Chap 3 The Basic Physical Laws used in Oceanography and Classifications of Forces and Motions in the Sea

3.1 Basic Laws

Conservation of Mass: Leads to ***Continuity Equation***.

Conservation of Energy: Conservation of heat leads to ***Heat Budgets***.
Conservation of mechanical energy leads to ***Wave Equation***.

Conservation of Momentum: Leads to ***Navier-Stokes Equation***.

Newton's Law of Gravitation: Used for deriving ***Tidal Equations***.

Conservation of Angular Momentum: Leads to ***Conservation of Vorticity***.

3.2 Primary Forces

Gravitation: Gives rise to pressure forces and tidal forces.

Wind Stress: Forces motion at the sea surface.

Thermodynamic Forces: Cause changes in density, leading to the ***Thermohaline Circulation***.

Atmospheric Pressure: Results in the ***Inverted Barometer*** effect.

Seismic: Results in ***Tsunamis*** driven by earthquakes.

The last two are much less important than the first three.

3.3 Dominant Forces for Ocean Dynamics

Thermodynamics:

– Evaporation cools surface waters and increases salinity, leading to an increase in density.
– Heating decreases density.
– Friction (viscosity) converts mechanical work to heat, but the production of heat is unimportant.

Wind Stress:

– Drives the surface circulation, especially the ***Ekman Circulation***.

– Mixes the surface layers producing the ***Mixed Layer***.
– Produces ocean surface waves.

Tidal:
– Produces tidal current.
– Tidal currents cause some *internal waves* and mixing.

3.4 Pseudo-Forces

Pseudo-forces:
– Apparent forces arising from motion in curvilinear or rotating coordinate systems.
– e.g. Inertial motion in a curvilinear coordinate system appears to be accelerated, and a pseudo force is needed to balance the acceleration.

Coriolis Force:
– A pseudo-force arising from inertial motion in a rotating coordinate system fixed to the Earth.

3.5 Coordinate System

Cartesian: – Normally used for describing local motion.
x – East, y–North, z–Upward.

***f*–plane:** – A Cartesian coordinate system in which the Coriolis force is assumed constant.
– It is useful for describing flow in regions small compared with the radius of the Earth and larger than a few tens of kilometers.

β–plane: – A Cartesian coordinate system in which the Coriolis force is assumed to vary linearly with latitude.
– It is useful for describing flow over areas as large as ocean basins.

Spherical: – Used for describing motion over large distances.

3.6 Motion in the Ocean

General Circulation:
– Permanent, time-averaged circulation of the ocean.

Meridional Overturning Circulation or Thermohaline Circulation:

– Circulation, in meridional plane, driven by density differences.

Wind-Driven Circulation:

– Near-surface circulation on all scales in the horizontal plane tends to be wind driven. The circulation can be caused by local winds or winds in other region.

Gyres:

– Wind-driven cyclonic or anticyclonic currents with dimensions nearly that of ocean basins.

Boundary Currents:

– Currents flowing parallel to coasts.

– Western boundary currents on the western edge of the oceans tend to be fast, narrow jets such as the ***Gulf Stream*** and ***Kuroshio***.

– Eastern boundary currents are weak, e.g. the ***California Current***.

Squirts or Jets:

– Long narrow currents, with dimensions of a few hundred kilometers, that are nearly perpendicular to west coasts.

Mesoscale Eddies:

– Turbulent or wavelike flows on scales of a few hundred kilometers.

Storm Surges:

– Changes in sea level driven by storms impinging on coasts with extensive shallow continental shelves such as the Gulf of Mexico and the North Sea.

3.7 Waves in the Ocean

Planetary Waves:

– Waves motions of many types which depends on the rotation of the Earth for a restoring force, including Rossby, Kelvin, Equatorial, and Yanni waves.

Surface Waves:

– Wave motion at the sea surface resulting from the large density contrast at the sea surface.

Internal Waves:

– Subsea wave motion resulting from vertical density gradients within the sea.

Tsunamis:

– Long surface waves with periods near 15 minutes driven by earthquakes.

Tidal Currents:

– Horizontal currents and internal waves driven by the tidal potential.

Shelf Waves:

– Waves with periods of a few minutes confined to shallow regions near shore. The amplitude of the wave drops off exponentially with distance from shore.

3.8 Conservation of Volume

The principle of conservation of volume follows from the fact that compressibility of water is small. As shown in Fig. 3.1, V_i, V_o, E, P and R stand for volume transport (m^3/s) of flow in and out, evaporation, precipitation and river inflow, respectively. The conservation of volume principle may be stated symbolically as:

$$V_i + R + P = V_o + E$$

Solving for ($V_o - V_i$):

$$V_o - V_i = (R + P) - E$$

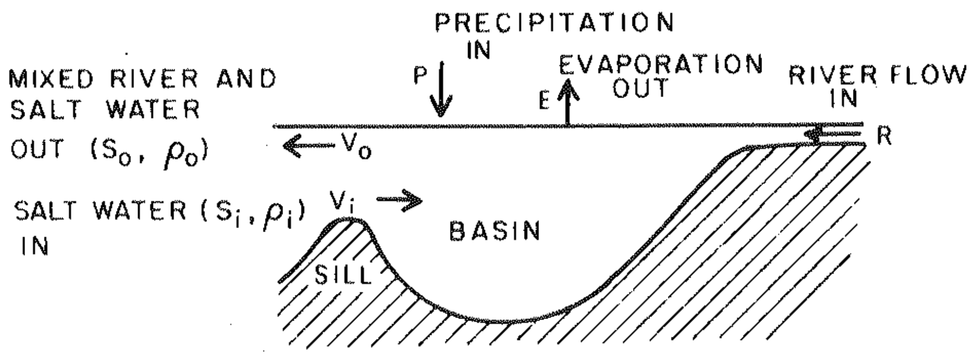

Fig. 3.1 Schematic diagram of basin inflows and outflows for conservation of volume discussion.

Which states that the net flow of water into the basin must balance precipitation plus river inflow minus evaporation when averaged over a sufficiently long time.

3.9 Conservation of Salt

The principle of conservation of salt asserts that the total amount of dissolved salts in the ocean is constant.

$$\rho_i V_i S_i = \rho_o V_o S_o$$

where ρ_i, S_i are the density and salinity of the incoming water, and ρ_o, S_o are density and salinity of the outflow. With little error, we can assume that $\rho_i = \rho_o$.

<Example> The Mediterranean Sea has a volume of around 4×10^6 km^3 (Fig. 3.2)

– If $V_i = 1.75$ Sv and the measured salinities gives $V_o = 1.68$ Sv then gives $(R+P-E) = -7\times10^4$ m^3/s.

– $V_i = 1.75\times10^6$ m^3/s $\approx 5.5\times10^4$ km^3/yr

– residence time (or flushing time) $Tm = 4\times10^6$ km^3/5.5×10^4 km^3/yr $\cong$ 70 yr.

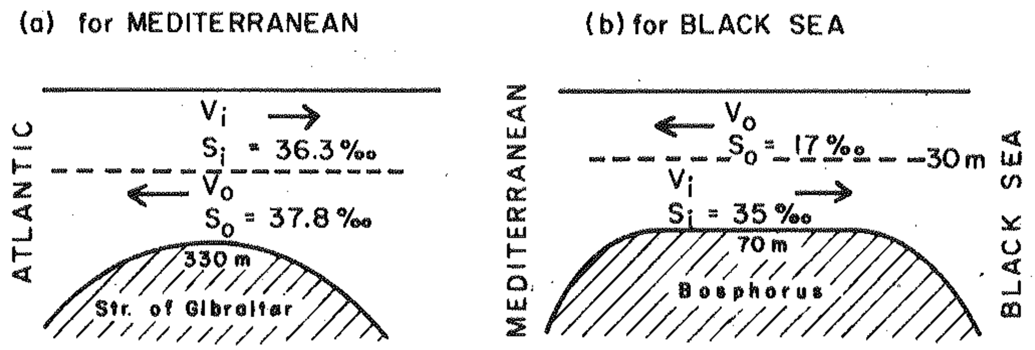

Fig. 3.2 Schematic diagram of inflow and outflow characteristics for: (a) Mediterra- nean Sea, (b) Black Sea.