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 2014 **MTMG16**

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

UNIVERSITY OF READING

Climate Change (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) In a simple energy balance model with zero heat capacity, the outgoing longwave radiation $\varepsilon' \sigma T_s^4$ is balanced by the absorbed solar radiation $S(1-\alpha)/4$. Explain what ALL the terms represent.

[10 marks]

(b) Assuming $\alpha = 0.3$, $\varepsilon' = 0.6$, $\sigma = 5.67 \times 10^{-8}$ $Wm^{-2}K^{-4}$ and $T_s = 289$ K in (a), if S were to decrease by 5 Wm^{-2} calculate the change in T_s required to restore energy balance. Quantify the change in radiative forcing ΔF and describe a possible mechanism leading to this change.

[10 marks]

(c) From (b) calculate the black body feedback parameter (Y_{BB}, $Wm^{-2}K^{-1}$) where $\Delta T_s = \Delta F / Y_{BB}$

[3 marks]

(d) A water vapour feedback $Y_{WV} = -1.5$ $Wm^{-2}K^{-1}$ applies. What term in the energy balance model in (a) will be directly affected? Quantify the effect of introducing this feedback on the change in T_s as calculated in (b) and explain the physical mechanism. What evidence do we have for the existence and magnitude of Y_{WV}?

[9 marks]

(e) Using the transient climate change equation and the product rule below, assuming a steady decrease in radiative forcing $\Delta F(t') = kt'$ (where $k < 0$ Wm^{-2}yr^{-1} and $\Delta F = 0$ Wm^{-2} at time $t'=0$) work out an expression for $\Delta T(t)$ in terms of k, Y, C_s and t. Illustrate $\Delta T(t)$ with a diagram.

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

$$\int_0^t kt' e^{Yt'/C_s} dt' = kt \frac{C_s}{Y} e^{Yt/C_s} - \frac{kC_s}{Y} \int_0^t e^{Yt'/C_s} dt'$$

[6 marks]

(f) From your answer to (e) derive an expression for $d\Delta T(t)/dt$ and comment on the shape of the curve. Compute when $d\Delta T(t)/dt$ is equal in magnitude (positive or negative) to 0.05 K/decade (assume $k = -0.01$ Wm^{-2}yr^{-1}, $Y = 1.5$ Wm^{-2}K^{-1} and $C_s = 30$ Wm^{-2}K^{-1}yr). Under what conditions is $d\Delta T(t)/dt = c(d\Delta F(t)/dt)$ a reasonable approximation (where c is a constant)?

[12 marks]

2.(a) Explain why changes in solar radiation at 65^{o}N in northern hemisphere summer are thought to be important in determining the timing of glacial cycles. What mechanism explains the solar radiation changes and what amplifying feedbacks are involved? Why were there unlikely to have been glacial cycles 10 million years ago?

[12 marks]

(b) Why were sea levels around 120m lower during the last glacial maximum 20,000 years ago when global surface temperatures were around 5^{o}C cooler compared with today?

[4 marks]

(c) What is the approximate rate of sea level rise over recent decades? Why are we committed to continued sea level rise long after greenhouse gas emissions are stabilised?

[6 marks]

(d) The top of atmosphere energy imbalance has been estimated to be around 0.6 Wm^{-2}. If all of this energy flux is absorbed by the upper 300m of the ocean, what is the rate of warming per decade of the upper ocean? Assume volumetric heat capacity is 4.1x10^{6} J m^{-3} K^{-1}.

[4 marks]

(e) How much will sea level rise (mm/decade) due to thermal expansion of this ocean layer, given a volumetric thermal expansivity of 0.2x10^{-3} K^{-1}?

[2 marks]

(f) Projections of future sea level rise by 2100 range from around 0.3m to 1.0m. Describe how these projections are made and what are the two primary factors that determine this range?

[10 marks]

(g) A new mechanism is discovered by which ice sheets can melt much more quickly than previously thought. Describe briefly how these new processes may potentially be parametrized within climate models.

[4 marks]

(h) Describe how adaptation and mitigation may be applied to reduce the impacts of sea level rise.

[8 marks]

3. An analysis of global temperatures over the recent decade has shown little discernible global warming at the surface. Articles published in the press are reporting these results as evidence against human-caused warming of climate. Write a report for ministers on the evidence for human-caused climate change and the relevance of recent temperature trends in the last decade to policy on avoiding dangerous climate change. Your report should cover the following points:

(a) Explain the link between changes in radiative forcing over recent decades, surface temperature change and ocean heating

[10 marks]

(b) Detail evidence from observations and simulations that indicates warming of climate including the role of uncertainty

[10 marks]

(c) Discuss the role of natural, unforced variability in determining decadal changes in surface temperature

[10 marks]

(d) Outline plausible causes of the recent lack of warming and relevance for projections of future climate change

[10 marks]

(e) The report should be concise (a maximum of 4 sides of A4 should be sufficient), clearly written and with a logical structure

[10 marks]

[End of Question paper]