Candidates are admitted to the examination room ten minutes before the start of the examination. On admission to the examination room, you are permitted to acquaint yourself with the instructions below and to read the question paper.

Do not write anything until the invigilator informs you that you may start the examination. You will be given five minutes at the end of the examination to complete the front of any answer books used.

April 2010

Answer Book
Data Sheet
Figure(s)
Any bilingual English language dictionary permitted
Calculators and programmable calculators are permitted

THE UNIVERSITY OF READING

MSc/Diploma
Course in Atmosphere, Oceans and Climate

Course in Applied Meteorology

Course in Mathematics
and Numerical Modelling of the Atmosphere and Oceans

MTMG21

Oceanography

Two hours

Answer **ANY TWO** questions

The marks for the individual components of each question are given in **[ ]** brackets. The total mark for the paper is 100.

1. The purpose of this question is to better understand the role of compressibility effects on density relative to thermal and saline effects.

We consider an ocean for which the equation of state is assumed to be a linear function of temperature, salinity and pressure, as follows:

$$\rho = \rho_0 \left[1 - \alpha(T - T_0) + \beta(S - S_0) + \gamma(P - P_a)\right] \quad (1)$$

The parameters are: ρ_0=1020 kg.m^{-3}, α=10^{-4} K^{-1}, β=0.8 10^{-3} (‰)$^{-1}$,

γ=5.10^{-10} Pa^{-1}, T_0=15^{o}C, S_0=35 ‰. P_a denotes the atmospheric pressure. We assume that locally, the temperature and salinity vary linearly with depth such that:

$T(z) = T_0 + \Gamma_t z$,

$S(z) = S_0 + \Gamma_s z$,

with Γ_t= 2^{o}C/km, and Γ_s= - 0.05 ‰/km.

(a) Assuming all other quantities fixed, compute the differences ΔT, ΔS, and ΔP required to induce a density change $\Delta\rho$=1kg.m^{-3}.

[9 marks]

Question 1 continues overleaf

Question 1 continued

(b) The ocean surface and ocean bottom are assumed to be located respectively at z=0 and z=-H, with H=4000 m.

(i) Write down the equation for hydrostatic balance **[4 marks]**

(ii) Compute a first order approximation of the hydrostatic pressure P(z) as a function of z by integrating the hydrostatic balance equation with the constant density ρ_0. Derive a first estimate for the hydrostatic pressure at the ocean bottom. **[4 marks]**

(iii) Show that by integrating the hydrostatic balance equation using Eq. (1) for density, taking into account vertical variations of T and S, as well as the approximate form of pressure derived in (i), a more accurate expression for the hydrostatic pressure is:

$$P = P_a - \rho_0 g z + \rho_0 g \left[\alpha \Gamma_t - \beta \Gamma_s + \rho_0 g \gamma \right] \frac{z^2}{2}$$

Evaluate your expression at the ocean bottom. **[7 marks]**

(iv) Evaluate the accuracy of treating ρ as a constant as compared with taking full account of the vertical variations of ρ in the estimation of the hydrostatic pressure at the ocean bottom. Express the error as a percentage. **[6 marks]**

(c) By using the information about the temperature and salinity profiles, and using your answer from question (b),

(i) Estimate the density at the surface and bottom, and hence the density difference between the surface and bottom. **[5 marks]**

(ii) Calculate the magnitude of the pressure effect on the computed density difference. **[5 marks]**

Question 1 continues overleaf

Question 1 continued

(d) This question aims at understanding the effect of compressibility on the height of the water column.

(i) Consider first the following problem: Two kilograms of water lying in a container of surface area 1 m^2 satisfy the above equation of state for $T=T_0$, $S=S_0$, and $P=P_a$. Estimate the height of the water column above the bottom of the container. **[3 marks]**

(ii) Assume that we are able in some ways to remove the compressibility effects in the above equation of state. Estimate the consequence of this on sea level by assuming that the mass of the water column does not vary in the experiment. Will the sea level increase or decrease? Calculate an estimate for the sea level change. **[7 marks]**

2. Observations of the oceans

(a) Define the term geoid, and describe qualitatively the reasons for its shape.

[5 marks]

(b) Write down the equations for geostrophic and hydrostatic balance for the oceans, defining each of the symbols involved.

Hence, show that the geostrophic velocity at the surface can be inferred from:

$$u = -\frac{g}{f}\frac{\partial \eta}{\partial y}, \quad v = \frac{g}{f}\frac{\partial \eta}{\partial x}$$

where η is the elevation of the free surface relative to the geoid, and where all other symbols have their usual meaning.

[10 marks]

(c) State whether the sea level is raised or lowered in the centre of a subtropical gyre and explain your answer in less than 100 words?

Assuming typical values for the various parameters, estimate the accuracy to which an altimeter must be able to measure the sea surface elevation in order to make meaningful estimates of the circulation within the interior of a subtropical gyre.

[10 marks]

(d) Say whether satellite altimetry is of more use for inferring the time-mean or the time-varying surface, and explain your answer.

[5 marks]

Question 2 continues overleaf

Question 2 continued

(e) Write down the equations of thermal wind balance in the oceans.

Hence show that the geostrophic velocity can be inferred from hydrographic data through the relations:

$$u = u_{ref} + \frac{g}{\rho_0 f} \int_{z_{ref}}^{z} \frac{\partial \rho}{\partial y} dz'$$

$$v = v_{ref} - \frac{g}{\rho_0 f} \int_{z_{ref}}^{z} \frac{\partial \rho}{\partial x} dz'$$

Clearly define each of the symbols in these relations.

[10 marks]

(f) Briefly discuss the kind of observations one could use to constrain the unknown level of no motion.

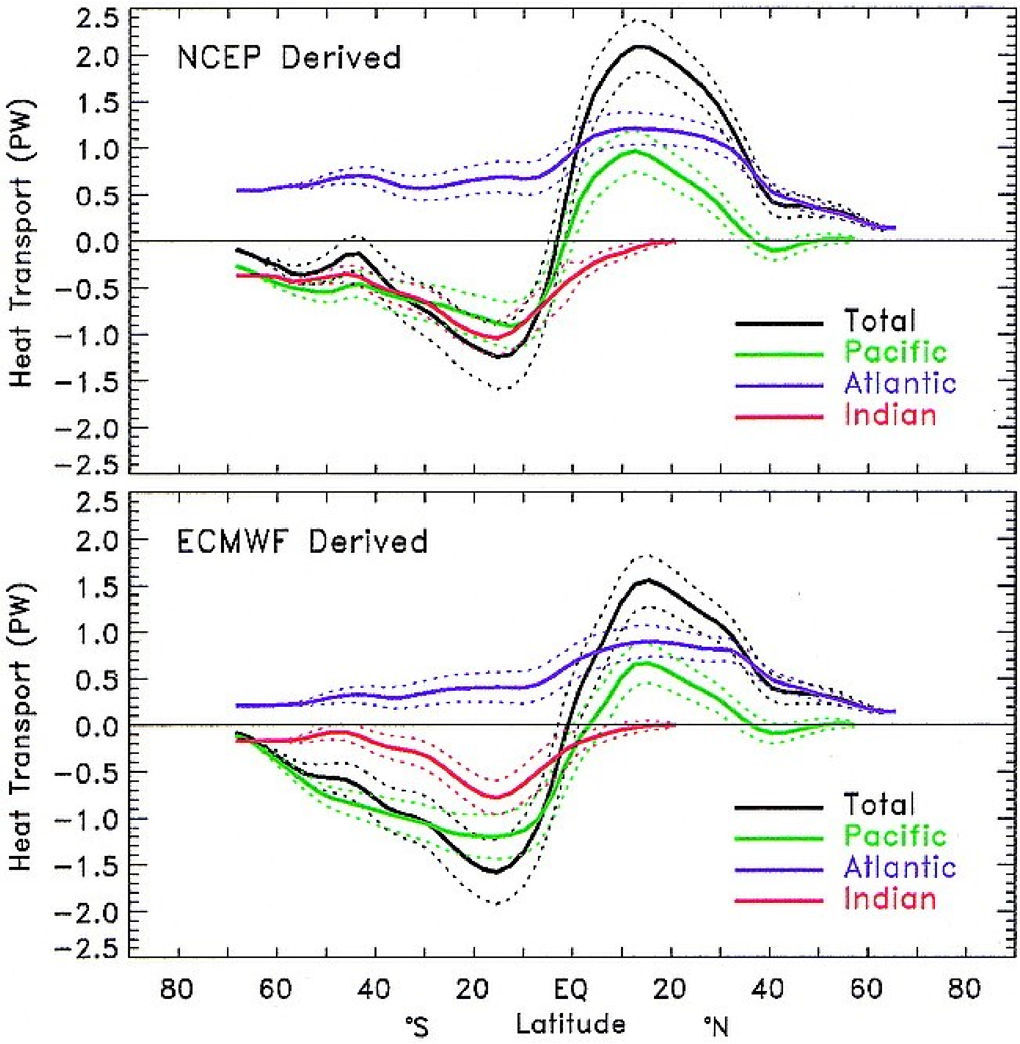
[10 marks]

Turn over

3. This question relates to general knowledge about the ocean circulation.

(a) Briefly discuss the major challenges in attempting to observe the large-scale ocean circulation. How do these challenges differ from those faced in attempting to observe the atmosphere? **[10 marks]**

(b) The following graphs shows estimates of the meridional heat transport in the major ocean basins using two different kind of datasets.



From the two graphs, estimate the error bars in estimating the ocean heat transport. Briefly discuss the extent to which these distributions can be understood in terms of the wind-driven circulation and thermohaline conveyor belt. **[10 marks]**

Question 3 continues overleaf

Turn over

Question 3 continued

(c) Give a physical explanation for the existence of a sound channel at a depth of approximately 1 km in the ocean.

Explain how this sound channel might be exploited to measure future changes in the large-scale structure of the oceans.

[10 marks]

(d) Briefly discuss the importance of upwelling/downwelling for the fishing industry and discuss this in the context of El Nino/La Nina episodes. **[8 marks]**

(e) Describe the most likely scenarios for the thermohaline circulation over the next century.

Your answer should include brief discussion of the underlying physical mechanisms, projections from state-of-the-art climate models, and discussion of any observational evidence for changes in the thermohaline circulation already underway. **[12 marks]**

(End of Question Paper)