Template for new SCAR Scientific Research Programmes

1. Name of the Proposed SRP: **SERCE: Solid Earth Response and influence on Cryosphere Evolution**
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3. Sponsoring SSG(s): Geosciences
4. Estimated SCAR funding required over the total programme lifetime (in US$): $120,000 over programme lifetime of 6 years
5. Abstract (250 words or less) The *Solid Earth Response and influence on Cryospheric Evolution* (SERCE) scientific research programme aims to ***<u>advance understanding of the interactions between the solid earth and the cryosphere to better constrain ice mass balance, ice dynamics and sea level change in a warming world.</u>*** This objective will be accomplished through integrated analysis and incorporation of geological, geodetic and geophysical measurements into models of glacial isostatic adjustment (GIA) and ice sheet dynamics. The programme is designed to synthesize and integrate the extensive new geological and geophysical data sets obtained during and subsequent to the International Polar Year with modeling studies, in a timeframe to contribute to IPCC AR6. SERCE will provide the international collaborative framework and scientific leadership to investigate systems-scale solid earth – ice sheet interactions across Antarctica and relate these results to global earth system and geodynamic processes. A series of expert workshops will produce synthetic science products based on extensive new geophysical data sets for Antarctica as well as improved data-modeling integration. Thematic science symposia and workshops, and ensuing published thematic journal issues, will propel the science of solid earth – cryosphere interactions beyond the current state of knowledge and contribute a body of new knowledge to the IPCC AR6 assessment. The SERCE programme will conduct major efforts in capacity building, training and public outreach using complementary strategies to achieve technical capacity via information exchange, analytical capacity via training schools, engagement of new polar researchers via thematic science sessions, and public outreach via the world wide web.

Introduction - scientific objectives and statement of task

The objectives of the program

The overarching objective of the *Solid Earth Response and influence on Cryospheric Evolution* (SERCE) scientific research programme is to:

Advance understanding of the interactions between the solid earth and the cryosphere to better constrain ice mass balance, ice dynamics and sea level change in a warming world.

This objective will be accomplished through integrated analysis and incorporation of geological, geodetic and geophysical measurements into models of glacial isostatic adjustment (GIA) and ice sheet dynamics. The programme is designed to synthesize and integrate the extensive new geological and geophysical data sets obtained during and subsequent to the International Polar Year with modeling studies, in a timeframe to contribute to IPCC AR6.

The proposed SERCE SRP will:

1. Coordinate key disciplinary studies aimed at advancing understanding of the interactions between the solid earth and the cryosphere and implement expert workshops to bring researchers in these studies together to facilitate interdisciplinary outcomes.
2. Communicate and coordinate with other international groups investigating solid earth – ice sheet interactions.
3. Work with SCAR action/expert groups and research programmes to promote interdisciplinary science on ice sheet mass balance and sea level change, and new, interdisciplinary applications of geophysical data.
4. Use the SCAR-IASC international framework to improve access to polar geodetic and geophysical data, and to provide an international framework for maintaining, and potentially augmenting, the remote autonomous observational infrastructure established by the POLENET consortium.
5. Increase capacity through provision of technological ‘best practices’, open data access, and research training relevant to SERCE science.

Scientific objectives of the SERCE SRP include:

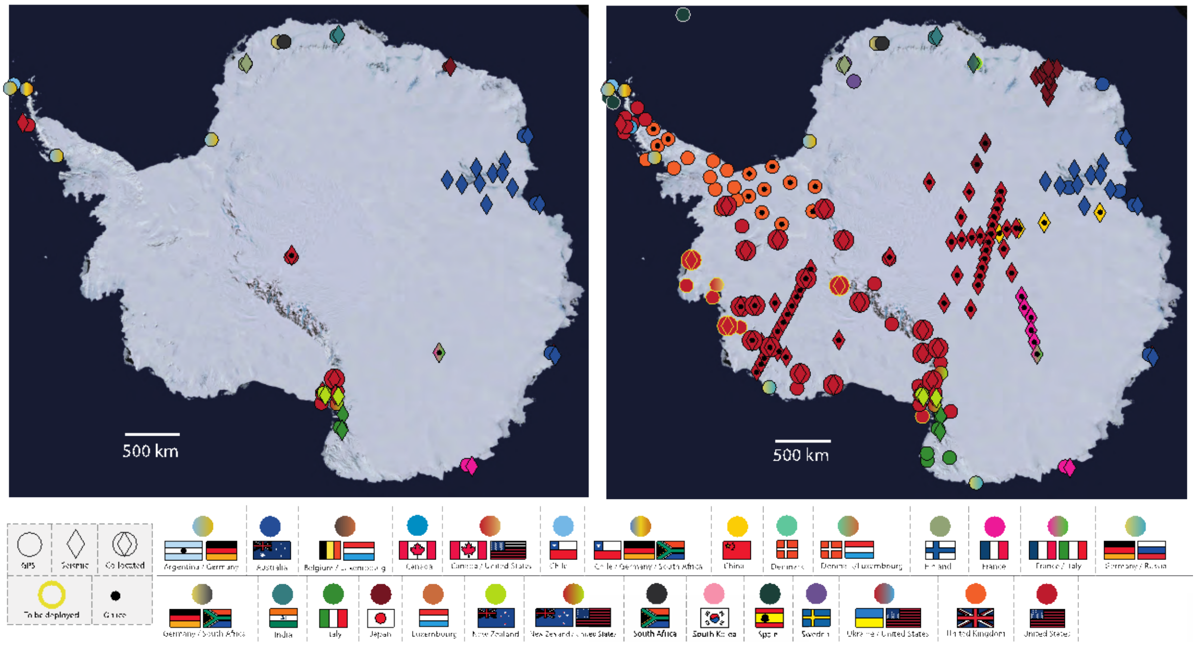
1. Integrate and synthesize geodetic observations obtained from the multinational POLENET geophysical network during IPY to obtain a crustal velocity field (vertical and horizontal) across the Antarctic continent.
2. Integrate and synthesize seismological data obtained from the POLENET geophysical network together with airborne and *in situ* geophysical data to map Antarctic lithospheric and upper mantle structure and rheological properties and to model heat flux from the solid earth to the base of the ice sheets.
3. Combine GPS vertical velocity fields with information on ice sheet histories from geological and glaciological information, to improve understanding of Antarctic ice sheet evolution from the Last Glacial Maximum (LGM) to the present – an outcome to be obtained through collaboration with the SCAR/IASC Ice Sheet Mass Balance (ISMASS) expert group.
4. Foster GIA modeling capabilities to incorporate lateral heterogeneity in earth rheology.
5. Develop improved models of glacial isostatic adjustment constrained by vertical crustal motion observations (objective 1), improved earth structure (objective 2), improved ice sheet history (objective 3), and next-generation models (objective 4).
6. Improve the estimates of present-day ice mass balance obtained from satellite observations. Provision of improved constraints on the rates of gravitational change and crustal uplift due to GIA will remove one of the largest uncertainties in analysis of satellite data for present-day change.
7. Document ice sheet boundary conditions and subglacial processes from geophysical

and glacial surface motion observations.
8. Determine seismicity levels in Antarctica and link to cryospheric and tectonic processes.
9. Better understand neotectonic processes through analysis of improved earthquake catalogues and horizontal crustal motion observations.
10. Improve the understanding of ionospheric and tropospheric processes through analysis of new POLENET space-geodetic observations – an objective driven through collaboration with the SCAR *GNSS Research and Application for Polar Environment* expert group.

Background - foundational knowledge

The polar regions have unique geodynamic environments where the solid earth, the cryosphere, the oceans, the atmosphere and the global climate system are intimately linked. Understanding polar environmental change is of global interest, particularly with regard to predicting the contributions of polar ice sheets to global sea level rise.

A scientific expert group of SCAR focused on Antarctic NeoTECtonics (ANTEC) was convened to promote and coordinate multidisciplinary, multinational research aimed at improving understanding of the unique neotectonic regime of the Antarctic plate. In particular, ANTEC's charter included encouraging and coordinating deployment of remote geodetic and seismic stations across the continent, encouraging installation of permanent instruments and regional networks of instruments (GPS, tide gauge, gravity, seismic), and coordinating sharing of instrumentation, logistics, and data. The efforts of the ANTEC group culminated in the POLENET geophysical deployments across the Antarctic continent, before and during the International Polar Year, and a spectacular new wealth of geodetic and geophysical data. These new data allow studies on key Antarctic science questions of synoptic scale for the first time.



Pre-IPY (left) and Syn/Post-IPY (right) deployment of geophysical sensors across the Antarctic continent. From Wilson et al. (2011)

Glacio-isostatic adjustment (GIA) is the response of the Earth to past and present-day changes in ice sheets and glaciers. In Antarctica GIA is an important, and in most regions, the predominant, process causing neotectonic crustal motions. GIA models combine an ice sheet history with an assumed Earth rheology to predict past and present crustal motion, sea-level change, and changes to the Earth's gravitational field. Current GIA models give different spatial patterns of uplift and also differ by about a factor of two in the peak predicted uplift rate, owing to the very different ice sheet histories that are assumed (e.g. Peltier, 2004; Ivins and James, 2005). Earth rheology is poorly known in the region, which also contributes directly to the variability in GIA model predictions.

The history of the Antarctic ice sheet during and since the Last Glacial Maximum (LGM) is an essential component of GIA models. Data constraining the magnitude and timing of ice mass change since the LGM are accumulating from glacial geological and related studies at individual locations, and synthesis efforts to compile these data into continent-wide ice models are reaching fruition (Whitehouse et al., 2012). In addition, there is ongoing active research into the role of plate configuration, vertical tectonics, and paleotopography in the inception of the Antarctic ice sheets.

Geophysical studies of the structure of the crust and mantle beneath Antarctica are essential for deciphering the geological evolution of the continent, but also have important bearing on the interactions between the solid earth and the cryosphere that rests upon it. To obtain more accurate earth models for GIA predictions, we need to know how the physical properties and thermal structure vary laterally and with depth in the East and West Antarctic crust and mantle. Permanent seismic stations at year-round research stations have allowed resolution of the structure beneath the continent at a horizontal scale of ~1000 km – sufficient to detect fundamental differences in the lithosphere beneath East and West Antarctica, but not to clearly define the structure within each sector. New seismological data from remote instruments deployed in sectors of both East and West Antarctica are revealing structure on scales of 100-200 km (Hansen et al., 2009, 2012; Heeszel et al., 2011; Lloyd et al., 2011). Seismological mapping of earth properties provides a proxy for mantle temperature, which can be used to predict heat flux to the base of the ice sheets, a fundamental control on ice sheet dynamics. Seismic imaging of the crust and mantle will assess causes for anomalously high elevations in East Antarctica, linked with ice sheet development, will provide information on heat flow and mantle viscosity that are key factors controlling ice sheet dynamics and the Earth's response to ice mass change (Aster et al., 2011; Wiens et al., 2012). A wealth of new data on subglacial earth structure and properties has been acquired from airborne geophysical missions in both East Antarctica and West Antarctica (e.g. Ferraccioli et al., 2011; Jordan et al., 2010; Young et al., 2011) which, together with the seismological data, provides key data over large spatial extents of the continent on subglacial properties for the first time.

In addition, our knowledge of the seismicity of the Antarctic continent has been limited by the sparse distribution of seismic stations. New data are beginning to reveal patterns of seismicity that appear to record glacial slip processes beneath outlet glaciers and subglacial magmatic activity (Lough et al., 2011). The new instrumentation to monitor seismicity will address the geodynamic paradox between active neotectonic processes vs. the low level of seismicity in Antarctica, and will contribute to understanding 'glacial earthquake' processes, which may be related to iceberg calving and changing basal conditions of the ice sheets due to a warming environment (Nettles and Eckstrom, 2010; Wiens et al., 2008; Danesi et al., 2007).

Geodetic studies, including GPS measurements of crustal motion, tide-gauge measurements of relative sea-level change, and gravity measurements of mass change, constitute essential elements in developing an understanding of the stability and mass balance of the cryosphere and of ongoing sea-level change. There is a critical need to understand the contribution to sea-level change due to changes in mass balance of the major ice sheets of the world, most importantly the Antarctic and Greenland ice sheets. Accurate measurement of millimeter-scale vertical and horizontal crustal motions is possible in only a few years if continuous GPS trackers are deployed (e.g. King et al., 2010), as achieved by POLENET, and time series from sites positioned around locations of historical and modern ice mass changes are beginning to provide more robust constraints on ice and GIA models (Bevis et al., 2009; Thomas et al., 2011; Wilson et al., 2011).

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

Owing to its remoteness and hostile environment, knowledge of Antarctic crustal motions, seismicity, and ice sheet evolution has remained poorly constrained relative to the northern hemisphere. New constraints on all aspects of Antarctic ice sheet history and dynamics, and on crustal motions and deep earth structure, are rapidly accumulating, however, and over the next 5-6 years many new data sets will be published which will serve to advance our understanding of ice dynamics and GIA. These include those from glacial geology (e.g., new and planned cosmogenic dating studies), marine geophysical surveys of ice sheet extent and retreat timing, direct measurement of GIA using GPS, and increased spatial resolution of geological and geophysical character of the solid earth beneath the ice sheets from *in situ* and airborne measurements. Complementary data are being acquired in the Arctic, particularly in Greenland. It is essential that an internationally coordinated approach to data analysis and synthesis be established in order to optimize the science outcomes of these new data sets. The SERCE scientific research programme will provide the international framework and scientific leadership to investigate systems-scale solid earth – ice sheet interactions across Antarctica and relate these results to global earth system and geodynamic processes.

As the results of satellite missions aimed at detecting and monitoring changes in ice mass in the earth's polar regions are emerging, it has become increasingly clear how important it is to advance our knowledge of systems-scale GIA patterns (e.g. Alley et al., 2007). Because the spaceborne platforms measure an integrated signal that includes a GIA component, accurately removing this component is essential to deriving ice mass balance. Many recent authors have shown that the so-called "PGR [post-glacial rebound] correction" applied to remove the GIA component is the largest source of error in ice mass balance estimates derived from the time-varying gravity measurements from the GRACE mission (e.g., Chen et al., 2009). Ongoing studies of rapid change of outlet glaciers have shown that ice dynamical responses resulting in increased evacuation of ice, at least in part related to changes in basal conditions of the glaciers and ice sheets, are important controls on ice mass change (e.g. Pritchard et al., 2009; Rignot et al., 2011; Zwally et al., 2011). It is clear that *in situ* constraints and ongoing synthesis and modeling efforts evaluating GIA and other processes and feedbacks between the cryosphere and the solid earth system are now more urgent than ever.

SCAR has the opportunity to take a leading role in advancing this aspect of understanding Antarctic environmental change. Strengthened scientific ties between a variety of SCAR groups will accelerate this. The SERCE programme will aim to promote integrative efforts such as:

- Improving ice sheet models, working with the SCAR/IASC Ice Sheet Mass Balance (ISMASS) expert group, and the proposed Past Antarctic Ice Sheet dynamics (PAIS) and Antarctic Climate 2100 (AntClim21) scientific research programmes, by combining GPS-derived uplift rates, knowledge of ice sheet substrate and basal heat flux derived from seismological observations, and ice sheet histories synthesized from glacial geology, marine geophysics and glaciological modeling.
- The GPS, seismic and meteorological data being collected by POLENET will be used by a global community that extends beyond the traditional polar community. The SERCE group will help to ensure that the POLENET data from the polar regions are incorporated in global studies of environmental change, including studies of tropospheric water vapour and space weather, by working with climate/weather and space weather experts of the SCAR physical sciences group, and in particular with the GPS for Weather and Space Weather Forecast (GWSWF) cross-disciplinary Action Group. This group is proposing to change to an expert group on GNSS Research and Application for Polar Environment (GRAPE). The SERCE and GRAPE groups will work collaboratively to apply GNSS data to better understand the cause-effect mechanisms driving the formation and evolution of ionospheric irregularities, to improve mapping of the distribution and evolution of

precipitable water vapour in polar regions, and to encourage both use of current GNSS data for multidisciplinary studies and to encourage establishment of a co-located network of high-rate GNSS receivers specifically for research on climate and space weather phenomena.

In addition, it is important to note that SCAR-SERCE is particularly timely in that other, international efforts with similar science objectives are drawing to a close, leaving SCAR with the opportunity to step into scientific leadership on solid earth – cryosphere science. In particular, the European Union's COST Action ES0701 Improved Constraints on Models of Glacial Isostatic Adjustment (http://www.cost.eu/domains_actions/essem/Actions/ES0701), concluded in March, 2012. The International Lithosphere Program's DynaQlim project (Upper Mantle Dynamics and Quaternary Climate in Cratonic Areas; http://dynaclim.fgi.fi/), which has a strong GIA focus, will terminate at the end of 2012. SERCE will serve to continue the momentum and advances achieved by these programs. To ensure that SERCE builds directly on the achievements of these programs, the leaders of these projects, Dr. Matt King and Dr. Markku Poutanen, will join the steering committee of SCAR-SERCE.

Experimental section and methodologies

The scientific work underpinning the SERCE research programme will primarily be carried out by individuals and teams of investigators funded by their national science foundations. Ongoing primary data collection, to include continuous GNSS measurements of crustal motions, seismological records from permanent and temporary sensor deployments, and *in situ* gravity measurements, will continue under the POLENET international collaborative umbrella. The role of SERCE is to facilitate data exchange, continental-scale data compilations and data products, collaborative data analysis programs, and pushing the science of solid earth – cryosphere interactions beyond the current state of knowledge. These SERCE outcomes will be achieved by the following means:

1. Expert Workshops

These workshops are designed to advance specific topical issues in the SERCE science agenda. Relatively small groups of experts (15-20) from the relevant disciplines and representing the global pool of engaged researchers will be assembled for 3-4-day working sessions. Early career researchers will be included in this total and a number of graduate students will be selected to attend via an application process. The expert workshops will constitute the principal use of SCAR-SRP funds for the SERCE project. The tentative plan/schedule for expert workshops developed by the SERCE programme planning group is:

2012: *3D Earth Structure assimilation in Geodynamic Modeling*

Convenors: Audrey Huerta, Pippa Whitehouse, Terry Wilson

The goal of this workshop is to bring together those on the data acquisition side who are (and will be) creating data products from seismological, GNSS and gravity data, with GIA modelers, in order to create a common framework for analysis techniques and data products. The outcome will be the identification of types and formats of data products that can be easily assimilated into models.

2013: *Error Assessment and Reference Frame for GNSS crustal velocity fields and GIA Models*

Convenors (tentative): Matt King, Michael Bevis, Reinhard Dietrich

Comparisons between predicted crustal velocities from GIA models and measured velocities from GNSS must be made in a common reference frame. Error assessment is vital to improving understanding of the range of modern ice mass balance estimates that rely of a so-called "Post-Glacial Rebound correction", including GRACE time-varying gravity and altimetry-based methods. The goal of this workshop is to bring together active researchers processing and modeling GNSS time series, developing reference frames for crustal velocity fields, and assessing the reference frame for GIA models. The outcome will establish uncertainties in results, frames, and intercomparisons that are required to incorporate results into IPCC assessments of changes in ice mass balance.

2014: *Constraints on Holocene ice mass change – tuning from GNSS crustal velocities and glacial geology and glaciological data*

Convenors (tentative): Michael Bentley, Erik Ivins, Pippa Whitehouse

Late Holocene changes in ice mass are poorly constrained by data (Bentley, 2010; Whitehouse et al., 2012), yet may have a significant effect on crustal motions, particularly in regions of weak earth rheology. This workshop will focus on compiling all data constraints on Holocene ice history for Antarctica, and comparing predicted uplift values from modeling with measured crustal velocities, to iterate on the best-constrained ice history model.

2015: *Integrating crustal heat flux constraints with ice sheet modeling and GIA modeling*

Convenors (tentative): Chris Carson, Alan Vaughan, Andy Nyblade, Phillipe Huybrechts, Wouter van der Wal

Heat flux to the base of ice sheets exerts a fundamental control on ice sheet dynamics. Heat flux models for Antarctica derived from seismological data (Shapiro and Ritzwoller, 2004) and from magnetic data (Llubes et al., 2006) yield very different results when input to numerical ice sheet models used in developing ice sheet history models (Whitehouse et al., 2012). The goal of this workshop is to compile and compare different geophysical constraints on heat flux and examine how these are implemented in different types of numberical ice sheet and GIA models, to identify optimal constraints.

2016: *Improving the skill of GIA models – benchmarking of techniques for modelling laterally varying earth properties*

Convenors (tentative): Pippa Whitehouse, Wouter van der Wal, Volker Klemann

Emerging results from POLENET observations in Antarctica in 2012 show that lateral variation in earth properties exert a fundamental control on the response of the earth to the thinning of ice sheets since the LGM. Currently, relative few attempts at producing GIA models with laterally-varying earth properties have been completed (e.g., Latychev et al., 2005; Kauffmann et al., 2005; Whitehouse et al., 2006; Wang et al., 2008; Klemann et al., 2008). In the 2012-2015 time frame, the modelling community will further develop these methodologies, using POLENET and other results as input. The goal of this workshop is to bring together experts on using geophysical measurements to derive earth rheology with GIA modelers developing these new modelling approaches in order to make a community assessment of the 'skill' of the models, how to assess uncertainties of both the input data and the models, and steps that are required to further improve modelling techniques.

2. Thematic Sessions at International Meetings & Thematic Journal Issues

Bringing together the range of disciplinary scientists required to fully address questions about solid earth – cryosphere interactions is a challenge that will be met through widely-advertised thematic sessions at international earth science and cross-disciplinary meetings. The SERCE group will engage with top science journal publishers to produce a series of thematic journal issues reporting the research presented at these symposia and workshops. This published record on SERCE science topics will constitute a critical body of work intended to contribute to the IPCC AR6 assessment in the 2016-2018 time period. A scheduled/tentative list of thematic sessions and venues developed by the SERCE programme planning committee is:

2012:

- SCAR Open Science Conference
  - SERCE Thematic Session: *SERCE: Solid Earth Response and Cryosphere Evolution*
    - Convenors: *Pippa Whitehouse, Douglas Wiens, Terry Wilson*

- AGU Thematic Session: *Interactions Between the Solid Earth and Cryosphere*
    - Proposed by T. Wilson, R. Aster & D. Wiens

<u>2013:</u>

- Thematic Workshop: *Understanding and modeling elastic/viscoelastic crustal deformation due to ice mass change*
    - Greenland: May 31 - June 02, 2013 (Sunday)
    - Co-Sponsored with International Association of Geodesy/SubComission 3.4: Cryospheric Deformation – Matt King & Abbas Khan, Convenors

<u>2014:</u>

- EGU Thematic Session: *Cryoseismology and Solid Earth – Ice Sheet Interactions*
    - Convenors (tentative): *Sridhar Anandikrishan, Stefania Danesi, Paul Winberry*
- SCAR Open Science Conference Thematic Session: *GPS velocity field & ice history models*
    - Convenors (tentative): *Michael Bentley, Ian Thomas, Pippa Whitehouse, Terry Wilson*

<u>2015:</u>

- SCAR International Symposium on Antarctic Earth Sciences Thematic Session: *Crustal Motions and Earth Rheology from GPS and Seismology*
    - Convenors (tentative): *Richard Aster, Erik Ivins, Douglas Wiens, Michael Willis*

<u>2016:</u>

- Thematic Session (AGU or EGU): *GPS and in situ Gravity Constraints on Ice Histories and GIA Models*
    - Convenors (tentative): *Matt King, Yves Rogister, Mirko Scheinert*

<u>2017:</u>

- Thematic session (AGU or EGU): *Improved 'PGR correction' for satellite measurement-derived ice mass balance*

3. Capacity Building, Training and Outreach Activities

Activities designed to 1) provide all SCAR nations with the technological capacity to contribute to primary data collection, and thereby augment large-scale, international, collaborative field data acquisition programs; 2) training students, early-career researchers, and interested scientists from all SCAR nations in the data analysis and modelling techniquest to investigate solid earth-cryosphere interactions; and 3) informing the public about science activities and outcomes, are all core pursuits of the SERCE program and are detailed in a following section.

Management and reporting (including a Scientific Steering Committee)

An international steering committee will be established for SERCE. A wide range of disciplinary experts will guide the science programme, and representatives from the many nations contributing to IPY and subsequent geophysical data acquisition will be assembled in the proposed *export workshops*, *thematic sessions*, and *training schools*. The SC will interact with SCAR, IASC, and the broader science community, to promote participation of the widest possible array of nations and researchers in SERCE activities. The convenors of the expert workshops will play the role of 'working group leaders', in identifying key workshop participants, ensuring participation of early career researchers and students, developing workshop agendas, and planning and implementing production and publication of workshop results.

The SC will meet in person at least biennally to review, assess and exchange results, and to promote integrated interpretation and modelling efforts; annual *ad hoc* meetings and/or communications via email and Skype will allow ongoing communication of the programme leadership.

The SERCE leadership will report annually to the SCAR executive on programme progress an biennially to the SCAR Geoscience Standing Scientific Group and the SCAR Delegates on programme achievements and future plans.

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

The SERCE programme planning group has developed a yearly plan of *expert workshops*, *thematic science sessions/workshops*, and *training schools*, detailed in this proposal. One primary set of milestones and metric of performance will be the implementation of this series of activities.

The *expert workshop* activities are designed to produce outcomes in the form of a series of synthetic science products for the continent and/or subregions of Antarctica, specifically:

- *GPS crustal motion velocities in a common reference frame*
- *Seismic maps of crust and mantle structure*
- *Grids parameterizing earth properties, derived from geophysical and geodetic measurements*
- *Maps and catalogue of earthquake distribution*
- *Improved ice history models for input to GIA models, derived from 'tuning' of ice models using crustal motion data*

The *expert workshops* will also yield:

- *Improved modeling capabilities for GIA, specifically for laterally-varying earth models*
- *Improved GIA models, incorporating GPS crustal motion and earth property data*

Publications stemming from these workshop results will be a second key performance metric. A third metric is provision of the synthesis products for the use of the global science community via the world wide web.

The time frame of the SERCE program is aimed at providing critical new research results, with uncertainties, in a published format that can then be assimilated into the IPCC AR6 assessment in the 2016-18 time period. The implementation milestones for this are built in to the schedule of *expert workshops* and *thematic sessions/workshops*. The achievement of publications meeting deadlines for the AR6 assessment is an additional programme metric.

A very important metric will be successful implementation of training schools by the SERCE science experts, including obtaining funding partners for the schools. The numbers of 'trainees' that participate is an additional key metric for the programme.

Data management plan

Primary data sets from the POLENET IPY programme currently have mixed status in terms of availability. GPS and seismic data collected by the USA ANET/POLENET array are openly available for download from the UNAVCO and IRIS data archives, respectively. Other contributors to the POLENET programme have established a verbal agreement for open data *within*/*between* data contributors of the POLENET consortium. The Technische Universität Dresden maintains a 'by permission' dissemination site for Antarctic epoch GPS data, with voluntary contributions from SCAR nations (http://tpg.geo.tu-dresden.de/ipg/forschung/scargps/scardata.htm), as part of the SCAR-GIANT expert group workplan. To progress toward open data availability to all SCAR nations and the global science community, the SERCE group will pursue the 'Virtual Observatory' concept to be implemented on a new web site. Initially this 'Virtual Observatory' will focus on an interactive map showing geophysical instrument deployments/measurements at remote sites and permanent bases, and provide information including location coordinates, sensor types, and contact person for the data. Where data is publicly available for download, the URL for the download site will be provided. The SERCE group will include a Steering Committee member who will guide an ongoing effort to make more primary data available for download via the web.

SERCE plans to produce a range of data products designed to promote accessibility of data between disciplines. These products are outlined in previous sections. All data products will be made accessible for download on the new SERCE web site.

Capacity building, education and training plan

The SERCE planning group has developed a multifaceted plan for capacity building, training and public outreach using complementary strategies.

Technical Capacity

SERCE will continue to disseminate 'best practices' for deployment of autonomous remote observatories developed by POLENET by:

1. Hosting 'pointers' to web resources reporting testing, design, and related information on facility web sites including the UNAVCO GPS facility and the IRIS-PASSCAL seismology facility.
2. Joining with our facility partners to promote 'polar technologies' theme sessions at international meetings, and presentations on remote observatory technologies at the annual Polar Technology Conference (http://polartechnologyconference.org/) and other venues.
3. Collaborating with other disciplines, and interdisciplinary partner groups (e.g GSWWF/GRAPE) to propagate remote system technologies to other disciplines and to facilitate co-located network deployments, using joint national logistics where appropriate.
4. Training workshops (see below)

Analytical Capacity & Training

1. SERCE will carry on the successful 'training school' program conducted by the European Union COST Action ES0701, and will co-sponsor and teach similar short course programs with the UNAVCO and IRIS Education/Outreach initiatives. We have coordinated the first proposed 'training school' with the DynaQlim program (which can provide some funding), and plan to seek additional funding for these schools from the U.S. National Science Foundation and the EGU training school funding programme. The draft schedule for these courses is:
    a. 2013: *Glacial Isostatic Adjustment Training School* (jointly sponsored with DynaQlim)
    b. 2014: *Remote Observatory instrumentation and emerging technologies* (with facility partners UNAVCO, IRIS and others)
    c. 2015: *Seismology & geodesy for cryosphere research* (jointly sponsored by UNAVCO, IRIS, SCAR, IASC?)
    d. 2016: *Glacial Isostatic Adjustment Training School*

Promotion of Solid Earth – Cryosphere Science

An important component of increasing capacity and inspiring young researchers to pursue SERCE-related science problems will come through thematic science sessions and linked workshops planned for international science meetings. A tentative schedule of topics and venues has been developed by the SERCE programme planning group, and provided above.

Public Education and Outreach

The primary means of communicating SERCE science to the public will be via a web site to be created for the programme. In addition to news and information on programme participants, activities, and achievements, SERCE will seek to record selected components of the training schools and provide them online to an additional student audience.

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Supporting information

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

Chief Officer:

Dr. Terry Wilson – Ohio State University, USA - http://www.geology.ohio-state.edu/TerryWilson/profile_contact.htm & www.polenet.org

Terry Wilson is currently a professor in the School of Earth Sciences and Byrd Polar Research Center, Ohio State University, USA. Wilson and her research group investigate the structural architecture of the Earth, how continents rift, and the interaction of the solid Earth and ice sheets in Antarctica, using structural field observations, geophysical data and GPS. She is currently the U.S. and international leader of the *Polar Earth Observing Network* research consortium that was launched during the International Polar Year.

Lead Investigators:

Dr. Erik Ivins – Jet Propulsion Lab, USA - http://science.jpl.nasa.gov/people/Ivins/

Erik Ivin's research interests include the use of time-variable space gravity, GPS and altimetry for monitoring cryospheric change, postglacial rebound and sea level change. He is a member of the GRACE Science Team, the Global Geodetic Observing System (GGOS) Working Group on "Contributions to Earth System Modeling", and is serving as NASA Lead Scientist for "Ice Sheet Mass Balance Intercomparison Exercise" (Joint with the European Space Agency).

Dr. Masaki Kanao – National Institute of Polar Research, Japan. http://polaris.nipr.ac.jp/~kanao/

Dr. Kanao investigates evolution of the earth in the polar regions, including relations between the solid earth and climate change, mainly through seismological studies. He also works in the NIPR's Polar Data Center, and is a member of SCADM under SCAR.

Dr. Matt King - Newcastle University; From August, 2012: Professor of Polar Geodesy, University of Tasmania, Australia. http://www.staff.ncl.ac.uk/m.a.king/

Matt King's principal research interests include improving understanding of Antarctic ice mass balance using data from the Gravity Recovery and Climate Experiment (GRACE); Using GPS measurements of 3d crustal movements to understand changes in the Antarctic ice sheet since Last Glacial Maximum and the structure of Earth (lithosphere & mantle); absolute sea level change over past few centuries using tide gauge data and GPS measurements of their vertical movement; and Ice sheet dynamics (ice streams and ice shelves), such as vertical tidal motion, tidal modulation of flow, and long-term changes in elevation and velocity.

Dr. Markku Poutanen, Finnish Geodetic Institute.

Markku Poutanen's research focuses on geodesy and geodynamics, including applications of GNSS and gravity measurements to glacial isostatic adjustment and geodynamic problems. Markku leads the International Lithosphere Program's DynaQlim (Upper Mantle Dynamics and Quaternary Climate in Cratonic Areas) project, is a member of the Steering Committee of the Global Geodetic Observing System of the International Association of Geodesy, and president of the Geodesy Division of the European Geosciences Union.

Dr. Yves Rogister – Ecole et Observatoire des Science de la Terre, University de Strasbourg, France. http://eost.unistra.fr/recherche/ipgs/dgda/dgda-personyves-rogister.

Yves Rogister's research interests include polar geodesy, Antarctic gravimetry and post-glacial rebound, Earth global dynamics, tidal deformation and dynamics of the liquid core. He is leading a long-term effort to complete repeat absolute gravity measurements around the Antarctic continent.

Dr. Alan Vaughan – British Antarctic Survey, U.K. http://www.antarctica.ac.uk/about_bas/contact/staff/profile/7192440a1114ffe0e3dabd280717 fdb2/personal/

Alan Vaughan has been an active scientist for twenty one years applying geology to solve tectonic and, more recently, palaeoenvironmental problems from a whole Earth perspective. This has involved six Antarctic field seasons. Alan has been a convenor of sessions on crustal heat flow in polar regions at EGU meetings, and has been the initiator of an effort to compile crustal heat flow information for Antarctica.

Dr. Pippa Whitehouse – Durham University, U.K.
http://www.dur.ac.uk/geography/staff/geogstaffhidden/?id=1553

Pippa Whitehouse studies glacial isostatic adjustment (GIA), and how this process can be used to understand changes in sea-level, solid earth deformation, and the volume of the global ice sheets during the last glacial cycle, and in the present day. Current research focuses on reconstructing the Antarctic ice sheet since the Last Glacial Maximum, and GIA modeling, including research into the effect of lateral heterogeneities in Earth structure upon GIA, and the implications of including this complexity upon inferences of ice sheet history and mantle viscosity.

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

Continental-scale data acquisition projects require international collaboration. SCAR initiatives laid the groundwork for the geophysical programs conducted during the International Poar Year that have vastly improved data coverage over the polar regions. These new data sets demand collaborative, international analysis efforts of equal scope. Successfully exchanging, compiling and jointly analysing data collected by multiple nations to achieve science products at continental spatial scales requires the international collaboration and coordination that is the hallmark of SCAR activities. The SERCE programme plan has been developed over several years drawing on the multinational science discussions that SCAR has facilitated. The breadth and focus of SERCE science activities will be continually improved by the multinational and multidisciplinary perspectives provided by the SCAR scientific groups and through coordination with the coeval SCAR research programmes.

III. International involvement and partnerships

Solid earth – cryosphere interactions are a strong current science focus, particularly with regard to controls on the dynamical behaviour of ice sheets during environmental change, contribution of Antarctic ice sheets to sea level rise in the last ~12,000 years, and modern ice mass balance. Two key international research programmes of the ILP and European Union (previously discussed) are transferring activities, in part, to the SERCE group. A current ESA-NASA funded activity, the *Ice Sheet Mass Balance Intercomparison Exercise* (aimed to contribute to IPCC AR5) has identified ongoing science issues that will be addressed by SERCE with the aim of contributing results to the IPCC AR6.

IV. Budget justification (other potential sources of funds)

The projected SERCE budget of c. 20k/year will be used to:

1. set up and maintain a programme web sit
2. sponsor *expert workshops*
3. support early career/student participation in *thematic sessions*
4. fund *training schools*

To fully fund these activities at the scale/scope envisioned, the SERCE group will seek additional support by:

1. Partnering with organizations with related objectives to sponsor workshops, thematic sessions and training schools. Identified and potential partners include:

- the DynaClim ILP project
- the IAG Sub-Commision 3.4
- IASC

2. Seeking funding for training school participant support from:
   - EGU training school programme
   - Facility partners with aligned Education/Outreach programmes, including UNAVCO and IRIS in the USA
   - Travel grants from the U.S. National Science Foundation and other national funding agencies

V. Other information (information useful to evaluators)

This proposal was assembled by Terry Wilson, based on the input of Alessandro Capra, Reinhard Dietrich, Erik Ivins, Matt King, Thomas James, Yves Rogister, Mirko Scheinert, and the large number of participants in SERCE planning meetings held at the Edinburgh ISAES meeting (June, 2011), the Buenos Aires SCAR meeting (July, 2010), and the St Petersburg SCAR meeting (July, 2008).