1. **Questions about fluid mechanics** (*3 points*, **for each Q** *1 point*).

   Q1: Name three different dimensionless parameters which can characterize the flow.

   Q2: Please state: The dimensionless Reynolds number is $Re = U/(L\nu)$ or $Re = UL/\nu$ or $Re = U^2L/\nu$? ν denotes the kinematic viscosity, L a length-scale L determined by the geometry of the flow, and U a characteristic velocity.

   Q3: Describe in words the Rayleigh-Bénard instability. The basic state possesses a steady-state solution in which there is no motion, and the temperature varies linearly with depth:

$$u = w = 0 \tag{1}$$

$$T_{eq} = T_0 + \left(1 - \frac{z}{H}\right)\Delta T \tag{2}$$

   When this solution becomes unstable, ... (please continue)

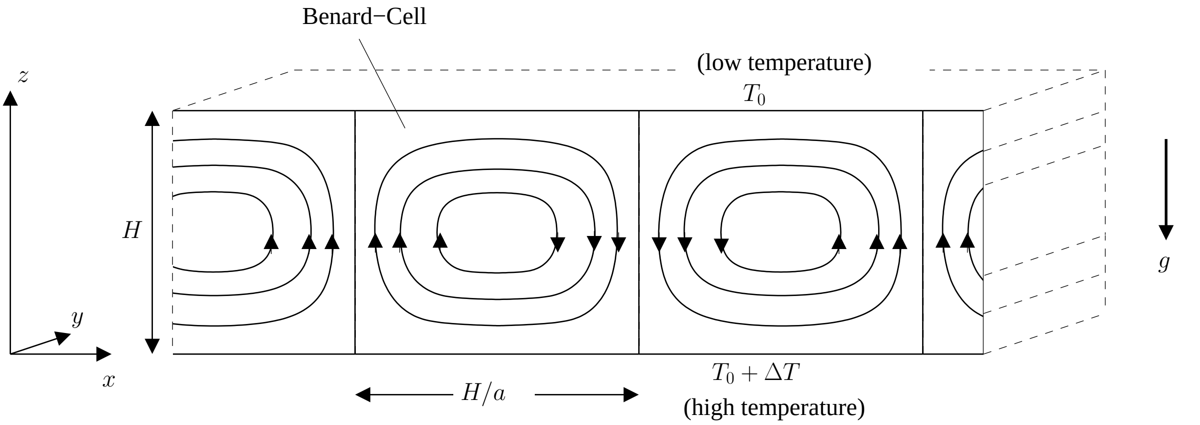

Figure 1: Geometry of the Rayleigh-Bénard system.

2. **Lorenz equations:** *(3 points)*

   Consider the Lorenz equations which were derived from the Rayleigh-Bénard system (Fig. 1) in the lecture:

$$\dot{x} = \sigma(y - x) \tag{3}$$

$$\dot{y} = rx - xz - y \tag{4}$$

$$\dot{z} = xy - bz \tag{5}$$

with $\sigma, r, b > 0$. σ is the Prandtl number. Furthermore, Rayleigh number $R_a \sim \Delta T$, critical Rayleigh number R_c, and $r = R_a/R_c$.

(a) Evaluate the equilibrium points.
(b) Determine the stability of the $(0,0,0)-$equilibrium through linearization! Control parameter is r.
(c) Show the symmetry: The Lorenz equation has the following symmetry $(x, y, z) \rightarrow (-x, -y, z)$ independent on the parameters σ, r, b.

3. **Lorenz equations on the computer:** *(3 points)*

Solve the Lorenz equations numerically using the parameters $\sigma, r, b = 10, 28, 8/3$ and $\sigma, r, b = 10, 0.8, 8/3$. Initial conditions: $(x_0, y_0, z_0) = (1, 3, 5)$ and (21,13,2). Provide the 4 solutions with the associated files in R markdown or Jupyter Notebook.

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

Consider the temperatures on May 8 in the years 2017 and 2018 in Fig. 2. 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. 3 (geostrophic balance). Explain your observation in words (not more than 4 sentences).

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 Smit Doshi (Smit.Doshi@awi.de), Dr. Qiyun Ma (Qiyun.Ma@awi.de).*

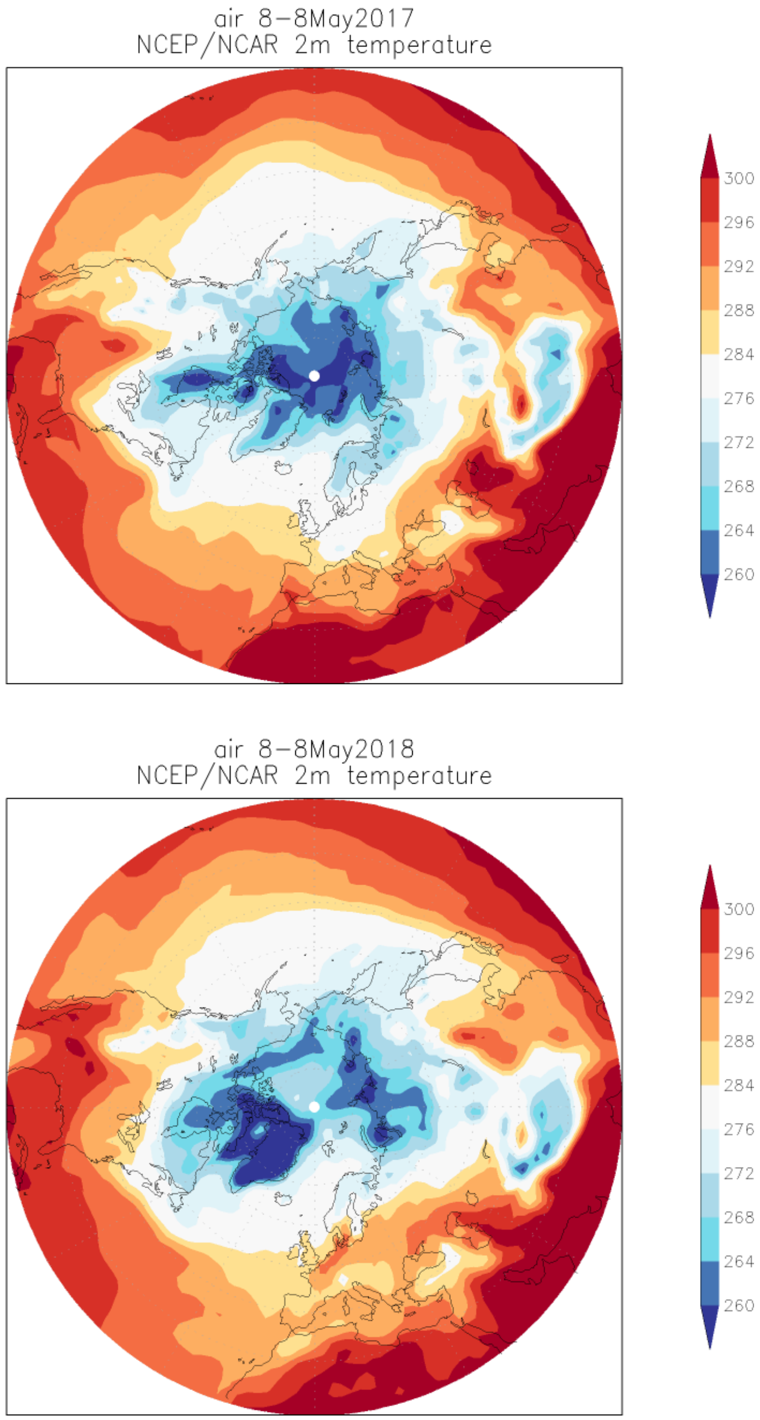

Figure 2: Surface Air Temperature (K) for May 8 in the years 2017 (upper) and 2018 (lower panel). Data are from the NCEP/NCAR reanalysis project (Kalnay et al., Bull. Amer. Meteor. Soc., 77, 437-470, 1996).

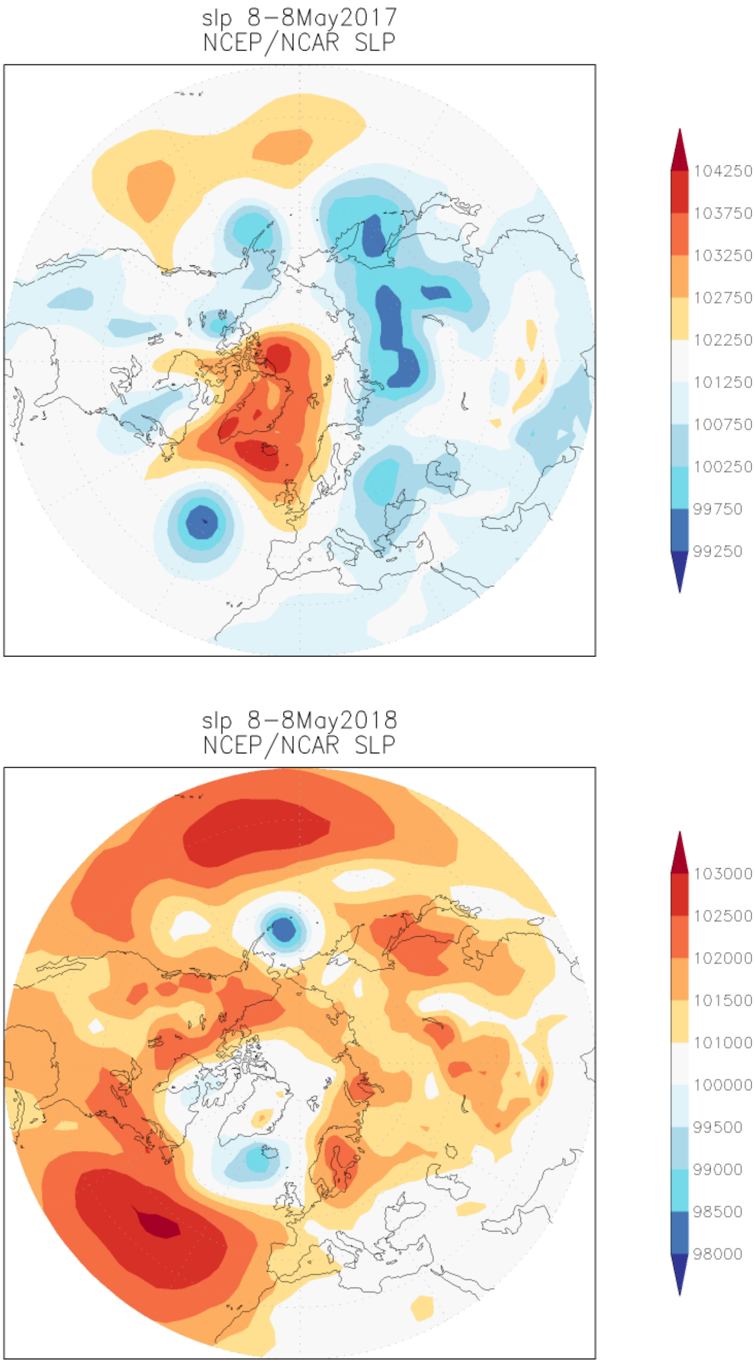

Figure 3: As in Fig. 2, but for Sea Level Pressure (Pa). The circulation in 2017 is characterized by a high pressure over Greenland, Iceland, and the Nordic Sea, and by surrounded low pressure systems.