Can you explain the key objectives of your research project, 'The Land Unknown'?

We don’t know enough about the Antarctic, and our sparse knowledge about the subglacial bed affects how well we can model changes in ice flow and sea level rise. Of course, it is expensive and time consuming to obtain observations in a place as remote and inhospitable as Antarctica. There is a need to combine our modelling and observational activities to best effect. Our objective is to think strategically about the ways in which Antarctica could activate its deep interior and to explore the limits of how we model the ice sheet in a way that is consistent with what has already been observed.

How did you become interested in climate and uncertainty quantification?

The common theme reaching across my different projects concerns questions on how well observational data addresses important hypotheses about the physics of the climate system and its components. My interest in this topic stems from my concern that we tend to test models with the same data that are used to develop them. While there is a lot of data being collected, we as a community do not do so well in synthesising that data and conducting the unique tests of modelling capabilities. To make quantitative statements about uncertainties, I require help from experts in the observation and modelling of physical systems in order to generate plausible alternate representations of what we don’t know.

What innovative techniques or methodologies have you employed to conduct your research?

There are numerous innovative components to our project, but three stand out in particular. The first is the mathematical model used to represent realistic interpretations of what we don’t know about Antarctic basal topography, for which Goff can take credit. The second is an ice flow model capable of data assimilation that uses available observations to make inferences about the subglacial bed that we cannot observe directly. The third is an open-source software infrastructure we developed called the Model Ensemble Control System (MECS) that we use to manage the workflow involved in estimating uncertainties. It combines the various models mentioned above within a statistical framework and manages the execution of thousands of ice sheet simulations over high performance computing resources.

In the coming few years, will your research take any new directions?

Our initial steps have gone a long way toward integrating once disparate communities who all have useful perspectives about the modelling and testing of how much ice sheets will affect future sea levels. One of the fundamental challenges facing our ability to quantify uncertainties of climate and sea level model projections is the treatment of biases that include the irreducible gap between models and data. It will be important to develop strategies to account for these modelling deficiencies and to represent observational limitations on assessments of climate change risk.
THERE WAS A notable rise in sea level throughout the course of the last century – some estimates suggest by as much as 19 cm. Satellite measurements since the early 1990s indicate that today the sea is rising at a rate of 3 mm per year. With sea level rise increasing the frequency of coastal flooding events, this constitutes a grave threat to coastal populations all over the world.

Global sea levels rise most dramatically when portions of glaciers and ice sheets once grounded on land accelerate into the ocean and melt. Satellite observations of Antarctica and Greenland suggest that ice sheets are more sensitive to climate change than once thought, meaning that it is essential they are monitored carefully so that we can understand how these changes are taking place. However, present understanding of the subglacial bed is very limited – and this affects how well changes in ice flow and sea level rise can be modelled. In its 2007 4th Assessment Report (AR4), the Intergovernmental Panel on Climate Change (IPCC) drew attention to this issue by suggesting that current knowledge was inadequate to make confident estimations about the upper bound in how changes in ice flow may affect future sea levels. While modern technology makes ice sheets easier to observe, there are often limits to what can be inferred from the geometry and motion of the surface ice. What scientists need to know is buried beneath kilometres of ice. Therefore, it is important to have a team with diverse expertise to interpret data for making predictions.

INVESTIGATING UNCERTAINTY

Dr Charles Jackson, a research scientist based at the Institute for Geophysics in the University of Texas at Austin, USA, is concerned about big-picture events such as high climate sensitivity, abrupt climate change and significant sea level rise. Specialising in climate and uncertainty quantification, Jackson is currently conducting an innovative research project into modelling ice sheets’ contribution to sea level rise. Working in close collaboration with two glaciologists, and with other scientists from a diverse range of backgrounds, he is primarily interested in exploring the limitations of current ice sheet models.

One critical factor impeding the ability to predict the sensitivity of ice sheets to environmental change is the uncertainty of the bed geometry. In view of this, the project researchers aim to produce a number of bed geometry maps for the Thwaites region of the West Antarctic Ice Sheet (WAIS) that best characterise the limitation of observations and models to predict the potential for ice sheets to accelerate: “The bed’s geometry and details about its composition, such as whether it is rock or sediment, and whether there are high or low geothermal fluxes and quantities of water present, hold the key to determining how rapidly Antarctica may deglaciate if forced to retreat by a warming environment,” Jackson explains.

Most of the available information about the bed comes from sparse airborne surveys or traverses across the ice sheet. However, seemingly insignificant features – some as small as a few kilometres – can have a demonstrable impact on ice flow. Data and modelling communities must take this into account in order to effectively identify, quantify and reduce the uncertainties in ice sheet mass balance projections.

In addition, the team is exploring how the sufficiency of knowledge can be measured. Approaching this issue through the lens of statistical inference, assessments of sources of uncertainty are measured against the strength of the observations that provide the constraint in the first place. Ultimately, these observational strategies and model development goals could be intertwined, consequently working to enhance knowledge about ice sheet contributions to sea level.

COLLAPSING ICE SHEETS

With some of the largest changes in surface elevation occurring in West Antarctica, Jackson is particularly fascinated by the WAIS and its subglacial bed. In the Amundsen Sea Embayment (ASE) – an area of the WAIS that is roughly the size of Texas – the ice sheet is thinning rapidly. Worryingly, this could lead to an acceleration of the flow that further steepens the ice sheet as it retreats deeper into the interior of the ASE. Essentially, this could be a precursor to the wholesale loss of the ASE ice sheet, raising the sea level by more than 1 metre.

While these changes to the ice sheet are widely attributed to regional warming of the ocean, there is currently not enough information to determine...
The researchers hope that their observational strategies and model development goals will be intertwined, consequently working to enhance knowledge about ice sheet contributions to sea level.

whether the observed changes are part of the cryosphere’s range of normal variability or whether the heat reaching these portions of ice sheet is due to recent anthropogenic climate change. In view of this discrepancy, Jackson and his team are seeking to ascertain which details of the bed’s 3D geometry may slow down or speed up a collapsing ice sheet.

The Thwaites glacier in the ASE is currently losing the most mass of all the glaciers in Antarctica. Because it sits on top of the deepest marine basin, scientists believe it could be vulnerable to large-scale mass wasting. While more data are needed to specify all the variables of the subglacial bed, the group’s plan is to explore what remains unknown and analyse how different specifications of the subglacial bed may affect assessments about the likelihood of the glacier collapsing when forced to retreat.

CONFRONTING CHALLENGES

The biggest challenge facing the scientists is the need to develop a robust strategy that determines which details about the bed have the greatest impact on sea level rise. Unfortunately, the available mathematical tools need to be adapted so that they can accommodate the large space of unknowns. Jackson and his team are working to solve this problem by setting up an experiment that runs a large ensemble of ice flow retreat simulations, each testing a plausible interpretation of available data: “From these simulations we will collect information about how rapidly the ice is retreating and statistically associate it with particular features of the bed,” he elucidates. “The hope is that we can summarise the primary structures that are associated with the greatest sources of uncertainty.”

However, the harsh weather and inaccessible terrain of the polar regions mean that the researchers often rely on satellite observations for monitoring change. With limited government budgets restricting what they are able to monitor, there is increased pressure on the team to ensure that the observations made are the right ones for developing and testing ice flow model predictions in the long run.

MAKING PROGRESS

So far, the researchers have made important strides in understanding how observations are collected and how uncertainty can be modelled. There have also been advances in the software and mathematical tools the researchers use to make their calculations. Crucially, these steps are leading to the synthesis of uncertainties and constraints that would reveal how much ice sheets could alter future sea levels.

Jackson and his team will continue to work towards providing an objective basis for collecting data that reduces uncertainties about the understanding of sea level change. Collaborating with enthusiasm and ingenuity, the results of this ongoing study will inevitably increase the ability of scientists to predict these changes with greater precision.

INTELLIGENCE

THE LAND UNKNOWN

ASSESSING DATA REQUIREMENTS FOR MODELING CHANGE IN THE ANTARCTIC ICE SHEET WITH AN EMPHASIS ON THE SUBGLACIAL BED

OBJECTIVES

To create a methodology to assess the impacts of imperfect knowledge concerning observations of the subglacial bed in Antarctica on projections of sea level rise. While there is an expectation that regions with bedrock elevations below sea level are relatively vulnerable to future change, this idea has not been evaluated in a manner that could produce a range of future scenarios together with their associated uncertainties.

KEY COLLABORATORS

Professor Christina Hulbe (Dean of Surveying) University of Otago, School of Surveying New Zealand • Professor Jesse Johnson The University of Montana, Department of Computer Science, Missoula, USA

Other collaborations include:

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CHARLES JACKSON works on problems concerning the use of data to test physics-based numerical models of the atmosphere, ocean and cryosphere particularly for phenomena that involve their interactions. Some example problems that he has worked on are abrupt climate change, the origin of cycles of ice age climate, projections of future climate and sea level rise. Jackson works with other scientists and statisticians to develop tools for quantifying uncertainties in models or data.