NTNU – Trondheim
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Department of Physics

Examination paper for FY3201 Atmospheric Physics and Climate Change

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Examination date: 4 June 2018

Examination time (from-to): 09:00 – 13:00

Permitted examination support material:

Single or Bi-lingual dictionary permitted
All calculators permitted
1 side of an A5 sheet with printed or handwritten formulas permitted

Other information:

Language: English

Number of pages: 5 + cover

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Date Signature

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EXAMINATION IN FY3201 ATMOSPHERIC PHYSICS AND CLIMATE CHANGE
Faculty for Natural Sciences and Technology
4 Jun 2018
Time: 09:00-13:00

Number of pages: 6

Permitted help sources: 1 side of an A5 sheet with printed or handwritten formulas permitted
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You may take:

Molar mass of dry air: ~29 kg/kmole
Molar mass of helium: ~4 kg/kmole
Molar mass of H_2O: ~18 kg/kmole

$N_A = 6.02 \times 10^{23}$ molecules/mole   Boltzmann's constant $k = 1.38 \times 10^{-23}$ J/K

273.15 K = 0 °C   1 hPa = 10^2 Pa = 10^2 N m^{-2} g=9.8 m s^{-2} and constant in z

Stefan–Boltzmann constant: $\sigma = 5.67\times10^{-8}$ W·m^{-2}·K^{-4}

Solar photospheric temperature, T_s = 5786 K   Radius of the Sun = 695800 km

Radius of the Earth = 6370 km   1 AU (Earth-Sun distance) = 150×10^6 km

Latent heat of vaporization water: $L_v = 2.5\times10^6$ J· kg^{-1}

Gas constant for water vapour: R_v=461 J·K^{-1}·kg^{-1}

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}

$\gamma = C_p / C_v$ $\kappa = R_d / C_p$ $R_d = C_p - C_v$ Γ_{da}=9.8 K/km

Clausius–Clapeyron relation: $e_s = 6.112\, hPa \cdot \exp\left[\frac{L_v}{R_v}\left(\frac{1}{273K} - \frac{1}{T}\right)\right]$

Answer all questions (English, Norwegian, or Swedish).
State all assumptions.
Good Luck!

1) (5%) Black body radiation

Sketch the relative spectral radiance as a function of wavelength or frequency for three blackbodies at temperatures $T_1 > T_2 > T_3$. Label the curves with their temperatures and give the units used for the axes.

2) (20%) Atmospheric Stability

The Voyager I spacecraft observed Titan, a moon of Saturn. It discovered a hydrocarbon aerosol layer at a pressure of 1000 hPa, where the atmospheric temperature was measured to be 88 K. Even though the surface temperature could not be measured, the surface pressure was measured to be 1500 hPa. For the dry Titan atmosphere, which is 80% nitrogen, the gas constant is R_T=290 $J{\cdot}K^{-1}{\cdot}kg^{-1}$, C_{PT}=1044 $J{\cdot}K^{-1}{\cdot}kg^{-1}$, and $g_T << g_{Earth}$.

a) Estimate the maximum surface temperature assuming the atmosphere is stable with respect to vertical motions. (7%)

b) The true surface temperature was measured later by Voyager II to be 94 K. Do you expect convection in Titan's atmosphere? Why or why not? (6%)

c) Assuming isothermal conditions, how many scale heights above the surface was the hydrocarbon aerosol layer? (7%)

3) (25%) Atmospheric thermodynamics, water vapour and structure

a. A commercial airliner suffers a sudden de-pressurization due to the loss of a cargo door. If the internal and external air pressures were 700 and 300 hPa respectively, and the internal temperature was 19°C before de-pressurization, determine the final internal temperature (assume it is an adiabatic process). (5%)

b. In practice, a fog formed in the airplane as it de-pressurized. What effect would this have on the final temperature? If the relative humidity in the cabin before it de-pressurized was 25%, how much would the final temperature change? (5%)

c. In the winter hemisphere, the 500 hPa level is usually at a height of about 6000 m at a latitude of 30°, and at a height of 5600 m at a latitude of 70°. What is the mean temperature of the layer of atmosphere between 1000 hPa and 500 hPa in each case? (5%)

d. Calculate the number density of CO_2 (425 ppmv) in the atmosphere at ground level (P = 1000 hPa, T = +20° C). (5%)

e. An air mass of temperature +10° C and pressure 1013 hPa contains 10 g/kg water vapour. Calculate the relative humidity. (5%)

4) Multiple Choice (30%):

There is only **one** correct answer so you must **choose the best answer**.
Answer A, B, C… (Capital letters).
Correct answer gives +3; incorrect or blank answers give 0.

Write the answers for the multiple choice questions **on the answer sheet you turn in** using a table similar to the following:

Question	a	b	c	d	e	f	g	h	i	j
Answer										

a. If the atmospheric pressure at the surface of the Earth is 1000 hPa, what is the weight of the atmosphere in kg?

A) $5x10^{15}$ B) $5x10^{16}$ C) $5x10^{17}$ D) $5x10^{18}$ E) $5x10^{19}$

b. If an atmospheric absorption line is saturated, describe what happens to the total absorption in the line if the absorber density continues to increase?

A) The total absorption stays the same
B) The total absorption begins to decrease
C) The total absorption continues to increase
D) The line becomes pressure broadened and absorption increases
E) The line becomes Doppler broadened and absorption increases
F) None of the above

c. In the two-stream approximation, the integral over wavelength and angle can be approximated as two streams at which angles to the vertical?

A) $\theta = \pm 24°$
B) $\theta = \pm 35°$
C) $\theta = \pm 42°$
D) $\theta = \pm 53°$
E) None of the above

d. Which of the statements below is wrong for a neutrally stable atmosphere?

A) The atmospheric lapse rate equals the dry adiabatic lapse rate.
B) A displaced parcel will not be forced from its new altitude.
C) The Brunt Väisälä frequency is an imaginary number.
D) The temperature of the parcel equals the atmospheric temperature at every pressure level.
E) The parcel's temperature change with altitude is constant.
F) None of the above.

e. In which layer of the atmosphere is ozone the major species?

A) Stratosphere
B) Mesosphere.
C) Troposphere.
D) Thermosphere.
E) Exosphere.
F) None of the above.

f. How do you find the Lifting condensation level on a Skew-T diagram?

A) Find the water vapour mixing ratio of the dew point temperature.
B) Find the intersection between the dry adiabat and the line of constant $\mu_S = \mu$
C) Find the region where the temperature starts to rise with altitude.
D) Find where the atmospheric lapse rate is equal to the dry adiabatic lapse rate
E) Find where the atmospheric temperature equals the dew point temperature
F) None of the above

g. In the northern hemisphere, in which direction will the Coriolis force direct air moving northward or southward?

A) North.
B) South.
C) East.
D) West.
E) Toward the right of the trajectory of the air
F) Toward the left of the trajectory of the air

h. How can we describe light scattering by clouds?

A. Mie scattering theory.
B. Rayleigh scattering theory.
C. Tyndall scattering theory.
D. Geometric scattering theory.
E. None of the above.

i. What wavelengths of sunlight are absorbed by molecular nitrogen in the troposphere?

A) Infrared.
B) Ultraviolet.
C) Radio waves.
D) Microwaves.
E) Visible.
F) None of the above.

j. In an isothermal atmosphere, two air parcels, one wet and one dry, are displaced upward. What happens to the parcel temperatures?

A) They remain constant since the atmosphere is isothermal.
B) Both parcels heat at the same rate as they get nearer to the Sun.
C) The wet air parcel cools faster than the dry one due to its thermal conductivity.
D) The dry air parcel cools faster than the wet one due to latent heat effects.
E) Both parcels cool at the same rate as the pressure drops.
F) None of the above.

5) (20%) Radiation

The optical depth for incoming short wavelength solar radiation (averaged over all wavelengths) is defined by:

$$\tau(z) = \int_z^{\infty} \rho \ \mu \ k \ dz$$

Where $\rho(z)$ is the air density, $\mu(z)$ is the mass mixing ratio of the absorbing species i, and k is the attenuation coefficient.

Assume an isothermal atmosphere with a scale height of H_e=7 km, a surface density, ρ_o = 1.2 kg/m^3, and a constant attenuation coefficient, k = 0.02 m^2/kg(i).

Then, for $\mu(z) = \mu_o \cdot \exp(-z/H_i)$, where μ_o at the surface = 0.01 and H_i = 4km:

a. Calculate the optical depth at 7 km and 2 km altitude (6%)
b. If we look at the downward flux irradiance of solar radiation with a zenith angle (angle measured from the zenith) χ, give an expression for the flux irradiance at height z in terms of the flux irradiance at the top of the atmosphere, F_∞, the optical depth $\tau(z)$ derived in part a, and χ. (3%)
c. If we take F_∞=400 W/m^2 and $\chi = 45°$, what is the flux irradiance at 7 km and 2 km altitude? (3%)
d. From the above results calculate the local warming in K/hour at 7 km and 2 km altitude due to the local absorption of solar ultraviolet light (note, this is an isobaric process with Cp = 1004 J/K/kg). (8%)