Exploring the Unknown of the Ross Sea in Sea Ice–Free Conditions

A team of polar scientists aboard the *OGS Explora,* cruising in rare ice-free conditions, discovered new evidence of ancient and modern-day ice sheet sensitivity to climatic fluctuations.

View of the Ross ice shelf from the *OGS Explora,* 9 February 2017. Despite the low temperature of the sea, water evaporates in the very dry and even colder air. Credit: Michele Rebesco (OGS)

By Laura De Santis, Florence Colleoni, Andrea Bergamasco, Michele Rebesco, Daniela Accettella, Vedrana Kovacevic, Jennifer Gales, Kim Sookwan, and Elisabetta Olivo 11 October 2018

An international team of scientists boarded the research vessel *OGS Explora* in the port of Hobart, Tasmania, on 19 January 2017, heading out on a 2-month expedition to unlock the secrets of Antarctic ice sheet response to past, present, and future climate change.

The team met the smallest extent of Antarctic sea ice recorded in the past 20 years.

The team, whose members hailed from Italy, Great Britain, China, Croatia, France, Spain, and South Korea, met the smallest extent of Antarctic sea ice recorded in the past 20 years. This unusual circumstance provided the rare

opportunity to circumnavigate the Ross Sea and collect unique data in places that are almost always covered by ice and had remained unexplored.

Funded by the Italian National Antarctic Research Program (PNRA) and the European EUROFLEETS (http://www.eurofleets.eu/np4/home.html) project, the scientists aboard the *OGS Explora (http://www.ogs.trieste.it/en/content/research-vessel-ogs-explora)* brought expertise in disciplines such as geology, geophysics, oceanography, glaciology, and climatology. The vessel itself, owned by the Italian National Institute of Oceanography and Applied Geophysics (OGS (http://www.ogs.trieste.it/en/content/research-vessel-ogs-explora)), was on its 11th Antarctic expedition.

The *OGS Explora,* sailing near Cape Washington during its 2017 expedition to the Ross Sea. Credit: Federica Cerino

Together, the ship-bound scientists sought answers to the following questions: What role does seafloor morphology play in the interaction between the Southern Ocean and the Antarctic ice sheet? Where exactly on the continental shelf do deep warm water, bottom water, and frigid ice shelf waters enter into and flow out of the basins? What does the morphology of the seafloor reveal about past ice sheet dynamics and ocean circulation?

The Ross Sea

The Ross Sea feeds into the Southern Ocean's Antarctic Bottom Water (AABW), the coldest and densest water mass in the world. As the seawater sinks, it ventilates and circulates the frigid waters of the abyss.

The southern boundary of the Ross Sea is the Ross ice shelf (https://eos.org/articles/fresh-insights-into-what-protects-antarcticas-ross-ice-shelf)—Earth's largest body of floating land ice—which starts floating at the grounding zone of some of the largest Antarctic ice streams. For a schematic of water currents below Antarctica's ice shelves and on the continental margin, see Figure 1.

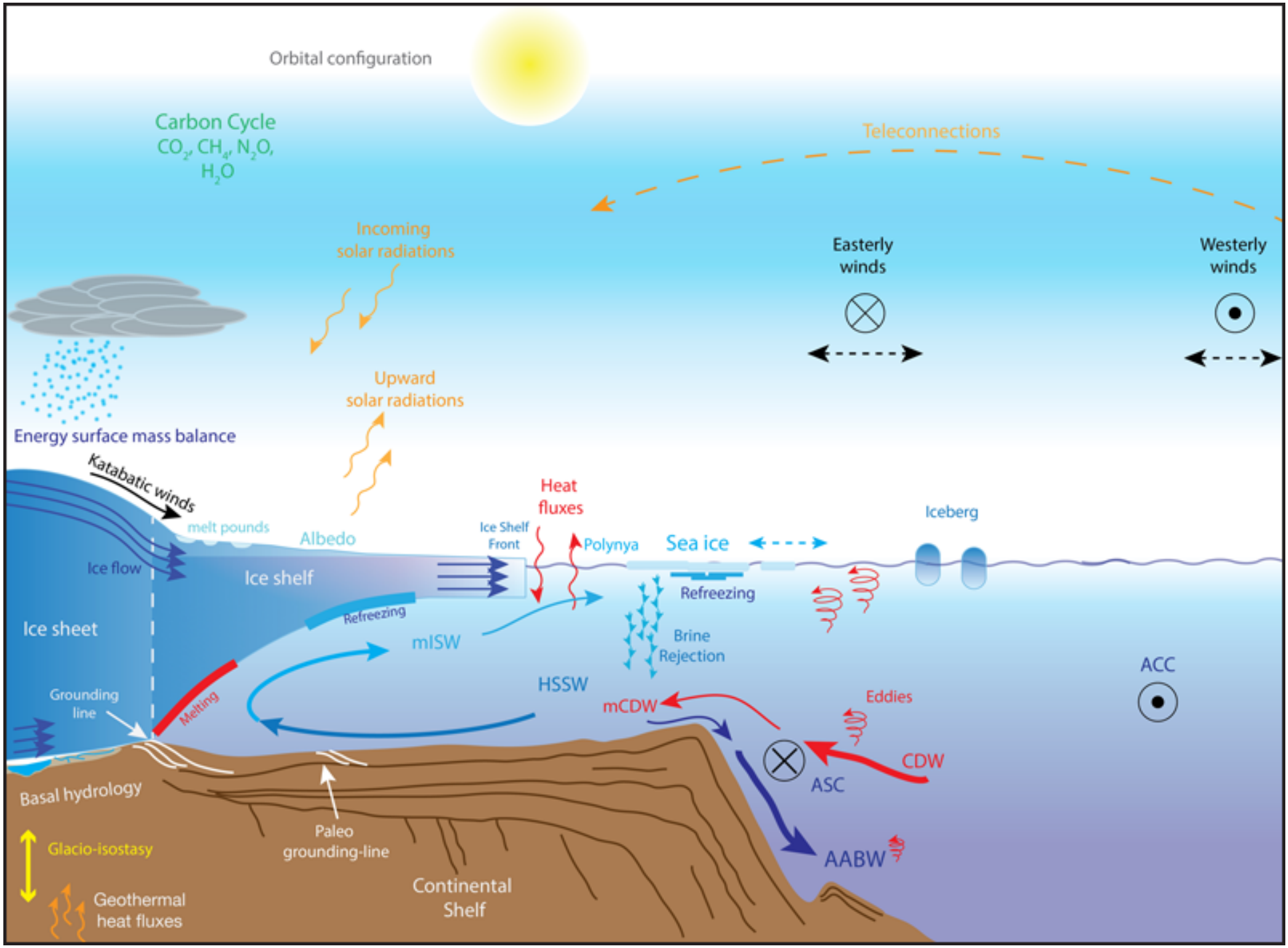

Orbital configuration
Carbon Cycle
CO_2, CH_4, N_2O, H_2O
Teleconnections
Incoming solar radiations
Easterly winds
Westerly winds
Upward solar radiations
Energy surface mass balance
Katabatic winds
Heat fluxes
Iceberg
melt pounds
Albedo
Ice Shelf Front
Polynya
Sea ice
Ice flow
Ice shelf
Refreezing
Refreezing
Ice sheet
mISW
Brine Rejection
ACC
HSSW
Grounding line
Melting
mCDW
Eddies
CDW
ASC
Basal hydrology
Paleo grounding-line
Glacio-isostasy
AABW
Continental Shelf
Geothermal heat fluxes

Fig. 1. Conceptual and simplified view of the Antarctic polar system, with the directions of the AABW, Antarctic Circumpolar Current (ACC), ASC, CDW, and High-Salinity Shelf Water (HSSW) marked. Also marked are modified CDW (mCDW) and modified Ice Shelf Water (mISW), so labeled because they represent distinct bodies formed by mixing currents. A circled X means flow into the image, and a circled dot means flow out of the image. Note that the oceanic processes represented in 2-D view for the purpose of the illustration might not occur at the same locations on the continental shelf. Credit: Modified from *Colleoni et al.* [2018]

Over the course of 30 to 40 million years, sediments accumulating on the ocean floor below the Ross Sea were preserved in the continental shelf basins, recording the historical advances and retreats of the Antarctic ice sheet. The Ross Sea is therefore a unique natural laboratory in which we can observe both modern (https://eos.org/features/on-the-rocks-the-challenges-of-predicting-sea-level-rise) and ancient (https://eos.org/articles/deja-vu-ocean-warmth-melted-ancient-west-antarctic-ice-shelf) sensitivities of frozen water masses—our cryosphere—to global climate warming. There, scientists can collect data relevant to ice melting, ocean freshening, circulation strength, seabed erosion and deposition by ice sheets, and oceanic bottom current flow.

Our Focus

The *OGS Explora* research team set out to gain a better understanding of the interaction between the Southern Ocean (https://eos.org/research-spotlights/a-complete-picture-of-southern-ocean-surface-circulation) and the Antarctic ice sheet. To determine the role of seafloor morphology in this interaction, we collected evidence for both modern and ancient glacier pathways, West Antarctic ice stream activity, and the flow of the Antarctic Slope Current (ASC). We also had other targets of investigation: to locate Circumpolar Deep Water (CDW) inflows to the continental shelf as well as Ross Sea Bottom Water (RSBW) and supercold Ice Shelf Water (ISW) outflows from the Ross Ice shelf (Figure 2).

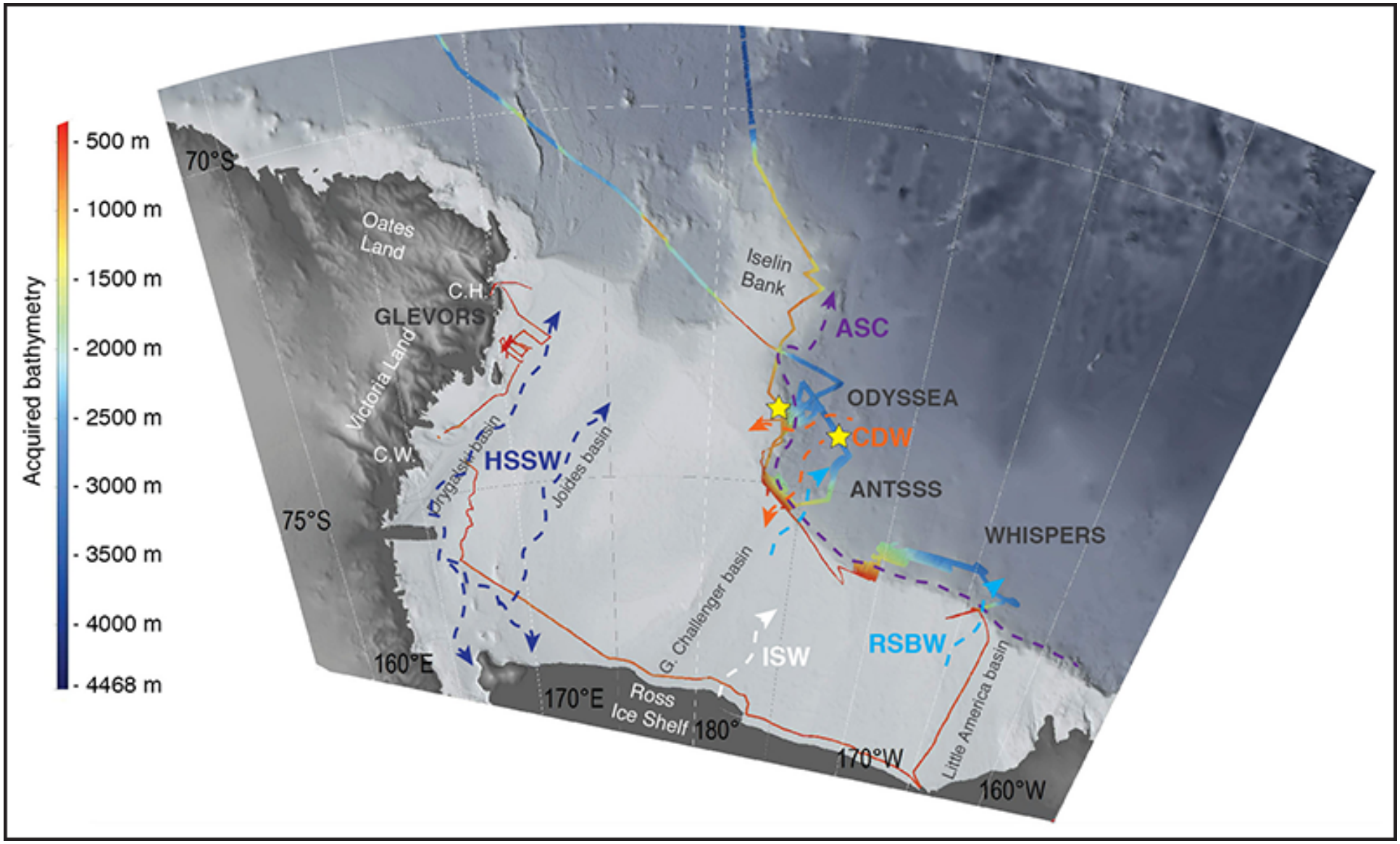
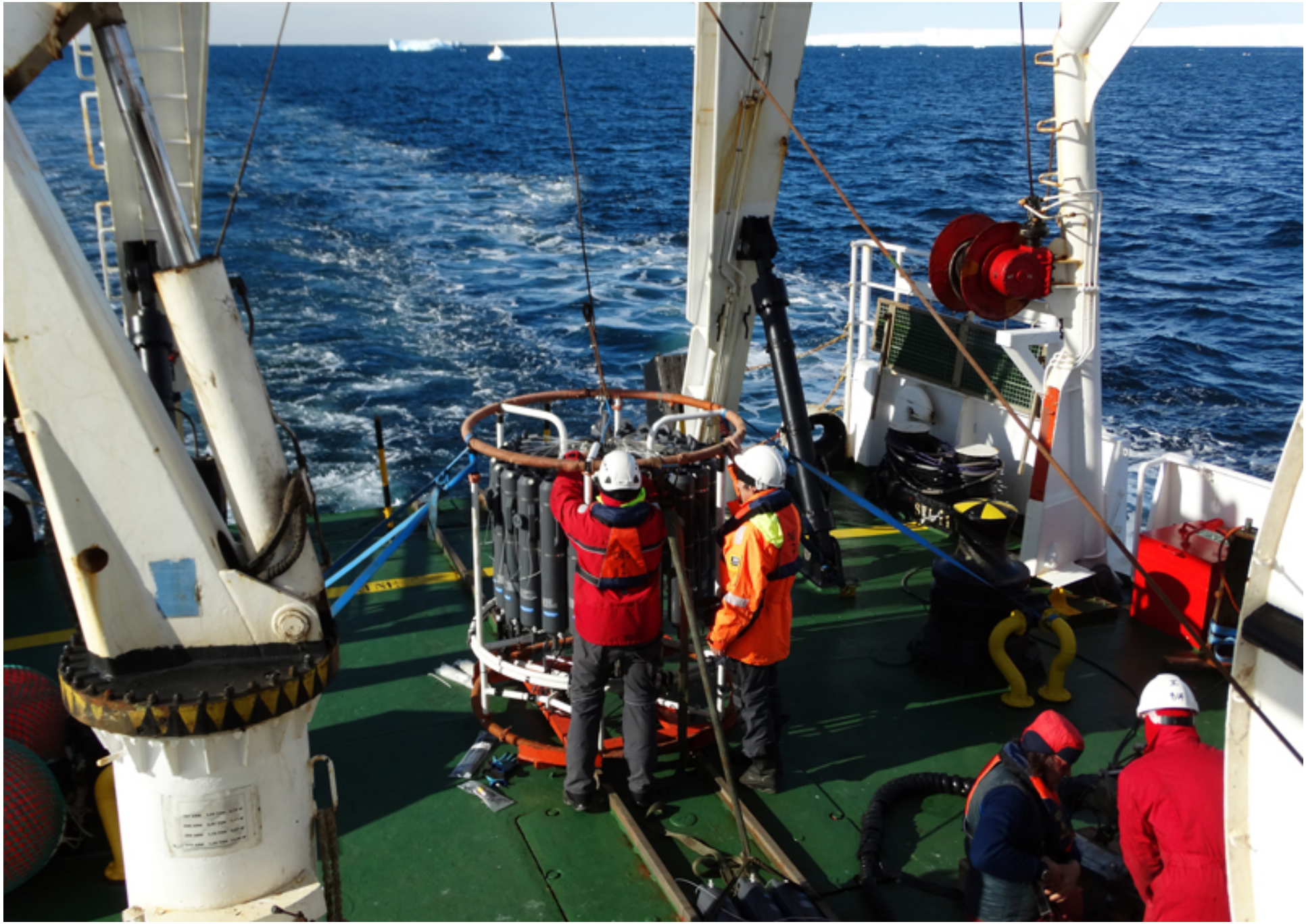


Fig. 2. A map of the 2017 *OGS Explora* multibeam survey, showing the principal water masses that form and mix in the Ross Sea. ISW is the Ice Shelf Water, which forms by melting of the Ross ice shelf; HSSW is the High-Salinity Shelf Water, which forms in the continental shelf region. CDW is the Circumpolar Antarctic Deep Water, which encroaches on the continental shelf; RSBW is the Ross Sea Bottom Water, which forms by mixing of

HSSW and CDW and flows downslope to feed the Antarctic Bottom Water (AABW); and ASC is the geostrophic Antarctic Slope Current, which flows westward around the Antarctic continental margin. The 2017 *OGS Explora* expedition was funded by the Italian National Antarctic Research Program (PNRA) and included the West Antarctic Ice Sheet History from Slope Processes (WHISPERS), the Ocean Dynamics from the Sediment Drifts of the Ross Sea (ODYSSEA), and the Glacial Evolution in the North-Western Ross Sea (GLEVORS) projects and an additional survey in the Southern Ocean over the Macquarie triple point (not shown). Another project achieved during the 2017 *OGS Explora* expedition is the Antarctic Ice Sheet Stability from Continental Slope Process (ANTSSS) that was funded by FP7/EU-EUROFLEETS-2. Data collected by the *OGS Explora* in 2017 were used in 2018 to help pick two sites for IODP Expedition 374 (stars). C.H. stands for Cape Hallett, and C.W. stands for Cape Washington; these are the sites of two photographs in this report. Credit: Daniela Accettella (OGS)

Capturing ocean processes at different timescales was complex and challenging. Previous studies [*De Santis et al.,* 1995; *Bergamasco et al.,* 2002; *Anderson et al.,* 2014; *Sauli et al.,* 2014] helped determine which sites to investigate. We measured ocean currents and water properties, and we located spots of water mass exchange across the edge of the continental shelf. One crucial part of the puzzle involved finding past imprints of these same ocean dynamic features in the sediments and paleomorphology of this continental margin.

The Tools We Used



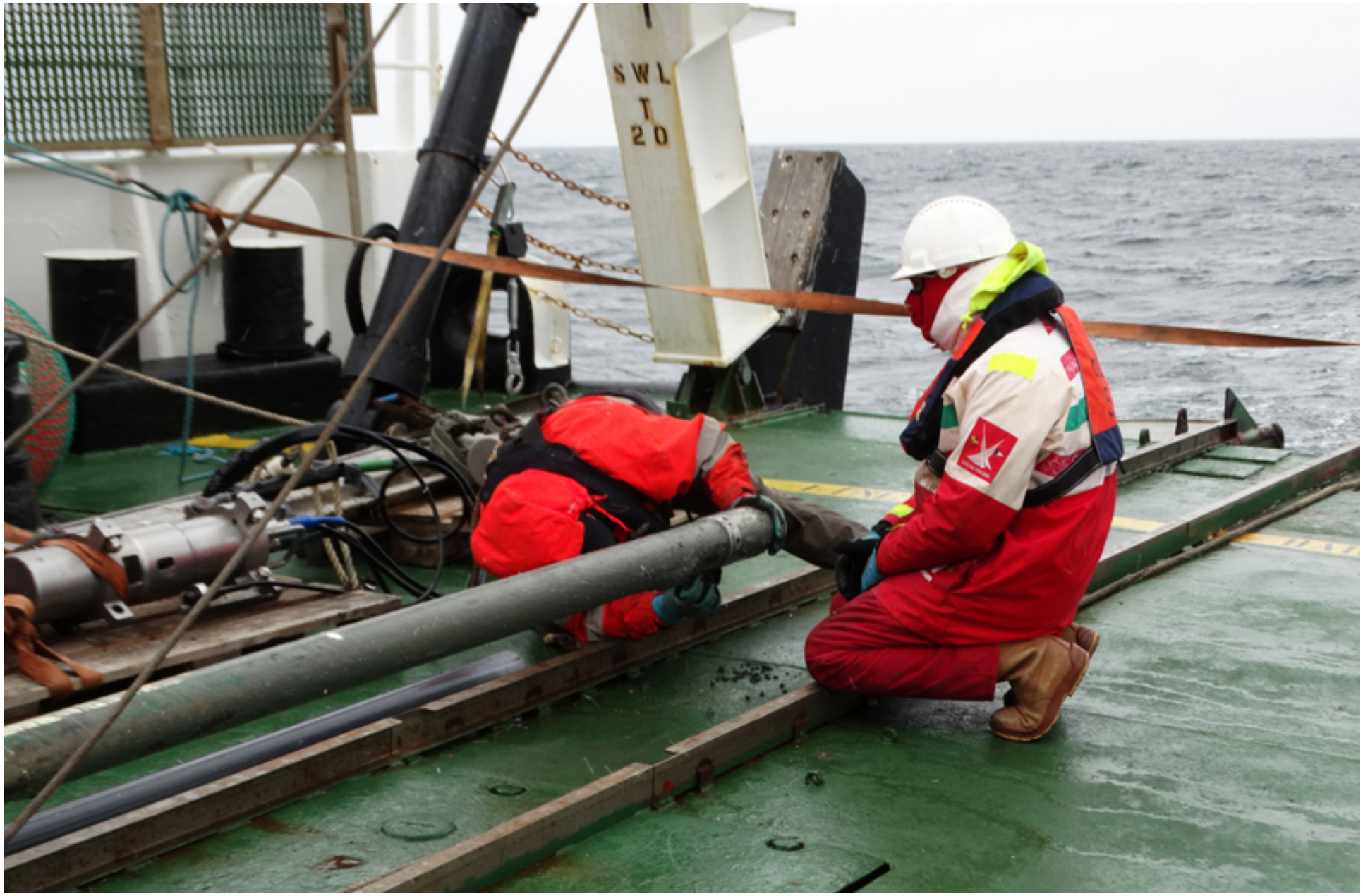
The stern of *OGS Explora* on its way to the Ross Sea during its 2017 expedition, showing technicians preparing and calibrating different oceanographic and geophysical tools on the vessel's back deck. In the center, technicians examine a "rosette," a carousel of bottles used for collecting water at various vertical depths. In the lower right, scientists test air guns, the active seismic source used to collect the seismic data. Credit: Laura De Santis

We used profiling tools to record multibeam sonar and subbottom chirp survey data from the seabed, in combination with acoustic Doppler current profiles (Figure 1). To measure oceanic temperature and salinity variations with depth, we carried out oceanographic transects across the continental shelf edge as well as along the front of the Ross ice shelf using expendable bathythermographs and temperature-conductivity-depth profilers.

Reflection seismic profiles were collected near Victoria Land, across the continental shelf edge of Glomar Challenger Basin and Little America Basin, and at the base of the continental slope on the flank of Iselin Bank, where previous campaigns [*Bergamasco et al.,* 2002] had captured the RSBW and ISW outflow and the CDW inflow.

What We Found

We observed wedge-shaped sedimentary landforms created by the advances and retreats of glaciers at the grounding zone between Coulman Island and Cape Hallett (Victoria Land). We also saw sediment drifts formed by bottom currents in a fjord, over shallow banks, and along the continental slope. We collected sediment gravity cores and box cores within these features. In addition, we studied key areas where the heat and salt exchange between the open ocean and the Antarctic ice sheet continues today as it likely has for millennia.



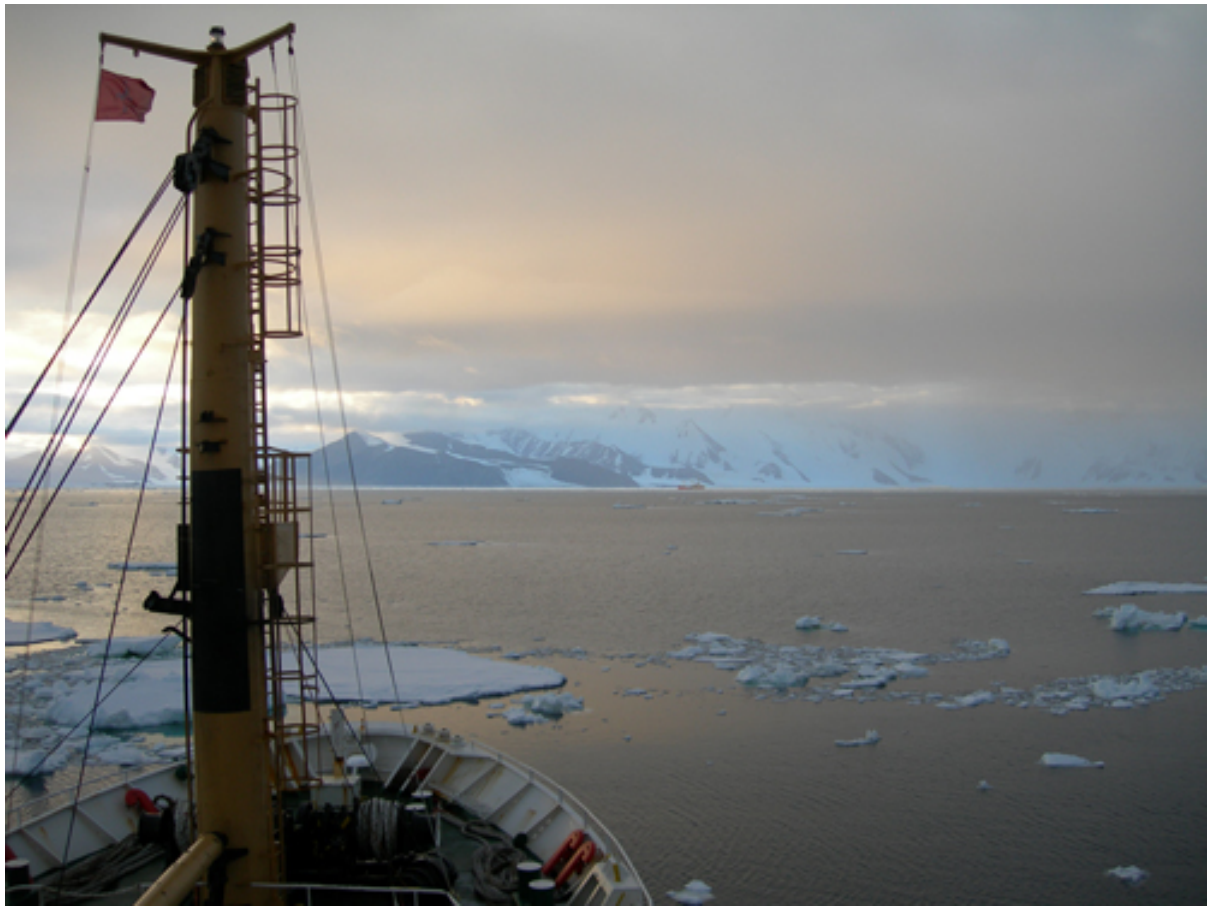
Scientists unscrew the cutting top of the gravity core to unthread its internal plastic liner. The liner contains mud recovered from below the seafloor during a 2017 expedition of the *OGS Explora* to the Ross Sea. Credit: Laura De Santis

We found that the supercold ISW outflow originates at the front of the Ross ice shelf at about 180° longitude. We measured temperature, outflow dynamics, and other water properties as the ISW spilled over the continental shelf edge, between the Glomar Challenger Basin and the Iselin Bank. Similar measurements were made to locate the ASC and CDW intrusions onto the continental shelf.

The data tell a story hundreds of thousands—up to millions—of years in the making, revealing the interconnectivity among ice masses.
We also imaged what looks to be imprints of past ocean dynamics and ice sheet meltwater pathways along and across the continental shelf edge, seen through seismic profiles and multibeam seafloor mapping (Figure 1). Preliminary analysis of the data revealed a variety of gullies along the continental shelf margin, possibly formed by changing hydrology patterns and different types of ice sheet flows, as well as by the exchange of ocean water masses across the continental shelf edge.

The data recorded during this expedition provide insights into how ocean dynamics influences the depositional and erosional processes of the continental margin as well as the ice sheet–ice shelf interaction with the ocean. They tell a story hundreds of thousands—up to millions—of years in the making, revealing the interconnectivity among ice masses such as the vast Ross ice shelf and the Victoria Land glaciers. The data also reveal the evolution of the continental shelf, its interaction with marine and glaciological processes, and features of synoptic ocean dynamics. Such processes have affected the stability of the West Antarctic ice sheet for more than 5 million years [*Naish et al.,* 2009], particularly during warm climate periods, when ice sheets probably retreated or collapsed [*Pollard and DeConto,* 2009].

Forward Flow



A view from the deck of the *OGS Explora* during its 2017 expedition to the Ross Sea. The mountains and glaciers beyond Cape Hallett rise in the background. Credit: Laura De Santis

The pioneering research initiated by the *OGS Explora* expedition is expected to launch a new generation of scientific projects. Data collected during the 2017 expedition were used to determine Ross Sea research sites for the 2018 International Ocean Discovery Program (IODP) Expedition 374. The 2018 expedition, which ran from 4 January through 8 March, collected cores and other data that will help those studying polar conditions to reconstruct the extent of the Antarctic ice sheet over the past 20 million years, during which Earth has undergone

significant changes in atmospheric-oceanic circulation, atmospheric carbon dioxide concentration, and global temperature. Understanding how an ice sheet responds to global past climate fluctuations will help predict its vulnerability (https://eos.org/scientific-press/glaciers-in-east-antarctica-also-imperiled-by-climate-change) to ongoing (https://eos.org/articles/new-maps-highlight-antarcticas-flowing-ice) and future (https://eos.org/editors-vox/warm-waters-in-west-antarctica) global (https://eos.org/research-spotlights/what-regions-are-most-at-risk-for-ice-loss-in-east-antarctica) climate (https://eos.org/editors-vox/icy-interactions) change (https://eos.org/articles/six-points-of-perspective-on-larsen-cs-huge-new-iceberg).

Observations from the polar regions, where the effects of climate change on the environment are amplified, are still too sparse. Subsequent expeditions can complete the seabed mapping and sampling and measure the water column changes that signal continental shelf-to-slope heat exchange processes, ocean water mass mixing, and ice sheet dynamics. The polar scientific community is eager to improve its understanding and predictions of climate system evolution—a fundamental step toward defining effective policy actions to mitigate potentially adverse effects of global climate change.

Acknowledgments

We thank the PNRA and European EUROFLEETS funding programs; Captain Franco Sedmak and crew; party chief Riccardo Codiglia; the technicians and scientific party of the expedition; Laura de Steur (Norwegian Polar Institute); Liu Yanguang (First Institute of Oceanography, Qindao, China); Robert McKay (University of Wellington, New Zealand), IODP Expedition 374 cochief officer; and Luca Gasperini (Consiglio Nazionale delle Ricerche), principal investigator of the PNRA/Macquarie project in the Southern Ocean. We also acknowledge IHS Markit, Paradigm, Schulmberger for Kingdom, Echos, and Vista academic free license.

References

Anderson, J. B., et al. (2014), Ross Sea paleo-ice sheet drainage and deglacial history during and since the LGM, *Quat. Sci. Rev.*, *100*, 31–54, https://doi.org/10.1016/j.quascirev.2013.08.020 (https://doi.org/10.1016/j.quascirev.2013.08.020).

Bergamasco, A., et al. (2002), Evidence of dense water overflow on the Ross Sea shelf-break, *Antarct. Sci.*, *14*, 271–277, https://doi.org/10.1017/S0954102002000068 (https://doi.org/10.1017/S0954102002000068).

Colleoni, F., et al. (2018), Spatio-temporal variability of processes across Antarctic ice-bed–ocean interfaces, *Nat. Commun.*, *9*(1), 2289, https://doi.org/10.1038/s41467-018-04583-0 (https://doi.org/10.1038/s41467-018-04583-0).

De Santis, L., et al. (1995), Seismic record of late Oligocene through Miocene glaciation on the central and eastern continental shelf of the Ross Sea, in *Geology and Seismic Stratigraphy of the Antarctic Margin*, *Antarct. Res. Ser.*, vol. 68, edited by A. K. Cooper et al., pp. 235–260, AGU, Washington, D. C., https://doi.org/10.1029/AR068p0235 (https://doi.org/10.1029/AR068p0235).

Naish, T., et al. (2009), Obliquity-paced Pliocene West Antarctic ice sheet oscillations, *Nature*, *458*(7236), 322–328, https://doi.org/10.1038/nature07867 (https://doi.org/10.1038/nature07867).

Pollard, D., and R. M. DeConto (2009), Modelling West Antarctic ice sheet growth and collapse through the past five million years, *Nature*, *458*(7236), 329–332, https://doi.org/10.1038/nature07809 (https://doi.org/10.1038/nature07809).

Sauli, C., et al. (2014), Late Neogene geomorphological and glacial reconstruction of the northern Victoria Land coast, western Ross Sea (Antarctica), *Mar. Geol.*, *355*, 297–309, https://doi.org/10.1016/j.margeo.2014.06.008 (https://doi.org/10.1016/j.margeo.2014.06.008).

Author Information

Laura De Santis (ldesantis@inogs.it (mailto:ldesantis@inogs.it)), National Institute of Oceanography and Applied Geophysics (OGS), Trieste, Italy; Florence Colleoni, Centro Euro-Mediterraneo sui Cambiamenti Climatici, Bologna, Italy; also at OGS, Trieste, Italy; Andrea Bergamasco, Istituto di Scienze Marine, Centro Nazionale delle Ricerche, Venice, Italy; Michele Rebesco, Daniela Accettella, and Vedrana Kovacevic, OGS, Sgonico, Italy; Jennifer Gales, Plymouth University, U.K.; formerly at National Oceanographic Centre, Cambridge, U.K.; Kim Sookwan, Korean Polar Research Institute, Incheon; and Elisabetta Olivo, OGS, Sgonico, Italy; also at University of Siena, Italy

Citation: De Santis, L., F. Colleoni, A. Bergamasco, M. Rebesco, D. Accettella, V. Kovacevic, J. Gales, K. Sookwan, and E. Olivo (2018), Exploring the unknown of the Ross Sea in sea ice–free conditions, *Eos, 99,* https://doi.org/10.1029/2018EO106159. Published on 11 October 2018.