Template for new SCAR Scientific Research Programmes

1. Name of the Proposed SRP: **Past Antarctic Ice Sheet dynamics (PAIS)**
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3. Sponsoring SSG(s): GeoScience
4. Estimated SCAR funding required over the total programme lifetime (in US$): **Expected duration of the programme 8 years** **20,000 $US / year = 160,000 $US**

5. Abstract (250 words or less)

The proposed SCAR Scientific Research Programme PAIS (Past Antarctic Ice Sheet dynamics) aims to improve understanding of the sensitivity of East, West, and Antarctic Peninsula Ice Sheets to a broad range of climatic and oceanic conditions. PAIS builds on the success of SCAR-ACE (Antarctic Climate Evolution), but with a new focus on the ice sheet rather than palaeoclimate reconstructions. 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 “ice-to-abyss” data transects, extending from the ice sheet interior to the deep sea. The data-transect concept will link ice core, 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. 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.

Proposal (maximum of 10 pages of text)

a. **Introduction - scientific objectives and statement of task (including contributions to SCAR's Strategic Plan) [10%]**
b. **Background - foundational knowledge [10%]**
c. **Scientific approach and rationale (including synergies with other SCAR programmes and products) [25%]**
d. **Experimental section and methodologies [15%]**
e. **Management and reporting (including a Scientific Steering Committee) [10%]**
f. **Milestones, outcomes, and results (including metrics of performance) [10%]**
g. **Data management plan [15%]**
h. **Capacity building, education and training plan [5%]**
i. **References**

A. Introduction – scientific objectives and statement of task (including contributions to SCAR's Strategic Plan)

PAIS aims to improve our understanding of the sensitivity of the Antarctic Ice Sheet and its contribution to sea level change in response to past changes in climate spanning a range of timescales- from Cenozoic times warmer than today, to the last glacial termination and the Holocene. Prediction of future scenarios of ice-sheet behaviour as a response to climate change requires guidance from geological history that reveals the timing, frequency and magnitude of environmental change. A series of linked objectives will deliver the goals of PAIS by:

1) focusing research on the more vulnerable areas of the ice sheet (West Antarctica and sectors of the East Antarctic margin) during past periods of elevated temperatures including recent warm interglacials and the more distant and much warmer greenhouse world.

2) linking continental records of ice sheet change with offshore records, including far-field palaeoceanographic and sea level records.

3) developing new palaeotopographic/palaeobathymetric reconstructions for key intervals so as to provide a robust framework for modelling the Antarctic environment, and;

4) integrating geologic, geophysical and ice core data to constrain and test a new generation of coupled Glacial Isostatic Adjustment (GIA)-Ice Sheet-Atmosphere-Ocean models.

To decipher the record of past responses of vulnerable sectors of the Antarctic ice sheet to climate, palaeoceanographic and sea level changes, PAIS will facilitate coordination of the scientific community in three ***Emerging Frontiers***:

- ***Frontier in Science:*** Antarctic ice sheet dynamics in a warmer world.

- ***Frontier in Strategy:*** Continent-to-abyss transects along specific ice sheet drainage systems (Figs.1 and 2).

- ***Frontier in Technological advances:*** Sub-glacial imaging measurements and sampling; improvements in sub-seafloor drilling - including the recovery of intact shelf records containing direct evidence of grounding-line behaviour; and the application of state-of-the-art coupled, predictive climate-ice-sea level models (Fig.1) to past conditions warmer than today and other times of ice sheet retreat.

To achieve these goals, PAIS will facilitate the formation and coordination of international programmes for the synthesis of existing data, and planning, acquisition and analysis of new data for integration with numerical modelling. Specifically, PAIS will:

- define data transects of high scientific value.
- engage with the community to form teams to take on international collaborative efforts to acquire and analyse data along the transects.
- coordinate teams to facilitate the sharing of information and knowledge to meet the long-terms aims of the programme.

The objectives of PAIS directly address several of the EMERGING FRONTIERS sections in the SCAR Strategic Plan 2011-2016 (pp 14-16), including the recovery of "geological records of past Antarctic ice sheet dynamics and integration of this knowledge into coupled ice sheet-climate models." In addition, PAIS has relevance to major international programmes. In particular, the International Ocean Discovery Programme (IODP), the Antarctic Drilling Programme (ANDRILL), and the European Project for Ice Coring in Antarctica (EPICA).

B. Background - foundational knowledge

The outline for a focused programme on Past Antarctic Ice Sheet dynamics was put forward at the 1st International ACE Symposium in Granada Spain, September 2009. The SCAR-ACE SRP, established in 2004 and ending in the summer of 2012, focused on linking the growing number of climate and ice sheet modelling studies with new geophysical surveys and geological studies on and around the continent. ACE has been instrumental in resolving a number of previously unanswered palaeoclimate science questions at critical “times-slices” in the evolution of the Antarctic cryosphere. These range from determining the mechanisms responsible for the onset of the first major Cenozoic glaciation of the continent ~34 million years ago, to the more recent West Antarctic Ice Sheet (WAIS) retreat and readvance events during the Pliocene and Pleistocene. ACE’s success came largely by promoting and facilitating major initiatives and field programmes that championed the “data-model paradigm”, including: ANDRILL, IODP programmes, airborne geophysical surveys such as AGAP and ICECAP, and sub-programmes and working groups including ANTscape, and CASP, among others.

Wide international participation in ACE was demonstrated during the Granada Symposium, which was attended by nearly 200 scientists and students from 16 nations. The symposium marked a major increase in the engagement of the broader palaeoclimatic, palaeoceanographic, glaciological, climate and ice sheet modelling communities, including scientists studying modern climatic, oceanographic, and glaciological processes.

The broader impacts of ACE on larger international programmes and capacity building is seen in the new IODP 2013-2023 science plan, which adopted a similar data-model philosophy with increased focus on polar regions, and with the potential to make substantial contributions to the Intergovernmental Panel on Climate Change (IPCC).

In addition to it’s indirect contribution to many high-impact publications in the primary scientific literature, including *Science* and *Nature* (see www.scar-ace.org), more direct ACE products include the publication of five major edited books and special volumes (Florindo, Cooper and O’Brien, 2004; Florindo, Nelson, and Haywood, 2008; Florindo and Siegert, 2008; Florindo, Harwood and Levy, 2009; Escutia, Florindo, Bentley, and DeConto, 2012).

While ACE clearly demonstrated the potential for past ice sheet history and behaviour to be reconstructed through a careful combination of geological and geophysical data with numerical ice sheet modelling (e.g., DeConto and Pollard, 2003; Naish et al., 2009; Pollard & DeConto, 2009), the records obtained under the ACE umbrella remain sparse and provide only the basic elements for determining Antarctic ice sheet behaviour in the past. To understand how the Antarctic Ice Sheet affects (and is affected by) climatic and oceanic processes, comprehensive records from ice to ocean are needed, at carefully chosen time intervals that provide the best analogues for future changes in the climate system and ocean. Hence, PAIS and the concept of ice-to-ocean transects was born (Fig.1).

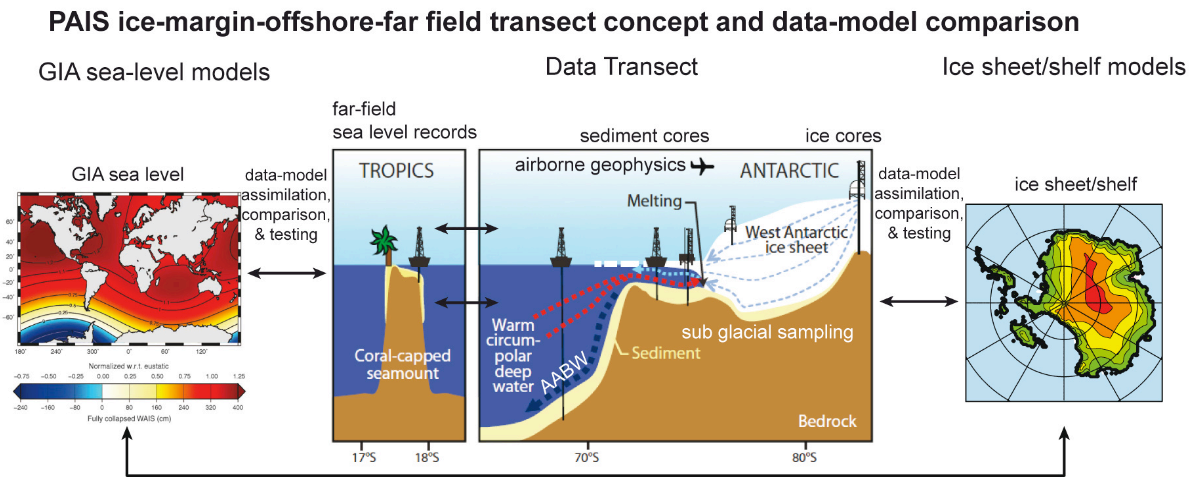

Figure 1. A schematic representation of the PAIS “ice-to-sea” transect concept, extending from the ice sheet interior, along an ice flowline, and offshore to the tropics. The meridional transect links Antarctic ice sheet changes to both proximal and far field records of ice volume, ice sheet geometry, and sea level. The data-data and data-model concept links on-ice, proximal, and far-field records with the new generation of ice sheet models, including GIA earth models of time-evolving global sea level. The GIA example (left) is from Bamber et al. (2009) representing the normalized sea level response to the loss of ice on West Antarctica. The schematic transect (middle) is after Schoof (2010) as depicted in the new 2013-2023 IODP Science Plan, and the continental ice sheet/shelf simulation of a past WAIS collapse (right) is from Pollard and DeConto (2009).

The framework for the transect approach has been established by the ANTscape and CASP projects with their integrated onshore-offshore approach for reconstructing past Antarctic landscapes. Some work on individual sectors has recently appeared e.g., by Sugden & Denton (2004) for the Mackay Glacier system, and Jamieson et al. (2005) for the Lambert Glacier basin. The selection of ice sheet drainage transects to be targeted by PAIS during the next decade (Fig. 2) evolved from a community drilling workshop during the ACE Symposium in Granada, Spain. The outstanding scientific questions for the next decade were developed and areas around the Antarctic margin were outlined as were as the locations around the Antarctic margin where these questions can be best addressed were identified (Figure in PRAMSO document available at http://www.scar-ace.org/).

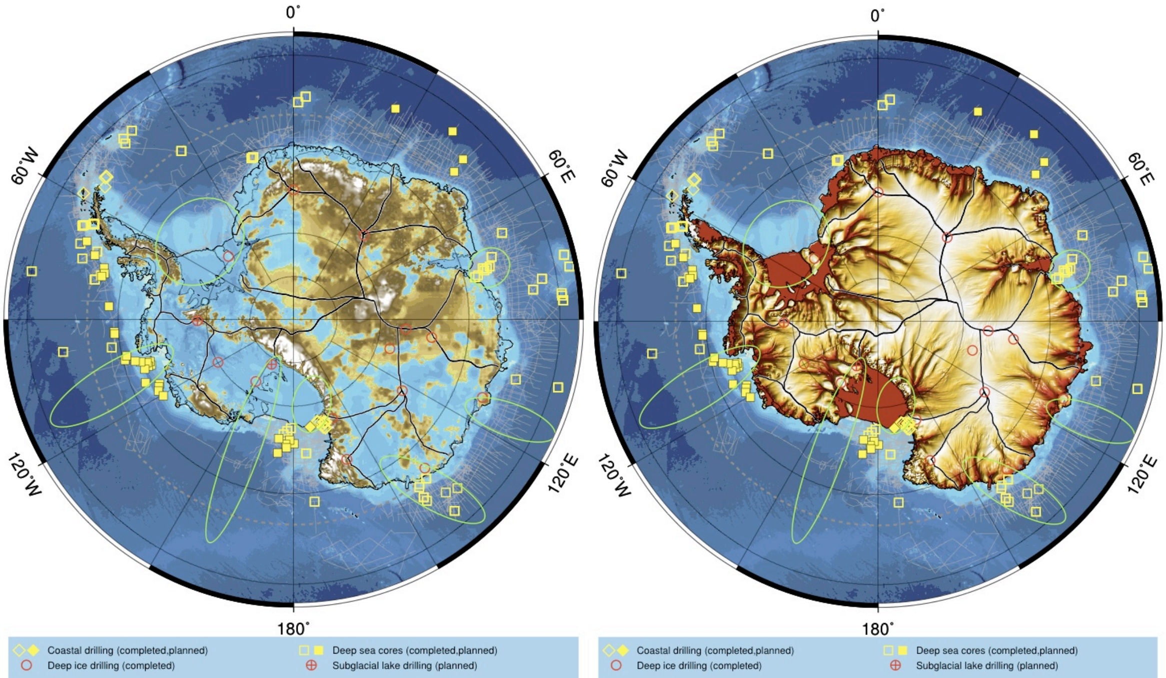

Figure 2. Integrated strategy and types of records from ice sheet-ice shelf-offshore transects along specific drainage systems (green elipses) of interest to PAIS to.reconstruct ice sheet dynamics and palaeoclimate from vulnerable areas of the Antarctic margin and the Southern Ocean. Vulnerable areas around the Antarctic margin are indicated by the bed elevation (i.e., marine-based ice sheet) (left), and the Antarctic ice sheet velocities (right) maps. Black lines delineate ice divides. Bed elevation and ice sheet velocity maps modified from Rignot et al., 2011a).

C. Scientific rationale and approach (including synergies with other SCAR programmes and products)

Scientific rationale

The Antarctic ice sheets, ice shelves, sea-ice, and surrounding marginal 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.

Antarctic palaeoenvironmental records are the primary missing link for reconstructing equator-to-pole temperature gradients through time, the key factor to determine the strength of "polar amplification" and climate sensitivity in general. These records are also directly relevant to ice sheet and sea level change, because the magnitude of accelerating ice sheet loss, both in Greenland and Antarctica, suggests that ice sheets will be the dominant contributors to sea level rise in coming decades, and their contribution will "likely" exceed current IPCC projections for the 21st century (Rignot et al., 2011b).

To understand Cenozoic Antarctic cryosphere evolution in the context of the Earth's climate system, PAIS will help coordinate palaeoenvironmental and tectonic studies along transects from the interior of the continent to abyssal plains (Figs. 1 and 2). These studies will preferably extend from specific drainage sectors, because it is expected that 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 also aims to advance our understanding of processes forming sediment archives that record transitions, thresholds, and rates of change when chronology makes it possible, especially during the past 1 million years. On this time scale, collaboration with the ice core community will provide high-resolution records of continental interior conditions that can be compared with the response of the WAIS and the larger East Antarctic Ice Sheets (EAIS).

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 CO_2 and temperatures during this century (Solomon et al., 2007). To achieve that aim, PAIS will focus 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 CO_2 levels that are close to what is forecasted for our near future (Solomon et al., 2007), 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) when significant grounding-line retreat is suspected around sensitive areas of the East Antarctic margin, which addresses the sensitivity of EAIS to relatively small increases in temperature and CO_2. Periods representing prolonged warmth include the Miocene Climate Optimum (17-14 Ma), and the persistent elevated temperatures and pCO_2 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.

Scientific approach and strategy

To decipher the record of past responses of vulnerable segments of the Antarctic ice sheet to climatic forcing, and oceanographic and sea level changes, PAIS will facilitate coordination of the scientific community with the three Emerging Frontiers. This strategy will allow us to understand how the Antarctic Ice Sheet affects and is affected by climate change, and to advance our understanding of processes involved in forming natural sedimentary archives. Sedimentary records from ice sheet-ice shelf-offshore transects along specific drainage systems will advance our current poor understanding of linkages between the ice sheet, ocean circulation, and deep/bottom water processes through time. Specific drainage basins will be targeted to account for different areas having different histories. The transect approach will also constrain and test sea level changes across latitudes based on GIA-ice sheet-ocean-climate models requiring coeval near-field and far-field sea level histories.

The transect concept also feeds into the work that has been conducted by the ACE sub-committees CASP and ANTScape who facilitate the reconstruction of palaeotopographies and palaeobathymetries. The reconstructions, critical for ice sheet and paleocurrent modelling studies, require a combination of offshore and sub-ice sheet geophysical and geological data. Good examples are the reconstructions of Antarctic topography at the Eocene-Oligocene transition 34 million years ago (Wilson & Luyendyk, 2009; Wilson et al., 2011), and the topographic controls on ice sheet dynamics in the Prydz Bay region at the Eocene-Oligocene transition (Stocchi et al., submitted).

Onshore

Onshore studies will allow palaeoclimatic and ice sheet events to be sampled in a transcontinental way. They will also allow us to best constrain past ice sheet behaviour and volumes more precisely, following the premise that some areas have different histories than others. Subglacial sedimentary basins (e.g., West Antarctic rifts, Wilkes Land, etc.) and lake sediments hold potential for further defining and broadening ice sheet histories. Furthermore, sampling bedrock also can provide ground truth data for palaeotopograhic reconstructions. Subglacial till and grounding-zone sediments can help constrain current and Holocene ice dynamics. It is also especially desirable that ice cores be used to provide records of environmental conditions for specific drainage areas, and precise chronological correlations and physical linkages between ice margin processes and continental climates, particularly at times when high-resolution marine records are available. This is most relevant for the Holocene, when correlations with well-dated, high-resolution marine records make such correlations possible.

Onshore transects will seek (1) geological sampling of sub-ice rock/sediment and water through ice boreholes, (2) rock sampling for cosmogenic surface exposure dating, and (3) surface instrumentation for fast radar and seismic (e.g. vibroseismic) surveys over ice sheets and ice shelves. The latter will complement regional ice sheet airborne/satellite surveys and will help identify future drill targets.

There is a strong cross-linkage to SERCE (Solid Earth Response and Cryosphere Evolution) with respect to integrating effects of the subglacial hydrological system on sliding conditions at the ice bed. Furthermore, all of these data are critical for establishing model boundary conditions and for data-model comparison.

Continental Shelf

Sediments of the continental shelves provide direct evidence of past grounding line/calving line oscillations. These proximal locations enables the study of processes related to ice dynamics, ice shelf extent, sea-ice cover, and oceanographic conditions, as well as the timing and rates of changes, which may differ among drainage basins. One of the main questions to be addressed is how the extent of grounded ice relates to palaeoclimate and palaeoceanic conditions. Incursions of relatively warm Modified Circum-polar Deep Water (MCDW) onto the West Antarctic continental shelf have been implicated in regulating WAIS behaviour on orbital and sub-orbital timescales. Therefore, palaeo-records of CDW flowing onto the Antarctic shelves through morphological depressions are urgently needed to understand the relationship between ice sheet variability and ocean circulation. Transgressive and regressive sedimentary facies successions related to water depth changes – if identified – can be used to determine regional sea-level variations in correlation with gravitational and visco-elastic effects of the build-up and retreat of the ice sheet (Bamber et al., 2009).

Bathymetric mapping produces images of glacio-morphological features and seabed substrate that help characterize ice flow dynamics and reconstruct – in combination with microfossil and lithofacies records from short sediment cores – the retreat process and timing since LGM. Seismic surveys will reveal the geometry and characteristics of glacial sedimentary basins, mark zones of pre-glacial to transitional and to glacial conditions, and locate buried morphological features of older grounded ice sheets. Shallow seabed and deep sediment drilling is required to obtain the necessary proximal records of the stratigraphic completeness and chronological precision to derive palaeoenvironmental conditions for past glacial variability. This mapping will facilitate strong cross linkages with AntEco by determining possible locations of biological refugia and migration pathways during glacial-interglacial cycles.

Continental slope-to-abyss

The Southern Ocean was a critical component in the development and subsequent variability of the Antarctic cryosphere. Today, as in the past, the Southern Ocean is a sensitive mixing pool of global water masses, a locus of high biological sedimentation, and it contains high-resolution continuous records of climate forcing and response. Continental slope-to-abyss transects will allow us to understand the interactions among cryosphere, hydrosphere and solid Earth by providing valuable palaeoenvironmental records (i.e., surface and deep ocean temperatures, sea ice extent, Antarctic Bottom Water formation, oceanic frontal system migrations, ocean circulation, nutrient distribution, and ocean productivity). A high priority will be the development of temperature reconstructions for high-latitude Southern Ocean sites in order to evaluate Earth system responses (e.g. polar amplification) and feedbacks (ocean circulation, ice albedo) and their influence on ice volume during past times of elevated pCO_2 (e.g. early Pliocene, Middle Miocene, Early Eocene). A key will also be the reconstruction of past deep ocean circulation/water mass variability (e.g. the production of AABW and the upwelling of NADW/CDW) using geochemical sedimentological proxies from these sites.

Synergies with other Programmes

Within SCAR, PAIS has links to SCERCE in topics related to past ice sheet dynamics and sea level; to AntEco in topics related to palaeoecology, evolution, and refugia; and to AntClim21 in topics related to cryosphere and sea level. In addition, PAIS has links to the ice core community via the International Partnership in Ice Core Sciences (IPICS) and through the ESF EuroPOLAR Project HOLOCLIP; to the palaeoclimate community via the Past Global Changes (PAGES) programme of the International Geosphere Biosphere Programme (IGBP); to the IASC programme on Arctic Palaeoclimate and its Extremes (APEX); and to drilling programmes such as the Antarctic geological DRILLing programme (ANDRILL), the SHallow DRIlling Programme (SHALDRIL), the International Ocean Discovery Programme (IODP), and ESF ERICON-AB.

D. Experimental section and methodologies

PAIS projects will use a range of established methods together with developing strategies and new technologies. In onshore areas these will include (Fig.1): (1) geological sampling through ice-water-sediment boreholes by ANDRILL and using subglacial Lake Ellsworth (SLE) and Subglacial Lake Whillans (WISSARD) style fast hot water drill access, and shallow coring technology (e.g. "WAISdrill"), including (a) new coring technology to recover complete ice proximal records of the last 5 glacial-interglacial cycles, and (b) associated clean technology and protocols to achieve non-contaminating subglacial access (e.g., Siegert et al., 2012). Additional onshore drilling may be carried out by new drilling technologies being developed in the US program and also in ice-free areas through the ICDP (International Continental Drilling Programme) and/or DOSECC (Drilling and Observing Earth's Continental Crust); (2) Surface geophysics instrumentation for fast radar and seismic surveys over the ice sheets and ice shelves, using, for example a vibroseismic source (cf. Eisen et al., 2010) and new ground-based and airborne radio-echo sounding approaches to image detailed ice base morphology (King et al., 2009; Jezek et al., 2011; Vaughan et al., submitted); (3) Surface exposure age dating can be achieved using established cosmogenic isotopic systems with enhanced precision (e.g., ^{10}Be) and new isotope systems (e.g., ^{14}C).

The subglacial "clean access" issue will be an important matter for the PAIS scientific committee to consider with SCAR and the Treaty Organisation. A wise strategy may be to first target frozen-bed areas or areas near grounding lines like the US WISSARD project. The focussed geophysical surveys mentioned above will complement broad airborne/satellite surveys of the ice sheet to provide required site surveys, and the combined new datasets will help locate future drilling targets by defining subglacial sedimentary basins and sediment distribution in subglacial lakes and beneath ice shelves.

Proximal to the modern WAIS grounding line, WISSARD (Whillans Ice Stream Subglacial Access Research Drilling) will provide new data applicable to a range of PAIS objectives. In offshore areas, frontier technological developments will include (Fig.1): (1) offshore sampling using seafloor drills (e.g., MeBo) and improving core recovery achieved by ship- and ice--based drilling into unconsolidated glacial sediments (e.g., IODP, SHALDRIL, ANDRILL); (2) improving sediment dating methods and developing new dating tools (e.g., application of relative geomagnetic palaeointensity dating) to overcome the problem of establishing high-resolution age models for Antarctic and Southern Ocean sediment cores that historically has been a major limitation for the interpretation of processes and rates of change; (3) detailed morphobathymetric mapping using state-of-the-art sonar systems mounted on ships, remotely operated vehicles and autonomous underwater vehicles, and high-resolution marine seismic surveys, to reveal locations where past ice margin and subglacial environments can be sampled, and locations where long-term, more continuous records can be recovered, such as sedimentary basins and sediment drifts.

In addition to new coring technologies, there will be a continuing role for established shipboard coring systems, including IMAGES (International Marine Past Global Changes Study). Particular applications of these systems will include recovery of expanded post-glacial records and coring relatively shallow water sites where foraminiferal carbonate may be preserved (e.g. MIS 31).

Both onshore and offshore drilling will present opportunities to measure heat flow, which is an important and still poorly-constrained boundary condition for present and past ice sheet models. PAIS will encourage measurements of heat flow to be made at every opportunity. Every borehole also presents an opportunity to gather continuous records of the nature and in-situ properties of the drilled formations through wireline geophysical logging, and PAIS will also encourage such logging. Again, these methodologies are highly complimentary to SERCE, focusing on ice sheet-solid Earth interactions.

E. Management and reporting (including a Scientific Steering Committee)

PAIS will be led by a 14-16 person steering committee (SC) that will include the broad range of expertise represented by PAIS science discussed above. The SC will include a Data Coordinator and a member from APECS. SC members will have 3-4 year terms. The founding co-chairs will stand down in 2016, to avoid complete rotations of the SC. The SC will meet at least once a year in coordination with major international symposia including AGU and EGU.

Six sub-committees are currently being established to implement the objectives of PAIS.

1. *Palaeoclimate Records from the Antarctic Margin and Southern Ocean* (PRAMSO): aims to provide the Antarctic climate and palaeoclimate communities with the coordination and support for proposed and developing drilling projects. This includes identification of site survey needs.
2. *Palaeotopographic-Palaeobathymetric Reconstructions*, aims to reconstruct circum-Antarctic stratigraphy and palaeobathymetry and the palaeotopography to show change in bedrock elevations, landforms, and geotectonic configurations of Antarctica over the past ~100 million years.
3. *Subglacial Geophysics*, is reconstructing bedrock roughness and drainage networks from land to the coast.
4. *Ice Cores and Marine Core Synthesis*. PAIS will provide the framework within which the sediment and ice core drilling, and ice sheet modelling communities can integrate.
5. *Recent Ice Sheet Reconstruction* group will focused on the last glacial termination, using a range of methods including proximal and offshore geophysical and sedimentological analyses of past groundling-line dynamics, and continental records of ice sheet thickness from exposure-age dating.
6. *Deep-Time Ice Sheet Reconstructions* will rely heavily on the coordination among numerical modelling communities, the *Palaeotopographic-Palaeobathymetric* sub-committee, and the broader palaeoceanographic communities providing indirect estimates of ancient ice volume via geochemical studies and sea-level histories from continental margins.

Membership of these committees will allow wide involvement in the PAIS programme in terms of expertise, gender and nationality. An appropriate model for the individual expertise of the committee is as follows:

Thematic components

1. Geophysics (sea-floor morphology, seismic stratigraphy, regional structure and basin analysis)
2. Sedimentology (glacial/interglacial sequences and processes onshore-nearshore-offshore, high resolution stratigraphy, etc.)
3. Palaeoceanography (ocean-basin history, water mass processes, sediment-ocean-air interfaces, sea ice, ice rafting, etc)
4. Geochemistry (tracer geochemistry, biogeochemistry, carbon cycle, ice-sheet and ice-rafted sediment provenance, etc.)
5. Geochronology and palaeomagnetism (age-dating techniques, rock-magnetic properties, chronostratigraphy)
6. Palaeontology (biostratigraphy, palaeoecology, evolution of polar biota, palaeoenvironmental proxies)
7. Ice sheet modelling (used to ‘test’ hypotheses derived from interpretation of the geological record and establish past accumulation patterns by integrating models results with internal ice-sheet layers identified by ice-penetrating radar)
8. Glacial Isostatic Adjustment (GIA) modelling

9. Palaeoclimate modelling (ice-sheet models coupled with atmosphere-ocean General Circulation Models (GCM's) to examine glaciation feedback mechanisms and to examine physical processes responsible for ice sheet configurations outlined in component 8)
10. Ice cores for marine-ice core comparisons over the past ~1 million years (air temperaturs vs surface water temperatures, CO_2, and ground-truthing palaeoclimate models)
11. Tectonics and climate change (interactions among climate change, ocean circulation, the ice sheet dynamics, and Antarctic tectonism).
12. Data management representative (geologic, geophysical, and glaciological data)
13. Technological development (drilling/coring/sampling systems, geophysical data acquisition).
14. APECS representative

F. Milestones, outcomes, and results (including metrics of performance)

Many PAIS continent-to-abyss transects will encompass more than the eight years of the proposed PAIS Programme, but they build on ongoing, planned, and to be planned projects that should guarantee important outcomes during the life of PAIS (Table 1, Fig. 2) and form the seed for such research projects to continue into the future. For example, ongoing projects include ANDRILL SMS and MIS Programmes, Subglacial Lake Ellsworth and WISSARD projects, and continental (ice cores)-shelf-offshore (marine sediments) transect in the Wilkes Land. Proposed projects include the IODP Amundsen Sea, ANDRILL Coulman High and Siple Coast; IODP Bellingshausen Sea and Eastern Ross Sea; various subglacial access targets (e.g., see http://icedrill.org/about/sab.shtml); and there are areas of potential great scientific interest where new data collection is essential (i.e., Weddell Sea, Budd Coast, Conrad Rise etc.).

The objectives of PAIS are particularly timely relevant to the stated objectives of the European Project for Ice Coring in Antarctica (EPICA) (in conjunction with the SCAR supported International Partnerships in Ice Core Sciences (IPICS)), whose long-term mission is to recover an ice core greater than 1 million years in age. EPICA has the potential to reach the MIS-31 event (1.07Ma), when according to sediment drill core records, WAIS appears to have retreated substantially and circum-Antarctic temperatures were particularly warm relative to today (Naish et al., 2009). PAIS' role in establishing cooperation between the geological and ice core drilling communities clearly has the potential to facilitate high-impact science discoveries, such as confirmation of the MIS-31 WAIS deglaciation.

New planning will be coordinated through community workshops. The first workshop will be held on 13th-14th July 2012, prior to the SCAR-Open Science Conference (15-20th July 2012). The workshop objective is to stimulate new Antarctic and Southern Ocean drilling proposals and ensuring coordination among existing ones, so that science objectives are tackled through a regional approach. A common overarching framework will be defined in order to integrate marine and continental coring.

G. Data management plan

PAIS will also foster continued development of the Antarctic Data Library System for Cooperative Research (SDLS), which was set up under the former SCAR-ANTOSTRAT project. 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 will not directly support other data archiving infrastructure, it will maximize the effectiveness of it's 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 will be:

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.

Table 1. Ongoing, proposed and future projects and workshops relevant to PAIS objectives.

PAIS Projects

Projects	***Location***	***Objectives***	***Year***
current			
ANDRILL SMS & MIS	Ross Sea	Pleistocene-Miocene glacial history	2007-2008
IODP 318	Wilkes Land	Holocene to Greenhouse palaeoclimate and glacial history	2010
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
Subglacial WISSARD (LISSARD & RAGES) Drilling	Whillans Ice Stream	Marine Ice Sheet Stability and Subglacial Life Habitats in West Antarctica	2009-2015
WAIS Divide	WAIS ice flow divide	Climate, ice sheet history and cryobiology	2010-2013
AGAP	Gamburtsev Mountains	Initial ice sheet formation, subglacial hydrological processes	2008-2009
proposed			
ANDRILL Coulman High	Ross Sea	Palaeogene to lower Miocene ice sheet behaviour & environments during greenhouse gas levels	2014
IODP 732	West of Antarctic Peninsula and Bellingshausen Sea	Late Miocene to Quaternary, Palaeoceanography, Ice Sheet History	To be scheduled
IODP 751	Eastern Ross Sea	Late Neogene grounding events at the Eastern Basin	Under revision
IODP 784	Amundsen Sea Embayment	Stratigraphy, glacial cycles, ice sheet collapse, circum-polar deep water,	Under revision
E Ross Sea shelf - SHALDRIL	Southeastern Ross Sea	Cenozoic evolution of West Antarctica and early development of WAIS	Approved currently on hold
Amundsen Sea shelf - MeBo	Amundsen Sea Embayment shelf	Basic shelf stratigraphy, glacial onset, LGM retreat ages	re-submitted in July 2012
Planned			
WAIS-Drill	West Antarctica	Ice sheet history from subglacial sediments	2015-
EPICA	Dome C, Dronning Maud Land	Deep ice core drilling	1996-ongoing
Wilkes Land shallow drilling	Eastern Wilkes Land	Ice sheet behaviour & environments from greenhouse to Pliocene	
IODP Weddell Sea	Weddell Sea continental slope and rise	High-resolution Pliocene climate and ice sheet variability	
IODP SE Pacific Ocean	SE Pacific deep-sea	Cenozoic suborbital climate variability, biogeochemical cycles, Antarctic ice sheets, tectonic evolution	
IODP SW Pacific Ocean	SW Pacific deep-sea	Cenozoic suborbital climate variability, biogeochemical cycles, Antarctic ice sheets, tectonic evolution	
ICECAP/ICEBRIDGE	Wilkes Land (Wilkes and Aurora subglacial basins, Victoria Land	Lithosphere and sub glacial conditions in East Antarctic basins	2008-ongoing

PAIS Workshops & Meetings

Antarctic Drilling Workshop	Portland, OR, USA		July 2012
PAIS: Palaeotopography-Palaeobathymetry subcommittee	Portland, OR, USA		July 2012
PAIS Steering Committee	Portland, OR, USA		July 2012
PAIS 1st Symposium	TBD		September 2013

The Integrated Ocean Drilling Programme (IODP) databases - http://iodp.tamu.edu/database & http://iodp.ldeo.columbia.edu/DATA/index.html, http://ssdb.iodp.org/. Holds all data generated during the IODP Expeditions of interest to PAIS (i.e., DSDP 28; ODP Legs 113, 119, 178, 188; IODP Exp. 318). In addition, it holds data from lower latitude Ocean Drilling (DSDP, ODP, IODP) Expeditions that may complement sites for the latitudinal transects planned for PAIS.

A data portal that will become relevant for PAIS continental slope-to abyss transects will be 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.

Antarctic and Southern Ocean Data from previous coring expeditions can be checked at the Google Earth link: http://campanian.iodp-mi-sapporo.org/google/data/iodp.kml

Other databases included NOAA NCDC/NSIDC, and national programmes metadata systems.

For data management within PAIS, a Data Coordinator will serve on the PAIS Steering Committee. A PAIS sub-committee on Data Management, guided by the Data Coordinator, will 1) engage in cross-linkage activities and the facilitation of cross-SRP data sharing via web-based utilities, and 2) maintain ongoing communication with national funding programmes, currently expanding their emphasis on responsible and cost-effective data management, protection, archiving, and sharing.

Other PAIS data management activities may include the targeting of resources to facilitate development of community-needed data compilations (such as BEDMAPII), open access of data-post processing methodologies and tools, and coordinated access to model codes and model output data files, facilitating data-model comparison among scientists with a range or expertise. One such example is comparison of model ice-sheet thickness through the last glacial cycle at a specific location, with trimline observations based on radiometric exposure ages (e.g., Ackert et al., 2011). PAIS will strictly adhere to data policy guidelines outlined in SCAR Report 39 (2011).

H. Capacity building, education and training plan

PAIS education and public outreach to engage the public in scientific efforts to document the behaviour of Antarctica's ice sheets will be linked to the activities conducted by international programmes such as ANDRILL and IODP, and national funded programmes. PAIS will liaise with the SCAR office to ensure effective communication and outreach, as set out in the 'SCAR Communications Plan' and 'A Strategy for Capacity Building and Education'.

PAIS will endeavour to support and encourage the next generation of Antarctic scientists by: 1) including young scientists in the leadership of sub-committees and the SC 2) encouraging young scientists to take part in PAIS meetings and workshops by offering bursaries for travel and subsistence. The level and number of the bursaries will be dictated by funds available; 3) funding of 1-2 graduate students a year to attend the Urbino Palaeoclimate School and the Karthaus Summer School on Ice Sheets and Glaciers in the Climate System. The condition of each bursary will be a report by the holder about their research and workshop experiences, which will be posted on the PAIS website.

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Supporting information (1 page)

I. Short biosketch and homepage URL for proposed Chief Officer(s) and lead investigator(s)

Carlota Escutia is a Research Scientist at Research Council of Spain (CSIC-Univ.Granada. She has held research positions at the US Geological Survey (USA) and the Ocean Drilling Programme/Texas A&M Universities (USA). Carlota's research focuses on the evolution and dynamics of the Antarctic cryosphere through the study of sediment archives and seismic stratigraphic interpretations. For this she participated in drilling expeditions in the Antarctic margin (i.e., ODP Leg 178), and led and was co-chief of the Integrated Ocean Drilling Programme (IODP) drilling of the East Antarctic Wilkes Land margin. She has been PI in numerous research projects in Antarctica funded by USA, Spain and Europe. In addition to a number of international science boards, Carlota currently serves as chair of ESSAC – the ECORD (European Consortium for Ocean Drilling) Science Advisory and Support Committee, and as co-chair of the SCAR-ACE (Antarctic Climate Evolution) Scientific Research Programmeme.

Rob DeConto (http://www.geo.umass.edu/faculty/deconto/Site/Home.html) is a Professor of Geosciences at the University of Massachusetts-Amherst. He maintains adjunct research positions at Columbia University and Victoria University of Wellington. Rob's background spans geology, oceanography, atmospheric science, and glaciology. He has held research positions at both the US National Centre for Atmospheric Research (NCAR) and the National Oceanic and Atmospheric Administration (NOAA). His research is focused on the polar regions- including fieldwork in Antarctica, the development of coupled climate-ice sheet models, and the application of those models to a wide range of past and future climate scenarios. Rob currently serves on a number of national and international science boards and advisory panels and he is currently co-chair of SCAR-ACE (Antarctic Climate Evolution).

II. Justification for SCAR sponsorship (why does SCAR support add value?)

The highly international, interdisciplinary nature of PAIS will be best served under the umbrella of an established, internationally respected committee of ICSU. As with ACE, it is expected that PAIS will be asked to provide science recommendations and supporting documentation on a number of coordinated international research programmes. Careful handling of the dependable, annual budget provided by SCAR will provide flexibility in terms of workshops, science coordination, and timely response to the most important and relevant scientific opportunities.

III. International involvement and partnerships

The very nature of PAIS science is international in scope. Even in its planning stages, PAIS has already established partnerships with IODP, ANDRILL, SHALDRIL, ICECAP, AGAP, EPICA, PLIOMAX, PALSEA, and WAIS, among other national Antarctic research centres and multi-national research projects. PAIS is also well aligned with other SCAR Programme Planning Groups, particularly Ant-ERA, AntClim21, and SERCE.

IV. Budget justification (other potential sources of funds)

Research proposed by PAIS will be funded mainly by national funding agencies. Funds requested from SCAR are aimed at the planning and integration of data through periodic workshops; and the dissemination of results.

V. Other information (information useful to evaluators)

In addition to the authors of this proposal, many scientists have contributed to development of PAIS. Specifically, the concept was initiated during the 1st ACE Symposium in Granada and developed during meetings of the ACE Steering Committee (SC) in the SCAR OSC in Buenos Aires and Fall AGU 2010 that were open to the community. The writing of this proposal has received direct advise from the following scientists: M. Siegert, P. Barrett, T. Naish, R. Dunbar, and P. Stocchi.