OCES 2003 Assignment 1, Spring 2021

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Set on: Tue 16th Feb; due: Tue 23th Feb

Model solutions and mark scheme

Problems

1. (a) Just plug some numbers in, and remember to take 1000 off. I make it -0.20 kg m^{-3}.

   (0.5 marks for getting 999.8*, 1 mark for giving answer as an anomaly, 0.5 marks for units.)*

   (b) As above, noting that using Kelvins or psu makes no difference in the conversion. I make it $+0.20$ kg m^{-3}.

   (0.5 marks for getting 1000.2*, 1 mark for giving answer as an anomaly, 0.5 marks for units.)*

   (c) Again, just plugging numbers in. The magnitude is required, so $|\Delta\rho| = 0.4$, and I make it that $b = 4/1000 = 4 \times 10^{-3}$ m s^{-2} (this is an acceleration).

   (1 mark for the value of b, 1 mark for giving answer in the right accuracy and in the form requested.)

   (d) This is a trick question of sorts and most of the information are irrelevant: there is no buoyancy force in the along-isopycnal direction, so the answer is zero. The associated buoyancy force would be the above buoyancy acceleration multiplied by density and volume, which ends up being 4 N.

   (2 marks for the answer, give 1 mark if some calculation leading to 4 N *was carried out leading to that value of force.)*

2. Have to just be a bit careful with whether we are in the Northern or Southern hemisphere for the geostrophic balance, Ekman upwelling and the cyclonic/anti-cyclonic, but otherwise the answers are as drawn on.

   (1) lower sea level in the center so green line $-\nabla p$ points into the eddy
   (2) Southern Hemisphere, so geostrophic flow to the left, and $\boldsymbol{u}_g$ points clockwise
   (3) clockwise flow is negative curl (hemisphere independent)
   (4) Southern Hemisphere so negative curl is cyclonic (coincides with eddy being a lower pressure zone)
   (5) (South of India) either that $\partial U/\partial y > 0$ so the curl being $-\partial U/\partial y$ means we have negative curl, or that any parcel of fluid is rotated clockwise, with is negative curl (hemisphere independent)
   (6) (East of India) anti-clockwise is positive curl and cyclonic in the Northern Hemisphere
   (7) (Wind near coast) Ekman flow pulls water away from coast since Northern Hemisphere, so this is Ekman upwelling
   (8) (South of India) Ekman flow is convergence in this case so is Ekman downwelling
   (9) (East of India) cyclonic eddy so divergence, so upwelling
   (10) (South of EQ) cyclonic eddy so divergence, so upwelling

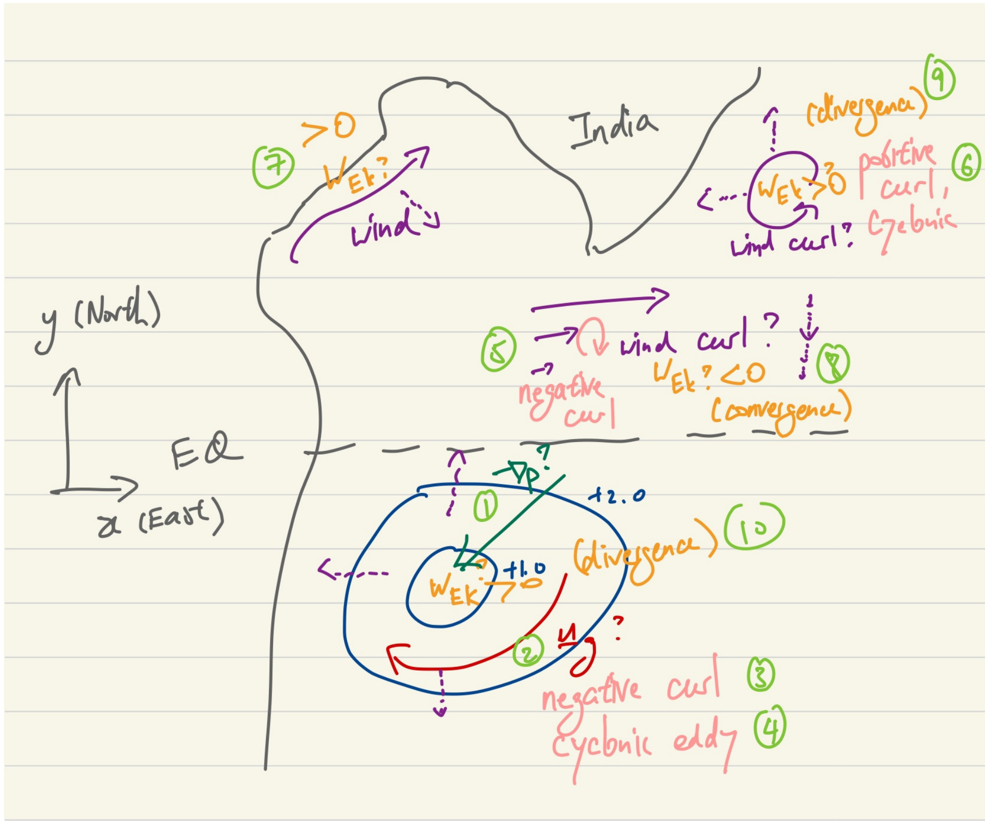

Figure 1: Also a high quality map.

(1 mark for each answer as marked on in figure; list produced for completeness. Only give marks if some sort of explanation is given, otherwise only give 0.5 marks.)

3. The Wikipedia article on cabelling is actually pretty good. Cabelling is a case where you mix two water-masses of the same density (but different temperature and salinity constituents) but you end up getting something else, because of the nonlinear equation of state; see diagram below. You cannot get this kind of case in a linear equation of state by pictorial arguments essentially, since any mixing of two analogous water parcels will always lead to something with the same density. A hypothetical but not entirely realistic case would be where you curvature in the nonlinear equation of state goes the other way (see diagram); then what you get is mixing that leads to a *lighter* watermass, which does not help with deep water formation.

   (1 mark for some attempt at explaining cabelling as long as there is some citation to a source, 1 mark for being explicit about mixing of watermasses with same density but different temperature and/or salinity constituents, 1 mark for some argument regarding linear EOS, 1 mark for constructing some valid nonlinear EOS where mixing leads to lightening.)

!? (No marks bonus question.) The paper by Gerkema *et al.* (2008) in Review of Geophysics is pretty comprehensive about the traditional approximation. More recent works include those of

- Colin de Verdière (2012), Journal of Physical Oceanography

- Tort *et al.* (2016), Journal of Fluid Mechanics
- Yano (2017), Journal of Fluid Mechanics
- Zeitlin (2018), Physics of Fluids.