MTMG02 Msc Atmospheric Physics exam.
Academic year 2010/2011.
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RUBRIK:
Exam duration: **three hours**.
Answer any **two out of three** questions.
Any calculator is allowed.
Any bilingual English language dictionary is allowed.
Textbooks or lecture notes are **not** allowed.

ADDITIONAL MATERIAL:
Atmospheric physics data sheet.

Question 1

An air parcel has pressure 1000 hPa, temperature 31.0°C, and a relative humidity of 70.0%. Assume the parcel is an ideal gas. You can use the tables in the data sheet provided.
The virtual temperature T_v, with respect to water vapour in air, is defined as

$$T_v = (1 + 0.61\,q)\,T.$$

a) State the definition of the specific humidity q. **[5]**
b) Calculate the density of the parcel to four significant digits. **[5]**
c) Calculate the virtual temperature of the parcel, in degrees Celcius, to three significant digits. **[5]**
d) Determine the dewpoint temperature, in degrees Celsius of the parcel to two significant digits. **[5]**

A typical value for the latent heat of evaporation L is

$$L = 2.5 \times 10^6 \,\mathrm{J\,kg^{-1}}.$$

e) Consider a case where a water surface loses 2 mm per day through evaporation. What is the corresponding mean latent heat flux in $\mathrm{W\,m^{-2}}$? **[6]**
f) Explain in less than a half page why L is the specific enthalpy difference between the vapour and the liquid phase of a substance, in equations:

$$L = h_v - h_l$$

with h_v and h_l the specific enthalpies of the vapour and the liquid, respectively. **[9]**
g) L is also called the enthalpy of vaporization. Explain how the enthalpy of vaporization, the enthalpy of melting, and the enthalpy of sublimation are related. **[7]**

From Dalton's law, we find that, assuming air is an ideal gas, the presence of air above a water surface does not alter the equilibrium vapour pressure above the surface. In that sense, the air above the water surface does not "hold" the water vapour.

h) In real (non-ideal) gases, molecules attract each other weakly. Do you expect the presence of a real gas above a water surface to increase or decrease the equilibrium vapour pressure? Explain why. **[8]**

(end of question 1)

Question 2

A typical lapse rate for the atmosphere is $\Gamma = 6.5\,\mathrm{K\,km^{-1}}$. The troposphere in a US Standard Atmosphere is defined by a temperature profile of

$$T(Z) = T_0 - \Gamma Z$$

with the surface temperature $T_0 = 288.2\,\mathrm{K}$, $\Gamma = 6.5\,\mathrm{K\,km^{-1}}$, and Z the geopotential height.

a) Explain the difference between the geopotential height Z and the geometric height z above the Earth's surface. Under what circumstances can the difference be ignored? **[5]**

b) A dry air parcel starting at $Z = 0$ is made to lift rapidly over a hill of 1000 m high. Estimate the difference in temperature between the parcel and the environment at the top of the hill. Is the parcel positively buoyant? **[6]**

If the surface parcel has water vapour in it, clouds can form at the top of such hills in an otherwise cloudless sky.

c) If the parcel started of with a relative humidity of 80% at a pressure of 1000 hPa, calculate whether it reached its lifting condensation level (LCL) before it reached the top of the hill (hint: consider the vapour mixing ratio). Explain your answer and state any assumptions you make. **[10]**

Diffusive growth of cloud drops or evaporation of cloud drops is described by the equation

$$r\frac{\mathrm{d}r}{\mathrm{d}t} = D\frac{\rho_r}{\rho_l}(\mathrm{RH} - 1).$$

We assume that the density ratio $\rho_r/\rho_l = 3 \times 10^{-6}$ is constant and that the vapour diffusion coefficient $D = 2 \times 10^{-5}\mathrm{m^2\,s^{-1}}$ is also constant. RH is the relative humidity of the environment and r is the radius of the drop.

d) Assume the relative humidity is also a constant. How long does it take for a drop of $50\,\mu$m to evaporate completely in an environment of 95% relative humidity? **[10]**

e) Clouds that form over the top of a hill typically do not form straight on top of the hill but more downstream from the top. Explain why this is, and explain how you expect this downstream displacement to vary with wind speed. **[7]**

f) Do you expect clouds that form this way over a hill typically to produce rain? Explain your answer. **[5]**

g) Explain why convective available potential energy (CAPE) is not necessarily a good indicator for the occurrence of convection. **[7]**

(end of question 2)

Question 3

The value of the solar constant is

$$S_0 = 1366\,\mathrm{W\,m^{-2}}$$

a) Give the definition of the solar constant. **[4]**

b) What are the possible sources of variation in the solar constant and what are the typical timescales of these variations? **[6]**

A satellite may require a thermal control system to keep its temperature at a suitable working level when in space. For simplicity, assume that the satellite is a perfect blackbody which is always exposed to the Sun.

c) If the satellite has no thermal control system, what is the equilibrium temperature at the exposed side of the satellite? **[5]**

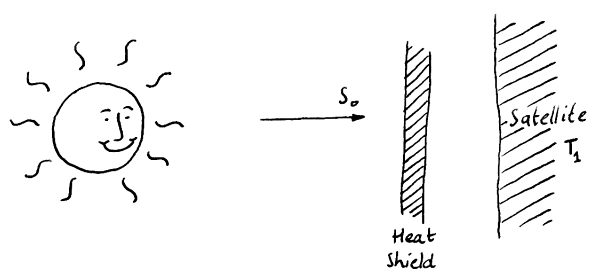
Now assume the satellite has a thermal control system which can dissipate energy away from the exposed surface at a rate per unit area of F.

d) If the satellite surface is to be kept at temperature T_1, demonstrate that the required F is

$$F = S_0 - \sigma T_1^4,$$

with σ the Stefan–Boltzmann constant. **[5]**

Now consider a heat shield around the satellite, to protect it against the solar radiation, see schematic below. Assume that the shield itself is also a blackbody.



e) Show that, to keep the exposed side of the satellite at the same temperature T_1, the required dissipation rate F is halved in size, when the heat shield is put around the satellite. **[10]**

f) Consider a satellite with a heat shield with a reflective surface on the exposed side. The reflective surface has a short-wave albedo of 0.95. What is the equilibrium temperature of the satellite when the thermal control system is switched off? **[5]**

Clouds are reflective for short wave radiation, while they can be considered as blackbodies for long wave radiation. In this respect, clouds act as a heat shield for the Earth with holes in it.

g) In the satellite case, the distance between the heat shield and the satellite did not matter. In the Earth case it does matter at which level the clouds are. Explain why there is this difference between the two cases. **[7]**

h) Explain why high clouds generally help to warm the Earth's surface while low clouds generally help to cool the Earth's surface. **[8]**

(end of question 3)