**On admission to the examination room, you should acquaint yourself with the instructions below. You must listen carefully to all instructions given by the invigilators. You may read the question paper, but must 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.**

**DO NOT REMOVE THIS QUESTION PAPER FROM THE EXAM ROOM.**

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**April 2016** **MTMG16 2015/16 A001**

**Answer Book**
**Any bilingual English language dictionary permitted**
**Any non-programmable calculator permitted**

**UNIVERSITY OF READING**

# Climate Change (MTMG16)

Two hours

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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) The net energy absorbed by the climate system (Q) can be defined as: $Q = (1 - \alpha) {}^{S}/_{4} - \varepsilon\sigma T_s^4$.
Define ALL the terms on the right hand side and explain what they physically represent.

[10 marks]

(b) If there is an instantaneous change in carbon dioxide concentration, which of the terms described in part (a) will change immediately?

[2 marks]

(c) In 1750, the atmospheric concentration of carbon dioxide ($C_o$) was around 70% of present day value (C). For the period 1750 to present, compute the radiative forcing, $\Delta F = A \ln(C/C_o)$ where A=6.3 $Wm^{-2}$.

[4 marks]

(d) Explain why your value in (c) is not an accurate estimate of the total radiative forcing that occurred in reality over the period 1750-present.

[6 marks]

(e) If $\Delta$F increases at the rate *G* $Wm^{-2}year^{-1}$ from $\Delta F = 0$ in 1750 up to the value calculated in (c) for 2015 the following relationship may be derived from the transient climate change equation ($\Delta T$ is the global mean surface temperature anomaly, t is time in years, $Y = -dQ/d\Delta T$ and $\tau$ is a constant):

$$\Delta T(t) = \frac{G}{Y}\left[t + \tau\left(e^{-t/\tau} - 1\right)\right]$$

(i) Explain what Y and $\tau$ represent physically and what determines their magnitude.

[8 marks]

(ii) Draw a schematic of $\Delta T$ against time, t, and quantify as far as possible the rate of warming as t becomes large in comparison to $\tau$.

[8 marks]

(f) Comment on how $\Delta T(t)$ influences impacts and adaptation strategies.

[8 marks]

(g) Define climate mitigation and state which term this will affect in the right hand side of the equation in part (e).

[4 marks]

2. (a) The table below displays global mean temperature anomalies with respect to the 1961-1990 climatology and a multivariate ENSO index (June to May ending on the year shown).

| YEAR | Temperature Anomaly (K) | Multivariate ENSO index |
|---|---|---|
| 2015 | 0.70 | 0.9 |
| 2014 | 0.57 | 0.0 |
| 2013 | 0.50 | 0.2 |
| 2012 | 0.47 | -0.4 |
| 2011 | 0.42 | -1.4 |
| 2010 | 0.56 | 0.9 |
| 2009 | 0.51 | -0.3 |
| 2008 | 0.40 | -0.9 |
| 2007 | 0.49 | 0.6 |
| 2006 | 0.51 | -0.1 |
| 2005 | 0.54 | 0.6 |
| 2004 | 0.45 | 0.3 |
| 2003 | 0.51 | 0.8 |
| 2002 | 0.50 | 0.1 |
| 2001 | 0.44 | -0.3 |
| 2000 | 0.30 | -0.8 |
| 1999 | 0.31 | -0.8 |
| 1998 | 0.54 | 2.5 |
| 1997 | 0.39 | 0.1 |
| 1996 | 0.18 | -0.3 |
| 1995 | 0.32 | 0.9 |
| 1994 | 0.21 | 0.7 |
| 1993 | 0.15 | 1.0 |
| 1992 | 0.11 | 1.5 |
| 1991 | 0.25 | 0.4 |

Using your knowledge of radiative forcing changes over the period, estimate the amplitude of global temperature variation relating to ENSO index variation and justify your answer.

[8 marks]

(b) Describe two mechanisms that explain why 2014 was approximately 0.5 K warmer than 1992.

[6 marks]

(c) Describe the main positive and negative feedback processes involved in the amplification and decay of El Niño events.

[8 marks]

(d) Discuss two possible mechanisms that could explain why global mean sea level fell following La Niña conditions in 2011.

[6 marks]

(e) If ocean temperatures were about 5$^{o}$C cooler in the last glacial maximum estimate global mean sea level change compared to present due to thermal expansion alone (assume a mean ocean depth of 4000m and a thermal expansivity of $10^{-4}$ $K^{-1}$).

Discuss how your estimate of sea level change compares with reconstructions of sea level change since the last glacial maximum.

[6 marks]

(f) Discuss the reasons why global temperatures increased between 15,000 and 10,000 years ago.

[12 marks]

(g) Briefly explain why human societies are committed to long-term sea level rise

[4 marks]

3. You are asked to give a talk about climate change to a local group with a range of interests and expertise. Write an essay or an outline of your talk (for example including sketches of slides with accompanying notes) which should cover:

   (a) Climate has always changed: outline how and on what time-scales climate has changed naturally in the past.

   [10 marks]

   (b) Is climate changing currently? Critically review evidence for three measures of global climate change covering the past 100 years.

   [10 marks]

   (c) Is current climate change unusual in the context of the past 1000 years and what are the most likely causes?

   [10 marks]

   (d) How is climate expected to change in the coming 100 years; what are the impacts and uncertainties? Use three examples.

   [10 marks]

   Marks will be awarded for logical structure and clarity of the essay/outline presentation.

   [10 marks]

(End of Question Paper)