

Revealing the polar past

Expert glacial geologist and palaeoclimatologist **Dr Chris Fogwill** outlines his research into the drivers and impacts of long-term Antarctic ice sheet change

DR CHRIS FOGWILL



To begin, could you provide an insight into your research on the stability of Antarctic ice sheets and their potential contribution to changes in sea level?

My chosen field of research focuses on the history of the Antarctic ice sheets and their interplay with global climate and sea level. The importance of this research reflects the enormous scale of Antarctic ice sheets and the fact that predicting ice sheet change is one of the key uncertainties in projecting future sea level rise. This is because the ice sheets lock up vast quantities of water, which has the potential to raise global sea levels at unknown rates.

Could you explain the main focus of your current research?

Given the short observational window in which we are able to explore ice sheet change in Antarctica, it is critical to investigate the past dynamic response of sectors of the Antarctic ice sheets to external forcing over millennia. This is where my research focuses, providing an insight into long-term ice sheet dynamics and putting recent observations into perspective. Specifically, I use rare cosmogenic nuclides produced in the upper centimetres of rocks exposed on mountains that today protrude through the ice sheet, which record the rate and timing of past changes in the

Icy insights

Researchers from the Climate Change Research Centre at the **University of New South Wales** are striving to further our understanding of the Earth's climate system, investigating the historical insights that can be revealed from ice sheets and what this means for the future

THE RISE IN sea level is one of the most worrying trends associated with global changes in average temperatures. Scientific research indicates that sea levels have been rising at a rate of 3.5 mm per year since the early 1990s, putting thousands of coastal cities and low-lying islands across the world at risk. Even small increases in sea level can have a destructive impact; for example, as seawater penetrates further inland, it can cause severe erosion, flooding and contamination of aquifers and crops, as well as loss of habitat for plants and wildlife.

Scientists believe that one of the principal reasons behind rising sea levels is ice loss in

Greenland and Antarctica, with increased heat from the oceans and atmosphere causing enormous ice sheets to melt or collapse at an accelerated pace. This hypothesis is backed up by satellite measurements, which suggest ice sheets are more sensitive to climate change than once thought. However, in its 2007 assessment, the Intergovernmental Panel on Climate Change (IPCC) suggested that current knowledge is inadequate to make confident estimations about how ice sheets may contribute to rising sea levels in the future. There is therefore an urgent need to explore the changes that have occurred the Earth's ice sheets over thousands of years, using a long-term perspective to forge a better understanding of recent observations

of ice sheet melting in the polar regions and to facilitate more accurate predictions about the extent of future rises in sea level.

Dr Chris Fogwill, a glacial geologist and palaeoclimatologist based in the School of Biological, Earth and Environmental Sciences at the University of New South Wales (UNSW), Australia, is conducting fundamental research into the drivers and impacts of long-term Antarctic ice sheet change. Using a range of innovative geochronological techniques, he is collaborating with a range of international physicists, geochemists and climate, ice sheet and ocean modellers to achieve his ambitious research aims. Specifically, Fogwill

surface of the Antarctic ice sheets. Rocks transported by the ice sheet are sampled from steep exposed bedrock surfaces, allowing us to reconstruct past surface elevation changes of different sectors of the continent.

What drew you to the study of glacial geology and climate change?

My background is in Oceanography and Geology, an interesting combination that led me to undertake a PhD in Glaciology, specifically the Patagonian Ice Fields in South America, bringing together my passion for understanding past climate and working in cold, icy mountainous places. My interest in Antarctica and ice was kindled at an early age when I first saw pictures of the Commonwealth Trans-Antarctic Expedition rescuing one of their snowcats from a crevasse. It had a lasting impression on me and made me desperate to visit the continent. Although, growing up in Devon, UK, the exact route of how I was going to get there was somewhat of a mystery! Eventually, after an apprenticeship as an engineer, I became an

Earth scientist and, since the completion of my PhD in 2003, I have worked in Antarctica every year. Given that on average I spend more than two months per year in Antarctica, I have spent almost two years of my life living in tents on the highest, coldest and windiest continent on Earth.

What is the most exciting part of your work?

While there are many exciting elements to my research, ranging from seeing data appear on the mass spectrometer to working in some of the most beautiful, remote and hostile localities on the planet, one of the main highlights of my work has been the identification and development of blue ice palaeoclimate records. This has been a truly unique discovery only made possible through my collaboration with Professor Chris Turney and logistical support by Antarctic Logistics and Expeditions (ALE). The ice forms a unique record that provides critically needed new insights into both climate and ice sheet dynamics in this important region of Antarctica.

Could you reveal your plans for future endeavours and elucidate your long-term objectives?

One of the most important aspects of my future research is integrating the new data from both the ice sheet and climate records and comparing them with those from other key locations on Earth. My collaboration with Turney and Dr Jonathan Palmer here in the Climate Change Research Centre at the University of New South Wales, Australia, as well as other international collaborators, is absolutely vital. The aim is to integrate all of these records on the same time scale – an ambitious goal, but one that is potentially possible with the recent advances that have been made. Understanding the phasing relationships between these records will provide insights into the signalling of global climate during major periods of climate and ocean reorganisations, a question that is critical if we are to better understand the sensitivity of the Antarctic ice sheets to global change.

is investigating the response of ice sheets and glaciers to climate forcing. Together with his research partners, he is reconstructing the configuration of the Earth's ice sheets over millennia in an effort to build feasible estimates of the past contribution of ice sheets to sea level rise and to formulate plausible projections for the future.

UNSTABLE ICE SHEETS

Fogwill's current investigation is centred on the East Antarctic Ice Sheet (EAIS), the largest of the three ice sheets that make up Antarctica. Interestingly, most research to date has concentrated on the West Antarctic Ice Sheet (WAIS), as scientists believe it to be the region's most unstable ice sheet. This is mostly due to the fact that large areas of the WAIS are well below sea level and slope downwards inland, meaning that even a small retreat could

lead to its destabilisation and subsequent disintegration. However, large swathes of the colossal EAIS are also found in deep basins below average sea level, suggesting that it could be similarly unstable. Fogwill is therefore working closely with ice sheet and ocean modellers in order to explore what may have activated the instability in the EAIS in past interglacial periods and how this could be applied to potential future incidences.

As part of their research, Fogwill and his team are investigating the Eemian, the interglacial period that is estimated to have taken place 130,000-114,000 years ago. During this period, sea level is thought to have been approximately six to nine metres higher than present – yet global temperatures are believed to have been only 2 °C higher than pre-industrial levels. In a quest to understand these remarkably high values, the researchers have

INTELLIGENCE

UNDERSTANDING THE DRIVERS AND IMPACTS OF LONG-TERM ANTARCTIC ICE SHEET CHANGE

OBJECTIVES

To improve estimates of the past contribution of ice sheets to sea level rise to enable better prediction of future sea level rise.

KEY COLLABORATORS

Professor Chris Turney; Dr Jonathan Palmer; Professor Katrin Meissner; Dr Paul Spence; Professor Matt England, Climate Change Research Centre (CCRC), University of New South Wales, Australia • **Dr Nick Colledge; Prof Lionel Carter; Professor Andrew Mackintosh**, Antarctic Research Centre, Victoria University of Wellington, New Zealand • **Dr Dylan Rood**, Scottish Universities Environmental Research Centre, Glasgow, UK • **Dr Kistina Hippe; Dr Lukus Wacker; Professor Rainer Weiler**, ETH Zurich, Switzerland • **Dr Tas van Ommen; Dr Andrew Moy; Dr Mark Curran**, Antarctic Climate and Ecosystems Cooperative Research Centre (ACE CRC), Hobart, Tasmania, Australia • **Professor David Sugden**, University of Edinburgh, UK

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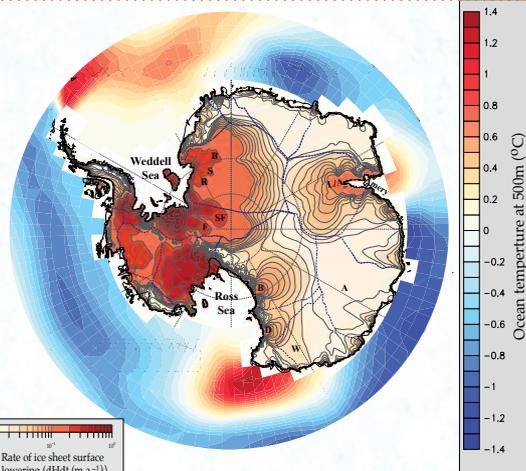
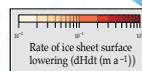
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CHRIS FOGWILL is a glaciologist, geochemist and palaeoclimatologist working to answer the big questions surrounding climate change, melting ice sheets and sea level rise. He is an Australian Research Council Future Fellow based at the Climate Change Research Centre at the University of New South Wales, Australia.



- Much of the ice sheet covering Antarctica is more than 3 km thick – more than twice the height of the UK's highest mountain Ben Nevis – and the continent is 25 per cent bigger than Europe

- Antarctica consists of three separate ice sheets, increasing in size from the Antarctic Peninsula Ice Sheet (APIS), West Antarctic Ice Sheet (WAIS) and the East Antarctic Ice Sheet (EAIS). Together these three ice sheets lock up enough fresh water to increase global sea level by some 60 m if they were to all melt; however, this is a very unlikely scenario. Present estimates suggest that these ice sheets contain 1.5 m, 3.5 m and 56 m of sea level equivalence, respectively



Southern Ocean temperatures (°C) at 500 m depth predicted at the Last Interglacial (from UVIC ESCM) and predicted ice sheet thinning from a glacial-interglacial ocean-forcing simulation (using PISM). The major East Antarctic Ice Sheet drainage basins that are predicted to be sensitive to ocean warming are seen in shades of red.

developed models and mechanisms that have uncovered significant outcomes: “Results from independent model ocean and high resolution ice sheet simulations suggest that parts of the EAIS that were previously considered ‘stable’ are potentially highly vulnerable to collapse from ocean warming, initiated by a polewards shift in westerly airflow,” Fogwill explains. In a collaboration with ocean modellers from the Climate Change Research Centre (CCRC), including Professor Katrin Mesiner, Dr Paul Spence and Professor Matt England, Fogwill proposed that the pervasive regional ocean warming predicted could trigger ice sheet drawdown, thereby making a significant contribution to the global sea level during the Last Interglacial period.

MAPPING THE METHODS

Promisingly, ice sheets are comprised of layers of snow and ice that contain trapped gases, dust and water molecules that can reveal deep insights into past climates. Fogwill is working with Dr Chris Turney, Professor of Climate Change at UNSW, in order to map regional climate changes through time using areas of exposed blue ice. Although these blue ice areas are located in some of the harshest and most hostile places on Earth, sampling is considerably easier and cheaper than traditional ice coring: “Once the structure of the exposed ice is understood, we can pick and choose ice of different ages to test key hypotheses, providing new insights into the forcing mechanisms of climate change,” Fogwill elucidates. “Sampling is undertaken with small ice drills and chainsaws, and can provide huge amounts of material for analysis.”

The sampling goes hand-in-hand with model simulations of ice sheet change,

enabling the researchers to understand the drivers underlying movement and melting. In collaboration with Dr Nick Colledge, a Senior Research Fellow at the University of Wellington, New Zealand, Fogwill is using the Parallel Ice Sheet Model (PISM) to obtain millennial-scale simulations of the ice sheets’ responses to external forcing. With its 5 km resolution across the Antarctic, the PISM provides vital estimates of ice flux and the corresponding sea level over time. Crucially, using the PISM to understand past changes in the Antarctic ice sheets, the researchers are able to forge a more nuanced understanding of current changes observed from satellites, leading to more informed predictions about what is to come.

FUTURE PROSPECTS

Importantly, Fogwill’s findings suggest that along with the WAIS, specific areas of the EAIS are extremely susceptible to ocean warming and sea level rise because of their geometries and connectivity with the Southern Ocean. The combined effects of migrating Southern Hemisphere Westerly (SHW) winds and ozone hole depletion appears to contribute to pervasive regional ocean warming, which could result in ice sheet drawdown in the EAIS and a subsequent rise in sea level of between 3 to 5 m.

Fogwill is keen to continue exploring long-term ice sheet and climate records, integrating his findings with data from other key locations on Earth and using these to reduce uncertainties regarding future sea level rise. With regional warming predicted to continue over the course of the next century, Fogwill’s work has significant socioeconomic implications for the future.