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.

DO NOT REMOVE THIS QUESTION PAPER FROM THE EXAM ROOM.

April 2016 **MTMG19/MT4YD / 2015/16/ A001**

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

UNIVERSITY OF READING

Tropical Weather Systems (MTMG19)

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) List 5 criteria that must be satisfied in order for a tropical cyclone to form. By considering these criteria, discuss the geographical regions where tropical cyclones are most likely to be observed

[10 marks]

(b) Explain why the presence of a monsoon system over the Indian region during northern hemisphere summer means that tropical cyclones are not likely to develop in the northern Indian Ocean during this period.

[5 marks]

(c) Explain the meaning and physical significance of the quantity:

$$\mathrm{CAPE} = \int_{p_1}^{p_2} R_d \left(T_p - T_e\right) d(\ln p)$$

[5 marks]

(d) Convection takes place over ocean with a surface temperature of 26°C. If the surface relative humidity is 80% and the surface pressure is 1000 hPa, draw the profile of temperature you would expect to observe within the convective cloud on the tephigrams provided. Now suppose the surface pressure falls to 900 hPa in the centre of the cyclone. The sea-surface temperature remains the same but the boundary layer is now saturated. Estimate the difference in CAPE between the two profiles (you may assume the tropopause is at 200 hPa). Explain the relevance of your result to tropical cyclone formation.
Remember to hand in your tephigram with your answer sheet.

[15 marks]

(e) Outline the WISHE theory of tropical cyclone intensification.

[15 marks]

2.

(a) The *Held and Hou* model gives a simple numerical description of the Hadley cell, allowing calculations of the meridional extent and strength of the overturning circulation.

What are the 5 main assumptions upon which the Held-Hou model is based?

[10 marks]

(b) Draw a sketch of the zonal mean tropical potential temperature (θ) distribution in both the initial equilibrium state and the new state determined by the presence of the Hadley cell.
State how both distributions are related to distance from the equator (y).
Indicate on your sketch the poleward limit of the Hadley cell and explain briefly why the Hadley cell cannot extend beyond this latitude.

[10 marks]

(c) The Held and Hou model predicts that the northward extent of the Hadley cell will be given by:

$$Y = \sqrt{\frac{5\Delta\theta g H}{3\Omega^2 \theta_0}}$$

where $\Delta\theta$ is the pole to equator temperature gradient, H is a scale height for the troposphere, θ_0 is a mean value of potential temperature for the troposphere and the other symbols have their usual meanings.
By putting in typical values for the above variables, calculate the northward extent of the Hadley cell (expressed in terms of latitude) if the rising branch is located at the equator.
Comment on the magnitude of your answer relative to the observed extent of the Hadley cell.

[10 marks]

(d) The zonal mean picture of the Hadley cell masks a lot of zonal asymmetries. State where you would expect the major rising branches of the Hadley cell to be during the northern hemisphere summer season.

[5 marks]

(e) Over the African continent, another complication to the simple view of the Hadley Circulation is the presence of the African Easterly Jet (AEJ). Describe the origins of the AEJ in terms of surface temperature.
Assuming that the July surface temperature of the Sahara at 25°N is around 35°C and in the Gulf of Guinea is approximately 26°C, use the equation for thermal wind balance as below to calculate the strength of the jet and state any assumptions you make.

$$\frac{\partial u}{\partial p} = \frac{R}{pf}\frac{\partial T}{\partial y}$$

Describe the other zonal jet structure over the West African region during summer and mention briefly its impact on the West African Monsoon.

[15 marks]

3.

(a) The mean state of the atmospheric circulation and ocean temperature distribution in the equatorial Pacific occurs as the result of strong coupling between the atmosphere and ocean. Use sketches and describe the mean state of the atmosphere and ocean in this region during both normal and El Niño conditions.
Explain the positive feedback process that is involved in both the maintenance of normal conditions and in the growth of an El Niño event.

[25 marks]

(b) In the delayed oscillator model of El Niño by Suarez and Schopf, the development of the NINO3 SST anomaly *T* is described by the following equation:

$$\frac{\mathrm{d}T}{\mathrm{d}t} = \alpha T - \beta T(t-\gamma) - \varepsilon T^3$$

Where α, β, γ and ε are constants and $T(t\text{-}\gamma)$ is evaluated at time $t\text{-}\gamma$. State what each of the terms on the right-hand side of this equation represents.

What physical process does the γ in the second term describe?

Given this equation, describe how the termination of an El Niño event is brought about in the Delayed Oscillator model.

[10 marks]

(c) Given what you know of sea-surface temperature variability in the east Pacific Ocean, comment on whether the Delayed Oscillator Model is a sufficient description of the observed variability.

[5 marks]

(d) The Madden-Julian Oscillation (MJO) is an intraseasonal oscillation typically found in the Indian Ocean and West Pacific. Describe the impact of a passing MJO on the West Pacific and hence how the phenomenon might be related to the onset of an El Niño event.

[10 marks]

(End of Question Paper)