THE UNIVERSITY OF NEW SOUTH WALES

SCHOOL OF PHYSICS

EXAMINATION – JUNE 2009

PHYS2810 – ATMOSPHERIC PHYSICS
PHYS2801 – ATMOSPHERIC SCIENCE

Time allowed – 2 hours

Total number of questions – 11

Attempt 6 (six) questions

The questions are of equal value

This paper may be retained by the candidate

Candidates are required to supply their own university approved calculator.

Answers must be written in ink. Except where they are expressly required, pencils may only be used for drawing, sketching or graphical work.

p3

Formulae

$$\frac{dp}{dz} = -\rho g \qquad p = \rho R T \qquad Z_2 - Z_1 = \overline{H} \ln(p_1 / p_2); \quad \overline{H} = R\overline{T} / g$$

$$dh = du + dw = du + p\,d\alpha = c_v\,dT + p\,d\alpha = c_p\,dT - \alpha\,dp \qquad c_p = c_v + R$$

$$\frac{T}{T_0} = \left(\frac{p}{p_0}\right)^{R/c_p} \qquad -\left(\frac{dT}{dz}\right)_{dry} = \frac{g}{c_p} \equiv \Gamma_d$$

$$e_s = 6.11\exp\left\{\frac{L}{R_v}\left(\frac{1}{273} - \frac{1}{T}\right)\right\} \qquad r = \frac{m_v}{m_d} = \frac{M_v}{M_d}\frac{e}{p-e} \cong \varepsilon\frac{e}{p}$$

$$\Gamma_s \equiv -\left(\frac{dT}{dz}\right)_{sat} = \frac{\Gamma_d}{1 + (L/c_p)(dq_s/dT)} \qquad V_{geo} = \frac{\Delta p}{\Delta x}\frac{2\Omega\sin\phi}{\rho}$$

$$E_\lambda = \frac{c_1}{\lambda^5\left[\exp(c_2/\lambda T) - 1\right]} \qquad \lambda_m = \frac{2897}{T}\,\mu m \qquad E = \sigma T^4$$

$$E_\lambda = E_0\exp(-\sigma_\lambda\sec\phi) \qquad \sigma_\lambda = \int k_\lambda\,\rho\,dz \qquad R_{vis} = \frac{3.91}{\beta_{ext}} \qquad \frac{TSP}{\beta_{ext}} = 2.5x10^5$$

Useful constants

Acceleration due to gravity	g	9.8 ms^{-2}
Standard atmospheric pressure		101325 Pa
Molecular weight of dry air	M_d	28.964
Molecular weight of water	M_v	18.016
Water vapour mass ratio	ε	0.622
Gas constant for dry air	R	287.05 J/kg/K
Gas constant for water vapour	R_v	461.5 J/kg/K
Specific heats of dry air	c_v	718 J/kg/K
	c_p	1005 J/kg/K
Density of dry air at 273 K, 101325 Pa		1.293 kg/m^3
Latent heat of vapourization of water at 273 K	L	2.5 x 10^6 J/kg
Solar constant	S	1368 W/m^2
Stefan-Boltzmann constant	σ	5.67 x 10^{-8} $W/m^2/K^4$
Radiation constants	c_1	3.74 x 10^{-16} W/m^2
	c_2	1.44 x 10^{-2} mK

Question 1

The Sun has a mean radius, R_S, and a temperature, T_S. It is a distance R from a planet with a solar constant S and effective temperature T_e and planetary albedo α.

a) Explain what is meant by the solar constant.

b) Show that the solar constant is related to the Sun's temperature by

$$S = \left(\frac{R_s}{R}\right)^2 \sigma T_S^4$$

c) Explain what is meant by the effective temperature of a planet.

d) Show that the effective temperature, T_S, for a planet a distance R from the Sun, is related to the radiative temperature, T_s by:

$$T_e = \frac{(1-\alpha)^{1/4}}{\sqrt{2}} \left(\frac{R_S}{R}\right)^{1/2} T_S$$

e) Are the effective temperature and the surface temperature of a planet the same? Explain the reasons for your answer.

f) Given that the Sun has a radius of 7 x 10^8 m and is 1.5 x 10^{11} m from Earth. If the Earth's albedo is 0.3, and the solar constant is 1400 Wm^{-2}, find the temperature of the Sun and the effective temperature of the Earth.

g) Find the wavelength of maximum emission for both the Sun and Earth.

Question 2

During a sunspot minimum the Earth's solar constant was measured to be 1364 Wm^{-2}. At that time the shortwave absorptivity a = 0.2, the longwave emissivity e = 0.95, and the planetary albedo α = 0.3. Given that the Earth's atmosphere can be modelled with a simple one layer climate model, with the above parameters, ground temperature, T_g, and atmosphere temperature, T_a.

a) Sketch a diagram showing the energy exchanges between the Earth and the atmosphere.

b) Set up the energy balance equations for the atmosphere and the ground.

c) Find the ground temperature, T_g and the atmosphere temperature, T_a.

d) Sulphate aerosols in the troposphere have been found to affect the surface temperature. Do they lead to warming or cooling? Explain the mechanisms involved and which parameter of the one-layer model is affected.

Question 3

a) Briefly describe what is meant by the term 'air pollution' and the difference between primary and secondary air pollution.

b) Describe the primary sources and some of the health and other problems associated with at least 3 of the following pollutants.

- i Particulate Matter (PM)
- ii Carbon Monoxide (CO)
- iii Sulphur Dioxide (SO_2)
- iv Volatile Organic Compounds (VOC)
- v Nitrogen Oxides (NOx)
- vi Tropospheric Ozone (O_3)

Question 4

a) One way of quantifying the greenhouse effect is via the definition

$$G = E - F$$

Explain what is meant by E and F, and which gases are the main contributors to G.

b) What does the forcing ΔF measure and how is it related to changes in surface temperature.

c) Explain briefly what is meant by the terms positive feedback and negative feedback, and giving an example of each if you can.

d) Radiative convective models can be used to investigate how changes in concentrations of atmospheric gases may lead to radiative forcing, ΔF. Describe briefly how such models work and advantage of using such a model?

e) Explain what is meant by the Global Warming Potential and why it is useful.

Question 5

In 2007 the IPCC released the Fourth Assessment Report on Climate Change. The Working Group 1 Report on the science states that:

'The understanding of anthropogenic warming and cooling influences on climate has improved since the Third Assessment Report (TAR), leading to *very high confidence* that the globally averaged net effect of human activities since 1750 has been one of warming, with a radiative forcing of +1.6 [+0.6 to +2.4]Wm^{-2}'.

a) What is meant by the term 'radiative forcing'?

b) What factors have led to the improved understanding of anthropogenic influences on climate?

c) Choose two examples of the observational evidence which support the conclusions of the IPCC report. Explain briefly what these observations are and why they support the conclusions of the IPCC Report.

Question 6

a) A heated plume leaves the cooling tower of a power plant with a temperature of 27°C. To what height will the plume ascend if the ambient temperature varies with altitude according to $T(z) = 19 - 6.5\,z$ (where T is in °C and z is in km)?

b) 5 kg of air, at a temperature of 7°C, rises from an initial pressure level of 950 hPa, to a final pressure level of 700 hPa. (i) If the process is isothermal, calculate the work done, and the amount of heat added in the process. (ii) If the process is adiabatic, determine the final temperature of the air, and calculate the work done.

c) The Clausius-Clapeyron equation (formula sheet) may be used to determine the boiling point of water, defined as that temperature at which saturation vapour pressure equals ambient pressure. Determine the boiling point at the top of Mt. Everest, 8848m above sea level, assuming a pressure of 315 hPa.

Question 7

An air parcel at 990 hPa has a <u>dew point temperature</u> of 13°C, and a relative humidity of 45%. Use the F160 chart to answer the following:

a) Find its
water vapour mixing ratio,
dry bulb temperature,
lifting condensation level,
wet bulb temperature,
potential temperature, and
equivalent potential temperature.

b) This air parcel is now lifted to the 580 hPa level, at the top of a mountain.
How much of the water vapour condenses?
Assume that 70% of the condensate precipitates: what is the remaining water mixing ratio (liquid plus vapour)?

c) This air parcel, with its remaining water content, now descends on the lee side of the mountain. What is the cloud base height?

d) If the air parcel now descends to the 1020 hPa level, determine its
temperature,
potential temperature,
mixing ratio,
dew point, and
wet bulb temperature.

Note: your workings on the F160 chart will be included in the assessment of this question.

Question 8

Explain the cloud droplet coalescence process, whereby small droplets may grow large enough to precipitate. In the process you should derive the equation

$$\frac{dR}{dt} \approx E\,wV/4\rho$$

carefully explaining (not just defining) each term, and its significance.

Question 9

The Earth's atmosphere acts as a "heat engine", to transport heat from equatorial to polar regions. Discuss the various mechanisms involved in this process in different regions of the globe. Your answer should include, but not be limited to, a discussion of key aspects of the general circulation of the Earth's atmosphere.

Question 10

Attempt 1 (one) only of the following:

a) Discuss the physical processes involved in different types of thunderstorms, such as ordinary cell thunderstorms, supercells and squall lines. Also discuss their life cycles.

b) Discuss the important characteristics, and the life cycle, of a tornado. Also outline the Fujita scale for wind damage.

Question 11

Attempt 1 (one) only of the following:

a) Discuss the concepts of climate classification as developed by Koppen and others. What meteorological parameters are considered when arranging such classifications? Give some examples of locations/regions, and relate this to what you know of the general circulation of the atmosphere.

b) Sketch a cross section through a cold front, indicating on it any relevant information such as air flow, temperature and cloud types. What are the typical slope, and speed, of a cold front? Construct a table of typical weather conditions associated with a cold front (northern hemisphere) covering winds, temperature, pressure, clouds, precipitation and dew point, before, during and after the passage of the front.

c) Discuss the phenomenon of turbulent flows in the atmospheric boundary layer. What are some of the different causes of turbulence? What are some of the effects of turbulence?