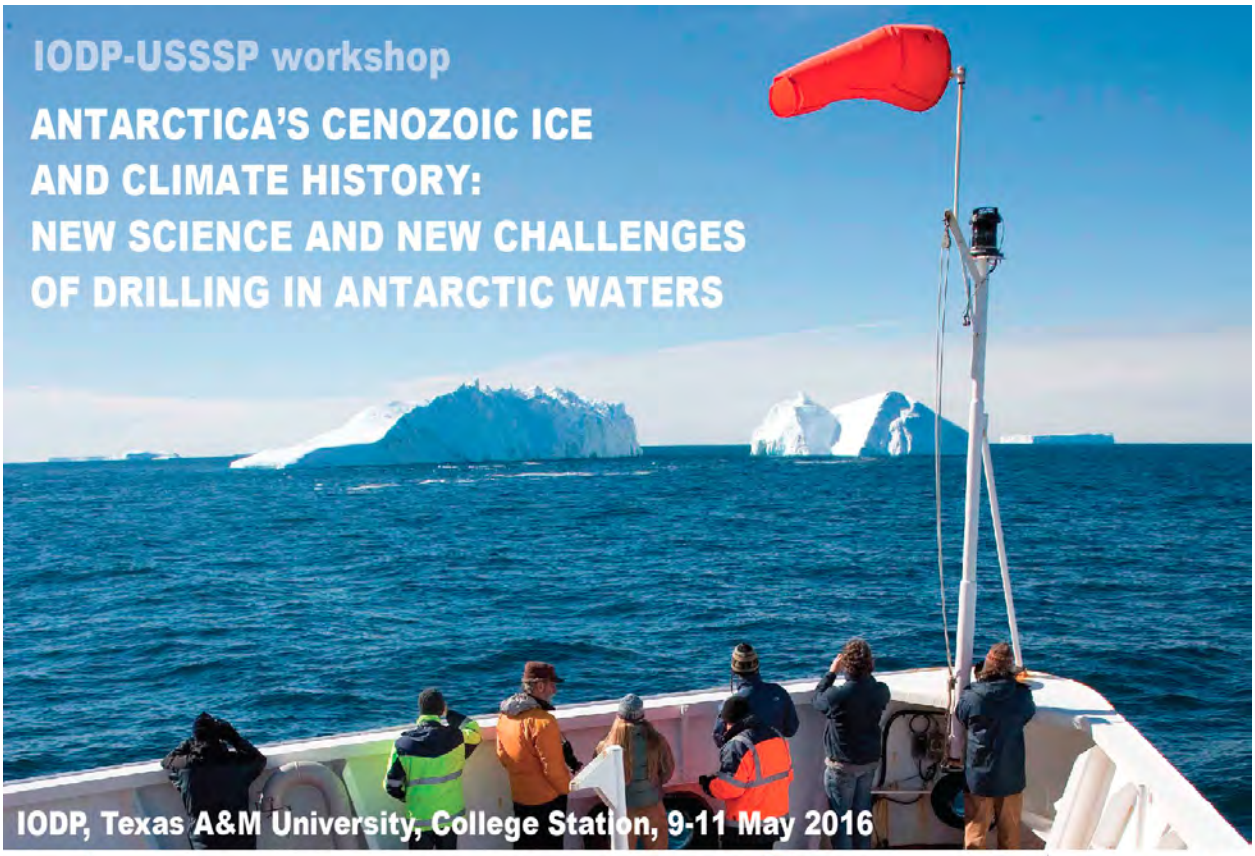
U.S. Science Support Program – Workshop Report

Antarctica's Cenozoic ice and climate history:
new science and new challenges of drilling in Antarctic waters
College Station, Texas, May 9-11, 2016



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1. Executive Summary

Antarctic and Southern Ocean marine sediments contain records of ice sheet dynamics and warm climates of the past. Understanding underlying processes, thresholds, and magnitudes of previous ice retreat and collapse in a variety of locations, when global temperatures and atmospheric CO_2 levels were higher than today, is essential to constrain numerical models and improve predictions of future sea-level rise. These scientific objectives are highlighted in the Climate and Ocean Change Challenges 1 and 2 of the 2013-2023 IODP Science Plan. At the time of the workshop, several proposals to collect Antarctic sediment records were in the IODP review system, but had not yet been scheduled for drilling. This workshop built on a broad effort to develop Antarctic margin drilling proposals, led since 2009 by the Past Antarctic Ice Sheet Dynamics (PAIS) research program of the Scientific Committee on Antarctic Research (SCAR).

The workshop was held at Texas A&M University on 9-11 May 2016, and brought together 84 senior, mid and early career Antarctic marine geologists and other experts to: (1) Gain an overview of the current proposals and what IODP drilling can bring to understanding Antarctic ice sheet retreat (and hence sea level rise) under warm climates; 2) Review sea ice and weather monitoring and forecasting products that can be used to plan drilling expeditions and make at-sea operational decisions; (3) Examine existing sediment cores from the Gulf Coast Repository that have revealed Antarctica's past glaciological history; and (4) Write a report to the JOIDES Resolution Facility Board (JRFB), which met the week following the workshop, to provide a focused summary of the workshop and a portfolio of drilling expeditions endorsed by the scientific community.

(1) Eleven IODP proposals for drilling in the Antarctic and Southern Ocean were presented and discussed, promoting coordination between proponent groups, cross fertilization of ideas, and synthesis of overall scientific aims. Presentations also included background common to all the proposals such as ice sheet modeling, glacial isostatic adjustment, and Cenozoic paleoceanography. This set the stage for the following three objectives.

(2) Sea ice and weather monitoring and forecasting tools were presented, including their practical use for expedition planning and at sea on the *RV N.B. Palmer* and *RV Polarstern*. Most of these products are freely available online from NASA, the European Space Agency, the US Naval Research Laboratory, and other institutes and agencies. Links to these resources are provided in this report.

(3) Classic DSDP, ODP and IODP Antarctic sediment cores were laid out in the core repository so that participants could examine the sediments on which much of the scientific knowledge of Antarctic climate evolution is based. Core examination also enabled conversations between early career scientists and more senior scientists (many of whom did the original work on the cores), transmitting expertise, stimulating new ideas, and encouraging the early career scientists to join the Antarctic drilling community by applying for future IODP expeditions and writing new drilling proposals.

(4) A letter was submitted to the *JOIDES Resolution* Facility Board describing a coordinated portfolio of three West Antarctic Ice Sheet (WAIS) IODP proposals 751 (Ross Sea), 839 (Amundsen Sea), and 732 (Antarctic Peninsula and Bellingshausen Sea). The portfolio's objectives are to a) reconstruct the Neogene-Quaternary orbital-scale dynamics of the WAIS, b) identify drivers of ice instability and their thresholds, especially of ocean forcing, for past WAIS retreat, and c) assess relationships between the Antarctic cryosphere, ocean circulation, and global climate. At the May 2016 JRFB meeting, the Ross Sea and Amundsen Sea proposals

were scheduled for drilling as Exp. 374 (2018) and Exp. 379 (2019), joining the already-scheduled George V Land Mission-Specific Platform Exp. 373.

2. Background

One of the most significant and pressing challenges for climate predictions is to resolve the unknown contribution of continental ice sheets to future sea-level rise. The parts of the Antarctic ice sheet grounded on bedrock below sea level (marine-based ice) are susceptible to retreat and melting in warmer climates. West Antarctic Ice Sheet (WAIS), with much of its bed >1000 meters below sea-level, has the potential to provide a major contribution to sea-level rise over the next century and beyond. The marine-based parts of the East Antarctic Ice Sheet (EAIS) are mostly more stable than those of the WAIS, but they contain a greater volume of ice and would contribute more to sea level rise in the longer term. Understanding underlying processes, thresholds, and magnitudes of previous ice sheet retreats and collapses, particularly for the WAIS, when global temperature and atmospheric CO_2 levels were higher than today, is essential to guide numerical model improvement and better predict future sea-level rise. These scientific issues are highlighted in the 2013-2023 IODP Science Plan and the Denver-2012 prioritization of that plan by the US IODP community as Challenge 1: How does Earth's climate system respond to elevated levels of atmospheric CO_2? and Challenge 2: How do ice sheets and sea level respond to a warming climate?

This workshop is part of a coordinated series of meetings and workshops since 2009 by the Past Antarctic Ice Sheet Dynamics (PAIS) research program through the Scientific Committee on Antarctic Research (SCAR; www.scar.org), an International Council for Science (ICSU) committee, to develop proposals for drilling the Antarctic Margin. PAIS has laid out a plan for drilling and modeling transects from deep water offshore Antarctica to proximal glacimarine to continental ice and climate records as a means to understand the heterogeneous response of the Antarctic Ice sheet to oceanic and atmospheric forcing.

In the broader setting climate change the 2015 UN Climate Change Conference in Paris requested that IPCC write a special report by 2020 to assess the climate impacts of climate stabilization at 2°C and 1.5°C and response of Antarctic Ice Sheets will comprise an important component of this report. Thus IODP has the chance to make fundamental scientific insights relevant to understanding future climate change over the next decades and centuries.

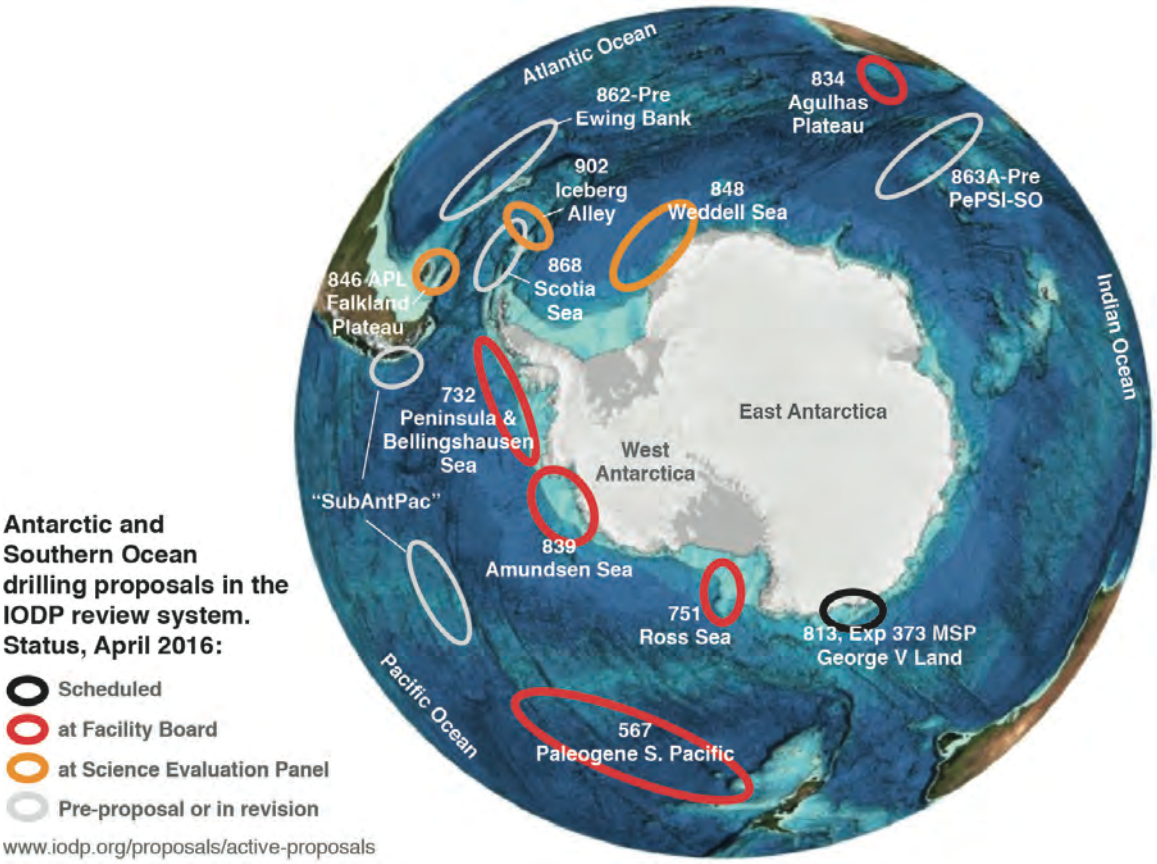


Figure 1. Locations of the IODP proposals and their status in April 2016, prior to the workshop, all but one of these proposals was represented by a proponent at the workshop. (See Figure 10 for the equivalent July 2016 map).

3. Objectives

The overarching goal of this workshop was to share and integrate the science objectives of the upcoming scheduled and proposed scientific drilling expeditions to Antarctic waters. At the time of the workshop, ten IODP Mission-Specific Platform and JOIDES Resolution drilling proposals for Antarctic waters were either scheduled (proposal 813, George V Land Antarctic Cenozoic Climate), at a Facility Board (proposals 732, 751 and 839), or at the Science Evaluation Panel (Fig. 1).

The first three workshop objectives were assigned approximately one day each of the three-day workshop. A fourth objective was to integrate the discussions of the workshop into a letter to the JOIDES Resolution Facility Board outlining an Antarctic IODP drilling plan for the next few years. The four objectives are described below:

(1) Produce an integrated overview of the science objectives of the drilling proposals currently in the IODP system, with particular focus on what each objective can contribute to understanding Antarctic ice behavior in the past, and future. We will also identify geographic areas and age windows that can best provide insight into Antarctica's past, provide ground-truth for ice sheet modeling work, and create a roadmap for new drilling proposals. The insights into ice sheet response under warm climates that are gained from drilling in Antarctic and Southern Ocean

waters are relevant to the IPCC and climate change policy makers; IODP is uniquely poised to provide this critical information.

(2) Establish best practices for assessing iceberg, sea ice, weather, and other logistical hazards in Antarctic waters. A state of the art understanding of likely ice conditions and weather is critical for assessing hazards before and during an expedition. We will discuss how best to use satellite images and weather data for year-to-year forecasting of open-water areas and for at-sea decision-making.

(3) Examine classic Antarctic sediment cores housed in the IODP Gulf Core Repository to illuminate Antarctica's past environments and marine glaciological history. This will provide an opportunity for seasoned Antarctic scientists to share experiences and knowledge with the next generation of Antarctic scientists.

(4) Write a meeting summary to be submitted to the *JOIDES Resolution* Facility Board prior to their next meeting (held the week following the workshop), with a workshop-endorsed plan describing a coordinated portfolio of mature Antarctic drilling proposals for drilling over the short and medium term,

4. Synthesis of proposals currently in the IODP system (Objective 1)

The first day of the workshop was designed to set the background scientific and IODP context, hear presentations of the proposed expeditions, and hold discussions on how to synthesize the objectives of the individual proposals, with the overall goal to understand what Antarctic IODP drilling can contribute to understanding Antarctic ice behavior in the past and future. The climate / ice sheet / sea level question is certainly not the only compelling science in the proposed expeditions, but as the IODP Challenge of widest societal relevance, it was the emphasis for the workshop.

Many of the proposals were developed under the umbrella of a series of meetings and workshops organized since 2009 by PAIS. However, each was written independently, and at the time of the workshop, only the abstracts, brief objectives, and drill site locations were publically available (at https://www.iodp.org/proposals/active-proposals). The workshop provided opportunity for discussion of common content, intersecting science topics, and collaborative opportunities. For the junior scientists, it provided a scientific overview, insight into the IODP proposal process, and helped them to decide which potential expeditions they might apply to sail on.

The day started with introductory presentations on the workshop aims (Trevor Williams, IODP, Texas A&M), previous Antarctic scientific drilling (Frank Rack, University of Nebraska, now at NSF), and the IODP proposal system (David Mallinson, East Carolina University). This was followed by 15-minute presentations on each of the proposals (Fig. 1):

Presentations on Antarctic and Southern Ocean proposals currently at the JR Facility Board:

- IODP-751 (now Exp. 374, Jan-Feb 2018) Ocean-ice sheet interactions and West Antarctic Ice Sheet vulnerability: clues from the Neogene and Quaternary record of the outer Ross Sea continental margin (Rob McKay et al.).
- IODP-839 (now Exp. 379, Jan-Feb 2019). Development and sensitivity of the West Antarctic Ice Sheet tested from drill records of the Amundsen Sea Embayment (Karsten Gohl et al.).
- IODP-732. Sediment drifts off the Antarctic Peninsula and West Antarctica (Jim Channell, Rob Larter, et al.).
- IODP-567. Paleogene South Pacific APC Transect: Heat Transport and Water Column Structure During an Extreme Warm Climate (Debbie Thomas et al.).

Updates on Antarctic and Southern Ocean drilling proposals:

- IODP-813-MSP (Expedition 373). Antarctic Cenozoic Climate from George V Land and Adélie Land shelf sediments (Trevor Williams, Carlota Escutia, et al.).
- IODP-848. Late Neogene to Quaternary ice-sheet and sea-level history of the Weddell Sea, Antarctica (Mike Weber et al.). At IODP Science Evaluation Panel (SEP).
- IODP-847. Plio-Pleistocene reconstruction of ice-sheet, atmosphere, and ocean dynamics in Iceberg Alley (Mike Weber et al.) Resubmitted to SEP, 1 April 2016.
- IODP-868 Scotia Sea (Javier Hernandez Molina et al.);
- Drake Passage (Gisela Winckler for Frank Lamy et al.);
- Agulhas Plateau (Gabi Uenzelmann-Neben et al.);

- IODP-MDP-863 ISOLAT – Conrad Rise (Minoru Ikeraha for Peterson et al.).

Over the last decade there has been rapid scientific progress in the fields of ice sheet and climate modeling, glacial isostatic adjustment and geographical distribution of sea level change, and in the Cenozoic paleoclimatic record. All of these fields provide necessary context for the proposed scientific drilling, and in turn, and the proposed drilling would provide ground truth for the models and proximal evidence of ice behavior for the global paleoclimate record. Therefore on the first afternoon of the workshop we invited overview presentations on ice sheet modeling (Rob DeConto), sea level and Glacial Isostatic Adjustment (GIA) (Jacky Austermann), and carbon dioxide, temperature, and ice volume over the Cenozoic (Amelia Shevenell).

The talks were followed by a wide-ranging discussion covering:

- The basics of how many Antarctic expeditions were in principle possible each year, given the sea ice and weather windows (one Antarctic expedition in a year, plus one Southern Ocean expedition)
- The importance of proposal teams working together as a community; the difficult question of proposal prioritization – this would be useful for the JRFB and should be based on the expedition science and the integrated multi-expedition science.
- Flexibility to go ice-free areas during an expedition if the primary sites are inaccessible: all the Antarctic proposals are designed to have many alternate sites that can achieve their main objectives; there was discussion of shared sites between proposals to provide still more options in the case of a heavy sea ice year – this is complicated but possible.
- The place of IODP Antarctic drilling in the wider context: the SCAR (Scientific Committee on Antarctic Research) PAIS (Past Antarctic Ice Sheet) initiative as an umbrella organization for Antarctic scientific drilling; the focus on WAIS (West Antarctic Ice Sheet) because it is already loosing ice; relevance of paleo ice scenarios to IPCC – IPCC has not included much of this in previous reports, yet the analogs for future ice scenarios are compelling.

Figure 2. Workshop participants discuss Antarctic IODP drilling on the first day of the meeting, in the Koldus meeting room on the main campus of Texas A&M University.

5. Sea ice and weather monitoring for expedition planning and at-sea operational decisions (Objective 2)

The second objective of the workshop was to discuss hazards to drilling in high southern latitudes, discuss operational strategies, and review monitoring and forecasting products for sea ice and weather in Antarctic waters. There is some past IODP experience of high latitude drilling, most recently in 2012 (Baffin Bay) and 2010 (Wilkes Land, Antarctica), but the return-time of the JR to Antarctica is infrequent, and in-house knowledge of high-latitude operations can be supplemented by knowledge from Antarctic research vessel operators and from the Antarctic marine geological research community, who work offshore of Antarctica every year.

Imagery from optical and radar satellite data has improved significantly over the last 10 years and can be used to show extents of sea ice and changes through the drilling season. This allows detailed planning of cruise tracks, drill sites, and expedition timing. Many of the satellite images are updated daily and are freely available online, and include optical images and both passive and active microwave radar images. These products and data were reviewed at the workshop in presentations showing examples of their use at sea on the *RV N.B. Palmer* and the *RV Polarstern*. Similarly, weather data such as temperature and wind speed is available as forecasts and as archives of past daily variability (weather station and reanalysis data), and can be used to anticipate weather conditions both before an expedition and for operational planning during an expedition. Currently, IODP cruise planning relies of commercial monthly average tabulated weather and sea state data.

Presentations on the second morning of the workshop covered:

- Satellite imagery of ice conditions (Michael Cloutier, Polar Geospatial Center, University of Minnesota)
- Ice monitoring on the *RVIB N.B. Palmer* (Frank Nitsche, Lamont-Doherty Earth Observatory).
- Sea ice monitoring on the *Polarstern* (Karsten Gohl, AWI Bremerhaven)
- Hazard management on Leg 178 (Antarctic Peninsula) and in Baffin Bay Exp 344S (Gary Acton, Sam Houston University)
- Examples of daily visual and microwave radar images for expedition planning (Trevor Williams, IODP, Texas A&M University).

5.1 Summary of sea ice and weather monitoring products

Prior to and during the workshop we made progress in identifying data sources and products to address questions of drilling in a harsh polar environment, including sea ice and weather assessment. We thank Paul Morin and Michael Cloutier (Polar Geospatial Center, University of Minnesota) and Sharon Stammerjohn (University of Colorado, INSTAAR) for pointing us to many of these products.

Hazards in the high latitude oceans can be divided into three categories:

1. Sea ice
2. Weather (low temperatures, high wind, icing, sea state)
3. Icebergs

Useful data on these hazards be divided into three time categories – past, present, and future:

1. Past seasonal patterns and variability (monthly and daily) – for expedition planning.
2. Daily monitoring at sea – for at-sea decision-making.
3. Forecasts – for at-sea decision-making.

Below we list the products that can be used for planning and operating drilling expeditions in Antarctic waters. The list is growing as new computer models and satellite sensors are developed. Most of these products are freely available online.

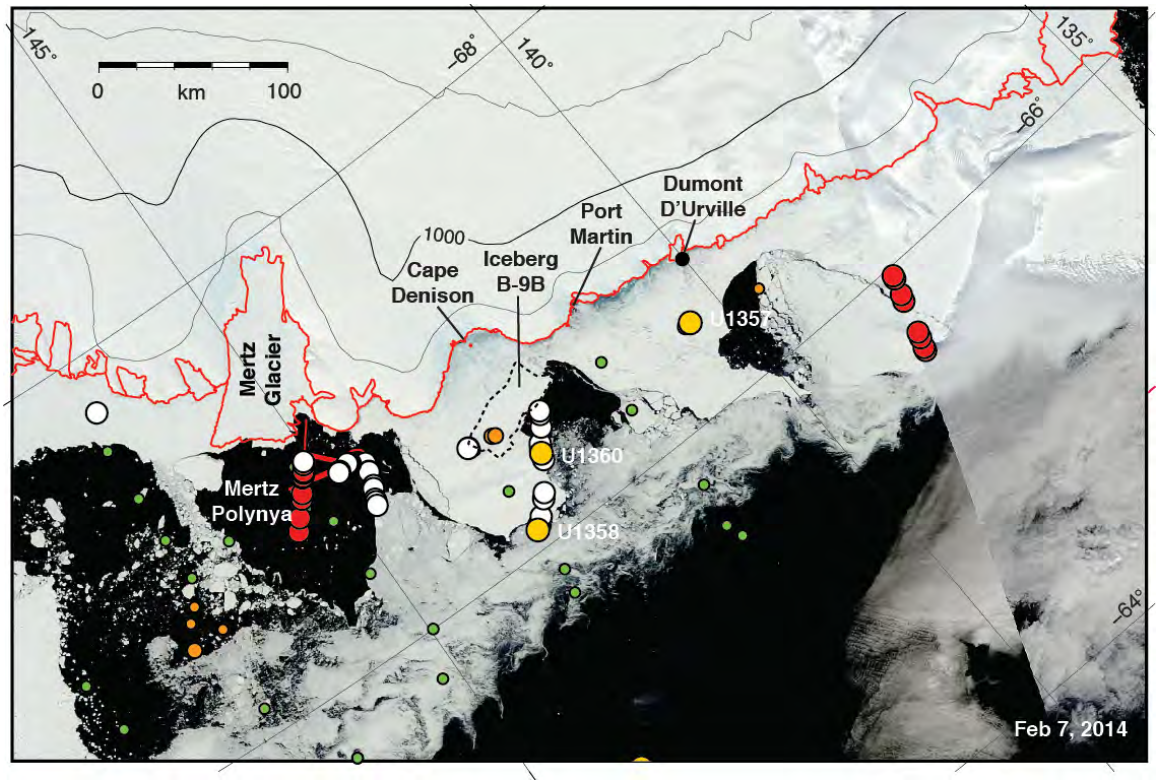


Figure 3. The MODIS Rapid Response System generates daily optical images of Antarctica, available in photo-like true color from both the Terra and Aqua satellites down to 250 m resolution. This example is for the Expedition 373 area, taken on February 4 2014, and has an overlay of the expedition's primary and alternate site locations. https://lance.modaps.eosdis.nasa.gov/imagery/subsets/?project=antarctica_regions&subset=Mertz_Tongue

5.2.1. Sea ice images

Commercial imagery:

- DigitalGlobe Worldview satellites – 30-50 cm spatial resolution panchromatic optical sensors. This commercial imagery is very high resolution but requires days/weeks to make useful products for specific applications. It can be made available for US government projects. https://browse.digitalglobe.com

Government satellite imagery:

- NASA MODIS Sensor (Moderate Resolution Imaging Spectrometer – a passive optical sensor) on Terra and Aqua satellites. 250m resolution. Twice daily images, available online within hours. High resolution but needs daylight and absence of clouds. See Fig. 3 for an example for the area of the George V Land proposal 813 sites:

https://lance.modaps.eosdis.nasa.gov/imagery/subsets/?project=antarctica_regions&subset=Mertz_Tongue.2015285
MODIS images are also available through NASA Worldview:
https://worldview.earthdata.nasa.gov

- Landsat 8, a joint NASA/U.S. Geological Survey (USGS) mission with Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) has high-resolution (<100 m) images available online some weeks after they were taken, providing snapshots of the extent and type of sea ice.
  https://lv.eosda.com
  https://eospso.nasa.gov/content/nasa-earth-science-data

- JAXA (Japanese Space Agency) AMSR-2 (Passive Microwave Sensor – not affected by clouds). Daily and archived data (back to satellite launch in 2012). It can be used to track the typical ice retreat and growth patterns over the course of the season, and thus find when prospective drill sites typically become accessible (Fig. 4).
  http://www.iup.uni-bremen.de:8084/amsr2/

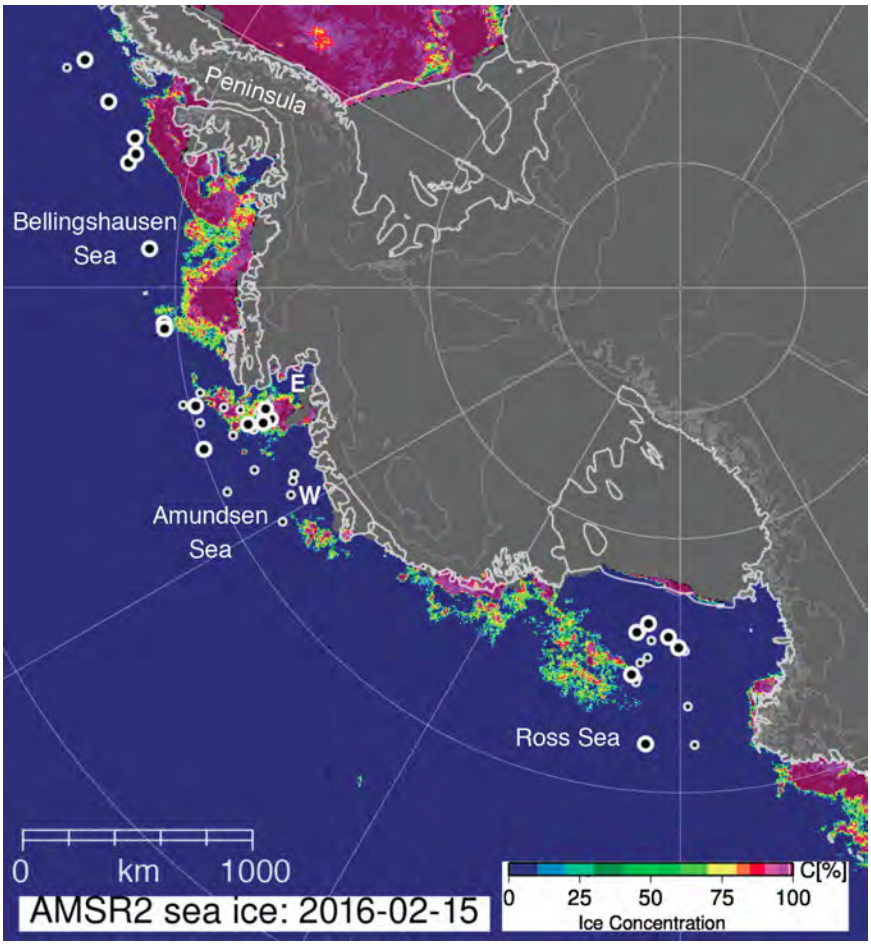


Figure 4. AMSR-2 passive microwave satellite image of sea-ice concentration for 15 February 2016 (http:\\www.iup.uni-bremen.de:8084/amsr2/), with an overlay showing proposed IODP drill sites Such daily sea-ice images for the last four years have helped us to understand seasonal patterns of sea ice and open water at the proposed drill sites. Primary and alternate sites are marked with large and small circles, respectively.

- ESA (European Space Agency) Sentinel-1A and sister satellites (Active Radar Sensor) Synthetic aperture radar (SAR).
  http://www.polarview.aq/antarctic

- DLR (German Aerospace Center) TerraSAR-X and TanDEM-X satellites. SAR imagery down to 20m or higher resolution, available in near-real-time in the Antarctic Peninsula area and used successfully in the 2015/2016 season by the *RV Polarstern* in the Weddell Sea.

- NSIDC (National Snow and Ice Data Center) DMSP satellite SSMIS daily polar gridded sea-ice concentrations:
  http://nsidc.org/data/seaice_index/

- The Polar Geospatial Center (PGC, www.pgc.umn.edu) can assist NSF-funded projects in/around Antarctica, though PGC more usually provides support for field studies on the continent itself. Products are available at the following links:
  - Antarctic maps: http://pgc.umn.edu/maps/antarctic
  - Viewer access: https://users.pgc.umn.edu/request/
  - Coordinate converter: http://www.pgc.umn.edu/tools/conversion
  - Stereo DEMs: http://www.pgc.umn.edu/elevation/stereo

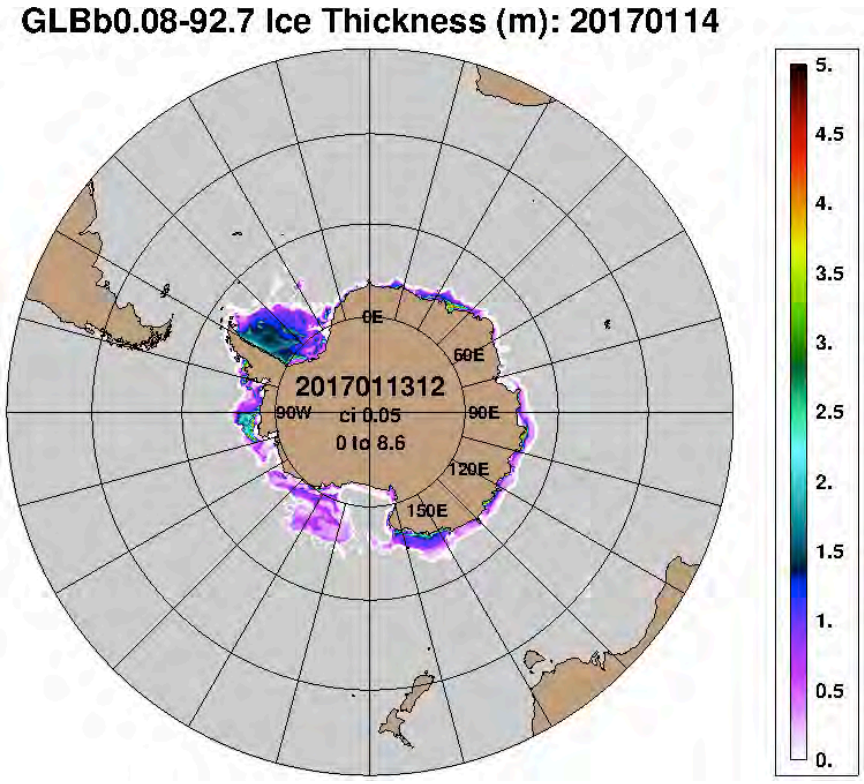


Figure 5. HYCOM/CICE model, showing the ice thickness (in metres) for 13 January 2017. This is a demonstration product using the Global Ocean Forecast System (GOFS) 3.1, which the US Naval Research Laboratory (NRL) is providing on an "as is" basis.

5.2.2. Sea ice models and forecasts

Sea-ice concentration, thickness, and temperature maps are produced by NRL (US Naval Research Laboratory, Stennis Space Center, Mississippi), using the HYCOM (Hybrid coordinate ocean model). Fig. 5 shows an example ice thickness map; these maps are also available as animated gifs to show changes through the season:
https://www7320.nrlssc.navy.mil/GLBhycomcice1-12/antarc.html

NRL is working on sea-ice forecasts using the Global Ocean Forecast System GOFS 3.1 model, which is running pre-operationally now and should become operational by the end of this year.

The latest research in Antarctic sea ice trends, processes, and predictions, was the subject of a recent National Academies sea ice workshop, 11-12 January 2016:
http://dels.nas.edu/global/prb/Antarctic-Sea-Ice-Workshop-Agenda

5.3. Weather

5.3.1 Sea state
Five-day forecasts from National Weather Service, NOAA Wavewatch III output:
http://polar.ncep.noaa.gov/waves/
e.g., Pacific wave height (Fig. 6)
http://polar.ncep.noaa.gov/waves/viewer.shtml?-multi_1-latest-pacific-hs-
e.g., Pacific wind speeds:
http://polar.ncep.noaa.gov/waves/viewer.shtml?-multi_1-latest-pacific-u10-

Note that the NOAA Wavewatch products are available for all the ocean basins, and so are useful in general for all ocean drilling expeditions. At this time we have not tracked down an easily usable archive of past sea state (wave height, etc), though clearly this is of interest for expedition planning.

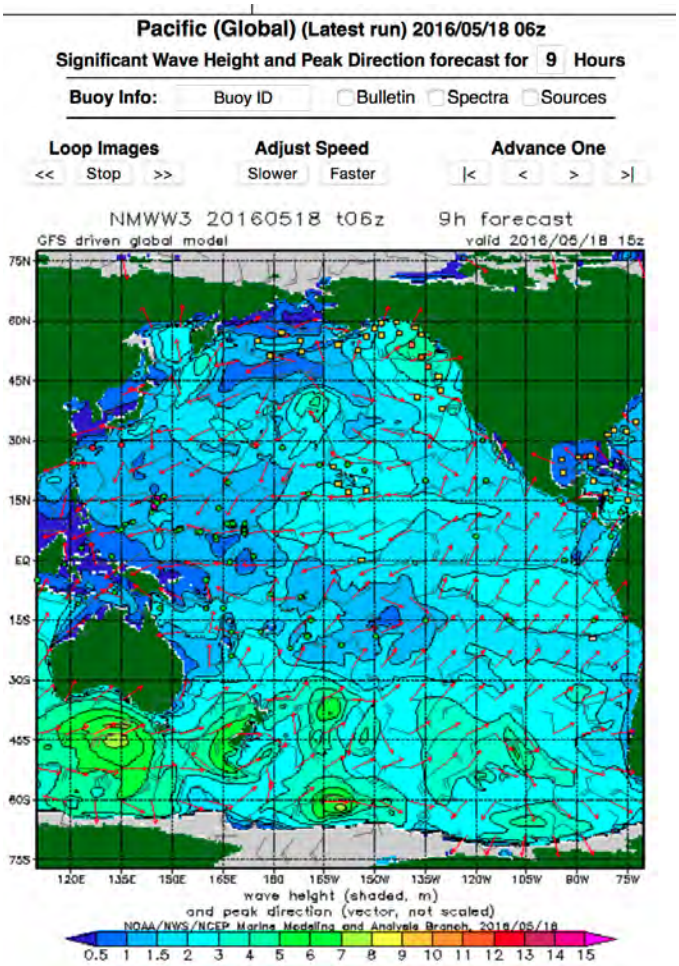


Figure 6. NOAA Wavewatch monitoring and forecasting. This image shows wave height for the Pacific Ocean for 18 May 2016. Eastward moving storm systems are common in the Southern Ocean, and visible as areas of high wave height in this image.

5.3.2 Current weather forecasts

The Antarctic Mesoscale Prediction System (AMPS) based at UCAR (University Corporation for Atmospheric Research), includes current and forecast temperature, wind speed, sea ice, clouds, and precipitation. Antarctic-wide and regional maps are available, for example for the Ross Sea (Fig. 7). Meteograms are also available for field stations on land.
http://www2.mmm.ucar.edu/rt/amps/

The archive of past AMPS forecast data maintained at Ohio State University:
http://polarmet.osu.edu/AMPS/

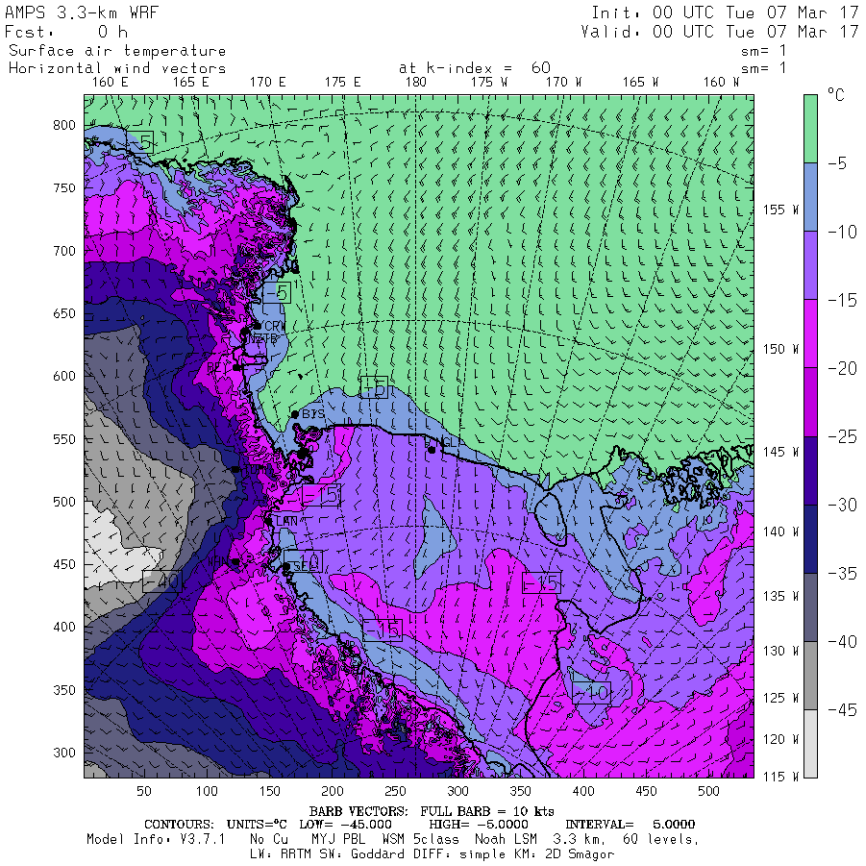


Figure 7. AMPS surface temperature and wind forecasts. Example for the Ross Sea, March 7, 2017.

5.3.3 Past weather information

Weather stations

Weather stations on the Antarctic continent provide a useful guide to conditions, but they are sparse, and restricted to the continent itself. *The Antarctic Meteorological Research Center (AMRC) and Automatic Weather Station (AWS) program* are United States Antarctic Program (USAP) sister projects focusing on observational Antarctic meteorological research, providing real-time and archived meteorological data and observations, and supporting a network of automatic weather stations in Antarctica. (Requires funds or access via NSF for the reanalysis data).
https://amrc.ssec.wisc.edu
http://amrc.ssec.wisc.edu/data/view-data.php?action=list&product=surface/plot

Reanalysis products

Past daily and monthly gridded model weather data are available from the *IRI/LDEO Climate Data Library:*

http://iridl.ldeo.columbia.edu

e.g., Diagnostic surface temperature from NOAA NCEP-NCAR CDAS-1: Climate Data Assimilation System I; NCEP-NCAR Reanalysis Project.:

http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCEP-NCAR/.CDAS-1/.MONTHLY/

For proposed site locations we can access past daily surface temperature, daily high and low temperature, wind speed, etc. (Fig. 8).

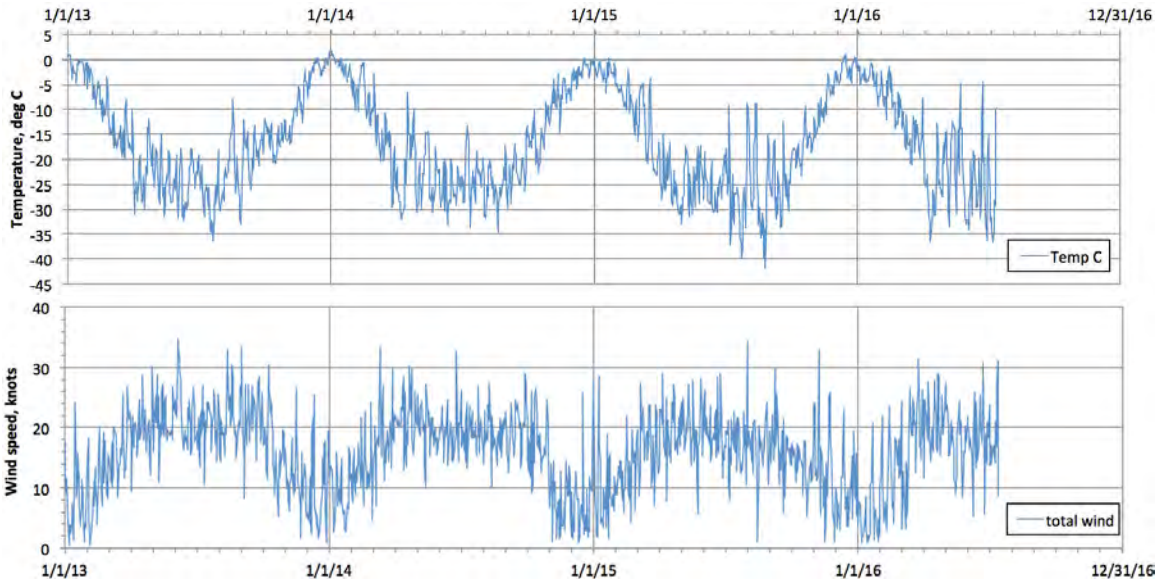


Figure 8. Daily average temperature and wind data from the *IRI/LDEO Climate Data Library* for the GVAL-1 site location in the Mertz Glacier area of Expedition 373 (George V Land). The period of relatively higher temperatures and lower winds (December-February) constrains the timing of the expedition, weatherwise.

5.4. Icebergs

Large icebergs (1 km in length or more) are visible in the MODIS optical imagery, and smaller icebergs can be monitored on radar and visually from the bridge of the *JR*. Icebergs do not typically move in a straight line, rather they can move in looping paths forced by currents, winds, and the Coriolis force. The *JR* procedures (iceberg management strategy) for icebergs that approach the ship are already established, and have been used previously in high-latitude expeditions. A circular exclusion zone around the ship is set according to the total time it would take to pull the drill string above the drill floor and the estimated time it would take the iceberg to reach the drilling location, based on its drift speed and direction.

6. Antarctic sediment cores from the Gulf Core Repository (Objective 3)

The Gulf Core Repository (GCR), located in the same building as IODP at Texas A&M University, holds the DSDP, ODP, and IODP sediment cores from the Southern Ocean and Antarctica. These cores have yielded much of what we know of Antarctic ice and climate in the past, and many of the scientists who made the original studies on these cores took part the workshop. Thus there was a unique opportunity to re-examine representative “classic” sediment cores, with group discussions led by scientists familiar with the cores and the science they represent, and transmission of knowledge to the next generation of Antarctic marine geologists (Fig. 9). It was our strategy that the young scientists will apply to sail on scheduled and pending expeditions, and will continue to be involved in the next generation of drilling proposals. Participants gained experience with description of glacial marine sediments and, through discussion, the modern set of analytical techniques (e.g. land and ocean temperature, provenance, etc) appropriate for use in Antarctic margin sediments.

Ten sets of sediment cores were chosen to cover the full range of marine environments, from the continental shelf out to the deep water, and from Holocene back to the preglacial Eocene. to cores. Cores included analogues to sediments expected to be drilled on the proposed expeditions, to provide insight into what type of material may be collected on those expeditions.

Figure 9. Discussion of archive Antarctic sediment cores from the IODP Gulf Coast Core Repository

Additionally, a side meeting was held in the IODP meeting room to introduce scientists who are new to IODP to the process of applying to sail on IODP expeditions, so that the future IODP scientists can write a compelling application and avoid some basic pitfalls. The meeting was led by David Mallinson.

Cores were laid out on tables in the repository and in adjacent rooms in IODP, as listed below. The standard IODP core naming convention, used below, is Hole-Core-Section. For example, 272-9R 1-3 refers to Sections 1 to 3 from Core 9R, the ninth rotary-drilled core from Hole 272 in the Ross Sea. Sections are typically 1.5 m long, and full cores are about 9.5 m long.

1. Sites 272, 271 (Miocene-Pliocene Ross Sea shelf) Examples of clast-rich silty clay, clast-free diatomite (mid-Miocene climate optimum?), structureless mud. *Relating to IODP-751, 839 (Expeditions 374, 379)*.
    - 272-9R 1-3 - mid-late Miocene clast rich silty clay.
    - 272-21R 2-4 - a mid Miocene diatomite lacking clasts (section 3 has bivalves)

2. Site 270 (Oligocene-Miocene Ross Sea shelf) Examples of marine transgression, diamictite, shallow marine mudstone, glacial rythmites). *Relating to IODP-751, 839*.
    - 270-24R 2-3 (glacial rhythmites)
    - 270-26R 6 (diamcitite - with shells)
    - 270-33R 4 (mudstone with clasts - articlated bivalves)
    - 270-43R 4-6 - the marine transgression (glauconitic sandstones and graded beds).

3. Sites 1096 and 1101 (Pleistocene Peninsula continental rise sediment drifts) Including MIS interglacials 5, 9, and 31. *Relating to IODP-732.*
    - 1096B-2H, 3-5 (spans MIS 5 and includes ash layer that can be widely correlated in marine and ice cores)
    - 1096B-3H, 3-7 (spans MIS 9 and a transition from ‘hard’ to ‘soft’ magnetic remanence)
    - 1101A-9H, 6-7
    - 1101A-10H, 1-3 (these 9H and 10H sections span the base of the Jaramillo Chron and MIS 31)

4. Sites 1097 and 1103 (late Miocene-Pliocene Peninsula shelf) Examples of diamictites, proglacial debris flows, and ice-distal muds. *Relating to IODP-751, 839*.
    - 1097A-36R, 1, 303.5-305 mbsf, Clayey silt (ice-distal marine facies), Late Miocene
    - 1097A-25R, 1, 198.1-199.6 mbsf, Diamicton (proglacial debris flow facies), Early Pliocene.
    - 1097A-17R, 2, ~132.1-133.1 mbsf, Diamicton and diamictite (subglacial deformation till facies), Pliocene.
    - 1103A-37R, 1-2, ~343.4-345.75 mbsf, Muddy sandstone and sandstone (proglacial debris flow facies), Late Miocene.
    - 1103A-34R, 1-3, ~314.5-318.6 mbsf, Diamictite (proglacial debris flow facies), Late Miocene?
    - 1103A-29R, 1-2, ~266.6-269.0 mbsf, Diamictite (proglacial debris flow facies), Pliocene.

5. Sites 1218 (equatorial Pacific) Eocene-Oligocene transition

- 1218C-17X Transition from radiolarian ooze up to calcareous ooze.

6. Site 689 (Eocene to Pliocene at Maud Rise) Sediments representing Antarctic ice sheet evolution through time, from a single site.
    - 689-1H, 2; 4H-2; 4H-5; 6H-4; 7H-4; 11H-4
    - 689-13H, 6, 7, CC Eocene-Oligocene transition
    - 689-14H, 1 Eocene-Oligocene transition
    - 689-20H, 2 Eocene pelagic sediments

7. Site U1361 (Wilkes Land continental rise) Pliocene sedimentary cycles - diatom-rich and silty clay alternations, ice-rafted debris, provenance from Wilkes subglacial basin.
    - U1361-5H, 1-2. Early Pleistocene “cooling” sections where silt continually increases, iceberg-rafted debris (IBRD) decreases and there appears to be more re-working.
    - U1361-7H, 6, 7, CC; U1361-8H, 1-2. Late Pliocene “cooling” sections; major IBRD events coincident with facies changes.
    - U1361-10H, 1-7. Early Pliocene “warmth” sections: 10H-2 to 10H-5 are a diatom-rich silty clay interval (10H-5) (glacial minimum) overlain by a massive and laminated mudstone.

8. Site 742 (Prydz Bay) Pliocene ice retreat in shelf sediments: diatomite and diamictite.
    - 742-15R, 1-4 +CC; 742-16R, 1-3

9. Micropaleontological examples from the IODP collection in the microscope room.

10. Sites 1098 and 1099 (Palmer Deep, Peninsula) Late-Pleistocene and Holocene Antarctic sediments showing ice retreat and calving bay facies. Draped lamination on glacial relief vs horizontal laminations. Bundled laminations tidal or evolution of seasonal productivity. Comparison of the deglacial facies at the two Palmer deep sites
    - 1098C-5H, 1-6, CC
    - 1099B-5H, 1-7, CC

11. Site 1166 (Cretaceous-Eocene Prydz Bay shelf) Examples of organic and mica-rich siltstone, and pre-glacial to glacial unconformity. *Relating to IODP-813.*
    - 1166A-15R, 1-7, CC (lower-Oligocene / upper Eocene and unconformity to overlying Pliocene diamicts)
    - 1166A-31R, 1-2, CC (Cretaceous organic-rich and mica-rich sediments)

7. Antarctic drilling in the context of the IODP Science Plan prioritization; a portfolio of West Antarctic proposals (Objective 4)

At the workshop we discussed nearly all of the Antarctic and Southern Ocean proposals in the IODP review system. However, only three of the proposals were currently under consideration for scheduling at the *JOIDES Resolution* Facility Board (JRFB). Given that the planned ship track of the *JOIDES Resolution* generally keeps to the southern latitudes, there was an opportunity in the next round of scheduling for one or more Antarctic expeditions to be included. Thus, at the workshop we prepared a letter for the JRFB making the case for the three proposals, outlining their integrated objectives in the context of the IODP science plan and addressing logistical challenges, as summarized below:

Three drilling proposals (751 in the Ross Sea; 839 in the Amundsen Sea; and 732 in the Bellingshausen Sea and Antarctic Peninsula), approved by the Scientific Evaluation Panel and at the JRFB at the time of the workshop, form a coherent West Antarctic Margin Portfolio of drillsites, that will illuminate the spatial and temporal variations of past Antarctic Ice Sheet dynamics and guide model skill for future predictions, by: 1) reconstructing the orbital-scale Cenozoic dynamics of the WAIS, 2) identifying drivers and their thresholds, especially of ocean forcing, for past WAIS retreat, and 3) assessing relationships between the Antarctic cryosphere, ocean circulation, and global climate. This is particularly timely because the 2015 UN Climate Change Conference in Paris requested that IPCC write a special report by 2020 to assess the climate impacts of climate stabilization at 2°C and 1.5°C and response of Antarctic Ice Sheets will comprise an important component of this report. The IODP expeditions will provide near-field ice sheet data to complement and constrain the far-field sea level and paleoceanographic data obtained by expeditions in the Southern Ocean.

The workshop addressed also the problems related to implement drilling expeditions around Antarctica, like the presence of sea ice, and proposed a strategy in a report to the JRFB to drill the three WAIS proposals over three successive austral summer field seasons. The decision of the JRFB at their meeting, held in the week following the workshop, was that the Ross Sea proposal is now scheduled in early 2018, the Amundsen Sea proposal is scheduled for early 2019, and the planned ship track returns to the Southern Ocean and possibly Antarctica in 2020. This is partly dependent upon the readiness of proposals in the South Atlantic Ocean, and indeed there are several South Atlantic proposals in the IODP system. The PAIS program is now engaging actions to stimulate and help these proposals to progress.

All three proposals in this West Antarctic Margin Portfolio are rated as excellent by SEP. While they have distinct objectives and approaches, we stress that their science objectives are complementary and thematically coordinated. The West Antarctic margin must be studied concurrently to obtain continental-scale understanding of how different locations responded to elevated levels of CO_2 and warming climates in the past. The overarching goals of the three proposals are directly aligned with the highest priority challenges (1 and 2) in the Climate and Ocean Change theme of the IODP Science plan (2013-2023), and are the most appropriate proposals currently at JRFB to address these challenges.

Challenge 1 (*How does Earth's climate system respond to elevated levels of atmospheric CO_2?)* requires drilling in the polar regions, since polar amplification makes these regions the most sensitive to CO_2 forcing, and thus drives the largest feedbacks in the climate system on orbital timescales. All proposals aim to target Neogene (Miocene to Pleistocene) records, and will characterize high-latitude polar amplification during the 400-600 ppm worlds of the Miocene Climatic Optimum and mid-Pliocene, respectively. All three proposals target high-resolution

records from the last interglacial, a period of moderate warming (0-2°C warmer with pCO_2 <280 ppm) and higher than present sea level (5-9 m). The zonal and meridional distribution of the sites is ideally suited to distinguish regional variations in ocean-ice sheet interactions.

The next highest priority, Challenge 2 (*How do ice sheets and sea level respond to a warming climate?),* is critically dependent on additional Antarctic drilling. The Amundsen Sea and Ross Sea proposals are fundamentally aligned as they will recover the first direct records of WAIS variability from the continental shelf beyond the Last Glacial Maximum (LGM), which are required to calibrate ice-sheet models and constrain the contribution of polar ice sheets to far-field sea-level records. The continental slope and rise records targeted in all three proposals will document oceanographic drivers or responses to that variability. The deep-water sites of proposals 732, 751, and 839 are located near the mouths of paleo-ice stream troughs on the continental shelf and thus should be highly sensitive to the initial retreat of the ice grounding zone from the shelf break. As ice dynamics and oceanographic regimes are highly variable with different ice melt and transport processes between the Ross Sea sector and the Amundsen Sea / Bellingshausen Sea sector, a single expedition alone will not address the full dynamics of WAIS (e.g., Pollard et al., 2015; DeConto & Pollard, 2016).

Each of the three proposals in this portfolio contribute uniquely to the overarching portfolio objective to decipher WAIS dynamics:

Proposal 751-Full2 (Ross Sea): The Ross Sea sites comprise a continental shelf to rise transect that will resolve relationships between climatic/oceanic change and WAIS evolution. Glacial retreat in the central Ross Sea was one of the largest Antarctic contributors to post-LGM sea-level rise, with models and geological data indicating that marine ice-sheet instability made a significant contribution to rapid sea-level rise events (e.g., Meltwater Pulse 1a). Proposal 751 seeks to understand the oceanic triggers for marine ice-sheet collapse in a region where the WAIS was most sensitive to change during glacial terminations. Sites proposed in 751 are ideally suited to develop a complete transect linking ice-proximal records from the inner Ross Sea continental shelf (e.g., ANDRILL sites) to near- and far-field abyssal ocean drill sites (e.g., ODP Legs 181, 138, and 198) to obtain a complete ice-proximal to far-field view of Neogene climate and Antarctic cryosphere evolution.

Proposal 839 (Amundsen Sea): The Amundsen Sea sector sites reflect the history of the 'weak underbelly' of the WAIS and are located in the region most sensitive to climate change. Major ice-mass loss in this region, which is the highest anywhere in Antarctica today, may have been a precursor to total WAIS collapses during periods of past warming and elevated atmospheric CO_2 levels. Oceanic processes drive present mass loss of the WAIS, with warm Circumpolar Deep Water (CDW) upwelling onto the shelf, melting ice shelves from below. These processes are best understood in the Amundsen Sea Embayment where CDW incursions onto the shelf are well documented today. It is therefore the ideal region to test the model-derived hypothesis that warm CDW incursions cause WAIS collapse. The glacial sedimentary record in the Amundsen Sea Embayment holds a 'pure' WAIS signal, unaffected by dynamics of other Antarctic ice sheets. Proposal 839 offers the opportunity to reveal much information regarding West Antarctica's Cenozoic paleoclimatic history from the greenhouse-icehouse transition of the Paleogene to the orbitally driven glacial-interglacial cycles of the Pleistocene.

Proposal 732 (Bellingshausen Sea/Antarctic Peninsula): The drill sites in the Bellingshausen Sea/Antarctic Peninsula sector would obtain a less proximal but still direct record of ice-sheet advance/retreat. Of all the sectors, this proposal has a high potential for demonstrably continuous records with high sediment accumulation rates and improved chronostratigraphic

control, thereby complementing the more proximal sites. The sections will constitute high fidelity Pliocene-Quaternary records of past change in West Antarctica and the adjacent ocean. Recent studies have shown that inflow of relatively warm water onto the Antarctic continental shelf is the main driver of contemporary marine ice-sheet retreat in West Antarctica, and existing long-term records and numerical models suggest ocean forcing has also been critical during periods of past ice retreat. Therefore, it is important to study the ice sheets and the adjacent oceans as a coupled system.

8. Workshop Outcomes

(1) A plan was submitted to the *JOIDES Resolution* Facility Board (JRFB) describing a portfolio of West Antarctic margin drill sites, based on IODP proposals 751 (Ross Sea), 839 (Amundsen Sea), and 732 (Antarctic Peninsula and Bellingshausen Sea). The West Antarctic Ice Sheet (WAIS) is particularly susceptible to retreat because much of it is grounded below sea level. The Portfolio's objectives are to a) reconstruct the Neogene-Quaternary orbital-scale dynamics of the WAIS, b) identify drivers of ice instability and their thresholds, especially of ocean forcing, for past WAIS retreat, and c) assess relationships between the Antarctic cryosphere, ocean circulation, and global climate. These objectives are critical for improving paleo-calibrated model-ensemble simulations of Antarctica's future response to business-as-usual greenhouse gas emissions, which currently estimate ~0.6 m to ~1 m of sea-level rise by the end of this century. The range of uncertainty is due to assumptions about the sensitivity of Antarctica's ice sheets to warm Pliocene conditions. At the May 2016 JRFB meeting, the Ross Sea and Amundsen Sea proposals were scheduled for drilling as Exp. 374 (2018) and Exp. 379 (2019), joining the already-scheduled George V Land MSP Exp. 373 (Fig. 10).

(2) Sea ice is an operational hazard for Antarctic drilling. However, imagery from optical and radar satellite instruments has improved significantly over the last 10 years and can be used to show daily extents of sea ice and typical ice evolution through the drilling season, which allows best planning of dates, ship tracks, and drill sites. Workshop presentations showed examples of sea ice and weather data, including their use at sea on the *RV N.B. Palmer* and *RV Polarstern*. Global and Antarctic regional weather forecasts and archives of daily weather data can be used to anticipate weather conditions both before an expedition and for operational planning during an expedition. Most of these products are freely available online from NASA, the European Space Agency, the US Naval Research Laboratory, and other agencies.

(3) During the workshop, classic DSDP, ODP and IODP Antarctic sediment cores were laid out in the core repository so that participants could examine the sediments on which much of the scientific knowledge of Antarctic climate evolution is based. Core examination also enabled conversations between early career scientists and more senior scientists (many of whom did the original work on the cores), transmitting expertise, stimulating new ideas, and encouraging the early career scientists to join the Antarctic drilling community by applying for future IODP expeditions and writing new drilling proposals.

In summary, the workshop promoted of a coordinated approach to Antarctic scientific drilling to recover the requisite ice-proximal geological data to understand cryosphere evolution and help models predict the rate and magnitude of sea-level rise that would result from Antarctic ice sheet retreat. The workshop helped to bring together the Antarctic scientific geological drilling community, and galvanize efforts towards the next round of Antarctic IODP drilling.

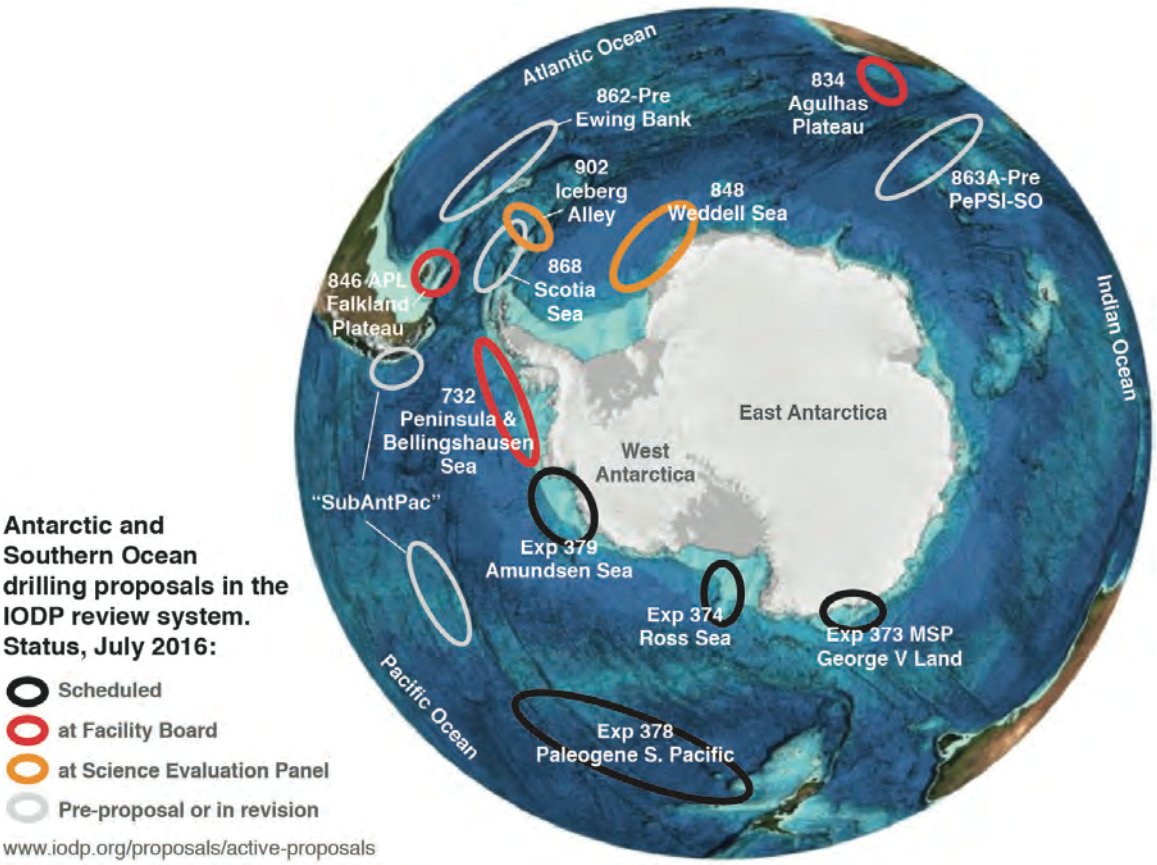


Figure 10. Locations of the IODP proposals and their status in July 2016, after the workshop, All but one of these proposals was represented by a proponent at the workshop.

9. Future Plans

Three Antarctic expeditions are now on the IODP drilling schedule (Fig. 10), and the science community represented at the workshop will work with JRSO and ECORD to carry out these expeditions safely and efficiently. During and following the expeditions, the community will work together to generate data from the new marine sediment cores to help understand Antarctic ice sheet dynamics and warm climates of the past, and to communicate these results to the public. The community will continue to develop existing and new proposals for scientific drilling, and continue to work closely with fellow scientists from related fields such as ice sheet modeling, paleoceanography, isostacy, and others.

The Antarctica's Cenozoic Ice and Climate History workshop is part of a coordinated plan developed since 2009 by the Past Antarctic Ice Sheet Dynamics (PAIS) research program through the Scientific Committee on Antarctic Research (SCAR; www.scar.org/pais), an International Council for Science (ICSU) committee, to stimulate Antarctic margin drilling proposals. Future workshops are planned to keep fostering drilling proposal submission, data-model integration, informing the community, and attracting and training students, including the two meetings described below.

A PAIS-funded PRAMSO (Palaeoclimate Records from the Antarctic Margin and Southern Ocean) workshop was held on 20 August 2016 in Kuala Lumpur (Malaysia) as side meeting of the SCAR-OSC conference. The workshop included discussion of ongoing activities related to IODP and other drilling projects from the Antarctic continental margins and Southern Ocean, including alternate sites strategy, staffing, recent results, plans for site surveys, and scientific gaps and geographical areas to address in future proposals.

A major PAIS conference will be held in Trieste (Italy) from 10-16 September 2017, to cover recent results that address still open questions in understanding the sensitivity of the Antarctic Ice Sheet and its contribution to past and future sea level and climate change, as it relates to the SCAR Horizon Scan (www.scar.org/horizonscan M.C. Kennicutt, S. Chown et al., Nature, 2014). Details of this meeting are available at pais-conference-2017.inogs.it

Appendix A: Workshop Program

Monday 9 May (Room 110/111, Koldus Building, Texas A&M University)

Proposed IODP Antarctic and Southern Ocean drilling; common themes and overview of science plans.

9:00 Introduction to the workshop agenda and objectives (Trevor Williams)
9:15 A short history of past Antarctic scientific drilling (Frank Rack)
9:30 Introduction to the IODP proposal system (David Mallinson)
10:15 *Presentations on Antarctic and Southern Ocean proposals at the JR Facility Board*:
IODP-751. Ocean-ice sheet interactions and West Antarctic Ice Sheet vulnerability: clues from the Neogene and Quaternary record of the outer Ross Sea continental margin (Rob McKay et al.).
IODP-839. Development and sensitivity of the West Antarctic Ice Sheet tested from drill records of the Amundsen Sea Embayment (Karsten Gohl et al.).
IODP-732. Sediment drifts off the Antarctic Peninsula and West Antarctica (Jim Channell, Rob Larter, et al.).
IODP-567. Paleogene South Pacific APC Transect: Heat Transport and Water Column Structure During an Extreme Warm Climate (Debbie Thomas et al.).
1:00 *Updates on Antarctic and Southern Ocean drilling proposals*:
IODP-813-MSP. George V Land and Adélie Land shelf sediments (Trevor Williams, Carlota Escutia, et al.). MSP expedition scheduled for Dec 2017 to Feb 2018.
IODP-848. Late Neogene to Quaternary ice-sheet and sea-level history of the Weddell Sea, Antarctica (Mike Weber et al.). At IODP Science Evaluation Panel (SEP).
IODP-847. Plio-Pleistocene reconstruction of ice-sheet, atmosphere, and ocean dynamics in Iceberg Alley (Mike Weber et al.) Resubmitted to SEP, 1 April 2016.
IODP-868 Scotia Sea (Javier Hernandez Molina et al.);
Drake Passage (Gisela Winckler for Frank Lamy et al.);
Agulhas Plateau (Gabi Uenzelmann-Neben et al.);
IODP-MDP-863 ISOLAT (Minoru Ikeraha for Peterson et al.).
2:30 Ice sheet modeling (Rob DeConto)
3:00 Sea level and Glacial Isostatic Adjustment (GIA) (Jacky Austermann)
3:15 Carbon dioxide, temperature, and ice volume over the Cenozoic (Amelia Shevenell)
3:30 Discussion: Where to drill and which ages, events, and high-CO_2 scenarios to target?

Tuesday 10 May (Room 110/111, Koldus Building / IODP-GCR)

Drilling in a harsh polar environment: sea ice, icebergs and weather assessment; planning for the unexpected.

9:00 Introduction to the ice and weather session (Trevor Williams)
9:15 Satellite imagery of ice conditions (Michael Cloutier, PGC)
9:45 Weather: forecasts of temperature, wind, and sea state; typical seasonal changes; available weather forecast and re-analysis products:
- Frank Nitsche – ice monitoring on the *RVIB N.B. Palmer*
- Karsten Gohl – sea ice monitoring on the Polarstern
- Gary Action – hazard management on Leg 178 (Ant. Peninsula) and in Baffin Bay.
- Trevor Williams – Daily visual and microwave radar images for expedition planning.

1:00 Five-minute presentations about each of the sets of sediment cores to be shown at the GCR in the afternoon:
1. Sites 272, 271 (Miocene-Pliocene Ross Sea shelf) Examples of clast-rich silty clay, clast-free diatomite (MMCO age?), structureless mud. *Relating to IODP-751, 839*.

2. Site 270 (Oligocene-Miocene Ross Sea shelf) Examples of marine transgression, diamictite, shallow marine mudstone, glacial rythmites). *Relating to IODP-751, 839*.
3. Sites 1096 and 1101 (Pleistocene Peninsula continental rise sediment drifts) Including MIS interglacials 5, 9, and 31. *Relating to IODP-732.*
4. Sites 1097 and 1103 (late Miocene-Pliocene Peninsula shelf) Examples of diamictites, proglacial debris flows, and ice-distal muds. *Relating to IODP-751, 839*.
5. Sites 1171 (S Tasman Rise) and 1218 (equatorial Pacific) Eocene-Oligocene transitions.
6. Site 689 (Eocene to Pliocene at Maud Rise) Antarctic ice sheet evolution through time.
7. Site U1361 (Wilkes Land continental rise) Pliocene sedimentary cycles - diatom-rich and silty clay alternations, ice-rafted debris, provenance from Wilkes subglacial basin.
8. Site 742 (Prydz Bay) Pliocene ice retreat in shelf sediments: diatomite and diamictite.
9. Micropaleontological examples from the IODP collection in the microscope room.
10. Sites 1098 and 1099 (Palmer Deep, Peninsula) Late-Pleistocene and Holocene Antarctic sediments showing ice retreat, calving bay facies, and laminations.
11. Site 1166 (Cretaceous-Eocene Prydz Bay shelf) Examples of organic and mica-rich siltstone, and pre-glacial to glacial unconformity. *Relating to IODP-813.*

Examination of Antarctic sediment cores in the Gulf Coast Core Repository.

3:00 Orientation to the IODP and GCR.
The sediment cores were organized into eleven stations (core tables), each focusing on a different Antarctic location or time interval. Groups will contain a mix of experienced and junior scientists. At each sediment core station, maps, seismic profile, data etc. provided the setting.

3:30 In parallel: breakout group to discuss the letter for the JOIDES Resolution Facility Board.

4:45 Introduction to how to make a good application for IODP expeditions (for students).

Wednesday 11 May (IODP / Gulf Coast Repository)

9:00 Guided examination of Antarctic sediment cores in the Gulf Core Repository.

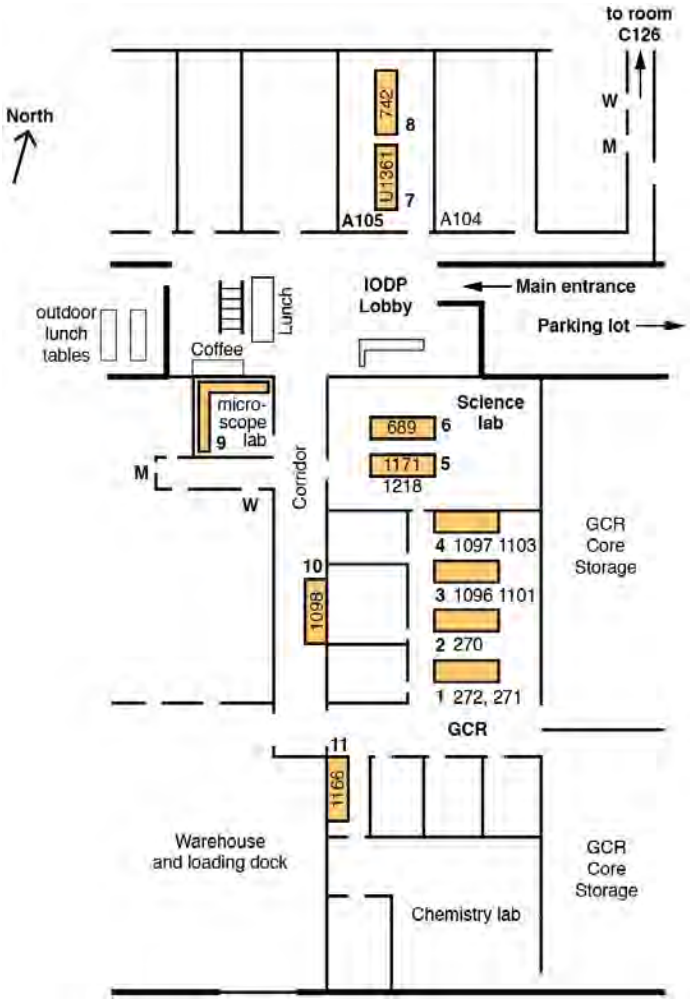
10:45 Four breakout groups to facilitate discussion about Antarctic drilling strategy, proposal strategy,

1:00 Plenary session recap and wrap-up.

2:00 Tours of the Gulf Coast Repository core store and facilities; smear slide classes.

5:00 Meeting close

IODP/GCR sediment core workshop layout:



Appendix B. Participation

The workshop organization and the US participation was funded by USSSP. MagellanPlus supported the participation of European lead/co-proponents of IODP proposals, early and mid career scientists and PhD students. A total of 84 participants attended the workshop, including early career to senior scientists, students, expedition proponents and IODP operators.

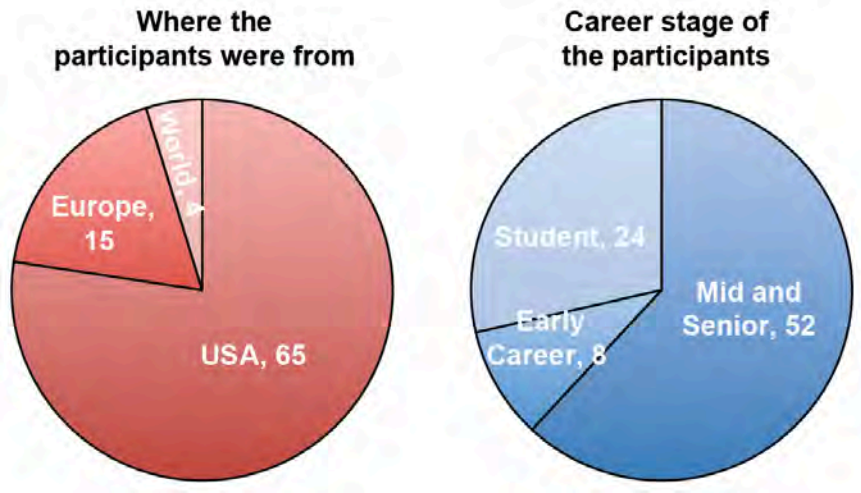


Figure 11. Workshop Participation

NAME	INSTITUTION
Gary Acton	Sam Houston University, USA
John Anderson	Rice University, USA
Jeanine Ash	UCLA, USA
Jacqueline Austerman	Harvard University, USA
Phil Bart	Louisiana State University, USA
Sjoerd Berends	Siem Offshore, USA
Rachel Bertram	Imperial College London, UK
Steve Bohaty	NOC, Southampton, UK
Imogen Browne	University South Florida, USA
Jim Channell	University Florida, USA
Brad Clement	Texas A&M University, USA
Michael Cloutier	Polar Geospatial Center, Minneapolis, USA
Jason Coenen	Northern Illinois University, USA
Ellen Cowan	Appalachian State University, USA
Rob DeConto	University of Massachusetts, USA
Laura De Santis	OGS Trieste, Italy
Justin Dodd	Northern Illinois University, USA
Eugene Domack	South Florida University, USA
Carlota Escutia	Instituto Andaluz de Ciencias de la Tierra, Spain
Sarah Feakins	University of Southern California, USA
Andrew Fraass	Smithsonian Institution, USA
Karsten Gohl	AWI, Bremerhaven, Germany
Michelle Guitard	University of South Florida, USA
Anna Ruth Halberstadt	Rice University, USA
David Harwood	University of Nebraska, Lincoln, USA
Daniel Hauptvogel	University of Houston, USA

CD Hillenbrand	British Antarctic Survey, UK
Katharina Hochmuth	AWI, Bremerhaven, Germany
Minoru Ikehara	Kochi University, Japan
John Jaeger	University of Florida, USA
Tom Janecek	NSF, Washington DC, USA
Denise Kulhanek	Texas A&M University, USA
Rob Larter	British Antarctic Survey, UK
Bridget Lee	University of California Riverside, USA
Chris Lowery	University of Texas Institute for Geophysics, USA
Melissa Luna	Wesleyan University, USA
David Mallinson	East Carolina University, USA
Mitch Malone	Texas A&M University, USA
Ellen Martin	University of Florida, USA
Yasmina Martos	British Antarctic Survey
Rob McKay	Victoria University of Wellington, New Zealand
David McInroy	ESO, Edinburgh, UK
Jennifer Middleton	Harvard University, USA
Yuribia Munoz	University of Houston, USA
Frank Nitsche	Lamont Doherty Earth Observatory, USA
Suzanne O'Connell	Wesleyan University, USA
Elisabetta Olivo	OGS Trieste, Italy
Sandra Passchier	Montclair State University, USA
Molly Patterson	University of Massachusetts, USA
Stephen Pekar	Queens College CUNY, USA
Michelle Penkrot	University of Florida, USA
Frank Rack	University of Nebraska, Lincoln, USA
Brendan Reilly	Oregon State University, USA
Delaney Robinson	University of Houston, USA
Alan Rooney	Harvard University, USA
Yair Rosenthal	Rutgers University, USA
Ari Salabarmada	Instituto Andaluz de Ciencias de la Tierra, Spain
Howie Scher	University of South Carolina, USA
Reed Scherer	Northern Illinois University, USA
Amelia Shevenell	South Florida University, USA
Lauren Simkins	Rice University, USA
Catherine Smith	University of South Florida, USA
Joe Stoner	Oregon State University, USA
Debbie Thomas	Texas A&M University, USA
Ellen Thomas	Yale University, USA
Gabi Uenzelmann-Neben	AWI, Bremerhaven, Germany
Kara Vadman	University of South Florida, USA
Tina van de Flierdt	Imperial College London, UK
Jonathan Warnock	Indiana University of Pennsylvania, USA
Sophie Warny	Louisiana State University, USA
Mike Weber	University of Köln, Germany
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