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
Tephigram
Any bilingual English language dictionary permitted
Calculators and programmable calculators are permitted

Final Examination for MSc

Course in Applied Meteorology
Course in Atmosphere, Oceans and Climate

MTMG19

Tropical Weather Systems

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) In parts of the Tropics, annual rainfall accumulations of 2000 mm are not uncommon. Calculate the latent heating rate generated by this amount of precipitation (in Wm^{-2}).

[5 marks]

If this rainfall is generated by condensation in convective clouds which extend through the depth of the troposphere, calculate a tropospheric heating rate in K per day.

[7 marks]

What is the main physical process that balances this condensational heating in the deep convective regions of the Tropics?

[3 marks]

(b) Define the meaning of the term *equivalent potential temperature* θ_e, and explain why it is a useful concept in tropical meteorology. For an air parcel at 1000 hPa with a temperature of 25°C and a specific humidity of 16g/kg, use the tephigram provided AND a numerical method to calculate the equivalent potential temperature of the parcel. Comment on any discrepancy between the 2 results you have obtained.

[13 marks]

Precipitating convective clouds produce downdrafts. What is the main mechanism responsible for generating such convective downdrafts?

[2 marks]

Draw a sketch of the typical vertical profile of θ_e in the tropical atmosphere. Use this sketch to explain why downdrafts which extend down to the surface generally originate from the mid to lower troposphere.

[6 marks]

Question 1 continues overleaf

Question 1 continued

(c) List 5 necessary conditions for the formation of a tropical cyclone. [6 marks]

Describe the WISHE mechanism of tropical cyclone intensification. You may wish to use a flow diagram to illustrate your answer. [8 marks]

2.

(a) Describe briefly the nature of the *Inter-tropical convergence Zone (ITCZ)*. Use hydrostatic balance to show that, over the tropical oceans, there will be a meridional over-turning circulation (the Hadley cell) with rising motion within the ITCZ and sinking motion at some higher latitude, linked by low level winds blowing into the ITCZ and upper level winds blowing away from the ITCZ. [20 marks]

(b) 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]

Angular momentum M is defined by

$$M = [\Omega a \cos\phi + u] a \cos\phi$$

Where Ω is the Earth's rotation rate, a is the earth's radius, ϕ is the latitude and u is zonal wind speed.

By applying conservation of momentum, show that the zonal velocity of an air parcel in the upper branch of the Hadley Cell starting at the equator with no zonal velocity must have a zonal velocity given by $\Omega y^2/a$ at a distance y north of the equator. [10 marks]

Question 2 continues overleaf

Question 2 continued

(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 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]

3.

(a) Describe the main characteristics (spatial scale, structure, seasonality, propagation speed and direction and longitudinal variation) of the *Madden-Julian Oscillation (MJO)*. Use one or more sketches to illustrate your answer.

What are the major impacts of the MJO on weather patterns around the globe?

[20 marks]

Question 3 continues overleaf

Question 3 continued

(b) It has been proposed that coupling between the atmosphere and ocean surface may act to enhance the eastward propagation of the MJO. Describe briefly, using sketches to illustrate your answer, how such a mechanism might operate.

In the clear sky/light wind region to the east of the MJO convection, latent heat flux due to evaporation from the sea surface is typically reduced by about $25 Wm^{-2}$, and solar heating of the sea surface is typically increased by about $10 Wm^{-2}$. If these flux anomalies are applied evenly through a 20 metre depth of ocean for a period of 10 days, calculate the sea surface temperature (SST) anomaly that would result. Comment on the magnitude of your answer relative to the observed SST anomalies associated with the MJO.

[20 marks]

(c) Describe how successive MJO events may be able to influence the state of the tropical Pacific ocean, even to the extent of initiating the onset of an El Niño event.

[10 marks]

(End of Question Paper)