2.500 Desalination and Water Purification
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Introduction To
Physical Oceanography

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Chapter 6

Temperature, Salinity, and Density

Heat fluxes, evaporation, rain, river inflow, and freezing and melting of sea ice all influence the distribution of temperature and salinity at the ocean's surface. Changes in temperature and salinity can increase or decrease the density of water at the surface, which can lead to convection. If water from the surface sinks into the deeper ocean, it retains a distinctive relationship between temperature and salinity which helps oceanographers track the movement of deep water. In addition, temperature, salinity, and pressure are used to calculate density. The distribution of density inside the ocean is directly related to the distribution of horizontal pressure gradients and ocean currents. For all these reasons, we need to know the distribution of temperature, salinity, and density in the ocean.

Before discussing the distribution of temperature and salinity, let's first define what we mean by the terms, especially salinity.

6.1 Definition of Salinity

At the simplest level, salinity is the total amount of dissolved material in grams in one kilogram of sea water. Thus salinity is a dimensionless quantity. It has no units. The variability of dissolved salt is very small, and we must be very careful to define salinity in ways that are accurate and practical. To better understand the need for accuracy, look at figure 6.1. Notice that the range of salinity for most of the ocean's water is from 34.60 to 34.80 parts per thousand, which is 200 parts per million. The variability in the deep North Pacific is even smaller, about 20 parts per million. If we want to classify water with different salinity, we need definitions and instruments accurate to about one part per million. Notice that the range of temperature is much larger, about 1°C, and temperature is easier to measure.

Writing a practical definition of salinity that has useful accuracy is difficult (see Lewis, 1980, for the details), and various definitions have been used.
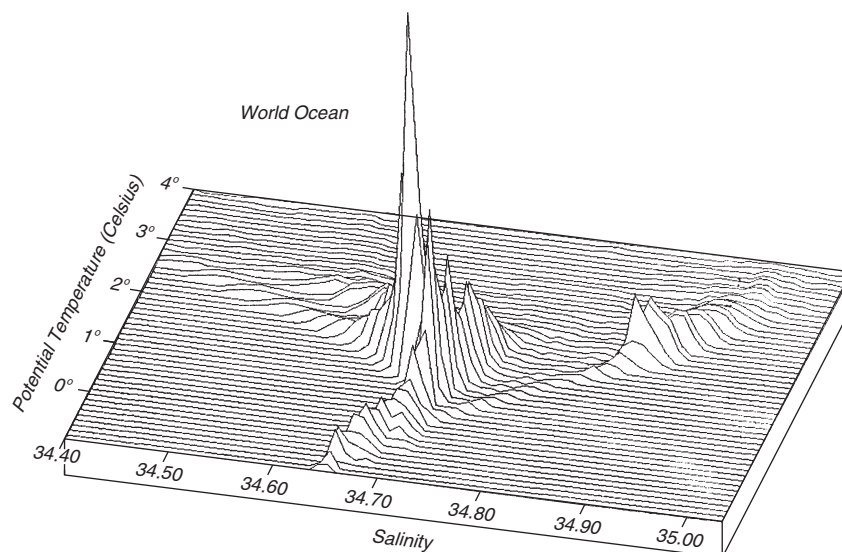
Figure 6.1 Histogram of temperature and salinity of ocean water colder than 4°C. Height is proportional to volume. Height of highest peak corresponds to a volume of 26 million cubic kilometers per bivariate class of 0.1°C and 0.01. After Worthington (1981: 47).

A Simple Definition Originally salinity was defined to be the "Totalamount of dissolved material in grams in one kilogram of sea water." This is not useful because the dissolved material is almost impossible to measure in practice. For example, how do we measure volatile material like gasses? Nor can we evaporate sea-water to dryness because chlorides are lost in the last stages of drying (Sverdrup, Johnson, and Fleming, 1942: 50).

A More Complete Definition To avoid these difficulties, the International Council for the Exploration of the Sea set up a commission in 1889 which recommended that salinity be defined as the "Total amount of solid materials in grams dissolved in one kilogram of sea water when all the carbonate has been converted to oxide, the bromine and iodine replaced by chlorine and all organic matter completely oxidized." The definition was published in 1902. *This is useful but difficult to use routinely.*

Salinity Based on Chlorinity Because the above definition was difficult to implement in practice, because salinity is directly proportional to the amount of chlorine in sea water, and because chlorine can be measured accurately by a simple chemical analysis, salinity S was redefined using chlorinity:

$$S = 0.03 + 1.805\,Cl \tag{6.1}$$

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."

As more and more accurate measurements were made, (6.1) turned out to be too inaccurate. In 1964 UNESCO and other international organizations appointed a Joint Panel on Oceanographic Tables and Standards to produce a

more accurate definition. The Joint Panel recommended in 1966 (Wooster, Lee, and Dietrich, 1969) that salinity and chlorinity be related using:

$$S = 1.806\,55\,Cl \tag{6.2}$$

This is the same as (6.1) for $S = 35$.

Salinity Based on Conductivity At the same time (6.2) was adopted, oceanographers had began 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. As a result, the Joint Panel also recommended that salinity be related to conductivity of sea water using:

$$S = -0.089\,96 + 28.297\,29\,R_{15} + 12.808\,32\,R_{15}^2$$
$$- 10.678\,69\,R_{15}^3 + 5.986\,24\,R_{15}^4 - 1.323\,11\,R_{15}^5 \tag{6.3a}$$
$$R_{15} = C(S, 15, 0)/C(35, 15, 0) \tag{6.3b}$$

where $C(S, 15, 0)$ is the conductivity of the sea-water sample at 15°C and atmospheric pressure, having a salinity S derived from (6.4), and $C(35, 15, 0)$ is the conductivity of standard "Copenhagen" sea water. Millero (1996) points out that (6.3) is not a new definition of salinity, it merely gives chlorinity as a function of conductivity of seawater relative to standard seawater.

Practical Salinity Scale of 1978 By the early 1970s, accurate conductivity meters could be deployed from ships to measure conductivity at depth. The need to re-evaluate the salinity scale led the Joint Panel to recommend in 1981 (JPOTS, 1981; Lewis, 1980) that salinity be defined using only conductivity, breaking the link with chlorinity. All water samples with the same conductivity ratio have the same salinity.

The *Practical Salinity Scale of 1978* is now the official definition:

$$S = 0.0080 - 0.1692\,K_{15}^{1/2} + 25.3851\,K_{15} + 14.0941\,K_{15}^{3/2}$$
$$- 7.0261\,K_{15}^2 + 2.7081\,K_{15}^{5/2} \tag{6.4a}$$
$$K_{15} = C(S, 15, 0)/C(KCl, 15, 0) \tag{6.4b}$$
$$2 \leq S \leq 42$$

where $C(S, 15, 0)$ is the conductivity of the sea-water sample at a temperature of 15°C and standard atmospheric pressure, and $C(KCl, 15, 0)$ is the conductivity of the standard potassium chloride (KCl) solution at a temperature of 15°C and standard atmospheric pressure. The standard KCl solution contains a mass of 32.435 6 grams of KCl in a mass of 1.000 000 kg of solution.

Lewis (1980) gives equations for calculating salinity at other temperatures:

$$S = 0.0080 - 0.1692\,R_t^{1/2} + 25.3851\,R_t + 14.0941\,R_t^{3/2}$$
$$\qquad - 7.0261\,R_t^2 + 2.7081\,R_t^{5/2} + \Delta S$$
$$R_t = C(S,t,0)/C(KCl,t,0)$$
$$\Delta S = \left[\frac{(t-15)}{1+0.0162\,(t-15)}\right]\left(0.0005 - 0.0056\,R_t^{1/2} - 0.0066\,R_t\right.$$
$$\qquad \left. - 0.0375\,R_t^{3/2} + 0.636\,R_t^2 - 0.0144\,R_t^{5/2}\right)$$
$$2^\circ C \leq t \leq 35^\circ C$$

An extension of (6.4) gives salinity at any pressure (see Millero 1996: 72).

Table 6.1 Major Constituents of Sea Water

	Ion		Atoms
55.3%	Chlorine	55.3%	Chlorine
30.8%	Sodium	30.8%	Sodium
7.7%	Sulfate	3.7%	Magnesium
3.7%	Magnesium	2.6%	Sulfur
1.2%	Calcium	1.2%	Calcium
1.1%	Potassium	1.1%	Potassium

Comments The various definitions of salinity work well because the ratios of the various ions in sea water are nearly independent of salinity and location in the ocean (table 6.1). Only very fresh waters, such as are found in estuaries, have significantly different ratios. The result is based on Dittmar's (1884) chemical analysis of 77 samples of sea water collected by the *Challenger* Expedition and further studies by Carritt and Carpenter (1959).

> The importance of this result cannot be over emphasized, as upon it depends the validity of the chlorinity: salinity: density relationships and, hence, the accuracy of all conclusions based on the distribution of density where the latter is determined by chemical or indirect physical methods such as electrical conductivity...—Sverdrup, Johnson, Fleming (1942).

The relationship between conductivity and salinity has an accuracy of around ± 0.003 in salinity. The very small error is caused by variations in constituents such as SiO_2 which cause small changes in density but no change in conductivity.

Instruments for measuring salinity are calibrated using Normal Standard Seawater (P-series). The standard water is made from large samples of water from the north Atlantic, carefully diluted to $S = 35$, which is distributed in 275 ml sealed glass ampoules. Each is labeled for its conductivity ratio and salinity according to the Practical Salinity Scale 1978 and distributed worldwide by Ocean Scientific International in England since 1989. Each sample is carefully calibrated using the standard KCl solution.