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

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

UNIVERSITY OF READING

MSc/Diploma
Course in Atmosphere, Ocean and Climate
Course in Applied Meteorology
Course in Numerical Modelling of the Atmosphere and Oceans

Paper MTMG16

Climate Change

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) An expression for the global heat balance of the climate system is

$$\Delta Q = -Y\Delta T + \Delta F$$

where ΔQ is the net downward radiative flux at the top of the atmosphere, ΔT is the globally averaged surface temperature change from equilibrium, ΔF is the radiative forcing, and Y is the climate feedback parameter. With reference to the above, derive an expression for the surface temperature change at equilibrium ΔT_{eq}, and show how one can derive the climate sensitivity in terms of Y from your expression.

[4 marks]

(b) For each of the following four greenhouse agents, say whether their concentrations have increased or decreased since pre-industrial times, and state how much have they each contributed to the total greenhouse forcing ΔF, to the nearest 0.3 Wm^{-2}: (i) tropospheric ozone, (ii) methane, (iii) carbon dioxide (iv) Nitrous oxide

[8 marks]

(c) It can be shown for a simplified model that for a transient climate perturbation, the temperature perturbation $\Delta T(t)$ is given by

$$\Delta T(t) = e^{-Yt/C_s} \int_0^t \frac{\Delta F(t)}{C_s} e^{Yt'/C_s}\, dt'$$

Where C_s is the heat capacity of the system.
Show that the temperature response to a perturbation ΔF that is switched on at time t=0, and held constant thereafter, is given by

$$\Delta T = \Delta T_{eq}\left(1 - e^{-t/\tau}\right)$$

where $\tau = C_s/Y$ and ΔT_{eq} is the equilibrium temperature change.

SKETCH this solution for positive *and* negative values of ΔF.

[12 marks]

Question 1 continued overleaf

Question 1 continued

(d) In the year 2000, the concentration of water vapour in the stratosphere fell suddenly. If this fall can be approximated as a sudden change in radiative forcing of $\Delta F = -0.1 W/m^2$, and the heat capacity of the climate system C_s is approximated by

$$C_s = \rho\, d\, C_p$$

where ρ is density (1000 kg/m^3), d is ocean depth (50 m), and C_p = 4000 JK^{-1}kg^{-1}, what is the induced temperature change ΔT after 10 years for the following two cases: (i) the magnitude of Y is 1.5 Wm^{-2}K^{-1}, and (ii) the magnitude of Y is 1.0 Wm^{-2}K^{-1}?

[12 marks]

(e) If this change is simply superimposed onto a climate that is warming at a rate of 0.15K/decade, what is the new average warming rate per decade between 2000-2010 for each of the two values of Y?

[6 marks]

(f) The depth of the ocean chosen in (d) was only 50m despite the oceans being 3000m deep on average. Why is this appropriate?

[8 marks]

2. (a) Tide-gauge records indicate that global average sea level has been rising at around 1.8 mm yr^{-1} on average during the last 50 years. Since 1993, global average sea level has been monitored also by satellite altimetry, and during that period the rate of rise has been about 3 mm yr^{-1}. Suggest some possible reasons why these two rates are different.

[12 marks]

(b) In 1815 there was an explosive volcanic eruption on Tambora in Indonesia. The following year of 1816 is known as “the year without a summer” in Europe. Explain how these events are connected and why the unusual conditions lasted for a few years.

[12 marks]

(c) From the mid-1950s to the mid-1990s, glaciers in Alaska were observed to have got thinner (i.e. their surfaces became lower) on average by 0.52 m $year^{-1}$. If the total area of glaciers in this region is 100 000 km^2 and the area of the world ocean is 3.6×10^{14} m^2, what rate of global average sea level rise would be produced by the discharge of the meltwater into the ocean? This is about the same rate as the contribution to sea level rise from the Greenland ice sheet, which has an area more than ten times bigger. Why didn’t Greenland make a larger contribution than Alaska?

[6 marks]

(d) Comment on the validity of the following statement: “sea-ice is a negative feedback on climate change because ice is bright and reflects sunlight”

[8 marks]

(e) Comment briefly on the validity of the following statements about climate change (3 marks each)
(i) “The warming over the last 100 years is very unlikely to be due to internal variability alone”
(ii) “Carbon dioxide in the atmosphere has reached levels unprecedented in the last 400,000 years”
(iii) “As a consequence of global warming the thermohaline circulation will shut down, plunging Europe into a new ice age”
(iv) “Sea levels will rise by 88cm by 2100”

[12 marks]

3. (a) What are the general causes for the occurrence of *internal* climate variability? Give specific examples. What is the main source of predictability for the internal climate variability?

[12 marks]

(b) Imagine you are presented with a time-series of a meteorological quantity (e.g. precipitation) for which you do not know the measurement error. How would you proceed to decide whether the time-series displays real variability of the measured quantity? If you conclude it does, how would you attempt to further characterise it as climate variability?

[16 marks]

(c) Write the equation that describes the mass flux of oceanic water that is upwelling from the depth into the Ekman layer within one deformation radius from the Equator for a given easterly wind-stress $-\tau$. What is the effect of equatorial upwelling?

[6 marks]

(d) Now suppose that the wind-stress τ is proportional to the zonal gradient of the sea-surface temperature T, such that $\tau=\alpha\partial T/\partial x$, where x is the longitude. If H is the depth of the Ekman layer, and ΔT is the temperature difference between the surface and the deep water (assumed constant), write an expression for the phase speed of the temperature signal. What is its sign?

[10 marks]

(e) Describe the link between the process just discussed and the evolution of El Niño events.

[6 marks]

(End of Question Paper)