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 2013 **MTMG16**

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

UNIVERSITY OF READING

Climate Change Exam (MTMG16)

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) A simple radiative energy balance model of the Earth can be written: $(S/4)(1–\alpha)=\varepsilon\sigma T_s^4$. State the meaning of ALL symbols and explain what the left and right hand sides of the equation represent physically. [10 marks]

(b) If there is a decrease in the sulphate aerosol burden over cloud-free regions, which single term in 1(a) will be primarily affected before radiative equilibrium is restored and by what mechanism? [4 marks]

(c) Using the simple model in 1(a) and assuming initial radiative equilibrium, if absorbed solar radiation was increased from 240 Wm^{-2} to 243 Wm^{-2} how much will T_s have to rise to regain radiative equilibrium if $\varepsilon = 0.59$ and $\sigma = 5.67\times10^{-8}$ $Wm^{-2}K^{-4}$? [5 marks]

(d) Briefly explain what non-cloud atmospheric processes, not considered in this example, may amplify this temperature change? Provide an example. [4 marks]

(e) Using the equilibrium climate sensitivity equation, $\Delta T_s = \Delta F/Y$ and assuming a radiative forcing of 3 Wm^{-2}, calculate the ΔT_s assuming that Y is the sum of black body feedback (Y_{BB} which should be estimated from 1c), water vapour feedback ($Y_{WV} = –2$ $Wm^{-2}K^{-1}$) and cloud feedback ($Y_C =$ 1 $Wm^{-2}K^{-1}$). [6 marks]

(f) Observational evidence finds that cloud radiative effects were incorrectly attributed to cloud feedback. Instead cloud feedback is found to be close to zero and the observed changes are in fact related to an additional radiative forcing of +1 Wm^{-2} related to indirect effects of aerosol concentration decreases. Briefly explain the mechanism for radiative forcing from indirect aerosol effects on cloud. [6 marks]

(g) What effect would the new discovery have on the estimated equilibrium temperature change? Quantify the new equilibrium temperature change. [5 marks]

(h) Discuss how uncertainty in radiative forcings and radiative feedbacks may influence our understanding of climate change in relation to the last 150 years. What tools are used to attribute changes over this period? [10 marks]

2.

(a) If there is a positive imbalance in the energy budget at the top of Earth's atmosphere over a period of decades, where in the climate system does this excess energy go? Which is the most important energy sink and why? [6 marks]

(b) In the transient climate change equation (below), explain which terms describe the top of atmosphere energy imbalance and which term relates to heat capacity? What is the implication of a larger heat capacity for climate change?

$$\frac{d\Delta T(t)}{dt} = \frac{1}{C_S}[\Delta F(t) - Y\Delta \mathrm{T}(t)]$$

[6 marks]

(c) Using an integrating factor, the transient climate change equation may be expressed as:

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

Assuming that a positive radiative forcing is introduced at t=0 and remains constant thereafter, integrate the above equation and draw a graph illustrating ΔT as a function of time, t. Derive an expression for the time at which ΔT=2 K. What would ΔF < 2Y imply? [12 marks]

(d) Briefly discuss the implications for adaptation strategies of a smaller value of Y and a larger C_s. Which term(s) in the transient climate change equation may mitigation strategies influence? [6 marks]

(e) Why are we "committed" to continued sea level rise after greenhouse gas concentrations are stabilised? [6 marks]

(f) 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. Over the period 1993-2003 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. [8 marks]

(g) What effect does La Niña have on regional and global sea level? [6 marks]

3. Write a short (2-3 page) popular science article detailing the mechanisms which are thought to explain glacial cycles over the last million years. In particular, consider:

- Observational evidence for past glacial cycles [5 marks]

- Details of the primary mechanisms proposed by Milankovitch including what latitude and season is thought to be crucial [12 marks]

- What amplifying factors and continental configurations are necessary to determine the global climate response [8 marks]

Finish your article by discussing the role that the ocean is thought to have played in determining rapid climate change during recovery from the last glacial maximum, and what are the implications for future responses to global warming? [15 marks]

Additional marks will be awarded for the logical structure and clarity of the article. [10 marks]

[End of Question paper]