

Physical Properties of Seawater

Brian K. Arbic

1. Temperature and salinity distributions
2. Seawater density and stratification
3. Water masses

Reading: Stewart Chapter 6 (Google “Bob Stewart oceanography book”)

Motivation

- The physical properties of seawater—temperature, salinity, pressure, density, and related quantities such as potential density, heat capacity, sound speed, and others—are of fundamental importance to physical oceanography.
 1. The potential density stratification (layered structure) of seawater is controlled by temperature and salinity.
 2. Temperature and salinity are two of the most important variables that control, and are controlled by, interactions between the ocean and atmosphere at the ocean surface.
 3. Sound is one of the most important probes we have for measuring various quantities in the ocean.
 4. Thermal expansion is a major factor in sea level rise.
 5. The large heat capacity of seawater is one of the reasons the ocean is important for climate.

Pressure in the ocean

- Pressure is measured in decibars (db).
- For every m of seawater the pressure increases by ≈ 1 db
- At sea level, atmospheric pressure is about 10 db. Thus at a typical open-ocean depth of 4000 m, the pressure is equal to 400 atmospheres.
- In modern oceanographic instruments, pressure is measured with strain gauges (pressure transducers).

Demonstration of pressure in the deep ocean

- Type “youtube head shrinkers university of washington” into google

Ocean temperatures

- Temperature “T” is arguably the most important physical oceanographic variable in the ocean.
 1. T often sets the rate of biological and chemical reactions
 2. T is the major factor determining latent and sensible heat transfers between the ocean and atmosphere, a critical factor in Earth’s climate
 3. T (and velocity) together set the rate of meridional (north-south) heat transport, another critical factor in Earth’s climate
 4. T and Salinity control the **potential** density and hence the stratification (layering) of seawater; in most regions, T is more important

Some modern methods for measuring ocean temperature

1. CTD's (Conductivity-Temperature-Depth sensors) are the primary instrument of choice for large-scale hydrographic surveys (surveys of temperature and salinity). They measure temperature with thermistors, which work on the principle that the electrical resistance of a wire is a function of temperature. Measurement uncertainty is about 0.001°C .
2. Ship-based CTD surveys are expensive because they require the ship to stop while the wire is spooled out.
3. XBT's (Expendable bathythermographs) also utilize the resistance of a wire to measure temperature. They can be dropped off of ships without requiring the ship to slow down, and are typically not as carefully calibrated.
4. Recently, CTD's have been mounted on profiling floats, gliders, and other autonomous vehicles for cheaper operation.
5. Satellites measure blackbody radiation to infer temperatures at the sea surface.

In-class exercise: Using the web to learn about ocean temperatures

- Type “Conductivity temperature depth WHOI” on google, which should lead you to the site
<http://www.whoi.edu/instruments/viewInstrument.do?id=1003>
- Spend a moment reading this page, then click on “View slideshow” on the right and note the bottles used to collect water samples, which are used to calibrate the CTD and measure biogeochemical tracers.
- Why are ship-based CTD measurements generally more accurate than autonomous measurements?

In-class exercise continued

- Type “Reynolds sst analysis” on google, which should lead you to the site
<http://www.nhc.noaa.gov/aboutsst.shtml>
- Click on both the Atlantic and Eastern Pacific maps and answer the following questions:
 1. What is the general north-to-south pattern of temperature change?
 2. What are some typical warm and cold temperatures you see on the map?
 3. Does the temperature change more sharply along the east coast of North America, or the west coast?

In-class exercise continued

- Type “WOCE Atlas UCSD” on google which should lead you to http://www-pord.ucsd.edu/whp_atlas/pacific_index.html
- Click on “Section-based plots and information” and find “P16” on the map.
- Set “Line number” to “P16”, and “Type of Information” to “Section Plots”, then click “go”
- Look for “CTD sections” and click on the leftmost plot

In-class exercise continued

- Click on “POT TEMP upper jpg” and “POT TEMP lower jpg” and answer the following questions:
 1. What are some typical temperatures in the upper ocean?
Deep ocean?
 2. Do temperatures change most rapidly in the upper ocean or deep ocean?
 3. Considering the north-to-south pattern of sea surface temperature and the vertical profile of ocean temperature, at what latitudes do you think water in the deep ocean originates?

Recap: In-class exercise

- Sea surface temperature is generally warm in low latitudes, cold in high latitudes, and changes rapidly across western boundary currents such as the Gulf Stream.
- Temperatures change most rapidly in the “thermocline” which is typically in the upper 500-1000 meters of the water column.
- Below about 1000 m, the water temperatures change slowly and are near freezing, even near the equator, meaning that deep waters source from high-latitude regions.

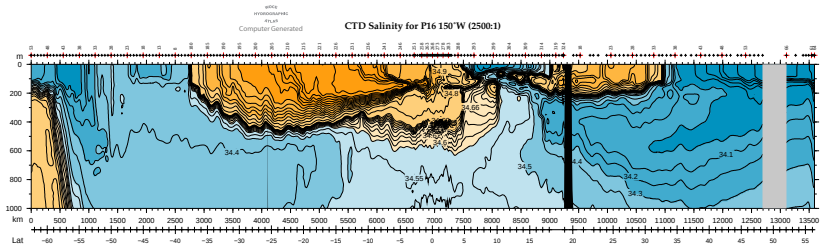
Potential temperature and compressibility

- Potential temperature (usually denoted by θ) is the temperature a fluid parcel would have if it were brought adiabatically to a specified reference pressure; **generally the sea surface unless otherwise specified.**
- An increase in pressure means that work is done compressing the water; this shows up as an increase in internal energy (hence temperature) of the water.
- For a decrease in pressure the water expands, does work on its surroundings, and hence experiences a decrease in temperature.

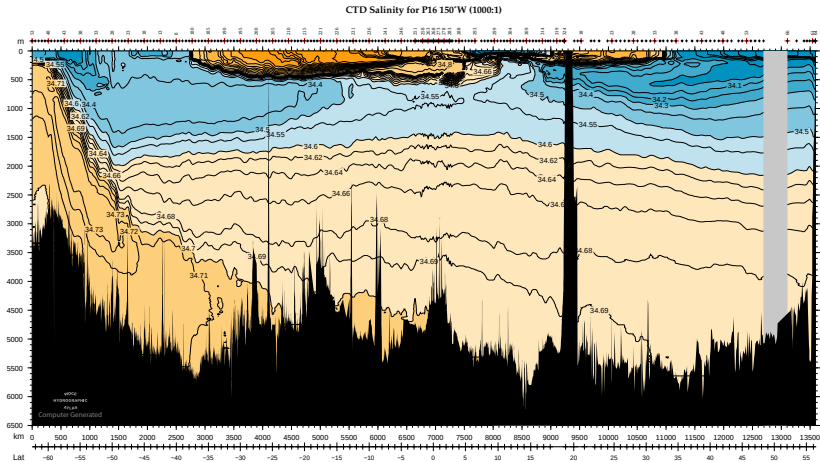
- The total amount of dissolved non-organic and non-volatile material in seawater is its salinity.
- In the open-ocean, a typical value is 35 ppt (parts per thousand), i.e. 35 grams of solids per 1 kg of seawater.
- All of the chemical elements exist in seawater, but about 87% of the dissolved salts are sodium chloride (NaCl).

- Today the standard method for determining salinity is based on the electrical conductivity of seawater, which is a function of the dissolved solids in the water. Present units of salinity are psu (Practical Salinity Units), and again a typical value in the open ocean is 35 psu. Measurement uncertainty is about 0.002 psu.
- The definition of salinity is quite subtle and still a matter of research. The quantity which can be conveniently and accurately measured—electrical conductivity—is related to, but not exactly equivalent to, the amount of dissolved material.

Salinity of P16—upper ocean (UCSD WOCE Atlas)



Salinity of P16—full water column (UCSD WOCE Atlas)



Salinity variations

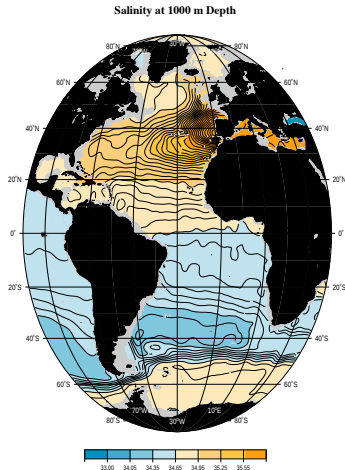
- Salinity varies over about 34 to 35 psu over most of the ocean volume.
- The largest salinity values are found in the surface of the subtropics, where evaporation rates are high.
- The tropics are slightly fresher due to greater rainfall.
- Surface salinities are generally lowest in high latitudes.
- Like temperature, salinity varies in the vertical, especially in the upper ocean; the region of large variations in the upper 500 or so meters is called the “halocline”.

Water masses

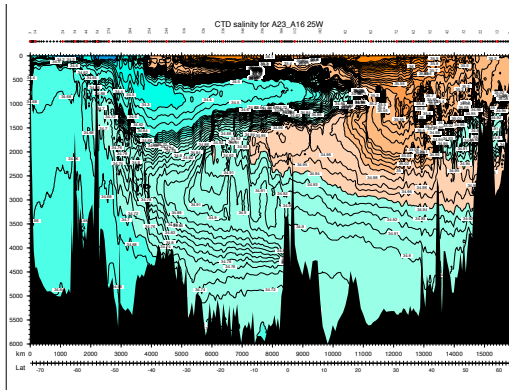
- Potential temperature and salinity are well-correlated over much of the world ocean.
- Potential temperature and salinity can be used to identify distinctive water masses which originate in well-known locations. In the Atlantic Ocean, below about 500-1000 m the waters consist of four main water masses:
 1. Mediterranean Water (warm and salty)
 2. Antarctic Intermediate Water (AAIW—cold and fresh)
 3. Antarctic Bottom Water (AABW—very cold and dense, the densest water mass in the world ocean)
 4. North Atlantic Deep Water (NADW—denser than AAIW, less dense than AABW), which sources from three locations
 - 4.1 Labrador Sea
 - 4.2 Denmark Strait
 - 4.3 Greenland Sea

Water mass identification in horizontal plot of salinity

- Salinity at 1000 m, taken from WOCE Atlantic Atlas
<http://www.bsh.de/aktdat/mk/AIMS/atlas/maps.html>



Water mass identification in vertical plot of salinity taken from http://sam.ucsd.edu/vertical_sections/Atlantic.html#a16a23



Need for an accurate equation of state

- We have seen that the differences in both temperature and salinity are quite small in the deep ocean.
- Since oceanic subsurface flow is along potential density surfaces (isopycnals), it's very important to have an accurate equation of state, along with accurate measurements of temperature, salinity, and pressure, to define these surfaces.
- We turn to the equation of state as our next topic.

Equation of state for seawater

- The equation of state for seawater is of the form $\rho = \rho(S, T, p)$, where ρ is density (in-situ density), S is salinity, T is temperature, and p is pressure.
- Seawater is extremely complicated. There is nothing like an ideal gas law for seawater. Instead the equation of state for seawater is determined empirically.
- The form of this function is known from careful laboratory work. It is represented by a huge polynomial which fits the data (for example, UNESCO equation of state EOS-80). Note UNESCO stands for United Nations Educational, Scientific, and Cultural Organization.

Equation of state for seawater

- A long list of thermodynamic properties can be computed from the equation of state—density, potential density, sound speed, heat capacity, potential temperature, etc. For instance sound speed c is given by $c^2 = \frac{\partial p}{\partial \rho}$

Nick Fofonoff, 1929-2003, the "father" of the modern equation of state

WOODS HOLE OCEANOGRAPHIC INSTITUTION

Celebrating 75 Years
of Ocean Research,
Education
and Exploration

[Home](#)

[Science Symposium](#)

[Employee Portraits](#)

[Main Page](#)

[Portrait Archives](#)

[WHOI 75th Book](#)

[Contact Us](#)

[WHOI 75th Donors](#)

[WHOI 75th Committees](#)

[WHOI 75th Merchandise](#)

[WHOI Home Page](#)

Employee Portrait Gallery — Nick Fofonoff



Nick Fofonoff was captured on film in his Clark Lab office in 1979. (Photo by Rob Brown)



New equation of state

- The equation of state is still a matter of research—in fact it was just revised in 2010. TEOS-10 is the new standard, supplanting EOS-80.

Trevor McDougall, the chair of the working group which established TEOS-10

http://www.teos-10.org/about_us.htm

IAA Messenger Express Geology Com...er Support GeoSci Infor... Technology mail.umich.edu U-M News Office of Science Programs Index of /~vgv09/fil

TEOS-10

Thermodynamic Equation Of Seawater - 2010

MENU

- Home
- Publications
- Software
- About us
- Contact us



The SCOR/IAPSO Working Group 127

Trevor J. McDougall *Chair*
CSIRO Marine & Atmospheric Research
GPO Box 1538
Tasmania 7001
AUSTRALIA
Tel: +61 (0)3 6232 5250
Fax: +61 (0)3 6232 5000
E-mail: Trevor.McDougall@csiro.au



Frank Millero, the only member of both the EOS-80 and TEOS-10 working groups

Frank J. Millero

Rosenstiel School of Marine & Atmospheric
Science
Division of Marine & Atmospheric
Chemistry
University of Miami
4600 Rickenbacker Causeway
Miami, Florida 33149-1098
USA
Tel: +1 305 421 4707
Fax: +1 305 421 4144
E-mail: fmillero@rsmas.miami.edu



Potential density

- Potential density, like potential temperature, is a quantity that is referenced to a particular pressure, so that compressibility effects can be dramatically reduced.
- For instance, $\sigma_{2000} = \sigma(S, T, p, 2000)$ is the potential density at 2000 db, i.e. the density a water parcel would have if brought adiabatically to 2000 db.
- Similarly, $\sigma_{4000} = \sigma(S, T, p, 4000)$ and $\sigma_0 = \sigma(S, T, p, 0)$