Oceans and the Global Environment: taking physics and chemistry outdoors

Peter Rhines\textsuperscript{1} Eric Lindahl\textsuperscript{2}
Bob Koon\textsuperscript{2}, Julie Wright\textsuperscript{3}

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www.ocean.washington.edu/courses/has221a-08

\textsuperscript{1}Prof. of Oceanography and Atmospheric Sciences; UW Honors Program
\textsuperscript{2}GFD Lab, School of Oceanography
\textsuperscript{3}M.S. in Biological Oceanography, UW
course goals

learn about the oceans of Earth, and their importance to plants, animals including humans
improve our relationship with the natural world…’Nature’
experiment
calculate
build ‘tools’ for your future (whether as a scientist or just a person)
consider ‘deep’ environmentalism…the growing understanding of interdependence within Nature, which has roots in philosophy and art as well as science, and implications to medicine, business, law, international relations, global poverty as well as to human-centered technologies.
course structure

- **Mon, Tues, Weds 9.30-12.00**
  - lecture…sometimes 1 hour, sometimes more
  - work on problems in small groups
  - write
  - introductory discussion for a lab or field excursion

- **Thurs 12-2.30 or 2.40-5.00**
  - lab or field excursion

The class web-page, [http://www.ocean.washington.edu/courses/has221a-08](http://www.ocean.washington.edu/courses/has221a-08) will have frequent postings including lecture material, assignments, calendar.

At present we have planned (for Thursday 28 Aug) an excursion by canoe and on foot to the wetlands of the UW Botanical Gardens near the campus, and to the School of Oceanography’s labs and instrument development facilities, as well as our labs in the School. We plan to explore ocean plankton with a video microscope during one of these visits.
**student responsibilities**

1. **keep a journal daily**  (in a roughly 8 ½ x 11” bound notebook…UW Bookstore)
   - class lecture notes
   - lab experiment notes and results; sketches (diagrams), graphs, explanations
   - problem solving notes and results
   - reading: most interesting ideas; least interesting content
   - short essays which will be assigned; start your essay the day it is assigned and let it ‘grow’ in your notebook. When it begins to look complete put it into your Google document; label it as a draft until you are happy with it (some of these will be quick-turnaround, due the next day). (~typically 2 to 3 page essays)

   As an aid to journal-keeping we will suggest some questions about the reading, lectures and in-class science problems which you can discuss in your journal.

2. **transcribe from these notes to a Google document**, which you and the instructors will ‘own’; details follow on the next page. *Note, don’t put your class lecture notes on the Google document…just the notes from reading books (or other sources..websites), problems you have worked on, essay drafts and final versions.*

   Your ‘homework’ for this short course will mostly consist of reading and writing your journal (including several major essays). Much of your journal writing can be done during class or lab time. *Note: some of your journal writing can be done directly with computer without being hand-written in your notebook.*

3. **Grading:**

   There will be two quizzes, roughly during week 2 and week 4. To do well on these review the reading, the lecture notes, the problems done in class and the labs. If you have difficulty on the first quiz there will be optional assignments that can offset an unhappy quiz grade (anyone can do these optional assignments to replace their lowest grade on quiz or journal material).

   We will not grade ‘on the curve’; that is we will not beforehand decide the mean or median grade and fit you all on it. This means that a really good class can all be graded ‘above average’ and conversely for a not-so-good class. It also means that you are not competing with each other for grades.
your e-journal: details

Your e-journal and the paper notebook will grow during the 4 weeks and will form part of your grade. To do this go to http://docs.google.com and register (if you happen to use Gmail you are already registered with Google and you can just click on documents on your Gmail Inbox page). Open your new document, use your surname as the filename, Mylastname-journal, click on the Share button, and add our email addresses (see below). You can simply write your text in a normal text document on your computer and later paste it into your Google Document. Be sure to keep a backup copy of your e-journal in a separate place (on your computer and/or a USB drive for backup). It is possible to scan sketches and figures and graphs to add them to your e-journal but this is tedious; just be sure you keep the paper version for us to see.

It is interesting to look at examples of good journals; for the labs there are some hard-bound lab books that you can look at, in room 206 Ocean Teaching Building.

- email addresses to share your e-journal: rhines@ocean.washington.edu, lindahl@u.washington.edu, bob.koon@gmail.com, jjoolzz@gmail.com
- Show the day’s date somewhere in your entries
  - 1. problem solving
  - 2. lab notes, sketches, graphs, conclusions
  - 3. textbook reading notes (what is the most interesting idea; what is the general message from the author; what was unclear or uninteresting in the reading?)
  - 4. essays: develop your drafts and final copy, improving as you go
- The journal entries do not need to be long. Quality means more than quantity. In particular minimize your cutting & pasting of web material.
reading for the course

- We have two paper textbooks: *The End of Nature* by Bill McKibben and *Mapping the Deep* by Robert Kunzig. We will also refer to oceanography texts; for example
  - *Introduction to Ocean Sciences* by Douglas Segar,
  - *Introduction to the World’s Oceans* by Sverdrup and Armbrust,
  - *Our Ocean Planet* by Robert Stewart, on line at

There are many other books and web resources that may be useful (though our time is limited). We will post other links and references on the class website.
Lecture 1: the oceans of Earth, and ‘deep time’

- There are two sides to this course: the oceans and global environment. We will develop scientific ideas about the world’s oceans, their climate and circulation and their biology. At the same time we will introduce global environment with a mixture of science and ‘philosophy’. These two sides have many points of contact; indeed the oceans cover some 70% of the Earth’s surface, contain most of its water, carbon and about ½ of its vegetable matter and oxygen production. But the main connection lies in the great impact that humans have had on the global environment, for example in global warming. The oceans play a vital role in global climate, and global biology.

- Studying the environment can be disheartening when we see how many problems there are, yet inspiring in its complexity, beauty and function…it works so well, generally speaking. Inspiring also in the work we must do to allow it to function. At the beginning of McKibben’s book you will read about ‘our sense of time’ and how important this is in dealing with environment.
Given that the environment is everything and everyone on Earth, how can we grasp it in a short course? We need an organizing principle. It could be

- ‘energy’, for the flow of energy governs much of both living and inanimate Earth. It could be the
- modern molecular biology with its power to reveal structure. It could be
- evolution, a remarkable scientific principle governing the long-term fate of animals, vegetables and whole ecosystems.

In this course we will most frequently use ‘energy’ to analyze systems, as well as other ideas from physics and chemistry. In a longer UW course of this kind we have started from ‘the mother of all energy’, the Sun, and followed energy flow and transformation to Earth and through living ecosystems of Earth.
Study of the oceans has developed, first and foremost, from direct observations. This is a difficult thing to do: our ships are so small and the seas so stormy. Lowering instruments to the sea floor is a slow business. This all began with early explorers who did scientific observation on the side.

But we have in just the past decade been able to develop new technologies that give us something like complete maps of the ocean waters (in all 3 dimensions). We cannot pretend the ocean will sit still to be ‘photographed’ since it is changing everywhere: both naturally and due to human influence. So we need to observe it daily, and that is now well underway.
Benjamin Franklin and his whaling-captain cousin Timothy Folger created the first map of the Gulf Stream, in the 1760s.
Roald Amundsen: first to reach the South Pole (1911), first to navigate through the Northwest Passage from Atlantic to Pacific (1903-06). His ship FRAM, below, had been built to reach the North Pole by Fridjoft Nansen. It can be seen in a special museum in Oslo, Norway.
HMS Challenger, 1873-76 the first significant, global oceanographic expedition
the clipper ship Cashmere sailed from Boston to Asia in the 1850s-60s
R/V Thompson  U.W.’s (276’ long) research vessel at the dock of the School of Oceanography (with it the R/V Barnes, for coastal research)
R/V Centennial, Friday Harbor Labs, UW in the San Juan Islands (58’ long) where 5-week long summer courses are given...mostly grad students but some undergrad opportunities)
research ships are expensive to run, so we have developed (here in UW Oceanography) remote undersea vehicles: the Seaglider, invented by Prof. Eriksen, travels through the depth of the sea measuring temperature, salinity, currents and biological fields.
For the first time we now have a global observing system for the oceans.....real-time oceanography similar to real-time meteorology...your accu-cast on the evening news.

- the TAO array of 70 moorings along the Pacific Equator..1/4 of the Earth’s circumference..for el Niño and its many global impacts

- the ARGO program (3000 profiling floats across the world’s oceans)

- satellites scanning the Earth for currents, temperatures, heat content, weather

- the Internet itself (a ‘central nervous system’ for Gaia, the Earth)
the Gulf Stream this morning... seen by NOAA infrared satellite sensors. We average for a week to get rid of clouds.

http://fermi.jhuapl.edu/avhrr/gs/
In winter the sea-surface temperature has much stronger variation (the thin layer of summertime warming being absent). Here it is 2 Feb 2008, with cold waters to the north, which have come south from Greenland region, and warm tropical/subtropical waters to the south. The Gulf Stream, strongly flowing and rich with swirling eddy motions and meanders, is the boundary between these waters.
The Ocean Influences Our Lives in Many Ways  

(from Stewart, Our Ocean Planet)

Most of the world’s water is in the oceans (97%), and it quickly, directly affects our fresh-water resources for agriculture, drinking, washing and for all the terrestrial ecosystems. Drought and deluge are extremes that affect us greatly.

Weather, storms, and violent hurricanes have strong dependence on the heat and moisture fed into the atmosphere from the oceans.

Global climate, The CO2 problem, global warming, and the ocean and all inter-related.
  - The ocean strongly influences climate including earth’s surface temperature, by influencing:
    - The amount of CO2 in the atmosphere,
    - The transport of heat from the tropics to polar regions,
    - The operation of the hydrological cycle, that is water, water vapor and ice
    - Earth’s carbon cycles.
  - Most of the oxygen in the atmosphere comes from the oceans.
  - The oceans may be responsible for abrupt climate change.
  - Will global warming plunge the world into the next ice age?

El Niño and other oceanic processes change weather patterns.
  - The ocean strongly influences weather patterns.
  - The largest source of year-to-year change in the weather is El Niño, which is a disruption of the interaction of the atmosphere and ocean in the Pacific.
  - A change of temperature of surface water in the western north Pacific and in the tropical Atlantic can cause drought in Texas, the great plains, and the west.

Deep-sea fisheries ocean are important.
  - Roughly 25% of the protein used by people comes from fish. Bering Sea fishery yields about ½ of US fish catch.
  - So many fish have been taken from the ocean that the fish populations have collapsed almost everywhere.
    - The loss of fish changes the marine food webs.
    - Changing food webs affect other life and processes in the sea.
  - How many fish can be caught?

Coastal ecosystems are vitally important: from microscopic plankton to fish and large mammals.
  - Coastal pollution seems to be the cause of large scale harmful algal blooms.
  - Pollution also seems to create dead zones in some regions.
  - What causes the dead zones off Mississippi in the summer?
  - Puget Sound, our large estuary, is rich with shell fish and fish habitats (including migratory salmon) yet it is not feeling well.

Coastal processes influence beaches and those who live and work near the beach.
  - Beaches are constantly being eroded away.
  - Structures along the beach in most areas will be destroyed in the long run.
  - Cost of protecting structures along the beaches is very high.
  - Why do some beaches lose so much sand that houses are destroyed.
The **ATMOSPHERE AND OCEAN** are thin layers of fluid at the surface of the Earth, which contain all the known life in the Universe.

- even within this thinness they are finely *layered*, like a parfait, by fluid density, the atmosphere’s temperature decreases upward

  at about 7°C per km...80% of the mass of the atmosphere is in the *troposphere*, the lowest 8 to 10 km. and the temperature decreases 50 to 70°C from sea level to that altitude

  The *stratosphere* above this level is more stratified, more stably layered.

  At the ground the pressure is about $10^5$ Newton.m$^2$ or Pascals. This simply reflects the weight of the air overhead.

  In the *deep sea* the pressure, also the weight per square meter of the water overhead, rises to typically 400 times the atmospheric pressure at sea level (water is 800 times denser than air at sea level. The upper 2.5m layer of ocean has the same heat capacity as the entire atmosphere above. The average ocean depth is 3800m yet the *water in the atmosphere* above if condensed would make a layer only **2.5 cm.** deep!)
reading assignment

- McKibben 1-46
- Kunzig 1-27 268-292 (Chap 13)
Water
- $104.5^\circ$ angle formed by hydrogen-oxygen-hydrogen tetrahedron;
- covalent bond within the water molecule yet ‘hydrogen bond’ between molecules
6-fold symmetry of ice crystals..snow-flakes
"Under the microscope, I found that snowflakes were miracles of beauty; and it seemed a shame that this beauty should not be seen and appreciated by others. Every crystal was a masterpiece of design and no one design was ever repeated. When a snowflake melted, that design was forever lost. Just that much beauty was gone, without leaving any record behind."

Wilson "Snowflake" Bentley 1925
water vapor can be seen with infrared sensors on satellites: here in the upper troposphere

Moving water is a stealth form of heat transport
latent heat required to evaporate water: $2.25 \times 10^6 \text{ J/kg}$
...compare with latent heat to warm water: $4184 \text{ J/kg}^0\text{C}$
Let's remove Greenland's ice (only temporarily)
Volume of water stored in the water cycle's reservoirs[9]

<table>
<thead>
<tr>
<th>Reservoir</th>
<th>Volume of water $(10^6 \text{ km}^3)$</th>
<th>Percent of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oceans</td>
<td>1370</td>
<td>97.25</td>
</tr>
<tr>
<td>Ice caps &amp; glaciers</td>
<td>29</td>
<td>2.05</td>
</tr>
<tr>
<td>Groundwater</td>
<td>9.5</td>
<td>0.68</td>
</tr>
<tr>
<td>Lakes</td>
<td>0.125</td>
<td>0.01</td>
</tr>
<tr>
<td>Soil moisture</td>
<td>0.065</td>
<td>0.005</td>
</tr>
<tr>
<td>Atmosphere</td>
<td>0.013</td>
<td>0.001</td>
</tr>
<tr>
<td>Streams &amp; rivers</td>
<td>0.0017</td>
<td>0.0001</td>
</tr>
<tr>
<td>Biosphere</td>
<td>0.0006</td>
<td>0.00004</td>
</tr>
</tbody>
</table>

Melting Greenland would raise the global sea level by about 7 meters.

as with the structure of the oceans, the structure of the solid Earth has only been understood for a few decades...in the monumental science of plate tectonics and continental drift. Fully accurate maps of the seafloor have only been created (using satellite measurements) in the past decade.
Topography of the sea floor, constructed from satellite radar altimetry and direct acoustic ‘soundings’ from ships (Smith & Sandwell)
ngdc topography--Hawaii
Figure 4.1 A cross section of the Earth showing its layers. Note that the thickness of the lithosphere has been greatly exaggerated in this diagram. If it were drawn to the correct scale, the lithosphere would appear as just a thin line at the Earth’s surface.
temperature of the ocean sea-surface
salinity of the surface of the sea (in kg of salt per kg of seawater…multiplied by 1000)….so typically 3%

Source: Aquarius satellite mission  http://aquarius.nasa.gov/education-salinity.php
Salt enters the seas from weathering of rocks on land, with streams and rivers carrying the dissolved solids in the form of ions of sodium, chlorine, calcium, potassium, magnesium, bromine…

It may also have entered from primordial seafloor…as ocean basins are cyclically created by plate tectonics.

So, why don’t the seas become saturated with salt eventually? That would be about 26.5% salinity (26.5 g of salt in 100 g. of seawater). There is a counterbalancing outflow of salt where it is deposited in the porous seafloor which is then carried down by plate tectonics, disappearing into the Earth’s mantle. There is actually a water plumbing system in the sediments beneath the seafloor.

The process of salt entering and leaving the oceans is very slow. The variations we see in salinity are due to its dilution and concentration by precipitation and evaporation (or, melting and freezing).

At a typical oceanic salinity of 3% (30 psu) the freezing point of water is lowered to -1.63 °C from 0°C for fresh water.


<table>
<thead>
<tr>
<th>Element</th>
<th>Percent in seawater</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen</td>
<td>85.84</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.091</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>10.82</td>
</tr>
<tr>
<td>Calcium</td>
<td>0.04</td>
</tr>
<tr>
<td>Chlorine</td>
<td>1.94</td>
</tr>
<tr>
<td>Potassium</td>
<td>0.04</td>
</tr>
<tr>
<td>Sodium</td>
<td>1.08</td>
</tr>
<tr>
<td>Bromine</td>
<td>0.0067</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.1292</td>
</tr>
<tr>
<td>Carbon</td>
<td>0.0028</td>
</tr>
</tbody>
</table>

Wikipedia image of NaCl salt: each ion has 6 nearest neighbors of the other kind. Chloride ions are larger, green. It can be viewed as two interlocked cubic lattices (face-centered)
**FIGURE CC6.1** The relationships among salinity, temperature, and density are complex. Generally, density increases as temperature is reduced or as salinity is increased. This figure is reproduced with additional information in Chapter 7 (Fig. 7.5a).
Density of water as a function of its temperature and salinity, at atmospheric pressure. Contours of constant density are shown projected on the base plane. Seawater lies mostly between $S = 32$ and 35 parts per thousand and $T = 0$ and $30^\circ\text{C}$. 
**FIGURE CC1.3** If cream (which has a lower density than coffee) is introduced at the surface of a cup of cold coffee, the cream forms a surface layer over the coffee. Between the cream and coffee layers is a zone within which the cream and coffee are mixed in proportions that change progressively with depth from pure cream to pure coffee. In this zone between the coffee and cream layers, there is a change in their respective proportions, which results in a sharp increase in density with depth. This zone in which density changes rapidly with depth is called a “pycnocline zone.” Vertical mixing between the two layers takes place only slowly across a pycnocline because the lower-density upper layer (cream) has no tendency to sink and the higher-density layer (coffee) has no tendency to rise.
section view of temperature (in degrees Celsius, actually ‘potential temperature’) from south to north in Pacific Ocean, at 150°W longitude (red=warm, blue=cold)

Southern Ocean   60°S       Equator               Hawaii           55° N Aleutian Islands

Each number at the top is the site of a lowered profile made from a ship. The section spans latitudes from about 63° South to 56° North (13,500 km).

Note vertical exaggeration of the figure; the isotherms are nearly horizontal.
salinity (in kg of salt per kg of seawater), $150^0 W$
(brown= large, blue= small)
density of ocean water 150° west, Pacific
add 1000 to these numbers to get density in kg per cubic meter. A typical value is 1027 kg/m³ varying by about 2 kg/m³ (also called ‘parts per thousand’).
dissolved oxygen (in micro mols per kg of seawater), $150^0 W$ (purple = large, yellow = small)
Nitrate concentration in sea-water, 150°W
(in micromoles nitrate per kg seawater)
the northern Atlantic Ocean…with its seafloor topography and the ice-mountain of Greenland (note vertical exaggeration of the picture! Greenland is about 3 km tall and 2000 km long…it lies between $60^\circ$ N and $83^\circ$ N, which is $\frac{1}{4}$ of the way from North Pole to Equator
Erika Dan temperature section from Labrador to Greenland to Ireland, 60N

(red = warm, blue = cold)

Worthington and Wright, 1962

surface

4 km deep
density, buoyancy, and Archimedes
Archimedes’ principle determines how much of a floating solid’s volume is below the surface. The solid floats at a depth such that the weight of the volume of water or other fluid that it displaces (that is, the volume of the part of the solid that is below the water or fluid surface level) equals the total weight of the solid. (a) Lower-density materials will float higher than higher-density materials. (b) Adding weight to a floating, low-density solid increases its mass and causes it to float lower and thus displace more water. The volume of water displaced will have a weight that is equal to the total weight of the floating solid plus the added weight that it supports.
the density of fresh-water ice is 0.917 grams per cubic centimeter…or 917 kg per cubic meter (kg/m³ or kg m⁻³); that is 92% of the density of fresh water or 88% of the density of typical, salty, cold ocean surface water. Among its many peculiarities, frozen water is less dense than liquid water. Most materials contract (become more dense) when frozen to solid form.

Water is a key participant in life, vegetable and animal. The temperature of Earth allows it to be in the liquid state, a fairly narrow range of temperature (100°C) in the greater scheme of things. Good luck on us!
hydrostatic pressure

- even though the oceans are moving, the pressure is nearly equal to the weight of the water and air above, per unit area.
water has a density close to 1 gram per cubic centimeter (or, 1 metric ton, 10³ kg per cubic meter); seawater is 2% to 3.5% denser than this

- variation of water density, \( \rho \), with temperature: thermal expansion coefficient
  0 to 3 \times 10^{-4} per degree C. (the slope of the graph of density \( \rho \) with temperature, \( T \), at constant pressure, \( p \))

- variation of water density, \( \rho \), with salinity ('haline' expansion coefficient): 0.8 \times 10^{-3} (the slope of \( \rho(S) \) where \( S \) is the salinity, kg of salt per kg of seawater).
  simply says that, dissolving salt in water (mostly sodium chloride) increases its volume only slightly (20%) as the salt ions hide nicely among the water molecules

- variation of \( \rho \) with pressure: compressibility, 4.5 \times 10^{-6} fractional volume change per decibar of pressure change (the slope of the graph of \( \rho \) as a function of pressure, \( p \)).

(the SI units for pressure, that is force per unit area, are Newtons per square meter, N m⁻². This is named the 'Pascal', and 100,000... \( 10^6 \)... Pascals make 1 ‘bar’, which is the average pressure of the atmosphere at the ground (note the word 'barometer'). Rather confusing but we end up with the decibar being 1/10 of a bar, and the decibar is approximately the hydrostatic pressure due to 1 meter of water (that is, the weight of a column of water 1 meter high and 1 square meter in horizontal area). The pressure at 10 meters depth in the ocean is due to the water plus all the atmosphere sitting on top of it. So, it is twice atmospheric pressure, saying that a 10 m high column of water weighs the same as all the atmosphere for each square meter of surface area. (Question: what is the mass of a column of atmospheric air with area 1 m²?)

This compressibility of water tells us the speed of sound (which is about 1500 meters per second).
Compare with air, where the sound speed is 343 m sec⁻¹ or 770 mph for dry air at 20°C. Solids are quite incompressible, hence they have a high speed of sound, 5100 m sec⁻¹ in steel.
buoyant continents float like icebergs on top of denser mantle

FIGURE CC2.3 Isostasy is the condition in which blocks of lithosphere float on the asthenosphere at the equilibrium level determined by Archimedes' principle. Above the compensation level (the depth at which the asthenosphere behaves as a fluid such that it can be displaced by floating lithospheric plates), the total weight of a column of continental crust plus mantle at isostasy will equal the total weight of a column of water, sediment, oceanic crust, and mantle. They do not quite do so in this figure, because the numbers are rounded.
density of ocean water 150° west, Pacific
add 1000 to these numbers to get density in kg per cubic meter. A typical value is 1027 kg/m³ varying by about 2 kg/m³ (also called ‘parts per thousand’).
question 1.1: how different is it to swim in Hawaii and to swim in Kansas?

question 1.2: Archimedes, according to legend, determined the king’s crown was gold, by knowing the density of gold. However the crown had a very elaborate shape, so he did not know its volume. “Aha” he said and fetched a basin of water. How did he use the water to learn the density of the metal in the crown?

question 1.3: how many barbers are there in New York city
question: what is the residence time $T$ of water in the ocean (that is, knowing the rate of rainfall and evaporation at the surface of the sea, how long on average does it take to renew the entire ocean?)

What is the residence time of water in the atmosphere?

In a steady-state system $T = \frac{M}{F}$ where $T$ is the residence time, $M$ is the mass of the system and $F$ is the inflow or outflow of mass in and out of the system (think of a river flowing in one end of a lake, and out the other). For water we can approximately use volume instead of mass because its density does not vary greatly.

The global precipitation rate is about $5.2 \times 10^{14}$ m$^3$/year

The total volume of water in the atmosphere is $1.3 \times 10^{13}$ m$^3$

The total volume of water in the oceans is $1.35 \times 10^{18}$ m$^3$

Note: it may be easier to think of an average vertical column of ocean and atmosphere: In that column there is about 2.5 cm (0.025 m) of water (as vapor or droplets) in the atmosphere, about 3730 m of seawater, and the average precipitation is about 1 m per year.

End Lecture 1