On admission to the examination room, you should acquaint yourself with the instructions below. You must listen carefully to all instructions given by the invigilators. You may read the question paper, but must 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 2016 **MTMG21/2015/6/A 001**

Answer Book
Data Sheet
Any bilingual English language dictionary permitted
Any non-programmable calculator permitted

UNIVERSITY OF READING

OCEANOGRAPHY (MTMG21)

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

   Hence show that the zonal geostrophic velocity as a function of depth is given by,

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

[10 marks]

   (b) Assume that the density of sea-water can be approximated by the expression:

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

   where $\alpha = 10^{-4}\mathrm{K}^{-1}$, $\beta = 0.8 \times 10^{-3}(\mathrm{g/kg})^{-1}$, and ρ_0, T_0 and S_0 are constant.

   A hydrographic section has been carried out in the meridional direction across the Antarctic Circumpolar Current. It is observed that horizontal temperature and salinity gradients are independent of height with a dependence on distance given by:

$$T - T_0 = A(y - y_0) \qquad \text{and} \qquad S - S_0 = B(y_0 - y)$$

   where y_0 is the location of the start of the section.

   Show that $u(z)$ is therefore given by the expression:

$$u(z) = u_{ref} - \frac{g}{f}(z - z_{ref})\left(\alpha A + \beta B\right)$$

[12 marks]

Question 1 continued overleaf

Question 1 contin'd

(c) If it is observed that $A = 2 \times 10^{-6}\text{K.m}^{-1}$, $B = 3 \times 10^{-7}(\text{g/kg}).\text{m}^{-1}$ and that the observed current at a depth of 4 km can be taken to zero, find the sea surface current.

[10 marks]

(d) Estimate the amount of energy (in Joules) necessary:

(i) to raise the sea level by 1 meter through uniform heating of the first 1 kilometer of the upper ocean.

(ii) to raise the sea level by 1 meter through melting land ice and dumping it into the ocean, assuming the temperature of the ice is $T = -20°\text{Celsius}$.

(iii) Show that the ratio of the former over the latter is approximately given by

$$r \approx \frac{\alpha c_p}{L_f}$$

(justify the assumptions made) and conclude as to which mechanism (thermal expansion or melting) is the most efficient for raising sea level.

Assume the following values: thermal expansion coefficient $\alpha = 10^{-4}\,\text{K}^{-1}$, heat capacity of water or seawater $c_p = 4000\,\text{J.K}^{-1}.\text{kg}^{-1}$, heat capacity of ice $c_{p,ice} = 2000\,\text{J.K}^{-1}.\text{kg}^{-1}$, surface area of the ocean $A_{ocean} = 3 \times 10^{14}\,\text{m}^2$, latent heat of fusion $L_f = 3.35 \times 10^5\,\text{J.kg}^{-1}$.

[18 marks]

2. A square ocean with solid boundaries located at $x = 0, L$ and $y = 0, L$ is exposed to a zonal wind stress at its surface,

$$\tau_s = -\tau_0 \cos\left(\frac{\pi y}{L}\right)\mathbf{i}$$

where $\tau_0 = 0.2\mathrm{N.m}^{-2}$, and **i** is the unit vector in the zonal direction.

(a) Write down the equation of Sverdrup balance.
Define a streamfunction ψ such that $\int_{-H}^{0} v\mathrm{d}z = \frac{\partial \psi}{\partial x}$.
Adopting suitable boundary conditions, show that

$$\psi = \frac{\pi\tau_0}{\rho_0\beta L}(L - x)\sin\left(\frac{\pi y}{L}\right).$$

Sketch $\psi(x, y)$.

[20 marks]

(b) By using the result of part (a), show that the maximum southward transport predicted by Sverdrup balance is:

$$T = \frac{\pi\tau_0}{\rho_0\beta}$$

and calculate T, giving your answer in Sverdrups
($\beta = 2 \times 10^{-11}\mathrm{m}^{-1}.\mathrm{s}^{-1}$).

[20 marks]

(c) Suppose that the gyre is closed by a frictional boundary current of width $\delta \sim r/\beta$ where $r = 10^{-7}\mathrm{s}^{-1}$.
Estimate a typical boundary current velocity (assume a typical value for the ocean depth).

[5 marks]

Question 2 continued overleaf

Question 2 contin'd.

(d) What would happen to the location of the western boundary current if the sign of the Earth rotation was reversed? (assuming everything else staying the same). Alternatively, if the Earth rotation was halved, would the total transport in western boundary currents increase or decrease? In each case, justify your answer.

[5 marks]

Turn over

3. Give a brief explanation (up to half a page) of each of the following. There is no need to give mathematical details, but your answers should describe the underlying physical principles in each case.

   (a) Why mesoscale eddy activity should not be neglected in ocean climate models, and how it can be accounted for.

   [10 marks]

   (b) Why the T-S properties of the ocean interior match those of the winter mixed layer.

   [10 marks]

   (c) Oceanographers use the term “ocean heat uptake” to refer to the increase in mean ocean temperature resulting from global warming. Using your knowledge of the ocean, discuss what you think are the important physical processes controlling ocean heat uptake.

   [10 marks]

   (d) Why is diapycnal mixing thought to be important in the ocean, and what are the main ways to estimate it?

   [10 marks]

   (e) What do oceanographers mean by the “spiciness” of seawater, and why is it important?

   [10 marks]

[End of Question Paper]