Norwegian University of Science and Technology
Department of Physics

<u>Subject contact during examination:</u>
Name: Patrick Espy
Tel: 41 38 65 78 (mob)

EXAMINATION IN FY3201 ATMOSPHERIC PHYSICS AND CLIMATE CHANGE

Faculty for Natural Sciences and Technology
03 June 2011
Time: 15:00-19:00

Number of pages: 2

Permitted help sources: 1 side of an A5 sheet with printed or handwritten formulas permitted
Bi-lingual dictionary permitted
Calculators meeting NTNU examination criteria are permitted

You may take:

Molar mass of water vapour ~18 kg/kmole $g=9.8$ m s^{-2} and constant in z
Molar mass of dry air ~29 kg/kmole   1 hPa = 10^2 Pa $=10^2$ N m^{-2}
273 K = 0 ^oC Latent heat of vaporization water = $L_v=2.6\text{x}10^6$ J· kg^{-1}
Scale Height, $H=R\cdot T/g$
Values for dry air: $C_p=1004$ J·K^{-1}·kg^{-1} $C_v=718$ J·K^{-1}·kg^{-1} $R_d=287$ J·K^{-1}·kg^{-1}
$\gamma = C_p / C_v$ $\kappa = R_d / C_p$ $R_d=C_p - C_v$ $\Gamma_{da}=9.8$ K/km

Answer all questions (and good luck!):

1) **(25%)** Weather balloons typically burst when they reach an atmospheric pressure of 100 hPa. Meteorologists release balloons at the Equator, where the atmosphere has a uniform, isothermal temperature of 35 ^oC, and at Svalbard, where the atmosphere has a uniform temperature of -35 ^oC. Assume dry air, and that the identical balloons start at 0 m where the surface air pressure at both sites is 1000 hPa.

a) At what height above the surface does each balloon burst? (10 %)

b) If the only wind was due to the temperature gradient between the Pole and the Equator, in which directions would the balloons drift? Why? (10 %)

c) Assuming the dry He inside each of the balloons does not exchange heat with its surroundings, what is the temperature of the gas in each balloon when it bursts? For Helium, take $R_{He}=2077$ J·K^{-1}·kg^{-1} and $C_p=5190$ J·K^{-1}·kg^{-1} (5 %)

2) **(25%)** Volcanic ash of 0.1μ ($1\mu=10^{-6}$m) radius is distributed with a constant mass mixing ratio of 3% in the lowest 10 km of an isothermal atmosphere of temperature 270 K. The atmospheric density at the surface is 1.29 $kg\cdot m^{-3}$, and the scale height for the atmosphere is 8 km. For 500 nm light, take the attenuation coefficient of clear air to be 0, and for ash to be 0.01 $m^2\cdot kg^{-1}$.

a) At ground level, what is the optical depth of 500 nm light for the sun directly overhead? (8%)

b) What is the atmospheric transmission in this case? (3%)

c) At what altitude does the optical depth = 1? (8%)

d) If the particle radius increased to 3 μ with the same mass mixing ratio, how would the extinction coefficient, transmission and asymmetry factor (ratio of forward to backward scatter) change for 500 nm light? (6%)

3) **(25 %)** A dry air parcel is raised adiabatically 2 km from a pressure, P_o=1000 hPa and a temperature of 285 K, to a pressure, P=783 hPa.

a) What is the temperature of the **air parcel** at 783 hPa? (5%)

b) If the atmospheric pressure as a function of altitude is given by the expression:

$$P = P_o\cdot(1 - \Sigma\cdot z)^{\alpha}, \quad \text{where } \Sigma = 0.02\ km^{-1}, \text{ and } \alpha=6.$$

What is the temperature of the air surrounding the parcel at 783 hPa? (9%)

c) Are these atmospheric conditions stable or unstable with respect to vertical motion? Why? (3%)

d) If the air parcel contains moisture that condenses as it ascends, will the air parcel be warmer or colder than a corresponding dry parcel? Why? (3%)

e) If the air parcel contains water, what mass mixing ratio of water must condense during its ascent in order to change the parcel air temperature by 10 K? (Assume the atmospheric mass is the mass of dry air.) (5%)

4) **Short Answers (25 %)**

a) What are the most important optical properties of a gas that allow it to create a greenhouse effect? (4 %)

b) With the addition of a greenhouse gas to the atmosphere, briefly describe the process by which the lower atmosphere warms. (4%)

c) What is meant by a radiative equilibrium temperature? (4 %)

d) If the greenhouse effect produces a warming in the troposphere, why is there a net 2 K/day radiative cooling in the upper troposphere? (5%)

e) In a radiative transfer model, what is the "two-stream" approximation? (4%)

f) Describe briefly the differences between the two most common numerical grid models. (4 %)