PHY392 Midterm Exam
28 February 2013
Duration: 50 minutes
Aids allowed: a non-programmable calculator
Possibly useful constants and equations are given at the end

1. (5 marks each, 15 marks total)

a) Briefly define climate sensitivity. According to the IPCC, what is the most likely estimate for the climate sensitivity?

Simulations with a general circulation model have been used to investigate the climate sensitivity to large changes in atmospheric ozone. Explain qualitatively the results below.

b) A simulation in which all the ozone above 30 km in altitude is removed shows a large tropospheric warming (1-3°C) and a very large stratospheric cooling (up to −80°C).

c) A simulation where all ozone in the upper troposphere is removed shows a 1°C cooling of the Earth's surface, while a simulation in which the same amount of ozone is removed, but in the lower troposphere, shows no significant temperature change.

2. (15 marks)

A small blackbody satellite is orbiting Earth at a distance far enough away so that the radiation flux density from Earth is negligible compared to that from the Sun. Assume that it is spherical with a radius of r = 1 m and that temperature is uniform over its surface.

a) If the satellite absorbs all the incident solar radiation, derive an expression for the temperature of the satellite. ***(7 marks)***

b) Suppose that the satellite suddenly passes into Earth's shadow. At what rate will it initially cool? The satellite has a mass $m = 10^3$ kg and a specific heat of $c = 10^3$ J kg^{-1} K^{-1}. ***(8 marks)***

3. (20 marks)

The thick CO_2 atmosphere of Venus is nearly opaque in the infrared, so observations of Venus in the infrared spectrum provide no direct information about the temperature of the ground. However, the atmosphere is nearly transparent to microwave radiation, so the microwave emission of the planet can be used to infer its surface temperature. Indeed, this is how the surface temperature was inferred in the 1960s.

a) Using the expression for blackbody radiation as a function of frequency

$$B(\nu,T) = \frac{2h\nu^3}{c^2}\frac{1}{e^{h\nu/kT}-1},$$

show that if ν_1 and ν_2 are in the frequency range (such as in the microwave) where $h\nu/kT \ll 1$, the total flux (W/m^2) per steradian emitted between ν_1 and ν_2 is $\frac{2}{3}(kT/c^2)(\nu_2^3 - \nu_1^3)$. This is the Rayleigh-Jeans approximation. ***(6 marks)***

b) Assuming that the ground radiates like a blackbody in the microwave, compute the net power (in W) radiated by Venus in the wavelength band from 1 millimeter to 100 millimeters, if the surface were at 737 K. ***(8 marks)***

c) At its closest approach, Venus is about 41 x 10^6 km from Earth. What microwave energy flux (in W/m^2) would be seen from Earth orbit by a microwave antenna directed toward Venus? (For comparison, the energy flux from a 1 W cell phone across a 10 km sphere is about 8 x 10^{-10} W/m^2). How much power from Venus would be collected by an antenna with an area of 100 m^2? ***(6 marks)***

Maximum exam marks = 50 points

USEFUL CONSTANTS AND FORMULAS

Constants

Gravitational constant	G	6.67×10^{-11} N m^2 kg^{-2}
Universal gas constant	R_g	8.3143 J K^{-1} mole^{-1}
Speed of light in vacuum	c	2.998×10^{8} m s^{-1}
Planck's constant	h	6.626×10^{-34} J s
Boltzmann's constant	k	1.381×10^{-23} J K^{-1}
Avogadro's number	N_A	6.02×10^{23} particles/mole
Stefan-Boltzmann constant	σ	5.67×10^{-8} W m^{-2} K^{-4}
First radiation constant	c_1	1.191×10^{-16} W m^2 sr^{-1}
Second radiation constant	c_2	1.439×10^{-2} m K

Planetary and Sun

Mean surface pressure on Earth	P_s	1.013×10^{5} Pa = 1013 mbar
Mean surface temperature on Earth	T_s	288 K
Earth's emission temperature	T_e	255 K
Mean surface density on Earth	ρ_s	1.235 kg m^{-3}
Earth's rotation rate	Ω	7.27×10^{-5} s^{-1}
Earth's mean radius	a	6.38×10^{6} m
Mean Earth-Sun distance	d_{Earth}	1.5×10^{11} m
Solar constant	L_0	1367 W m^{-2}
Mean Earth albedo	A_p	0.30
Venus' mean radius	a_{Venus}	6.05×10^{6} m
Mean Venus-Sun distance	d_{Venus}	1.08×10^{11} m

Properties of Dry Air

Specific heat at constant pressure	c_p	1005 J kg^{-1} K^{-1}
Specific heat at constant volume	c_v	718 J kg^{-1} K^{-1}
Air density at 273 K, 1013 hPa	ρ_0	1.293 kg m^{-3}
Gas constant for dry air	R	287 J kg^{-1} K^{-1}

Equations

$$d\Omega = d\left(\frac{A}{r^2}\right) = \sin\theta \; d\theta \; d\varphi$$

$$B_\lambda(T) = \frac{2hc^2\lambda^{-5}}{\exp\left(\frac{hc}{\lambda kT}\right) - 1} = \frac{c_1\lambda^{-5}}{\exp\left(\frac{c_2}{\lambda T}\right) - 1}$$

$$B_v(T) = \frac{2hv^3c^{-2}}{\exp\left(\frac{hv}{kT}\right) - 1}$$

$$e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \cdots$$

$$F_\lambda = \pi B_\lambda$$

$$T_s = (n+1)^{1/4} T_e$$