OCES 2003 Assignment 3, Spring 2024

Inusuke Shibemoto

Set on: Mon 15th Apr; due: Mon 22nd Apr

Model solutions and mark scheme

Problems

1. (a) Since we are in the geostrophic regime it's largely going to be related to f/H contours. In order for $|f|/H$ to be constant with H is decreasing, $|f|$ needs to decrease. Since the magnitude $|f|$ decreases towards the equator, the flow should deflect equator-ward.

   (1 mark for geostrophic flow should be along lines of constant f/H, 1 mark for argument leading to northward deflection here, 1 mark for equator-ward deflection.)

   (b) f_0 would be around 10^{-4}, while for a geostrophic eddy with $U = 10^{-1}$ and $L = 10^5$ in standard units, $U/L \sim 10^{-6} \ll 10^{-4}$ (still small even with $L = 10$ km $= 10^4$ m), so it is relatively small enough to be ignored.

   (1 mark for sensible estimations of U/L and f_0, and 1 mark for appropriate comparison.)

2. (a) Water being denser would actually lead to a decrease in sound speed, so it's the stiffness or compressibility that is different (sea water is less compressible than air; makes sense somewhat since we are dealing with pressure waves).

   (0.5 mark for K_s and 0.5 mark for explanation.)

   (b) Refraction, as wave propagation changes direction.

   (1 mark. Do not accept diffraction, since that's for interference across slits/corners.)

   (c) Phase and group speeds are the same if we are talking about non-dispersive waves.

   (1 mark for something relating to they are the same)

   (d) Idea here is that changes in temperature distribution would change the density, so changing the sound speed (increase in temperature would increase the sound speed), so by measuring changes in the sound speeds accordingly one could in principle infer for the changes in the temperature distribution. This could be done by appropriately placed instruments that do some 'pings' in the ocean, and receivers that measure when the 'pings' are coming in. The tricky thing is of course picking this out among the ambient noise, and other issues such as bounces and multiple arrival time of signals.

   The Wikipedia article provides a comprehensive explanation and history of the method.

   (Up to 4 marks for any of the following: 1 mark for temperature affect density, 1 mark for measuring changes in sound speed, 1 mark for a relevant pictorial schematic, 1 mark for some mention of instruments, 1 mark for listing some possible challenges, 1 mark for references.)

3. (a) Under conditions where hydrostatic and geostrophic balance hold, the vertical flow shear is related to horizontal gradients in the density.

(1 mark for hydrostatic and geostrophic balance (no half marks here), and 1 mark for the second part of the sentence. Deduct half marks for every 10 words over the 30 word limit.)

(b) The isopycnals are largely flat, so the horizontal gradients in density are small, and we expect the flow shear to be small. This would suggest a weak circumpolar transport, contrary to what we know about the Antractic Circumpolar Current being the largest ocean current by transport in the world. By comparison, the potential or neutral densities have a distinct meridional slope in that region, consistent with a large vertical shear.

(1 mark for flat isopyncal and 1 mark for weak shear / flow. Deduct half marks for every 10 words over a 50 word limit.)

(c) Circumpolar transport would be a proxy for the Southern Ocean stratification, with larger transport related to larger meridional tilts in the isopycnals and deeper Southern Ocean pycnocline. Assuming the isopyncals in the ocean basins are largely flat (because there is no equivalent of an ACC in the basin regions), since isopycnals are connected, the Southern Ocean stratification deepening would in principle drag the global stratification down and make it all deeper, with significant effects on the overturning circulation and heat content (e.g., Mak *et al.*, 2022 for a global ocean model). The large increase of ACC transport in the blue would imply a deep global pycnocline, while the model truth in green suggests no such sensitivities exist (so existing climate models might be displaying a larger modelled sensitivity that seems to be erroneous).

(Up to 4 marks for a combination of the following: 1 mark for relation between transport and Southern Ocean stratification, 1 mark for links between Southern Ocean and global stratification, 1 mark for some flatness comment about global isopycnals, 1 mark for consequence on overturning circulation or similar, 1 mark for blue displaying large sensitivity in Southern Ocean / global stratification to changes in forcing, 1 mark for reference(s). Allow marks accordingly if these are encoded in some sensible pictorial schematic. Take marks off as appropriate if it is too long and/or content is largely irrelevant, but don't give an overall negative mark.)

(d) We would need to do an *integral* to get the velocity from thermal wind shear relation (hence the hint on the derivative). But with an integral, even if the density gradients are zero, the integral of zero might be a constant that is not necessarily zero. This means that unless one makes some assumptions about that integration constant (e.g. it is zero below some depth), then the actual flow is defined up to an ill-determined constant. This is sometimes called the *level of no-motion* problem.

(Give up to 2 marks for a combination of the following: 1 mark about integral, 1 mark about the existence of an integration constant, and 1 mark for a relevant reference. Allow marks accordingly if these are encoded in some sensible pictorial schematic.)

!? (Bonus question, no marks + for interest only) The speed of sound in the medium has now changed. However, what is going on really is that we still have the same resonator (your voicebox) and forcing frequency (your vocal chord), and it is the *natural vibration frequencies* that have changed, where the voicebox wants to resonate more at the higher frequencies if helium is concerned. That's why the overall sound to someone else is higher, because the 'normal' frequencies are not excited as much. (If you have never heard sulfur hexafluide in action, try this video: `https://www.youtube.com/watch?v=u19QfJWI1oQ`.)

This would be the reason why different ways of producing the same pitch might sound drastically different: the concert A (A4) from a tenor voice (e.g., tenor singer, cello, bassoon, horn, trombone) sounds very different to that produced on a soprano voice (e.g., soprano singer, flute, oboe, violin) and among themselves, because different frequencies are being sounded by the different instruments (but also at different *tessituras*; A4 is high-ish for tenor voices and have a bit more carrying power).

Ocean warming would lead to a decrease in density, so probably would be closer to the helium case than the sulfur hexafluride case. I seem to remember Chris Hughes at Liverpool gave a talk on something related, and may have papers on something similar (e.g. `https://agupubs.onlinelibrary.wiley.com/doi/full/10.1002/2016GL069573`?)