Beltran Catherine[1], Golledge Nicholas R.[2,3], Ohneiser Christian[4], Kowalewski Douglas E.[5], Sicre Marie-Alexandrine[6], Hageman Kimberly J.[7], Smith Robert[1], Wilson Gary S.[1], Mainié François[6].

Rapid Antarctic ice sheet retreat under low atmospheric CO_2

1. Department of Marine Science, University of Otago, New Zealand
catherine.beltran@otago.ac.nz
2. Antarctic Research Centre, Victoria University of Wellington, New Zealand
3. GNS Science, New Zealand
4. Department of Geology, University of Otago, New Zealand
5. Department of Earth, Environment, and Physics, Worcester State University,, USA
6. Sorbonne Universités (UPMC, Univ. Paris 06)-CNRS-IRD-MNHN, LOCEAN Laboratory, France.
7. Department of Chemistry, University of Otago, New Zealand

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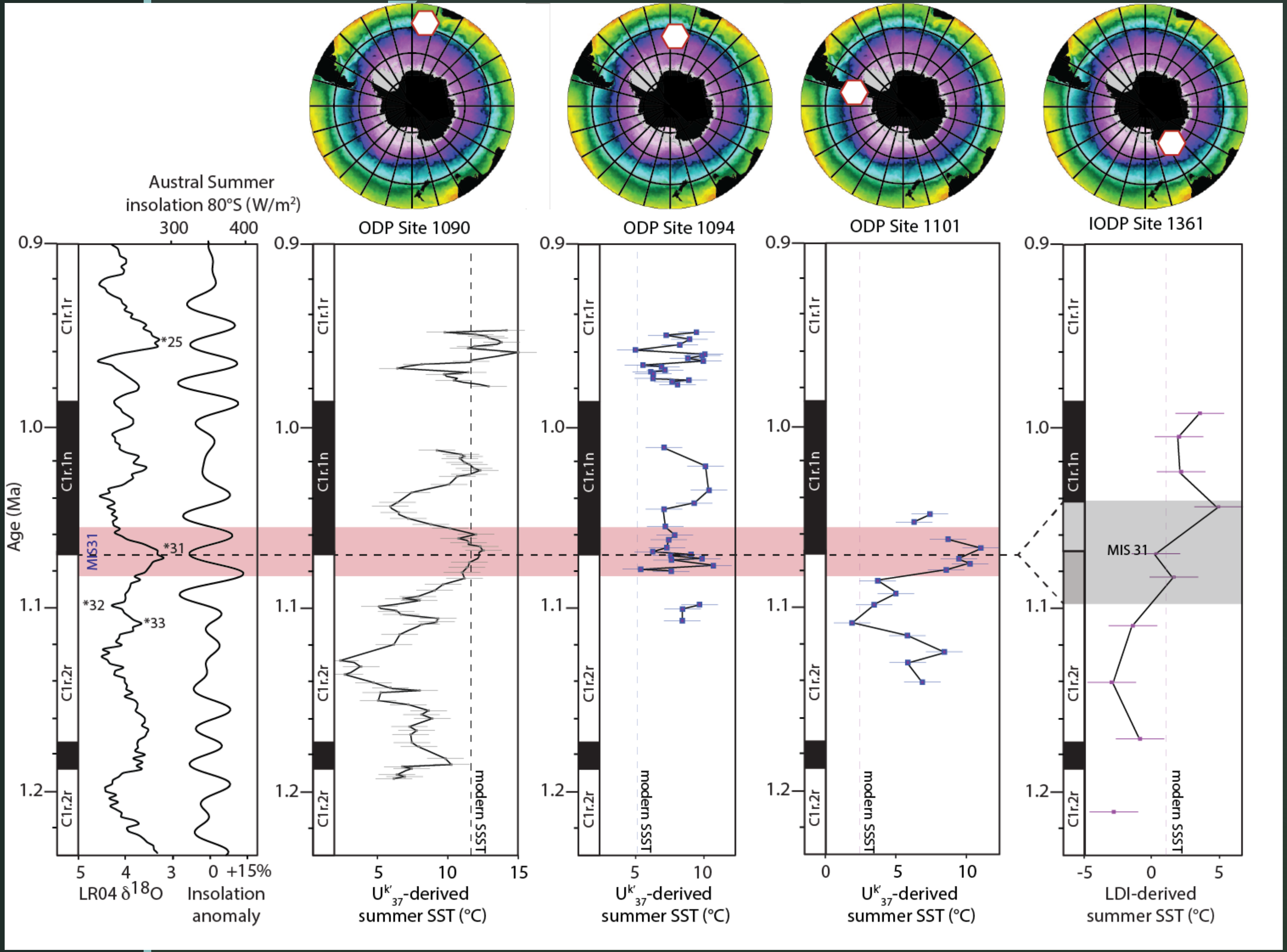
Highlights

- We quantify precisely the magnitude of ocean warming using the first Southern Ocean molecular paleo-temperature reconstructions during the warm Marine Isotope Stage 31 (MIS31- 1.085 and 1.055 million years ago).
- Our data show a sustained surface Southern Ocean warming and a collapse of the Antarctic and sub Antarctic ocean fronts during that warm period and under low atmospheric CO_2 concentrations.
- We use sea surface temperature reconstructions to test the scenarios for the Antarctic Ice Sheet retreat during MIS31 using coupled ice-sheet/ice-shelf model.
- We propose a two-step model for deglaciating West Antarctica which involves mild ocean warming (a new temperature threshold) which forces ice margin retreat followed by rapid ocean warming as the ice sheet retreats.
- Our work shows that the Paris Agreement target temperature of 1.5°C is sufficient to drive runaway retreat of the West Antarctic Ice Sheet. We derive this conclusion from the robust, ocean temperature proxy record and ice sheet simulation.

Early Pleistocene Southern Ocean sea surface temperatures



Alkenone ($U^{k'}_{37}$) and Long Chain Diols Index-based SSTs throughout MIS31.

We show time series of deep-sea benthic $\delta^{18}O$ record (‰) (Lisiecki and Raymo, 2005), austral summer insolation at 80 °S and insolation anomaly relative to present (Laskar et al., 2004).

MIS31 interglacial duration is highlighted in red. The black dotted horizontal line shows the age of MIS31's peak (*31).

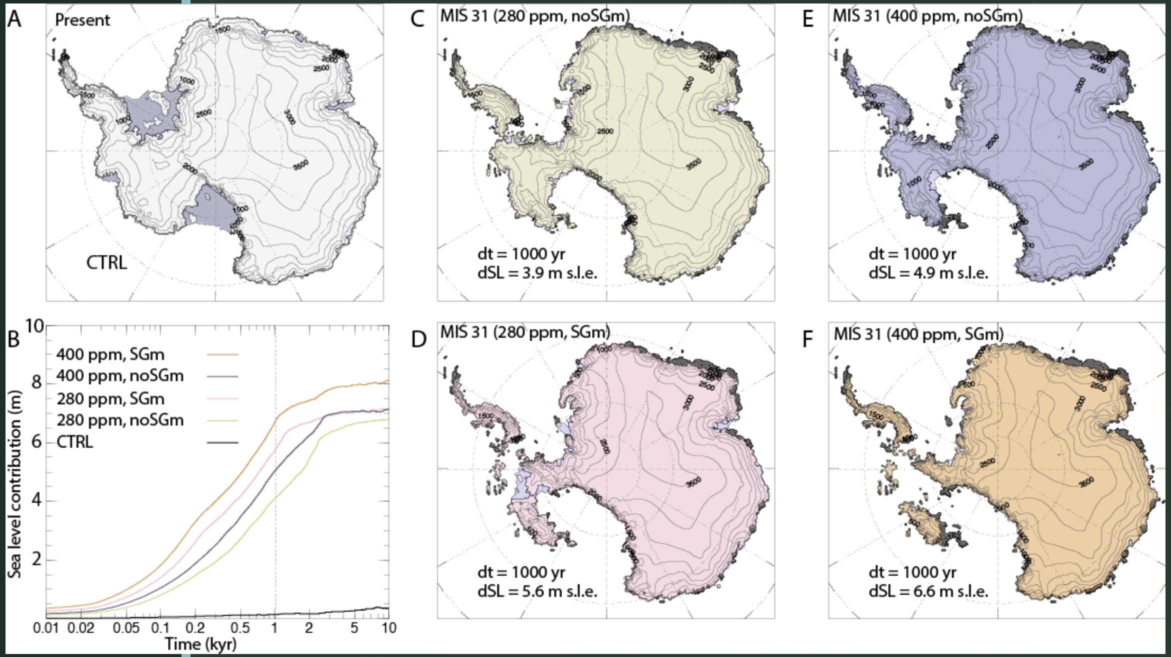
Due to the uncertainties on the age model at Site 1361, MIS31 peak is highlighted in grey.

Each map indicates the site locations.

Our results show a significant polar amplification during MIS31, with a reduced latitudinal SST gradient of ~ -0.3 °C/ °latitude.

Modelling the AIS during MIS 31

- ❖ To investigate the degree of ice sheet retreat in relation to our SST records we conducted a suite of numerical simulations that use climate fields from a regional climate model (DeConto et al., 2012 - RCM).
- ❖ We used the Parallel Ice Sheet-Model, which is an open source three-dimensional thermodynamic coupled ice sheet/ice-shelf model.

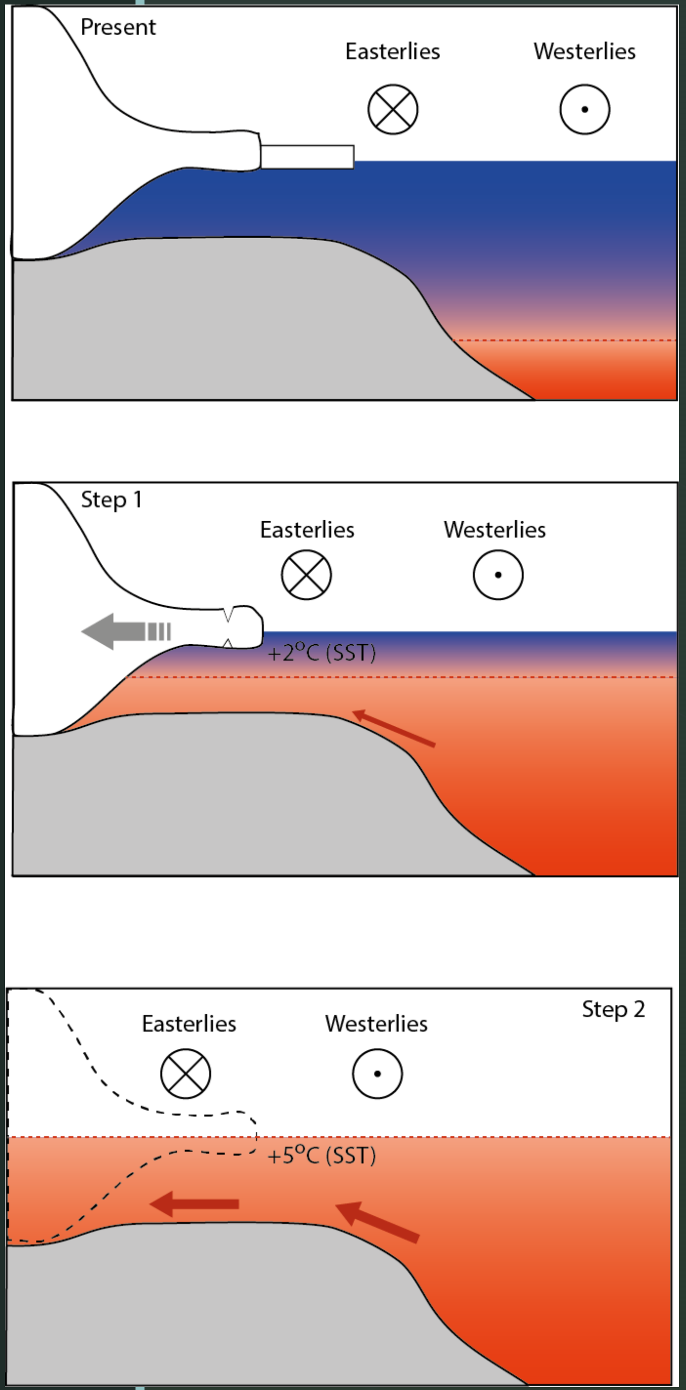


Snapshots of ice distribution for ice sheet experiment runs of 1000 years (dt).

Conservative groundling line behaviour (no SGm, C. and E.)
Dynamic grounding line (SGm, D. and F.)
Each with two extreme CO_2 scenarios (280 ppm and 400 ppm).

A. represents the modern ice distribution
B. dSL is the sea level contribution from ice melting expressed in s.l.e (sea level equivalent)

- ➢ In all simulations, the WAIS melted within a few centuries (Panels B, C, D, E and F) whereas the EAIS responded more slowly.
- ➢ The grounding line scenario and CO_2 forcing have no significant impact on the spatial extent of ice loss is observed after 5kyr.
- ➢ We show that 2-m of sea-level rise from ice loss occur within a few centuries (Panels B) and
- ➢ We show that persistent elevated SSTs would cause complete collapse of the WAIS, with additional thinning around the margins of the EAIS (i.e. the Wilkes Land basin, Weddell Sea, Aurora Basin).



MIS 31, a two-steps warming

[Step 1] *increased advection of warmer deep waters*

Unusual MIS31 orbital configuration lead to ~ 2kyrs of warm and long summers initiating a mild Southern Ocean surface SST increase and reduced sea ice development.

Southward (poleward) migration of the Westerly Winds and the easterly coastal winds warmed the Antarctic coastal waters. Initiation of basal melting of ice shelves and retreat of the marine-based grounding lines.

Our numerical ice sheet model demonstrates that a 0.5 °C ocean warming at the ice margin for ~ 200 years is sufficient to cause ice retreat and that most of it can occur in less than 2000 years.

[Step 2] *run over ice melting at the maximum of MIS31 warmth*

The surface warming in the coastal regions (9.5 °C at ODP Site 1101 and 5 °C at IODP Site 1361) took place after complete loss of the WAIS and was likely amplified by ocean stratification feedbacks.