1. **Rossby, gravity, and Kelvin waves** *(5 points)*

   Start with the shallow water equations

$$\frac{\partial u}{\partial t} - fv = -g\frac{\partial \eta}{\partial x} \quad (1)$$

$$\frac{\partial v}{\partial t} + fu = -g\frac{\partial \eta}{\partial y} \quad (2)$$

$$\frac{\partial \eta}{\partial t} + H\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) = 0 \quad (3)$$

   with H=const. as mean depth and η as surface anomaly.

   a) With the elimination of the fast gravity waves in equation (3)

$$\frac{\partial \eta}{\partial t} = 0$$

   derive the dispersion relation for divergence-free Rossby waves! Ansatz: Introduce a streamfunction for u,v: $\Psi \sim \exp(ikx + ily - i\omega t)$

   b) With the assumption of $f = f_0 = 0$ derive the dispersion relation for gravity waves! The restoring force is related to gravity. Ansatz: take one of the equations (1,2,3) and derive the solution.

   c) Kelvin waves:
   What is the dispersion relation for Kelvin waves?
   Make a sketch of the coastally trapped Kelvin wave on the Northern Hemisphere ocean basin.
   Make a sketch of the equatorial trapped Kelvin waves.

   d) Explain the difference between dispersive and non-dispersive waves!
   You could use the $\omega(k)$ formula for Rossby and Kelvin waves.

2. **Advection** *(3 points)*

   A ship is steaming northward at a rate of 10 km/h. The surface pressure increases toward the northwest at a rate of 5 Pa/km. What is the pressure tendency recorded at a nearby island station if the pressure aboard the ship decreases at a rate of 100Pa/3h?

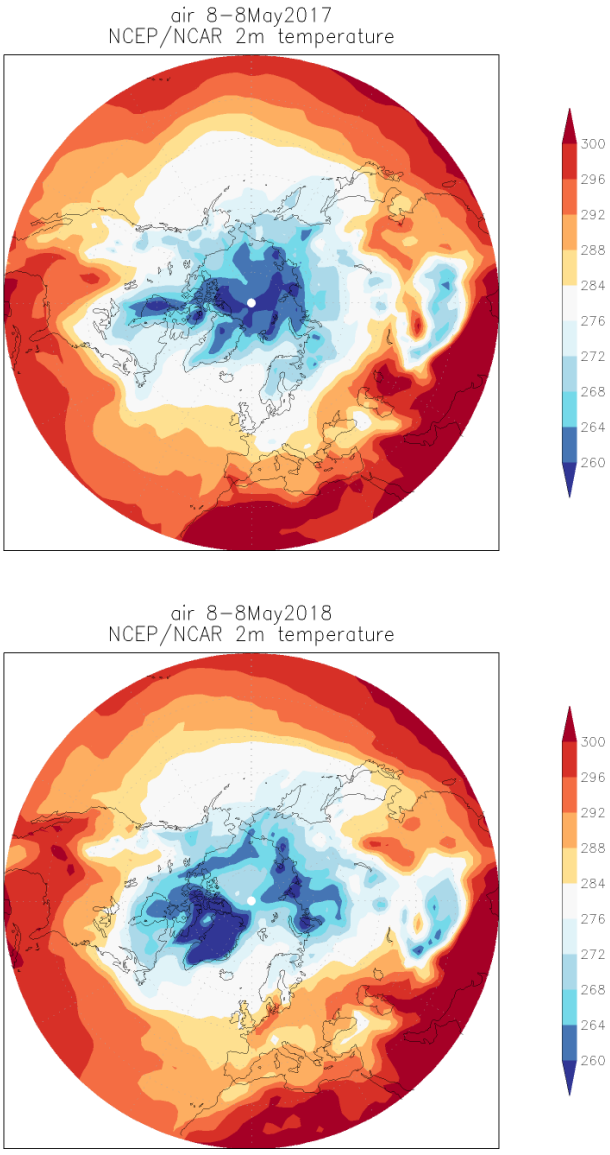

Figure 1: Surface Air Temperature (K) for May 8 in the years 2017 (upper) and 2018 (lower panel). Data are from the NCEP/NCAR reanalysis project (Kalnay et al., Bull. Amer. Meteor. Soc., 77, 437-470, 1996).

3. **Circulation and temperature in May 2017 and 2018** *(2 points)*

   Consider the temperatures on May 8 in the years 2017 and 2018 in Fig. 1. The temperature differences over Central and Northern Europe are striking. Explain the temperature differences over this area by the large-scale atmospheric circulation. The associated circulation can be derived from the Sea Level Pressure (Pa) patterns in Fig. 2 (geostrophic balance). Explain your observation in words (not more than 4 sentences).

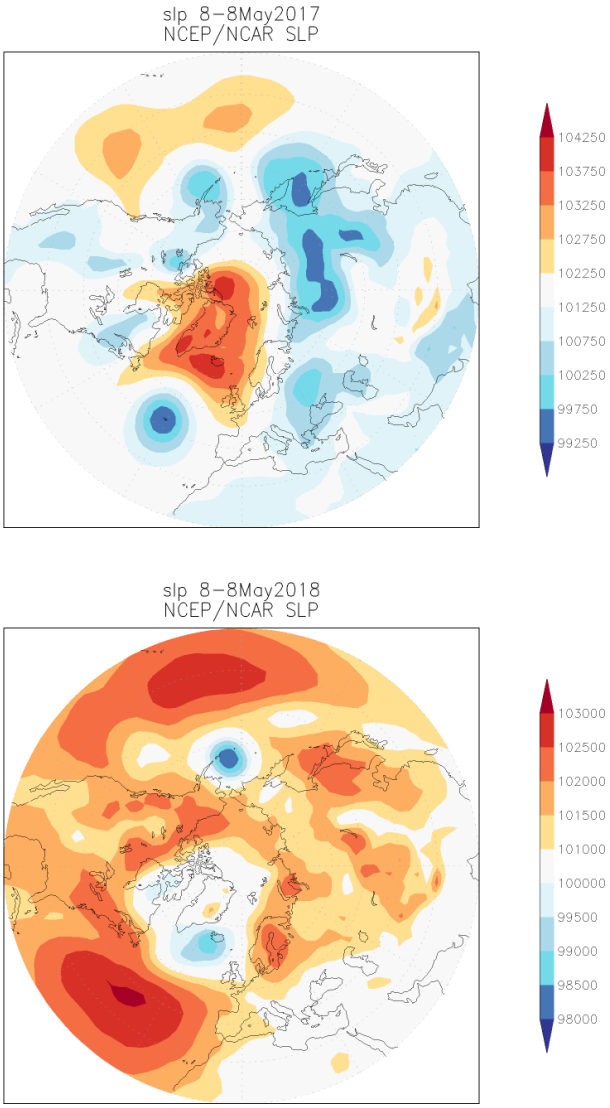

Figure 2: As in Fig. 1, but for Sea Level Pressure (Pa). The circulation in 2017 is characterized by a high pressure over Greenland, Iceland, and the Nordic Sea, and by surrounded low pressure systems.

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).*