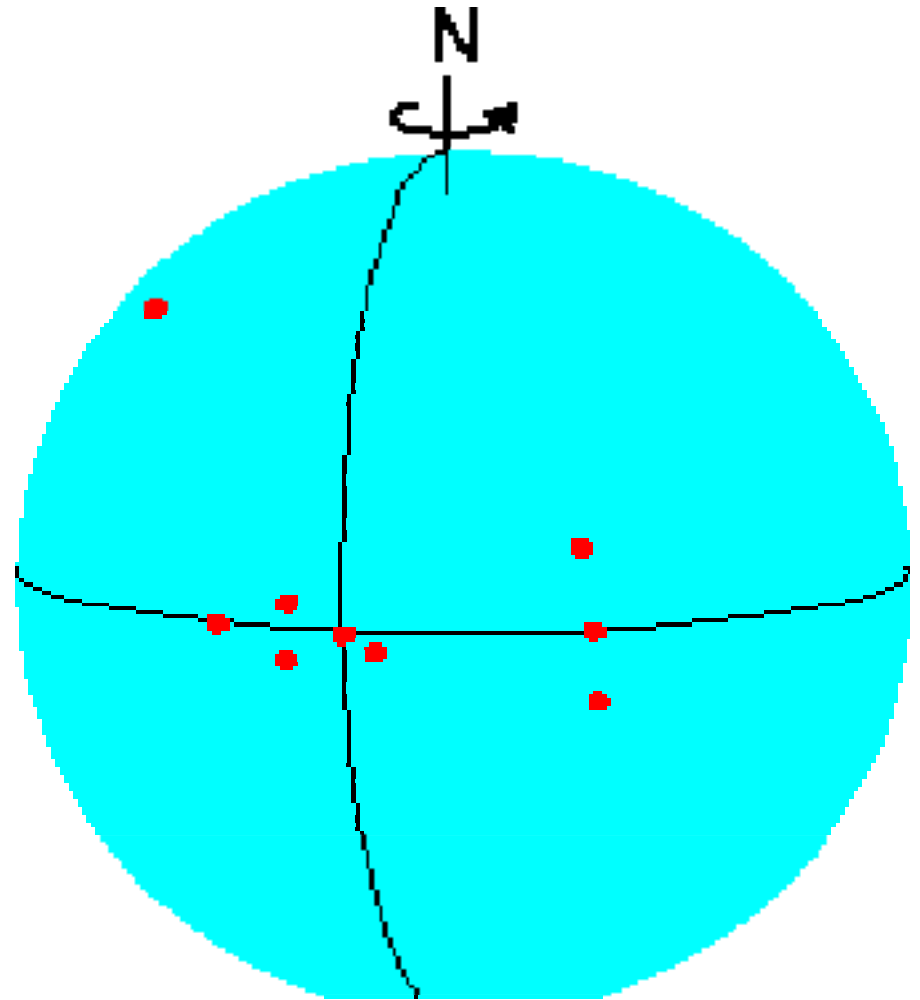
At the equator (latitude 0°), an object is moving at a speed of about **1700 km/hr**.

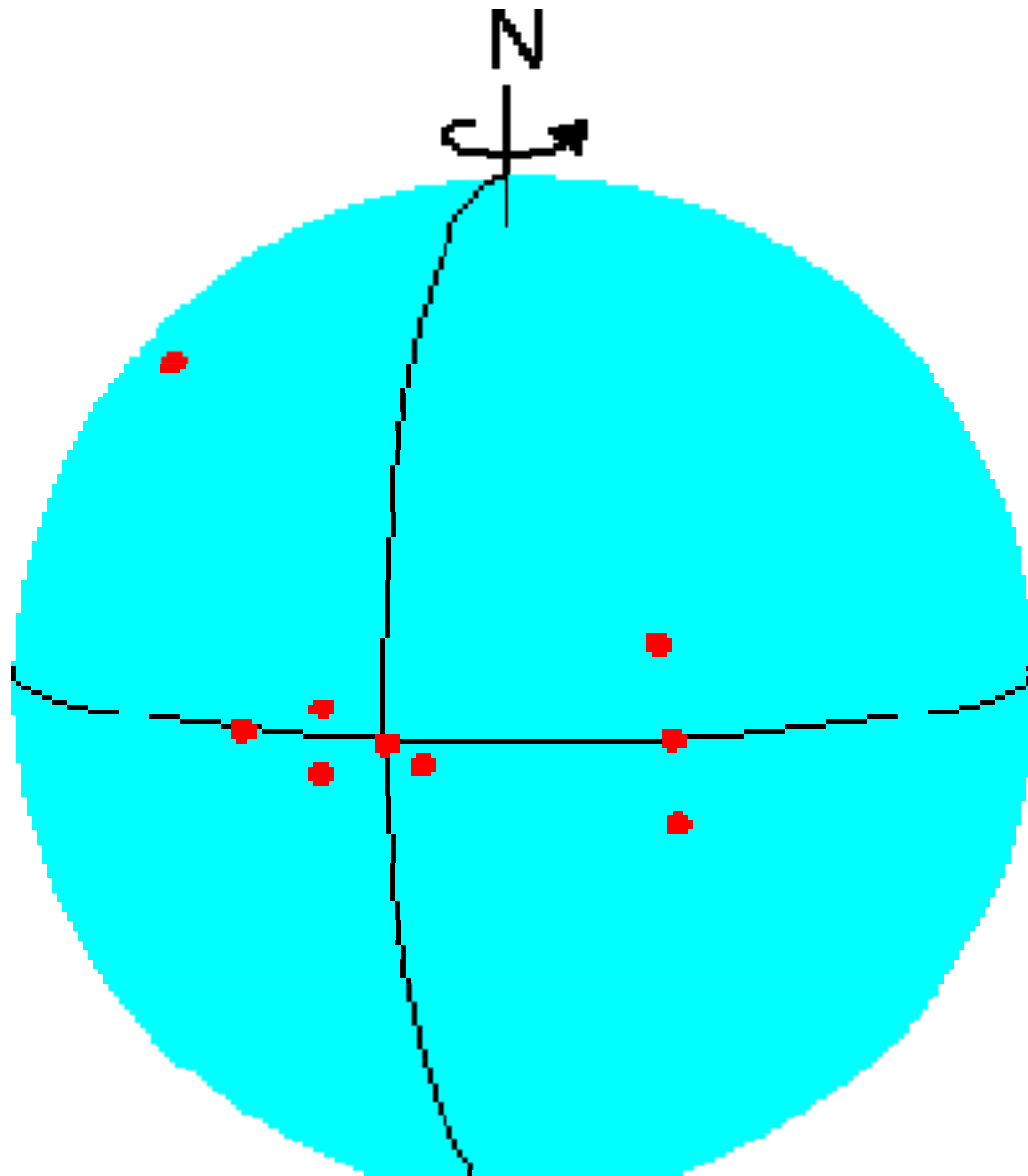
At the pole (latitude 90°), an object moving hardly at all due to the earth's rotation.

Here in Los Angeles (latitude 34°N), an object is moving at a speed of about **1400 km/hr (=860 miles/hr!)**.



If an initially motionless object moves from the equator northward, it will move closer to the earth's axis of rotation, and will have to acquire speed in the direction of the earth's rotation. This results in an apparent deflection to the right. Similarly, an initially motionless object at the equator moving southward into the southern hemisphere will undergo an apparent deflection to the left.





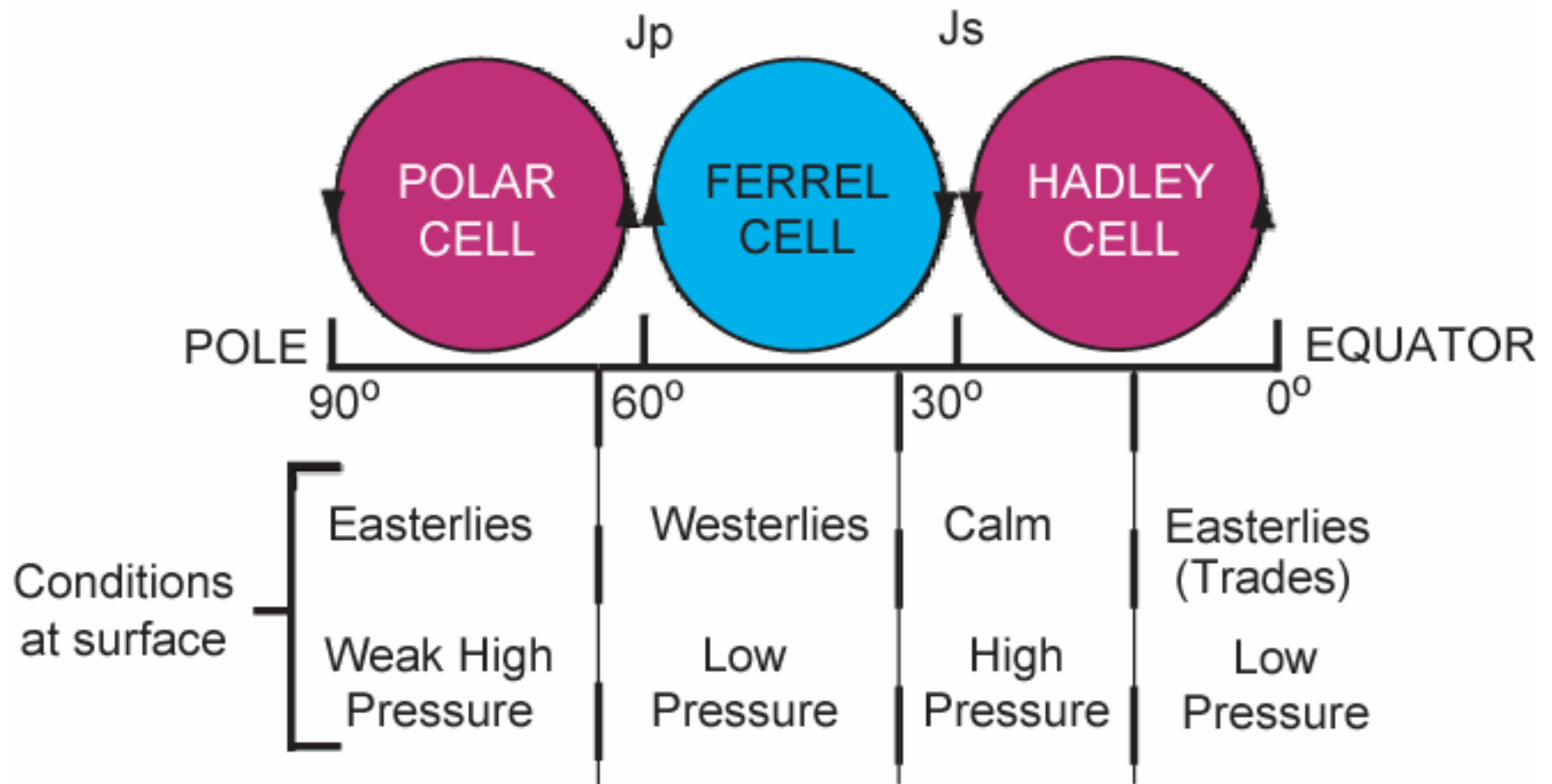
It turns out that all objects moving in the northern hemisphere are deflected to the right by the **Coriolis force**, while all objects moving in the southern hemisphere are deflected to the left. It is easy to see how this can result in curved trajectories of objects moving on the earth's surface.

The west-to-east
direction is referred to as
the **zonal direction**.

The south-to-north
direction is referred to as
the **meridional direction**.



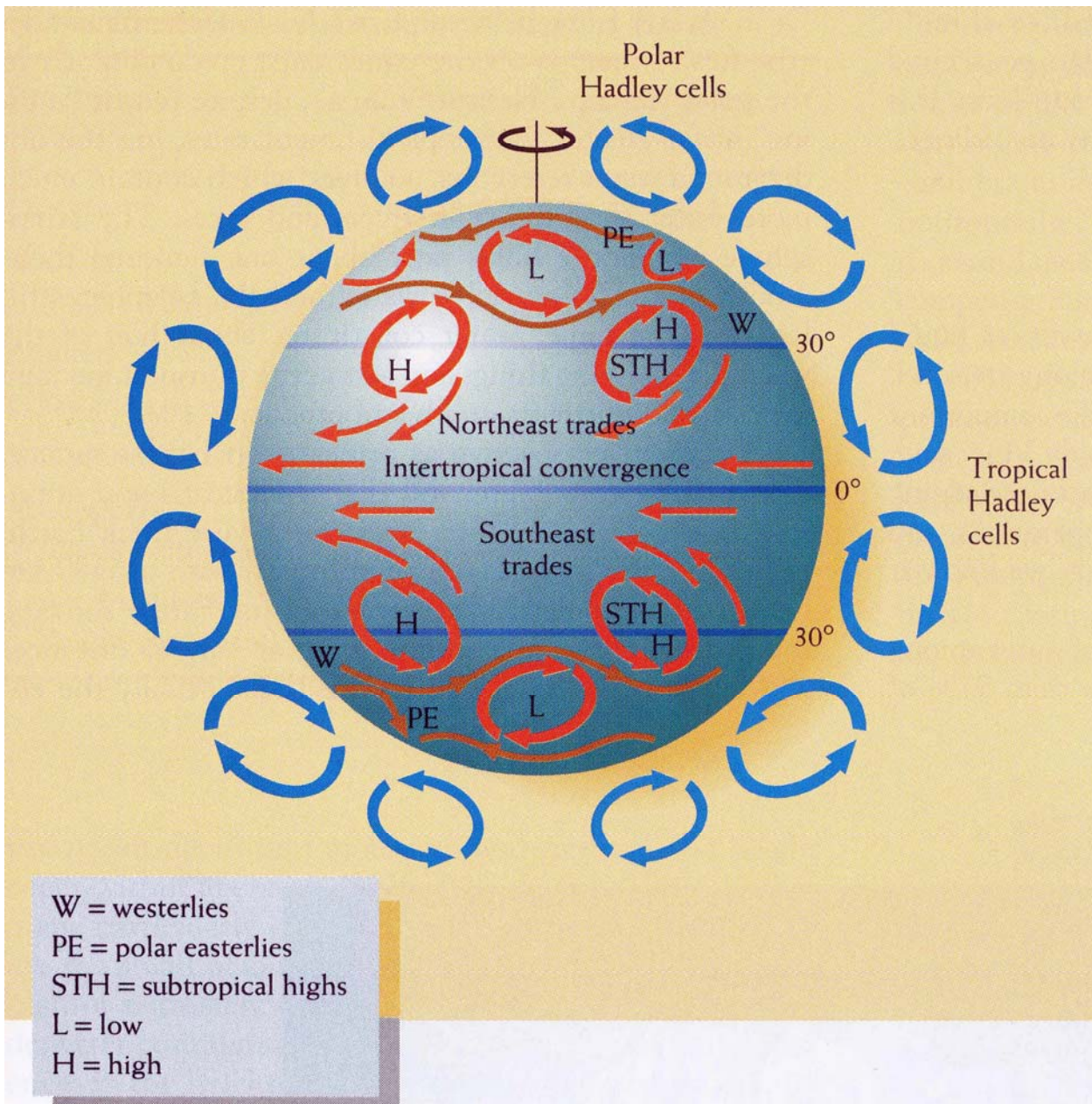
NORTH-SOUTH VERTICAL SECTION TROUGH TROPOSPHERE



Three north-south circulation cells in each hemisphere:

- 1. A thermally direct^(*) circulation in the tropics (Hadley Cell), with rising motion around the equator and sinking motion at about 30° latitude.**
- 2. A thermally indirect^(*) circulation in the middle latitudes (Ferrel Cell), with rising motion at 60° and sinking motion along with the Hadley Cell at about 30°.**
- 3. Another weaker direct^(*) circulation in the polar regions (polar cell) with rising motion at about 60° and sinking motion over the pole.**

(*) direct (indirect): warm (cold) air rises and cold (warm) air sinks.

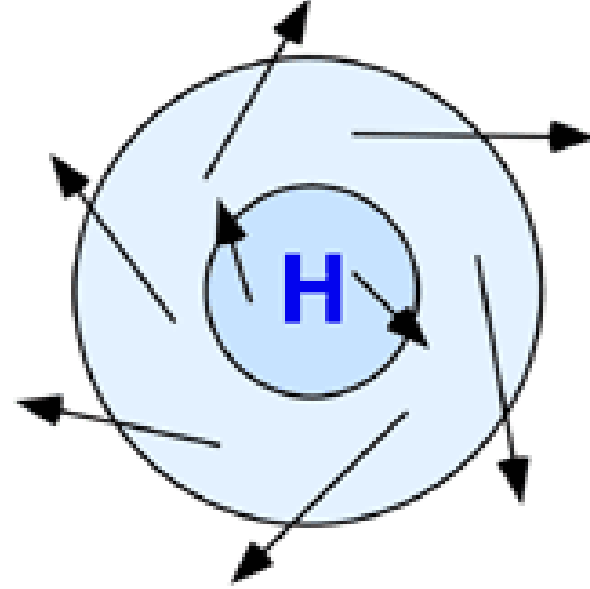
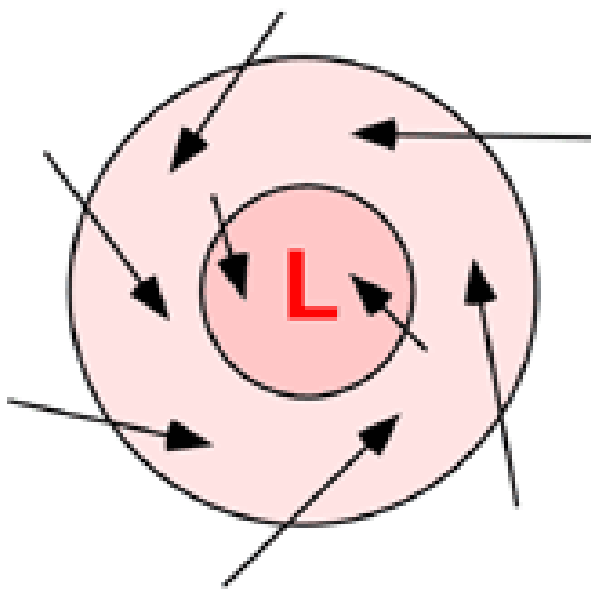


On the Earth's surface, the diagrams refer to surface winds. The transient highs (H) and lows (L) we see on daily weather maps are primarily lower atmospheric features, whereas the Hadley circulation can extend vertically as much as 20 km.

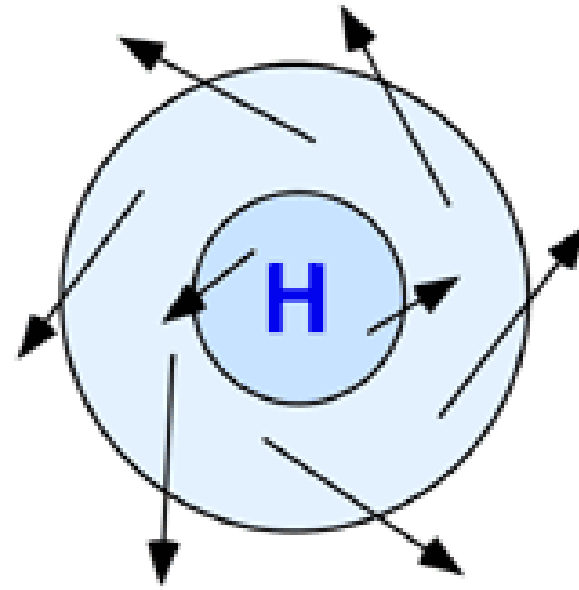
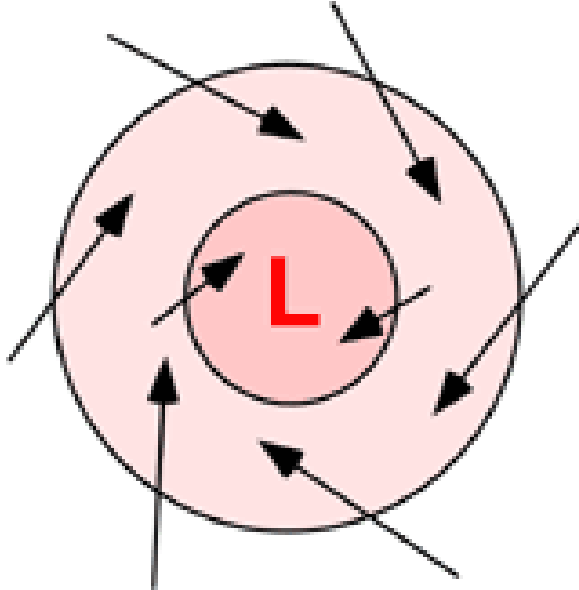
PRESSURE

Air is not evenly distributed on the earth's surface. In areas where there is less air, pressure at the surface is **low, while in areas where there is more air, pressure at the surface is **high**. **Air moves from regions of high to low pressure to even out the distribution.** However, as air moves towards low pressure, it comes under the influence of the **Coriolis Force**.**

NORTHERN HEMISPHERE



SOUTHERN HEMISPHERE



Hurricane Katrina 2005

Air moving toward low pressure at the center of the hurricane is deflected to the right, resulting in a spiral trajectory of air toward the hurricane's center. This is visible in the clouds generated by the storm.



Weather vs Climate

Weather is the short-time-scale (< a few days) evolution of the of the atmosphere.

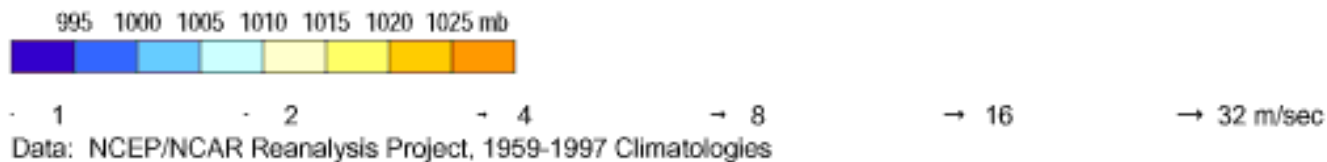
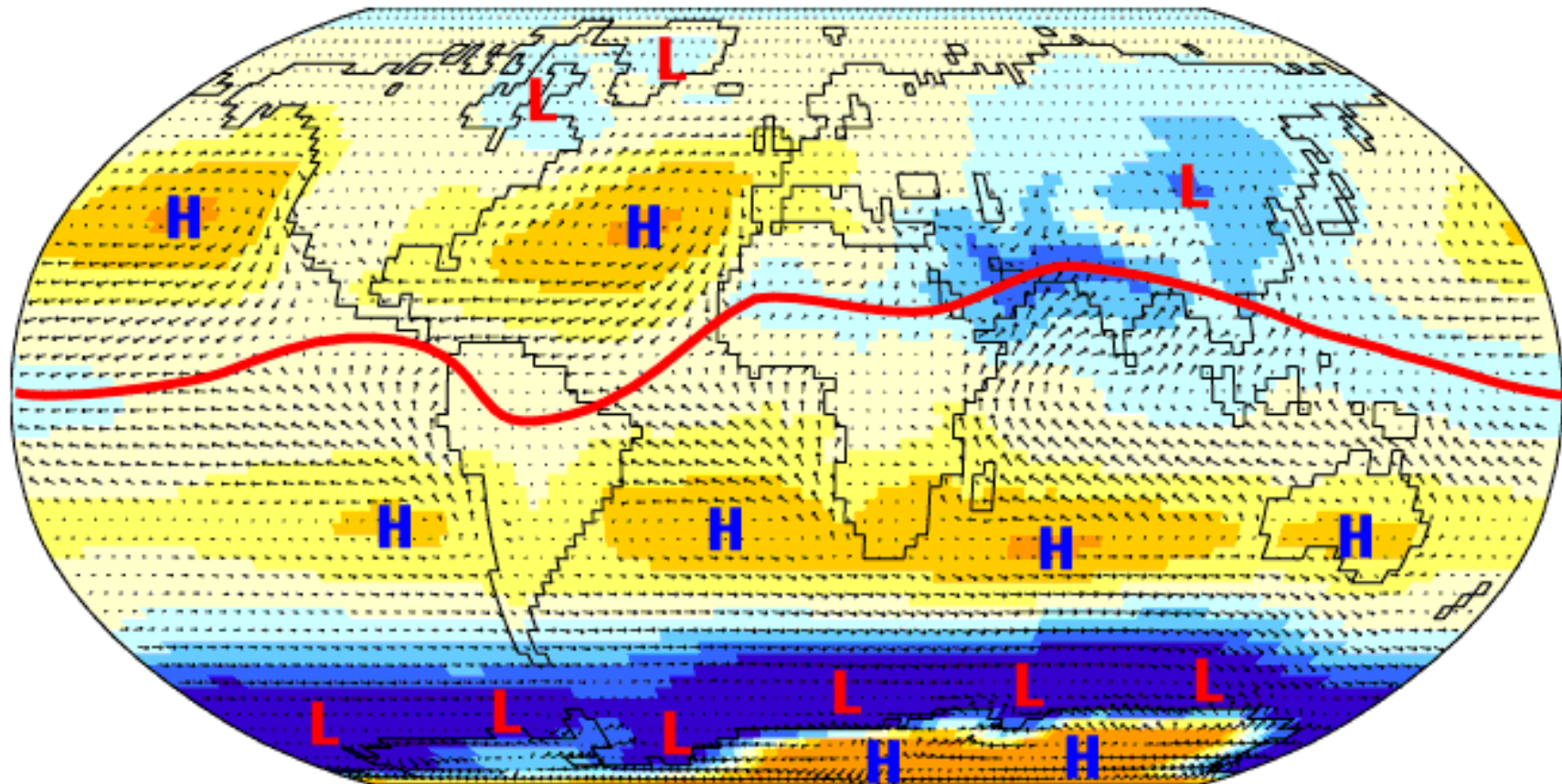
Climate is the statistics of weather. It refers to the mean (or average) weather and the deviation from the mean during a particular period.

Weather prediction. The evolution of the state variables of the atmosphere is governed by nonlinear dynamics (i.e. “chaos”), and is therefore inherently unpredictable beyond a certain period of time.

Climate prediction. There is no reason to doubt the predictability of the statistics of weather.

Sea-Level Pressure and Surface Winds

Jul



Climatological surface winds are organized by zones of high and low pressure. Note the subtropical high pressure zones over ocean basins stemming from relatively cool temperatures there.

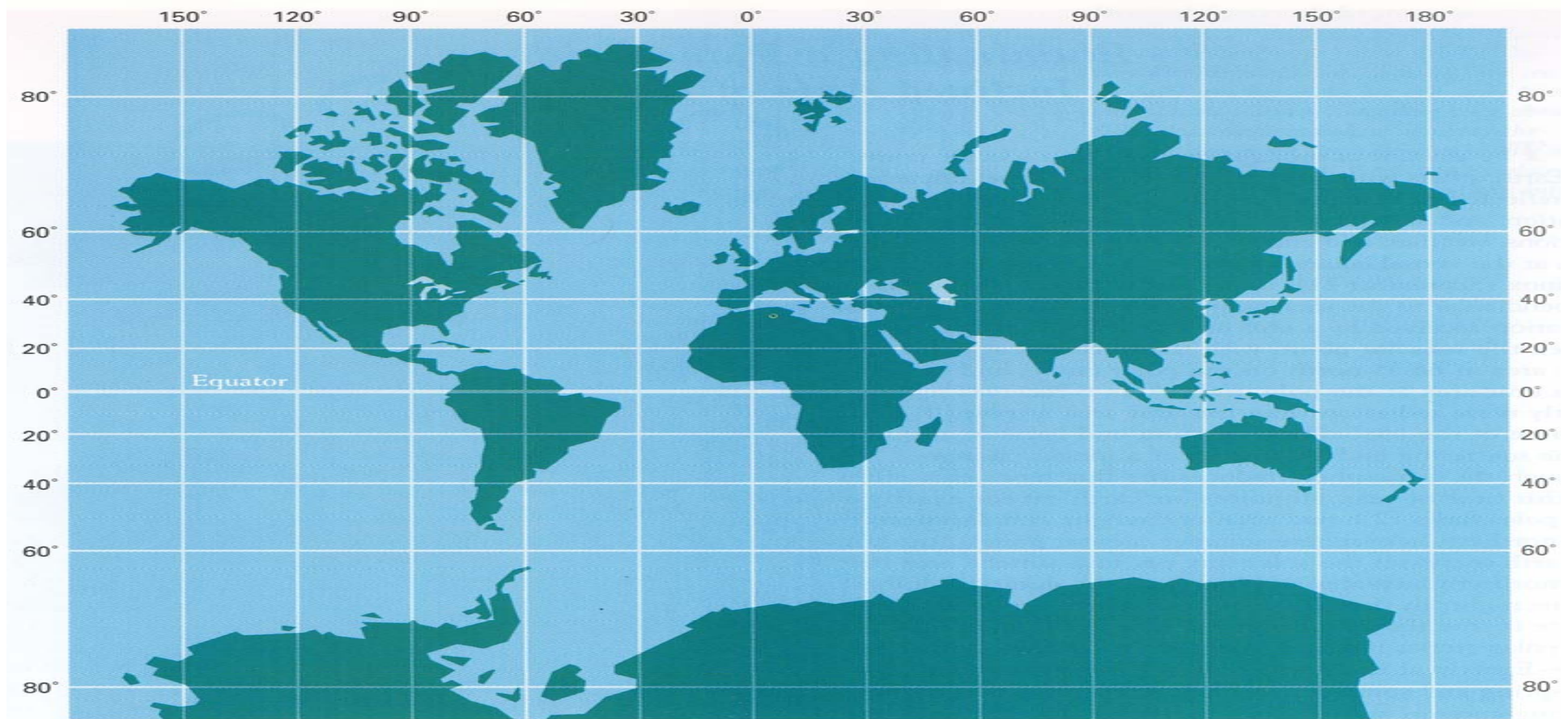
Persistent features of the atmospheric circulation

Inter-tropical convergence zone (ITCZ). The east-west-oriented band of intense convection located over the warmest regions of the tropics.

Sub-tropics. The large areas of sinking, typically located at about 20° latitude, that compensate for the rising motion of the ITCZ. Little precipitation falls in these regions.

Monsoon. A tropical seasonal phenomenon driven by contrasts in land-sea temperature. When the land is warm relative to the ocean, air rises over the land, drawing in moist air from the ocean. Intense precipitation typically follows on land.

Mid-latitude jet stream. An intense air current that moves to the east in both hemispheres. The jet stream is turbulent, particularly in wintertime.

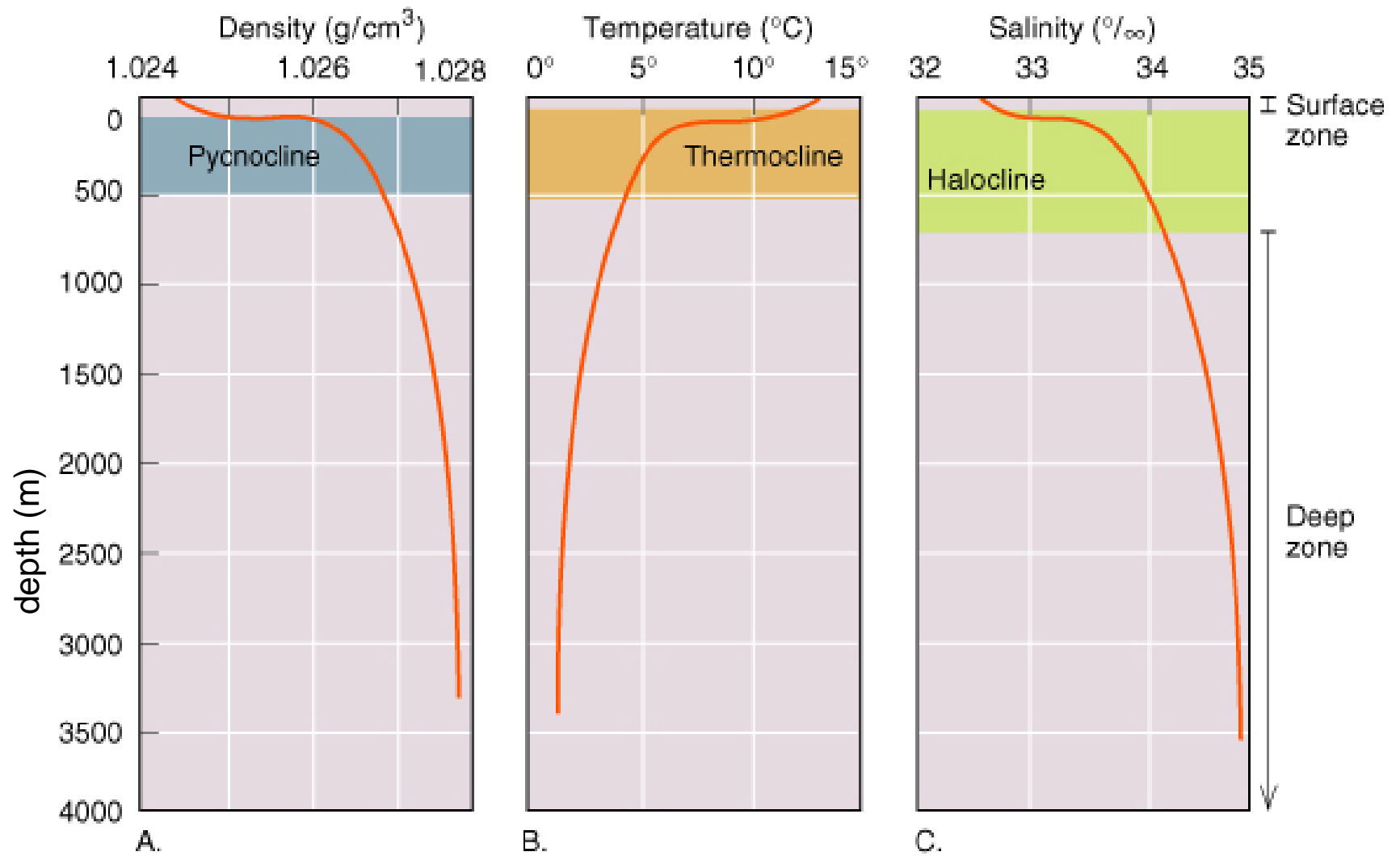


The positions of the continents and the oceans on the surface of Earth (Mercator projection).

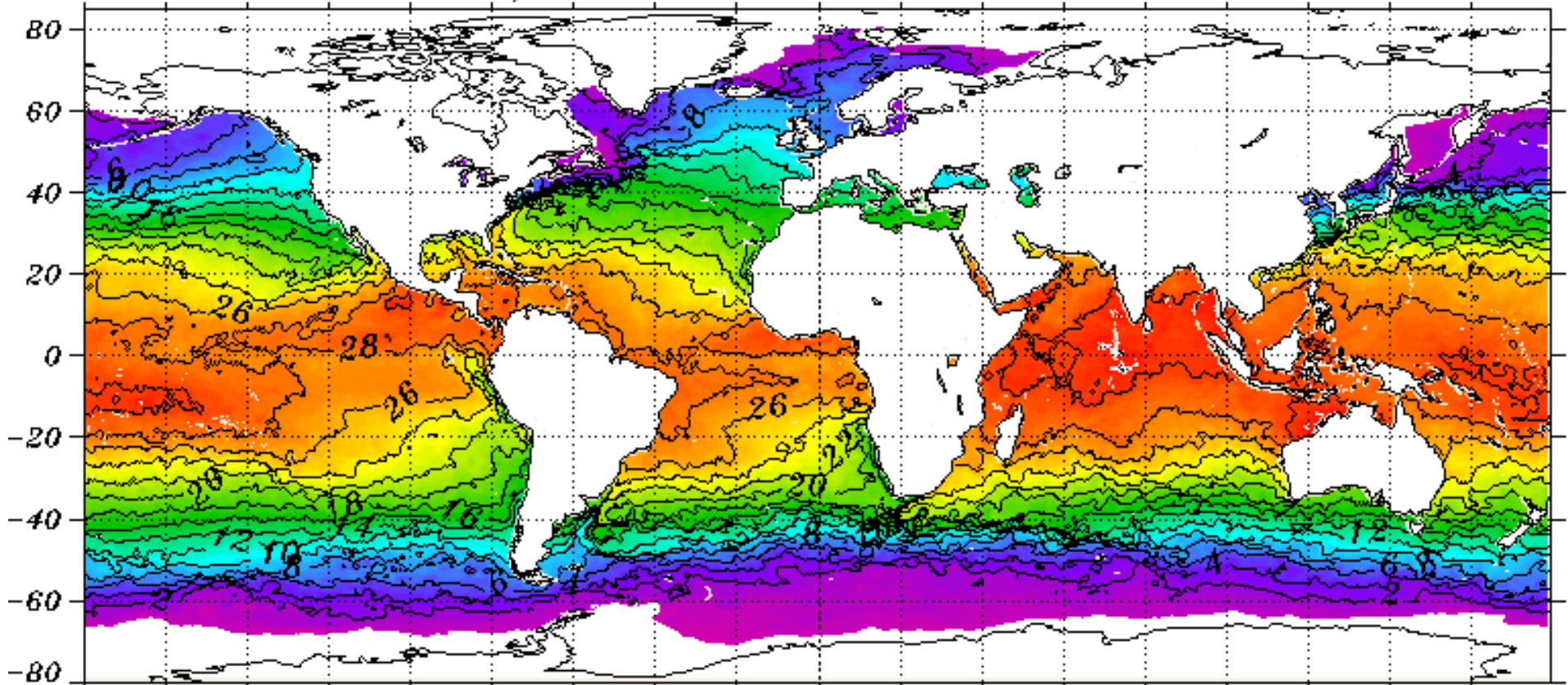
Temperature, salinity, and density are the key variables describing the state of the ocean. Density is a function of both temperature and salinity. As water warms, it expands and becomes less dense. Dissolved salts are heavier than water, so density increases with salinity.

Unlike the atmosphere, **the ocean is heated from above**. Therefore, the warmest temperatures are at the surface of the ocean. Because warmer water is lighter, this creates a stable environment, with little vertical motion. This is why the deep circulation of the ocean is so sluggish compared to the atmosphere.

Vertical distribution of temperature, salinity, and density



NOAA/NESDIS SST 50KM GLOBAL ANALYSIS



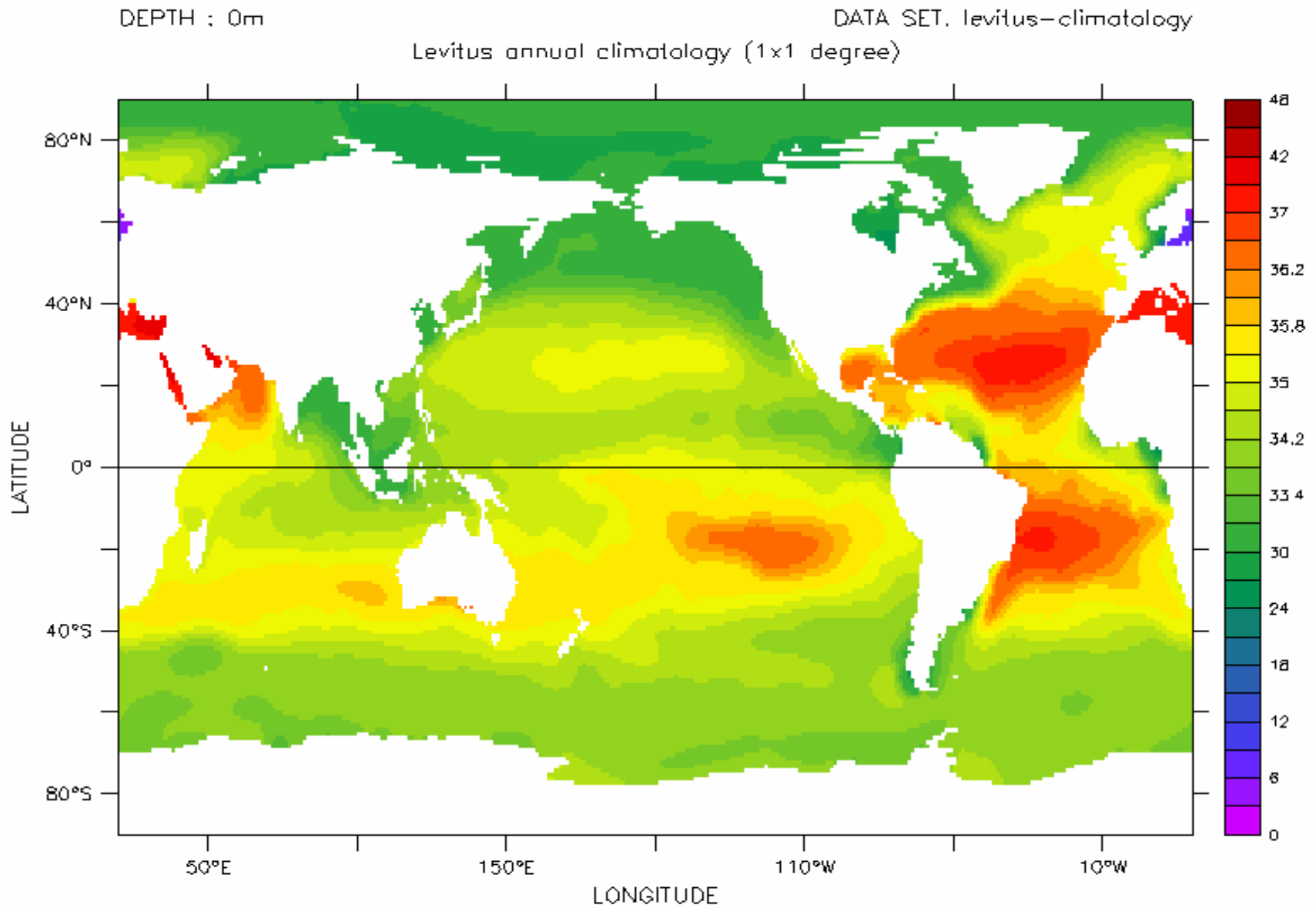
-180 -160 -140 -120 -100 -80 -60 -40 -20 0 20 40 60 80 100 120 140 160

NOAA-16 OPERATION DAY/NITE 4/19/2005 through 4/23/2005

SST in degrees C (ice is white, brown is unreliable)



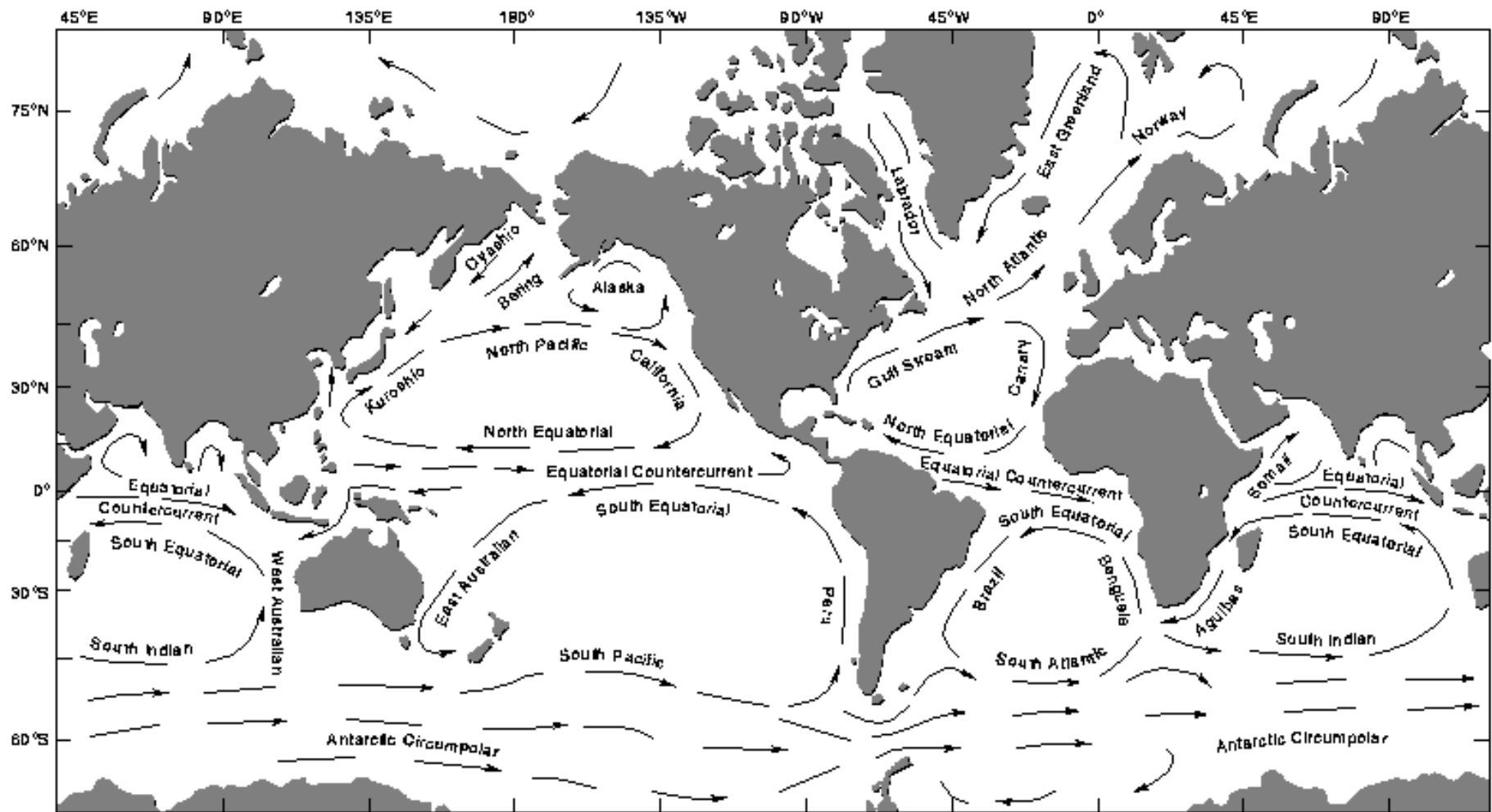
A snapshot of recent sea surface temperatures



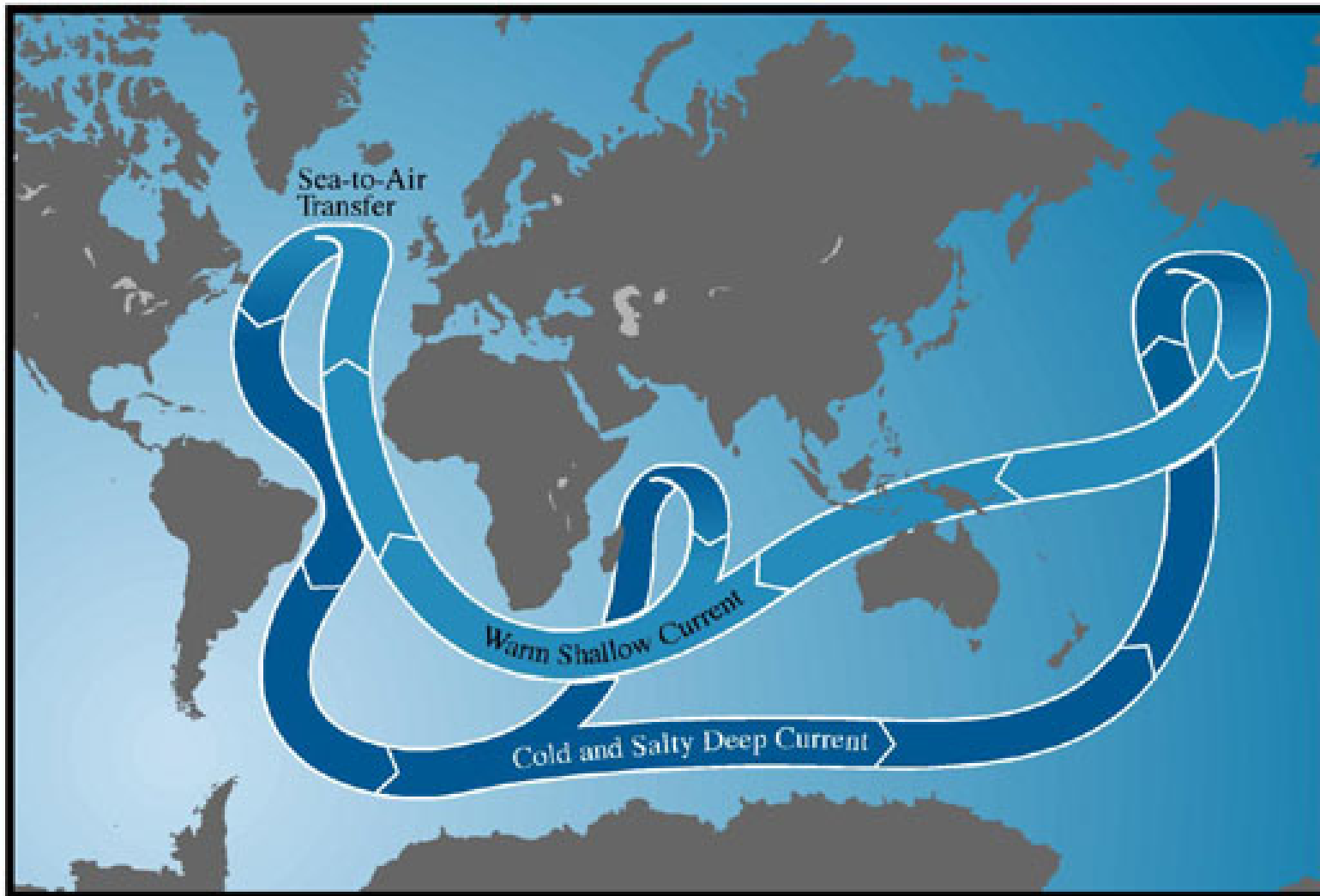
**sea surface salinity
climatology**

SALINITY (PPT)

← Salinity is measured in
parts per thousand



The surface ocean circulation is organized into gyres, which rotate clockwise in the northern hemisphere, and counterclockwise in the southern hemisphere.



Because of its high salinity, North Atlantic water is more susceptible to sinking than other waters with the same temperature. This is therefore a major sinking region of the **global thermohaline circulation**. The Southern Ocean is also a site of deep convection. All of the deep water of the entire ocean originates in one of these two regions.