Chapter 5:Ocean Processes and Climate Phenomena

5.1 Pressure, temperature, salinity, and some thermohaline dynamics

The oceans cover over 70% of the earth with a relatively thin layer of water. The oceans are divided into a mixed layer (typically between 100 m and 1000 m deep) which is separated from the deep ocean below by the thermocline.

Solar energy warms the oceans from above, so the temperature of the water is higher nearer the surface and the surface layer of the ocean is stable.

Stable means; as the height the ocean increase the temperature also increase.

Ocean Processes and Climate Phenomena

Importance of the Ocean

- **Earth's present climate is intrinsically affected by the ocean—the climate without the ocean would be different in many essential ways:**
- **Without the evaporation of water from the sea surface, the hydrological cycle would be different;**
- **without ocean heat transport and uptake, the temperature distribution of the globe would be different;**
- **and without the biota in the ocean, the total amount of carbon in the atmosphere would be many time its current value.**
- **44% of the world's population live within 150km of a coastline**

Ocean Processes and Climate Phenomena

Water / Land

- **All Earth**
  - **71% water**
  - **29% land**
- **Northern Hemisphere**
  - **61% water**
  - **39% land**
- **Southern Hemisphere**
  - **81% water**
  - **19% land**

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Ocean Basins

- Pacific Ocean – Largest, average depth 3940 meters
- Atlantic Ocean – half size of Pacific, relatively narrow, and bounded by almost parallel continental margins.
- Indian Ocean – slightly smaller than Atlantic, and largely in Southern Hemisphere.
- Arctic Ocean – 7% the size of the Pacific Ocean and is little more than one quarter as deep as the rest of the ocean

Water Reservoir

Water reservoir	Percent total
Oceans	97%
Icecaps and glaciers	2.2%
Groundwater	0.7%
Lakes and streams	0.013%
Soil moisture	0.013%
Atmosphere	0.0009%
TOTAL	100%

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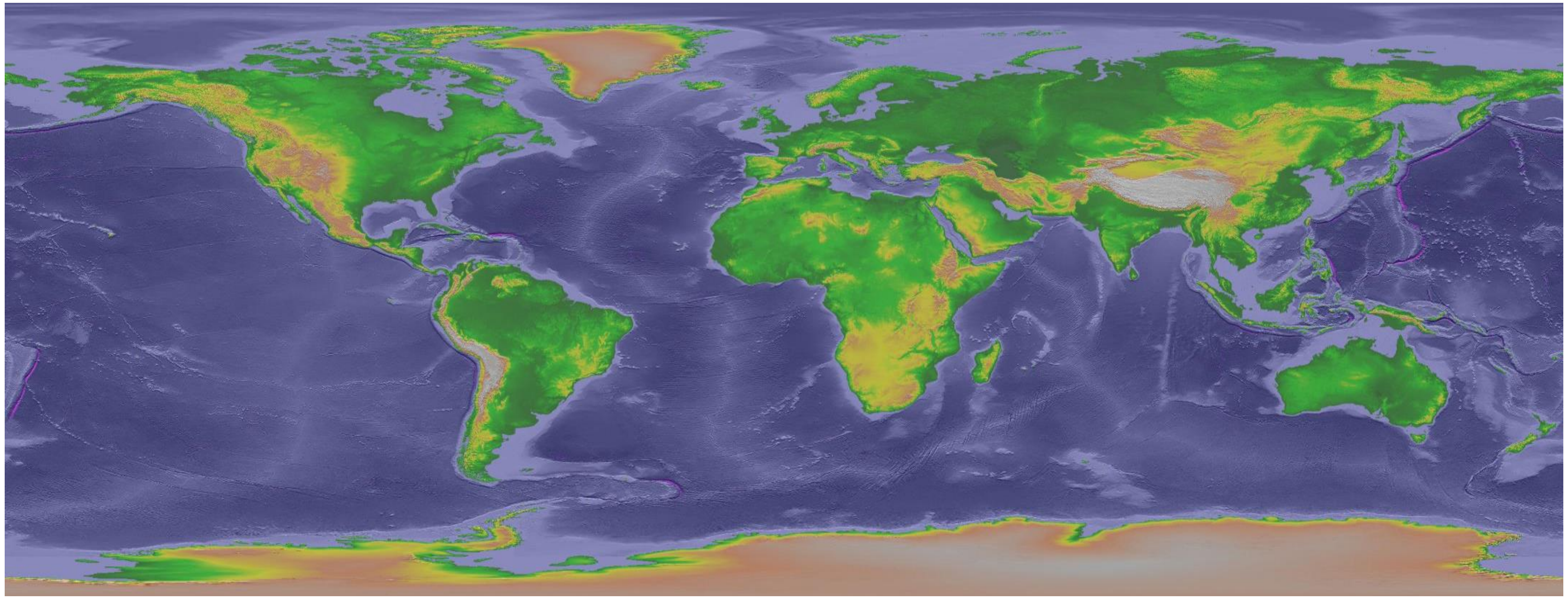
Volume of Water vs. Land

- **Volume of continents above sea level = 1/18 of ocean**
  - **Average Elevation on continents = 840 m (2,750 ft)**
  - **Average depth of ocean = 3800 m (12,500 ft)**



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Heat content / heat capacity

- **Water is a key to Earth's climate system**
  - **97% in oceans; 2% in glacial ice; < 1% elsewhere**
- **Absorption and storage of solar heat is strongly affected by the presence of liquid water because of its high heat capacity.**
  - **Heat capacity: a measure of the ability of a material to absorb heat.**
  - **Heat capacity = Mass× Specific heat**
    $(J\ K^{-1}\ m^{-3}) = (kg\ m^{-3}) \times (J\ kg^{-1}\ K^{-1})$
- **Heat capacity of water is higher than any of earth's other surfaces. Ratios of the heat capacities: water: ice: air: land: 60: 5: 2: 1.**
- **Low-latitude oceans are earth's main storage tanks of solar heat. Sunlight penetrates into and heats the upper 10's of metres of the ocean, especially in the tropics where the radiation arrives from the sun high in the sky.**

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- **Comparison between atmosphere and ocean**

  - **Thermal capacity of atmosphere**
    $= c_p \times$ mass of atm per unit area
    $= c_p\, p_s/g = 1.02 \times 10^7\ \mathrm{J\,K^{-1}m^{-2}}$

  - **Thermal capacity of ocean depth d_w**
    $= c_w \times$ mass of ocean per unit area
    $= c_w\, \rho_w\, d_w = d_w \times 4.2\mathrm{x}10^6\ \mathrm{J\,K^{-1}m^{-2}m^{-1}}$

Thermal capacity of atmosphere ~ 2m of water

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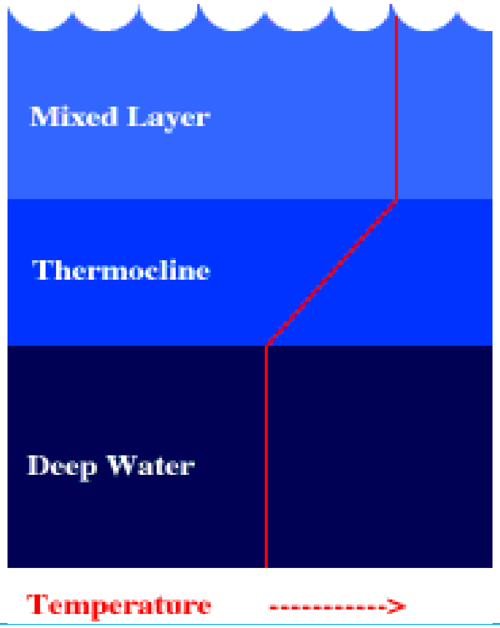
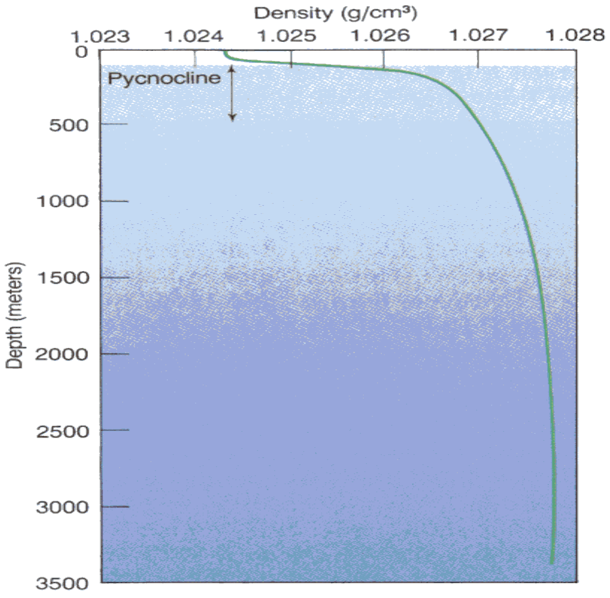
Ocean Layers

Thermocline is the transition line that separate the upper part which is mixed and stable or temperature gradient and the lower part which is deep and negative temperature gradient(instable).





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1. **Surface Mixed Layer** - a warm, less dense layer that floats on the ocean surface; May be from 50 - 200 m thick with a uniform density

2. Bottom boundary is the pycnocline /thermocline-----Strongly influenced by winds

3. **Intermediate Layer** - water between the SML and 1500 m depth

4. **Deep Water** - extends from 1500 m to 4000 m (not in contact with seafloor)

5. **Bottom Water** - below 4000 m

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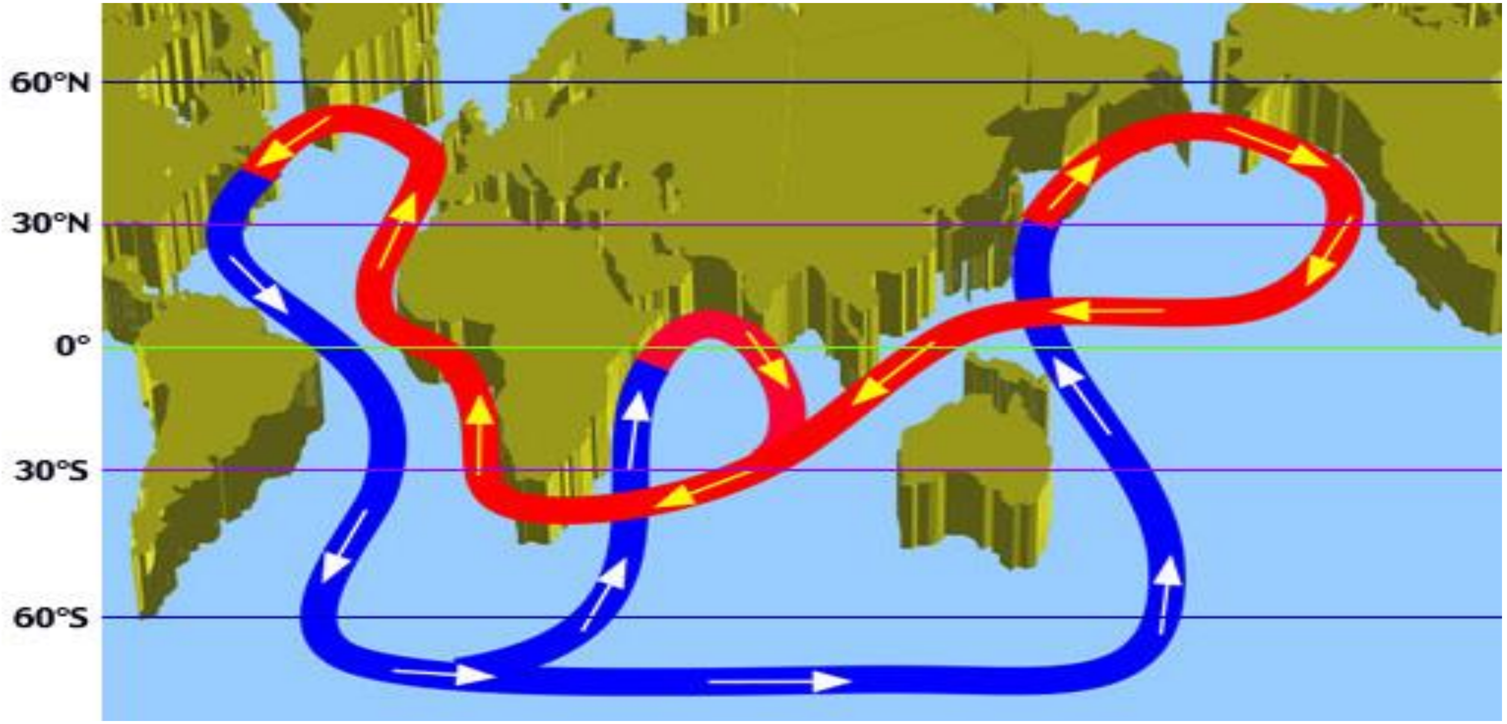
Warm surface waters and cooler sub-surface waters form a giant circulation pattern of current, transporting nutrients and salts round the world

- In this figure, warm near-surface currents are in red, while colder deep currents are in blue



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- **General Features**
  - **Ocean currents are classified as *Wind-Driven* or *Thermohaline***
    - **Wind-driven currents are set in motion by moving air masses**
    - **Thermohaline currents are due to differences in density, is**
      - **most common in deeper waters and associated with**
      - **vertical motion**

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At low latitudes, solar heating is strong and fairly constant through the year, and the stability of the thermocline is able to keep the mixed layer fairly shallow. In middle latitudes the strength of the solar heating changes seasonally.

Generally thermocline depth vary with latitude and seasons

Pressure is the force exerted on a unit surface that is oriented perpendicular to the direction of that force.

The pressure in sea is one of the thermodynamic variables of seawater, determining together with temperature and salinity a range of seawater properties, e.g., density, specific heat, sound velocity, etc.

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When the oceanic motions are restricted to low frequencies (no surface waves, internal waves, or convective motion), vertical accelerations can be ignored and the vertical momentum equation is to a very high accuracy approximated by the hydrostatic equilibrium:

$$\boxed{\frac{\partial P}{\partial z} = -\rho g}$$

Here z is the vertical coordinate (upward positive), ρ is the density of seawater and g is the gravitational acceleration.

Density of seawater depends on temperature and salinity

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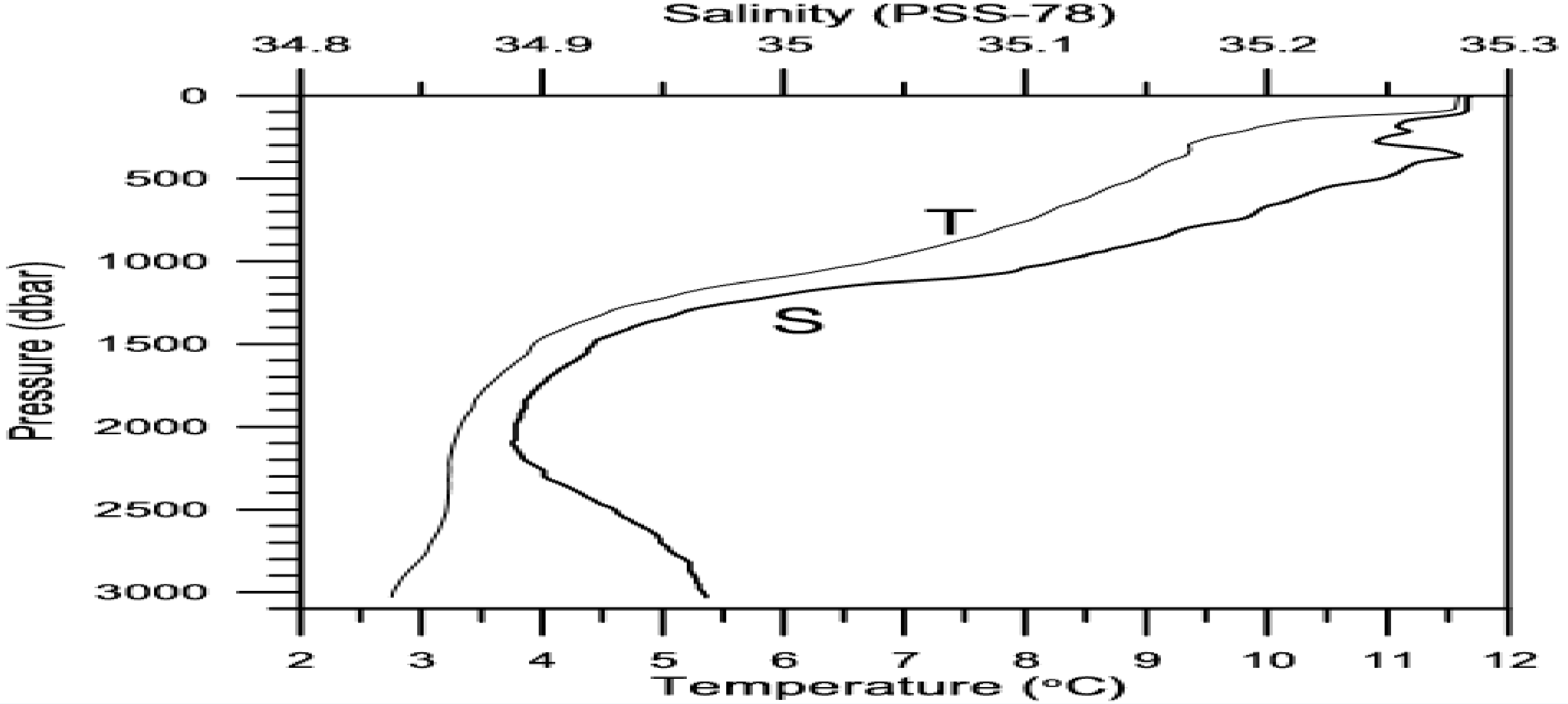
Temperature: A thermodynamic temperature, expressed in this way, is known as the Celsius temperature with unit symbol °C. The temperature of the ocean is mainly in the range of –2 to +35°C.



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Salinity: Salinity is the total mass of dissolved material in one mass unit of seawater.

A precipitation excess over the ocean will increase the freshwater fraction in the surface water, thereby decreasing the salinity.

An evaporation excess withdraws water from the ocean and will increase the sea surface salinity.

Density: Meridional density gradients are often assumed to drive the overturning THC.

Increase of density at the sea surface due to heat loss to the atmosphere or evaporation may generate a static unstable stratification, with the denser water on top.

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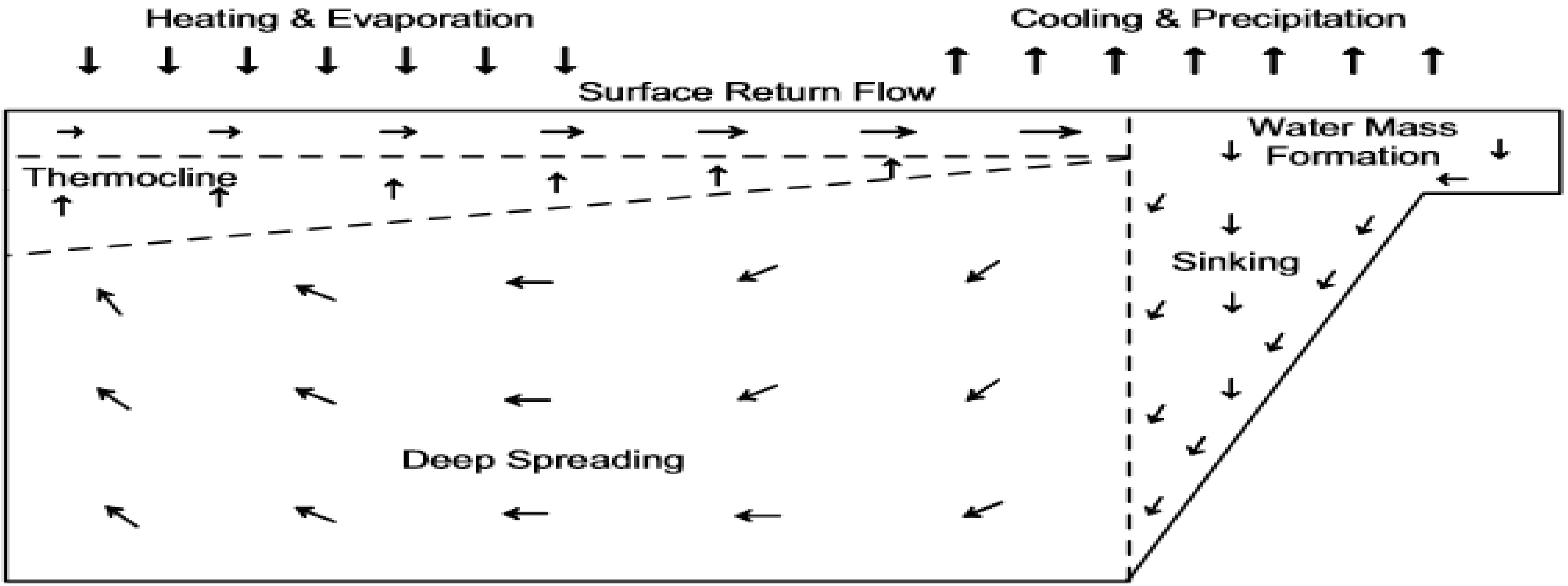
5.2 Dynamics of the THC

The concept of the thermohaline circulation often is used in climatological and oceanographic publications.



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Thermohaline circulation is a circulation driven by mechanical stirring, which transports mass, heat, freshwater and other properties in the meridional/zonal direction. This term generally refers to the circulation associated with differences in temperature and salinity in the ocean

Mechanical stirring is supported by external sources of mechanical energy from wind stress and tidal dissipation.

Variability of the thermohaline in the ceanic circulation does vary greatly over long time scales.

There is evidence from paleoproxies that thermohaline circulation and the associated water mass formation/erosion has been through great changes on decadal to centennial and millennial time scales.

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The major problem associated with the thermohaline circulation is that it varies on time scales of centennial to millennial.

Theories of oceanic circulation and numerical models need to be verified by observations.

Thus for our understanding of thermohaline circulation under climate conditions different from the present comes mostly from incompletes sources, including paleoproxies, theories, and numerical simulations.

By definition, the thermocline is a thin layer where the vertical gradient of temperature is a local maximum.

There are many types of thermocline,including the diurnal thermocline, the seasonal thermocline, the main thermocline, and the abyssal thermocline.

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The diurnal thermocline exists in the top layer of the upper ocean, and it is closely related to the diurnal cycle.

The seasonal thermocline exists in the upper hundred meters of the ocean, and is closely related to the seasonal cycle in the upper ocean.

The main thermocline exists within the depth range of 100–800 m.

Because it is far away from the sea surface and shielded from the direct forcing in the seasonal cycle, it is also called the permanent thermocline.

The abyssal thermocline exists in the deep ocean

Motions in the ocean are intimately related to density, the pycnocline, defined as a subsurface layer of local maximum of a vertical density gradient, may be more important dynamically.

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However, in most cases, the contribution of salinity to the density is much smaller than that due to temperature, and therefore the thermocline and the pycnocline are closely linked to each other.

The depth of the main thermocline varies greatly with geographic location.

It is rather shallow near the eastern boundaries of the equatorial regimes due to equatorial upwelling driven by the easterlies at low latitudes.

It is also shallow along the eastern boundaries of the Southern Hemisphere, owing to the strong coastal upwelling driven by thealong-shore component of thetradewind.

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Thus,the shallowness of the main thermocline in the separts of the ocean is associated with the relatively cold surface temperature induced by local wind driven upwelling,and these areas are called the“cold tongues”in the oceans.

The main thermocline in the western part of the equatorial oceans is deeper than in the eastern part because warm water is piled up under the equatorial easterly

In the Pacific Ocean this body of warm water is called the Warm Pool. Both the Warm Pool and the Cold Tongue play vitally important roles in the global climate system

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The thermocline is much deeper at mid latitudes, primarily due to the down ward pushing associated with the negative wind stress curlin the subtropics.

In the western part of the subtropical gyre of the North Atlantic Ocean (North Pacific Ocean).

The thermocline in the Southern Hemisphere is relatively shallower, and isabout500m (450m) for the South Atlantic Ocean (South Pacific Ocean).

The difference in thermocline depth reflects the difference in wind stress forcing and the stratification in different oceans.

In the North Atlantic Ocean, stratification is relatively weak, due to high salinity induced by strong evaporation.

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The vertical temperature gradient of the main thermocline also varies greatly over the world’s oceans.

Within the subtropical gyres, the gradient is on the order of 2–4$\circ$C/100m;

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Air-sea interaction (cooling, evaporation, and precipitation) already modifies the warm surface currents flowing from the tropics to the source region of deep water before they arrive there.

In some regions of the ocean upwelling of the deep water to shallower levels will take place whereby, due to turbulent mixing with shallower water, temperature, salinity, and density adapt to the overlying layers of the ocean.

The upwelled water returns to the regions where the deep convective mixing takes place.

The ocean circulation is a physical system, described by conservation equations for heat, salt, momentum, etc

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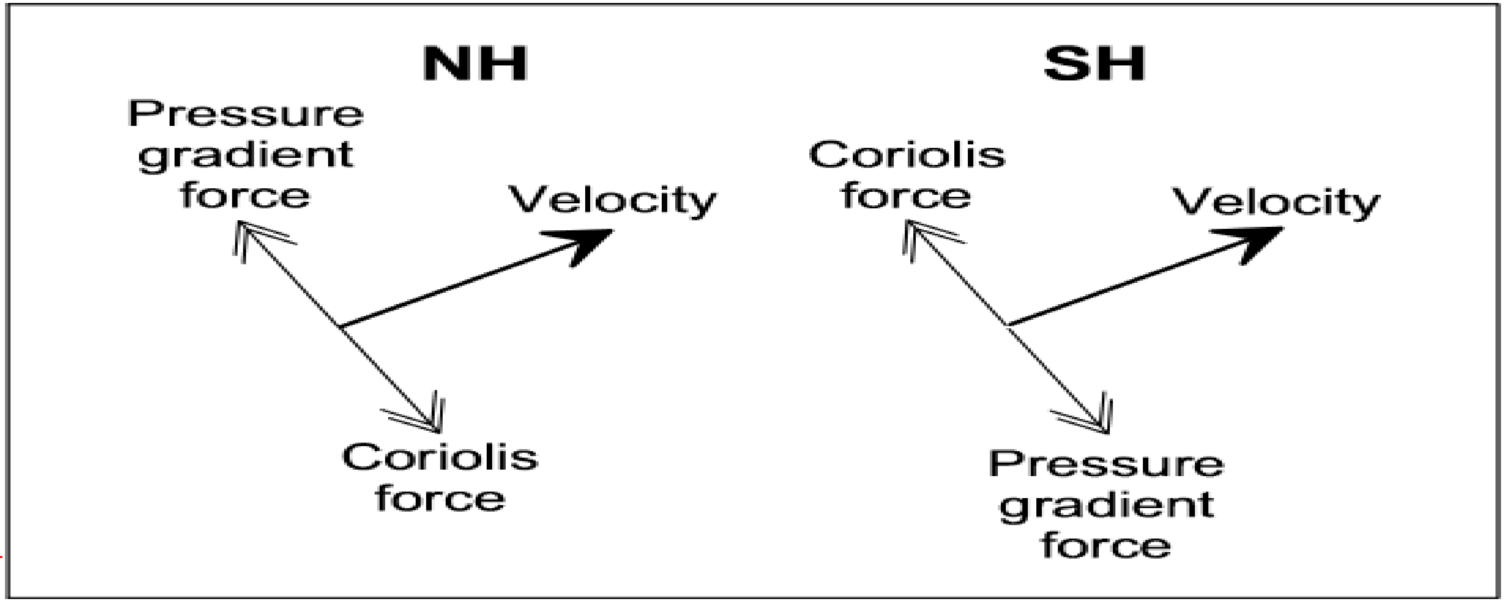
Outside the thin turbulent boundaries near the sea surface and the bottom, the dynamics of the ocean circulation are well described by the geostrophic balance.

Geostrophic and near-geostrophic flow is the wind flow when pressure gradient force balanced by Coriolis force.



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For most of the ocean's interior the large-scale horizontal currents can be described accurately by a balance between the Coriolis force and the pressure gradient, where friction and acceleration terms can be ignored. This is called the geostrophic balance:

$$fv = \frac{1}{\rho}\frac{\partial P}{\partial x}\bigg|_z \quad , \quad fu = -\frac{1}{\rho}\frac{\partial P}{\partial y}\bigg|_z \quad \text{or}$$

$$fv = g\frac{\partial z}{\partial x}\bigg|_p \quad , \quad fu = -g\frac{\partial z}{\partial y}\bigg|_p \quad .$$

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The current velocity, pressure, and density fields in the ocean, when not in balance, have a tendency to adapt mutually to fulfill the geostrophic balance, the so-called geostrophic adjustment.

Ocean circulation occurs by large-scale meridional pressure gradient

Meridional pressure gradient generated by the density difference between cold polar latitude waters and the warmer water at subtropical and tropical latitudes.

The large-scale meridional (north - south) baroclinic pressure gradient will result in zonal (east - west) geostrophic currents.

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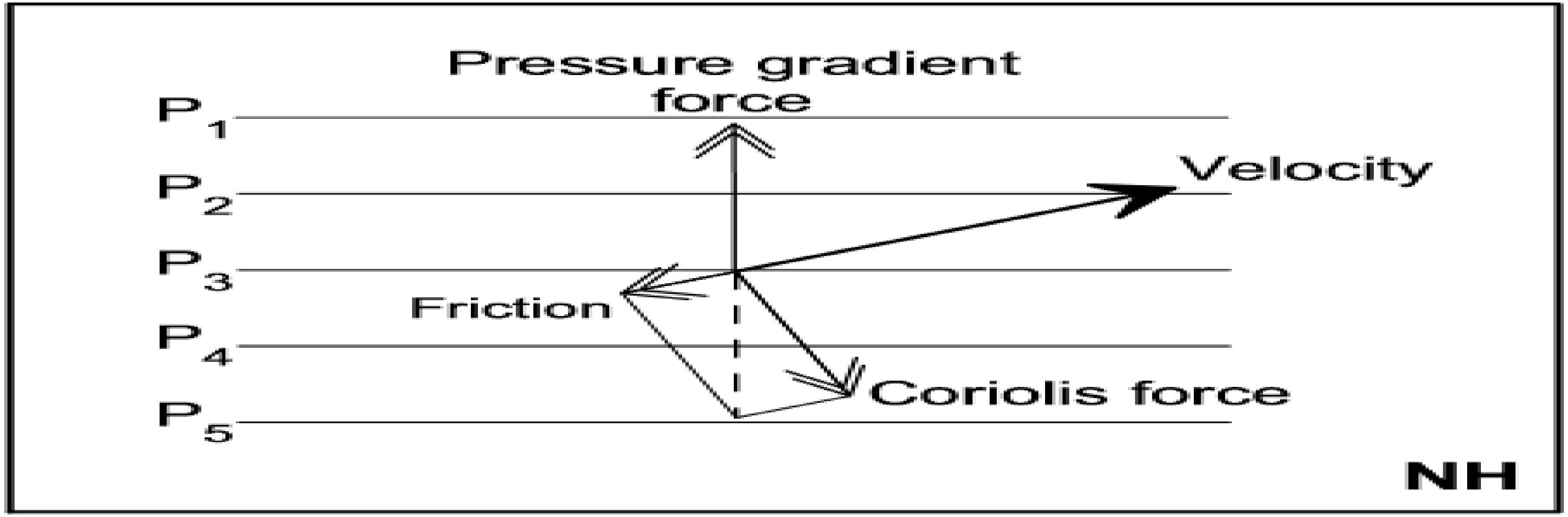
Near-geostrophic balance (friction, Coriolis and pressure gradient force)



The Coriolis parameter f equals zero at the equator. There the geostrophic balance no longer can be applied.

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5.3 Theory of gyre-scale circulation

Our theoretical understanding of ocean circulation is based primarily on the conservation laws for mass and momentum.

The momentum equation, relative to fixed axes on a rotating earth, is,

$$\rho\frac{\partial u}{\partial t}+\rho(u\cdot\nabla)u-\rho f\times u-\rho g-\nabla p+d=0$$

where u is velocity, t time, f the Coriolis vector, g gravity, p pressure and d the viscous stress due to small-scale processes

Away from the boundaries, the ocean is observed to be primarily geostrophic, that is to say the main balance is between the Coriolis term and the horizontal pressure gradient.

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5.4 The abyssal circulation

The first was that surface water down wells into the deep ocean in a few localized regions near the poles.

Second, they assumed that upwelling occurs fairly uniformly throughout the deep ocean as a result of the vertical mixing due to breaking internal waves.

Another key idea was the realization that uniform upwelling in the deep ocean acts like Ekman suction at the sea surface and so produces similar Sverdrup gyres.

Finally, they realized that the flow could be completed by a series of deep western boundary currents with the three main oceans connected by the flows in the Antarctic Circumpolar Current.

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5.5 Tropical Ocean Circulation

Most of the heat absorption into the global oceans, and much of the freshwater absorption, occurs in the tropics.

Furthermore, Sea Surface Temperature (SST) is sufficiently high in the tropics that deep atmospheric convection can and does occur over it.

Movements of deep convection patterns, which affect climate globally, depend sensitively on small changes in SST.

More importantly, especially in the Pacific, near-equatorial currents and temperatures have major inter-annual variability associated with the El Niño Phenom.

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At low latitude, the Coriolis force is weak. This feature of the momentum balance allows the tropical circulation to involve a greater contribution from the divergent component of motion and to be thermally direct.

In the tropics, the temperature distribution is relatively flat (Fig. 6.3). Implied is little available potential energy to drive large-scale motion. The primary source of energy for the tropical circulation is, instead, latent heat release inside organized convection.

Downward motion of the easterlies is usually more irregular than that

End

Next Chapter:6