OCES 2003 sort of finals, Spring 2021

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Set on: Thurs 14thth May; due: Thurs 14th May

Blurb

- The final has a maximum mark out of 30
  - 24-26 is roughly around the A- boundary
  - anything below 12 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
  - zero for the whole course
  - academic suspension, expulsion etc.

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

  - copying from others and/or websites like Chegg; when found, both the copier and (where relevant) the person copied from will at a minimum get zero for the assessment (in line with university policy), with possibility for failing the whole course, and possibly with academic suspension (repeated cases will lead to expulsion)
  - 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 will most likely lead to an Academic Misconduct case being filed (see `https://acadreg.ust.hk/generalreg.html\#b`)
- You do not have to cite lecture materials from this course, unless you want to

Problems

1. **(3 marks)** Do we get planetary Rossby waves if we are

   (a) on a flat Earth?

   (b) on a non-rotating Earth?

   (c) at the equator of a rotating Earth?

   Justify your answers (no marks for just guessing).

   (*Miffy's hint*: what is the associated dispersion relation?)

   [3 marks]

2. **(6 marks)** This question concerns formation of deep and abyssal waters by overflows, specifically the dense waters formed in the Mediterranean Sea and the Weddell Sea.

   (a) Assuming a linear equation of state, work out the associated densities (there is no distinction between potential and in-situ here) for the following, with everything in standard units (temperature in degrees Celcius):

	α	β	T_0	S_0	T	S
Med Sea	2.1×10^{-4}	2.0×10^{-4}	10.0	35.0	12.9	40.0
Weddell sea	1.3×10^{-4}	2.0×10^{-4}	−2.0	35.0	−1.0	34.6

   Give your answers in standard units and accurate to 2 decimal places, taking $\rho_0 = 1026$ kg m^{-3}.

   [2 marks]

   (b) In about 50-100 words, explain what *overflows* are and how they contribute to the MOC.

   [2 marks]

   (c) In the calculations above it might appear the abyssal waters should really be made up of Mediterranean waters rather than waters of Antarctic origin (this gives you a slight hint on what answer you should be getting), when in fact we know from observations that abyssal waters are of Antarctic origin. Say Miffy uses the bathymetry on the Atlantic side of the Med Sea as a scratching post, so that the bathymetry there is very *rough*. With that information, speculate some *dynamical* reasons (rather than *thermodynamical* ones, e.g. I should use better numbers and/or equation of state) that possibly resolves the apparent contradiction. (In reality the steepness, roughness and water export rate probably all matter.) Use around 100-150 words or so.

   [2 marks]

3. **(8 marks)** Consider the Southern Ocean circulation and impact on global circulation from a momentum balance point of view.

   (a) In around 100-150 words or so, briefly explain why interfacial form stress is also called eddy form stress, associated with baroclinic mesoscale eddies.
   (*Miffy's hint*: Your answer should include the terms *Rossby number* and *thermal wind* somewhere)

   [3 marks]

   (b) Since eddy form stress mediates vertical momentum transfer, what happens to the ACC circumpolar transport if Miffy uses her miraculous cat powers to artificially kill the baroclinic mesoscale eddies in the ACC, assuming the wind is still putting the same amount of momentum into the system?

Make the assumption that any momentum that actually reaches the bottom of the ocean is removed from the ocean system by the topographic form stress.

[2 marks]

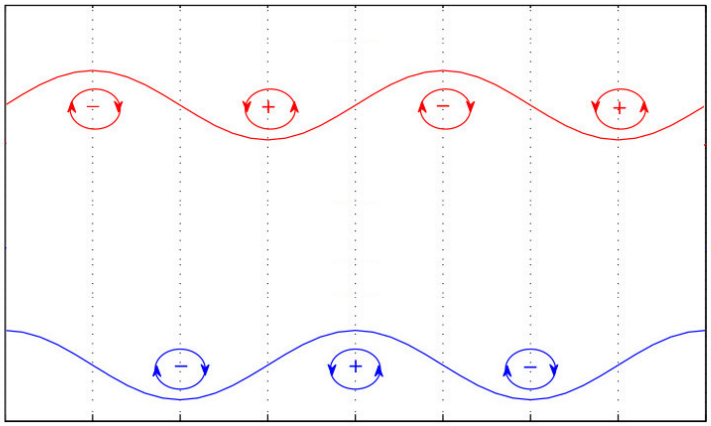
(c) Argue what happens to the ACC isopycnal slopes and therefore global pycnocline depth if we can artificially kill the eddies in the ACC (in a numerical ocean model for example). Speculate on the time-scales for significant change to occur (years? decades? centuries? millennia?), and also on what happens to the overall AMOC strength in terms of total transport.

[2 marks]

(d) Suppose Miffy in her infinite cat wisdom decides to kick the Earth so that it spins the other way round relative to the usual Earth's rotation axis (the one pointing out of the North Pole). Do any of the answers to the previous parts in this question change? Justify your answer (no marks for guessing).

[1 mark]

4. **(4 marks)** We revisit counter-propagating Rossby waves as a mechanism for explaining shear instabilities, and the role of certain *critical layers*, where the Doppler shifted wave speed is zero, i.e. $U_0 - c = 0$. Consider the configuration of two counter-propagating Rossby waves in an unstable configuration as sketched below:



(a) Which direction is the bottom blue wave propagating towards by its own self-induced acceleration? Justify your answer (by drawing, describing and/or otherwise).

[1 mark]

(b) State the magnitude (in degrees, radians or wavelengths, whatever) of the phase shift θ_0 between the top red and the bottom blue wave. From that, draw on a middle (green) wave between the top red and the bottom blue wave such that the middle green wave has the same wavenumber as the other waves, but with an added request from Miffy such that the middle wave has a phase shift where the middle waves leads the red by $\theta_0/2$, and lags the blue by $\theta_0/2$. From that, sketch on the sign of the vorticity anomalies *at the nodes* associated with this middle green wave for the overall configuration to be less unstable, i.e. the presence of the critical layer has a stabilising influence in this case.

[3 marks]

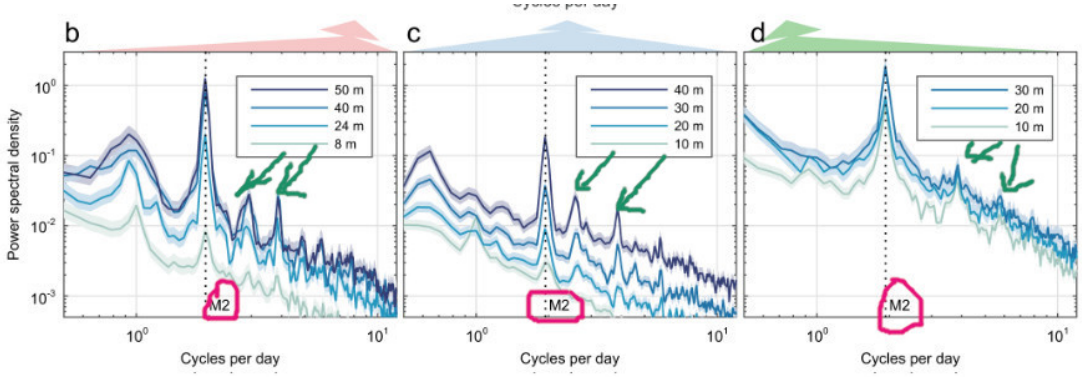
5. **(9 marks)** This question explores a bit of the physics behind Alex Wyatt's guest lecture, regarding internal waves and their effect on coral ecosystems. The reference is below, but reading the paper probably won't help with anything except beyond part (*a*), which is a tiny portion of the overall marks anyway.

Wyatt, A. S. J, Leichter, J. J., Toth, L. T., Miyajima, T., Aronson, R. B., and Nagata, T (2020)
Heat accumulation on coral reefs mitigated by internal waves
Nature Geosci., **13**, 28–34, doi:10.1038/s41561-019-0486-4

(a) In around 50-100 words, describe how internal waves can help coral ecosystems to acclimatise to increasing heat from ocean warming (so how the physics can influence the ecology).

[1 mark]

(b) The following graph is from the supplementary material (Fig. S1) of Wyatt *et al.* (2020), which shows the power spectrum of internal waves:



What does M2 within the red circles refer to? With your answer, work out the standard frequency (rather than angular frequency) in units of Hz corresponding to that largest spectral peak, giving your answer accurate to five decimal places in the form 1.23456.

[2 marks]

(c) There are some peaks marked on by Miffy with green arrows, which correspond to waves with shorter frequencies. If we make the assumption that the forcing is only at the location of the largest peak highlighted in the previous question (it isn't but roll with this assumption), speculate on what leads to the non-zero signal you are seeing at these larger frequencies.

Or, put another way, since the graph shows 'power' (think of it as energy maybe, or wave amplitude), you have a transfer of power from the dominant forcing frequency to higher frequencies, but what causes these kind of transfers?

[2 marks]

(d) Speculate two pieces of observation equipment you might use to measure these internal waves. Justify your answer, and discuss a little about the relative advantages and disadvantages of the two piece of equipment you select, and the frequency and duration of measurements you might need to actually measure the internal waves.

[2 marks]

(e) One suggestion is that mesoscale eddies (satisfying small Rossby number dynamics) in nearby deeper regions can reduce the amount of internal waves propagating into these shallow regions housing coral ecosystems, by deepening the upper level thermocline (and thus pycnocline) so that there is no longer a connection between deep and shallow regions on which internal waves can propagate along. If these regions with coral ecosystems are in the Southern Hemisphere, would it be anti-clockwise and/or clockwise flowing mesoscale eddies that lead to this effect? Justify your answer.

[2 marks]