Chap 2 Properties of Sea Water relevant to Physical Oceanography

2.1 Definition of Salinity

1. **A simple definition of Salinity:** The total amount of dissolved materials in sea water in grams of salts per kilogram of water
   – The average salinity is about 35 gm/salts/kg water
   – This is expressed as 35 parts per thousand (ppt) or 35 ‰

The above definition is not useful because the dissolved material is almost impossible to measure in practical.

2. **A more complete definition of Salinity:** "The total amount of solid materials in grams contained in one kilogram of sea water when all carbonate has been converted to oxide, the bromine and iodine replaced by chlorine and all organic matter completely oxidized."

The definition was used until about 1966, when it was replaced by a definition based on conductivity.

3. **Salinity based on Chlorinity:** Salinity is directly proportional to the amount of chlorine in sea water.

$$S\,(‰) = 0.03 + 1.805\,Cl\,(‰)$$

where *chlorinity Cl* is defined as "the mass of silver required to precipitate completely the halogens in 0.328 523 4 kg of the sea-water sample."

4. **Salinity Based on Conductivity:** Oceanographers had begun using conductivity meters to measure salinity. The meters were very precise and relatively easy to use compared with the chemical techniques used to measure chlorinity.

Salts:

Chlorine	55.0%	Sodium	30.6%
Sulphate	7.7%	Magnesium	3.7%
Calcium	1.2%	Potassium	1.1%

However, the modern definition of salinity has been replaced by one (called practical salinity, symbol S) based on the electrical conductivity of sea water. For example, S = 35.00 or S = 35.00 psu (practical salinity units).

2.2 Geographical Distribution of Surface Temperature and Salinity

1. The distribution of temperature at the sea surface tends to be ***zonal***, that is, it is independent of longitude (Fig. 2.1).
   – The deviations from zonal are small.
   – Equatorward of 40°, cooler waters tend to be on the eastern side of the basin.
   – North of 40°, cooler waters tend to be on the western side of the basin.

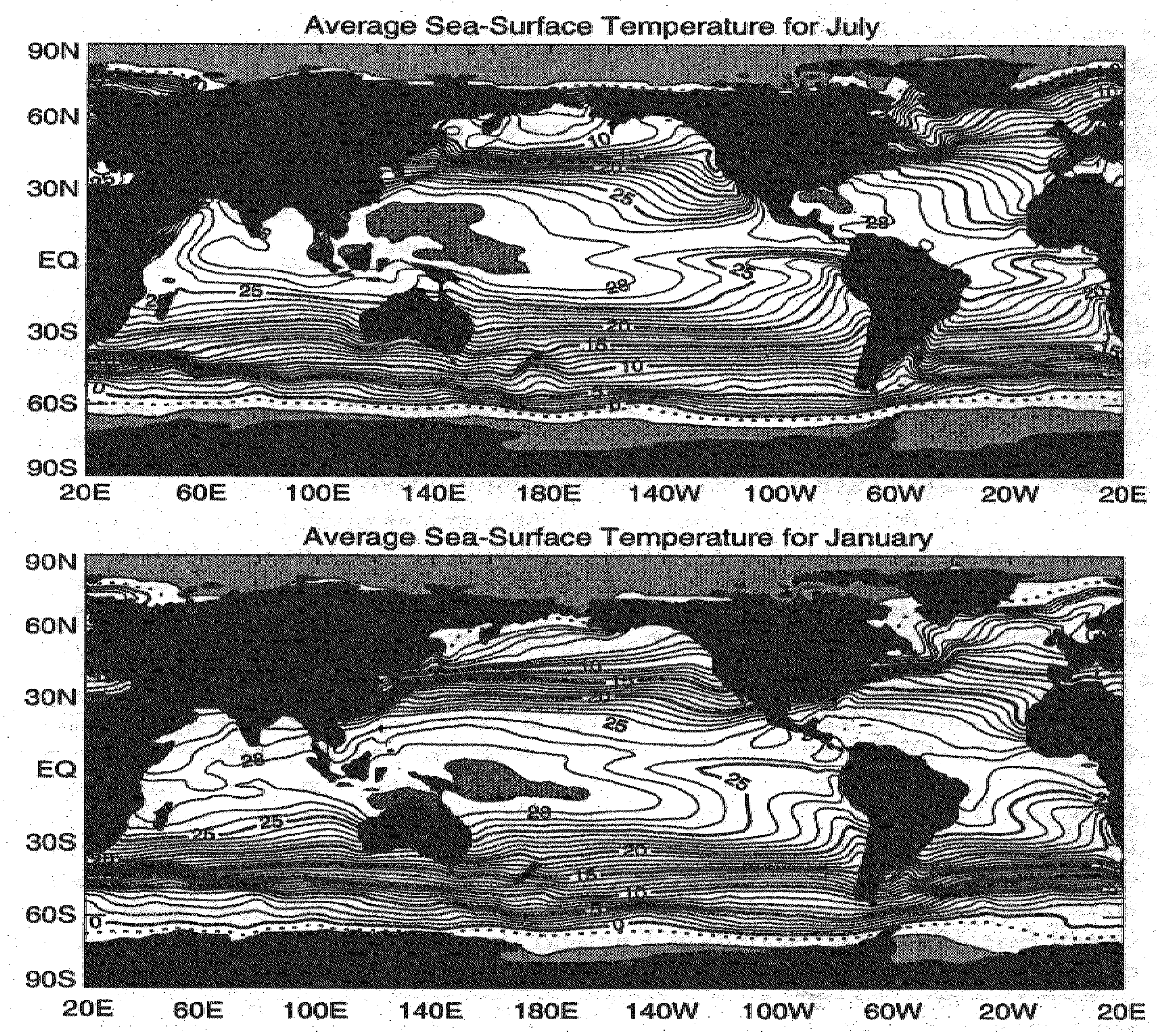


Fig. 2.1 Mean sea-surface temperature calculated from the optimal interpolation technique (Reynolds and Smith, 1995) using ship reports and AVHRR measurements of temperature. Contour interval is 1°C with heavy contours every 5°C. Shaded areas exceed 29°C.

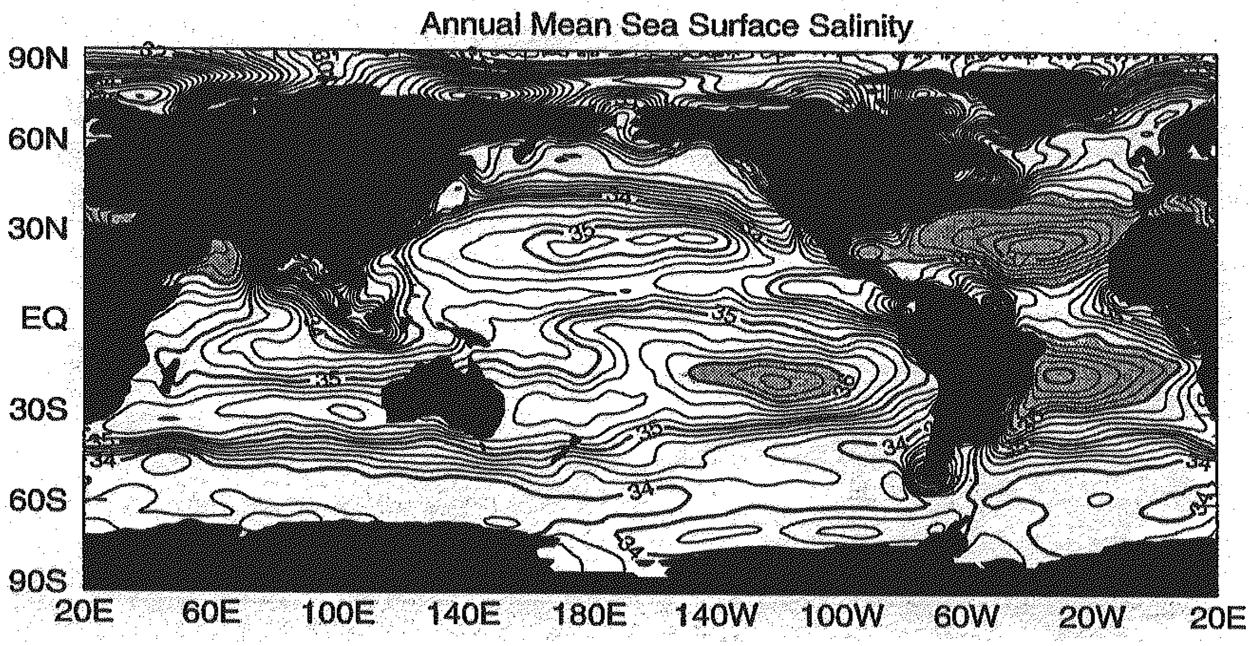


Fig. 2.2 Mean sea-surface salinity. Contour interval is 0.5 psu. Shaded areas exceed 36 psu. (Levitus, 1982).

2. The distribution of sea-surface salinity also tends to be zonal.
   – The saltiest waters are at mid-latitudes where evaporation is high.
   – Less salty waters are near the equator where rain freshens the surface water, and at high latitudes where melted sea ice freshens the surface waters (Fig. 2.2).
   – The zonal average of salinity shows a close correlation between salinity and evaporation minus precipitation plus river input (Fig. 2.3).

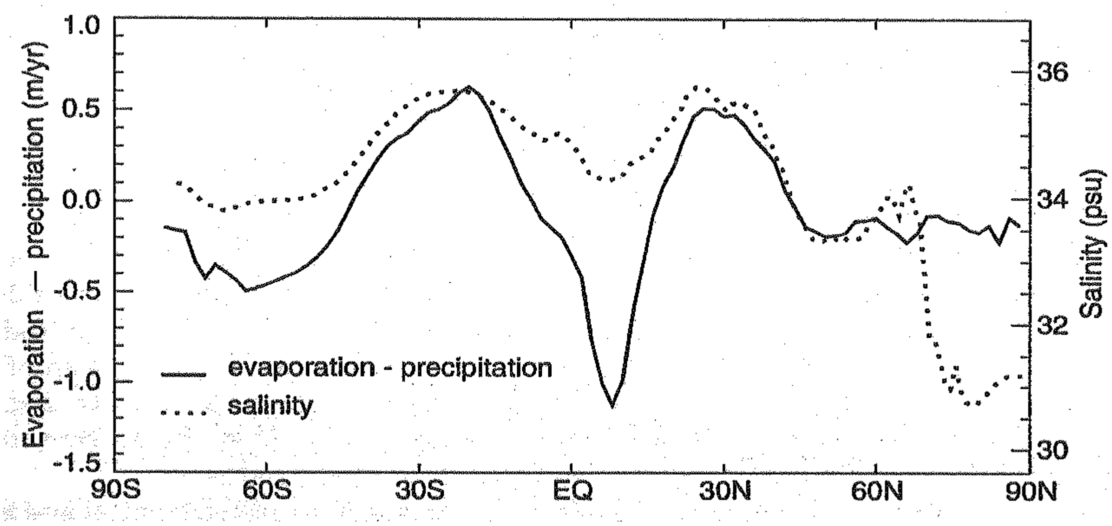


Fig. 2.3 Zonal average of sea-surface salinity calculated for all ocean from Levitus (1982) and the difference between evaporation and precipitation.

Importance: Knowledge of the distribution of temperature and salinity is used for determining distributions of currents using a variety of methods.

Features: The different water masses of the oceans are predominately horizontally stratified. There is also a distinct tendency for patterns to be zonal.

Knowledge: Comes from measurements of temperature and salinity made by oceanographic ships at "hydrographic stations."

Hydrographic Station: Place where water properties are measured from the surface to some depth, or to the bottom, using instruments lowered from a ship.

General Properties: 50% of the water in the ocean has:
$1.3°C < T < 3.8°C$
$34.6 \times 10^{-3} < S < 34.8 \times 10^{-3}$
Mean values are: $T = 3.5°C$ and $S = 34.7 \times 10^{-3}$

2.3 The Oceanic Mixed Layer

– Wind blowing on the ocean stirs the upper layers leading to a thin ***mixed layer***.

– constant temperature and salinity from the surface down to a depth where the values differ from those at the surface.

– typically the temperature at the bottom of the layer must be no more than 0.02– 0.1° colder than at the surface.

– roughly 10–200 m thick over most of the tropical and mid-latitudes (Fig. 2.4a).

– tends to saltier than the deeper layers except at high latitudes (Fig. 2.4b).

– The mid-latitude mixed layer is thinnest in late summer when winds are weak, and sunlight warms the surface layer.

– In fall, early storms mix the heat down into the ocean thickening the mixed layer, but little heat is lost. In winter, heat is lost, and the mixed layer continues to thicken, becoming thickest in late winter. In spring, winds weaken, sunlight increases, and a new mixed layer forms (Fig. 2.5).

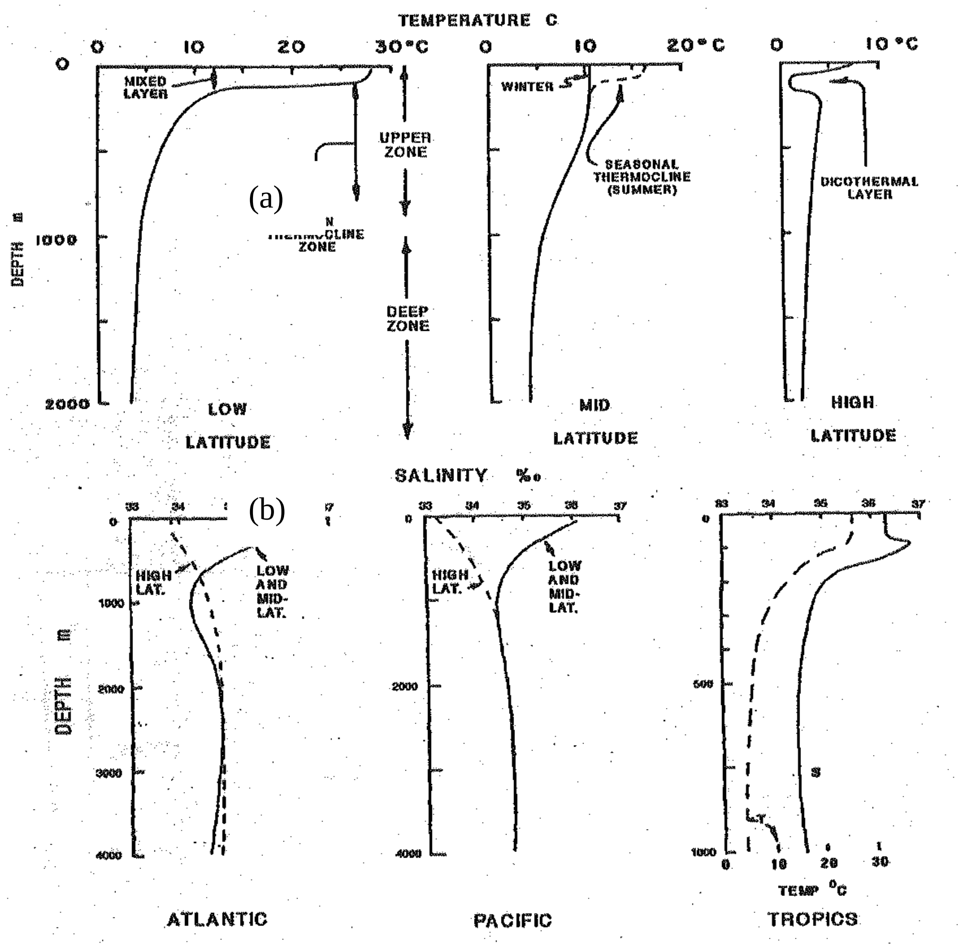


Fig. 2.4 Typical temperature (a) and mean salinity (b) profiles in the open ocean (Pickard and Emery, 1990).

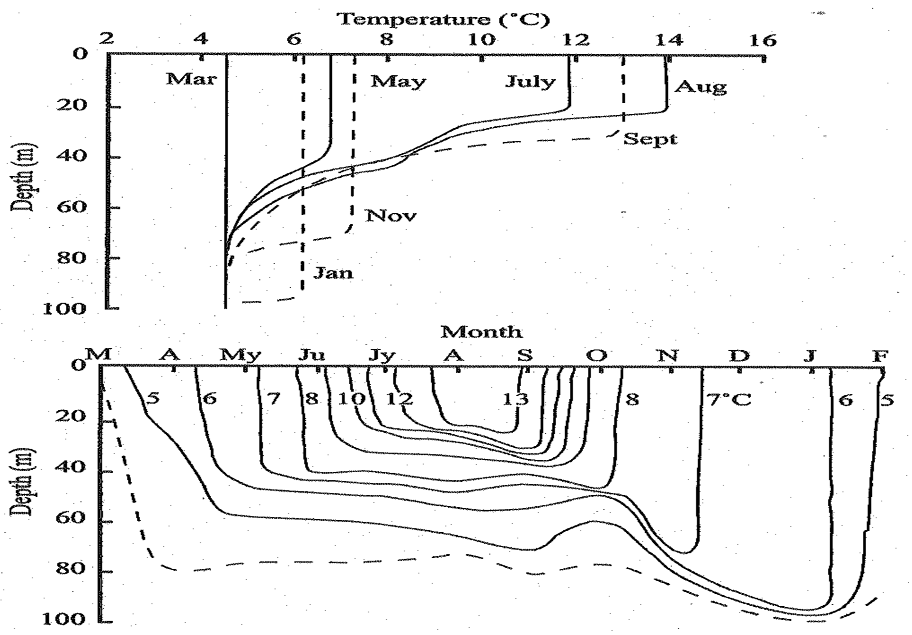


Fig. 2.5 Growth and decay of seasonal thermocline at Ocean Station "Pappa" at 50°N, 145°W in the North Pacific (Pickard and Emery, 1990).

2.4 Potential Temperature, Potential Density, and Sigma

Potential Temperature (θ): the temperature of a parcel of water at the sea surface after it has been raised ***adiabatically*** from some depth in the ocean.

– Raising the parcel ***adiabatically*** means that it is raised in an insulated container so it does not exchange heat with its surroundings.

– Potential temperature is calculated from the temperature in the water at depth, the ***in situ*** temperature.

Density $\rho(s, t, p)$: Using Standard Mean Ocean Water of known isotopic composition, assuming saturation of dissolved atmospheric gasses.
– It is typically 1027 kg/m^3.

Sigma(s ,t, p): For simplification, physical oceanographers often quote only the last 2 digits of the density, a quantity called the ***density anomaly*** or $\sigma(s, t, p)$.
$\sigma(s, t, p) = \rho(s ,t, p) - 1000 \text{ kg·m}^{-3}$
– $\sigma(s, t, p)$ is typically 27.00 kg·m^{-3}

Sigma-t: For studies of the surface layers of the ocean, compressibility can be ignored, and a new quantity σ_t is used:
$\sigma_t = \sigma(s, t, 0)$

– This is the density anomaly of a water sample when the total pressure on it has been reduced to atmospheric pressure (i.e. zero water pressure), but the temperature and salinity are ***in situ*** values.

– About 90% of the volume of the world ocean has values in much smaller range from –2 to 10°C and 34 to 35 in salinity (Fig. 2.6).

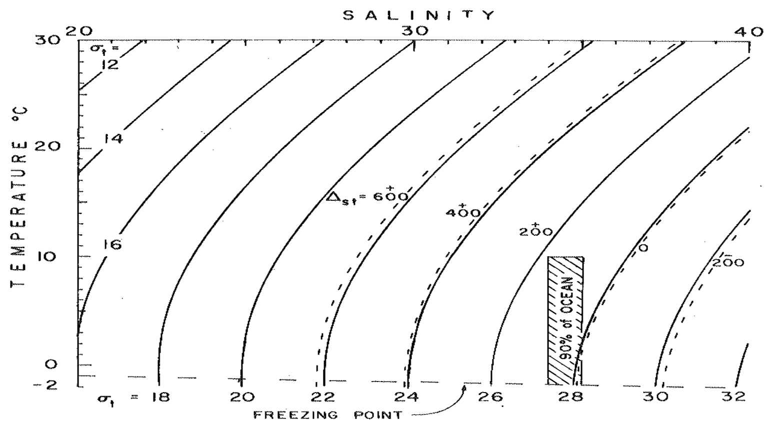


Fig. 2.6 Values of density (as σ_t) and thermosteric anomaly ($\Delta_{s,t}$) as functions of temperature and salinity over ranges appropriate to most of the oceans.

Potential Density: For studies of processes deeper within the ocean, compressibility cannot be ignored. Because changes in pressure primarily influence the temperature of the water, the influence of pressure can be removed, to a first approximation, by using the potential density.

– the density of a parcel of water raised adiabatically to the surface.

– **Sigma-theta:** $\sigma(\theta) = \sigma(s, \theta, 0)$.

– Allow us to compare density of water samples from different depths (Fig. 2.7).

– Water tends to flow along surfaces of constant potential density.

– $\sigma(\theta)$ is not useful for comparing density of water at great depths because the relation between density and temperature and salinity is non-linear.

Sigma-4: If samples from great depths are compared, it is better to use sigma values for a depth of 4 km.

$\sigma(4) = \sigma(s, \theta, 4000)$

– Use of σ_θ can be misleading when comparing densities of water at great depths.

– For example, two water samples having the same density but different temperature and salinity at a depth of 4 km can have noticeably different density when moved adiabatically to the sea surface (Fig. 2.8).

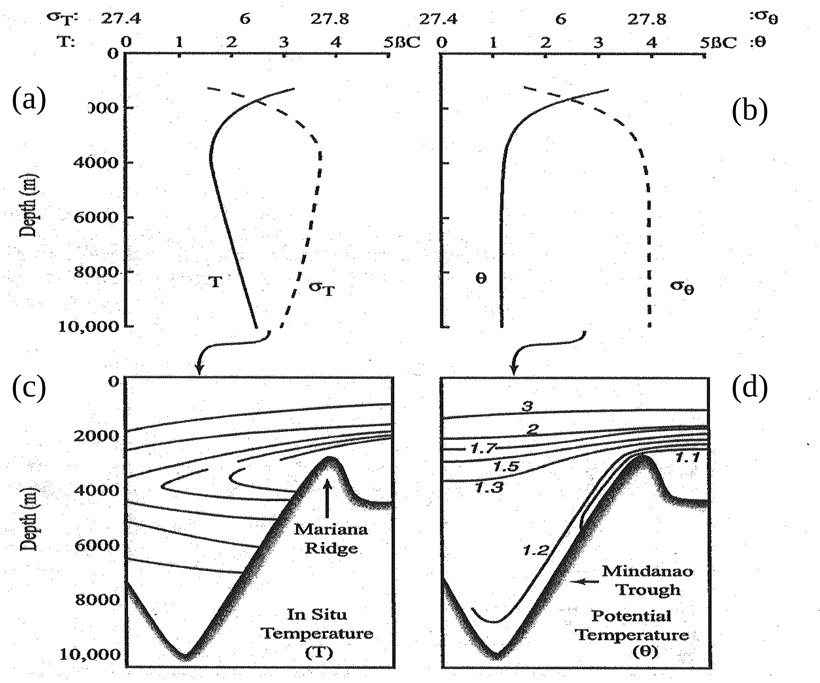


Fig. 2.7 Profiles of *in situ* and potential temperature and density in the Mindinao Trench in the Pacific: (a,b) vertical profiles, (c,d) vertical section (Pickard and Emery, 1990).

2.5 Specific Volume and Anomaly

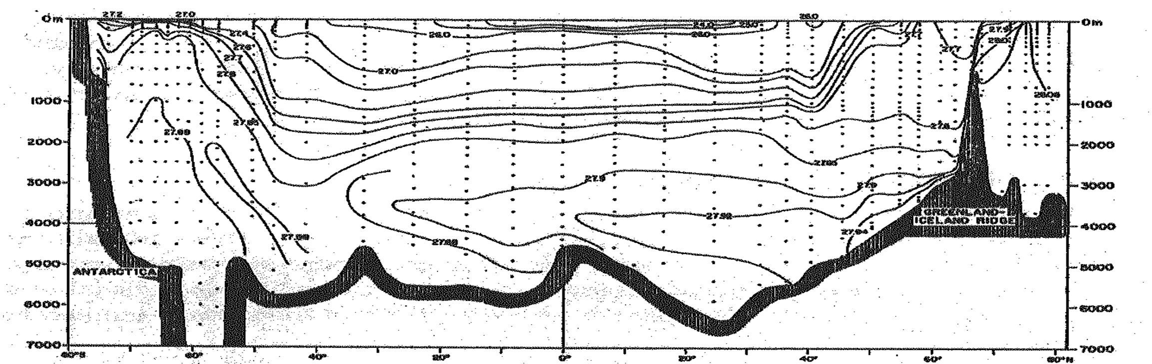
Specific Volume:

– Specific volume is the reciprocal of density.

– Units are m^3/kg.

– The symbol is $\alpha_{s,t,p}$.

(a)



(b)

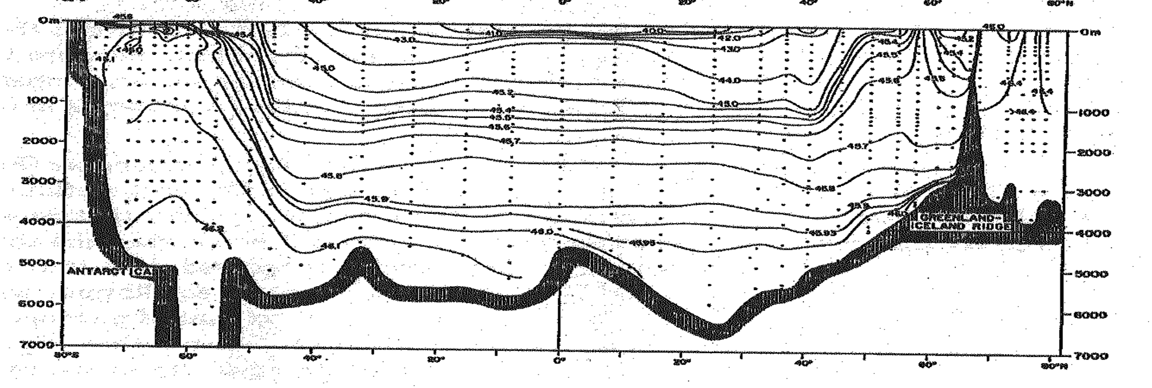


Fig. 2.8 Vertical sections of density in the western Atlantic. Depth scale changes at 1000m depth. Hydrographic stations are noted by dots. (a) Sigma-θ, showing an apparent density inversion below 3,000 m. (b) Sigma(4) showing continuous increase in density with depth. (Lynn and Reid, 1968).

(1) For a one-component fluid

$\rho = \rho(T, p) \quad \Rightarrow \quad \alpha = \alpha(T, p)$

<Ex> For a perfect gas, Equation of state is

$$\alpha = \frac{RT}{p}$$, where R is the Gas constant.

(2) For sea water — multi-component fluid

$\alpha = \alpha(s, T, p)$

Specific Volume Anomaly (δ):

– Specific volume anomaly is defined as:

$$\delta = \alpha_{s,t,p} - \alpha_{35,0,p}$$

– where $\alpha_{35,0,p}$ was chosen so $\delta > 0$.

Bjerkness and Sandstrom (1910) show that δ can be written as the sum of several components:

$$\delta = \delta_s + \delta_t + \delta_{s,t} + \delta_{s,p} + \delta_{t,p} + \delta_{s,t,p}$$

Montgomery and Wooster (1954) pointed out the sum of the first 3 terms is adequate for describing water masses. They called the sum

Thermosteric Anomaly ($\Delta_{s,T}$):

$$\Delta_{s,T} = \delta_s + \delta_t + \delta_{s,t}$$

Typical values of **($\Delta_{s,T}$)** are $50 \sim 250 \times 10^{-8}$.

($\Delta_{s,T}$): In water of depth less than about 1000 m the thermosteric anomaly, $\Delta_{s,T}$ is the major component of δ. $\delta_{s,p}$ and $\delta_{t,p}$ may often be neglected.

Relationship of $\Delta_{s,T}$ to σ(*t*):

$$\begin{cases} \alpha(s,t,0) = \dfrac{1}{\rho(s,t,0)} = \dfrac{1}{1000 + \sigma_t} \\ \alpha(s,t,0) = \alpha(35,0,0) + \Delta_{s,T} \end{cases}$$

where $\alpha(35,0,0) = 0.97266 \times 10^{-3}\ \mathrm{m^3kg^{-1}}$, thus

$$\Delta_{s,T} = \left(\frac{1000}{1000 + \sigma_t} - 0.97266 \right) \times 10^{-3} \quad \mathrm{m^3kg^{-1}}$$

σ_t	23.00	24.00	25.00	26.00	27.00	28.00	$\mathrm{kg \cdot m^{-3}}$
$\Delta_{s,T}$	485.7	390.3	295.0	199.9	105.0	10.3	$\times 10^{-8}\ \mathrm{m^3kg^{-1}}$

2.6 Some Definitions

Zonal: Bounded by circles of latitude; East-West bands.

Meridonal: Bounded by circles of longitude; North-South bands.

Equatorial: Zones near the equator.

Tropical: Between the Tropics of Capricorn and Cancer; 23.5°N < Latitude < 23.5°S.

Subtropical: Zones on the poleward side of the tropical zone.

Polar: For oceanography, within the Arctic region.

Pycnocline: Region, in the vertical, where density increases rapidly with depth.

Thermocline: Region, in the vertical, where temperature decreases rapidly with depth.

Mixed Layer: Surface layer of constant density, temperature, and salinity produced by turbulent mixing by the wind.