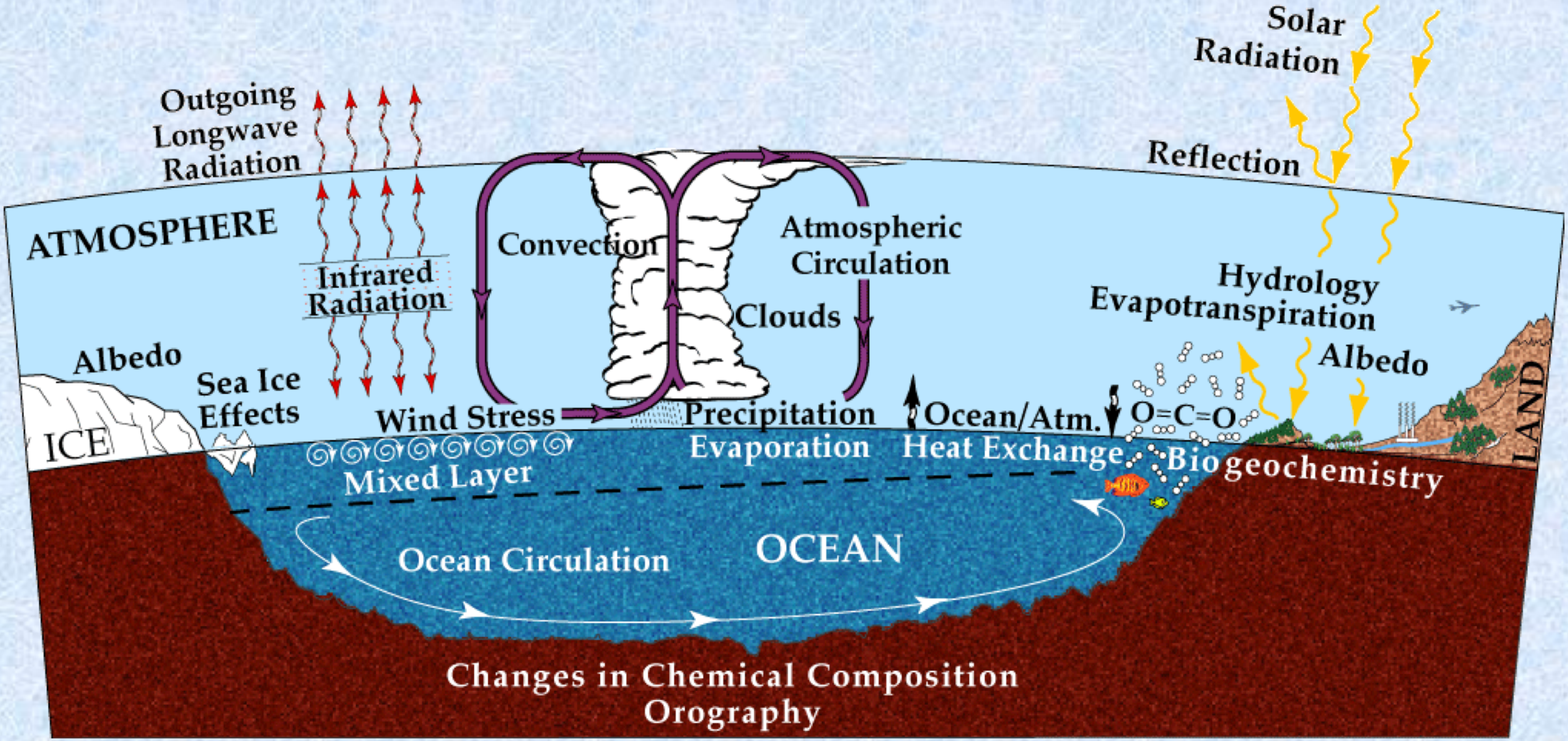
Schematic of components of the climate system



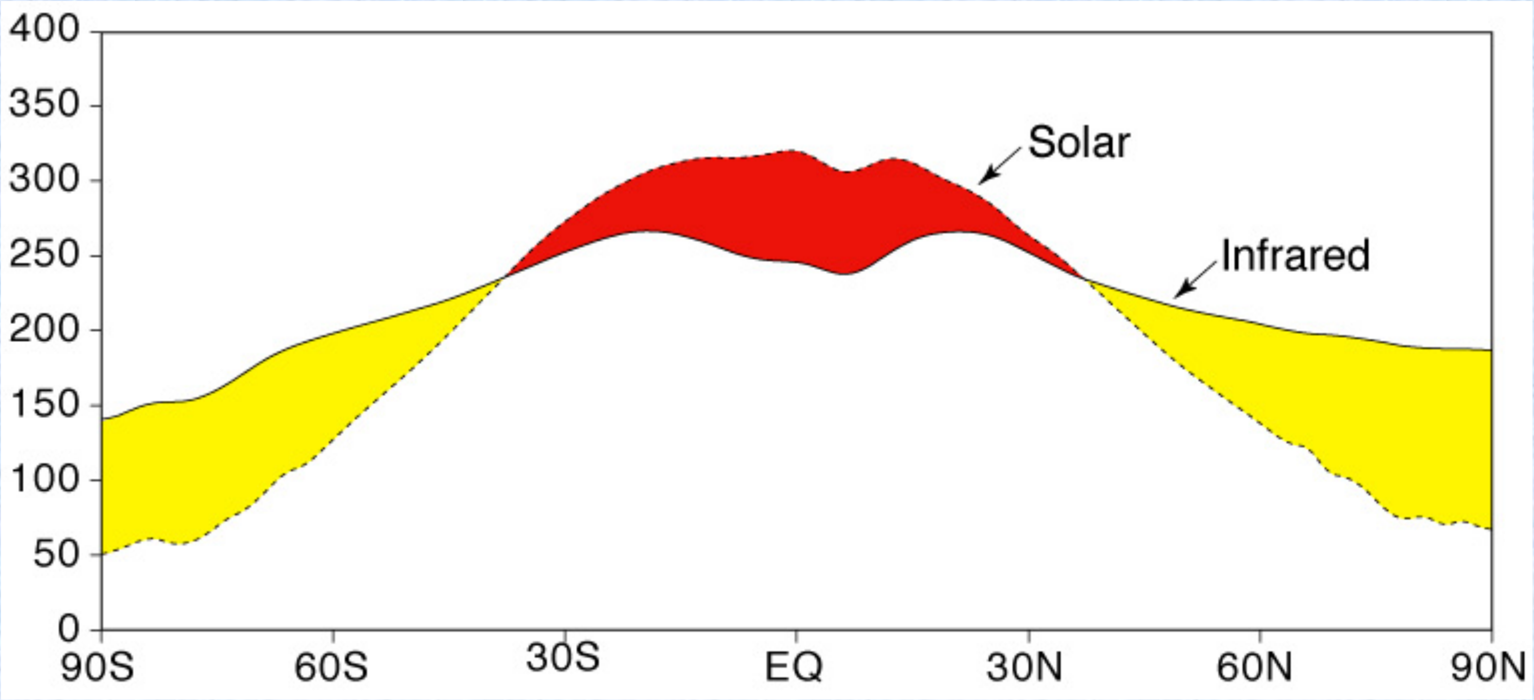
Neelin, 2011. *Climate Change and Climate Modeling,* Cambridge UP

Gradients of rad. forcing and energy transport

- **Differences in input of solar energy between latitudes ⇒ temperature gradients.**
- **These gradients would be huge if it were not for heat transport in ocean & atmosphere and heat storage in ocean.**
  - **e.g., North Pole in winter time would be extremely cold.**
- **Outgoing longwave radiation varies much less as a function of latitude because:**
  - **atmospheric and oceanic transports are very effective at reducing temperature gradients.**
  - **the ocean stores some heat from the previous summer.**

Neelin, 2011. *Climate Change and Climate Modeling,* Cambridge UP

Annual average net solar energy input and output of infrared radiation to space from Earth



- **Differences between solar input and compensating IR is due to north-south heat transport.**

Neelin, 2011. *Climate Change and Climate Modeling,* Cambridge UP

Heat transport in the Oceans

- **The oceanic heat transports are accomplished by moving warm water into cooler regions and cooler water toward warmer regions.**

- **This can occur through horizontal motions, or through warm surface waters moving into northern cold polar regions, sinking and returning southward.**

- **It can be due to climatological currents, such as the Gulf stream, which would carry warm water northward even if it did not vary in time, but heat transport can also be due to time varying currents, such as the ocean eddies.**

Neelin, 2011. *Climate Change and Climate Modeling,* Cambridge UP

The Oceans

- **The oceans cover 72% of the area of the Earth's surface and they reach an extreme depth of nearly 11 km.**
- **Their total volume is equivalent to that of a layer 2.6 km deep, covering the entire surface of the Earth.**
- **The mass of the oceans is approx. 250 times as large as that of the atmosphere.**
- **The density of sea water is linearly dependent on the concentration of dissolved salt.**

Neelin, 2011. *Climate Change and Climate Modeling,* Cambridge UP

The Oceans

- On average, sea water in the open oceans contains approx. 35 g of dissolved salts per kg of fresh water, with values typically ranging from 34 to 36 g /kg

- Due to the presence of these dissolved salts, sea water is approx. 2.4% denser than fresh water at the same temperature.

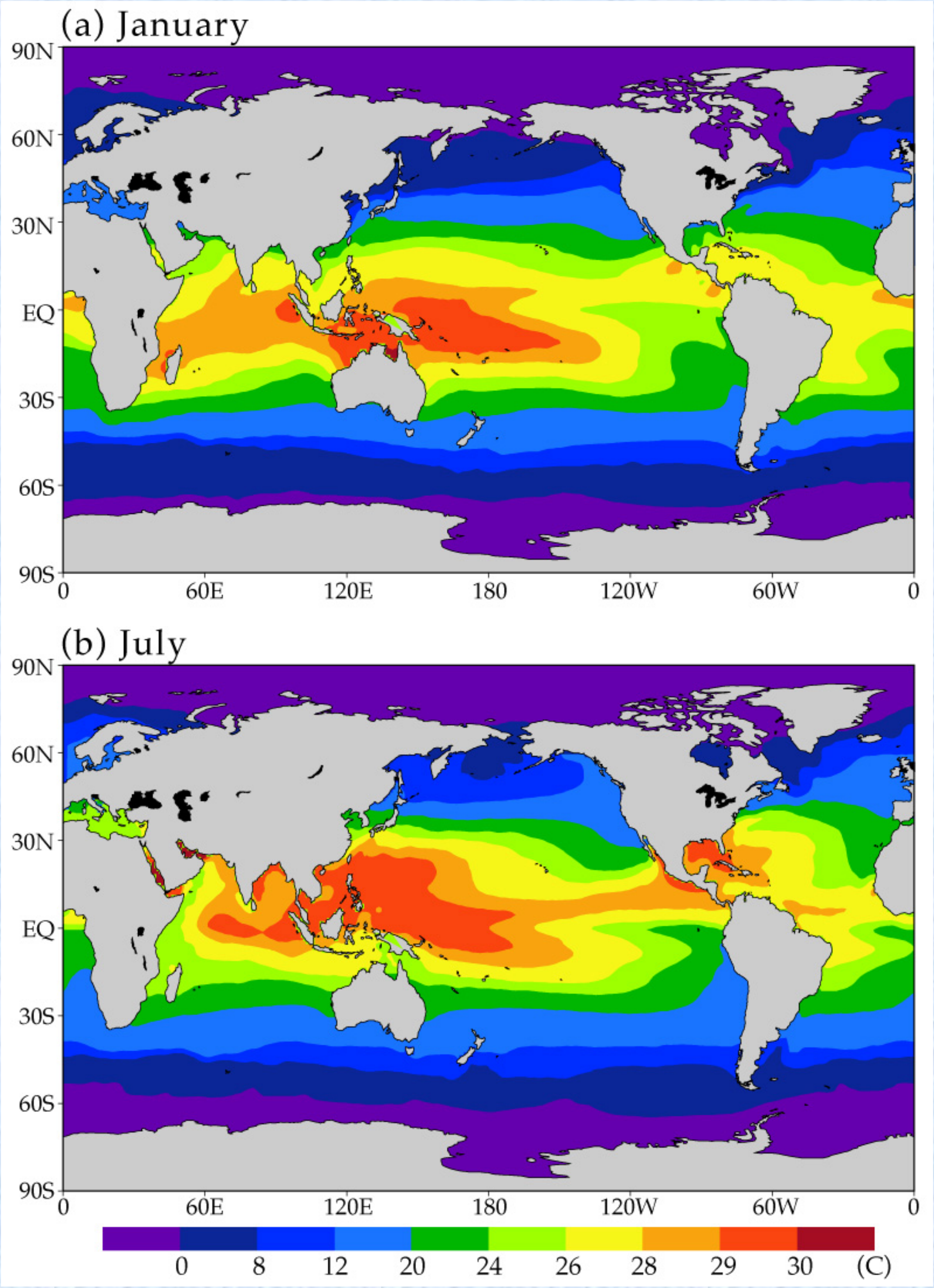
- The density of sea water is a rather complicated function of temperature T, salinity s, and pressure p. The pressure dependence of density in liquids is much weaker than in gases

Neelin, 2011. *Climate Change and Climate Modeling,* Cambridge UP

Ocean circulation

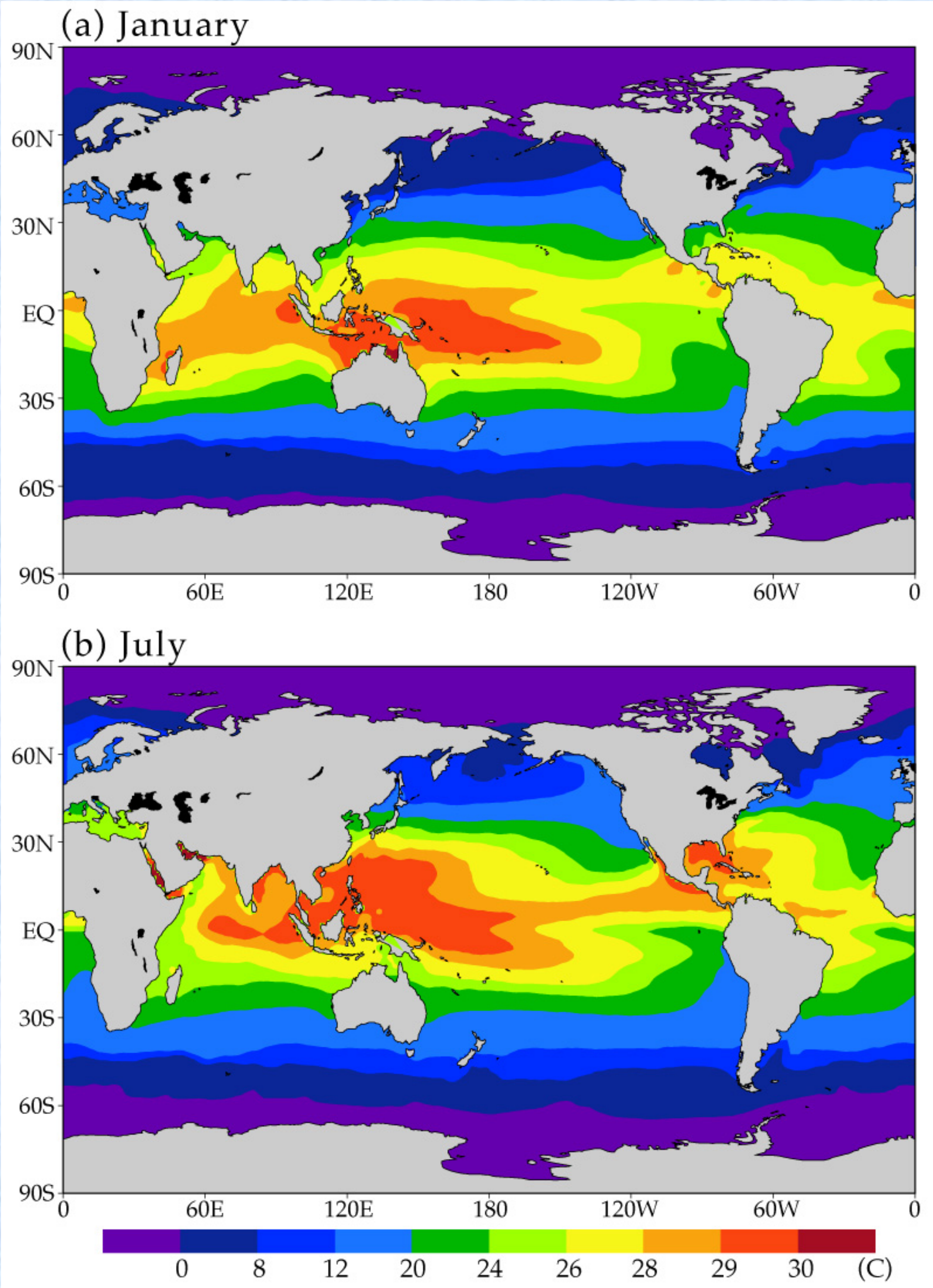
Sea surface temperature climatology - January

Sea surface temperature climatology - July



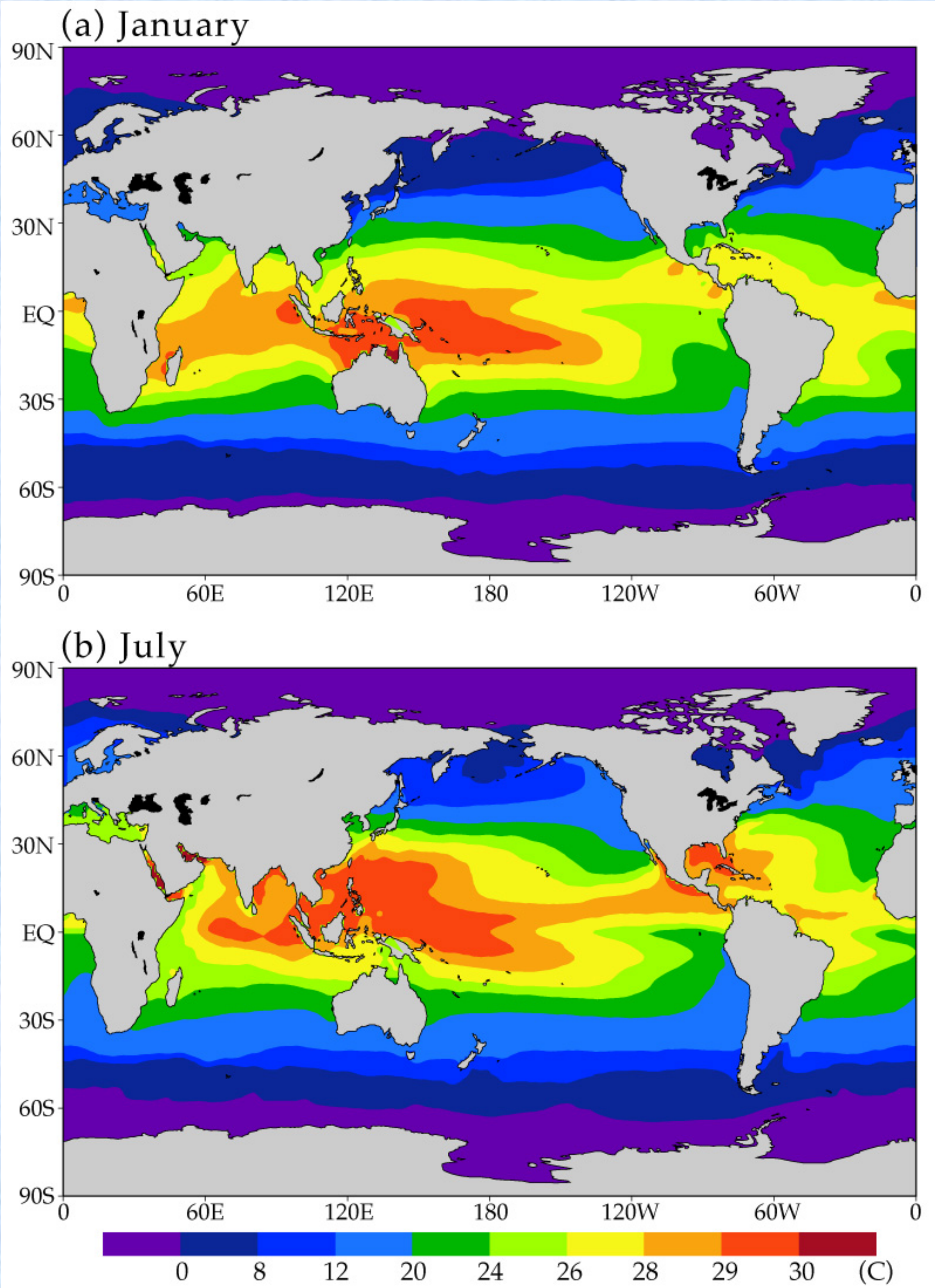
Neelin, 2011. *Climate Change and Climate Modeling,* Cambridge UP

- SST is warmest in tropics; approaches freezing in higher latitudes (-2 C); strongest SST gradient occurs at midlatitudes.
- SST is not perfectly symmetric about the Equator.
- Variations in longitude. e.g., eastern Pacific is relatively cold.
- **Equatorial cold tongue**: along the equator in the Pacific.
    - maintained by upwelling of cold water from below.



Neelin, 2011. *Climate Change and Climate Modeling,* Cambridge UP

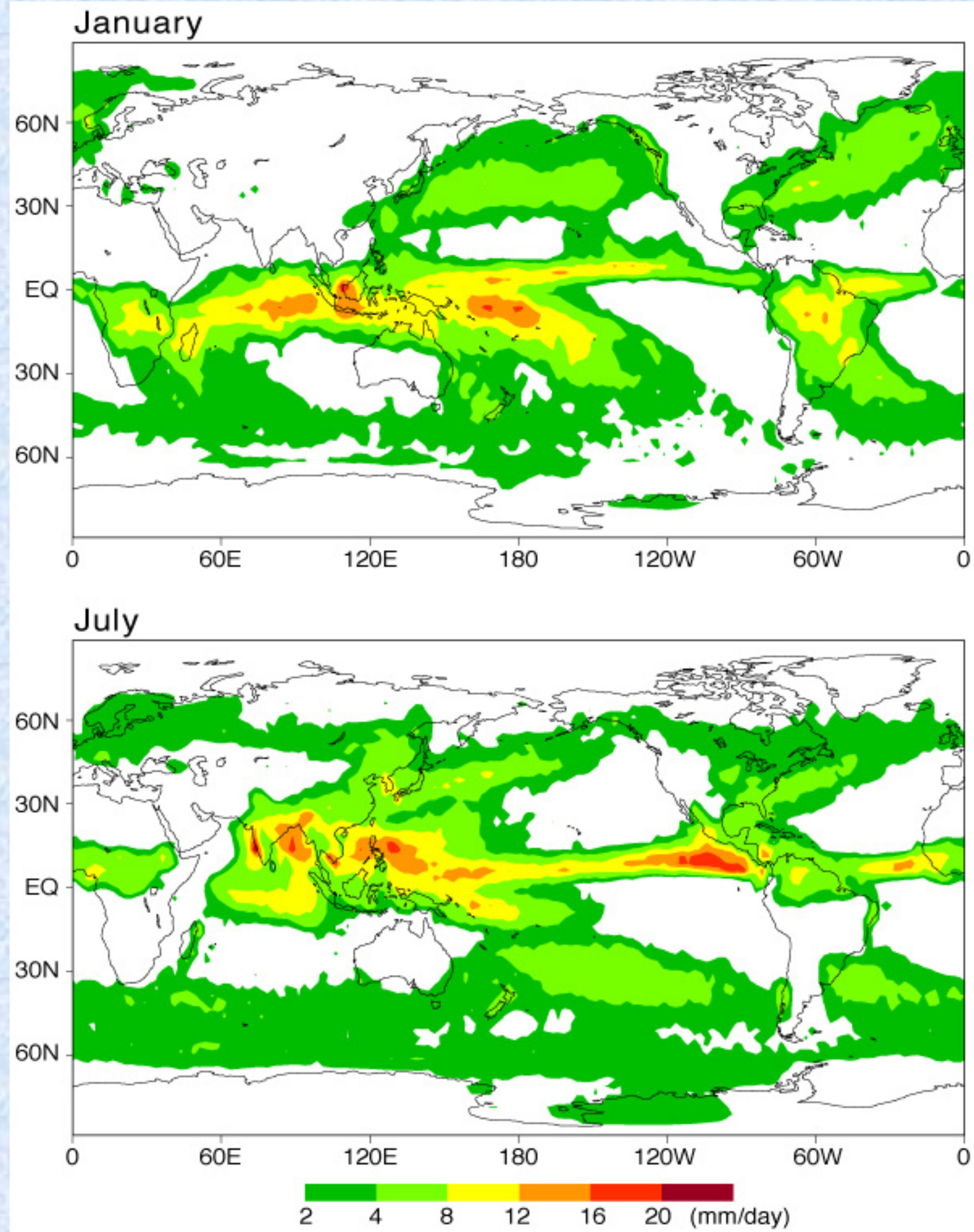
- **Rainfall over oceans has a close, though not perfect, relationship to SST pattern**
  - **in the tropics it tends to rain over SST that is warmer than SST in neighboring regions.**



Neelin, 2011. *Climate Change and Climate Modeling,* Cambridge UP

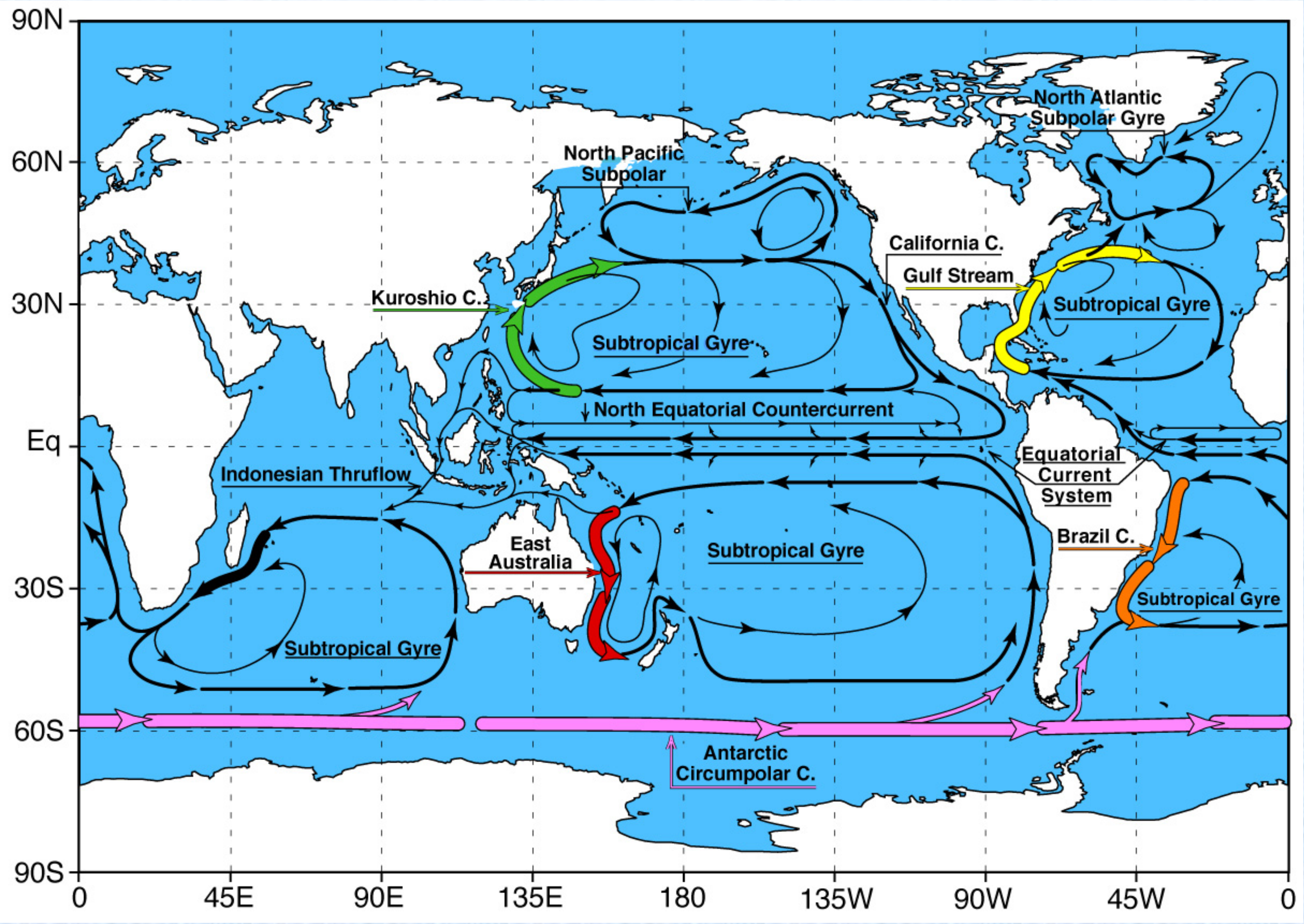
January precipitation climatology

July precipitation climatology



Neelin, 2011. *Climate Change and Climate Modeling,* Cambridge UP

Ocean surface currents



Neelin, 2011. *Climate Change and Climate Modeling,* Cambridge UP

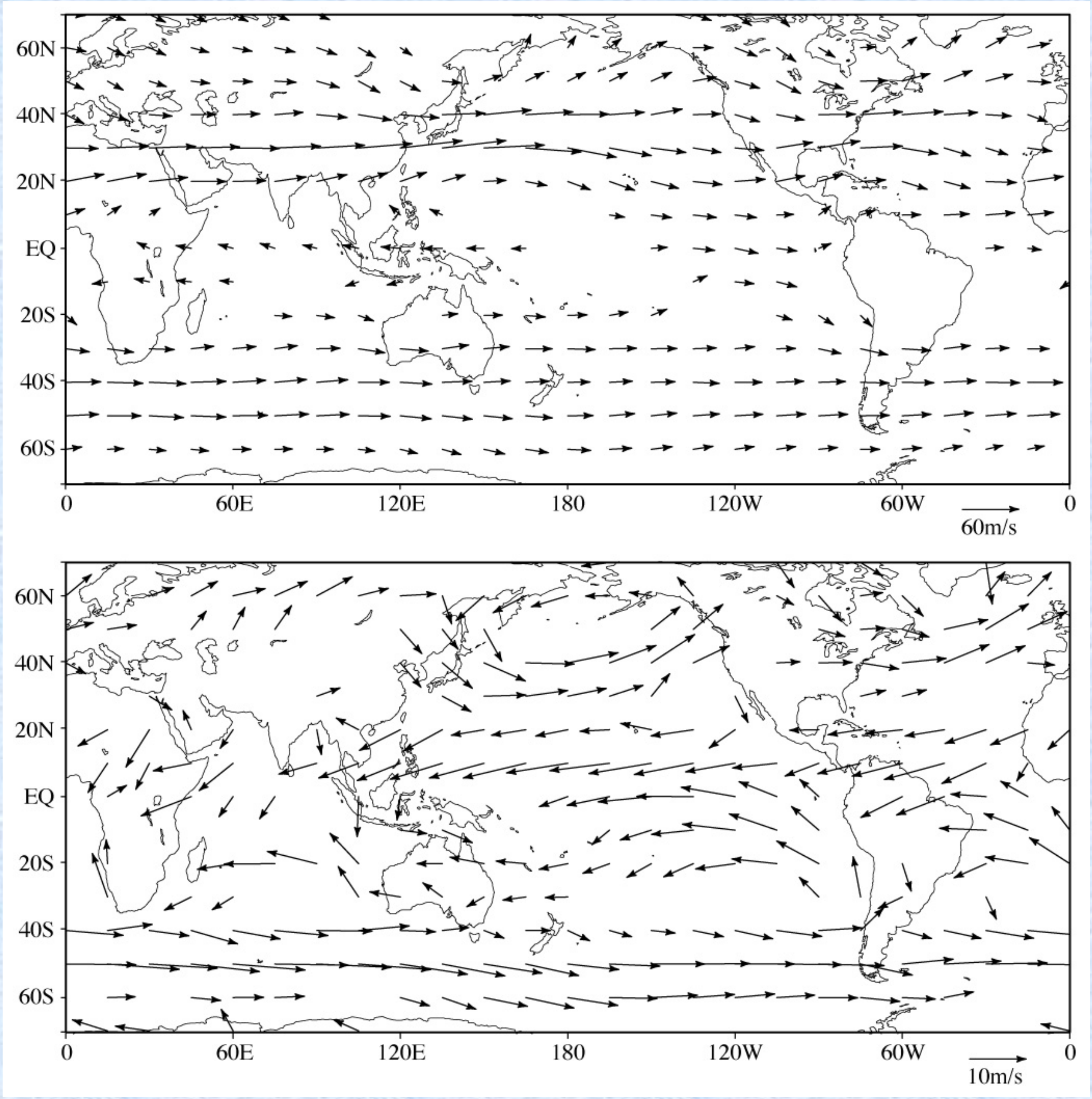
Figure 2.15

DJF climatology for upper (200 mb) level winds

- **Note subtropical jets; strong near storm tracks.**

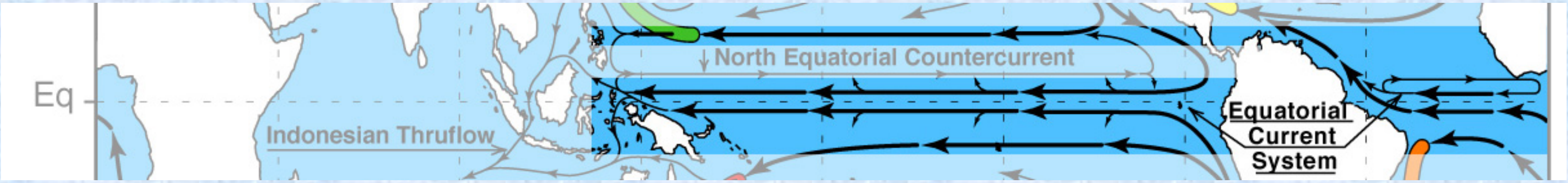
DJF climatology for lower (925 mb) level winds

- **Note strong tropical Pacific trade winds.**

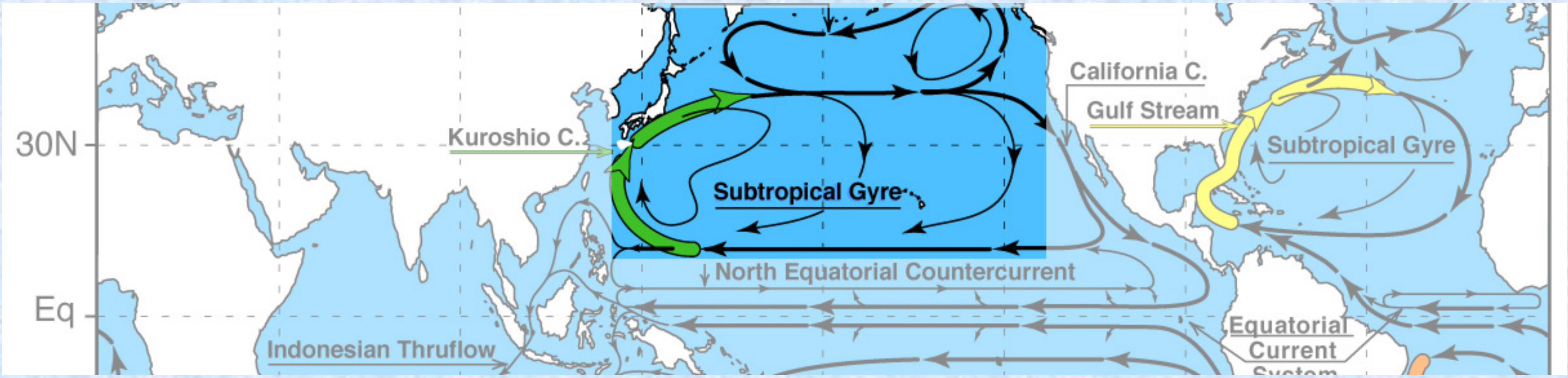


Neelin, 2011. *Climate Change and Climate Modeling,* Cambridge UP

Ocean surface currents (cont.)

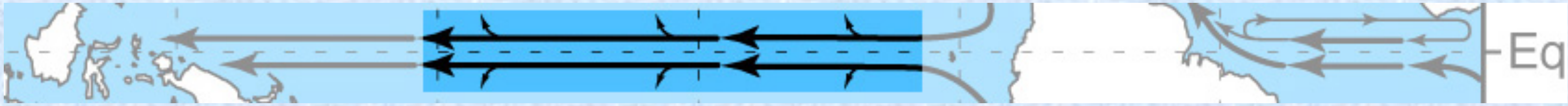


- Along the Equator, currents are in direction of the wind (easterly winds drive westward currents [note terminology!]

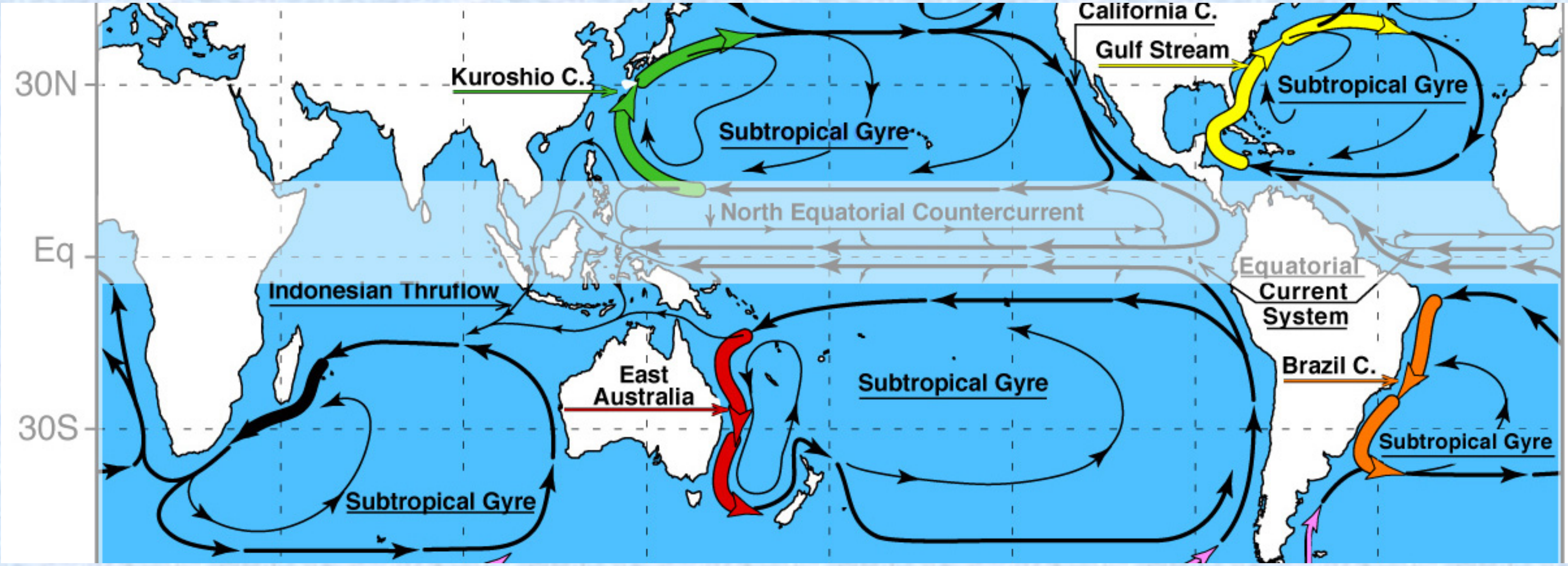


- Off the Equator, currents need not be in the direction of the wind. Currents set by change of the zonal wind with latitude and Coriolis force ("zonal" = east-west direction)

Neelin, 2011. *Climate Change and Climate Modeling,* Cambridge UP



- **Just slightly off the Equator, small component of the current moves poleward; important because it diverges ⇒ produces upwelling**

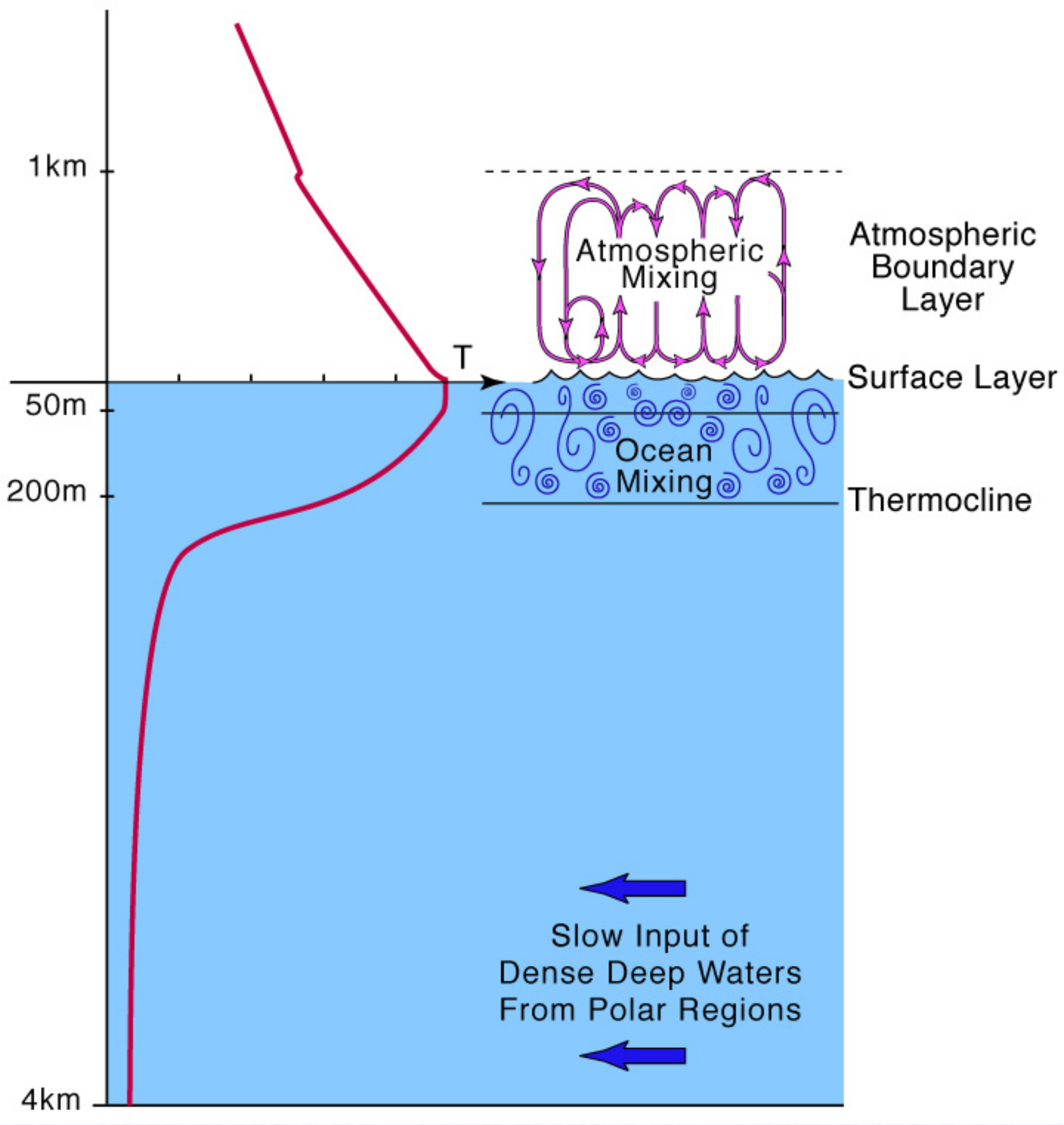


- **Circulation systems known as gyres. In the subtropical gyres, currents flow slowly equatorward in most of basin. Compensating return flow toward poles occurs in narrow, fast western boundary currents (Gulf stream, the Kuroshio, Brazil currents).**

Neelin, 2011. *Climate Change and Climate Modeling,* Cambridge UP

Ocean vertical structure

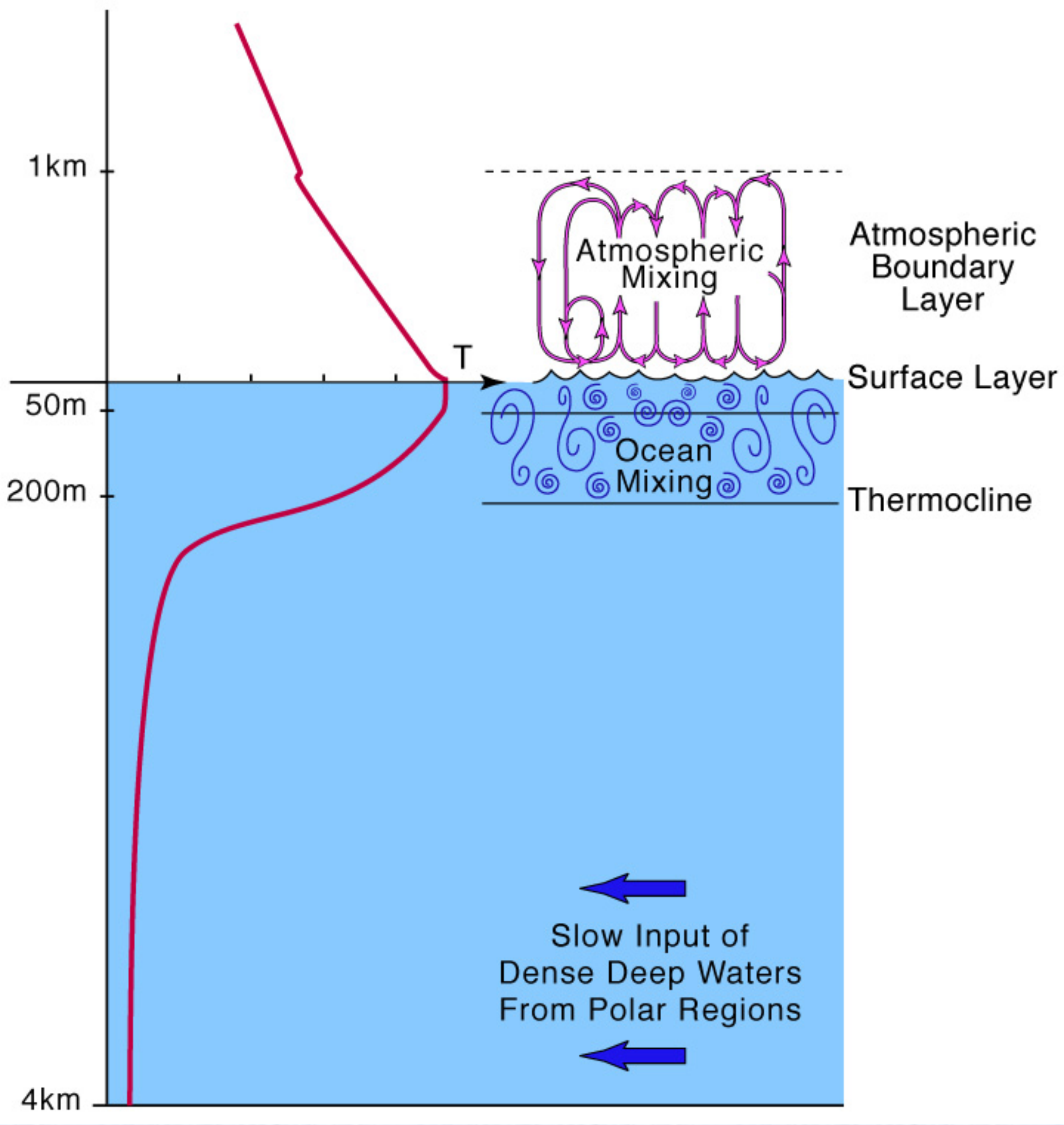
- Ocean surface is **warmed from above** ⇒ lighter water over denser water ("**stable stratification**").
  - incoming solar radiation warms upper 10 m. Turbulence near the surface mixes some of this warming downward.
  - mixing driven by wind-generated turbulence and instabilities of surface currents.



Neelin, 2011. *Climate Change and Climate Modeling,* Cambridge UP

Ocean vertical structure (cont.)

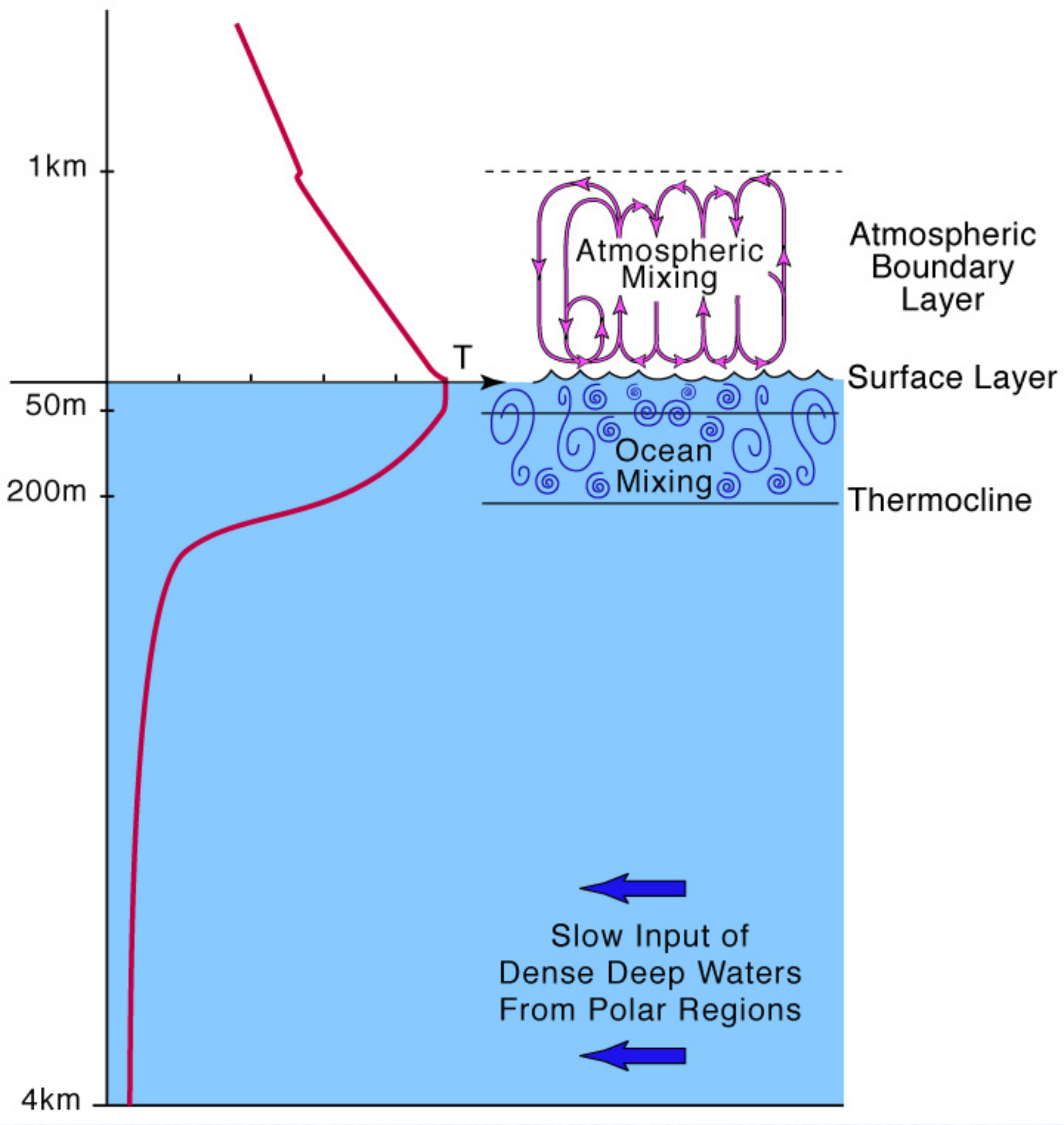
- **At thermocline, any mixing of the denser fluid below into lighter fluid above requires work ⇒ limits the mixing.**
- **Deep waters tend to remain cold**
  - **on long time scales, import of cold waters from a few sinking regions near the poles maintains cold temperatures.**



Neelin, 2011. *Climate Change and Climate Modeling,* Cambridge UP

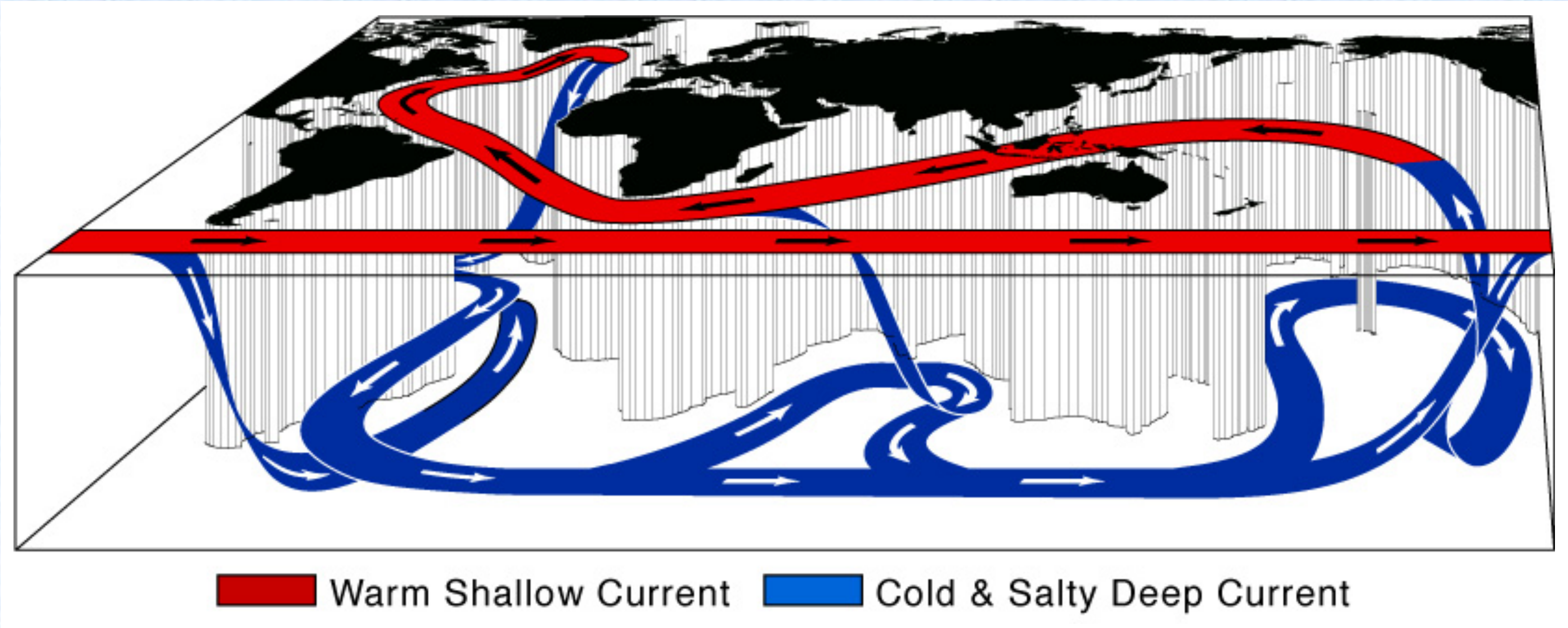
Ocean vertical structure (cont.)

- **Ocean surface is directly warmed by solar radiation ⇒ loses heat to atmosphere.**
  - **air temperature a few meters above the surface tends to be slightly colder than the surface temperature.**



Neelin, 2011. *Climate Change and Climate Modeling,* Cambridge UP

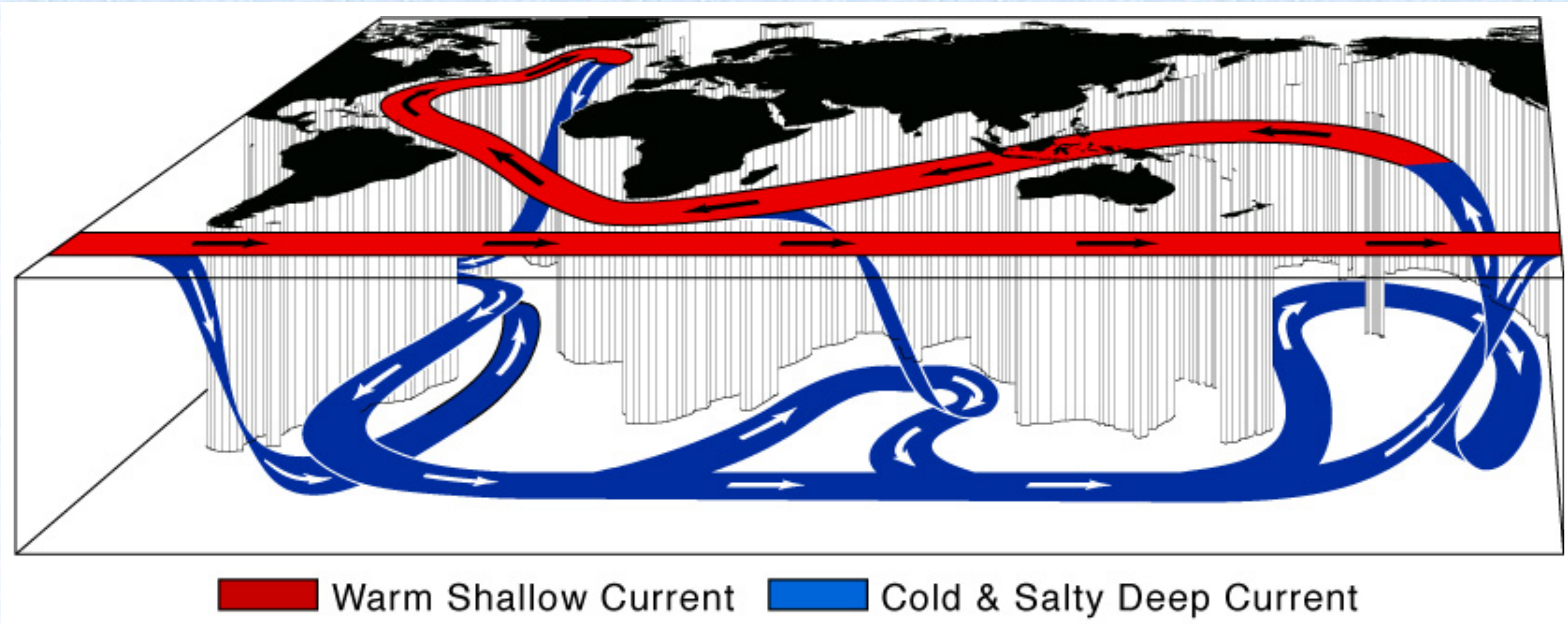
The thermohaline circulation



- ***Salinity*** **(concentration of salt) affects ocean density in addition to temperature.**
- **Waters dense enough to sink: cold and salty**
- ***Thermohaline circulation*****: it's the deep overturning circulation (thermal for the temperature, haline from the greek word for salt, hals).**

Neelin, 2011. *Climate Change and Climate Modeling,* Cambridge UP

The thermohaline circulation (cont.)



- **Deep water formation in a few small regions that produce densest water**
  - **e.g., off Greenland, Labrador Sea, regions around Antarctica.**
- **Small regions control temperature of deep ocean ⇒ potential sensitivity.**
  - **likely player in past climate variations.**

Neelin, 2011. *Climate Change and Climate Modeling,* Cambridge UP

The thermohaline circulation (cont.)

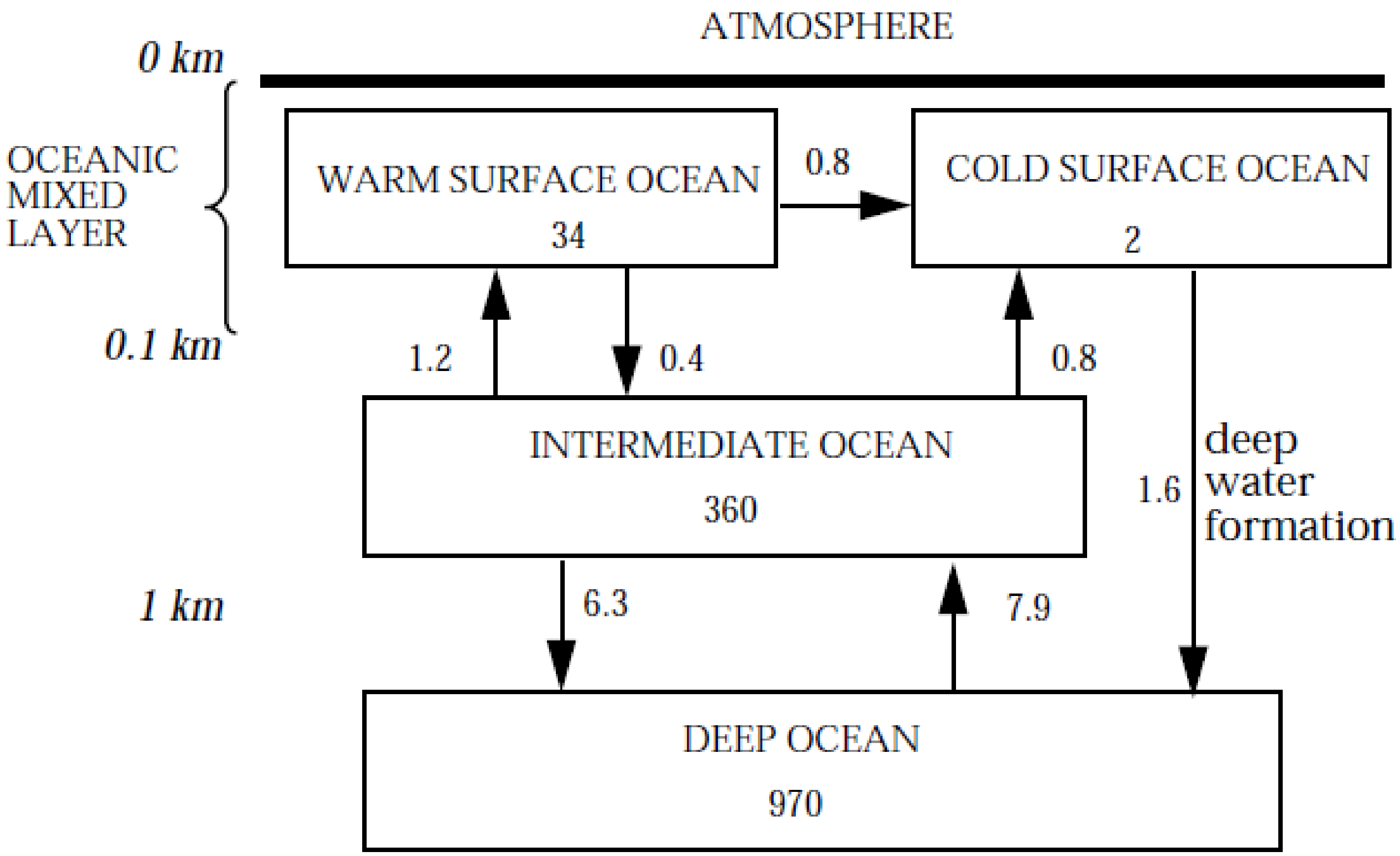


Figure 6-9 Box model for the circulation of water in the ocean. Inventories are in 10^{15} m^3 and flows are in 10^{15} m^3 yr^{-1}. Adapted from McElroy, M.B., *The Atmosphere: an Essential Component of the Global Life Support System*, Princeton University Press (in press).

The thermohaline circulation (cont.)

- Water parcels that are not in contact with the ocean surface tend to conserve temperature and salinity as they move over long distances. Hence, water masses (layers of water extending over large areas that exhibit nearly uniform temperature and salinity) can be tracked back to the regions of the mixed layer in which they were formed by exchanges of heat and mass with the atmosphere.

- Among the important water masses in the Atlantic Ocean:
  - **North Atlantic deep water (NADW)**, formed by the sinking of water along the ice edge in the Greenland, Iceland, and Norwegian Seas
  - **Antarctic bottom water (AABW)**, formed by sinking along the ice edge in the Weddell Sea (gulf of the Antarctic peninsula)

The thermohaline circulation (cont.)

- **Important for biogeochemical cycles (nutrients etc.) !!**

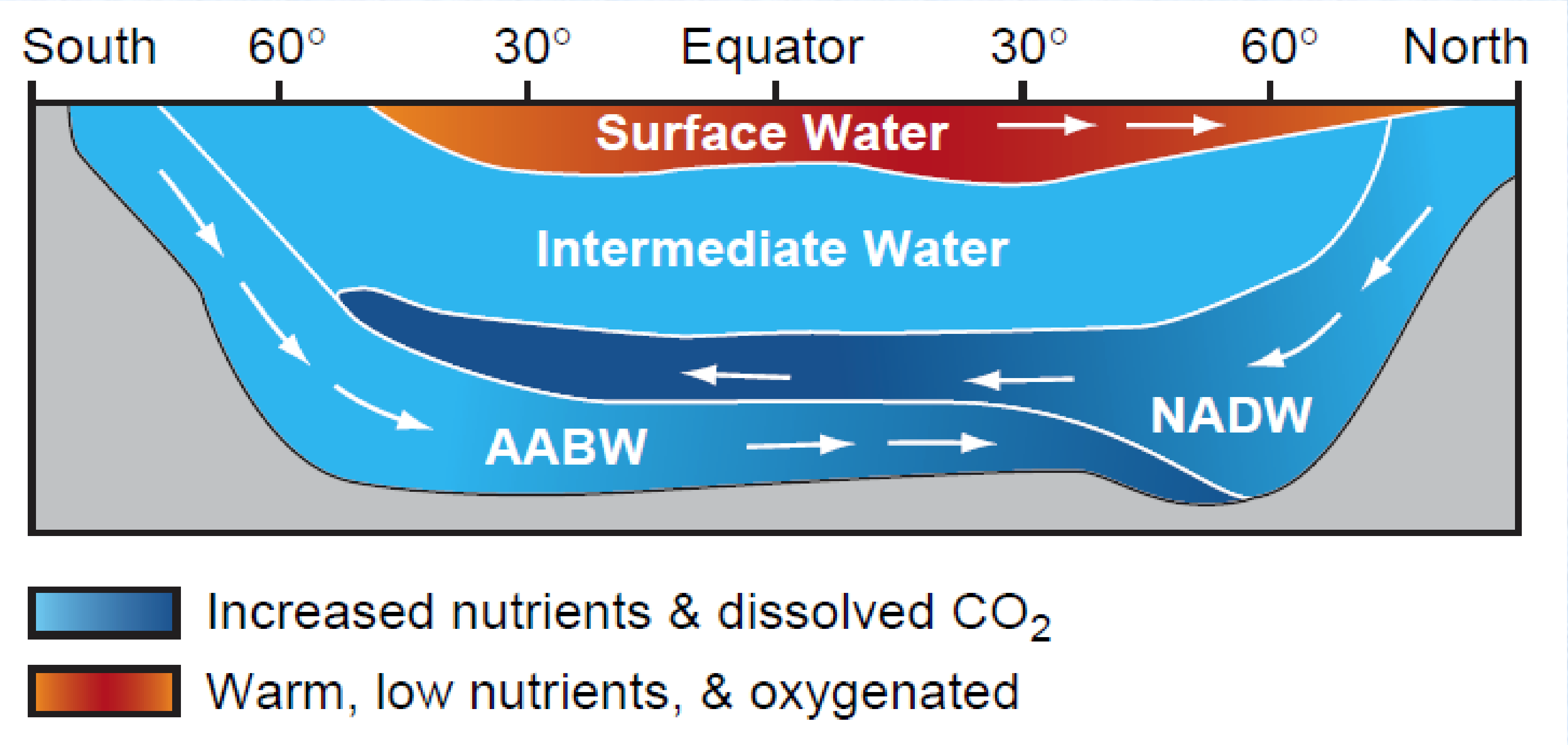


Fig: Idealized cross section of the thermohaline circulation in the Atlantic Ocean. In this diagram, Intermediate Water comprises several different water masses formed at temperate latitudes.