1. **Rossby wave formula (long waves in the westerlies)** *(5 points)*

   a) Assume a mean flow with constant zonal velocity $u = U = const > 0$ and a varying north-south component $v = v(x,t)$ which gives the total motion a wave-like form. Furthermore, h =const.

   Write down the vorticity equation for this specific flow! Remember that the vorticity equation is

   $$\frac{D}{Dt}\left(\frac{\zeta + f}{h}\right) = 0 \tag{1}$$

   b) Use a) and the ansatz

   $$v(x,t) = A\cos[(kx - \omega t)] \tag{2}$$

   to determine the disperion relation $\omega(k)$, the group velocity $\frac{\partial\omega}{\partial k}$, and the phase velocity $c = \omega/k$.

   c) Derive the wavelength $L = 2\pi/k$ of the stationary wave given by $c = 0$.

2. **Conservation of potential vorticity:** *(3 points)*

   An air column at 53°N with $\zeta = 0$ initially streches from the surface to a fixed tropopause at 10 km height. If the air column moves until it is over a mountain barrier of 2 km height at 30°N, what is its absolute vorticity and relative vorticity as it passes the mountain top?

   Assume: $\sin 53° = 0.8; \sin 30° = 0.5$
   The angular velocity of the Earth $\Omega = 2\pi/(1\text{ day})$.
   Potential vorticity: $(\zeta + f)/h$

3. **Questions about the course** *(3 points)*

   a) Please write down the barotropic potential vorticity equation for large-scale motion!

   b) What are the two dominant terms in the horizontal momentum balance for the large-scale dynamics at mid-latitudes?

   c) What are the names of the 3 meridional cells in the atmosphere?
   Draw a picture with the direction!

Notes on submission form of the exercises: *Working in study groups is encouraged, but each student is responsible for his/her own solution. The answers to the questions can be send until the due date (12:00) to Hanna Knahl (hanna.knahl@awi.de), Alexander Thorneloe (alexander.thorn@awi.de).*