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 2014 **Answer Book**

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

UNIVERSITY OF READING

MTMW20 (Global Circulation of the Atmosphere & Oceans)

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) You are given that $\overline{v'T'}$ is a diagnostic for an extratropical storm track.

Define all the symbols in this expression. What is the significance of a northern hemisphere maximum in $\overline{v'T'}$ for

(i) the growth of weather systems?

(ii) the climate system?

[10 marks]

(b) Discuss the oceanic and atmospheric factors that are thought to be important in determining the existence, longitudinal structure, and seasonality of the North Atlantic storm track.

[20 marks]

(c) Based on theoretical ideas concerning the impact of baroclinicity and moist processes, give brief arguments that suggest how the North Atlantic storm track may change with global warming.

[10 marks]

(d) Give a physical argument, supported by a sketch, why extratropical storms act to reinforce the midlatitude jet through eddy zonal momentum fluxes. Explain how this is connected to Rossby-wave propagation.

[10 marks]

2. (a) Starting from the horizontal momentum equation in the steady-state form $\rho f\, \boldsymbol{k}\times\boldsymbol{v} + \nabla p = \partial \boldsymbol{\tau}/\partial z$, show that the ageostrophic 'Ekman' mass transport in the atmosphere is $\boldsymbol{M}_{\mathrm{Ek}} = f^{-1}\, \boldsymbol{k} \times \boldsymbol{\tau}_{\mathrm{S}}$ where $\boldsymbol{\tau}_{\mathrm{S}}$ is the surface stress. Also derive the corresponding expression for this mass transport in the ocean.

[15 marks]

(b) From the mass conservation equation in steady-state form,

$\nabla\cdot(\rho\boldsymbol{v}) + \partial(\rho w)/\partial z = 0$, show that the vertical motion at the top of the atmospheric boundary layer is given by $\rho w = \boldsymbol{k}\cdot[\nabla\times(\boldsymbol{\tau}_s/f)]$, and that the same expression also applies at the bottom of the oceanic boundary layer.

[8 marks]

(c) For the case of tropical easterly and midlatitude westerly surface winds, draw a sketch indicating the direction of the horizontal Ekman flux and associated vertical motion in the atmosphere and ocean.

[7 marks]

(d) From the Sverdrup relation $\beta v = f\,\partial w/\partial z$ and using results from the Ekman theory obtained in 2(a,b,c), explain briefly why there is a southward flux of water in the middle of the northern hemisphere oceanic subtropical gyres.

[5 marks]

(e) Taking a typical latitudinal length scale for a subtropical oceanic gyre, typical atmospheric horizontal velocities across the gyre and an approximate value of the atmospheric drag coefficient, estimate the value of the vertical velocity w at the bottom of the oceanic boundary layer.

Hence, taking a typical depth of the ocean, estimate the equatorward flow v in the ocean.

[15 marks]

3.(a) Discuss very briefly what is meant by

(i) the Hadley cell in the atmosphere;

(ii) the thermohaline circulation in the ocean.

[6 marks]

(b) Given that the mass flux in the Hadley cell has magnitude 6×10^{10} kg s^{-1}, that the lower branch at 1 km altitude has typical temperature 20°C and humidity 12 g/kg, and the upper branch at 13.5 km altitude has temperature -60°C and negligible humidity, evaluate the poleward moist static energy flux due to the Hadley cell.

[12 marks]

(c) Given that the volume flux in the thermohaline circulation is 20 Sv (1 Sv = 10^6 m^3 s^{-1}), estimate the northward energy flux due to this circulation in the northern hemisphere, assuming that the difference in temperature between the upper and lower branches is 6°C.

[7 marks]

(d) Discuss the sources and sinks of angular momentum, and the relation to the zonal flow, in (i) the lower and (ii) the upper branches of the Hadley cell.

[15 marks]

(e) Discuss briefly some of the physical processes that are relevant for driving the thermohaline circulation.

[10 marks]

[End of Question paper]