PhD Position
Stability of Antarctic ice shelves: Implications in terms of sea level

SECTOR: Higher Education Institution

LOCATION: France, Grenoble

RESEARCHER PROFILE:
☐ First stage researcher,

INSTITUTION: Univ. Grenoble Alpes, University of Innovation

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Key figures:
- + 50,000 students including 7,000 international students
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- 180 different nationalities
- 1st city in France where it feels good to study and 5th city where it feels good to work
- ISSO: International Students & Scholars Office affiliated to EURAXESS
REFERENCES:

Internal Strategic Partnership with the University of Swansea
SUBJECT TITLE: Stability of Antarctic ice shelves: Implications in terms of sea level
RESEARCH FIELD: Glaciology, modelling, finite element code, ice rheology, field work, Antarctica
SCIENTIFIC DEPARTMENT (LABORATORY’S NAME): Institut des Géosciences de l’Environnement
DOCTORAL SCHOOL’S: Terre, Univers, Environnement
SUPERVISOR’S NAME: Emmanuel Le Meur

SUBJECT DESCRIPTION:

State of the art / Scientific or technologic challenges:

It is now granted that the Antarctic ice sheet (AIS) has been losing mass for the last 25 years (Sheperd et al., 2012). One of the main uncertainties in its contribution to global sea-level rise over the coming centuries is the dynamical response of the marine based sectors to atmospheric and oceanic forcing, as they may become unstable and possibly collapse (Ritz et al., 2015, De Conto and Pollard, 2016, Cornford et al., 2016, Pattyn, 2017, Golledge et al., 2017).

The floating ice shelves that fringe a large portion of the AIS exert an important stabilizing buttressing effect onto the flow of ice from the grounded portion of the ice sheet (Fürst et al., 2016). When the bedrock slopes down from the coast towards the interior of the ice sheet, a reduction in the buttressing force provided by the ice shelf may lead to an unstable retreat of the grounding line (GL), the transition between floating and grounded ice (Schoof, 2007). This mechanism is known as the Marine Ice Sheet Instability (MISI), and some studies suggest that some portions of the West AIS have already begun an irreversible retreat (Favier et al., 2014, Seroussi et al., 2017). Correctly representing the GL dynamics in numerical ice flow models has been a challenging task, and after several marine ice sheet model inter-comparison exercises (Pattyn et al., 2012, 2013), many models have gained in maturity. Minimal requirements for the proper representation of GL dynamics are a fine mesh resolution and higher-order physics, requiring advanced numerical methods to deal with realistic large-scale centennial simulations. Among the new generation of ice sheet models that has recently emerged, Elmer/Ice (Gagliardini et al., 2013) and BISICLES (Cornford et al., 2013, Cornford at al., 2015) are particularly recognized for their treatment of the GL problem.

While ice-shelf thinning due to higher ocean temperature and increased sub-ice shelf melt, is currently taken into account by the models, there are other physical processes that may lead to a partial or complete loss of buttressing and which are not all well understood and represented. In particular, the last decades have witnessed the collapse of several major ice shelves in the Antarctic peninsula; Larsen A in 1995 followed by Larsen B in 2002. These events have led to an up to 8-fold increase in the ice fluxes of their main contributory glaciers (e.g. Scambos 2004, Rignot 2004).

More recently, the Larsen C underwent a large calving event last summer raising concerns about its stability. The effect of a total loss of buttressing from the Antarctic ice shelves has been assessed in recent studies (Cornford et al., 2016, Pattyn, 2017, Golledge et al., 2017) and is part of an ongoing inter-comparison exercise (ABUMIP, endorsed by ISMIP6) that aims at investigating end-members for the contribution of the AIS to sea level rise. The missing processes are associated with high-frequency loadings and a viscoelastic model of the ice rheology is required to account for the resulting short term effects. However, large scale ice flow models dealing with century scale projections neglect the elastic part and rely on a purely viscous ice rheology model.

Hydro-fracturing is one of the major processes thought to trigger ice-shelf collapse. In the context of global melting, growing melting ponds and lakes tend to weaken the mechanical integrity of the ice shelf especially after sudden drainage leading to strong stress gradients. Early efforts treat the problem as the purely elastic bending of a plate (Banwell et al., 2013). However, a viscoelastic constitutive relation, though more complicated, is more appropriate to properly describe the specific time-dependence, consisting of an instantaneous response followed by viscous modes...
as later proposed by Mac Ayeal and Sergienko (2015). DeConto and Pollard (2016) suggest that another instability mechanism, the Marine Ice Cliff Instability (MICI) could be triggered by increased hydro-fracturing, leading to more than a meter of sea level rise contribution by 2100.

The increased spatial and temporal resolution of the observations has shown that the ice flow can be influenced by ocean tides up to 100km upstream of the GL. Several processes have been put forward to explain the observations including tidally-modulated changes in ice shelf buttressing (e.g. Robel et al., 2017). Again, at tidal loading frequencies, the ice rheology is viscoelastic. Moreover, the measurement of the tidally induced vertical motion of ice-shelves by InSAR (Interferometric Synthetic Aperture Radar) has become a common tool to determine GL position. Fitting the tidal fringes with an appropriate viscoelastic model, in contrast to the traditional elastic beam model (e.g Park et. al., 2013) will allow a better determination of the GL position.

The aim of the project is to better understand these processes by a combination of process-based numerical modeling and observations.

**Scientific approach and work plan:**

The first aim of the project will consist of implementing a new viscoelastic rheology model in the finite-element code Elmer/Ice. The new model will then be verified, using synthetic, simple geometry cases with known behaviour. Validation of the model will then be carried out by modelling Astrolabe Glacier in the Terre Adélie Land where a rather comprehensive field survey has been carried out over the last few years. The available data there comprise ice surface displacements in the vicinity of the grounding line from a permanent network of GPS beacons measuring almost continuously since 2011. These data have been complemented by ground geodetic surveys which acted as ground truthing for establishing numerous DEMs and velocity maps from satellites (Pleiades, SPOT, see Berthier et al. (2014)) in the framework of a collaboration with the LEGOS in Toulouse. One extra advantage from this test zone is that the effects of the tidal forcing have already been assessed, notably from an innovative geodetic method for locating the grounding line (Le Meur et al., 2014). Since tides are recorded at the nearby Dumont d’Urville station and the protocols for measuring the vertical effects on the shelf are mastered, simulating these displacements in response to the tides will offer a strong validation of the implemented viscoelastic rheology.

The model, once effective, will allow for addressing the issue of the effects of the fast varying flexing stresses at the upper surface of the shelf from the sudden draining of surface lakes. The resulting mechanisms appear to be timely topics in the context of the now proven global warming leading to increasing melting events over the Antarctic coastal fringe (Bell, 2017). A first application of the new model will assess the environmental conditions that led to the well documented break up of the Larsen B ice shelf. Having tested the model against past events in the Larsen B ice shelf, the next step will be to simulate future possibilities for collapse of the neighbouring Larsen C ice shelf. Consequences on the overall upstream ice mass loss will also be addressed as part of a more general aim consisting at predicting the future contribution of West Antarctica to sea level.

It is anticipated that a significant part of the work could be done under a PhD thesis shared between the 2 partners. Within this frame, the first task of the candidate would consist of a scientific review of the viscoelastic models published in the literature, before embarking on the programming of new Elmer Fortran modules. At the same time, testing over simple cases as well as against the Astrolabe data should be carried out in Grenoble for half the duration of the thesis (1.5 yr) because of the presence there of several significant contributors to the development of the Elmer/Ice code and because corresponding field studies are led by IGE. The second half of the thesis would be carried out at Swansea University whose staff have been deeply involved in the data collection for the concerned areas.

Last, the PhD candidate will be given the opportunity to participate to one field season so as to get acquainted with the real world. One possibility could consist in getting involved in the new observation protocols we plan over the Astrolabe Glacier in order to better constrain the environmental setting leading to shelf destabilization. For instance, we plan to make use of our recently acquired AUV for characterizing the ponding effect and producing the required
surface DEMs and velocity maps at an intermediate resolution between that of satellites and that of local ground surveys.

**Results and deliverables:**

A new rheology module in the Elmer code will constitute the first deliverable of the project. As part of the philosophy followed by the Elmer Community, this module is meant to be shared amongst the scientific community and this will become feasible once the corresponding code will have been duly validated against real case data. That would bring a major step forward in the glaciological community since it will facilitate the treatment of various glaciological problems for which a viscoelastic rheology appears necessary such as the effects of tides on ice flow in ice streams (Rosier et al., 2016) or the hydro-fracturing of shelves as envisaged in this project (Banwell and Macayel, 2015). In parallel the project should set a framework for more data observations on the concerned ice shelves, specifically the Larsen C which represents a timely issue.

A second deliverable will consist of a much better understanding of the physics and the environmental conditions underlying the recently observed break-up of West Antarctic ice shelves. For instance, the growing occurrence of melting ponds and lakes in a warming climate and their effect upon the mechanical integrity of ice shelves will have to be considered. The well documented Larsen B events (in terms of both environmental settings and corresponding response) will be considered to better constrain the model. That will prepare the way for a more thorough investigation of the Larsen C ice shelf, where a chain of events leading to collapse may be under way and deserves attention. The ability to accurately model the future behavior of large ice shelves such as Larsen C will be essential in the prediction of the West Antarctic Ice Sheet’s response to climate change.

**International positioning of the project:**

This project is meant to make the most of the complementary skills and expertise of staff from the 2 invoked partners. IGE is hosting several specialists of the Elmer finite element code who significantly contributed to the development and dissemination of the more specific Elmer/Ice code dedicated to numerous glaciological problems. Among them, Olivier Gagliardini has concentrated on implementing different sliding laws (Gagliardini et al., 2013) whereas Fabien Gillet-Chaulet (also intended to supervise this thesis) thoroughly exploited surface data acquired over ice sheets in order to inverse the basal conditions (Gillet-Chaulet et al., 2012). More work on the grounding line dynamics with corresponding impacts on the stability of ice shelves/ice sheets has also been carried out in the frame of the team (Durand et al., 2009, Favier et al., 2014).

As for field studies, after setting up the Astrolabe test zone in the Terre Adelie Sector of Antarctica, E. Le Meur has been constantly supervising the various surveys and notably the permanent GPS network that continuously monitors surface displacements of the glacier in the vicinity of the grounding line (Le Meur et al., 2014). He was (is) PI of 2 major programs funded by the French National Research Agency allowing for the corresponding field activities and through which a scientific collaboration was established with the University of Texas and led to 4 airborne geophysical campaigns aiming at characterizing the large outlet glaciers of the Wilkes sector of Antarctica.

The glaciology group at Swansea University offers expertise in model development and application, data assimilation, remote sensing, and ice shelf field work. PI Stephen Cornford is the European lead developer of the BISICLES ice sheet model (Cornford et. al., 2013), and has substantial experience of developing ice sheet models for high performance, large scale applications, including comprehensive near future projections of the West Antarctic Ice Sheet (Cornford et. al., 2015) and Antarctica as a whole (Cornford,. et. al. 2016). Co-PI Adrian Luckman lead the UK NERC MIDAS project, well known for tracking the punctuated growth of a 160 km long rift across the Larsen C ice shelf in 2016 and 2017, which ultimately led to the calving of one of the largest icebergs ever observed. This combination of model development and remote sensing experience will allow for a high fidelity simulations of the historical Larsen B and future Larsen C- ice shelves.
IGE and Swansea PI have already a strong history of collaboration through modeling intercomparison experiments (MISMIP3d (Pattyn 2013), MISOMIP (Asay-Davis 2016)) and projections of forthcoming evolution of Antarctica outlet glaciers. In particular their mutual efforts led to the first demonstration of the current unstable retreat of Pine Island Glacier featured in a high profile paper (Favier et al. 2014). Built on past interactions, the present project is meant to make the most of the complementary skills and expertise of staff from the two partners: by furnishing the appropriate modeling tool, IGE will help improving the interpretation of the data gathered over Larsen ice shelves by Swansea group. This will strengthen our collaboration with further longer term objectives in mind: building a strong core group around Elmer/Ice developments and applications to build an ambitious project within H2020 framework. In particular we are part of a consortium building a project to the H2020 2018-2020 work program “Climate action, environment, resource efficiency and raw materials” where a dedicated call is proposed on the changing cryosphere (LC-CLA-07-2019) with a specific action to assess the processes controlling changes to global ice mass balance including ice dynamics. This will lay the foundation for building a wider european community using and developing Elmer/Ice with a common strategy and workplan.

Finally, Elmer/Ice may in the long term become the single major European ice sheet model. Elmer/Ice has its focus on high physical fidelity, while other models focus on performance. Notably, the BISICLES ice sheet model (developed by the Swansea PI) is suitable for simulations of the entire Antarctic ice sheet, and is the ice sheet component of the UK Earth Sytem Model Phase 1. With future increases in computational power, and the introduction of performance oriented components to Elmer/Ice, we can envisage a future where the development efforts associated with these two models are merged to the benefit of the whole ice sheet modeling community.

References:

Applicants must hold a Master’s degree (or be about to earn one) or have a university degree equivalent to a European Master’s (5-year duration).

Applicants will have to send an application letter in English and attach:
- Their last diploma
- Their CV
- A short presentation of their scientific project (2 to 3 pages max)
- Letters of recommendation are welcome.

Address to send their application: emmanuel.lemeur@univ-grenoble-alpes.fr, s.l.cornford@swansea.ac.uk

SELECTION PROCESS
Application deadline: 15/08/2018 at 17:00 (CET)
Applications will be evaluated through a three-step process:

- Pattyn, F.: Sea-level response to melting of Antarctic ice shelves on multi-centennial time scales with the fast Elementary Thermomechanical Ice Sheet model (f.ETISh v1.0), The Cryosphere Discuss., in review, 2017
1. Eligibility check of applications 20/08/2018
2. 1st round of selection: the applications will be evaluated by a Review Board early September 2018. Results will be given around mid of September 2018.
3. 2nd round of selection: shortlisted candidates will be invited for an interview session in Grenoble at the end of September 2018. (if necessary)

TYPE of CONTRACT: temporary-3 years of doctoral contract
JOB STATUS: Full time
HOURS PER WEEK: 35
OFFER STARTING DATE: 1/10 or 1/11 2018

Salary: between 1768.55 € and 2100 € brut per month (depending on complementary activity or not)

Co-funding partner:
Scientific department (laboratory’s name): University of Swansea, Department of Geography, College of Science
Address: Singleton Park, Swansea, SA2 8PP, UK
Supervisor’s name: Stephen L Cornford

Number of months supported by the Université Grenoble Alpes: 18 months
Number of months supported by the Université of Swansea: 18 months