

# Temperature, Salinity, Density and Ocean Circulation

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Two of the most important characteristics of seawater are temperature and salinity – together they control its density, which is the major factor governing the vertical movement of ocean waters

# Temperature Distribution in the Ocean

The temperature of seawater is fixed at the sea surface by heat exchange with the atmosphere. The average incoming energy from the sun at the earth's surface is about four times higher at the equator than at the poles. The average infrared radiation heat loss to space is more constant with latitude. As a result there is a net input of heat to the earth's surface into the tropical regions, and this is where we find the warmest surface seawater. Heat is then transferred from low to high latitudes by winds in the atmosphere and by currents in the ocean.

Water is transparent, so the radiation penetrates some distance below the surface; heat is also carried to deeper levels by mixing. Due to the high specific heat of water, diurnal and seasonal temperature variations are relatively small compared to the variations on land; oceanic temperature variations are on the order of a few degrees, except in very shallow water. Most solar energy is absorbed within a few meters of the ocean surface, directly heating the surface water and providing the energy for photosynthesis by marine plants and algae. Shorter wavelengths penetrate deeper than longer wavelengths. Infrared radiation is the first to be absorbed, followed by red, and so on. Heat conduction by itself is extremely slow, so only a small proportion of heat is transferred downwards by this process. The main mechanism to transfer heat deeper is turbulent mixing by winds and waves, which establishes a **mixed surface layer** that can be as thick as 200-300 meters or even more at mid-latitudes in the open ocean in winter or less than 10 meters in sheltered coastal waters in summer.

# Salinity Distribution in the Ocean

The salinity of surface seawater is controlled primarily by the balance between evaporation and precipitation. As a result the highest salinities are found in the so-called sub-tropical central gyre regions centered at about  $20^{\circ}$  to  $30^{\circ}$  North and South, where evaporation is extensive but rainfall is minimal. The highest surface salinities, other than evaporite basins, are found in the Red Sea.

**Salinity (S)** = grams of dissolved ( $<0.5 \mu\text{m}$ ) inorganic ions per kg of seawater. The average salinity of seawater is  $S = 35$  which means that SW is 3.5% salt and 96.5%  $\text{H}_2\text{O}$  by weight.

Why is salinity important?

1- Salinity, along with temperature, determines the density of seawater, and hence its vertical flow patterns in **thermohaline** circulation.

2- Salinity records the physical processes affecting a water mass when it was last at the surface.

- precipitation/evaporation – salts excluded from vapor
- freezing/thawing – salts excluded from ice

3- Salinity can be used as a **conservative** (unchanging) tracer for determining the origin and mixing of water types.

# How is Salinity Determined?

1- Boiling seawater, so that residual salts can be weighed, **does not work**. Volatiles are lost in the process (HCl, CO<sub>2</sub>, Br and I); High temperatures are required to drive off water from hygroscopic salts (e.g. from CaCl<sub>2</sub> • xH<sub>2</sub>O). You always come up "light".

A- bromide (and iodide) salts are volatile at high temperatures (~500-600 °C) and lost

B- MgCO<sub>3(s)</sub> decomposes to MgO and CO<sub>2</sub> and Ca(HCO<sub>3</sub>)<sub>2</sub> makes CaO<sub>(s)</sub> + H<sub>2</sub>O + 2CO<sub>2</sub>. The CO<sub>2</sub> gas is lost

C- CaCl<sub>2</sub> • xH<sub>2</sub>O and MgCl<sub>2</sub> • xH<sub>2</sub>O both decompose to give HCl<sub>(g)</sub> which is lost.

2- Analyze all major ions and sum. Problems: 11 separate analyses, and some are difficult to make, lots of work, cumulative errors are large.

3- Sorensen's Gravimetric Method – Add HCl and Cl<sub>2</sub>, heat to 480 °C and weigh salt residue:

A- reaction = Cl<sub>2</sub> + 2Br<sup>-</sup> → 2Cl<sup>-</sup> + Br<sub>2</sub> (the latter is volatile, as is I<sub>2</sub> formed from I<sup>-</sup>)

B- This reproducible procedure corrects for loss of Br and I salts (converts them quantitatively to Cl<sub>2</sub> before they are lost), but there is no correction for CO<sub>2</sub> loss.

Sorensen's Titration Method – Used because the gravimetric method is a pain. Utilize the "law of constant proportions" or "Marcet's Principle"; Chlorinity approach (Cl% ); Measure Cl % (which actually gives the sum of all halides; Cl<sup>-</sup> + F<sup>-</sup> + Br<sup>-</sup> + I<sup>-</sup>) by titration with AgNO<sub>3</sub> to precipitate AgCl, AgBr etc.. The titration gives the grams of Cl equivalent in 1 kg seawater.



**Chlorinity (Cl)** = mass of chlorine equivalent to total mass of halogen in 1 Kg seawater. Salinity = 1.80655 Cl. This approach is fast, precise and not a bad approach.

4- The modern approach is to measure salinity in a **salinometer** by **conductance**.

A- sample conductivity is determined as a ratio to a standard of KCl in pure water (at 15 °C and 1 atm pressure). Accordingly, salinity has no units using this method.

B- "**practical salinity**" is calculated for a seawater sample using a polynomial expression in terms of the conductivity ratio (R), the actual temperature (t) of the sample, and a flock of fitting constants (a, b and k):

$$S = a_0 + a_1 R^{1/2} + a_2 R + a_3 R^{3/2} + a_4 R^2 + a_5 R^{5/2} + [(t - 15) / (1 + k(t - 15))] (b_0 + b_1 R^{1/2} + b_2 R + b_3 R^{3/2} + b_4 R^2 + b_5 R^{5/2})$$

C- The typical precision of this method is 1/40,000, equivalent to ~0.001.

Surface seawater salinities largely reflect the local balance between evaporation and precipitation.

A- Low salinities occur near the equator due to rain from rising atmospheric circulation.

B- High salinities are typical of the hot dry gyres flanking the equator ( $\pm 20$ - $30$  degrees latitude) where atmospheric circulation cells descend.

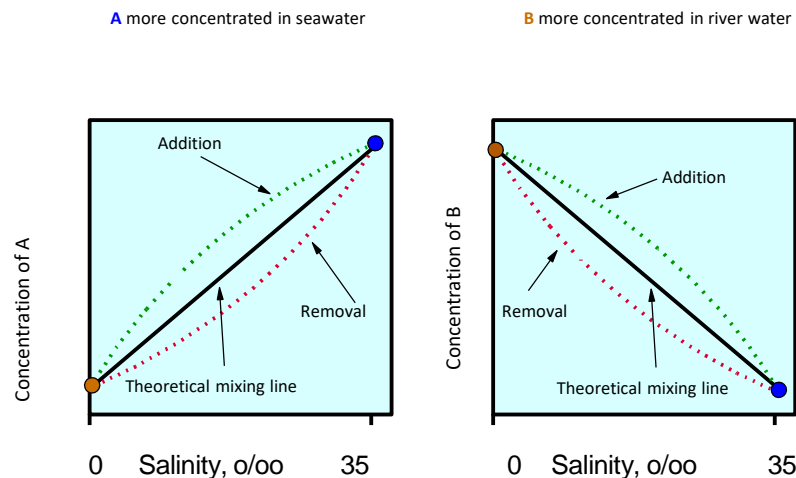
C- Salinity can also be affected by sea ice formation/melting (e.g. around Antarctica)

D- The surface N. Atlantic is saltier than the surface N. Pacific, making surface water denser in the N. Atlantic at the same temperature and leading to **downwelling** of water in this region this difference is because on average N. Atlantic is warmer ( $10.0^{\circ}\text{C}$ ) than N. Pacific ( $6.7^{\circ}\text{C}$ ). This is mostly because of the greater local heating effect of the Gulf Stream, as compared to the Kuroshio Current. Warmer water evaporates more rapidly, creating a higher residual salt content.

The influence of surface fluctuations in salinity due to changes in evaporation and precipitation is generally small below 1000 m, where salinities are mostly between about 34.5 and 35.0 at all latitudes. Zones where salinity decreases with depth are typically found occur at low latitudes and mid latitudes, between the mixed surface layer and the deep ocean. These zones are known as **haloclines**.

# Salinity as a Conservative Tracer for Water Mixing in Estuaries

As seawater mixes with river water in estuaries, a conservative seawater component (e.g. a major ion) will co-vary directly in concentration with salinity. A component that is added during mixing will curve up in concentration versus a conservative mixing line (yielding an up "banana plot").



A component that is lost during mixing will curve down in concentration versus a conservative mixing line (yielding a down "banana plot") as shown in the figures above.

Such non-conservative behavior will only be evident if the addition or loss process is relatively rapid versus water mixing in the estuary.



# Seawater Density

Because the seawater signatures of temperature and salinity are acquired by processes occurring at the air-sea interface, we can also state that the density characteristics of a parcel of seawater are determined when it is at the sea surface. Temperatures of seawater vary widely (-1 to 30 °C), whereas the salinity range is small ( $35.0 \pm 2.0$ ). The North Atlantic contains the warmest and saltiest water of the major oceans, the Southern Ocean (the region around Antarctica) is the coldest, and the North Pacific has the lowest average salinity.

This density signature is locked into the water parcel when it sinks. The density will be modified by mixing with other parcels of water, but if the density signatures of all the end member water masses are known, this mixing can be unraveled and the proportions of the different source waters to a given parcel can be determined. To a first approximation, the vertical density distribution of the ocean can be described as a three-layered structure.

Water Mass	Temp (°C)	Salinity
North Atlantic Central Water	8-19	35.1-36.5
Antarctic Circumpolar Water	0-2	34.6-34.7
Antarctic Intermediate Water	3-7	33.8-34.7
North Pacific Intermediate Water	4-10	34.0-34.5
North Atlantic Deep Water	2-4	34.8-35.1
Antarctic Bottom Water	-0.4	34.7

## Conservative Tracers

A solute that is chemically and biologically inert (no transformation losses with time) but could exhibit an adsorption capacity that results in loss from solution.

## Isohaline

An imaginary line connecting all parts of the ocean that have the same salinity.

خط وهمي يربط جميع أجزاء المحيط التي لها نفس الملوحة.

## Halocline

a level of marked [change](#), esp. increase, in the salinity of sea water at a certain depth

## Down – Welling

Downwelling is the process of accumulation and sinking of higher density material beneath lower density material, such as cold or saline [water](#) beneath warmer or fresher water or cold air beneath warm air.

## Hygroscopic salts

hygroscopic means a substance is able to [absorb](#) or [adsorb water](#) from its surroundings

## Isotherms

a type of equal temperature at a given date or time on a geographic map

## Seasonal thermocline

Thermocline, oceanic water layer in which water temperature decreases rapidly with increasing depth

## Permanent thermocline

Thermocline التغيرات في درجة الحرارة بسبب الانخفاض بالاعماق بالنسبة للبحار والمحيطات