**Question 1: Vorticity**

2a) Briefly describe the physical meaning of planetary, relative, absolute and potential vorticity.

2b) The following eddy is located at 35°S:

![Diagram of eddy with vorticity vectors](image)

i) Calculate and describe what happens to the relative, planetary and absolute vorticity if the eddy moves to 60°S? What quantity is conserved?

ii) What happens to the relative, planetary and absolute vorticity if the eddy moves to 60°N?

2c) Say that the eddy at 35°S is in water 500m deep and moves into water 100m deep. Assuming that the eddy has not changed latitude, calculate the eddy’s new relative vorticity. What quantity has been conserved?

**Question 2: Ekman motion (you will need your Assignment 2 Matlab plots to answer these questions)**

3a) Ekman motion in NCEP observations

i) In 1 paragraph, describe the main features of the observed u-component of the wind stress (NCEP). Be sure to explicitly reference your figures in your discussion.

ii) Calculate (by hand) the Ekman layer velocities at the following points: a) 15°S, 250°E; b) 50°S, 100°E. For these calculations, you may assume that $K=0.1m^2s^{-1}$, $\rho=1000kgm^{-3}$, but you must calculate $f$ yourself.

iii) Calculate (by hand) the vertical Ekman pumping velocity in the following regions: a) 15°-25°S, 250°E; b) 50°-60°S, 100°E. For these calculations, you may assume that $\rho=1000kgm^{-3}$, 1° of latitude=111km, and you may use the same values of $f$ from part...
ii). You may also assume that there is no gradient in the v-component of the wind-stress.

iv) Would you expect a biological response in any of these three regions? If so, what would it be?

3b) Comparison of observed and simulated Ekman motion
   i) In 1 paragraph, compare the main features of the u-component of the wind stress between the observations (NCEP) and the two models. Which model does the best job of reproducing the wind-stress?

   ii) Using the same regions in 3aii), calculate the Ekman layer velocities in both CSIRO and NASA models. Describe how the velocities differ between the models and the observations. You may use the same values of $K$, $\rho$, and $f$ as in 3aii.

   iii) Using the same regions in 3aiii), calculate vertical Ekman velocities in both CSIRO and NASA models. You may use the same values of $\rho$, and $f$ as in 3aiii and assume there is no gradient in the v-component of the wind stress. How does the vertical Ekman velocities differ between the observations and the two models? How does this affect the biological response in the three regions?

3c) Future projections of Ekman motion: In ~2 paragraphs, qualitatively compare how u-wind stress and associated Ekman motion is projected to change over the next century between the two models. How does the amplitude of the changes compare to the amplitude of the mean u-wind stress itself? Has the biological response changed between the end of the 20th and 21st centuries in these 2 regions? If so, how and why?

Question 3: Ocean Waves

4a) The phase speed for a surface wave is given by:

$$c = \sqrt{\frac{g\lambda}{2\pi} \tanh \left( \frac{2\pi h}{\lambda} \right)} \quad (1)$$

Derive the shallow and deep-water approximations of $c$.

4b) Consider the diagram below showing a set of wave crests approaching the coast. The topography of the shoreline is sketched.
i) Using the shallow water approximation, calculate the phase speed $c$ of the surface waves at points A, B, and C.

ii) Explain what happens to the waves crests they approach the coast.

iii) Assuming the waves travel with constant frequency $\omega = \frac{2\pi}{T}$, with $T$ (period) = 20 seconds, calculate the wavelength at points A, B and C (you will need the values for $c$ obtained in (i) above). What happens to the wavelength of the surface waves as they approach the coast?

4c) Two storms are affecting the Australian coastline. The first storm is located 100km offshore of Sydney and generates waves of wavelength 15 m. The second storm is located 75 km offshore of Perth and generates waves of wavelength 10 m. Calculate which waves will reach land first.