Modelling the isostatic response from glacial erosion of an Arctic continental shelf

1. **Introduction and Background**

   High-latitude continental margins have developed from the repeated growth of grounded ice sheets onto the shelf, in contrast to their glacier-free low-latitude counterparts. For the Arctic Barents Sea continental margin north of Norway, such ice sheets repeatedly covered and shaped the continental shelf over the last 2.7 million years. Large volumes of sediment eroded from the shelf and surrounding land areas (sediment unloading) was transferred by paleo-ice streams within the ice sheet to the adjacent continental slope (sediment loading). Estimates of up to 1000 m of glacial erosion of the shelf areas are based on a volumetric mass balance approach, quantifying the erosional products and considering their likely source areas. However, this approach do not account for the combined isostatic response resulting from sediment and ice loading and unloading. Therefore, the aim of this project is to develop and solve a “state-of-the-art” model to study the response of the crust to this loading and unloading of sediments and ice.

   The isostatic response of the crust can be modeled by coupling several classical dynamical models from physics (e.g., Watts, 2001; Wangen, 2010). By considering the mechanical and thermal properties of the interacting materials with models of erosion processes (Newman and Turcotte, 1990; Sornette and Zhang, 1993), one may in principle construct mathematical models suitable for discretization and numerical solution. However, these nonlinear models are in general hard to solve, and the complicated and often poorly understood boundary conditions pose additional practical obstacles. In particular, the evident spatial inhomogeneities are often neglected in the modeling. In this project, the inclusion of spatial inhomogeneous and temporal nonstationarities will be central to improve our understanding of the space-time glacial impact on continental margins. An original aspect of the proposal is that we want to couple tractable theoretical models with state-of-the-art estimators of key crustal parameters, e.g. the use of multi-taper spectral estimators (Hanssen, 1997) to estimate the flexural rigidity of the lithosphere (Ojeda and Whitman, 2002; Kirby, 2014).

2. **Aim of Research**

   This project will focus on the following research questions:

   a. What is the optimal geodynamical model that couples elasticity/viscoelasticity of the crust, mantle viscosity, thermal transients, nonstationary sedimentation processes, and erosion? What are the constrained numerical solutions to this model? From the modelling:
   
   b. What was the rate of subsidence of the outer margin caused by the sediment loading?
   
   c. How did the inner part of the Barents Sea margin respond to the sediment loading?
   
   d. What was the additional effect of ice sheet loading/unloading for the pattern and rate of the isostatic response?

   Why study this research topic? This project will contribute to (1) ongoing academic research projects on the paleoclimate of this area and the results may be used in (2) basin modelling by the academia and industry in their studies on the evolution of sedimentary basins in this area:

   - Subsidence and/or uplift of the crust would have affected paleo-water depth on long time scales. This may have influenced on the pattern of ocean circulation of this area and the establishment and growth of marine-based ice sheets (the Barents Sea Ice Sheet) – i.e. the evolution of the paleo-climate of Arctic Europe on a longer time scale.
- The applied aspect of this project is that it may increase the understanding of the migration pattern of hydrocarbons within sedimentary basins of the Barents Sea shelf and by this explain the presence and location of shallow reservoirs as well as the distribution of pockmarks.

3. Methods
In this project, we will use state-of-the-art 1D and 2D numerical models to model the response of the crust, and an ice sheet model for the long-term development of the Barents Sea Ice Sheet. Results from basin modelling will be integrated if applicable. The successful candidate is expected from his/her expertise to make the necessary recommendations for selection of the modelling tools.

4. Career development
The project will for the candidate result in increased knowledge on the paleoclimate and evolution of sedimentary basins at northern high-latitudes where the influence of ice sheets resulting in erosion and uplift has been a major issue. It will also allow for integrating observational studies and modelling results to parameterize and test own observations, important for the candidates own research as well has his/her ability to communicate within multidisciplinary teams.

5. Transferable research-related skills
The successful candidate will be full-time on this project. Communication of results is an important part of the work and the candidate is expected to publish results in international scientific journals, present at relevant conferences and contribute to the ongoing research of the ARCEX project. During the project period it will also be possible to participate in data collection through fieldwork and/or cruises to develop expertise in this part of the work.

6. Supervisors and collaborators
The main supervisors for this project will be:
Prof. Jan Sverre Laberg, Prof. Alfred Hanssen, and Assoc. Prof. Tom Arne Rydningen
At the Research Center for Arctic Petroleum Exploration (ARCEX) at the Dept. of Geology, University of Tromsø – the Arctic University of Norway (http://www.arcex.no/), we have a strong expertise on the development of glaciated continental margins (Laberg, Rydningen) and physical, statistical and numerical modelling of nonlinear and nonstationary dynamical phenomena (Hanssen). So far, isostatic modelling has not been part of our activities, therefore, the proposed project represents the first part of establishing and integrating numerical modelling as a new activity within our field of research. At UiT, we have available a massively parallel computing facility (“Stallo”, Norway’s most powerful computer) intended for scientific high-performance computing (HPC). We will use Stallo as a computational platform for the numerical simulation codes and data analysis in this project. The post doctor will gain experience and training in using a state-of-the-art HPC facility, and we will be able to solve our models efficiently and accurately. In addition, our academic and industry partners have expertise on the geological history of the Barents Sea area and the activity proposed here adds new skills to the ongoing activity. It also complements other ongoing joint projects with our academic partners including the Alfred Wegner Institute in Germany and the Italian National Institute of Oceanography and Experimental Geophysics, Trieste, Italy.

7. References (to be/not to be included)