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 2011

Answer Book
General Data Sheet
Any bilingual English language dictionary permitted
Only Casio-fx83 calculators are permitted

THE UNIVERSITY OF READING

MSc Examination for Courses in Sciences

Global Circulation of the Atmosphere & Oceans

MTMW20

2 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. You are given that the Ekman mass flux in the vertical in both the oceans and atmosphere is

$$\rho w = \mathbf{k} \cdot \left(\nabla \times \frac{\boldsymbol{\tau}_s}{f} \right)$$

where $\mathbf{k}$ is a unit vertical vector, $\boldsymbol{\tau}_s$ the surface stress, w the vertical velocity, ρ the density, and f the Coriolis parameter.

(a) Why is this flux the same in both the atmosphere and ocean?

[5 marks]

(b) For a region with a lower tropospheric anticyclone, determine the sign of this mass flux and sketch the vertical circulations in the region in both the atmosphere and ocean.

[8 marks]

(c) For this same region, use the Sverdrup relation

$$\beta v = f \frac{\partial w}{\partial z}$$

to determine the meridional direction of the average oceanic flow below the boundary layer. Give an interpretation of the Sverdrup relation in this case as a vorticity balance.

[10 marks]

(d) Using the Ekman mass flux and the Sverdrup relation, and any additional typical scales and parameters that you should state, estimate the meridional mass flux per unit distance in longitude in the middle of the subtropical North Atlantic Ocean. You are given that $\boldsymbol{\tau}_s = \rho c_D |\mathbf{v}| \mathbf{v}$, where the notation is standard.

[23 marks]

(e) Using the result of (d) and taking a typical zonal scale, estimate the meridional flux of mass in the subtropical North Atlantic.

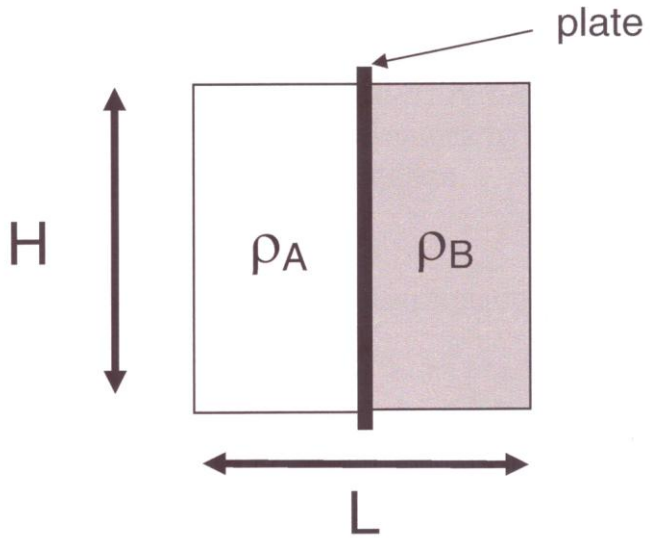
[4 marks]

2.

(a) (i) Sketch the meridional distribution of Absorbed solar radiation, Outgoing Longwave radition and Net radiation at the top of Earth's atmosphere. [5 marks]

(ii) Describe the meridional flux of energy that this distribution of Net radiation implies. Include in your answer an estimate of the peak flux of energy and a description of its location. [7 marks]

(b) (i) A three-dimensional box of dimension LxL and depth H is filled with two fluids of different density ρ_A and ρ_B where fluid B is denser than A. The two fluids are separated by a solid plate and arranged as shown in the diagram:



Assuming incompressibility, and therefore neglecting internal energy, derive an expression for the total (gravitational) potential energy present in the system. [6 marks]

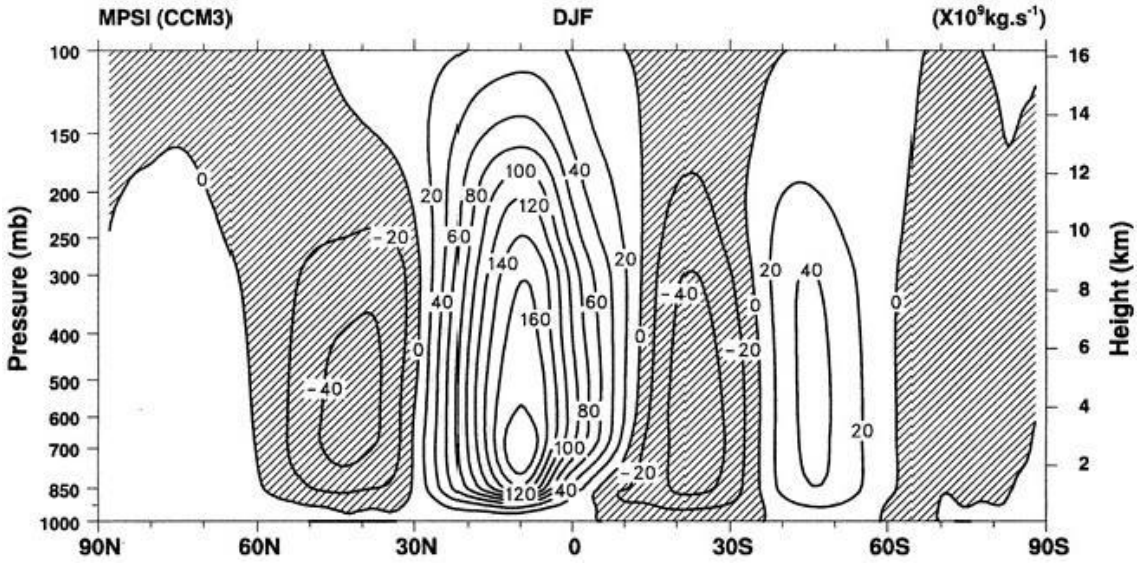
(ii) When the plate is removed, the fluid will re-arrange itself to a more stable state. Derive an expression for the total (gravitational) potential energy in the final stable equilibrium configuration. [4 marks]

(iii) By combining your answers to (i) and (ii), derive an expression for the available potential energy in the initial configuration. [6 marks]

Question 2 continues overleaf

Question 2 continued

(c) The figure shows the average meridional mass streamfunction for the DJF season. The contour interval in the figure is 20×10^9 kg.s^{-1}.



(i) Describe the locations of the Hadley and Ferrel cells in the figure. [2 marks]

(ii) If the mass of the atmosphere in the tropical belt is 2.6×10^{18} kg, estimate the minimum time, in days, it would take for the Hadley circulation to overturn an equivalent mass. [4 marks]

(iii) If the meridional mass streamfunction is averaged on isentropic surfaces rather than pressure surfaces a different picture of the circulation emerges. Describe and explain the differences in the diagnosed circulation revealed using isentropic averaging. [4 marks]

Question 2 continues overleaf

Question 2 continued

(d) (i) Estimate the total energy per unit mass of an air parcel in the sub-tropical jet at the edge of the Hadley circulation. Assume that the parcel has zero specific humidity, negligible meridional and vertical motion and is at a temperature of -70^{o}C. [3 marks]

(ii) Assume the air parcel followed the mean meridional streamlines shown in question (c), conserving its energy during its transit. Estimate the specific humidity of the parcel close to the ground at the equator. You may ignore variations in density. [5 marks]

(iii) The Hadley circulation as a whole can be viewed as an atmospheric flow in which various energy conversions take place. Describe two processes which transfer energy to the atmosphere in the Hadley circulation and the form of atmospheric energy which is increased during the transfer. [4 marks]

3. Describe briefly any four (4) of the following atmospheric phenomena and processes, indicating physical mechanisms and/or competing theories as far as is applicable:

(a) The Quasi-Biennal Oscillation (QBO)

(b) The Madden-Julian oscillation

(c) The Asian Summer monsoon

(d) El Nino Southern Oscillation (ENSO)

(e) Atmospheric blocking

Credit will be given for explanation and informative sketches. Each topic carries the same mark.

[50 marks]

(End of Question Paper)