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 2009

Answer Book
Data Sheet
Map for use with Q1
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. To quite a good approximation the large-scale, mean wind patterns in the Tropics can be reproduced by applying the Shallow Water Equations on an equatorial β-plane and forcing with a pattern of heating which corresponds to the release of latent heat in the main regions of tropical deep convection.

   (a) Figure 1, provided with this paper, shows observed near-surface wind vectors for the month of December. Clearly *sketch on this map* the geographical distribution of latent heating in deep convection that you would expect to lead to this pattern of winds, and write a short statement justifying your sketch. State which aspects of the observed wind pattern would *not* be reproduced by forcing the Shallow Water Equations with tropical latent heating by deep convection. [15 marks]

   (b) The equations below are the Shallow Water Equation set applied on an equatorial β-plane.

$$\frac{\partial u'}{\partial t} - \beta y v' + \frac{\partial \Phi'}{\partial x} = 0, \quad \frac{\partial v'}{\partial t} + \beta y u' + \frac{\partial \Phi'}{\partial y} = 0 \quad \text{momentum equations}$$

$$\frac{\partial \Phi'}{\partial t} + c_e^2 \left[\frac{\partial u'}{\partial x} + \frac{\partial v'}{\partial y} \right] = H \quad \text{thermodynamic/continuity equation}$$

   List the approximations and simplifications which are made in order to reach this set of equations.
   State what the term c_e represents in the thermodynamic/continuity equation. How would you expect an increase in the static stability of the tropical atmosphere to affect this term? [15 marks]

   (c) By setting *H* and *v'* to zero in the above equations, show that the simplest possible solution to the Shallow Water Equations takes the form of a wave equation which will have solutions of the form;

$$u' = \hat{u}(y) e^{ik(x-ct)} \quad \text{where} \quad \hat{u}(y) = u_0 e^{\frac{-\beta y^2}{2c}}$$

   Sketch a plan view of the pattern of wind and geopotential height anomalies described by this solution and state how you would expect these anomalies to propagate. [20 marks]

2.

(a) Describe the particular combination of factors that lead to the generation of monsoon climates in the Tropics. Given these factors, state where and at what time of year monsoons actually occur in the Tropics. [10 marks]

(b) The **Indian** and **West African** monsoons have quite different characteristics despite being the result of the same basic driving mechanism. Discuss the factors that lead to the very different nature of these two monsoon systems. What are the main causes of sub-seasonal variations in rainfall in these two monsoons? [20 marks]

(c) Seasonal forecasts of the strength of the Indian Monsoon are made each year by the Indian Meteorological Department (IMD) in April prior to the monsoon onset. Describe briefly the method used to produce these forecasts. There is no need to list the specific parameters used.

Three of the parameters used in the IMD seasonal forecast model are;

1. NINO3 SST anomaly during the previous summer
2. Eurasian snow cover during the preceding December
3. Arabian Sea SST during January and February prior to the monsoon

For each of these factors, state whether the correlation between it and the All India Rainfall total for the monsoon season is positive or negative. Describe the physical mechanism(s) that would lead to the observed relationship between each of these factors and the monsoon rainfall total. [20 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. Describe, using sketches where appropriate, the mean state of the atmosphere and ocean in this region and explain how atmosphere-ocean coupling is crucial to the state you have described.

[25 marks]

(b) An El Niño event can occur when the tight coupling between atmosphere and ocean in the equatorial Pacific breaks down. What process occurs which brings about this breakdown in coupling? Describe the subsequent sequence of events that then lead to the development of El Niño.

[15 marks]

(c) 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;

$$\frac{dT}{dt} = \alpha T - \beta T(t-\delta) - \varepsilon T^3$$

Where α, β, δ and ε are constants for the system.

State what each of the terms on the right-hand side of this equation represents.
What physical process does the δ in the second term encapsulate?

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

[10 marks]

(End of Question Paper)