NS-2553

Hertentamen Klimaat, straling en thermodynamica – 16 maart 2010

Openboek-tentamen: nee

Enkele opmerkingen vooraf:

- formuleer je antwoord nauwkeurig
- let op spel- en taalfouten
- denk aan de eenheden
- schrijf duidelijk en vermijd doorhalingen
- constanten en formules op de laatste pagina
- succes!

Exercise 1

a) Consider a cloud with a vertical extent of 200 m, a cloud drop number concentration of 75 cm^{-3} and an average droplet radius of 12.5 mm. Calculate the cloud liquid water content, the liquid water path (i.e., the vertically integrated liquid water content), and the cloud optical thickness.

b) A cloud with equal dimensions and liquid water content forms under more polluted conditions. Now, the droplet number concentration is 225 cm^{-3}. Calculate the liquid water path and the cloud optical thickness for this cloud.

c) Compare both cloud albedo's. The cloud albedo A can be approximated from the optical thickness t using: $A \approx \frac{\tau}{\tau + 6.7}$

d) assuming that the cloud droplets do not absorb shortwave radiation, calculate the average radiative forcing at the top-of-atmosphere (TOA) between both clouds.

Exercise 2

An air parcel at the surface (1000 hPa) has an initial temperature of 293 K, and a relative humidity of 75%. The parcel ascends adiabatically.

a) Calculate the dew point temperature at the surface. At what altitude is the parcel exactly saturated?

b) Calculate the temperature, water vapor pressure and relative humidity for the parcel at 250 m and 1000 m altitude. Also calculate the mixing ratio of liquid water (in g/kg).

Exercise 3

In this exercise we will examine the Arctic stratosphere during polar night.

a) Consider a layer of air, centered at 30 km altitude and with a thickness of 5 kilometers. The temperature is 233 K. Show that the density of the air is approximately 15 g/m^3.

b) Assume the average emissivity of the air is 0.05, and that the layer does not receive energy from the sun (polar night) or from below. Calculate the emission flux of longwave radiation and the initial cooling rate of the air.

c) When the temperature drops below -80°C, polar stratospheric clouds (PSC's) are formed. Briefly explain how PSC's may affect the destruction of the polar stratospheric ozone layer.

Exercise 4

The average global temperature has increased over the past decades, very likely due to emissions of long-lived greenhouse gases. An area of uncertainty around this change involves the observation that the majority of the increase comes from nighttime temperatures and not so much from daytime temperatures. One hypothesis to explain these differences involves the role of atmospheric aerosols - very tiny particles released into the atmosphere from various combustion processes. How might the aerosol hypothesis explain why nighttime temperatures have increased over the past 40 years, while daytime temperatures have remained essentially unchanged?

Exercise 5

a) The optical thickness of a cloud is given by $\tau = \sigma \int N(z)dz$, with σ the scattering cross section of a droplet (m^2), $N(z)$ the drop concentration profile in the cloud (m^{-3}), and z the height in the cloud (m). The optical thickness for sunlight can also be approximated by:

$$\tau = 2.4\left(\frac{LWC}{\rho_l}\right)^{2/3} N^{1/3}\Delta z$$

with LWC the liquid water content (g/m^3) and ρ_l the specific density of water (g/m^3), and Δz the cloud thickness. The equations give the same results when two important assumptions are made. What assumptions are meant here? Show that both equations are equal.

b) Show that a change in droplet number concentration N causes a change of the optical thickness according to $\frac{\Delta\tau}{\tau} = \frac{1}{3}\frac{\Delta N}{N}$.

Constants and equations

Heat capacity air at constant volume/pressure:	$717 / 1004\ J^{-1}\ K^{-1}\ kg^{-1}$
Latent heat of evaporation/condensation:	$L = 2500$ J/g
Molecular mass of water / air:	18 / 29 g/mole
Gas constant:	$R = 8.314\ J\ mole^{-1}\ K^{-1}$
Specific gas constant for water vapor:	$R_v = 462\ J\ kg^{-1}\ K^{-1}$
Specific gas constant for air:	$R_d = 287\ J\ kg^{-1}\ K^{-1}$
Specific density of water:	$r_w = 10^6\ g\ m^{-3}$
Stefan-Boltzmann constant:	$s = 5.67*10^{-8}\ W\ m^{-2}\ K^{-4}$
Solar constant:	$S = 1368\ W\ m^{-2}$

Clausius Clapeyron: $e_s(T) = 10^{\left(9.4041 - \frac{2354}{T}\right)}$ (T in K, e in hPa)

pressure-altitude relation: $p = p_0 \exp(-0.125 * z)$ (z in km, p_0 = 1013 hPa)
