

PAIS - Past Antarctic Ice Sheet Dynamics



<http://www.scar.org/srp/pais>

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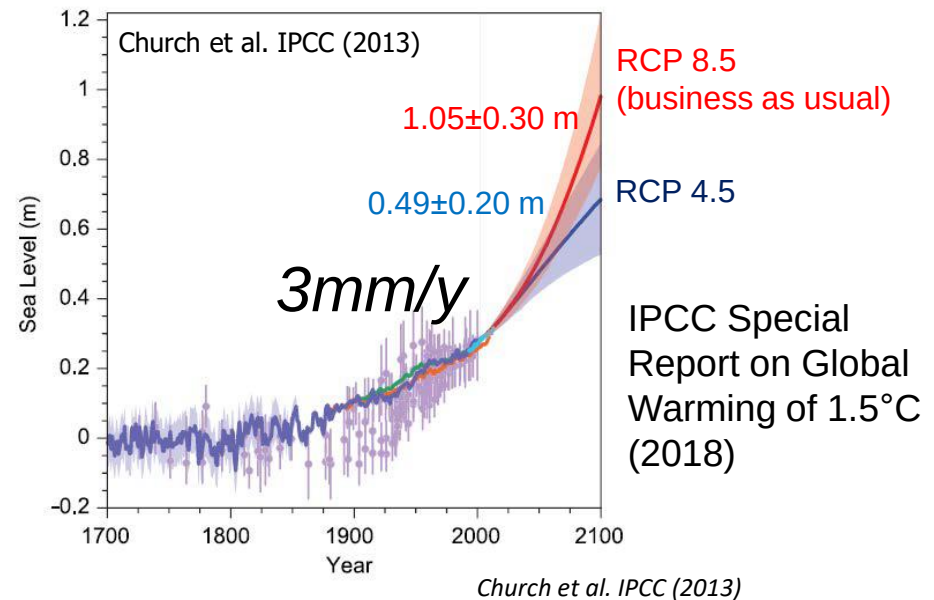
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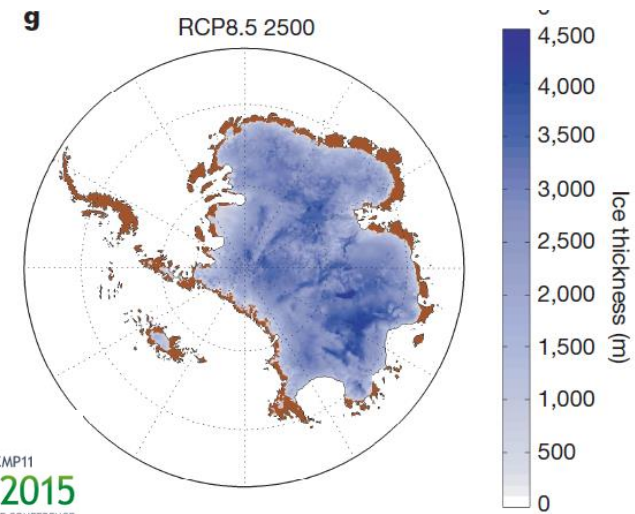
- The overarching goal of PAIS is to improve confidence in predictions of Antarctic ice sheet and sea-level response to future climate change and ocean warming.



- PAIS is strongly aligned with one of the six priorities of the SCAR Horizon Scan (Kennicutt, Chown *et al.*, 2014): **“Antarctic ice sheets and sea-level - Understand how, where and why ice sheets lose mass”.**



Based on current understanding, only the collapse of marine-based sectors of the Antarctic ice sheet, if initiated, could cause global mean sea level to rise substantially above the likely range during the 21st century....IPCC AR5, 2013



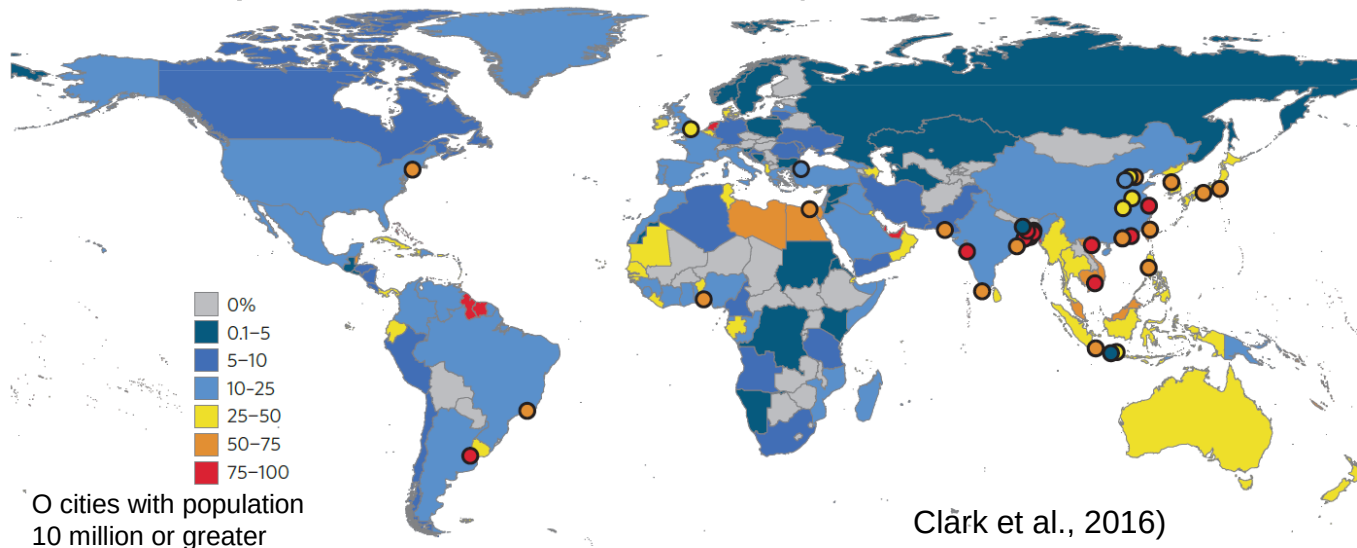
DeConto & Pollard (2016)

<https://media.nature.com/original/nature-assets/nature/journal/v531/n7596/extref/nature17145-sv3.mov>

Crowded – warming – vulnerable



Populated areas affected by sea-level rise



% of the population-weighted area for each nation or megacity below the projected long-term local mean sea level from emitting 1,280 Pentagrams Carbon (ca. Representative Concentration Pathways RCP 2.6)

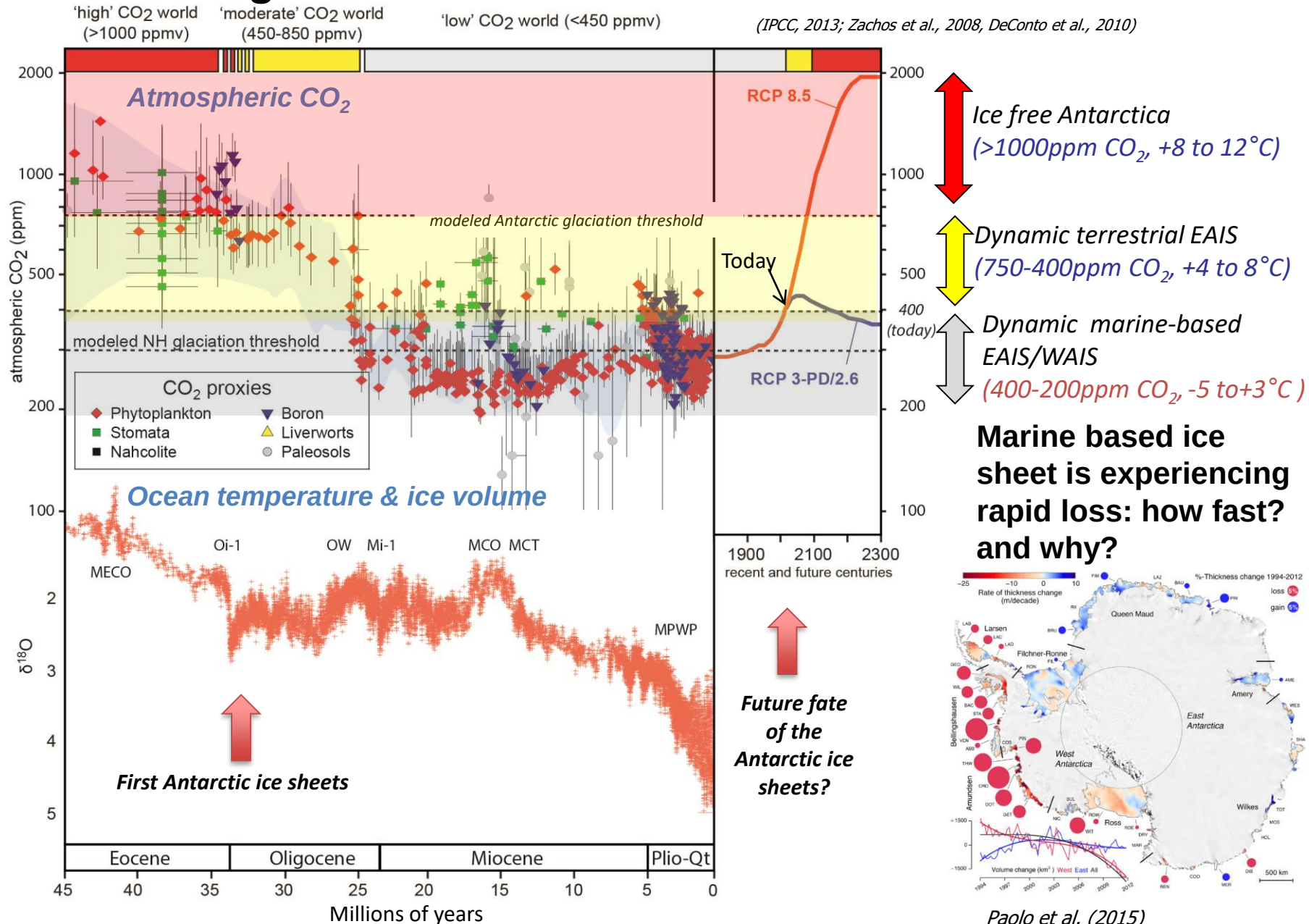


Dissemination of policy-relevant PAIS research and contributions to the IPCC 5th Assessment Report

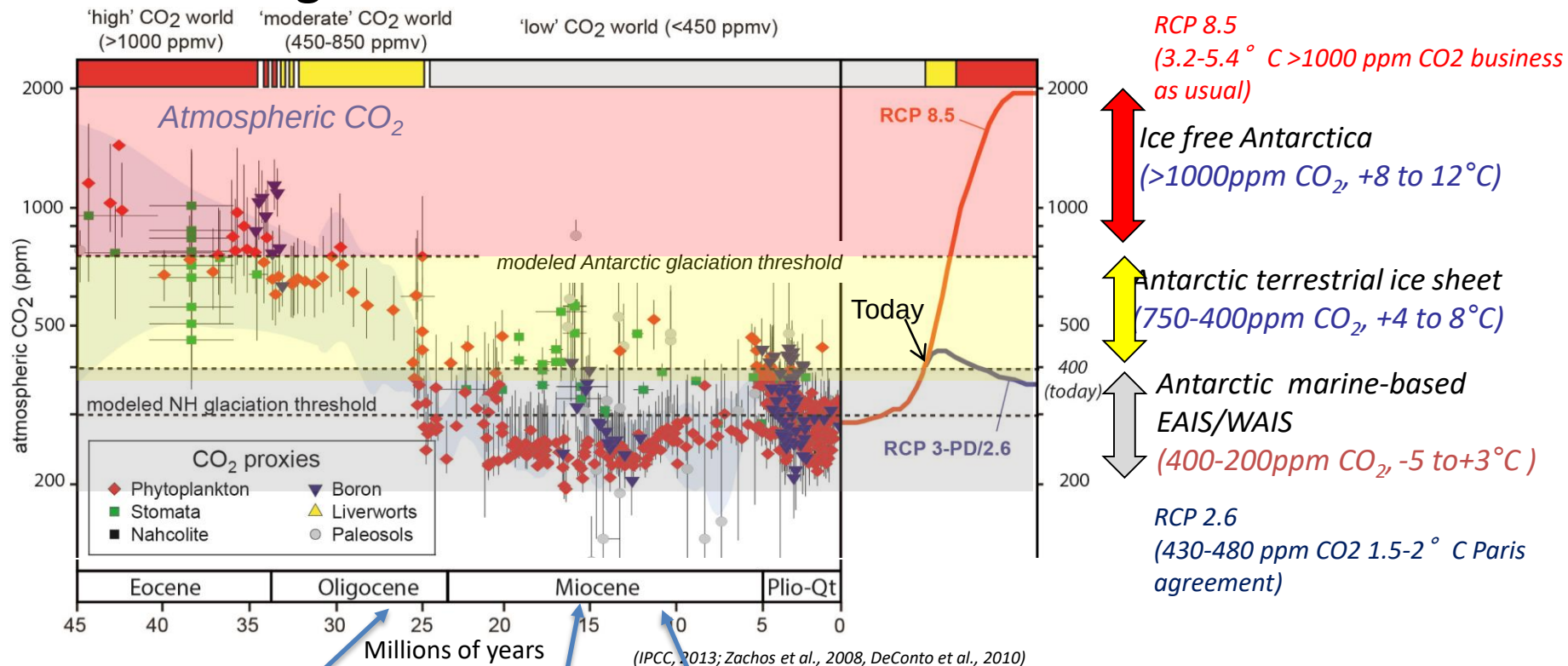


- There is *high confidence* that the volumes of the Greenland and WAIS were reduced during periods of the past few million years that were globally warmer than present. *Chapter 5 executive summary*
- New temperature reconstructions and simulations of past climates show with *high confidence* polar amplification in response to changes in atmospheric CO₂ concentration. For high CO₂ climates *Chapter 5 executive summary*.
- There is *high confidence* that global mean sea level was above present during some warm intervals of the mid-Pliocene (3.3 to 3.0 million years ago), implying reduced volume of polar ice sheets *Chapter 5 executive summary*.
- The atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased to levels unprecedented in at least the last 800,000 years. ***Summary for Policymakers.***

PAIS aims at assessing Antarctic ice sheet sensitivity and thresholds to a broad range of climatic and oceanic conditions



model-data past simulations to predict Antarctic ice sheet future rate of changes

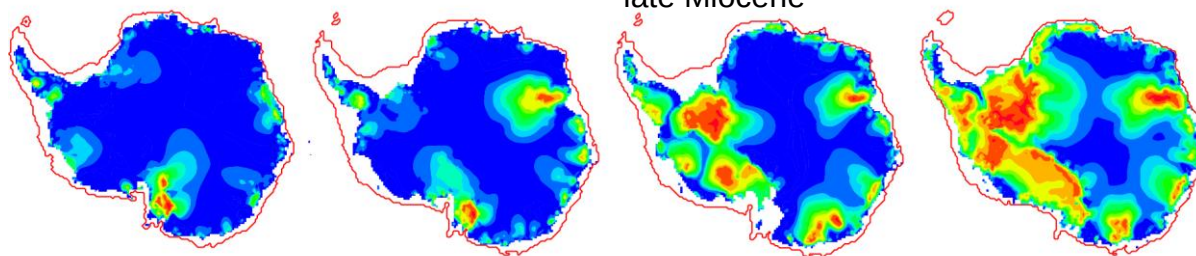


Early Miocene

mid Miocene

late Miocene

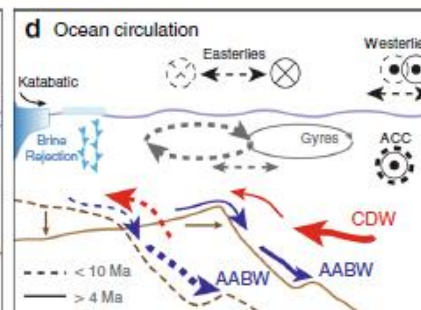
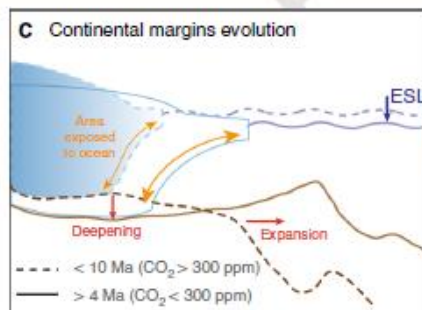
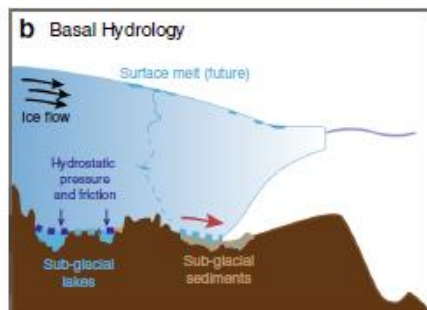
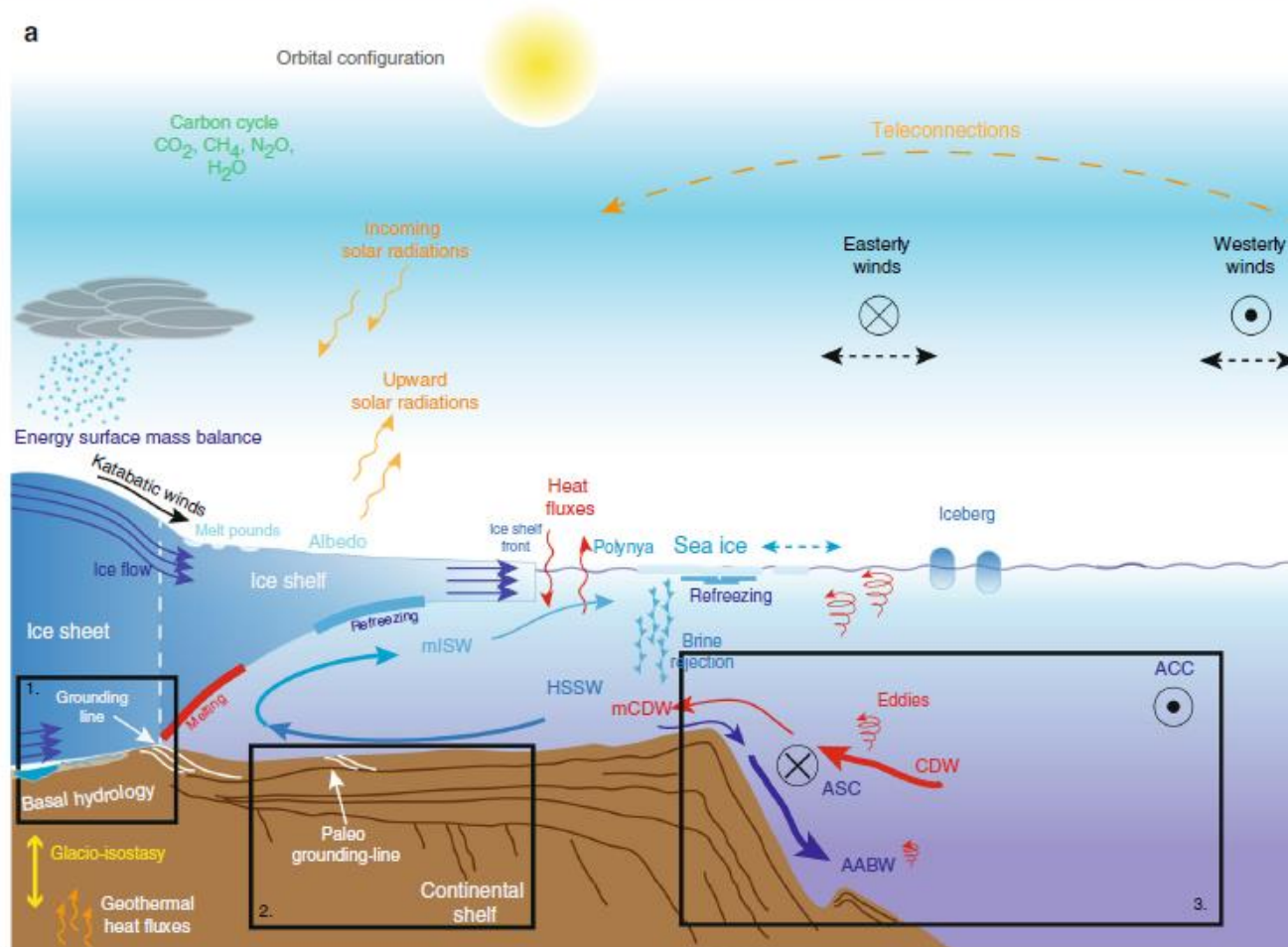
Modern



Bedrock deepening

Simulated ice sheet sensitivity to climatic conditions

Colleoni, F., De Santis, L., Montoli, E., Olivo, E., Sorlien, C. C., Bart, P.J. Gasson, E. G. W., Bergamasco, A., Sauli, C., Wardell, N., Prato, S., Scientific Reports. 2018, volume 8, 11323



Spatio-temporal variability of processes across Antarctic ice-bed-ocean interfaces: observations of present day and past environments

Colleoni et al.,
2018
Nature
Communications
volume 9,
Article number: 22
89 (Open access
DOI:
10.1038/s41467-
018-04583-0).

The PAIS approach



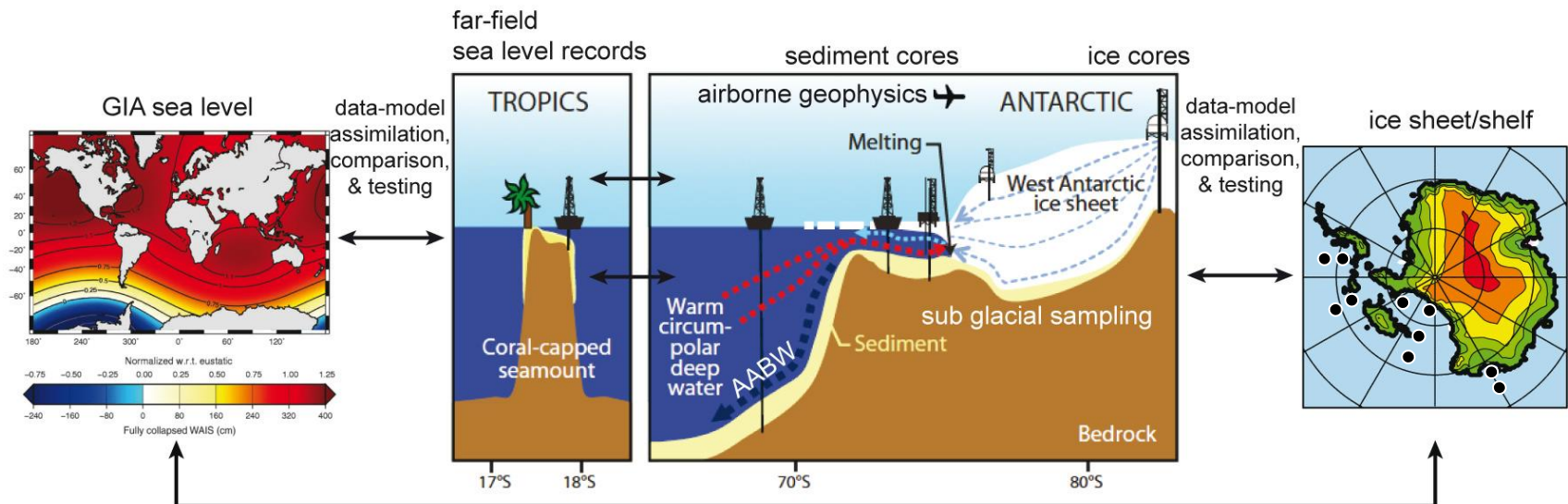
- Development of “ice-to-abyss” drilling transects, extending from the ice sheet interior to the deep sea.
- Reconstruct of past ice sheet behaviour and sea level.
- Integrate data and models to enable testing of ice sheet and glacial isostatic adjustment models coupled to general circulation models.
- **Use these same models for future sea-level predictions!**

PAIS ice-margin-offshore-far field transect concept and data-model comparison

GIA sea-level models

Data Transect

Ice sheet/shelf models



Capacity building

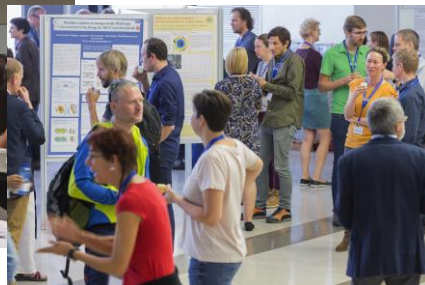
- supporting the planning of new data-acquisition missions using emerging technologies;
- encouraging data sharing and integration of spatially targeted transect data with modelling studies;
- initiating/expanding cross linkages among Antarctic research communities.

Schools – training courses

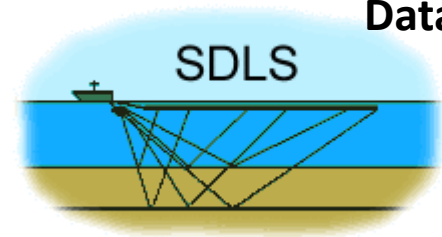


Texas AM May 2016 & 2019

Workshops-conferences



Data banks



International campaigns

Exp 374 Ross Sea
Exp 379 Amundsen Sea
Exp 382 Scotia Sea



PAIS international research symposium

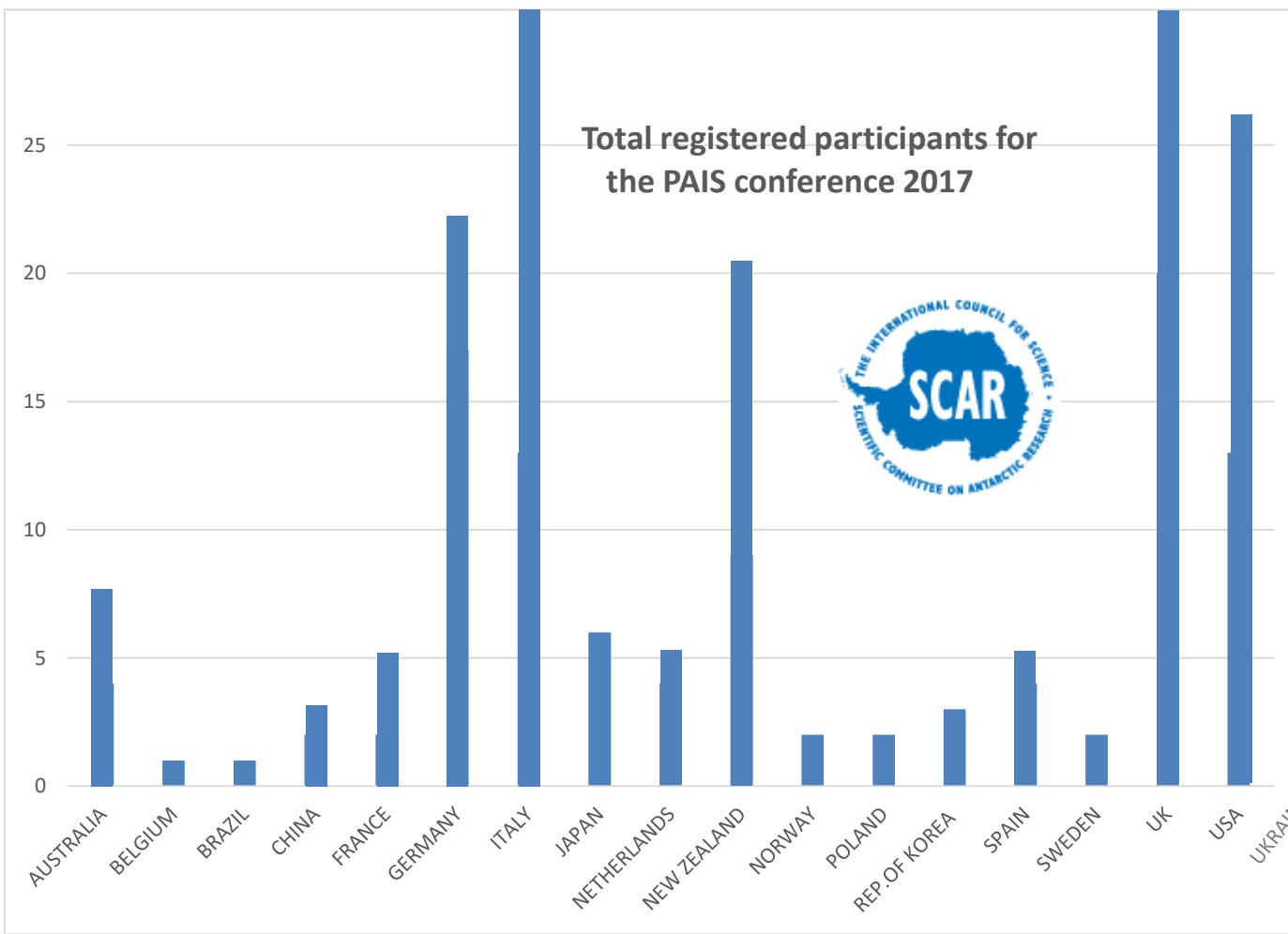
September 10-16th 2017 in Trieste (Italy)

<http://www.scar-pais.org/index.php/conference>



- Plenaries, posters, workshops, panel discussions on emerging issues and challenges for PAIS
- Strategic planning for future PAIS and beyond
- IPCC AR6 contribution – improving projections of Antarctic ice mass loss
- Improved interdisciplinary research collaboration (paleo and evolutionary biology, oceanography, far-field linkages and implications)
- Linkages with other SCAR SRPs and Expert Groups

White Paper <http://www.scar-pais.org/index.php/documents/13-pais-conference-2017-white-paper/file>



Cross Linkages within SCAR

Reveal Antarctica's history.



SERCE
ice dynamics: crustal
response, gateways
opening and sea level
changes (from post Last
Glacial Max vs 60 Ma).

Understand how, where and why ice sheets
lose mass.

AntarcticClimate²¹

AntClim21
Proxies of climate
variability, ice sheet and
Southern Ocean dynamics
(Holocene, Last Glacial
Maximum and last
interglacial)

Ice Sheet mass loss
estimate directly
contributing to sea
level rise

Learn how Antarctic life evolved and survived

State of the Antarctic Ecosystem Ant-eco
paleoenvironments, biota evolution, use genetic signature
to check gateways, land bridges and refugia



Studies investigating
the impacts of
ocean acidification
on polar marine
calcifying organisms

SCAR Expert Groups: ADMAP, ANTPAS, GIANT, IBSCO, IPICS, **ISMASS**

SCAR Action Groups: CGG, GeoMap, ANTOS, **Ocean Acidification**

The PAIS subcommittees



- Palaeoclimate Records from the Antarctic Margin and Southern Ocean
- Palaeotopographic-Palaeobathymetric Reconstructions
- Subglacial Geophysics
- Ice Cores and Marine Core Synthesis
- Deep Time Archives
- Recent Ice Sheet Reconstructions

The PAIS subcommittee Palaeoclimate Records from the Antarctic Margin and Southern Ocean



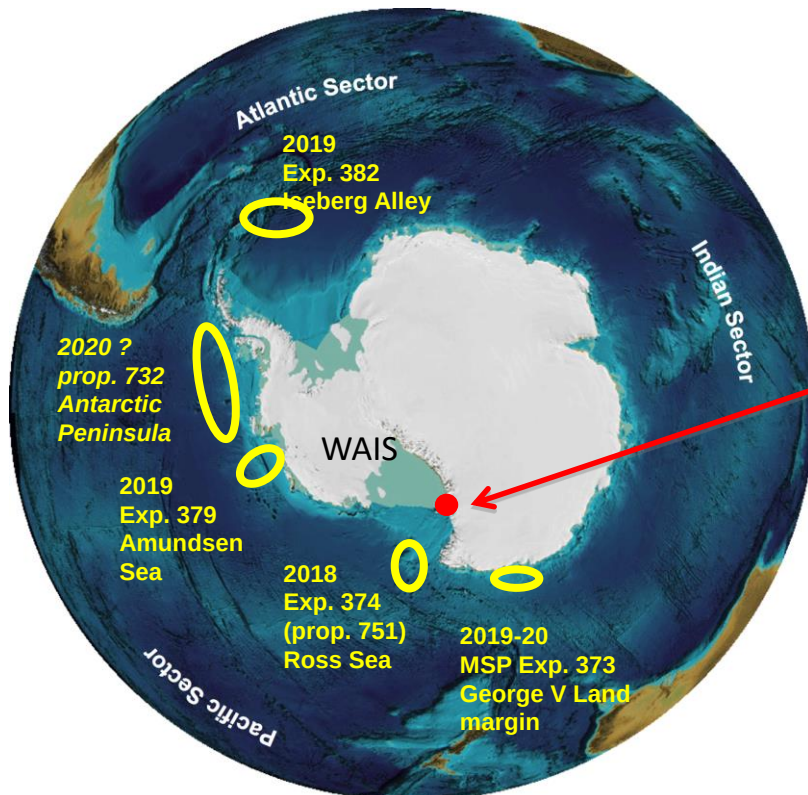
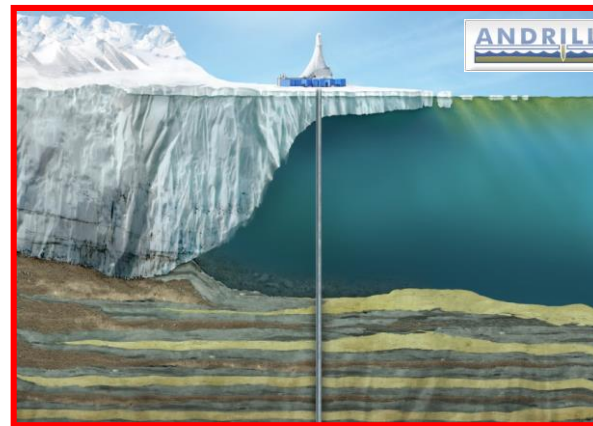
Co-ordination of the Antarctic paleoclimate community to secure scheduling of a US\$50 million transect of Antarctic IODP drilling expeditions (Wilkes Land, Ross Sea, Amundsen Sea, Scotia Sea) in 2017/2018 and 2018/2019. SCAR-EXCOM endorsed the action for COMNAP-IODP coordination

The Antarctic response to Miocene and Pliocene warmth & contribution to Pliocene higher sea-level

ANDRILL (2006-08)

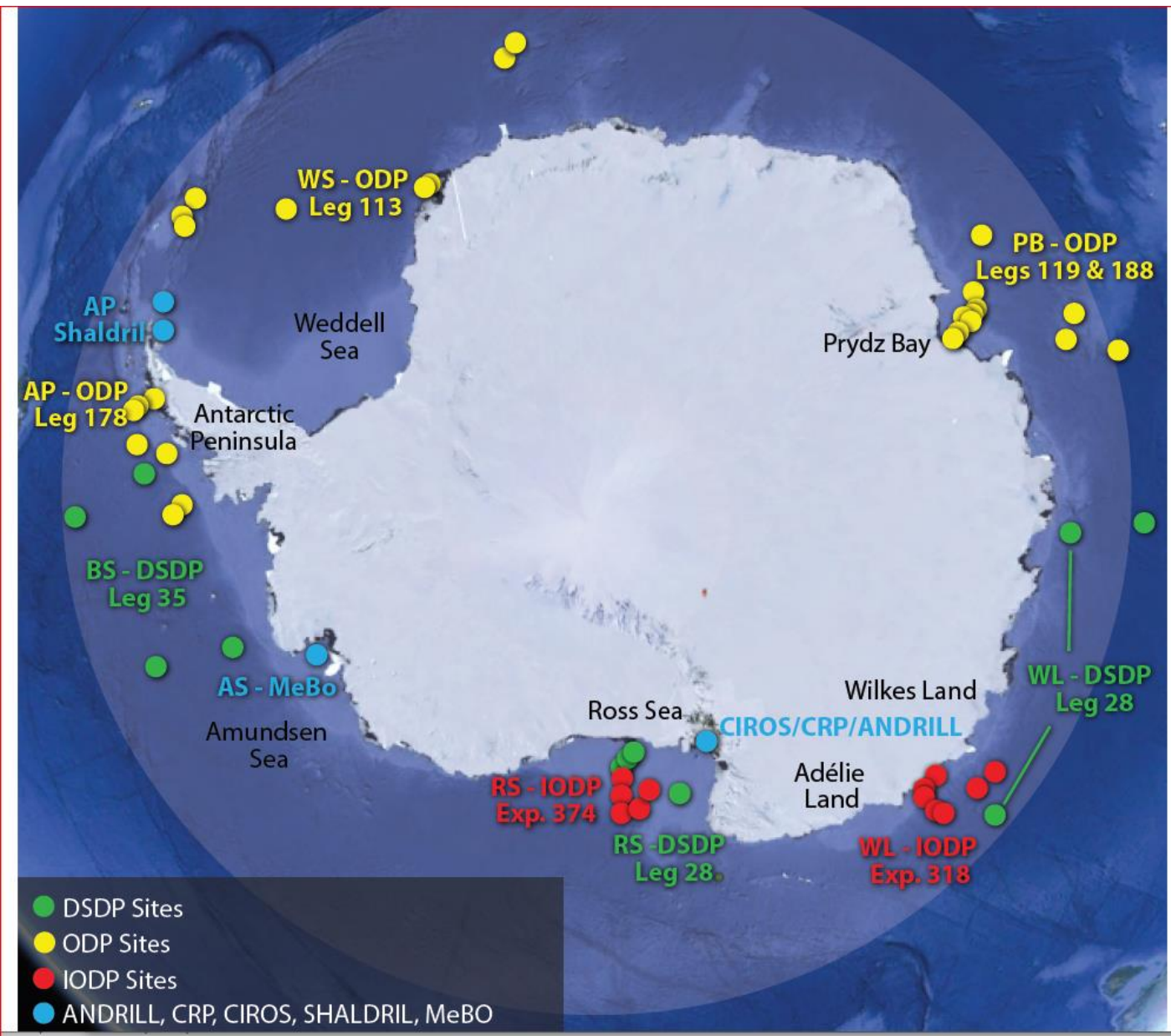
Direct evidence of West Antarctic Ice Sheet collapse

IODP exp 318 (2010), exp 374 (2018), exp 379 & 382 (2019)

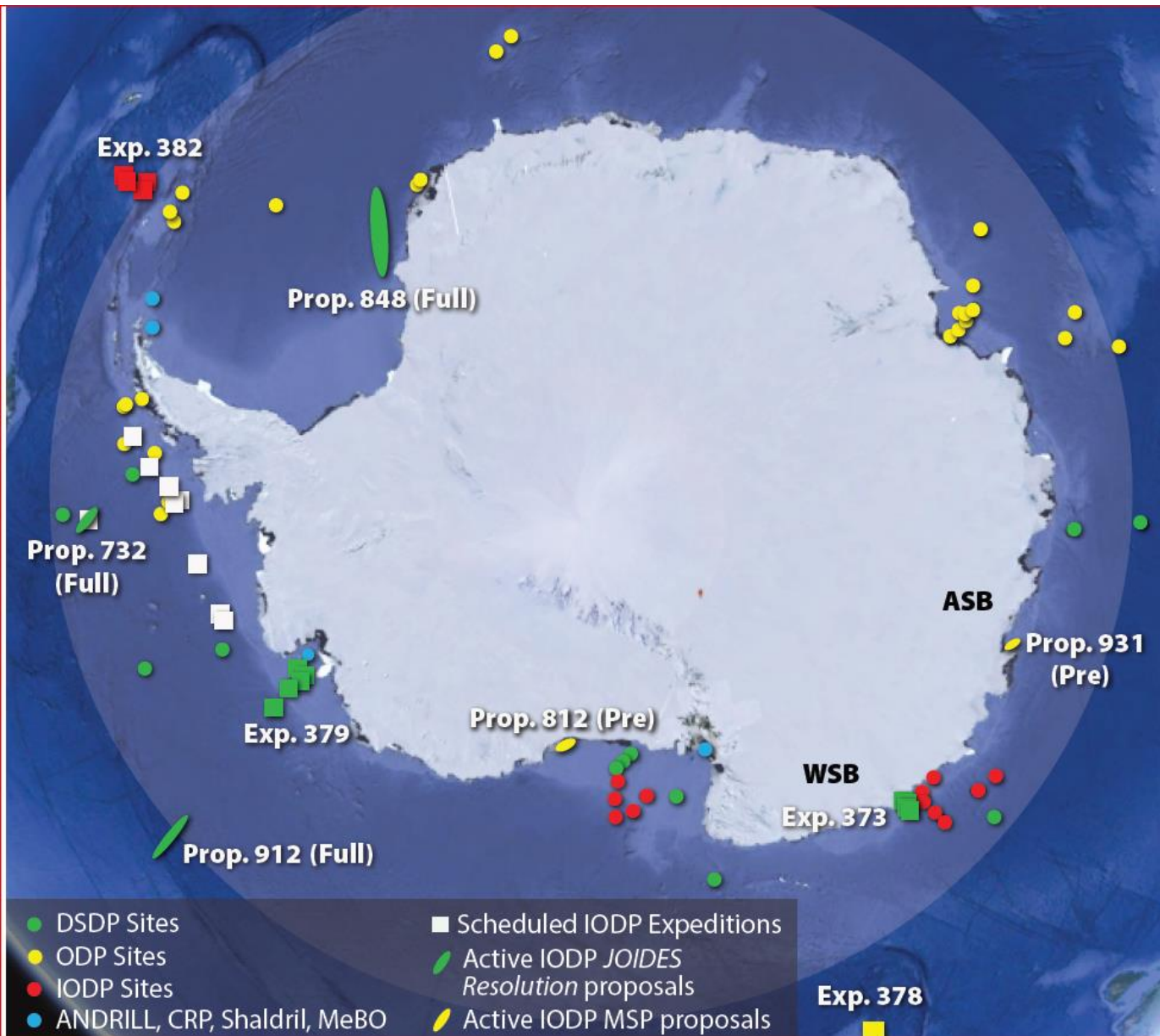


Direct evidence of East and West Antarctic Ice Sheet retreat and AABW dynamics

Greenhouse Antarctic 50 million years ago. Cooling after Tasman gateways opening



Escutia, C., R.M.
DeConto, R.
Dunbar, L. De
Santis, A.
Shevenell, and T.
Naish. 2019.
Keeping an eye on
Antarctic Ice
Sheet stability.
Oceanography
32(1): 32-46,
<https://doi.org/10.5670/oceanog.2019.117>
(Open Access)



Escutia, C., R.M. DeConto, R. Dunbar, L. De Santis, A. Shevenell, and T. Naish. 2019. Keeping an eye on Antarctic Ice Sheet stability. *Oceanography* 32(1): 32-46, <https://doi.org/10.5670/oceanog.2019.117>. (Open Access)

Watch the full video: <https://www.youtube.com/watch?v=UyWoai0OHxA>

Antarctic Scientific Deep Sea Drilling: A Long History

Kim Kimberly

DVDP-1, MSSTS-1
1974, 1979

CIROS & CAPE
ROBERTS 1984-1999

ANDRILL
2006-2008

DSDP 1968 - 1983
Legs 28 & 29

ODP 1985 - 2003
Legs 113, 119, 178, & 188

IODP 2003-2013
Exp. 318

IODP 2013 - 2023
Exp. 374, 379, 382

1970

1980

1990

2000

2010

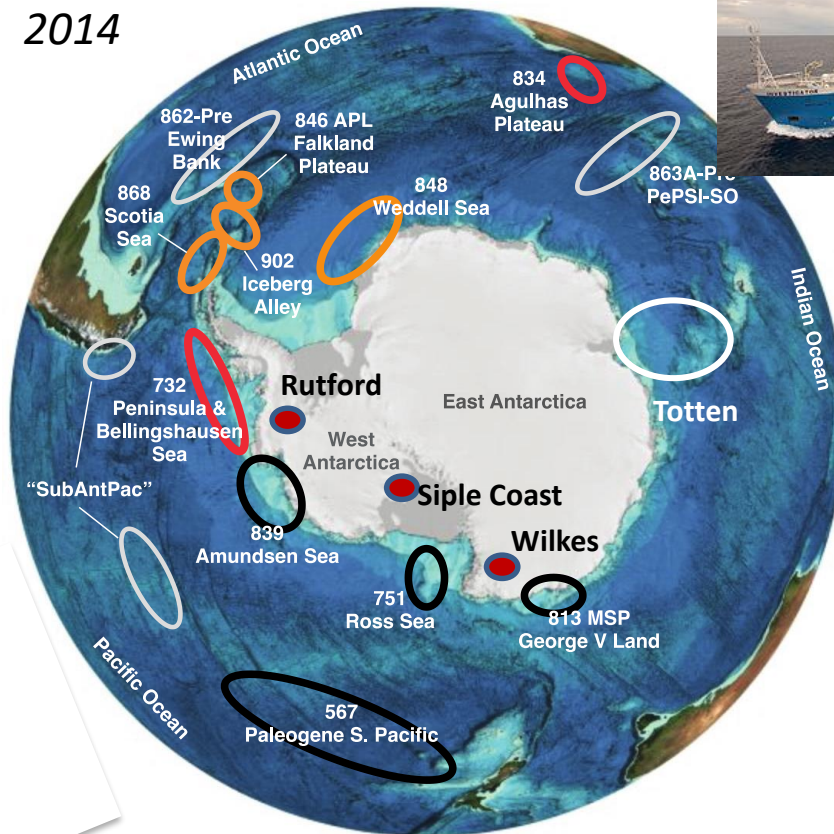
2020

And on the SCAR Past Antarctic Ice Sheet dynamics program: <http://www.scar-pais.org>

All PAIS subcommittees: Palaeoclimate marine Records; paleotopo-bathymetry; subglacial geophysics; ice-marine cores synthesis; recent reconstructions

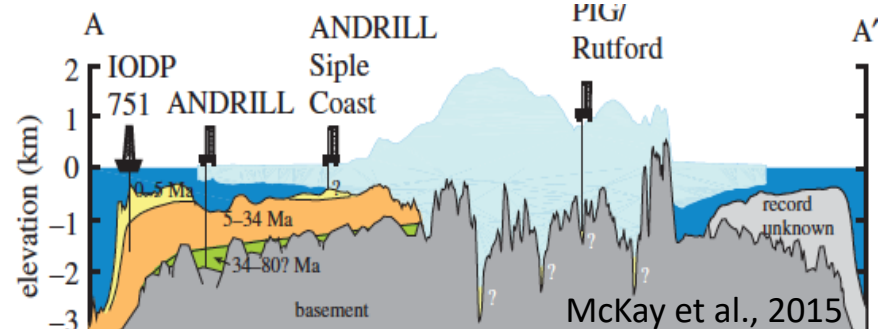
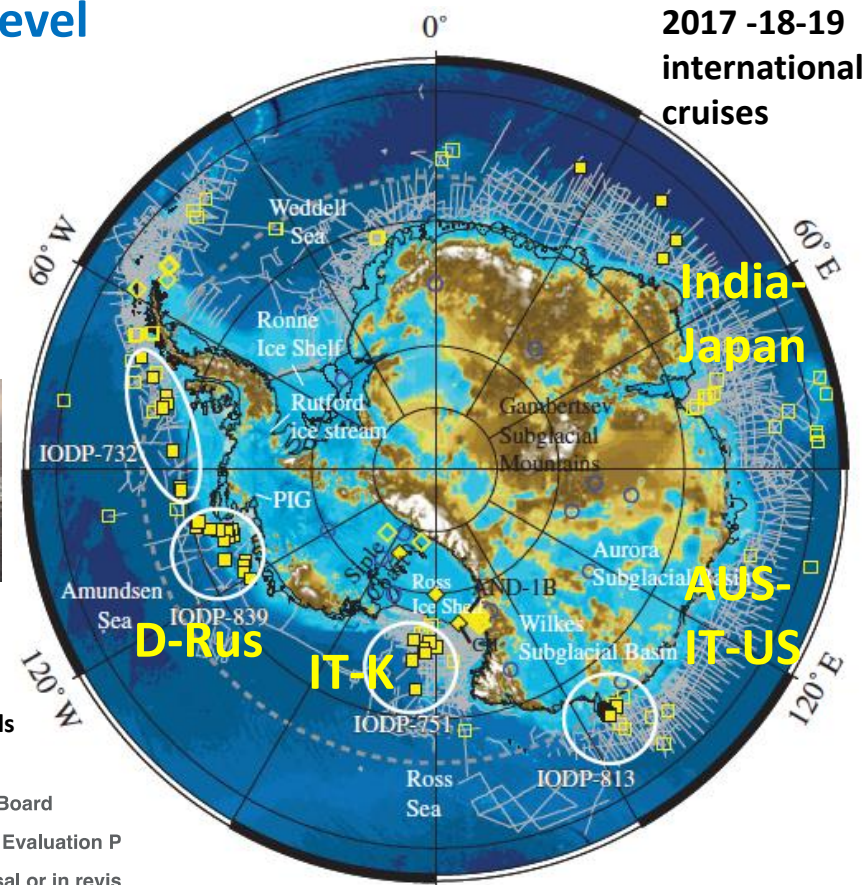
The contribution of Antarctica to abrupt sea-level rise during the Last Deglaciation

Bentley et al., Quaternary Science Reviews 2014; Weber et al., Science 2014, Rebesco et al., Science 2014; (Golledge et al., Nature Communications 2014

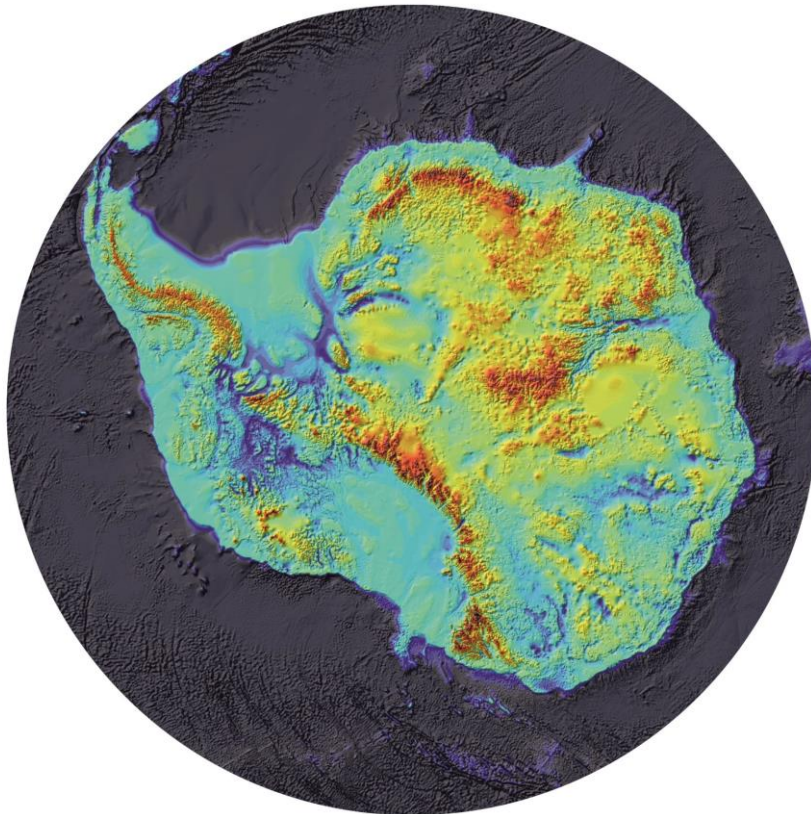


IODP proposals

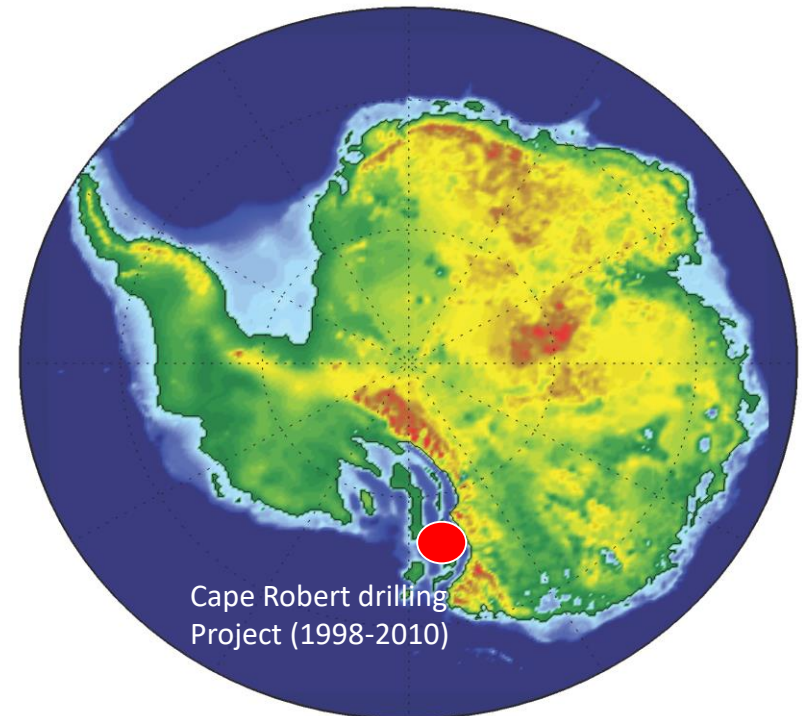
- Scheduled
- at Facility Board
- at Science Evaluation P
- Pre-proposal or in revis



Bedmap2 subglacial bed elevation



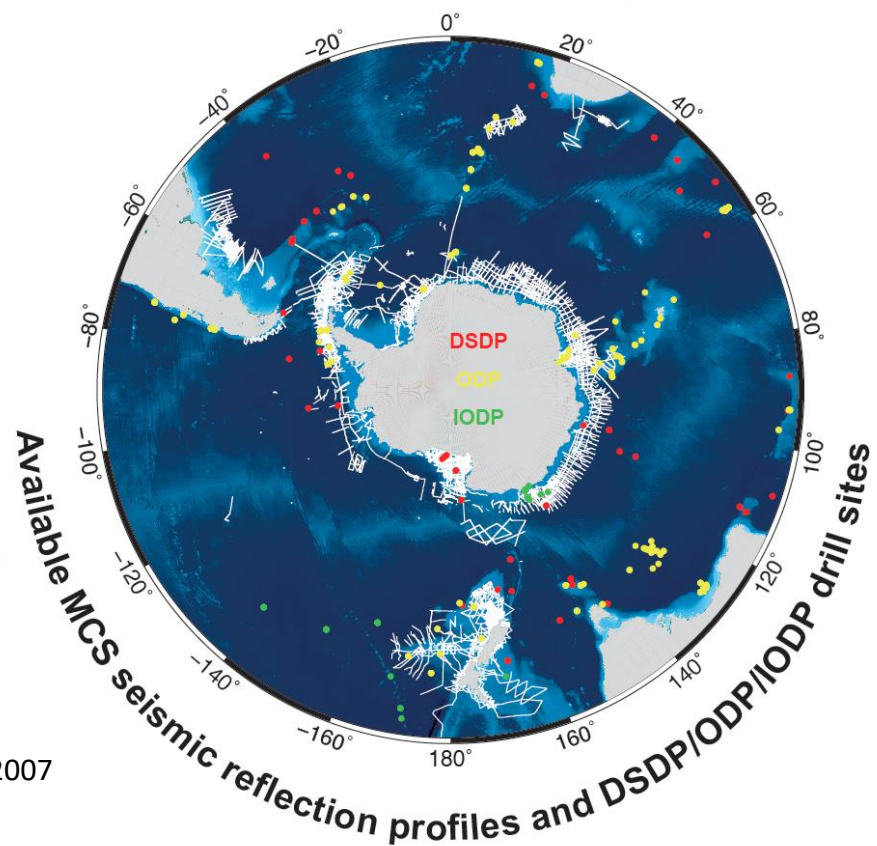
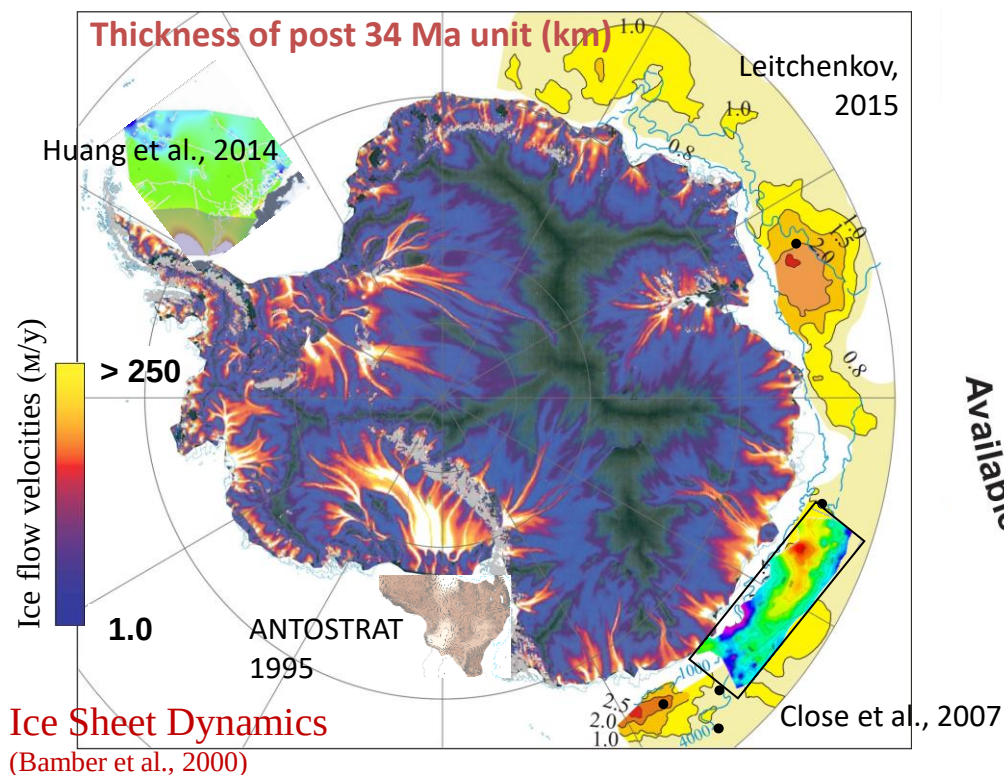
34 Ma reconstructed topography Wilson et al., 2010

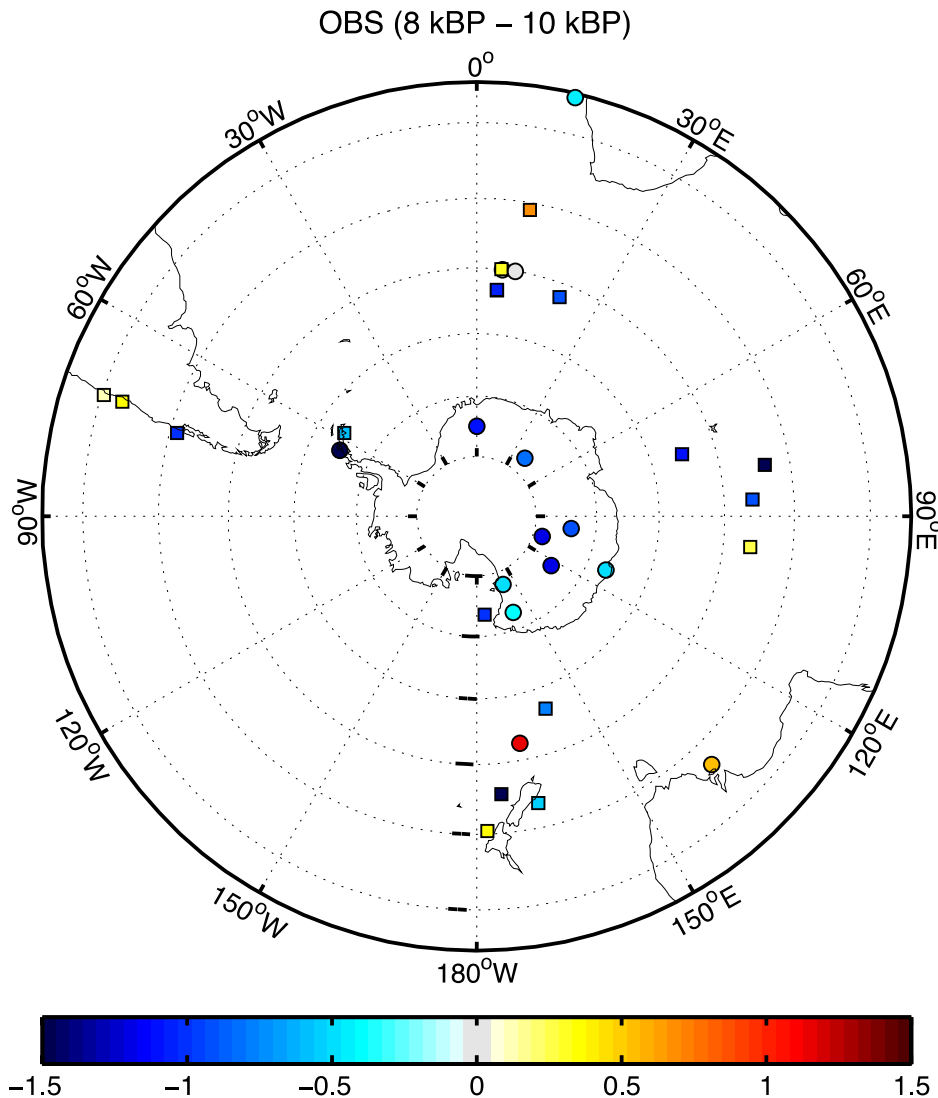


The PAIS subcommittee Palaeotopographic-Palaeobathymetric Reconstructions



Integration of completed projects into large-scale Southern Ocean grids including conjugate continental margins. Focus on relevant time periods in Cenozoic (e.g. Eocene, E/O, MMCO, Pliocene, Pleistocene). Differential eroded volume estimates, Paleoclimate modelling scenarios





ESF Polarclimate project: HOLOCLIP - Synthesis integrating ice and marine data with LOVECLIM climate model

Observation data from ice and marine cores at high latitudes over the Holocene (temperature differences between snapshots at 10, 8, 6, 4 and 1 ka BP)

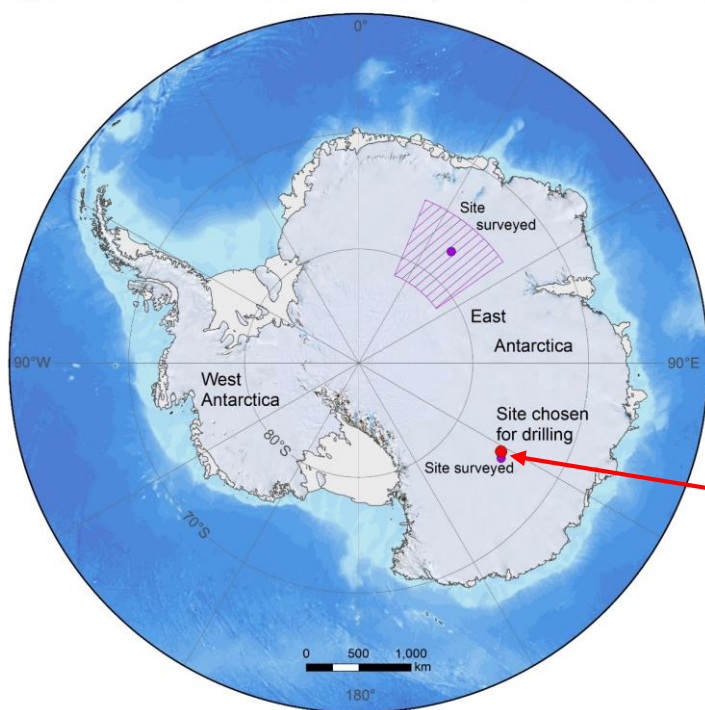


Beyond EPICA:

The quest for a 1.5 million year ice core

BEYOND
EPICA
OLDEST ICE

Beyond EPICA - the search for a 1.5 million year old core ice in Antarctica



On 1st June 2019 the EU project Beyond EPICA has started. It will last 6 years.

For info, please visit:

<https://www.beyondepica.eu/>

Site chosen for drilling:
Little Dome C, 40 km
from Concordia station

PAGES article and Marsden and NERC proposals:

On recovering Last Interglacial changes in the Antarctic ice sheet

Louise C. Simé, A.E. Carlson¹ and M. Holloway^{1,2,3,4}

The sensitivity of the Antarctic ice sheet to ocean warming is a major source of uncertainty in projecting future sea levels. Antarctic ice from the Last Interglacial sampled in ice cores provides key information to better quantify this sensitivity.

Quantifying the sensitivity of the Antarctic ice sheet (AIS) to increasing ocean temperatures is central to improving projections of global sea-level rise. Capron et al. (2014) compiled strong evidence of a Southern Ocean sea-surface temperature anomaly of up to +3.9 ± 2.8°C 125,000 years ago (125 kyr BP) compared to the present, and sea-level indicators for the Last Interglacial (LIG; around 129 to 116 kyr BP) suggest that this was the last time that global mean sea level (GMSL) was substantially higher than present (Dutton et al. 2015). This strongly suggests that pinning down the response of the AIS during the LIG should give insight into the last time the AIS was substantially smaller than today.

Ice-sheet modeling, alongside other lines of evidence, suggest the potential for massive loss of West Antarctic ice that is grounded below sea level (e.g. DeConto and Pollard 2016). Isotopic analysis of marine sediments and the NEMO Greenland ice core indicate that Greenland likely provided a relatively small ~2 m contribution to maximum LIG sea levels (NEMO Project Members 2013; Colville et al. 2011), so the reconstructed LIG GMSL peak of +6 to 9 m implies that the AIS experienced very significant melt during the LIG (Dutton et al. 2015). However, hunting for more direct evidence of AIS changes during the LIG has thus far proved to be surprisingly difficult, and the ultimate goal of deriving rates of AIS volume change has yet to be achieved.

Terrestrial observations of the extent of the AIS during the LIG are lacking due to subsequent growth of the AIS to its last glacial maximum volume. However, some evidence exists in the marine realm to constrain the LIG AIS. A tephra layer in the ANDRILL sediment core from the Ross Sea shows that at some time in the last 240 kyr, the Ross ice shelf was absent, potentially during the LIG (McKay et al. 2012). According to some ice-modeling studies, if the Ross ice shelf was to completely melt, the West Antarctic ice sheet (WAIS) would also deglaciate (e.g. DeConto and Pollard 2016). A recent study from a marine core off East Antarctica used Neodymium isotopes to show that the portion of the AIS overlying the Wilkes subglacial basin significantly pertained to a smaller-than-present extent during the LIG (Wilson et al. 2018). While similar studies near other sectors of the AIS could provide fruitful information on the LIG extent of the AIS, none of these approaches have, on their own, permitted the definitive establishment of AIS changes during the LIG.

The attractions of ice-core data

Antarctic ice cores are an attractive proposition for reconstructing AIS changes: several ice cores from East Antarctica covering the LIG period have been placed on an improved chronology using new gas and ice stratigraphic links (Bazin et al. 2013). The age uncertainty on this improved chronology is approximately 1500 years during the LIG, which is excellent compared to most other LIG data. Air content measurements from such ice cores have been used to attempt to infer changes in East Antarctic surface elevation over the past 200 kyr (e.g. Martinerie et al. 1994). However, Bradley et al. (2012) demonstrated that existing East Antarctic ice-core sites would experience negligible elevation change in response to a past WAIS collapse, and unknown in firm modelling make the conversion from air content to atmospheric pressure, needed to infer elevation changes, highly uncertain. However,

water isotope ($\delta^{18}O$) data has been measured with a precision generally better than 0.1‰ on these same ice cores. These well-dated and precise measurements (Fig. 1) hold the tantalizing prospect of establishing accurate rates of AIS change during the LIG. Steig et al. (2015) and Holloway et al. (2016) tackled the question of whether changes in the AIS, particularly ice loss from West Antarctica, would exert a significant control over the $\delta^{18}O$ signal recorded in Antarctic ice cores. Using $\delta^{18}O$ -enabled climate modeling, both demonstrated that significant West Antarctic mass loss or gain would cause major changes that should be observable in ice cores from both West and East Antarctica. Key patterns in ice-core $\delta^{18}O$ can be generated by melt from the AIS via resulting influences on atmospheric circulation, sea surface temperatures, and sea-ice extent around Antarctica (Holloway et al. 2017).

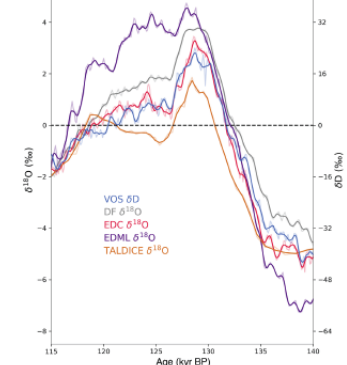


Figure 1. Last Interglacial (~125 kyr BP) $\delta^{18}O$ and $\delta^{18}O$ anomalies (relative to the most recent 3 kyr BP) from the Vostok (VOS), Dome Fuji (DF), Dome Concordia (DC), Dome C (DC), Dome Concordia (DC), Dome Concordia (DC), and Dome Concordia (DC) ice-core records. Raw ice-core data (light lines) are shown as well as a smoothed record (dark lines). The locations (filled circles) of these ice cores are shown in Figure 2.

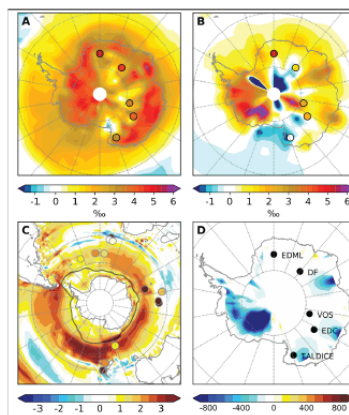


Figure 2. (A) Anomalies in Antarctic $\delta^{18}O$ from a 125 kyr BP ice-core climate model experiment relative to the corresponding pre-industrial experiment. (B) As in (A) but for a 125 kyr BP experiment including no-melt forcing and Antarctic ice-sheet topography equivalent to the minimum ice-sheet extent (DeConto and Pollard 2016). (C) Simulated summer (JFM) sea surface temperature anomalies (reconstructed anomalies from Capron et al. 2014) are shown as filled circles and winter sea-ice extent scaled corresponding to (A). (D) Antarctic elevation anomalies corresponding to (B) and locations of measured ice-core $\delta^{18}O$ anomalies shown in (A), (B), and Figure 1. See Holloway et al. (2018) for more details.

All of these aspects exert a strong and readily identifiable influence on $\delta^{18}O$ at the Antarctic ice-core sites (Holloway et al. 2016, 2018).

Constraints from ice-core data thus far Holloway et al. (2016) investigated whether the distinctive peak in $\delta^{18}O$ observed in ice cores at ~128 kyr BP (Fig. 1) was due to the loss of West Antarctic ice, but concluded that it was extremely likely that the WAIS was largely still intact at 128 kyr BP. A recent extension of this work (Holloway et al. 2018) using a fully coupled, isotope-enabled climate model demonstrates that the reconstructed penultimate deglacial meltwater event (around 0.2 Sv of meltwater input to the North Atlantic region over around 4 kyr) appears to explain the peak at 128 kyr BP in $\delta^{18}O$, via the well-known bipolar seesaw mechanism; these results indicate that meltwater input over ~3500 years can generate the whole ice-core $\delta^{18}O$ signal at 128 kyr BP (Fig. 2A). The succession of events is thus: (i) Meltwater from Northern Hemisphere ice sheets caused warming of the Southern Ocean; (ii) This in turn melted Antarctic

sea ice over a period of around 3–5 kyr BP; and (iii) The loss of sea ice subsequently imprinted itself on the ice cores as a peak in $\delta^{18}O$ (Holloway et al. 2017). This work also indicates that the climate models used here appear to be capable of accurately capturing key timings and processes during past warm periods.

Of course, the work described above does not address the main aim, which is to uncover AIS change throughout the entire LIG. In particular, determining how the AIS may have responded after the 128 kyr BP ice-core $\delta^{18}O$ peak (itself a response to the reconstructed Southern Ocean warming and sea-ice retreat; e.g. Fig. 2C) is yet to be a focus of ice-core modelling research (e.g. Holloway et al. 2016). The research performed to date does, however, provide key results to build upon:

- It establishes confidence in both climate models and in our understanding of LIG atmosphere and ocean dynamics.
- It also means that we now know with some confidence that the LIG $\delta^{18}O$ peak (shown in Fig. 1) was caused primarily by Antarctic

sea-ice retreat in response to relatively high Southern Ocean temperatures, themselves generated by meltwater from the penultimate deglaciation.

- It indicates that the AIS was likely resilient to higher-than-present sea surface temperatures and reduced Antarctic sea ice during the early LIG, since the AIS was largely intact at 128 kyr BP. Parts of the AIS could, however, have melted shortly after 128 kyr BP (e.g. Fig. 2B) in direct response to the warming, but this has yet to be established.

Next steps

Focused study on the period following the ice-core $\delta^{18}O$ peak (~125 kyr BP, Fig. 1) may provide important information on the magnitude and timescales of AIS change in response to a period of reduced sea ice and Southern Ocean warming. An example is illustrated in Figure 2B: ice-core $\delta^{18}O$ data at 125 kyr BP may be better explained using a reduced AIS configuration relative to present day, suggesting substantial continental ice loss in the 3 kyr period following the reconstructed LIG Antarctic sea-ice minimum.

Based on these recent advances, we suggest that the next steps should include: (i) checking, using $\delta^{18}O$ -enabled models, how ice cores may respond to other types and magnitudes of AIS changes (e.g. Fig. 2B), (ii) assessing whether our current ice-core data are sufficient to establish AIS changes; and (iii) obtaining new LIG ice-core data as necessary to constrain the models. Once these steps have been taken, we may find ourselves in a position to be able to pin down the most likely timing and contribution of the AIS to GMSL during this past warm interval.

AFFILIATIONS

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CONTACT

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- Bradley, S. et al. (2012) *Global Planet Change* 88–89: 64–75
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- Colville, J. et al. (2011) *Science* 333: 420–423
- DeConto, R., Pollard, D. (2016) *Nature* 531: 191–197
- Dutton, J. et al. (2015) *Science* 349: aea0119
- Holloway, M. et al. (2016) *Nature Climate Change* 7: 1229
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- Holloway, M. et al. (2018) *Geophys Res Lett* 45: 11,921–11,929
- Martinerie, P. et al. (1994) *Geophys Res Lett* 21: 10555–10558
- McKay, M. et al. (2012) *Quat Sci Rev* 34: 93–112
- NEMO Project Members (2013) *Nature* 493: 489–494
- Steig, E. et al. (2015) *Geophys Res Lett* 42: 4863–4868
- Wilson, D. et al. (2018) *Nature* 561: 393–398

Recent article on obtaining Past Antarctic ice sheet information from ice cores.

The PAIS future directions



data

Within the framework of the SCAR Horizon Scan and ARC Roadmap, PAIS is looking forward 10 years to the logistical and operational requirements of future data acquisition projects such as:

- IODP and other offshore and nearshore geological drilling programs,
- subglacial drilling and investigations,
- High resolution ice core – marine core correlations
- research cruises for cross-disciplinary sea bed mapping and for collecting geophysical data for paleo-bathymetric and paleo-geographic reconstructions of the Antarctic margin.

modelling

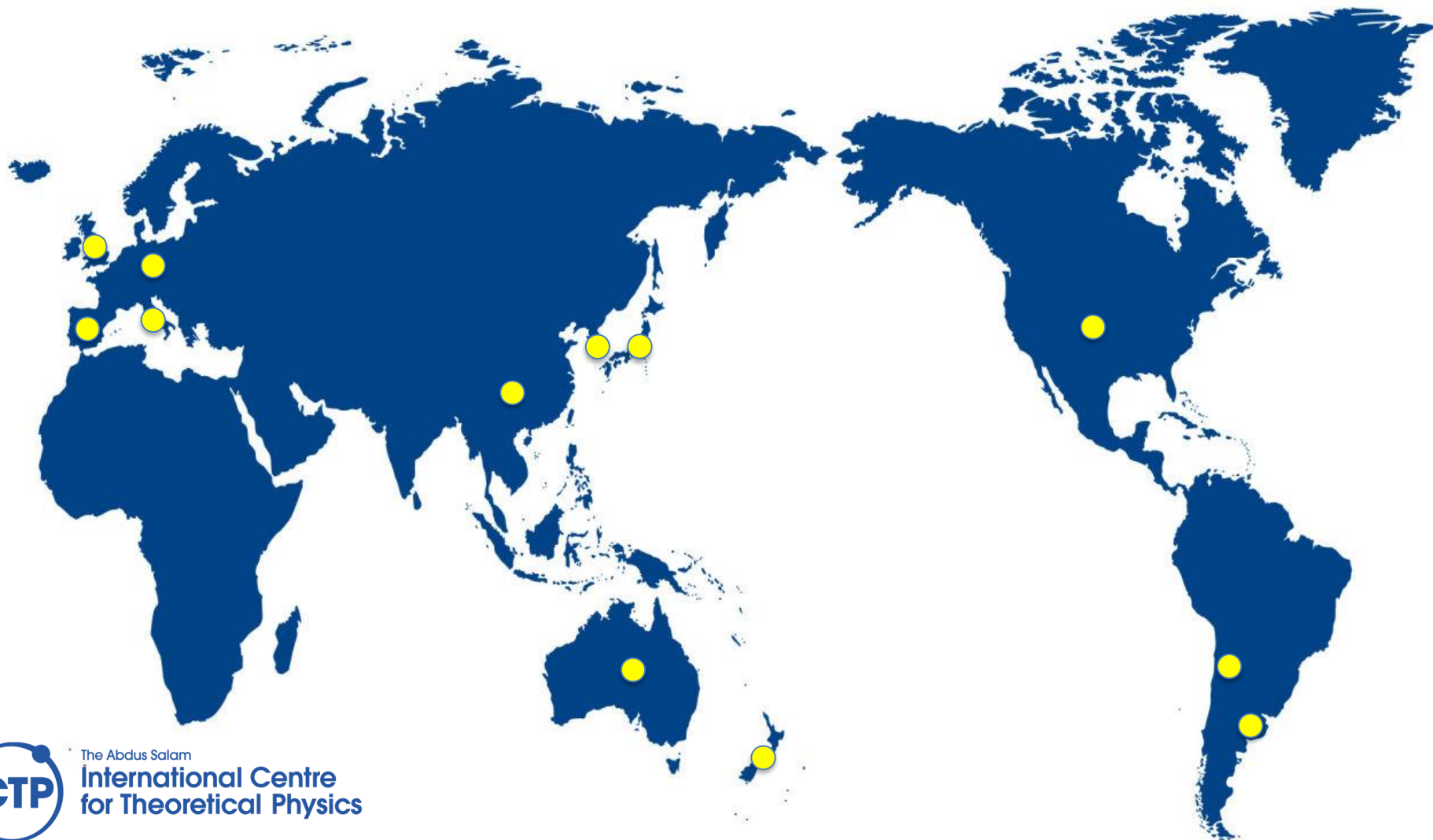
Ice sheet models FOR PREDICTING THE FUTURE are now using geological constraints in a quantitative sense (Ritz, DeConto, Pollard, Golledge etc.), to test and tune model physics, but the available data are limited:

- Need better constraints on timing and rate (e.g. MWP-1A, LIG),
- Antarctic contribution to 6-9m SLR during the Last Interglacial 125,000 years ago poorly constrained
- Challenge to couple dynamic ocean and ice sheet models.
- Need better paleo-bathymetry, paleo-topography, paleogeography



Steering Committee

12 countries



Budget

- Workshops organization
- Conference attendance (early career and students travel support)
- School attendance travel support (ECORD summer school)
- Web page