Assignment 4 for EEPS 1520:
Ocean Circulation and Climate or,
Notions for the Motions of the Oceans

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1   Contacts

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2   Getting Help!

I am usually available by email. You can make an appointment other times. Just check my calendar at `http://fox-kemper.com/contact` and suggest a time that works for you.

The most important commands in matlab are 'help' and 'lookfor'. The first one allows to to get a description of any matlab function, for example, '≫ help plot' tells you about the function named 'plot'. The second one allows to to search for keywords within a function description (in case you don't know or can't remember the name of the function).

3   Introduction

As you know, our assignments are structured to resemble a scientific journal's peer review process. So, when in doubt about procedures, try to understand the assignments in that context. I am listing together all of the pieces for the paper at the same time here, so that you can see the full flow all at once (even though there are different due dates on each piece).

4   Reading

Chapter 11 of *Wunsch* (2015) is excellent for the Meridional Overturning Circulation. Chapters 4, 5, 6, 7 and 8 all cover different aspects of waves and eddies.

5   Homework 4

Each of the subsections here is a homework problem that you should complete, make a pdf of the results, and turn in through canvas.brown.edu. Please include screenshots (as .pdf) or script files (as .m) if that is needed.

5.1 Software & Data

5.1.1 ECCOv4r2 Version Details

This version is ECCO v4 release 2. It simulates the Earth over the 240 month period from 1992 to 2011. Data and readme files may be found at `http://mit.ecco-group.org/opendap/ecco_for_las/version_4/release2`.

There are three different temporal collections of data that are useful for our purposes. The monthly directory contains many of the model output variables, depending on time (240 months), latitude, longitude, and depth (50 levels). The files in this format are big (e.g., the salinity file is just over 3 gigabytes in latlon spatial gridding). Two dimensional variables, such as wind stress, are 50 times smaller. The directories ending with _climatology contain the average over all years of all variables for each month, that is, the typical January, the typical February, etc. For many projects, this climatological version will be adequate, and the data files are 20 times smaller. Finally, I have made you an average of the climatology, so it no longer has any seasonal information. This average of the whole model is in directories ending in _avg, and is 240 times smaller than the _monthly directory.

There are three versions of spatial grids that we use. The nctiles_ spatial gridding is the native grid of the model, but it is confusing as it is laid out in 13 different files for each variable and the grids do not align with latitude and longitude easily. The interp_ spatial griddings are interpolated versions of the nctiles_ model onto a uniform global grid. The interp_ gridding is useful, but some errors are introduced by interpolation. The interp_monthly and nctiles_monthly is available here: `ftp://mit.ecco-group.org/ecco_for_las/version_4/release2/interp_monthly`. The latlon_ gridding is the best of both interp_ (the grids are all lat-lon) and nctiles_ (the grids presented are what the model uses), but the parts of the globe where nctiles_ are not oriented along meridians and parallels is just omitted. The latlon_monthly is available here: `http://fox-kemper.com/data/ecco_for_las/version_4/release2`. As a starting point, I recommend using the latlon_ version if possible, and then the interp_ if you want to go polar, and finally the nctiles_ only as a last resort.

5.1.2 Earlier Versions

In previous versions of this course, I have used versions of this model that did not include the Arctic (v2.199 and v3.73 and v4r1). However, the newest version v4r2 is significantly better in many respects. So, we will use that one.

5.1.3 Where to Find

I have created copies of the most crucial files for your analyses. The files needed to do only the homework problems here can be downloaded from: `http://fox-kemper.com/data/ecco_for_las/version_4/release2`. These files are all averaged in time over the whole of the 240 months, to make for smaller files and easier analysis. Some of the original files are located at `ftp://mit.ecco-group.org/ecco_for_las/version_4/release2`, in case I have forgotten any files.

There are "normal year" climatologies (averages over all 20 januaries, then all 20 februaries, etc.) which are available for many of the files that can be downloaded. There are all time averages (avg) files, and there are the monthly mean "monthly" files, which are 240 times bigger than the avg files and 20 times bigger than the climatologies.

5.1.4 Integrater-Based Code

I am also providing a few pieces of code using my integrater codes. Each version of these codes is in a self-contained directory, where all of the parameters, equations, and plotting functions are kept. To run

these codes, open matlab, relocate to within the unzipped directory, and execute

```
>> integrater
```

to run the code. You can then go change the settings by opening other files in the same directory. Use the README.txt file to guide which parameters are kept in which files. Most of the time, the only files you will need to change are globalparm, initcond, and initopt. Each of these files is commented.

5.2 Meridional Overturning Circulation

1. Write an equation for the depth-integrated, or barotropic, volume transport streamfunction.

   Based on the meridional velocity v, you could write

   $$\Psi(x,y,t) = \int_{x_w}^{x} \int_{-H}^{0} v(x,y,z,t)dzdx \tag{1}$$

   (Not required, but useful:) By conservation of mass, if the surface is not allowed to move this is equivalent to

   $$\Psi(x,y,t) = -\int_{y_s}^{y} \int_{-H}^{0} u(x,y,z,t)dzdy \tag{2}$$

   Note that $\partial\Psi/\partial x = \int_{-H}^{0} vdz$ and $-\partial\Psi/\partial y = \int_{-H}^{0} udz$.

2. Write an equation for the zonally-integrated meridional overturning volume transport streamfunction.

   This is deceptively similar to the preceding, but it depends on different integral bounds.

   $$\Psi(y,z,t) = \int_{x_w}^{x_e} \int_{z}^{0} v(x,y,z,t)dzdx \tag{3}$$

   Note that here the z-derivative is proportional to the meridional velocity and above the x-derivative is.

3. Run the moc.m (start_up, then moc from `http://fox-kemper.com/data/ecco_for_las/version_4/release2/moc.m`) code. To run this code, place moc.m in the same place as the NVELMASS and llgrid.mat from the latlon_avg data (`http://www.fox-kemper.com/data/ecco_for_las/version_4/release2/latlon_avg/`). Identify the major meridional overturning cells and barotropic gyres, and compare their magnitude and sign (sense of rotation). Note that the latlon data is limited in northern extent (where the grid gets wonky). You only need to explain Figures 1 and 2. Figures 3 and 4 show how to break up the MOC into its constituents basin-by-basin, which may be useful for papers.

5.3 Waves

1. Write an equation for the frequency ω, phase velocity ω/k, and group velocity $\partial\omega/\partial k$ of arbitrary depth surface gravity waves (with k and $l = 0$). Note their limits in deep and shallow water. (Wunsch 4.12, 4.14)
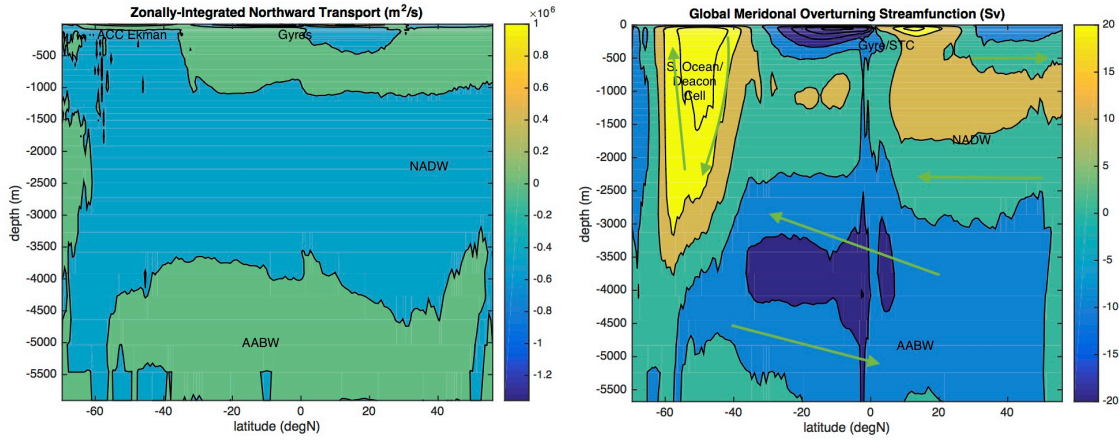
Figure 1: **Meridional Overturning Circulation**

$$\omega = \sqrt{gk \tanh kH} \tag{4}$$

$$c_p = \frac{\omega}{k} = \sqrt{\frac{g}{k} \tanh kH} \tag{5}$$

$$c_g = \frac{\partial \omega}{\partial k} = \frac{g \tanh(kH) + gkH \operatorname{sech}^2(kH)}{2\omega} \tag{6}$$

Shallow water case ($kH \ll 1$):

$$\omega = \sqrt{gk^2 H} \tag{7}$$

$$c_p = \frac{\omega}{k} = \sqrt{gH} \tag{8}$$

$$c_g = \frac{\partial \omega}{\partial k} = \sqrt{gH} \tag{9}$$

Deep water case ($kH \gg 1$):

$$\omega = \sqrt{gk} \tag{10}$$

$$c_p = \frac{\omega}{k} = \sqrt{\frac{g}{k}} \tag{11}$$

$$c_g = \frac{\partial \omega}{\partial k} = \frac{1}{2}\sqrt{\frac{g}{k}} \tag{12}$$

2. Run the gravity1d integrater code (from `http://www.geo.brown.edu/research/Fox-Kemper/models/matlab/gravity1d.zip`). To do so, download the zip, unzip it, and change directories into the one resulting. Alter H in globalparm.m and which dispersion relation is used in initopt.m to show that dispersion and depth are strongly related.

3. Alter gravity g in globalparm.m. Does it affect dispersion? What does it affect in the resulting figures?

No, gravity does not affect dispersion (as we might guess from the formulae above). However, it does affect the speed of the waves, as they all are proportional to $\sqrt{g}$. Yes, deep water is dispersive and shallow water is not. Depth affects the shapes of the evolving waveforms in Fig. 2, but doesn't affect the power spectra.

4. Write an equation for the frequency, phase velocity, and group velocity of Rossby waves (with k and $l = 0$). Contrast the short $(kL_d \gg 1)$ and long $(kL_d \ll 1)$ waves in terms of their dispersion.

From slide 52 of 17.LargeWaves with $l = 0$,

$$\omega = \frac{-\beta R^2 k}{1 + R^2 k^2} \tag{13}$$

$$c_p = \frac{\omega}{k} = \frac{-\beta R^2}{1 + R^2 k^2} \tag{14}$$

$$c_g = \frac{\partial \omega}{\partial k} = \frac{-\beta R^2 (1 - k^2 R^2)}{(1 + k^2 R^2)^2} \tag{15}$$

Short waves $(kR \gg 1)$:

$$\omega = \frac{-\beta}{k} \tag{16}$$

$$c_p = \frac{\omega}{k} = \frac{-\beta}{k^2} \tag{17}$$

$$c_g = \frac{\partial \omega}{\partial k} = \frac{\beta}{k^2} \tag{18}$$

Long waves $(kR \ll 1)$:

$$\omega = -\beta R^2 k \tag{19}$$

$$c_p = \frac{\omega}{k} = -\beta R^2 \tag{20}$$

$$c_g = \frac{\partial \omega}{\partial k} = -\beta R^2 \tag{21}$$

5. Run the hovmuller.m code (start_up, then hovmuller from `http://fox-kemper.com/data/ecco_for_las/version_4/release2/hovmuller.m`. Place hovmuller.m in the same place as the data file ETAN from either latlon_monthly or interp_monthly). Explain the westward propagating signals.

6   Plans 4

You now have some experience with making a plans document. Again, you will produce one. However, this time there are some specific constraints on what you will calculate (see below), so take that into account as you prepare your plans.

For the plans document, you will outline what plans you have for the project, including as many details as you have collected by this time. Here are some critical points to make in the plans document, which will help me to better advise you in moving to the paper stage.

- Describe your region (e.g., which water mass and meridional overturning? Coastal waves, equatorial waves, mid-ocean waves?) and timeframe or timescale of interest.
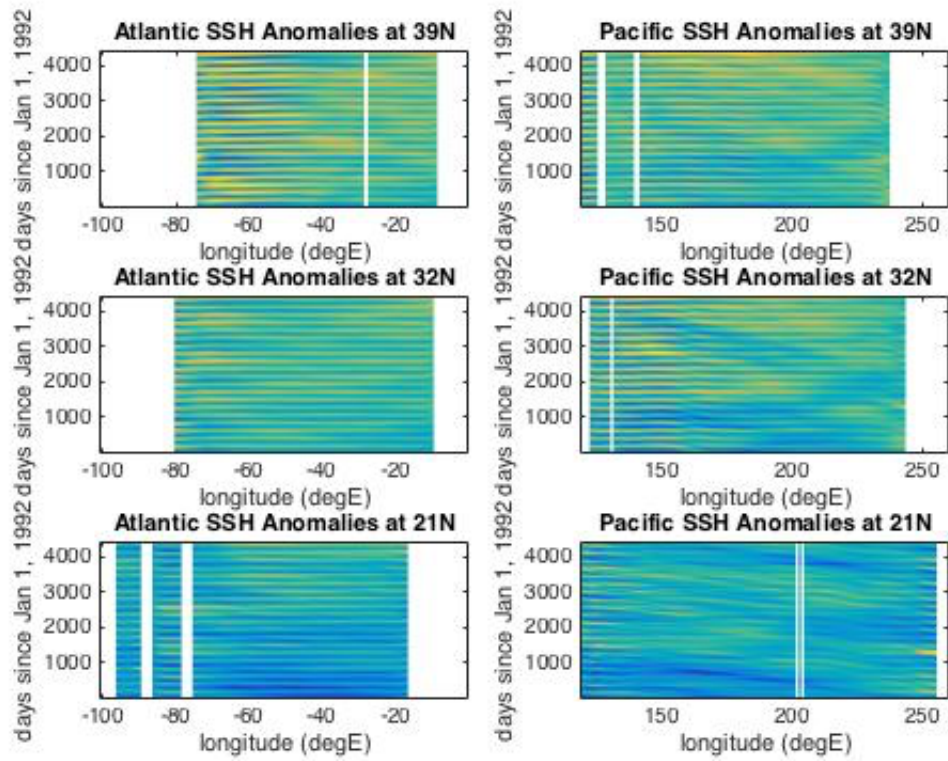
- Give a working title.

Figure 2: **Hovmuller diagrams of SSH.**

- Make a list of 1-3 hypotheses you plan to address.

- Identify specific journal articles, papers, or subsections of the book that are relevant. Briefly summarize what they say that is relevant to your planned paper, and what missing hypotheses to test that you will try to test. Look back at comments on previous plans to help in the selection.

- Here you may use ECCOv4 release 1, or other datasets. It is my expectation that you will produce figures in either case.

- MOST IMPORTANT. If possible, include draft versions of the figures you plan to use in your paper, based on the real data and the real metrics you plan to calculate. Normally, if you can get to this stage, completing the paper on time is no problem. If you are unable to produce figures that you need, you should indicate this, so that I can help.

- If you are unable to get to the preceding step, give your fallback plans if all else fails. Because of the reviewing process and timeframe, you will *not* be able to get an extension on the paper deadline if things don't go smoothly. You can include more figures in the revised version of the paper if you figure it out after you turn in the first version of the paper.

7 Paper 4

As you plan your paper, go through my paper primer document, available on the webpage.

7.1 Topic Choice 1: Tumbling Dice

The goal here is to choose a region/basin to analyze the meridional overturning circulation and main watermasses. You may benefit from using ECCO data.

- Find a region of interest based on a review paper or an observational campaign to ground your choice of location.

- Using the code from the HW, and the ECCOv4 dataset to get started quantifying the watermasses and overturning.

- You can contrast the model results versus other observations, or otherwise describe the situation. At this point, you are ready to be on your own!

Don't be afraid to piggyback off of other published work. Use Google Scholar or Web of Science to locate articles by keyword, and then see what they say. Feel free to use the matlab references, and refer to similar projects.

7.2 Topic Choice 2: Wavy Gravy

The goal here is to choose a type of wave and a region where they are important. You may benefit from using ECCO data if you are studying Rossby or Kelvin waves, all other waves are too small to be resolved in that model. However, feel free to find other papers presenting wave data or download your own wave data from the National Data Buoy Center (`www.ndbc.noaa.gov`).

- Find a wave category of interest based on a review paper or an observational campaign to ground your choice of location.

- You may choose to use the code from the HW, either the ECCOv4 hovmuller data or the integrater code to get started.

- You can contrast the model results versus other observations, or analyze other wave data, or write a review paper on a particular category or behavior of waves not covered in class.

Don't be afraid to piggyback off of other published work. Use Google Scholar or Web of Science to locate articles by keyword, and then see what they say. Skim through the chapters of *Wunsch* (2015) 4, 5, 6, 7, 8–which topics appeal to you? They all cover different aspects of waves. Feel free to use the matlab references, and refer to similar projects.

8 Reviews 4

As you plan your reviews, go through my review primer document, available on the webpage.

You will read and review two of your colleagues work. You can look at the peer reviewing primer for more details as to how to proceed. Be sure that you are actually critical where you see room to improve ("Everything looks great! Good work!" is not a useful review unless it is *totally* true), but do not be heedless of feelings or unfriendly. Make sure you comment on the *science* as well as the presentation and writing. For example, it is more important to catch unfounded claims that to fix spelling errors. Do you believe the metrics used? Do you understand the fundamentals of the dataset and measurement technique? Do you suspect that the data is cherry-picked? Etc.

9 Revisions 4

Learning how to respond to reviews, both positive and negative, is a crucial part of any scientist's (or just person's) training. You've done a couple now, so it should be pretty automatic. Don't forget the response primer document!

References

Wunsch, C., *Modern observational physical oceanography: understanding the global ocean*, Princeton University Press, 2015.