SDM 14c
Agenda Item: 4.2.3
Person Responsible: T Naish et al.

XXXV SCAR Delegates Meeting

Davos, Switzerland, 25-26 June 2018

Proposed Scientific Research Programme Planning Group: Antarctic ice sheet dynamics & global sea level

Report Authors
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Summary
This paper outlines, the proposal for the establishment of a Programme Planning Group for developing a Scientific Research Programme (SRP) provisionally entitled Antarctic Ice Sheet Dynamics and Global Sea Level (AISSL). The SRP addresses a first-order question about Antarctica's contribution to sea level. It encompasses geoscience, physical sciences and biological sciences, of the way in which interactions between the ocean, atmosphere and cryosphere have influenced ice-sheets in the past, and what expectations will be in the future with a special focus on quantifying the contributions to global sea level change. Proposed initial Chief Officer is Tim Naish (New Zealand), and another 2 Co-Chief Officers will be identified. Proposed initial core membership includes 55 members from 14 SCAR countries. The aim of the SRP is to "quantify the Antarctic ice sheet contribution to past and future global sea-level change, from improved understanding of climate, ocean and solid Earth interactions and feedbacks with the ice, so that decision-makers can better anticipate and assess the risk in order to manage and adapt to sea-level rise and evaluate mitigation pathways".

The proposed programme is structured into 4 themes:
1. *Improved understanding of atmosphere-ocean forcing processes of marine-based ice sheet dynamics.*
2. *Improved understanding of solid Earth feedbacks on ice sheet dynamics and regional sea-level variations.*
3. *Improved understanding of spatial and temporal changes in Antarctica's ice sheets during the LGM and deglaciation, and for past "warmer-than-present" interglacials and high CO_2 worlds.*
4. *Improved projections of Antarctic contribution global sea-level change – consequences and impacts.*

The programme better aligns and integrates high-quality research previously conducted within the ANTCLIM21, PAIS, ANTECO and SERCE SRPs, in Themes 1-3 to more effectively quantify future sea-level projections. Themes 1-3 feed into Theme 4, which is policy-facing and will include social scientists to help deliver (e.g. IPCC) and implement revised sea-level projections within a risk assessment/policy context. The outcomes will include improved projections, and their associated risk profiles that will be of of broad interest to decision-makers, civil society, business, industry, agricultural, infrastructure, finance and insurance sectors.

XXXV SCAR Delegates Meeting

Davos, Switzerland, 25-26 June 2018

Recommendation

Delegates to consider the proposal and decide whether to approve establishment of the Programme Planning Group.

Summary Budget 2017 to 2020

	2017	2018	2019	2020
	Spent	Request	Request	Request
(US$)	N/A	$ 5 000	$ 10 000	$20 000

Proposed Scientific Research Programme Planning Group

Scientific Research Programme Title

Antarctic Ice Sheet Dynamics and Global Sea Level.

Proposed Scientific Research Programme Outline

Context:

The SCAR president, Steven Chown, is articulating a vision of a future research strategy that more directly addresses the role Antarctica plays in the rapid pace of environmental change, the risks facing humanity and the growing global sustainability problems it brings. SCAR will continue to provide rigorous, defensible scientific evidence to the ATS and its Agreements - The Protocol for Environment Protection (CEP) and the Commission on the Conservation of Antarctic Marine Living Resources (CCAMLR), but in addition it aims to expand its partnerships and influence, such as its engagement with the Intergovernmental Panel on Climate Change and United Nations Framework Convention on Climate Change (UNFCCC). In particular, SCAR recognises the importance of the global adoption of the Sustainable Development Goals, and initiatives to give effect to them, such as Future Earth.

An overarching theme of global reach continues to be improved understanding of the response of Antarctica's ice sheet and the Southern Ocean to climate change and reduced uncertainty in estimates of the ice sheet's contribution to sea level rise. The urgency and scale of these strategic research priorities requires:

- Multi-disciplinary international collaboration including expertise and alignment of resource and data-sharing
- Access to new satellite data, autonomous vehicles, instruments and observatories that can access the ice sheet interior, the ocean, the cavity under ice shelves, the base of ice sheets, and sediments and rocks under the ocean and the ice sheet
- More access to aircraft, ships, and over-snow traverse capability
- Commitment to long-term stable funding
- Use of emerging technologies for energy and for storing and communicating data in real time
- Access to remote areas of Antarctica all year round

Organisations like SCAR are uniquely set up to co-ordinate the resources of many nations to address such a large transdisciplinary global science challenge.

XXXV SCAR Delegates Meeting

Davos, Switzerland, 25-26 June 2018

Background:

Over the past eight years, four of SCAR's Scientific Research Programmes (SRPs) (PAIS, ANTCLIM21, SERCE & ANTECO) have seen a convergence of activity concerned with understanding the role of Antarctica and the Southern Ocean in the dynamics of the Earth System. Among the many outcomes thereof, one of the most significant is investigation of interactions between the atmosphere, ocean, cryosphere, and basal topography, and their outcomes for ice-sheet mass balance. In addition to a wide range of more traditional outcomes of the interdisciplinary work, novel areas of endeavour to inform the past behaviour of ice sheets have also been developed. The use of genomics to constrain past ice-sheet configurations provides one example (Strugnell et al. 2018*, Quaternary Science Reviews*).

The global significance of this work is clear. The behaviour of both the West (WAIS) and East (EAIS) Antarctic Ice Sheets has significant implications for global sea level (e.g. Golledge et al., 2015, *Nature*; DeConto & Pollard 2016, *Nature*). Into the future, quantifying the pace of sea level rise and our long-term commitment to higher seas is essential. Improved understanding of Antarctic ice sheet contribution to future sea-level rise was one of the most urgent research priorities to emerge from the IPCC 5th Assessment Report (IPCC, 2013). The outcomes that address this are necessary to provide evidence to assess the risks associated with climate change mitigation pathways (Rintoul et al. 2018). They will also determine the adaptation required to avoid the potentially profound impacts on society, both economically and in terms of progress against the sustainable development goals (Chown & Duffy 2018, *Nature Ecol. Evol.)*.

Recognition of the importance of understanding Antarctica's contribution to sea level is provided by the recent IPCC Special Report on Oceans and Cryosphere, SCAR's Horizon Scan Outcomes (Kennicutt et al. 2015, *Nature*), and the focus of a range of national programs on these questions, including through bilateral and multilateral collaboration. Broad agreement exists that although much is known, a great deal of work still needs to be done to understand how ice-sheet behaviour depends on ocean-cryosphere-atmosphere interactions, bed topography, basal conditions, and glacial isostatic adjustment.

In effect, understanding how ice sheets have responded in the past to changes in the Earth System, and influenced it, and how they will do so in the future, so affecting sea-level rise, are questions of great international interest and urgency. Indeed, the Horizon Scan made clear that this is one of a small handful of international interdisciplinary scientific endeavours that SCAR should be facilitating The global community will be depending on Antarctic scientists to deliver progress in this area, in collaboration with their colleagues across the globe.

The Proposal:

The proposal here is to establish a programme planning group to develop a SCAR Scientific Research Programme to address this need. The potential structure of the new programme is outlined in Fig. 1. The programme better aligns and integrates research previously conducted within the ANTCLIM21, PAIS, ANTECO and SERCE

SRPs, in Themes 1-3 to more effectively quantify future sea-level projections. Themes 1-3 feed into Theme 4, which is policy-facing and will include social scientists to help deliver (e.g. IPCC) and implement revised sea-level projections within a risk assessment/policy context. The outcomes of the programme will be of broad interest to decision-makers, civil society, business, industry, agricultural, infrastructure, finance and insurance sectors. We have included expertise in philanthropic development on our organising group (Rob Dunbar) to leverage additional funds to support the research. The programme provides a co-ordinating framework that will augment other important research initiatives and consortia.

Aim of the new programme:

Quantify the Antarctic ice sheet contribution to past and future sea-level change, from improved understanding of climate, ocean and solid Earth interactions and feedbacks, so that decision-makers can better anticipate and assess the risk in order to manage and adapt to sea-level rise and evaluate mitigation pathways.

Rationale for the new programme:

Global mean sea level (GMSL) has increased by ~22 cm since 1880 and will continue to rise well beyond the 21st century. The IPCC AR5 (IPCC, 2013) predicts between 52 and 98 cm of SLR by 2100, for its range of future emission scenarios known as the representative concentration pathways (RCPs). The problem is that since 2013 multiple new lines of scientific evidence indicate a significantly higher plausible GMSL rise for RCP 8.5 - upper bound of the IPPC range. Improved understanding of the complex response of the Greenland and Antarctic ice sheets has led to this correspondingly larger range of possible 21st century SLR than previously thought (e.g. Golledge et al., 2015, *Nature*; Ritz et al., 2015, *Nature*; DeConto & Pollard, 2016 *Nature*; Oppenhiemer & Alley, 2016, *Nature*).

The models used for sea level projections show that acceleration in mass loss observed by satellites over the last 10 years will continue (e.g. Shepherd et al., 2012, *Science*; IMBIE, 2018, *Nature*) , resulting in the polar ice sheets becoming the dominant contributor to GMSL by mid-century. However, the response of Antarctica to projected warming still remains the single greatest uncertainty in SLR projections for the coming decades to centuries.

SCAR scientists are at the forefront of research designed to reduce this uncertainty. Because the vulnerable (marine-based) sectors of the Antarctic ice sheet sit below sea-level and are capable of non-linear and rapid melting in response to a warming southern ocean, a critical step involves understanding the role of ocean dynamics and coupling a dynamic ocean model to our ice sheet models.

Sea-level change from land-based ice melting does not cause globally uniform sea level rise (SLR). The delivery of ice to the ocean changes Earth's gravitational field and rotational state. This, together with the accompanying viscoelastic response of the solid Earth to ice loss (a process known as glacial isostatic adjustment; GIA), means that locations near a melting ice sheet experience less SLR than more distant locations, with deviations reaching 30% of the global mean. Crucially, these solid earth processes also feedback into ice sheet dynamics (Gomez et al. 2010, *Nature*). Understanding the role of GIA and mantle dynamics within the ice sheet system is a critical area of enquiry.

The skill and performance of ice sheet models have been developed and tested within the SCAR PAIS programme on past warm climate analogues constrained by geological data. These models indicate Antarctica may contribute as much as an additional 80 centimetres of global SLR by 2100 under the "business as usual", high-emissions scenario where CO_2 levels reach 800 parts per million by the end of the century. The models also show that if a given CO_2 threshold is passed, Antarctica's ice sheets will continue to melt for centuries to come even after CO_2 levels and atmospheric temperatures have stabilised. This commitment to ongoing multi-metre SLR is because of the heat trapped in the ice sheet and ocean system, and the longevity of CO_2 in the Earth's atmosphere (centuries to millennia).

Because the magnitude of climate forcing projected for the next century has not been experienced by Earth for more than 3 million years, paleoclimate reconstructions of past Antarctic ice sheet response provide critical insights into its future behaviour. The influence of both ocean dynamics and solid Earth deformation on ice sheet dynamics can be assessed against these past warm climate analogues.

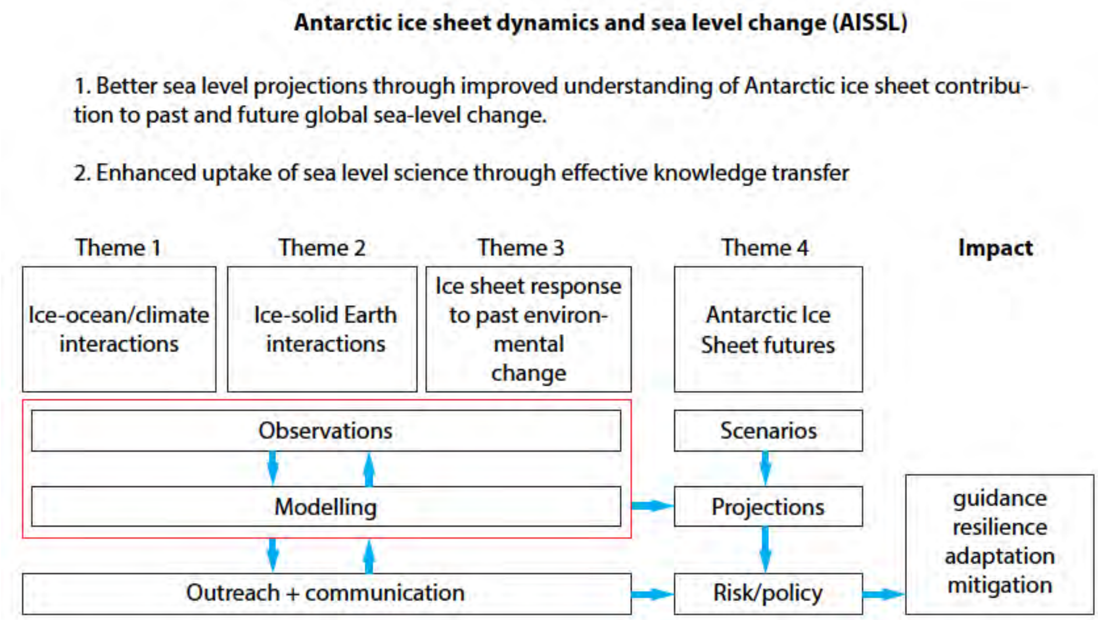

Figure 1. Proposed programme structure

Themes for a future SRP discussed at the PAIS Conference in Trieste include:

Below is a list of themes that emerged from discussions at the PAIS Conference in Trieste, September, 2017. While the list looks comprehensive, there is still much work be to be done. Priorities need to be identified and an implementation plan developed. This will be the work of the planning group.

XXXV SCAR Delegates Meeting

Davos, Switzerland, 25-26 June 2018

1. ***Improved understanding of atmosphere-ocean forcing processes of marine-based ice sheet dynamics***
   - Improved understanding of the processes of ocean and atmospheric forcing of marine-based ice sheet dynamics. Models are highly parametrised and critically need observations (e.g. ice shelf surface and subglacial melt rates, ocean temperatures, circulation, freshwater flux and stratification, surface melt) for validation and testing (both for past warm climate analogues and present observations).
   - Improved surface mass balance changes (over long and short scales), ice core elevation changes, water isotopes analysis/modelling
   - How do changes in atmospheric circulation influence ocean heat transport to the grounding lines? What are the important feed backs (e.g. meltwater flux and stratification, sea-ice)?
   - This involves strategically-located geological drilling (such as Ross Sea Exp. 374 IODP) and ocean observations that can reconstruct and measure the outflow of Antarctic Bottom Water, the inflow of Circumpolar Polar Deep Water and along slope flow, as well as sub-ice shelf oceanographic observations and sediment cores.
   - What is the role of atmospheric warming in ice shelf dynamics (e.g. hydrofracture, MICI)?
   - Direct evidence of boundary conditions critical for modellers including, subglacial conditions/hydrology, ice shelf cavity, bathymetry/topography (present and past).
   - Improved coupling of ice sheet and ocean dynamical models that incorporate key (missing) processes and boundary conditions critical for reducing the uncertainty of the Antarctic ice sheet contribution to global sea-level.
   - Balance needed between complexity, spatial and temporal scale. Models that are fit for purpose for addressing both local/regional/continental/global scale and short term and long term questions.
   - Past (last millions of years) and present regional atmospheric circulation (pathways of moisture advection, wind direction and strength) and local katabatic winds driving sea ice/polynya variability and related bottom water formation reconstructed from integration-comparison of coastal and inland ice core with sediment core data and models.

2. ***Improved understanding of solid Earth feedbacks on ice sheet dynamics and regional sea-level variations.***
   - Coupling of GIA models to ice sheet models to better understand near-field sea-level change and feedbacks on ice sheet dynamics, and reconcile far-field reconstructions of sea-level change for past, present and future. The latter is critical for improving regional sea-level projections.
   - Identification of regions of weak mantle viscosity, where feedbacks on ice dynamics will be strongest, and consideration of spatially-variable mantle viscosity within coupled GIA-ice sheet models.
   - Modelling of the role of dynamic topography on ice sheet dynamics.
   - Coupled GIA-ice sheet and 2- and 3-D stratigraphic erosion-sedimentation models to interpret continental margin geological records correctly in terms of

ice sheet volume and sea-level variability and local uplift or subsidence of subglacial bed and sea floor.
- Geothermal heat flux measurements (also for ice sheet modelers) and ice rheology (particularly for PAIS ice sheet modelers)

3. ***Improved understanding of spatial and temporal changes in Antarctica's ice sheets during the LGM and deglaciation, and for past "warmer-than-present" interglacials and high $C0_2$ worlds.***
- This LGM and deglaciation (last 24,000 years) spans the last natural experiment of global warming the Earth has experienced. It provides an opportunity to evaluate both the processes and rate of ice sheet thinning and retreat on different sectors of the ice sheet margin, including evaluating the role of MISI. Age control remains an issue, but marine sediment ramped pyrolysis radiocarbon dating provides an opportunity for improvement, also with integration with cosmogenic geomorphological approaches.
- The non-linear response of Antarctica's marine sub-glacial basins and contribution to global meltwater pulses remains a policy-relevant open question.
- Addressing this theme requires an integrated modelling data acquisition approach, that combines targeted marine sediment cores, sub-ice shelf cores, sea bed mapping (swath bathymetry), and geomorphic cosmogenic isotope studies of outlet glacier thinning, integrated with (ideally) coupled ice sheet-GIA-ocean/climate models. The last deglaciation is critical for identifying and evaluating key processes, feedbacks and rates relevant to modelling IPCC scenario projections.
- What happened to the Antarctic ice sheet during the last interglacial period (~125,000 years ago), when far-field sea-level reconstructions suggest global sea-level was up to 9m higher than today. One ice sheet model suggests Antarctica was capable of providing up 6m GMSL equivalent. This is arguably one of the most important outstanding questions paleoclimate should address, as it has major implications for understanding ice sheet sensitivity to very small increases in global or hemispheric surface temperature. This is also the case for other Late Quaternary "super-interglacials" (MIS 11 and 31) and the Pliocene warm period (400ppm CO2 world).
- Addressing this issue requires a multi-disciplinary integrated approach involving:
  i. Drilling transects of holes through the West Antarctic ice sheet to access bedrock and possible marine sediments that may have been ice free to reconstruct paleo seaways and ice sheet extent. These will provide robust constraints for ice sheet models of smaller-than-present ice sheet extents. These will compliment IODP drilling offshore of these sectors. As technology develops this will also involve drilling into an EAIS subglacial basin (e.g. Wilkes).
  ii. Use of "molecular clock" genomic evolutionary biological techniques to reconstruct timing and existence of past sea-ways through west Antarctica.

iii. Use of last interglacial reconstructions from ice cores to understand ice sheet elevation changes, proximity of marine conditions (etc.).
iv. Use of "molecular clock" genomic evolutionary biological techniques to reconstruct timing and existence of past sea-ways through west Antarctica.
v. Use of last interglacial reconstructions from ice cores to understand ice sheet elevation changes, proximity of marine conditions (etc.).

4. ***Improved projections of Antarctic contribution global sea-level change – consequences and impacts***
- Bi-polar-interhemispheric connections (e.g. ocean see-saw, antiphase ice sheet growth and hidden ice)
- Reconciliation of tropical-Antarctic teleconnections (e.g ENSO-SAM, influence on ITCZ)
- Reconciliation of far-field sea-level reconstructions with Antarctic ice volume change and implications for sea-level budgets.
- New Antarctic ice sheet projections are incorporated into global and regional sea-level projections (e.g. IPCC).
- Novel approaches to evaluate projections and provide society with an Antarctic risk assessment framework, by evaluating the process and statistical uncertainties and produce annual risk probability of sea-level rise and associated processes, such that modern changes are incorporated with the emerging understanding of past rates of rapid sea-level rise.
- These sea-level projections and risk profiles will be made available for specific risk assessment for industry, society and goverments.
- An integrated risk and policy assessment is undertaken that considers the revised sea-level projections under a range of political and societal scenarios to develop a suite of policy options.
- Drawing on lessons from framing theory, suitable methods for communicating the research results to the wider public and decision-makers are being explored.

Capacity building
A key focus for the new programme, and thus part of the Proposed Planning Group's remit, is to ensure that the new programmes builds capacity in the SCAR community. The programme will build on best practice from existing SRPs where there have been considerable successes in running summer schools, training courses, online webinars, ensuring Early Career Researchers (ECR) and those from newer Antarctic programmes work closely on the science questions. This has often involved close working with APECS, and we include some members in the core membership and will seek increasing engagement with the ECR community as we approach the start of a programme.

Proposed Chief Officers
Tim Naish (New Zealand) & TB

XXXV SCAR Delegates Meeting

Davos, Switzerland, 25-26 June 2018

Budget

Planned use of funds for 2018 to 2020

Year (YYYY)	Purpose/Activity	Amount (in USD)	Contact Name	Contact Email
2018	Planning meeting	5 000	T Naish	Timothy.naish@vuw.ac.nz
2019	Planning meeting	20 000	T Naish	Timothy.naish@vuw.ac.nz
2020	Launch meeting	20 000	T Naish	Timothy.naish@vuw.ac.nz

Briefly describe funds usage and desired results

- 2018: Establish work plan with Chief Officer and small part of core group meeting.
- 2019: Meeting to finalise the draft of the Science and Implementation Plan.
- 2020: Meeting at SCAR 2020 to initiate the SRP and draw in additional members.

Percentage of the budget to be used for support of early career researchers

2018: 20%
2019: 20%
2020: 20%

XXXV SCAR Delegates Meeting

Davos, Switzerland, 25-26 June 2018

Proposed Core Membership

Name	Nationality	SCAR role or affiliation	Expertise
Tom Bracegirdle	UK	Chief-officer Antclim21, IPCC	climate dynamics
Lara Perez	UK	PAIS, ECR	marine geophysics
Mike Bentley	UK	PAIS	paleoclimatology
Jan Strugnell	AUS	Chief-officer ANTECO	genetics
Peter Convey	UK	Chief-officer ANT-ERA	terrestrial paleoecology
Pippa Whitehouse	UK	Chief-officer SERCE	geodynamics
Nancy Bertler	NZ	Chief-officer Antclim21	ice cores
Joellen Russell	USA	Antclim21, CMIP6	oceanography
Tim Naish	NZ	Chief-officer PAIS, IPCC	paleoclimatology
Laura DeSantis	Italy	Chief-officer PAIS	paleocenaography
Catherine Ritz	France	ISMASS, ISMIP co-chief	glaciology
Florence Colleoni	Italy	PAIS, AntClim21, ECR	climate ice sheet modelling
Frank Nitsche	Germany	PAIS	marine geophysics
Rob Dunbar	USA	PAIS, Philanthropy	paleoclimatology
Richard Levy	NZ	PAIS	paleoclimatology
Jae Il Lee	Korea	PAIS	paleoclimatology
Heidi Roop	USA	ECR eductaion	climate policy
Sun Bo	China	PAIS, SERCE	geology glaciology
Terry Wilson	USA	SERCE, SCAR Vice President	geology/tectonics
Kathy Licht	USA	PAIS	paleoclimatology
Marcelo Leppe	Chile	PAIS, ANTECO	paleobiology
Matt King	Australia	Chief-officer SERCE	geodesy
Katherine Hendry	UK	SOOS, ECR	oceanography
Stewart Jamieson	UK	PAIS	geology
Karsten Gohl	Germany	PAIS, ECR	geology
Mathieu Casado	Italy	PAIS, APECS	ice cores
Barbara Stenni,	Italy	PAIS	ice cores
Denise Kulhanek	USA	PAIS, IODP	paleontology

XXXV SCAR Delegates Meeting

Davos, Switzerland, 25-26 June 2018

Name	Nationality	SCAR role or affiliation	Expertise
Sharon Robinson	Australia	ANTECO	terrestrial paleoecology
Nerida Wilson	Australia	ANTECO	genetics
Ian Hogg	Canada	ANTERA	terrestrial paleoecology
Rob DeConto	USA	PAIS, IPCC	ice sheet modeling
Natalya Gomez	Canada	PAIS SERCE	geodynamics
Jacqueline Austermann	USA	PALSEA3, SERCE, PAIS, ECR	geodynamics
Andrea Dutton	USA	PAIS, PALSEA3	paleo sea-level
Louise Sime	UK	PAIS	ice cores
Steven Rintoul	AUS	Antclim21, IPCC	oceanography
Michiel van den Broeke	Netherlands		surface mass balance
Jan Lenaerts	USA		surface mass balance
Minoru Ikehara	Japan	PAIS	paleoceanography
Anna Wahlin	Sweden	SOOS	oceanography
Martin Siegert	UK	PAIS subglacial lakes	glaciology
Huw Horgan	NZ	PAIS	glacial geophysics
Samantha Hansen	USA		geodyamics
Doug Wiens	USA		geodyamics
Jacqui Halpin	USA		geodyamics
Kirsty Tinto	USA	SERCE ROSETTA	airborne geophysics
Fausto Ferraccioli	UK	ADMAP	airborne geophysics
Jacqueline Stefels	Netherlands	BEPSII	biogeochemistry
Rob Bingham	UK	AntArchtecture	radar
Iliana Wainer	Brazil	ANTCLIM21	oceanography
Tina van de Flierdt	UK	PAIS	geochemistry
Nick Golledge	NZ	PAIS, IPCC	ice sheet modelling
Carlota Escutia	Spain	PAIS	paleoclimatology
Daniela Liggett	NZ	HASSEG	social science
Nerilie Abram	Australia	Antclim21, IPCC	climate dynamics/paleoclimatology
Ian Goodwin	Australia	PAIS, Antclim21	paleoclimatology
Steven Chown	Australia	SCAR President	ecology