Ice Sheet Stability - iSTAR

Science Plan

1. Summary

Limitations in our understanding of ice sheet dynamics mean that models are currently unable to adequately describe contemporary ice mass loss rates. The result is that they cannot provide confident predictions of future mass loss rates. Such predictions and their resultant impact on sea-level rise estimates are important for both climate modellers and coastal planners. The £7.4M NERC programme on *Ice Sheet Stability* is a response to the requirement to provide better projections of future ice sheet stability.

2. The Research Programme's Objective

The objective of this programme is to improve understanding of the key ice sheet and ocean processes that affect ice sheet stability, and to enable the incorporation of this understanding into models leading to an improved ability to predict future ice sheet behaviour. The programme will focus on the West Antarctic Ice Sheet, with an emphasis in the Amundsen Sea sector and Pine Island Glacier.

3. Scientific Background

The great ice sheets of Antarctica contain major reservoirs of freshwater. Changes in these ice sheets will induce large changes in global sea level and in freshwater flux to the oceans, which in turn can affect ocean circulation and climate. Although many factors contribute to sea level rise, the Fourth Assessment Report of the Intergovernmental Panel on Climate Change identified the cryosphere as the largest source of uncertainty in predictions of future sea level rise over the 50-200 year time horizon. There is evidence from the geological record of rapid changes in sea level that imply dramatic changes in the Antarctic ice sheets. However the controls on such changes are not well understood. Limitations in our understanding of ice sheet dynamics mean that ice sheet models are currently unable to describe adequately contemporary ice sheet mass loss rates as measured for instance by satellites, or to provide confident predictions of future loss rates on time scales of the next few hundred years. Such predictions are vital for coastal planners concerned with sea defences, and for climate modellers concerned with the behaviour of the meridional overturning circulation.

Within the Antarctic, attention focuses particularly on the West Antarctic Ice Sheet (WAIS) and the Amundsen Sea sector, due to the recent acceleration of ice loss and the potentially unstable nature of its grounding line. There are significant gaps in our knowledge of the fundamental processes regulating ice flow and dynamics, and we expect results from this programme will lead to an improved prediction of ice sheet mass loss rates over centennial time scales and better predictive models. These improvements will then be available for use in ocean circulation and sea-level-rise models.

The WAIS rests on a bed ~2 km below sea level. This is a situation that leads to potential instability of the ice sheet associated with the inland migration of the grounding line (separating ice resting on bedrock from floating ice shelves). The region is too cold for surface melt driven by atmospheric warming to be an important cause of mass loss. Rather it is the melting induced by relatively warm ocean water flowing under the adjoining ice shelves that represents the main driver. This will, of course, be in part driven indirectly by the atmospheric circulation. This programme must therefore improve fundamental understanding of the interaction of ice with the oceans and the resulting ice sheet response. To this end the programme has been structured with four components ranging from the continental shelf break and the question of how warm water arrives at the ice sheet, through to variability of the ice mass balance within the region.

4. Strategic Context
The importance of research in this area was identified by the NERC Polar Sciences Working Group Report, and this programme has been developed to deliver against challenges posed by the NERC Climate System and Earth System Science themes. Programme outputs will also contribute to the Coastal Systems programme being developed within the Natural Hazards theme.

5. The Research Programme Science Deliverables
The programme objective (Section 2) will be addressed via four deliverables ranging between the ocean and the interior of the WAIS. Each will be implemented as specified in a separate *Implementation Plan*, which should be read in conjunction with this document.

The key ice streams experiencing mass loss in the WAIS are Pine Island, Thwaites and Smith Glaciers in the Amundsen Sea sector of the WAIS. The ice shelves into which these ice streams drain are known to experience high rates of basal melt and to be in contact with relatively warm Circumpolar Deep Water (CDW). Variability in the melt experienced by the ice shelves attributed to both fluctuations of the quantity of CDW entering sub-ice shelf cavities and to the processes by which the heat content of sub-ice shelf cavity waters is used to drive ice melt. The effect of this forcing seems likely to have resulted in the inland retreat of the grounding line by over 20 km in recent decades, with associated changes in ice-stream dynamics and the mass budget of the region. The four overarching deliverables targeted here are considered to be of great importance in improving understanding of the scientific issue defined by the programme and are listed from the ocean into the ice sheet interior for the sake of clarity.

Deliverable A:
Increased understanding of the processes driving ocean heat transport on to and across the continental shelf towards ice shelves, and the sources of variability in that transport.

Recent modelling and the very limited number of oceanographic observations from the area suggest that the upwelling of CDW on to the continental shelf may be sporadic and sensitive to changes in the local atmospheric circulation patterns. Once on the continental shelf, CDW is likely to be modified by the complex bathymetry of the Amundsen Sea as well as a host of shelf-sea processes before interacting with the WAIS. Deliverable A seeks to improve our understanding of both the exchange of ocean water on to the continental shelf and its passage across the continental shelf to ice shelf cavities.

Key scientific questions that will be addressed by Deliverable A are:

i. What processes govern the influx of CDW on to the continental shelf?
ii. What factors influence the distribution and properties of CDW once on the continental shelf and how do they affect the delivery of heat to ice shelf cavities?
iii. How variable are these processes on time scales up to centennial?

Deliverable B:
Increased understanding of the sub-ice shelf processes that lead to changes in the melt rate experienced by ice shelves.

The interaction between the ice shelf and water occupying the sub-shelf cavity is crucial in determining the rates and patterns of melt experienced by the ice shelf and, therefore, the potential for ice thinning and grounding-line migration. This interaction is controlled by the rate at which heat is exchanged between the ocean and the underside of the ice shelf. However, the extent to which sources of mixing energy associated with the buoyancy-driven circulation are important in controlling the pattern and intensity of melt is unknown, as is the importance of factors such as the detailed geometry of the cavity. The impact of changes in the characteristics of the water masses entering this system on

the patterns and rates of melt is crucial to our ability to predict future change yet very poorly constrained by observation.

Key scientific questions that will be addressed by Deliverable B are:

i. How do conditions within the sub-ice shelf cavity respond to changes in oceanographic conditions at the ice front?
ii. What factors govern the spatial distribution of melt experienced by the ice shelf and how might these factors change?

Deliverable C:
Increased understanding of the nature and dynamics of the processes controlling the response of Pine Island Glacier to grounding line migration.

The grounding line is the interface between the floating section of the ice shelves and the grounded interior of the WAIS. It is known to be migrating inland and under current conditions this retreat may continue to the significant detriment of the stability of the WAIS. The migration of the grounding line is also thought to alter the stress regime and dynamics of flow within the trunk of PIG, potentially leading to changes in its interactions with underlying till and lateral margins. However, the processes that could control the rate of migration and its consequences for the interior of the ice sheet are not well understood.

Key scientific questions that will be addressed by Deliverable C are:

i. What is the current configuration of the grounding line, and what is the nature of its control on the Pine Island Glacier?
ii. How do dynamic effects (including internal ice processes, deformation rates, longitudinal stresses, diffusion and lateral drag) propagate upstream of the grounding line?
iii. How dynamic are the properties of the bed and till?

Deliverable D:
Improved estimates of the contribution to sea level change from the Amundsen Sea Sector.

As the grounding line changes and migrates it affects the overall mass balance of the WAIS and its contribution to global sea level change. At present, this contribution is uncertain because of issues related to the use of data from a variety of different sources. It is profoundly important to understand these data sources, so that more refined estimates of the expected sea level rise can be produced.

Key scientific questions that will be addressed by Deliverable D are:

i. What is the variability both in a spatial and temporal sense of the region's ice mass balance?
ii. What are the observational uncertainties in the current measurement techniques?

6. Relationship to other initiatives

It is anticipated that this Research Programme will make a significant contribution to the Living With Environmental Change programme, particularly Objective A: to predict the impacts of climate change and to promote sustainable solutions through mitigation and adaptation. The programme is expected to be of interest to the coastal management community, including the EA, Defra and DECC, as well as the ocean circulation and climate change communities.

The *Ice Sheet Stability* research programme will seek to build on existing UK and international activities, such as the EU ice2sea programme, new technologies and data from satellites such as Cryosat. It is intended to continue the successful scientific and logistical partnerships with American, Canadian, German, Korean and Swedish researchers; and to forge new partnerships where they will help meet the programme aims.