University College Dublin
An Coláiste Ollscoile, Baile Átha Cliath

SUMMER EXAMINATIONS 2005/2006

SCMXF0028/SCMXP0028 MSc in Meteorology

Synoptic Meteorology and Climate Dynamics
MAPH P312

Extern examiner: Prof. Frank Hodnett
Head of School: Prof. Adrian Ottewill
Examiner: Dr. Rodrigo Caballero*

Time Allowed: 3 hours

Instructions for Candidates

Answer **four (4)** of the following six questions. Each question carries 25 marks.

Instructions for Invigilators

Non-programmable calculators may be used during this examination.

P.T.O.

Question 1

- (*10 marks*) Recalling that the upward flux of longwave radiation in a gray-gas atmosphere takes the form

$$I^+(\tau) \;=\; \sigma T_s e^{-\tau} \;+\; \int_0^\tau \sigma T(\tau')^4 e^{-(\tau-\tau')} d\tau',$$

  where τ is optical depth, T is atmospheric temperature and T_s is surface temperature, provide a mathematical definition of the effective emission level z_e. Assume that the absorption coefficient is vertically uniform and that density decays exponentially with height with a constant scale height.

- (*10 marks*) Discuss the role of the temperature lapse rate in determining the strength of the greenhouse effect (assume $T_s = T(0)$).

- (*5 marks*) Compute the emission temperature T_e for Mercury. Given that its atmosphere exerts a surface pressure of 10^{-15} mb, estimate the mean surface temperature on Mercury. Data: the mean orbital radii for Mercury and Earth are 57.9×10^6 km and 149.6×10^6 km respectively, the solar constant at Earth is 1380 W m^{-2} and the Stefan-Boltzmann constant is 5.67×10^{-8} W m^{-2} K^{-4}. The planetary albedo of Mercury is 0.1.

Question 2

- (*10 marks*) Describe qualitatively the stages of synoptic development in the Norwegian cyclone model. For each stage, sketch the disposition of fronts, pressure and precipitation fields.

- (*15 marks*) Consider an idealized geopotential distribution

$$\Phi(x, y) = \Phi_0 - f_0(Uy - A \sin kx \sin \ell y)$$

  where Φ_0, U, A, k, ℓ and f_0 are constants.

  (i) Derive expressions for the geostrophic wind components and relative vorticity field.

  (ii) Show that the advection of relative vorticity by the wave component of the geostrophic wind vanishes.

  (iii) Sketch the geopotential field and relative vorticity and indicate the regions of maximum positive and negative vorticity advection.

Question 3

- (*15 marks*) Explain, using quantitative arguments, why it is a reasonable approximation on Earth (and especially in the Southern Hemisphere) to consider surface temperature as the response to *annual mean* insolation.
- (*10 marks*) Taking annual-mean insolation as the relevant forcing, *qualitatively* discuss the main mechanisms controlling the mean equator-to-pole temperature gradient on Earth.

Question 4

- (*10 marks*) Explain the distinction between *climate forcing* and *climate feedback*, and give a mathematical discussion of how feedbacks act to amplify or mitigate the direct response to increased greenhouse gas concentration.
- (*10 marks*) List and *briefly* describe the major feedback mechanisms in the climate system, and then discuss the physical mechanisms underlying water vapour feedback in detail.
- (*5 marks*) Estimate the *direct* surface temperature response to a doubling of atmospheric CO_2 concentration, assuming the doubling raises the emission level by 300 m and the temperature lapse rate has a typical midlatitude value.

Question 5

- (*15 marks*) Give the mathematical definition of the meridional mass streamfunction ψ and show how it is related to zonal-mean meridional and vertical wind. Sketch the annual-mean meridional mass streamfunction.
- (*10 marks*) Explain qualitatively how a horizontal temperature gradient in a non-rotating, hydrostatic fluid leads to an overturning circulation. Describe the energy conversions occurring in this circulation.

Question 6

- (*15 marks*) Starting from Schwarzschild's equations in a gray-gas atmosphere

$$\frac{dI^+}{d\tau} = \sigma T^4 - I^+$$

$$\frac{dI^-}{d\tau} = -\sigma T^4 - I^-,$$

  derive the radiative equilibrium temperature profile.

- (*10 marks*) Qualitatively describe how dry and moist convection will affect the temperature profile.

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