GFD-2  OC-513  Spring 2010  
P.B. Rhines  MWF 10.30-11.20  Ocean Teaching Building 207  
Outline of the course material

GFD-2 is, with Waves (OC 515), the final core course in Physical Oceanography’s (PO) dynamics sequence. Following classical fluid dynamics and GFD-1, we have the chance both to review basics and to apply them to the observed ocean circulation.

Dynamics of course applies at all length scales, from fine-scale turbulence to internal waves to tides and then to the energy-containing mesoscale eddies and Rossby waves, finally to the general circulation of the oceans, which intimately interacts with that of the atmosphere. Here we consciously emphasize the large scale. Those of you who are intent on working on ocean mixing and internal waves for example, should say so: we are small enough to do some fine tuning and some individualized instruction (for example in the term projects).

Which brings up term projects. Each of you will carry out an independent reading/research problem lasting much of the term. Suggestions will be given, but you can also suggest problem areas relevant to your research.

Resources. Never before have we had so much access to observations, numerical models, theory and lab models. It is not overstating to say that about 3 years ago, for the first time, oceanography finally put in place a global nearly-synoptic observing system consisting of ARGO floats (many of which are launched by UW faculty), global satellite altimetry, surface drifters along with the targeted observations from moorings, Seagliders and classic ship-based hydrography/chemical tracers. The TAO array run by PMEL-NOAA of about 70 moorings strung across the equatorial Pacific could be called the ‘worlds largest scientific detector’. You would think that doing PhD research would be as easy as falling off a log, since the community of physical oceanographers is still small. (But, it isn’t.)

Here is a list of topics for the course. Not all of them will be thoroughly discussed but we will touch on most.

- geostrophic flow  
  planetary and relative vorticity => potential vorticity 
  thermal wind 
- rotation and stratification: the layered, stiffened ocean fluid 
- Ekman dynamics and air/sea interaction: pumping up the interior ocean circulation 
- wind-driven circulation of a one-layer ocean 
  spin-up of the circulation from rest: Rossby waves 
- stratification and the ‘quiet’ interior water column 
  mapping the global potential vorticity 
- meridional overturning: the ‘conveyor belt’ and global heat/fresh-water balance 
  mixing and water-mass transformation: the buoyancy/mixing ‘sea’-saw 
- dynamics of high and low latitude: 
- the Southern Ocean: circulation of ‘channel’ oceans vs. ocean basins
• deep convection and ‘cold subduction’: Arctic and subpolar Atlantic
• tropical circulations and el Niño-Southern Oscillation
• physical circulation controls exerted on tracers, global chemistry and biology

**Note on textbooks:** We now are overflowing with books (texts and monographs) on GFD. Gill’s *Atmosphere-Ocean Dynamics* is my choice for the classic reference but he does not do much vorticity dynamics. Pedlosky’s GFD text is excellent for 1- and 2-layer models of waves and instability of quasi-geostrophic flows and for ideas of scaling approximations. We have Vallis’ book *Atmospheric and Oceanic Fluid Dynamics*, which is modern and vorticity oriented; I used it as a GFD-1 text last year, though in the end that course material was dominated by lecture notes. Salmon’s text *Lectures in Geophysical Fluids Dynamics* is elegant, theoretical, good for basics but narrow in scope. Cushman-Roisin is excellent at the basic level as is Kundu and Cohen. J.R.Holton’s *Dynamic Meteorology*, in its 4th edition, is really an excellent complement to the GFD texts. It starts at a basic level but takes you far, introducing advance ideas like the omega equation and baroclinic instability. Ian James’ *Introduction to Circulating Atmospheres* is like Holton not taking you to a very advanced level but introduces the key methods for understanding the GFD of the atmospheric general circulation. Back in classical FD, there are texts like G.K.Batchelor’s *Fluid Dynamics* which excels in formal mathematics of the subject, a small book by D.J. Acheson (*Elementary Fluid Mechanics*) and a fluids book written by great physicists: Landau and Lifshitz’ *Fluid Mechanics*.

The sad thing though is that none of these texts, excepting Gill’s and James’ make a serious attempt at using observations. Observationalists, as a rule, rarely write text-books. Wallace & Hobbs undergraduate text *Atmospheric Circulation: an introductory survey*, in a new edition, is worth looking at in this respect.

**Monographs:** Specialized books that are meant to describe a subfield are also numerous: classics like J.S.Turner’s *Buoyancy Effects in Fluids*, M.J.Lighthill’s *Waves in Fluids*, R.X.Huang’s *Ocean Circulation*, Andrews, Holton and Leovy’s *Middle Atmosphere Dynamics* are examples. With the loss of the Oceanography Library we must hike up the hill to find the books of PO, but it is very important not to ignore them. Did we say ‘Atmosphere Dynamics’? Yes: the GFD of the atmosphere has much in common with ocean dynamics, and in addition the two fluids couple together to make the climate system. Better not to ignore the air overhead.

Another remark about omission: hard-core theoretical work is not carried out by many oceanographers today. Much more widely, people built, use and interpret numerical circulation or climate models. But, beware of giving a research seminar of the form “Here is what I changed in my ocean model (or climate model) and here is what happened.”. Experiments are good, but dynamics goes deeper than changing parameters, playing with parameterizations and seeing what happens. A little theory can take you a long way.

**Note on background from physics and mathematics:** Sometimes you hear that physical oceanography is an ‘application of classical physics’. In some ways it is, but the oceans are so rich with complexly interacting phenomena that PO is far more than applied physics. Nevertheless, reading or re-reading a good basic physics text can be very helpful in GFD. Richard Feynman’s 3-volume paperback set, *Feynman Lectures on Physics*, is particularly exciting. The power and elegance of the subject is remarkable, all the way from Newton to
Einstein and beyond. At the level of simple experiments with charges and current coils one must confront relativistic ideas. And, the mathematical methods are in many cases similar to PO. Feynman gives a brief review of vector calculus in Volume 2 (pp 2.1-2.12; more also in Chapter 3). Also in Vol. 2 he gives a 24 page introduction to fluid dynamics (chaps 41 and 42). Feynman used to use fluids as an example of remarkable complexity arising from simple-looking equations. Visit him at http://en.wikipedia.org/wiki/The_Feynman_Lectures_on_Physics

In Feynman’s 12-page review, for example, we learn to think of $\nabla \times \vec{A}$ as the circulation of the vector $\vec{A}$ about a closed curve in the fluid…which is a graphically useful alternative to the partial derivatives involved in $\nabla \times A$. Electromagnetism produced by coils and current loops is expressed naturally in these terms.

**GFD Lab** ([www.ocean.washington.edu/research/gfd](http://www.ocean.washington.edu/research/gfd)). Another resource we can use to view geostrophic flow, thermal wind, circulation, Kelvin and Rossby waves, etc. is the lab in Ocean Sciences 107. We have just completed a course, ‘Experimenting with Fluids’ where 10 student projects were developed over winter quarter. These, and some of our GFD demonstrations may be of interest in GFD-2 ([www.ocean.washington.edu/research/gfd/oc569a-2010](http://www.ocean.washington.edu/research/gfd/oc569a-2010)).