OCES 2003 Assignment 3, Spring 2023

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Set on: Fri 14th Apr; due: Fri 21st Apr

Blurb

- Assignments have a maximum mark out of 20, although you will see that there are 22 marks available to get in total, i.e. if you get 22/20 you still only get credit for 20/20
  - 16-17 is roughly around the A- boundary
  - anything below 8 is probably a fail
- Please show working in calculation
  - no working + wrong answer = no credit whatsoever
  - some working + wrong answer = partial credit
  - generically, give things to 2 decimal place and provide the appropriate units (marks are allocated for these), unless otherwise specified
- No answers except the 'hard' ones should need more than a paragraph / half a page, and excess answers that are not to the point will be penalised
- Type up the assignment or send a photo of your written up work in (the former is preferred), and the only request I have is no Microsoft Word documents (you can type up things with Word but export it as a pdf if you do)
  - write in full sentences where appropriate
  - particularly poor and/or scrappy presentation will have a mark that can be taken off
- There will be a rigid mark scheme, and model solutions will be available in due course
  - the TAs only mark the stuff, you should come to the instructor for arguing marks, and note the re-marking can result in marks going up or down

!!! By handing something in, you agree to the usual Academic Honour code and Integrity declarations. For more, see `http://qa.ust.hk/aos/academic_integrity.html`. Cases for plagiarism (whether intended or not, it is the "act" that matters) gets a penalty ranging from

  - zero on the question concerned
  - a fixed penalty starting from around 1/3 of the total marks
  - zero for the whole assignment/midterm/final

  The following counts as plagiarism (and is a non-exhaustive list):

  - copying word for word *any* (i.e. one or more) sentence without quote marks regardless of whether it is cited or not, e.g. *Yer a Jedi, Harry* (Gandalf of House Stark)
    * use quote marks if need be, e.g. "*Yer a Jedi, Harry*" (Gandalf of House Stark), although don't do it too often, because then one could argue you are not passing any of your thoughts through
    * any more than around three usages in text is probably excessive
  - copying without citation or wrong citation, e.g. "*Yer a Jedi, Harry*", or "*Yer a Jedi, Harry*" (Jon Snow of Tatooine)
  - changing a few words but sentence largely the same, e.g. *You, Harry, sir, are a Jedi* (Mithrandir of Winterfell)

- Turnitin will pick out most of the aforementioned things
- Cases can be contested but will lead to an official review, where the penalty may go up and/or down, and could result in an Academic Misconduct case being filed (see `https://acadreg.ust.hk/generalreg.html#b`)

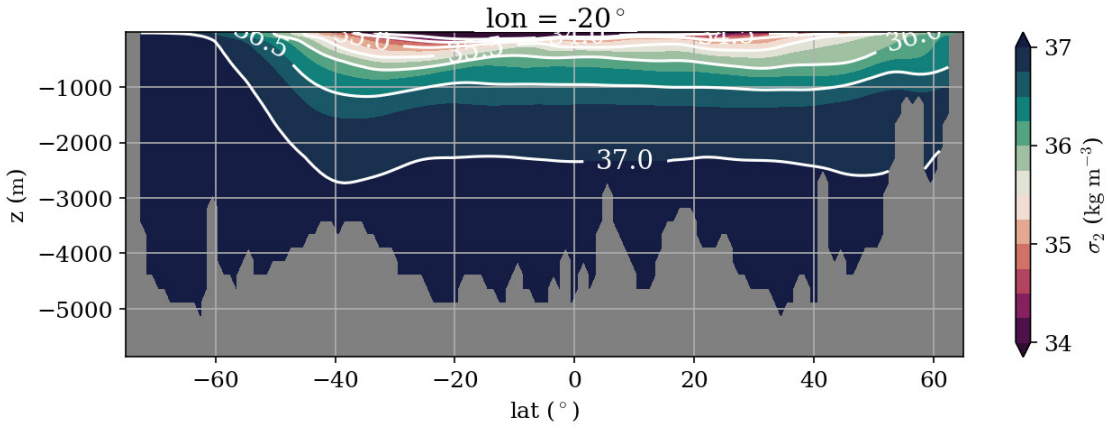
Problems

1. Question relates to thermal wind shear relation.

   (a) Describe what thermal wind shear relation entails and under what conditions thermal wind shear holds in less than thirty words (do not use equations).

   [2 mark]

   (b) Explain in less than a hundred words why the following meridional section implies an eastward Antarctic Circumpolar Current that is increasing in strength as you go from depth towards the ocean surface in the region between 70 to about 40° S:



   (Use equations if you like, but take increasing y to be towards the North for consistency with the conventions used in the course. Equations don't contribute to word count, but use of equations do not contribute to any of the marks.)

   [2 marks]

   (c) It has been suggested by research papers that there are instances in the past where the modern day equivalent of the Drake passage was completely closed, so that there are no open latitudes in the ocean (e.g. in the late Eocene about 40 million or so years ago). State what we would expect to see in the flow and stratification in what would be the equivalent of the Southern Ocean in that case, and what implication this might have on the global overturning circulation. You should do this in around a hundred words, and cite any sources you do use if you choose to use external sources.

   (Note: This is <u>not</u> the same case as Munday et al. 2015 that was referenced in the lectures. In that case there are no open latitudes but both the Drake passage and the Tasman sea are open. Here I really mean what would be the modern day Southern America and Antarctica is connected by land.)

   [2 marks]

2. An important climate mode of variability is the El-Niño Southern Oscillation (ENSO). The general understanding is that the trigger is in the equatorial Western Pacific, although the most notable signature is actually in the equatorial Eastern Pacific. One proposed mechanism for the teleconnections is to do with *waves*, which we will explore a little here.

   (a) On or just off of the equator, in which horizontal direction (E, N, S, W, some combination thereof) do equatorial Kelvin waves propagate in, given they propagate cyclonically?

   [1 mark]

   (b) On the equator, given $f_0 = 0$, why do we still have Rossby waves? Explain your answer in less than ten words.

   [1 mark]

   (c) The *barotropic* equatorial Kelvin wave has dispersion relation $\omega = k\sqrt{gH}$. Are these waves dispersive, and why?

   [1 mark]

   (d) Compute the phase speed for the equatorial (barotropic) Kelvin wave phase speed using $g = 10$ m s^{-2} and $H = 4$ km, giving your answer to the nearest m s^{-1}. From that, work out the *crossing time* for the equatorial Kelvin waves to propagate across the Pacific, assuming the equatorial Pacific is about 20,000 km wide, giving your answer to the nearest *hour*.

   [2 marks]

   (e) The actual observed crossing time for equatorial Kelvin waves (e.g. via SSH anomalies associated with the waves observed from satellites) is closer to 2 months. Work out the implied phase speed for this case, giving your answer to the nearest m s^{-1}; take 2 months = 60 days for reproducibility purposes (the answer you will get is going to be a bit higher than what is going to be quoted online).

   [1 mark]

3. (Continuing somewhat from previous question.) The much slower wave speed that is actually observed is to do with the 1st *baroclinic* mode, arising because the ocean has density stratification. It is generally understood that Kelvin waves propagate the disturbance from one end to the other, while equatorial Rossby waves do the propagation in the opposite direction.

   The first baroclinic Rossby wave has a zonal phase speed given by

   $$c_{p,x} = \frac{-\beta}{k^2 + l^2 + 1/L_d^2},$$

   where $\beta = 10^{-11}$ m^{-1} s^{-1} is the planetary β, k and l are the zonal and meridional wave numbers, and $L_d = NH/f_0$ is the relevant Rossby deformation radius.

   (a) Estimate a value for L_d at around 10° N if we take $N^2 = 10^{-4}$ s^{-2} and $H = 1000$ m. Give your answer of L_d to the nearest 100 km.

   [2 marks]

   (b) For a single Rossby wave (so we can use the phase speed), work out the wavenumber k if the zonal wavelength is 4000 km, giving your answer in the form $a.bc \times 10^d$ m^{-1}, where a, b, c, d are whole numbers and in units of (units should really be cycles per meter). With that, using the computed L_d from the previous part to the nearest hundred km and assuming $l = 0$ for simplicity, compute the crossing time for Rossby waves to propagate across the equatorial Pacific assuming again a distance of 20,000 km. Give your computed crossing time to the nearest month, and you can assume 30 days in a month for simplicity.

(Hint: your velocity and your crossing time will be a bit larger and longer respectively than what is quoted in the literature or from a Google search, the latter because of the 20,000 km assumption.)

[4 marks]

4. (Also continuing somewhat from previous two questions.) Look up and describe in your own words the mechanism of how the Rossby and Kelvin waves are argued to mediate the oscillation of the ocean mixed layer depth as part of the ENSO cycle, referencing the different crossing times as calculated from the previous two questions as appropriate. Don't make it more than about a page, cite any sources you do use, and feel free to include diagrams as long as they are cited and actually helps the narrative you are trying to make. Extremely irrelevant and/or wrong details as well as going over the page limit will result in marks being deducted (although you can't get an overall negative mark for this question).

   (Hint: the search that you might want do is for the *delay oscillator ENSO* or something like that. Vallis also talks a bit about it in his book, although only in the second edition. Fei-Fei Jin's 1997 paper may or may not be useful: `https://doi.org/10.1175/1520-0469(1997)054<0811:AEORPF>2.0.CO;2`.)

   [4 marks]

!? (Bonus question, no marks + for interest only) Look up or derive yourself why, under conditions where thermal wind shear relation is appropriate, the zonal interfacial form stress is directly related to the advection of meridional buoyancy, i.e.

$$\tau^x_{\text{form}} \sim \overline{p' \frac{\partial h'}{\partial x}} = -\overline{\frac{\partial p'}{\partial x} h'} \sim \overline{v' b'},$$

where p', h', v' and b' are respectively the perturbations of pressure, isopycnal layer, meridional and buoyancy, x is the zonal direction, and the overbar is some average, normally taken to be the zonal average. (Form stress here is to do with the correlation between the pressure and gradient of layer depths, essentially as described pictorially in the lectures.)

(Hint: Vallis has a description of this, as would most 'standard' theoretical geophysical fluid dynamics books, probably under the heading *Eliassen–Palm flux* or something similar.)