What We Study in Physical Oceanography

When we observe the sea, we notice that the water is moving over a whole range of different scales. We see waves on the surface, and their breaking upon reaching the shore. Over a longer time scale, we see the sea level rise and fall, due to tides. Mariners have long known that the sea water is moving systematically, forming a current, in certain parts of the ocean. Furthermore, if you look into the sea in those parts where currents are particularly vigorous – such as the Admiralty Inlet, the Tacoma Narrows, and Agate Passage north of Bainbridge Island, around here – you will see that the water is often churning vigorously due to chaotic fluid motion called turbulence.

These movements of water are of great importance, first and foremost, because they carry all kinds of things along with them – sea life, pollutants, sediments, and so on. Even those things that can move by their own power, such as fish and boats, must contend with the current. They also carry energy, and effects of breaking waves have a great impact on the geology of the shoreline because of the energy associated with them.

Furthermore, sea water has its own physical characteristics. The two most important are temperature and salinity; the former reflects the heat that is contained in the sea water, and ocean currents are important agents that redistribute heat on a global scale, thus affecting regional and global climate profoundly. The ocean water is also under varying pressure – from the atmospheric pressure at the sea surface to over four hundred times greater than that at the ocean floor. The three properties together delineate habitats for different marine life, and determine the density of water.

In physical oceanography, we study *movement of water* in the sea – how they are caused, what defines them, how they change over time, and so on. We also study *physical properties of water* and how they change over time. As we shall see, these two aspects of the physics of the ocean are closely connected, and we need to understand both together.

The Physical Quantities, the Continuum Hypothesis, and Some Notations

As indicated above, the sea water is characterized by its temperature and salinity, which I will denote algebraically as T and S respectively. We will use the Celsius unit (C) for the former, and parts per thousand (permil, or PSU) for the latter. We will also denote pressure as p; the unit for this is Pascal (Pa), which is Newtons per square meter. We will also use the atmospheric pressure (atm): 1 atm = 10^5 Pa; and the unit decibar (db): 1 decibar = 10^4 Pascal. The advantage of the decibar is that one decibar is almost equal to the pressure increase associated with going one meter deep; so that it can be used as an approximate depth value.

We know that these three properties determine the density of the sea water, denoted by ρ (greek "rho"). Density is mass contained in a unit volume, and we will use the unit of kilograms per cubic meter (kg/m^3). As it turns out, for the sea water this varies only between about 1020 and 1040 kg/m^3 at most; so we commonly drop the first two digits. The resulting notation is called sigma-t (σ_t).

The mathematical relationship between temperature, salinity, pressure and density is called the *equation of state.* For the sea water, a highly accurate form of this equation has been determined from a number of precise measurements and is expressed in terms of an algebraic equation that gives density as a function of the other three parameters. This so called UNESCO Equation of State (UNESCO, 1981; Fofonoff and Millard, 1983) is used in all precise scientific study. You can find online calculators for this equation of state: For instance,

http://www.phys.ocean.dal.ca/~kelley/seawater/density.html

Roughly speaking, however, sea water density increases with increasing pressure and salinity, and with decreasing temperature. A good, simple approximate equation that gives density in our unit is of the form

$$\rho = 1025.97 + \alpha(T - 8.4) + \beta(S - 35) + kp$$

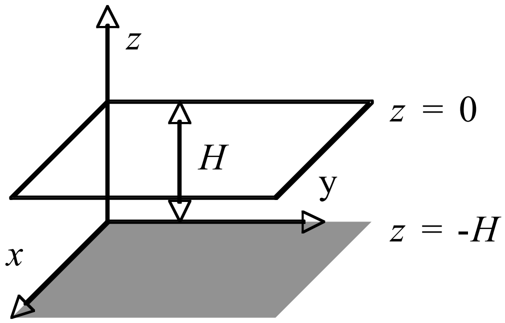
where α = -0.15 $kg\, m^{-3}\ {}^{o}C^{-1}$, β=0.78 $kg\, m^{-3}\ ppt^{-1}$, and k=4.5 X $10^{-3}\, kg\, m^{-3}\ db^{-1}$. Temperature, salinity and pressure should be given in Celsius, PSU and decibars respectively.

For the purpose of this course, you can use this equation unless I specify otherwise.

All these quantities are *scalar quantities*, characterized by magnitude only. Currents, on the other hand, are characterized by velocity, which has both magnitude and direction. Such quantity is called a *vector quantity*. A convenient way to visualize a vector such as velocity is as an arrow, whose length is proportional to the magnitude (*speed*) and which points in the direction of the current.

In studying the ocean, we assume that all these quantities – temperature, salinity, pressure, density, velocity – can be determined at every point inside the ocean, and at all times. This is a reasonable assumption at the level of current meter measurements and water samples, and is called the *Continuum Hypothesis*. When we get down close to the molecular scale, most of these quantities become ill-defined; however, we can definitely consider them as well-defined for oceanographic study.

We specify a point in space using a coordinate system. For the most part, we use a *Cartesian coordinate system* consisting of two straight horizontal coordinates (whose directions depend on the problem we consider) and one vertical coordinate. We denote the horizontal coordinate locations with *x* and *y*, and the vertical coordinate with *z*. By convention, we choose *z*=0 to be the

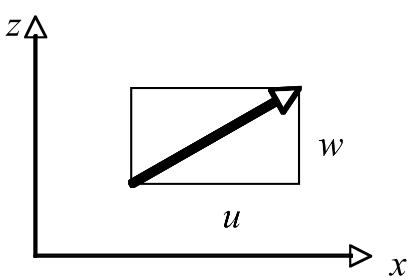


average, undisturbed sea surface, and measure z as *positive upward*. So for the most part, z in the ocean interior is *negative!* If a point is at depth 400m, then z = -400m. It may take some getting used to this convention!

We denote temperature at a point (x,y,z) and at time t as $T(x,y,z,t)$, and similarly for other quantities.

For very large scale problems, it may become more convenient to use *longitude* and *latitude* for the horizontal components. I shall introduce the appropriate notation when this becomes necessary.

Finally, vectors can be specified in terms of their *components* along the coordinate axes. For velocity, I shall denote the x and y components with u and v respectively, and the z (vertical) component with w.



Fofonoff, N.P., and R.C. Millard Jr., 1983: "Algorithms for computation of fundamental properties of seawater", UNESCO Tech. Paper in Marine Science 44.

UNESCO, 1981: Tenth report of the joint panel on oceanographic tables and standards. UNESCO Tech. Paper in Marine Science 36, 25 pp.