Examination Climate and Atmosphere, June 20, 2014

The examination is checked by the second examinator: prof.dr. H.A.J. Meijer.

All problems have equal weight.

Final mark = 0.9 * mark examination + 1 for active cooperation at practicum City Climate.

Some equations and constants:

S_0 = 1361 Wm^{-2}; g = 9.81 ms^{-2}; R = 287 J $kg^{-1}K^{-1}$; c_p = 1005 J/kg; Earth radius = 6.37 10^6 m; albedo earth = 0.298; p_0 = 1013 hPa; average temperature near the earth surface 288 K; σ = 5.67 10^{-8} W $m^{-2}K^{-4}$. Saturated water vapor pressure $e_s = 611 \exp[17.67\, T/(T+237.3)]$ (T in ^{0}C)

Potential temperature: $\theta = T\left(\frac{p_0}{p}\right)^{\kappa}$ with $p_0 = 1000$ hPa and κ= 2/7

Nyquist frequency: $N = \text{sqrt}\left(\frac{g}{\theta_E}\frac{d\theta_E}{dz}\right)$

Equation of motion: $\frac{D\mathbf{u}}{Dt} + \frac{1}{\rho}\nabla p + g\hat{\mathbf{z}} + f\hat{\mathbf{z}} \times \mathbf{u} = F$

Geostrophic wind: $\mathbf{u}_g = \frac{\hat{\mathbf{z}}}{f\,\rho} \times \nabla p$

Frontal slope by Margules: $\tan\gamma = \frac{2\,\rho\,\Omega\Delta u}{g\,\Delta\rho}$

Problem 1

Use the mean temperature and $p = 1000$ hPa at the surface and assume that the temperature in the atmosphere is given by the dry adiabatic lapse rate.

a) Why is this a poor approximation in the troposphere?
b) Why does this approximation not hold in the thermosphere?
c) Derive a relation between pressure and height in the adiabatic atmosphere.
d) Calculate the height that divides the atmospheric mass into equal parts, so 50% of the mass is below that level.
e) What is the temperature on top of the atmosphere? Explain your answer.

Problem 2

Given: the temperature at the 800 hPa level is 260 K and the lapse rate is -6.4 K/km

a) Calculate the potential temperature at 800 hPa.
b) Calculate the adiabatic lapse rate at 800 hPa.
c) Calculate the Nyquist frequency at 800 hPa.
d) Explain in words what kind of vertical motion occurs at 800 hPa.
e) Some lenticular clouds are observed at 800 hPa behind a mountain ridge. Calculate the distance between succeeding clouds when the wind velocity is 12 m/s.

Problem 3

Assume that air flows pole ward with conservation of angular momentum.

a) At what height and latitudes could this be an acceptable approximation?
b) Calculate the zonal velocity that arises after pole ward transport over 10^0 and initial zero zonal velocity for two cases: start at the equator and start at 80^0.
c) Explain the significance of your answer for the strength of the Hadley- and polar cells.

Problem 4

The temperature of the 500 hPa level at 60 ^{0}N is 260 K and the height h of that level around a low pressure system is given by: $h = 5300 + 250\ e^{-r^2/R^2}$ where r is distance from the center and $R = 500$ km.

a) At which radius is the highest geostrophic wind velocity?
b) Calculate the maximum geostrophic wind.
   If you cannot find an answer, use $u_g = 30$ m/s
c) Is the geostropic assumption valid? Compare the Coriolis acceleration with the centripital acceleration.
d) Is the real wind velocity higher or lower than the geostrophic wind? Motivate your answer.
e) Do the highest wind velocities occur around low or high pressure systems? Motivate your answer and compare with your answer of problem 4d.

Problem 5. The figure below shows the zonal mean temperature in January, February and March.

a) Explain the temperature minimum high above the equator.
b) Estimate the potential temperature at that temperature minimum
c) Calculate the geostrophic wind at 70 ^{0}N on the levels 950 and 700 hPa
d) Calculate the thermal wind at 70 ^{0}N on the levels 950 and 700 hPa
e) Explain why a thermal wind can blow in this area with almost constant temperature.