Assignment 2 for EEPS 1520:
Ocean Circulation and Climate or,
Notions for the Motions of the Oceans

Baylor Fox-Kemper

November 12, 2024

1   Contacts

The professor for this class is: Baylor Fox-Kemper
baylor@brown.edu
401-863-3979
Office: GeoChem room 133
http://fox-kemper.com/teaching, http://fox-kemper.com/1520

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 first 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   Homework 2

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 part of the .pdf) or script files (as .m) if that is needed.

5   Reading

You should read: Section 9.5 of *Wunsch* (2015) about state estimates. More details about the specific state estimate we will use are in (ECCO4r2: *Forget et al.*, 2015), which is what you should cite as the

source of this data for your paper. The mathematical basis of state estimation (and its relation to inverse problems) is covered in Appendix B of *Wunsch* (2015).

Sections 3.3 and 3.4 of *Wunsch* (2015) cover how to think about equations of motion of fluids. Section 10.1 covers Ekman theory and related ideas.

Again, you will want to have 5-10 papers cited in your Paper 2, and it's a good idea to identify them in time for Plans 2.

5.1 MITgcm ECCO v4, Release 2

This homework and paper we will begin working with one particular simulation of the MIT General Circulation Model (MITgcm: *Adcroft et al.*, 2008). This particular simulation is the Estimating the Circulation and Climate of the Ocean (ECCO v4 release 2) simulation (ECCO4r2: *Forget et al.*, 2015). This kind of simulation has been built by a consortium of scientists worldwide (`http://www.ecco-group.org/`).

I have chosen this particular model for us to analyze because,

1. It is a state-of-the-art modeling framework.

2. Not just the vague variables, such as salinity and temperature, are saved. Also available are the advective & diffusive fluxes, winds, surface forcing, etc. Thus, unlike observations in the real world, we will have *everything we need to understand the behavior of the model*.

3. This model is data-assimilating. It is constrained to closely resemble a suite of satellite and in situ data (which you can access directly here: `ftp://mit.ecco-group.org/ecco_for_las/version_4/release2/input_ecco/`). Thus, as closely as possible, it resembles the real world (except without data gaps).

4. The model's numerical basis is finite volume discretization. This framework is identical to that we have been discussing in class, with fluxes into and out of the faces of gridded volumes, and each volume contains tracers and momentum.

5.1.1 This 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/release1/contents.html`. The news release is at `http://www.ecco-group.org`.

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). However, the newest version v4 is significantly better in many respects. So, we will use that one.

5.2   Ekman Exercise

This portion of the homework is to get you used to calculating the Ekman transport. You can use the latlon_avg version of the model.

1. Write an equation that relates the zonal wind stress to the meridional Ekman mass transport. Be clear about units and directions. (see Wunsch eq. 10.6)

2. Write an equation that relates the meridional wind stress to the zonal Ekman mass transport. Be clear about units and directions. (see Wunsch eq. 10.6)

3. Write an equation that relates the wind stress curl to the vertical Ekman mass transport. Be clear about units and direction. (see Wunsch eq. 10.13)

4. What is the rate at which salt is carried into a grid cell of volume V by the fluxes above (given uniform salinity S)? What are the units of the divergence of the salt flux integrated over the grid cell?

5. What is the rate at which heat is carried into a grid cell of volume V by the fluxes above (given uniform potential temperature T)? What are the units of the divergence of the heat flux integrated over the grid cell? Here you will need to use the density and specific heat to convert from potential temperature to energy.

6. Suppose salty water is brought upward (ADVr_SLT+DIFr_SLT) at a rate so that a freshwater flux (oceFWflux) of $1m/yr$ is balanced by horizontal flow (ADV?_SLT+DIF?_SLT). If the upwelling rate is $0.1m/day$, how much saltier is the upwelled water than the water flowing out horizontally? (This balance is the essence of the $hconv + zconv \approx 0$ balance we have discussed in class).

7. Suppose cold water is brought upward at a rate so that a warming solar surface flux of $200W/m^2$ is balanced. If the upwelling velocity is steady at $1m/day$, how much colder must the deeper water be than the horizontal outflow water to bring about this balance? (This balance is the essence of the $hconv + zconv \approx 0$ balance discussed in class).

5.3   Curl Versus Wind Versus Ekman Exercise

For this part, you'll examine the mass transports produced by Ekman transport, and these will have consequences for heat and salt budgets which may focus your paper.

1. Download the oceTAUE, oceTAUN, oceCURLTAU, oceCURLTAUbyF, NVELMASS, and WVEL-MASS from the latlon_avg files here: `http://fox-kemper.com/data/ecco_for_las/version_4/release2`

2. Plot oceTAUE at 39.9300N and 40.69105 and oceTAUN at 40.3116N at all longitudes. (e.g., $plot(lone(abs(late - 39.9300) < 0.1), oceTAUE(abs(late - 39.9300) < 0.1))$

3. Plot oceTAUE/$(f\rho_0)$ versus the upper 70m northward volume transport (relative to the flow below) from NVELMASS: $(f = 2 * 2 * \pi/(24hr3600s/hr)\sin(lat))$, be careful to take sind function since latitude is in degrees!

```
>> uplayer=10*(sum(NVELMASS(:,:,1:7),3)-7*NVELMASS(:,:,8));
%Upper layer mass transport anomaly based on differences from the 75m depth velocity
>> plot(lonn(abs(lat-40.31)<0.1),uplayer(abs(lat-40.31)<0.1));
% Plot the upper layer mass
>> hold on  % plot the next figure on top of the last
>> tauavg=0.5*(oceTAUE(abs(late-39.9300)<0.1)+oceTAUE(abs(late-40.69105)<0.1);
>> ekman=-tauavg/1029/(2*2*pi/(24*3600)*sind(40.3116)));
>> plot(lone(abs(late-40.69105)<0.1),ekman);
>> hold off
```

4. Plot oceCURLTAUbyF/ρ_0 versus WVELMASS along the same latitude.

6 Plans 2

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 and timeframe of interest.

- Give a working title.

- 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.

- Identify datasets that you have located that are relevant. Indicate whether you have been successful in opening them (i.e., have you mastered the file format?), locating the relevant dates/locations (have you mastered the data subselection/data layout?), and which figures you intend to create (have you designed the most important metrics for your problem?).

- 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 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 2

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

7.1   Topic: I Get Around

The goal here is to choose a region, timeframe, and straightforward diagnostic of the Ekman transport in that region. You will relate the Ekman transport of some other property (salt, heat/potential temperature, nutrients, etc.) to observations in that region.

- Find a region of interest based on the Ekman transport and its consequences. For example, download a wind stress dataset from ECCO, COADS, etc. There are some wind files that I have pre-processed (see links above). These already have wind stress curl calculated, too. Can you find a region of particularly strong offshore or onshore wind stress? An area where wind stress is variable throughout the year? Alternatively, you might examine maps of sea surface temperature or chlorophyll to look for upwelling (presumably Ekman-driven) and choose that region–you could make these maps yourself from satellite data or just find them online. Alternatively, you might choose a region based on interest or based on another paper that mentions Ekman or wind-driven processes.

- Choose a subregion of your domain, based on the patterns of SST, SSS, and other data you might have (chlorophyll, etc). Relate the changes you see in SST or SSS to the effect you are interesting in examining (e.g., upwelling causes chlorophyll and causes colder SSTs).

- Use the total transport fluxes into this region to identify the primary balance of mass, and either heat or salt (depending on which you found to be anomalous in the previous step). Determine the dominant balance in the mass and heat or salt budgets for this subregion.

  1. Use the ECCO latlon files to examine the mass flowing into and out of your region. Which is largest, the horizontal flux in the x-direction (EVELMASS*cross-sectional area), the y-direction (NVELMASS*area), or the vertical (WVELMASS*area)? Does the largest flux balance itself (e.g., zonal in E=zonal out W)? If not, which flux supplies the difference? At the end of this exercise, you should know which direction supplies the most water and which direction loses the most. NOTE: It is not required for you to examine the budget of every gridpoint in the domain, just into and out of your interesting subregion (which is the sum of over certain gridcells' faces). Pay particular attention to the most near-surface gridcell. It will have a lot of the Ekman transport. The whole of the Ekman transport should be above the MXLDEPTH.

  2. Now examine the wind field in your domain. If you saw an important zonal mass transport, is there a meridional wind? If you saw a meridional transport, is there a zonal wind? If there is a vertical transport, is there a wind curl? You might check against the velocities (UVELMASS, VVELMASS) to confirm your assessment. How much of the mass transport can be explained by the winds (see homework problem)?

  3. Now repeat step 1 using either the salt budget or the heat budget, depending on your topic at hand. Where is the salt or freshwater arriving? What about the heat? In this case, you will have to consider fluxes through the top surface from the sun or freshwater. These are part of the oceFLUX files.

4. Now examine the ADV?_SLT or ADV?_TH files. These represent only the advective fluxes of salt or theta. The units are in cubic meters per second times the transported property ($psu = gm/kg$ for salt or $°C$ for potential temperature). Use the results from the homework problem to convert these fluxes into units/time of the conserved quantity (i.e., Watts=Joules/s or kg of salt/s). Do these advective fluxes nearly equal the total fluxes in EVELMASS, NVELMASS, WVELMASS? What does that imply?

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.

8 Reviews 2

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 2

Learning how to respond to reviews, both positive and negative, is a crucial part of any scientist's (or just person's) training. There are a number of things to consider, which I'll just itemize here.

- Your first paper was *not a draft*, it was a complete version of a *completed scientific work* in your opinion. Thus, if the reviewers (and editor, a.k.a. me) don't point out anything, you don't have to change anything.

- If you do have reviews to respond to, you should make a short "response to reviewers" document, which might just be a text set of comments, a text file attached to the revised document, or a cover email to go with the revised version of the paper.

- You may catch your own mistakes that were missed by the reviewers, it is OK to change these, too. Please itemize them in the response to reviewers document.

- You should consider very carefully whether the reviewer is right before making changes. Generally, make all "easy" changes that are suggested by the reviewer. Things like clarifying unclear sentences or phrases, making notation more consistent, labeling figures better, etc., are all in this category. You should expect that the reviewer is reading more carefully than any other readers you are likely to get, so if they don't understand what is going on easily no one else is likely to either!

- You don't have to go through small suggestions one at a time in the response document, just say you took all suggestions.

- Some reviewers will make complicated suggestions, like additional computations, rearranging sections, deleting or adding figures, etc. Consider whether the outcome is guaranteed to be an improvement of the overall work. If you are sure the reviewer is wrong, just politely decline to make

the change. If you aren't sure, give it a try, but don't be afraid to compare to the original before accepting the change. Whatever you do, explain your process and thinking in the response to reviewers document.

- The reviewers are not perfect, and they are equally or perhaps more likely to misunderstand what you've done than to point out something you've done incorrectly. Be careful to figure out which before you make any changes. Most often, the changes you make will just be to clarify what you've done rather than change what you've done. On the other hand, good reviewers will catch inconsistencies in your work that are important to understand or fix as you finalize your revision.

References

Adcroft, A., J. M. Campin, S. Dutkiewicz, C. Evangelinos, D. Ferreira, G. Forget, B. Fox-Kemper, P. Heimbach, C. Hill, E. Hill, et al., The mitgcm user manual, 2008.

Forget, G., J.-M. Campin, P. Heimbach, C. N. Hill, R. M. Ponte, and C. Wunsch, ECCO version 4: an integrated framework for non-linear inverse modeling and global ocean state estimation, *Geoscientific Model Development*, *8*, 3071–3104, doi:10.5194/gmd-8-3071-2015, 2015.

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