University College Dublin
An Coláiste Ollscoile, Baile Átha Cliath

SEMESTER II EXAMINATION 2009/2010

ACM 40480

Climate Dynamics

Extern examiner: Prof. Keith Shine

Head of School: Dr. Mícheál Ó Searcóid

Examiner: Dr. Rodrigo Caballero*

Time Allowed: 2 hours

Instructions for Candidates

Answer **two (2)** of the following 3 questions. Each question carries 50 marks.
A list of values of physical constants can be found on the last page.

Instructions for Invigilators

Non-programmable calculators may be used during this examination.

Question 1

a) (*20 marks*) Consider a vertically-continuous atmosphere in radiative-convective equilibrium. Explain, in qualitative terms, why atmospheric and surface temperatures increase when the infrared opacity of the atmosphere increases (e.g. by addition of carbon dioxide). Assume the temperature lapse rate is fixed. Under what conditions would the atmosphere *cool* in response to increasing opacity?

b) (*10 marks*) Give a brief, qualitative discussion of *water vapour feedback* in the atmosphere.

c) (*20 marks*) Define the term *climate sensitivity*. Give a mathematical treatment showing how water vapour feedback affects climate sensitivity.

Question 2

a) (*15 marks*) Sketch the structure of the zonal-mean overturning circulation in the atmosphere during boreal winter (December-February), clearly labeling the various cells and giving a rough indication of their latitudinal extent. Overlay on this picture a sketch of the zonal-mean zonal wind. On a separate diagram, sketch a plot of the zonal-mean precipitation in the same season. Give a brief explanation of the processes leading to the various precipitation maxima.

b) (*20 marks*) Consider a parcel of air that starts at the Equator with $\overline{u} = 0$ (where $\overline{u}$ indicates the zonal-mean zonal wind) and moves poleward while conserving its angular momentum. Compute $\overline{u}$ as a function of latitude. Consider an atmosphere in which the zonal-mean zonal wind has the structure you have just computed all the way from the equator to the pole near the tropopause, but is zero at the ground. Assuming that the atmosphere is in thermal wind balance, what would be the equator-pole temperature difference?

c) (*15 marks*) Sketch the structure of the zonal-mean eddy momentum flux in the atmosphere. On a separate plot, sketch the zonal-mean surface wind. Explain the connection between these two fields.

Question 3

a) (*15 marks*) Explain how the Earth's obliquity gives rise to the seasons.

b) (*20 marks*) Discuss 4 physical effects that play an important role in controlling the mean equator-pole surface temperature gradient. For each effect, state clearly whether it tends to increase or decrease the gradient.

c) (*15 marks*) Write down a mathematical expression defining the *moist static energy*. Discuss the poleward transport of moist static energy by the Hadley cell.

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