Topic of proposed PhD project

MECHANICAL MODELING AND SEISMIC ANALYSIS OF THE SOURCES OF GLACIAL EARTHQUAKES IN POLAR REGIONS

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Host lab/ Team: **Institut de Physique du Globe de Paris, Seismology team – (UMR7154) and Centre des Matériaux, Mines ParisTech - (UMR 7633)**

Financing: Doctoral contract with or without assignment

For more information and application go to http://ed109.ipgp.fr, section: Offres de these (PhD offer). You must apply on the Doctoral School website

Problem overview

The flow of marine-terminating polar glaciers is strongly affected by climate change. A key problem is how to quantify the mass loss of these glaciers. The work proposed in this PhD project will make it possible to conduct spatio-temporal monitoring of the mass loss due to iceberg calving, an essential component of the overall mass changes.

Iceberg calving is strongly coupled with the dynamics of glaciers. This coupling is still poorly understood due to the lack of knowledge concerning the processes involved and the difficulty of measuring the phenomena. In this context, the seismic signals generated and continuously recorded during these episodes provide a unique tool to study them.

Glacial earthquakes have magnitudes between 4.6 and 5.2. They are recorded at teleseismic distances and are mostly located on the marine-terminating glaciers of the Greenland polar ice-sheet. The increasing number of seismic events detected is correlated with the thinning and retreat of glaciers. Glacial earthquakes are characterized by the presence of long-period surface waves (~10-100s) with radiation patterns that describe a force at the origin aligned with the direction of the glacier flow. These earthquakes have been associated with the detachment of very large icebergs (~km^3), that rotate slowly, impacting the glacier terminus. The generated contact force is responsible for the co-seismic displacement of the glacier.

Until very recently, the sources of glacial earthquakes were characterized with very restrictive force models, making it difficult to interpret them in terms of physical processes. Through the PhD work of Amandine Sergeant (2016), we recovered the histories of the forces at the origin of glacial earthquakes by inverting seismic waveforms, without relying on any a priori force model. The recovered forces have been shown to provide more physical information than those reported in the literature. By coupling this inversion with the analysis of a movie that recorded iceberg calving on an instrumented site, we have shown that several processes can be involved in the generation of the seismic wave: ice avalanche, iceberg calving and capsize of a first and a second iceberg, and acceleration of the ice-melange made of floating ice debris (**Figure 1 a-c**, video 1, video 2). These sources generate forces in the glacier system with different amplitudes, durations and spectral signatures. Given the variable nature of the processes involved and the complexity of the iceberg calving phenomena, the determination of iceberg dimensions from seismic signals is a major challenge.

Mechanical modeling of the calving process, initiated in the PhD work of A. Sergeant, is a powerful tool that can be used to guide the seismic inversion. The dynamic iceberg model that we have developed, based on the Finite Elements method, takes into account dynamics of iceberg-ocean interactions and contact with the glacier's terminus (**Figure 1 d-f**). The coupling of mechanical modeling and seismology has made it possible, for the first time, to determine the volume and the position of an iceberg by comparing a catalogue of forces simulated in 2D to the forces inverted from seismic data. This approach is thus very promising for the estimation of mass loss due to iceberg calving.

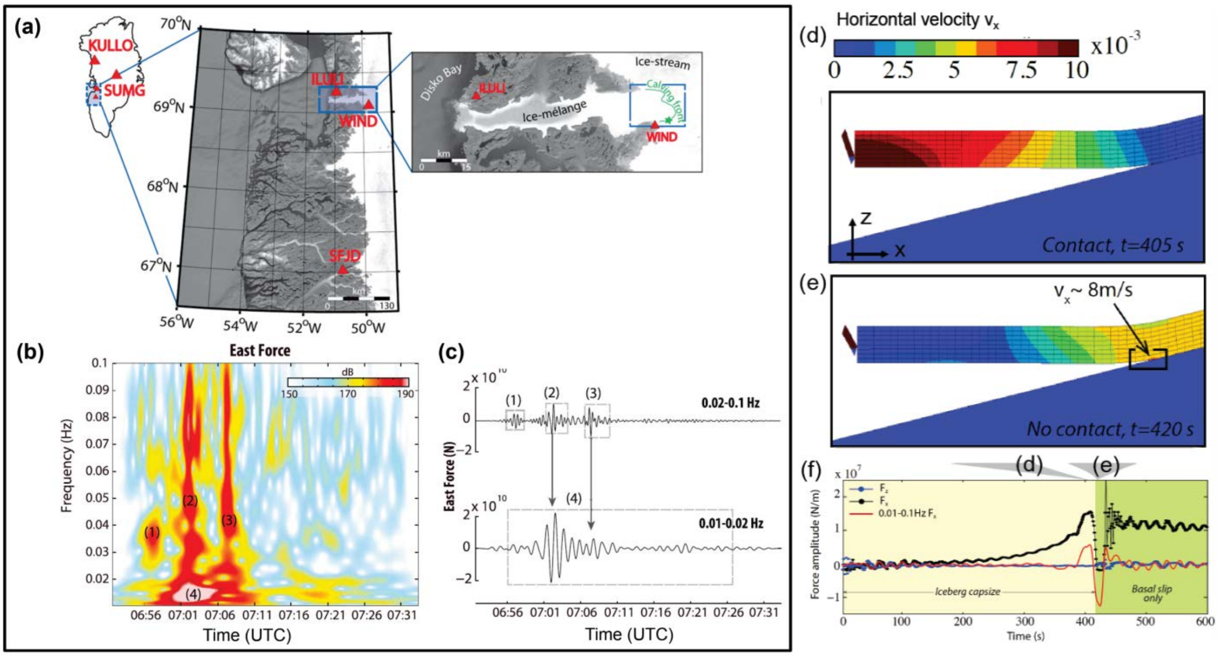

Figure 1 : (a) Landsat images of Jakobshavn Isbrae (West-Greenland) and seismic stations used for the inversion of the force of a glacial earthquake whose spectral and temporal changes (Est-component) are shown in (b, spectrogram) and (c), respectively. The force complexity illustrates the different processes involved, i. e. (1) an ice-avalanche, (2-3) the calving and overturning of two successive icebergs, and (4) the ice-melange acceleration in the glacial fjord. (d)-(e) Numerical modeling using the Finite Elements method of the glacial tongue and the iceberg, and (f) simulation of the force generated during the calving. On the force filtered between 0.01 and 0.1 Hz (red), we can see a signal related to the normal force applied to the terminus by the iceberg (light yellow area corresponding to (d)) and a seismic signal generated by the basal sliding (green area corresponding to (e), after iceberg detachment.

Proposed PhD project

Several key questions must still be answered to fully exploit the coupling between mechanical modeling and seismology. Does basal sliding of the glacier on the bedrock generate part of the observed seismic waves? What is the deformation of the glacier during iceberg detachment and how does it affect the seismic signal? How does the full there-dimensional modeling enrich the model? How does local topography influence contact forces? Can mechanics-seismology coupling be used to characterize smaller icebergs creating much weaker earthquakes? How can information be extracted from high frequency seismic signals? Can seismic signals be used to quantify changes in the mass loss of Greenland ice-sheet?

We propose to tackle these questions in this PhD project. Three topics will be developed:

1 – Mechanical modeling

We will continue improving the iceberg calving model based on the Finite Element software Z-set (www.zset-software.com) developed by the Centre des Matériaux at Ecole des Mines de Paris and by ONERA. A simplified fluid/structure interaction model to simulate iceberg calving has already been implemented in the code as well as viscous friction model and a realistic ice rheology will be used to model glacier flow. A significant part of the work will involve taking into account relevant friction laws at glacier-bedrock interface, because this friction controls the transfer of stresses to the solid Earth. The finite-element model will then be extended to simulate real 3D cases.

2 –Characterization of the glacial earthquakes catalogue and quantification of the spatio-temporal change of mass loss related to icebergs

We will create a data base of seismograms recorded by regional networks, extracted from the data base of glacial earthquakes recorded at the global scale. The forces at the origin of glacial earthquakes will be calculated using waveform inversion methods without any a priori assumptions concerning the source function. The inverted forces will be compared to the Finite-Element simulation in order to recover the icebergs characteristics (in particular their volume).

3 –Study of the optimal characteristics of a seismic network in view of improving the catalogue

We will extend this approach to the calving of smaller icebergs that cannot be detected at the global or even regional scale. We will choose a strategic site with a seismic station located near the calving front so as to detect smaller sources that will be characterized and simulated numerically.

Supervision team

The PhD student will be supervised by a **multidisciplinary** team:
Anne Mangeney (Professor, University Paris Diderot, IPGP): Geophysical flows
Vladislav Yastrebov (Research associate CNRS, Centre des matériaux, Mines ParisTech): Numerical mechanics and contact/friction mechanics
Olivier Castelnau (Research Director, CNRS, PIMM laboratory, ENSAM Paris): Mechanics of Materials
Jean-Paul Montagner (Professor, University Paris Diderot, IPGP): Seismology
Eleonore Stutzmann (Physicist, IPGP): Seismology

Student profile

We are looking for a candidate with a solid background (Master of science or equivalent) in mechanics, modeling and/or geophysics. The candidate should like numerical modeling and data processing, and show high motivation, rigor, autonomy, curiosity and insight. She/he should be open-minded and possess strong analytical skills. The capacity to work in a multidisciplinary team is also an important factor. Mastering object oriented programming is an advantage.

Working conditions

The candidate will have a working contract of 3 years funded partially by the Direction Générale de l'Armement (DGA). She/he will be registered at the Doctoral School of IPGP. The candidate will have the possibility of teaching at University Paris Diderot if she/he so desires.

Application

Applications should be sent by email to anne.mangeney@gmail.com and vladislav.yastrebov@mines-paristech.fr. The application should include the following documents: CV, a letter expressing your motivation, copies of your diplomas, marks, and possible reference letter(s).

Contacts

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