



WP

14

Agenda Item:

2.2.5

Person Responsible:

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EXCOM 2015

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Past Antarctic Ice Sheet Dynamics (PAIS)

Executive Summary

Title: Past Antarctic Ice Sheet Dynamics (PAIS)

Authors: C. Escutia, R. DeConto, K. Gohl, R. Larter, R. Powell, L. De Santis, M. Bentley

Introduction/ Background:

The overarching goal of PAIS is to improve confidence in predictions of ice sheet and sea level response to future climate change and ocean warming. For this, PAIS aims to improve understanding of the sensitivity of East, West, and Antarctic Peninsula Ice Sheets to a broad range of climatic and oceanic conditions. Study intervals span a range of timescales, including past “greenhouse” climates warmer than today, and times of more recent warming and ice sheet retreat during glacial terminations. The PAIS research philosophy is based on data-data and data-model integration and intercomparison, and the development of data transects, extending from the ice sheet interior to the deep sea. The data-transect concept will link ice core, continental, ice sheet-proximal, offshore, and far-field records of past ice sheet behaviour and sea level, yielding an unprecedented view of past changes in ice sheet geometry, volume, and ice sheet-ocean interactions. These integrated data sets will enable robust testing of a new generation of coupled Glacial Isostatic Adjustment-Ice Sheet-Atmosphere-Ocean models that include new reconstructions of past and present ice bed topography and bathymetry. PAIS will accomplish its objectives by: 1) facilitating the planning of new data-acquisition missions using emerging technologies; 2) encouraging data sharing and integration of spatially targeted transect data with modelling studies; and 3) initiating/expanding cross linkages among Antarctic research communities.

Important Issues or Factors:

PAIS continent-to-abyss transects build on ongoing and planned projects and therefore guarantee continuous deliverables. PAIS has invited new members to the SC and plans to conduct a rotation of the co-chief officers at the end of 2015. PAIS plans to organize a Symposium in 2017 with budgetary implications (i.e., request to carry forward PAIS funding).

Recommendations/Actions and Justification:

Support for PAIS plans for the remaining life of the Programme and input from EXCOM on PAIS plans based on the SCAR Strategic Plan and the Horizon Scan outcomes.

Expected Benefits/Outcomes:

Publications and science relevant to large international programmes/initiatives and policy makers, enhancement of SCAR profile.

Partners:

ANDRILL, IODP, ICDP, AntECO, APECS, IGBP-PAGES, IPICS, ISMASS, SCADM, SCERCE, SHALDRIL and other SCAR Expert and Action Groups.

Budget Implications:

Request for confirmation of SCAR science programme funding at current level until the internal progress review. PAIS funding to be carried forward to help with organization costs on PAIS Symposium in 2017.

Past Antarctic Ice Sheet Dynamics (PAIS)

1. Rationale for the Programme

The Antarctic cryosphere and surrounding seas play a fundamental role in the global ocean/climate system, affecting global sea level, ocean circulation and heat transport, planetary albedo, air-sea gas exchange, and marine productivity. Obtaining a history of Antarctica's role in these global processes is therefore crucial for understanding past and future ice-ocean-atmospheric and tectonic feedbacks within Earth's climate system. Despite the critical role of Antarctica and the Southern Ocean in the global system, key geological and geophysical data from this region are lacking. In part, this is because Antarctica's massive ice sheets hide most of the Cenozoic geological record. Terrestrial records from rock exposures around the Antarctic margin provide snapshots of regional climate, but these records are geographically sparse and difficult to date. Coastal and open marine records provide a better-dated and more complete window into Antarctic ice sheet behaviour. However, these records are also sparse in their local coverage (i.e., representing coastal or offshore conditions, but not both) and there are many areas of the Antarctic margin without any records recovered.

To understand Cenozoic Antarctic cryosphere evolution in the context of the Earth's climate system, PAIS coordinates palaeoenvironmental and tectonic studies along transects from the interior of the continent to abyssal plains. These studies preferably extend from specific drainage sectors, because different regions of the ice sheet undoubtedly will have different histories. These records, integrated with state-of-the-art coupled GIA-ice sheet-ocean-climate models have the potential to substantially advance our understanding of forcings, magnitudes and rates of response, and feedbacks at the ocean-ice interface, thus improving ice sheet model parameterizations. PAIS aims to constrain past ice sheet dynamics that are relevant to future scenarios of ice sheet behaviour and sea level change as a response to elevated CO₂ and temperatures during this century (IPCC, 2013). To achieve this aim, PAIS focuses on temporal targets that span the last deglaciation to the early Cenozoic greenhouse world, with the main focus on periods of rapid warming and climatic conditions warmer than present. These intervals include: a) the transition from the Last Glacial Maximum (LGM) to early Holocene warmth; b) Pleistocene "super-interglacials" (e.g., MIS5, MIS11, MIS 31), long suspected as being times of significant WAIS retreat; and c) times of elevated global temperatures and CO₂ levels that are close to what is forecasted for our near future (IPCC, 2013), such as the Pliocene PRISM interval from ~3-3.3Ma and the extended period of maximum warmth during the early Pliocene (4.2 to 3.7 Ma). Other periods of prolonged warmth include the Miocene Climate Optimum (17-14 Ma), and the persistent elevated temperatures and pCO₂ levels exceeding 1000 ppmv prior to the formation of continental Antarctic ice sheets 34 million years ago. This greenhouse world includes temperature spikes (hyperthermals) lasting ~100,000 years, somewhat analogous to the conditions projected for a continued "Business As Usual" carbon emissions scenario.

2. Important Issues or Factors

i) Scientific Highlights

M. O. Patterson, R. McKay, T. Naish, C. Escutia, F. J. Jimenez-Espejo, M. E. Raymo, S. R. Meyers, L. Tauxe, H. Brinkhuis and IODP Expedition 318 Scientists. 2014. Orbital Forcing of the East Antarctic Ice Sheet during the Pliocene and Early Pleistocene. Nature Geosciences, Vol 7: 841-846 The paper by Patterson et al (2014) reveals that before 3.5 million of years, under a warm climate state, the East Antarctic Ice Sheet demonstrates high sensitivity on orbital timescales to a relatively small increase in atmospheric CO₂ concentration and mean global surface temperature. With atmospheric CO₂ concentrations and global surface temperatures projected to remain above 400 ppm and >+2°C beyond 2100, these results have implications for the equilibrium response of the Antarctic ice sheets, and suggest that the marine margins of the EAIS, as well as the marine-based West Antarctic Ice Sheet, may become increasingly susceptible to ocean warming, with the potential for widespread mass loss raising sea level by metres over the coming centuries to millennia.

Pollard, D., DeConto, R.M., Alley, R.B. 2015. Potential Antarctic Ice Sheet retreat driven by hydrofracturing and ice cliff failure. *Earth and Planetary Science Letters*, 412: 112-121 Geological data indicate that global mean sea level has fluctuated during the last ~25 million years, at times reaching 20 m or more above modern. Most climate and ice sheet models however, have not been able to simulate significant East Antarctic Ice Sheet from continental size, given that atmospheric CO₂ levels were relatively low throughout this period. The paper by Pollard et al (2015) apply a simple Pliocene-like warming scenario incorporating the combined mechanisms of Marine Ice Sheet Instability, melt-driven hydrofracturing and cliff failure that cause a very rapid collapse of West Antarctic ice, on the order of decades. This is followed by retreat of East Antarctic basins within several hundred to a few thousand years. The total Antarctic ice loss corresponds to ~+17m sea-level rise, in good agreement with high-stands in geologic sea-level records, although uncertainty in the geologic records themselves should be considered.

Weber, M. E. , Clark, P. U., Kuhn, G., Timmermann, A., Spreng, D., Gladstone, R. Zhang, X. , Lohmann, G., Menviel, L., Chikamoto, M. O., Friedrich, T., Ohlwein, C. 2014 Millennial-scale variability in Antarctic ice-sheet discharge during the last deglaciation. *Nature* , Vol 510: 134-138 The paper by Weber et al (2014) provide high-resolution Iceberg Rafted Debris (IBRD) records that capture a spatially integrated signal of Antarctic Ice Sheet (AIS) variability during the last deglaciation. They document eight events of increased iceberg flux from various parts of the AIS between 20,000 and 9,000 years ago, in marked contrast to previous scenarios which identified the main AIS retreat as occurring after meltwater pulse 1A, and continuing into the late Holocene epoch. The highest IBRD flux occurred 14,600 years ago, providing the first direct evidence for a potential Antarctic contribution to meltwater pulse 1A. Climate model simulations with AIS freshwater forcing identify a positive feedback between poleward transport of Circumpolar Deep Water, subsurface warming and AIS melt, suggesting that small perturbations to the ice sheet can be substantially enhanced, providing a possible mechanism for rapid sea-level rise.

ii) Progress against prior work plan, including metrics of performance.

Since the last report, we have made substantial progress in programmes that cover some of the original objectives for PAIS (Table 1 of the Implementation Plan in appendix 1).

Progress related to Current Programmes listed in our Implementation Plan:

- Work continues in the nearly 2000 m of sediment core collected during the IODP Expedition 318 drilled the Wilkes Land margin (*Escutia et al., 2011*). Until now the focus has been on greenhouse paleoenvironments (*Pross et al., Nature, 2012; Bjil et al, PNAS, 2013*), the greenhouse-icehouse transition (*Stocchi et al., Nat. Geos., 2013; Houben et al., Science 2013*), the early icehouse paleoenvironments (*Houben et al., Science, 2013*), and the early Pliocene warmth (*Cook et al., Nat. Geos., 2013; Patterson et al., Nat. Geos, 2014; Orejola et al., 2014; Reinardy et al., 2014*). The focus is changing now to the Oligocene, the late Oligocene-Miocene climate transition leading to the Mi-1 event, the Pleistocene and the ultra-high Holocene record. A synthesis paper of the results to date (*Escutia et al., 2014*) has been published in *Developments in Marine Geology Series: Earth and life processes discovered from subseafloor environment, vol. 7*.
- Whillans Ice Stream Subglacial Access Research Drilling (WISSARD) project had its first successful borehole operation in the 2012-13 field season. The target was clean-access entry and sampling of Subglacial Lake Whillans. All goals were achieved including high-definition video imaging of lake sediment; *In situ* measurements were made of the lake water; and water and sediment samples were recovered (*Fricke et al., 2012; Tulaczyk et al., 2013*). The 2014-15 austral field season involved subglacial access from the ice plain over the grounding zone of Whillans Ice Stream using a specially designed hot-water drill to cleanly bore through a half mile of ice. Data gathered from samples of sediment taken in the grounding zone will provide clues about the mechanics of ice sheets, its interaction with ocean and sediment, and their potential effects on sea-level rise.
- The Antarctic Geological Drilling programme (ANDRILL) continues to develop results from its SMS and MIS Projects. These projects have resulted to date in more than 100 publications in peer-reviewed journals, including *Nature*, and in 17 theses and dissertations. ANDRILL is now developing a portfolio of programmes for future drilling in addition to the existing Coulman High Project.

- Over the past year, researchers, engineers and officials involved in the Lake Elsworth drilling project, funded by the UK Natural Environment Research Council, have carried out and responded to several internal reviews into the reasons for the failure to drill into the lake deep beneath the West Antarctic Ice Sheet during the 2012 field season. A paper by Siegert et al., 2014 in the *Annals of Glaciology* summarizes the problems suffered drilling at Lake Ellsworth and provides options for setting them right. Engineering work will be required to develop improved technology for a more reliable drill, but they say that success is achievable.

Progress related to Approved Programmes listed in our Implementation Plan:

- Shallow drilling on the Amundsen Sea Embayment shelf and in Pine Island Bay with MeBo, scheduled to take place in February to March 2015 on RV Polarstern cruise PS90 (Gohl et al.), had to be cancelled due a severe damage of the port-side propeller of the vessel. The programme has been re-scheduled for the 2017 season.
- IODP 813 ‘Greenhouse to Icehouse Antarctic paleoclimate and ice history from George V Land and Adélie Land shelf sediments’ (Williams et al.) is scheduled to be drilled during the 2018 season. The program plans to utilize the RockDrill-2 (seabed drill of British Geological Survey, max 50 m), to sample outcropping strata on the shelf. A Kick-off meeting to plan for operational needs is planned for 17 September 2015 in Edinburgh.
- The IODP JOIDES Resolution (JR) ship track should allow for drilling the Antarctic margin possibly during Antarctic seasons 2017-2018/2018-2019. The PAIS community plans to argue for having two programs drilled by IODP and a letter to the IODP Joides Resolution Facility Board (JR FB) is now being prepared with that purpose. There are at present three IODP proposals for scheduling by the JR FB: 1) Proposal 732-Full (Sediment drifts Antarctic Peninsula) by Channel et al.; 2) Proposal 751-Full2 (Ocean-ice shet interactions & WAIS vulnerability) by McKay et al., and 3) 839-Full Sensitivity of WAIS in the Amundsen Sea) by Gohl et al.
- Work continues in preparations for the implementation of the Tottem Glacier (Armand et al.) seismic and coring cruise in 2017.

Progress related to Proposed and Planned Programmes listed in our Implementation Plan:

In addition to progress on the proposed programmes that are now in the calendar of operations or being considered for it (i.e., IODP 732-Full, 751-Full2, 813-Full, 839-Full, see above) we report on progress on other proposed or planned programmes:

- IODP proposal 848-Pre ‘Late Neogene ice-sheet and sea-level history of the Weddell Sea, Antarctica’ (Weber et al.) After review of the pre proposal, SEP has requested a full proposal to be submitted.
- Several IODP proposals in the system have now been deactivated but proponents have been strongly encouraged to re-submit. These are: 1) IODP proposal 847 ‘Plio-Pleistocene reconstruction of ice-sheet, atmosphere, and ocean dynamics in Iceberg Alley (Scotia Sea)’ (Weber et al.); 2) IODP proposal 861-Pre MSP ‘Cenozoic formation of the Antarctic glacial landscape investigated by low-temperature thermochronometry (W Antarctic Peninsula)’ (Balco et al.).
- IODP proposal 834-Full Drilling a transect from the Agulhas Plateau into the Transkei Basin: A keyhole into the Cretaceous Hothouse World”(Unzelmann et al.,) has been sent to external review by SEP.
- ANDRILL Coulman High (Luyendyk, Levy et al.) was not funded by NSF, and the IODP SEP deactivated the proposal. The ANDRILL Coulman High Project team is now considering different options to move this programme forward.

iii) Changes in the Implementation Plan.

- PAIS has updated the membership of the Steering Committee as indicated in the Appendix 2, and plans to conduct a rotation of chief officers at the end of 2015. The present chief officers will remain in the Steering Committee as ex-officio for one year.

3. Outputs/Deliverables

i) Publications

A selection of PAIS publications showing the breadth of the community are listed below:

- M. O. Patterson, R. McKay, T. Naish, C. Escutia, F. J. Jimenez-Espejo, M. E. Raymo, S. R. Meyers, L. Tauxe, H. Brinkhuis and IODP Expedition 318 Scientists. 2014. Orbital Forcing of the East Antarctic Ice Sheet during the Pliocene and Early Pleistocene. *Nature Geosciences*, Vol 7: 841-846.
- Pollard, D., DeConto, R.M., and Alley, R., 2015. Potential Antarctic Ice Sheet retreat driven by hydrofracturing and ice cliff failure. *Earth and Planetary Science Letters*: 112-121.
- Gasson, E, DeConto, R. and Pollard, D., 2015. Antarctic bedrock topography uncertainty and ice sheet stability. *Geophysical Research Letters* v. 42, issue 13: 5372-5377.
- Yamane, M., Yokohama, Y., Abe-Ouchi, A., Obrochta, S., Saito, F., Moriwaki, K., and Matzuzaki, H., 2015. Exposure age and ice sheet model constraints on Pliocene East Antarctic ice sheet dynamics.
- De Boer, B., Dolan, A., Bernales, J., Gasson, E., Goelzer, N.R., Sutter, J., Huybrechts, P., Lohmann, G., Rogozhina, I., Abe-Ouchi, A., Saito, F., Van De Wal, R.S.W., 2015. Simulating the Antarctic ice sheet in the late-Pliocene warm period: PLISMIP-ANT, an ice-sheet model intercomparison Project. *Cryosphere* 9 (3):881-903.
- Ladant, J.B., Donnadiou, Y., Dumas, C., 2014. Links between CO₂, glaciation and water flow: Reconciling the cenozoic history of the antarctic circumpolar current. *Climate of the Past*, 10 (6): 1957-1966.
- Griener, K.W., and Warny, S., 2015. *Nothofagus* pollen grain size as a proxy for long-term climate change: An applied study on Eocene, Oligocene, and Miocene sediments from Antarctica. *Review of Paleobotany and Palynology* 221:138-143.
- Teitler, L., Florindo, F., Warnke, D.A., Fillippelli, G.M., and Taylor, B., 2015. Antarctic Ice Sheet response to a long warm interval across Marine Isotope Stage 31: A cross-latitudinal study of iceberg-rafted debris. *Earth and Planetary Sciences*, 409:109-119.

In addition, three synthesis papers and a special volume have been published:

- Escutia, C., Brinkhuis, H., and the Expedition 318 Science Party. 2014. From Greenhouse to Icehouse at the Wilkes Land Antarctic margin: IODP 318 synthesis of results. In *Developments in Marine Geology 7: Earth and life processes discovered from seafloor environment*. Stein, R. (AWI/Paleoclimate), Blackman, D. (Scripps/Solid Earth), Inagaki, F. (JAMSTEC/Biosphere), and Larsen, H.-C. (IODP-MI) (Eds.): 295-328.
- Lavoie, C., Domack, E. W., Pettit, E. C., Scambos, T. A., Larter, R. D., Schenke, H.-W., Yoo, K. C., Gutt, J., Wellner, J., Canals, M., Anderson, J. B., and Amblas, D., 2015. Configuration of the Northern Antarctic Peninsula Ice Sheet at LGM based on a new synthesis of seabed imagery. *The cryosphere*, 9:613-619.
- Barron, J.A., Stickley, C.E., and Burkry, D., 2015. Paleooceanographic and paleoclimatic constraints on the global Eocene diatom and silicoflagellate record. *Palaeogeography, Palaeoclimatology, Palaeoecology* 422: 85-100.
- *Scotia Arc Evolution: Global Implications*, edited by Andrés Maldonado, Ian W.D. Dalziel, Philip T. Leat. *Global and Planetary Change* Volume 123, Part B, Pages 151-414 (December 2014).

PAIS is planning a high-profile summary paper on Cenozoic Antarctic Ice Sheet Evolution.

ii) Major reports, including linkages to major SCAR activities (e.g., advise to the Treaty or IPCC)

Involvement of members of the PAIS scientific community in international programmes and networks has provided science-based advice to SCAR activities and major scientific programs and Policy makers. To date, members of the PAIS scientific community have been involved in the following reports:

- Lead authors for the International Ocean Drilling Program (IODP) Science Plan 2013-2023.
- Lead and contributor authors for the ERICON Science Perspective 2015-2030: Scientific Research in Polar Seas.
- Lead and Contributing Authors of 5th Assessment Report (AR5 - 2013): The Physical Science Basis. Intergovernmental Panel of Climate Change (IPCC).
- Invited participation in the COP19 “Day of the Cryosphere: Climate Change Today in Polar and Mountain Regions” (7 November, 2013, Warsaw, Poland). A side activity to the United Nations Framework Convention on Climate Change.
- SCAR Lecture in PAIS topics to the ATCM XXXVII-CEP XVII meetings (30 April, 2014, Brasilia, Brasil).
- Invited participants in the SCAR Horizon Scan retreat (21-23 April, 2014, Queenstown, New Zealand).
- Professor Tim Naish awarded the 2014 Martha T Muse Prize for Science and Policy in Antarctica.
- Members of the Antarctic Portal Editorial Group (since 2015).
- Members of the SCAR Structure Review Group (April 2015).
- A PAIS Whitepaper has been submitted to the COMNAP Antarctic Roadmap Challenges (ARC) Project to be considered during the ARC workshop in Tromso at the end of August 2015.

PAIS will continue to provide reports on its activities to SCAR as required. In addition, PAIS will contribute, when requested, reports for international and national programmes, and government bodies.

iii) Workshops and meetings

PAIS work on facilitating coordination and collaborations between different multidisciplinary and interdisciplinary international groups is largely conducted through community workshops and meetings. In Some of the completed activities since our last report and future activities include:

- MOCA Joint Model-data workshop for the Late Pleistocene evolution of the Greenland and Antarctic ice sheets LGGE, Grenoble, May 22nd-24th, 2014
- Multiproxy approach to the reconstruction of climate of the Pliocene Workshop, Barcelona, Spain, September 2014.
- PAIS Subcommittee meetings during the SCAR OSC, Auckland, New Zealand, 2014. PRAMSO and SDLS (23 August, 2014)
- PAIS open community and Steering Committee meetings during the SCAR OSC, Auckland, New Zealand, 25 and 27 August 2014, respectively.
- PAIS Town Hall and Steering Committee meetings during the XII ISAES, Goa, India, July 2015.
- “Polar Marine Diatom Workshop” Salamanca, Spain, 19th-24th July 2015.
- “Advanced course in organic-walled dinoflagellate cysts”, September 13th to 19th 2015 in Heidelberg, Germany.

In addition, PAIS convenes scientific sessions and additional meetings of the Steering Committee and subcommittees during large international meetings such as AGU and EGU 2015-2016, SCAR OSC 2014-2016, ASLO (Spain) 2015, and XII ISAES in Goa (India) 2015.

PAIS plans to have a PAIS Symposium in 2017. It is expected to be similar in size and format to the 1st ACE Symposium held in Granada in September 2009.

iv) Education and Outreach

- PAIS contributed to support the “Polar Marine Diatom Workshop” Salamanca, Spain, 19th-24th July 2015. This is a training course for PhD and Master students giving them a unique opportunity to interact and discuss topical issues in the Polar Regions. Diatoms are very diverse, abundant and ecologically specialized, therefore, they are perfect indicators of environmental changes. Main topics include: 1) The evolution of sea-ice communities and sea-ice extent; 2) Variations in the diatom assemblage across oceanographic fronts; 3) Pelagic-benthic coupling based on the evolution of diatom communities; 4) The timing of climatic events in polar regions; 5) The modern environmental change relative to climatic or other natural and/or anthropogenic environmental impacts. The workshop was attended by 45 persons of which 25 were PhD students and 5 were early career researchers with no permanent position. The participants represented 15 countries in total. 26 came from European institutions from France, Germany, Greece, Italy, Norway, Poland, Portugal, Russia, Spain and UK, and 19 from Australia, Japan, Republic of Korea and the USA. PAIS funding was used to support 8 PhD students and 2 early career researchers.
- PAIS provided 10.000 US\$ funding for four students and two keynote speakers to attend the XII International Symposium on Antarctic Earth Sciences. In addition, PAIS provided 6000 US\$ to the XII ISAES organizers for student travel support.
- PAIS has contributed with funding to the “Advanced course in organic-walled dinoflagellate cysts”, September 13th to 19th 2015 in Heidelberg, Germany.

v) Databases

PAIS supports continued development of the Antarctic Data Library System for Cooperative Research (SDLS). The SDLS now contains most processed data from marine multichannel seismic surveys that have been carried out around Antarctica. The SDLS provides open access worldwide to Antarctic multichannel seismic-reflection data collected by many countries to study the structure of Earth's crust of Antarctica. The new website that now provides open access to Antarctic multichannel seismic-reflection data online is <http://sdls.ogs.trieste.it/> -- Operated and administered at the Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS) by Nigel Wardell.

While PAIS does not directly support other data archiving infrastructure, it will maximize the effectiveness of its limited budget by encouraging responsible archiving of data and samples to established data centres and repositories. Among these databases the most relevant to the data to be generated by PAIS are: 1) PANGAEA the data Publisher for Earth & Environmental Science- <http://www.pangaea.de/> This data repository holds all data from the two past ANDRILL drilling seasons will receive data from the future Coulman High drilling (Table 1), as well as a wealth of data from marine sediment cores from the Southern Ocean. 2) The IODP data bases and core repositories <http://www.iodp.org/access-data-and-samples> also hold all cores and data obtained during past Antarctic margin and Southern Ocean drilling by the Deep Sea Drilling Project (DDP), the Ocean Drilling Program (ODP) and the Integrated Ocean Drilling Program (IODP). 3) The IPEV IMAGES Programme Sub-Antarctic and Antarctic portal - http://gcmd.gsfc.nasa.gov/KeywordSearch/Home.do?Portal=amd_fr, which contains data from both marine and ice core records. Other databases included NOAA NCDC/NSIDC, and national programmes metadata systems.

vi) Data and information activities

International and national programmes of relevance to PAIS produce video journals, video animations and blogs (e.g., <http://andrill.org/static/media.html>; <http://www.youtube.com/watch?v=uvzrK24YJyQ>). Brochures are available for all major international drilling initiatives. Links to videos and brochures will be made available through the PAIS webpage.

4. Budgetary Implications

Main expenditure to date is related to the funding of PAIS meetings, workshops, training schools and travel support for students and early career researchers in 2014 and 2015. Future expenses include student support

and support for workshops and meetings during AGU Fall meeting 2015, the EGU 2016, the SCAR-OSC 2016 in Kuala Lumpur (Malaysia). We also request EXCOM for permission to carry forward 2015 and 2016 PAIS funding to support the organization of the PAIS Symposium in 2017 at a location yet to be determined. We request funding at the same level for the next two years.

5. Future Plans

2015-2017:

- Shallow drilling on the Amundsen Sea Embayment shelf and in Pine Island Bay with MeBo is scheduled to take place in February to March 2017 on RV Polarstern cruise PS90 (Gohl et al.);
- Field seasons for Tottem Glacier (Armand et al) seismic and coring cruise 2015-2016;
- Preparation for the implementation of national field programs in 2015-2017;
- . Preparation for IODP drilling on the continental shelf of the Wilkes Land margin (IODP proposal 813-Full) in 2017. Kick-off meeting scheduled for the 17 September 2015 in Edinburgh (UK);
- XXXIV SCAR Meetings and Open Science Conference, 22 August-3 September Auckland, New Zealand: PAIS sessions, workshops and business meetings as indicated above;
- Continue analyses in data from ANDRILL SMS and MIS; and Wilkes Land IODP Expedition 318. Integration with other ODP Legs, CRP and data-model comparisons;
- Continue guiding the revision of IODP and ANDRILL proposals being reviewed by science panels and national programmes;
- Continue fostering the development of new proposal to the IODP and other international programmes (i.e., ICDP).
- PAIS is planning a high-profile summary paper on Cenozoic Antarctic Ice Sheet Evolution.
- PAIS has just submitted a whitepaper to the CONMAP Antarctic Roadmap Challenges (ARC) Project to be considered during the ARC workshop in Tromso at the end of August 2015. Members of PAIS will take part in this workshop.
- PAIS sessions in major international meetings (SCAR OSC, AGU, EGU, ISAES and ASLO, 2014-2015);
- Multidisciplinary session during the SCAR OSC in 2016 titled: "The Antarctic ice sheet from Past 2 Future" proposed by PAIS, AntClim21, ISMASS and SCERCE.
- PAIS support to the Advanced course in organic-walled dinoflagellate cysts", September 13th to 19th 2015 in Heidelberg, Germany.
- Support for other PAIS-related workshops and business meetings to be conducted in parallel with international meetings as indicated above;
- Organization of the PAIS Symposium in 2017.
- PAIS reports to SCAR;
- Input to databases;
- Outreach via National/International Programmes.
- Work on cross-linkages with other programmes (i.e., ice-core & marine core integration, develop links with SERCE and PAIS);

Appendices

Appendix 1: Table 1 of the Implementation Plan. This table is unchanged from the original Implementation Plan. Updates on progress of projects are included in section 2ii of the main text of the report.

Projects	Location	Objectives	Year	Implementation 2013-2015
Current				
ANDRILL SMS & MIS	Ross Sea	Pleistocene-Miocene glacial history	2007-2008	Continue review of sedimentary cores from SMS & MIS programmes. Comparison-integration with Exp 318, ODP Legs & CRP, and available onshore data. Provide data to numerical GIA-ice sheet modelling community.
IODP 318	Wilkes Land	Holocene to Eocene Greenhouse palaeoclimate and glacial history	2010	Continue review of sedimentary cores from Exp 318. Comparison-integration with ANDRILL, CRP, ODP Legs, and available onshore data. Work on Holocene ice-core and marine-core integration. Provide data to numerical GIA-ice sheet modeling community. Workshop planned for 2014
Subglacial Lake Ellsworth	30 km from the ice divide between Pine Island Glacier and the Institute ice stream	Life forms in the water and clues to past climate in the lake-bed sediments	2009-2014	Continue drilling to sample subglacial/lake sediments. Review of sediment data & provide data to numerical ice sheet modeling community.
Subglacial WISSARD (LISSARD & RAGES) Drilling	Whillans Ice Stream	Marine Ice Sheet Stability and Subglacial Life Habitats in West Antarctica	2009-2015	Analyze water, sediment and geophysical data and samples collected during the 2012-2013 field season. Planning of the 2013-2014 field season.
WAIS Divide	WAIS ice flow divide	Climate, ice sheet history and cryobiology	2010-2013	2013 field season ended: Ice cores record of past climate and greenhouse gases in the atmosphere that extends back 68,000 years. WAIS divide meeting, 24-25 September, Scripps (USA)
AGAP	Gamburtsev Mountains	Initial ice sheet formation, subglacial hydrological processes	2008-2009	Continue review of data obtained and provide data to numerical ice sheet modeling community.

Approved				
Amundsen Sea shelf - MeBo	Amundsen Sea Embayment shelf	Basic shelf stratigraphy, glacial onset, LGM retreat ages	Approved 2014-15	Planning and implementation of MeBo drilling in the Amundsen Sea
Totten Glacier seismic and coring cruises (US, Australia)	Totten Glacier	Basic shelf stratigraphy, Pleistocene ice sheet dynamics, LGM retreat.	Approved 2014 & 2015	Planning and implementation of NSF eastern Wilkes Land dredging & Totten Glacier surveys Planning and implementation of Australian led international coring cruise to the Totten Glacier
E Ross Sea shelf - SHALDRIL	Southeastern Ross Sea	Cenozoic evolution of West Antarctica and early development of WAIS	Approved currently on hold	
Proposed				
IODP 732-Full2	West of Antarctic Peninsula and Bellingshausen Sea	Sediment drifts off the Antarctic Peninsula and West Antarctica; Late Miocene to Quaternary paleoceanography & ice sheet history	At JR-FB to be scheduled	Possibly scheduled for 2016/17
IODP 751-Full2	Eastern Ross Sea	Ocean-ice sheet interactions and West Antarctic Ice Sheet vulnerability: clues from the Neogene and Quaternary record of the outer Ross Sea continental margin	submitted Oct. 2013. Panel has sent for external review	Continue fostering IODP proposal for Eastern Ross Sea IODP drilling. PAIS co-funding for writing workshop (June 2013, USA) for the submission of a revised proposal to the IODP in October 2013.
IODP 839-Full (former 784-Full2)	Amundsen Sea Embayment	Development and sensitivity of the West Antarctic Ice Sheet tested from drill records of the Amundsen Sea Embayment	Re-submitted Oct 2013. Panel has sent for external review	Continue fostering IODP proposals for Amundsen Sea Embayment.
ANDRILL Coulman High	Central-southern Ross Sea	Palaeogene to lower Miocene ice sheet behaviour & environments during greenhouse gas levels	Re-submission to NSF and ICDP in Jan 2014 and IODP in Apr 2014	Continue fostering IODP proposal for Coulman High
IODP 813-Full	Eastern Wilkes Land; Adélie Land & George V Land shelf	Greenhouse to Icehouse Antarctic paleoclimate and ice history from George V Land and Adélie Land shelf sediments	At the ECORD-FB to be scheduled	Possibly scheduled for 2015/16 or 2016/17; suitable ship must be allocated
IODP 847-Pre	Drake Passage	Plio-Pleistocene reconstruction of ocean, atmosphere and ice-sheet interactions through the Drake Passage	submitted Oct. 2013. Panel recommended to submit full proposal	Continue fostering IODP proposal for Drake Passage/Scotia Sea

IODP 848-Pre (former 829-Pre)	Weddell Sea	Late Neogene ice-sheet and sea-level history of the Weddell Sea	Re-submitted Oct. 2013 – Panel recommended to submit full proposal	Continue fostering IODP proposal for Weddell Sea
Planned				
WAIS-Drill	West Antarctica	Ice sheet history from subglacial sediments	2015-	
EPICA	Dome C, Dronning Maud Land	Deep ice core drilling	1996-ongoing	
IODP southern Indian Ocean (former IODP 824-Pre)	Conrad Rise, Del Caño Rise, South Indian Ocean	Antarctic Cryosphere and Southern Ocean Responses to Glacial-Interglacial Climate Change: Transect drilling across the Indian Ocean sector of the (ACC)	Re-submission planned for Oct 2014	
IODP SW Pacific Ocean	SW Pacific paleoceanography between New Zealand and Ross Sea	Cenozoic suborbital climate variability, biogeochemical cycles, Antarctic ice sheets, tectonic evolution	Submission planned for Oct 2014	
IODP-MSP Antarctic Peninsula	Pacific Antarctic Peninsula shelf	Paleohistory of Antarctic Peninsula ice streams, Boyd Strait and Palmer Deep outlet systems	Submission planned for Oct. 2014	
ICECAP/ICEBRIDGE	Wilkes Land (Wilkes and Aurora subglacial basins, Victoria Land)	Lithosphere and sub glacial conditions in East Antarctic basins	2008-ongoing	
Rapid Access Ice Drill (RAID)	Antarctic Ice Sheet	Development of rapid access ice drill for deep drilling of basal ice sheets and sub-ice bedrock in Antarctica	First tests in 2015; expected scientific projects from 2017/18	
IODP 821-Full2	SE Pacific paleoceanography (SEPAP)	Cenozoic suborbital climate variability, biogeochemical cycles, Antarctic ice sheets, tectonic evolution	submitted Oct. 2013 – Panel rejected-	Continue fostering IODP proposal for SE Pac Ocean

Appendix 2: PAIS Steering Committee. New proposed membership is highlighted in red.

Name	Affiliation	Country	Expertise - relevance to PAIS
Carlota Escutia, co-chair	IACT-Univ Granada	Spain	Seismic stratigraphy, Sedimentology - Paleoclimate and ice sheet records, IODP
Robert DeConto, co-chair	Univ. of Massachusetts	USA	Ice sheet modelling
Robert Larter	British Antarctic Survey	UK	Geology and Geophysics – Paleo-ice sheets
Karsten Gohl	Alfred Wegener Institut	Germany	Geophysics - Lithospheric processes, MeBO, IODP
Laura De Santis	OGS	Italy	Geophysics - Glacial evolution, PRAMSO
Ross D. Powell	Northern Illinois University	USA	Sedimentology and Geophysics - Subglacial geology and marine-ending glaciers
Michael Bentley	Durham University	UK	Glacial geomorphology, Cosmogenic dating – Ice sheets and sea level
Barbara Stenni	University of Trieste	Italy	Ice Cores
Rob McKay/Tim Naish	Victoria University of Wellington	New Zealand	Cyclostratigraphy – Ocean - Climate history
Julia Welner	University of Houston	USA	Sedimentology - Glacial processes
Paolo Stochhi	NIOZ	The Netherlands	GIA modelling
Jongkuk Hong	KOPRI	South Korea	Seismic and radar - Subglacial geology
Yusuke Sugamuna	NIRP	Japan	Paleomagnetism-Geochronology
Alex Payne	Victoria University of Wellington	New Zealand	Technological development
Anton van Putte	Royal Belgium Institute for Natural Sciences	Belgium	SCADM
Sun Bo	Polar Research Institute of China	China	Glaciology

Marcelo Reguero y Marcelo Leppe	Facultad de Ciencias Naturales y Museo, Universidad Nacional de La Plata Instituto antártico Chileno	Argentina Chile	Paleontology
J. Abel Flores P. Bjiil	Universidad de Salamanca Universidad de Utrecht	Spain The Netherlands	Paleoceanography
Liaison from ANTVOLC (J. Smellie)	University of Leicester	UK	Geology, volcanism – ice sheet land records
TBN			Geochemistry
TBN			APECS