University College Dublin
An Coláiste Ollscoile, Baile Átha Cliath

SEMESTER I EXAMINATION 2010/2011

ACM 40490

Physical Meteorology

Extern examiner: Prof. Peter A. Clark

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. Values of physical constants may be found at the end of the paper. Calculators may be used for this exam.

Instructions for Invigilators

No particular instructions.

Question 1

The atmosphere of Mars is composed mostly of carbon dioxide, along with some nitrogen and argon, with the following number fractions: CO_2: 97%; N_2: 2%; Argon 1%. The molecular masses are CO_2: 48 AMU; N_2: 28 AMU; Argon: 40 AMU. The composition can be assumed constant (well mixed) throughout the atmosphere. The surface pressure is 7 hPa.

a) (*10 marks*) What is the mass mixing ratio of N_2?

b) (*15 marks*) State Dalton's law, and derive an expression for the gas constant for a mixture of gases. Compute the value of the gas constant for the Martian atmosphere.

c) (*5 marks*) Suppose the surface temperature is 200 K. What is the number density at the surface? What is the mass density at the surface?

d) (*20 marks*) Assume that the Mars atmosphere is isothermal at a temperature of 200 K. What are the approximate values of pressure and mass density at an altitude of 10 km? What temperature would a parcel attain if it were taken adiabatically from an elevation of 10 km to the surface?

Question 2

Pressure (hPa)	Temperature (°C)	Dew point (°C)
1000	13	10
940	9.5	8
900	7	5
780	−2	−3
700	−6	−11
600	−11	−18
500	−20	−25
400	−34	

Table 1:

Given the sounding data in Table 1, answer the following questions using the tephigram printed on Page 4 where necessary. In each case, explain your reasoning using sketches a appropriate.

a) (*10 marks*) Plot the sounding on the tephigram in Page 4. Is the sounding stable, unstable or conditionally unstable?

b) (*10 marks*) Estimate the dew point at 400 hPa assuming the relative humidity is the same as that at 500 hPa.

c) (*10 marks*) Estimate the wet-bulb temperature at 600 hPa.

d) (*20 marks*) Suppose the sounding was taken before dawn and when the sun rises it begins to heat the surface. Air near the surface is gradually heated and eventually becomes statically unstable, forming a shallow, well-mixed convective layer. Estimate the temperature to which near-surface air must be heated in order for clouds to begin forming at the top of the convective layer. Assume that the humidity near the surface remains constant at all times.

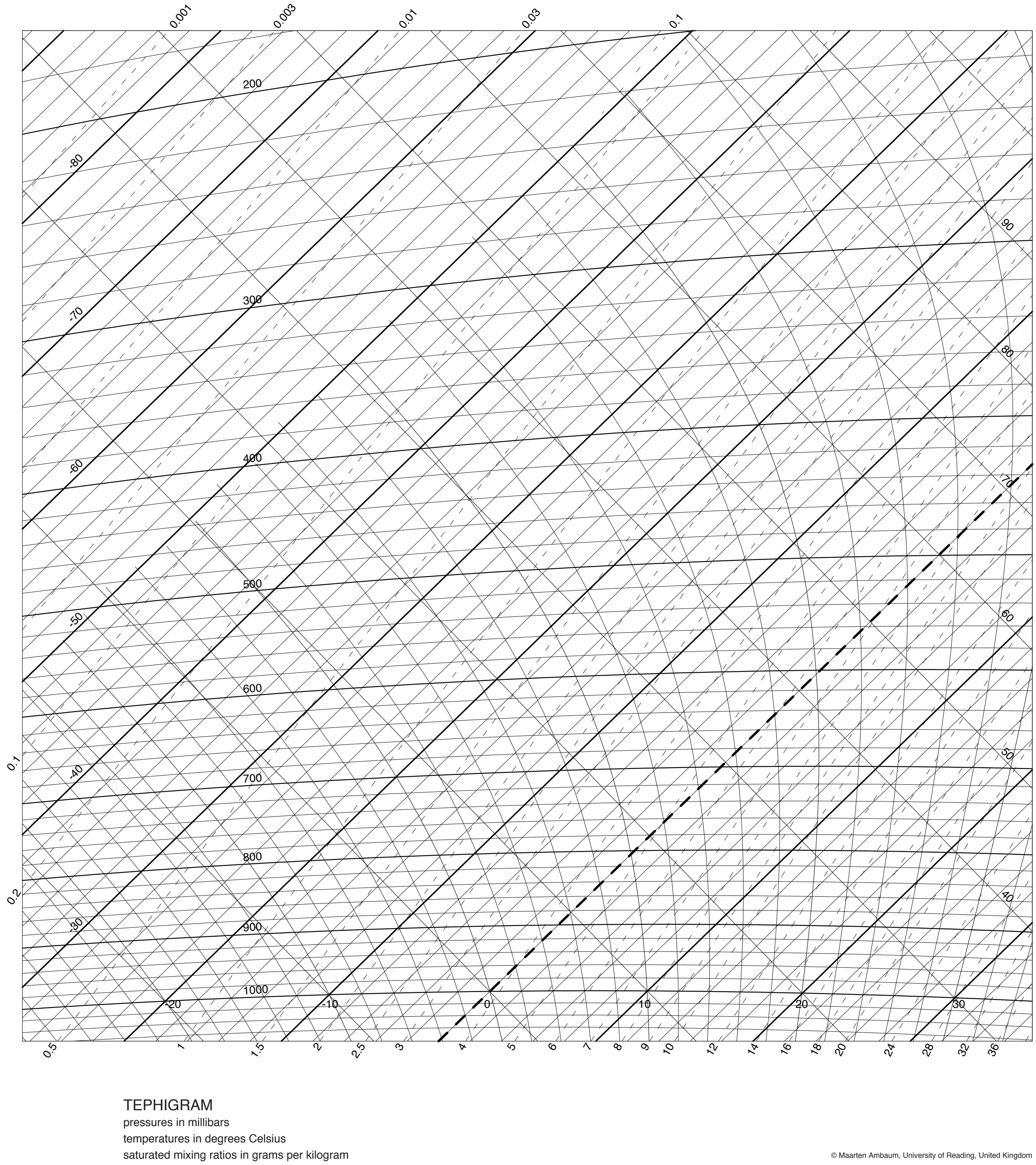
TEPHIGRAM
pressures in millibars
temperatures in degrees Celsius
saturated mixing ratios in grams per kilogram
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Figure 1:

Question 3

Figure 2 overleaf shows the infrared radiance spectrum measured by a satellite as it passed over the Antarctic ice sheet. Answer the following questions, explaining your reasoning in all cases.

a) (*10 marks*) Sketch the spectrum and identify the water vapour window and the spectral features associated with carbon dioxide and ozone.

b) (*10 marks*) Estimate the temperature at the surface and at the tropopause. Assume the surface is at an elevation of 3 km, where the pressure is 800 hPa, and the tropopause is at 10 km, where the pressure is 300 hPa. Estimate the average oscillation period of gravity waves in the atmosphere, recalling that the Brunt-Vaisala frequency is

$$N = \left(\frac{g}{\Theta} \frac{d\Theta}{dz} \right)^{1/2}$$

c) (*10 marks*) Give a *rough* estimate of the rate at which the surface is losing energy due to infrared radiation. Explain whether your estimate is likely to be an overestimate or an underestimate of the true infrared cooling rate.

d) (*20 marks*) The number fraction of CO_2 in the atmosphere is observed to be 0.00038. Given that CO_2 has a molecular mass of 44 AMU and air has a mean molecular mass of 29 AMU, compute the mass mixing ratio of CO_2.

Recall that the optical depth is defined as

$$\tau = \int_0^z k_a \rho_a dz,$$

where k_a is the mass absorption coefficient and ρ_a is the mass density of absorbers. Recall also that the effective emission level is located at the height where $\tau = \tau_\infty - 1$, where τ_∞ is the optical depth at the top of the atmosphere ($z \to \infty$). Given that CO_2 has a peak absorption coefficient of $k_a = 10^4$, compute the atmospheric pressure at the effective emission level corresponding to this peak. Assume that k_a and the mass mixing ratio are constant, and that the atmosphere is in hydrostatic equilibrium.

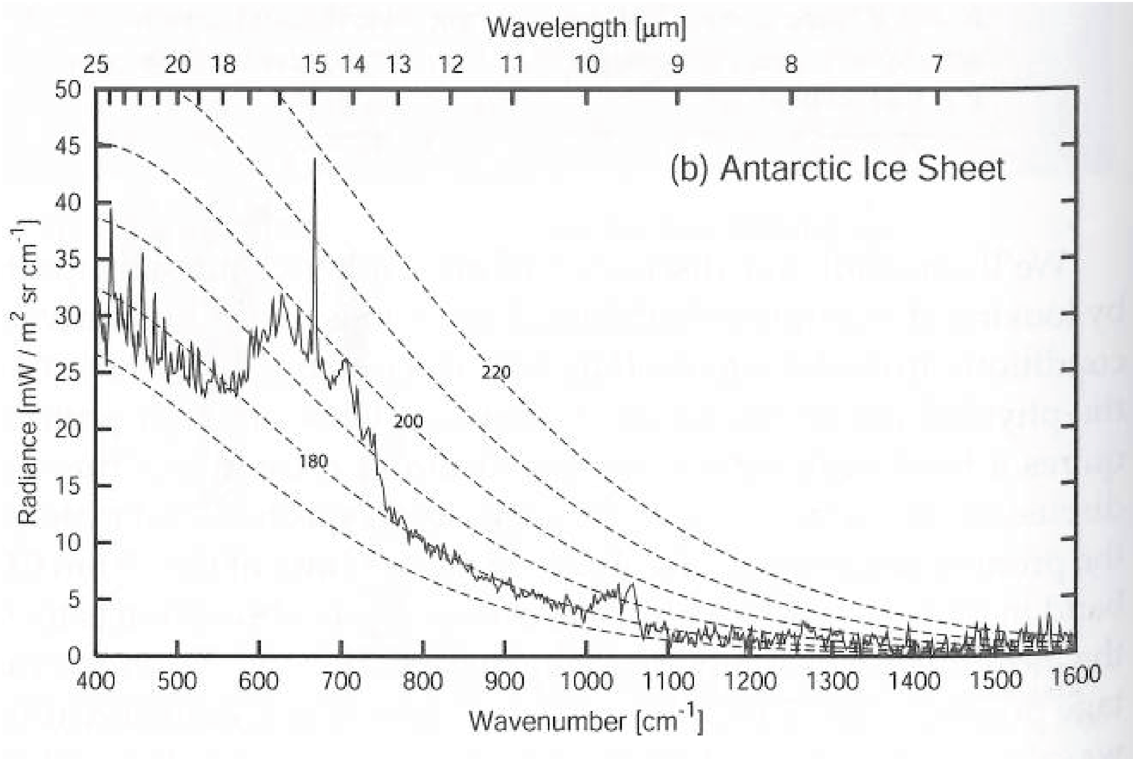

Figure 2:

Values of physical constants

Gravitational acceleration $g = 9.8$ m s^{-2}
Gas constant for dry air $R_d = 287$ J K^{-1} kg^{-1}
Specific heat capacity of dry air at constant pressure $c_{pd} = 1004$ J K^{-1} kg^{-1}
Gravitational acceleration on Mars $g = 3.7$ m s^{-2}
Stefan-Boltzmann constant $\sigma = 5.67\times10^{-8}$ W m^{-2} K^{-4}
Boltzmann's constant $k = 1.38\times10^{-23}$ m^2 kg s^{-1} K^{-1}
Atomic mass unit AMU $= 1.661\times10^{-27}$ kg
Specific heat capacity at constant pressure of $CO_2 = 735$ J kg^{-1} K^{-1}
Specific heat capacity at constant pressure of $N_2 = 1040$ J kg^{-1} K^{-1}
Specific heat capacity at constant pressure of Argon $= 520$ J kg^{-1} K^{-1}

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