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SCAR Delegates Meeting 2020

Solid Earth Response and influence on Cryospheric Evolution (SERCE)

Final Report

Summary

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The overarching objective of the Solid Earth Response and influence on Cryospheric Evolution (SERCE) scientific research programme has been 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 was achieved through integrated analysis and incorporation of geological, geodetic and geophysical measurements into models of glacial isostatic adjustment (GIA) and ice sheet dynamics.

In brief,

- SERCE has helped *transform* GIA science
- SERCE has *accelerated and broadened research* on GIA modelling, ice sheet modelling, glacial seismology, and other related fields, by training new cohorts of researchers through co-sponsored Schools
- SERCE has *advanced understanding* of Antarctic geothermal heat flow and its impact on ice sheet dynamics
- SERCE has *elevated global understanding* of the role of Antarctic ice mass balance in future sea-level change

SERCE has been particularly effective at facilitating the development of new communities which have opened new areas of scientific endeavour. The two major community-building achievements are:

- Building a new generation of scientists working on understanding glacial isostatic adjustment (GIA) and notably the observation and modelling of spatial variations in solid Earth properties and their feedbacks on the ice sheet; and
- Facilitating the creation of a multidisciplinary community of scientists focused on quantifying spatially variable geothermal heat flow (GHF)

These communities have been built through support of Early Career Researchers (ECRs) to travel to SERCE-supported meetings, including workshops and two highly successful GIA training schools which attracted a total of 87 in-person attendees and >100 virtual attendees. About 75% of SERCE funds have supported ECRs.

SERCE has represented its aims through a series of statements regarding scientific priorities. SERCE issued statements directed toward national funding bodies to continue and extend networks of GPS and seismic instruments, and to support the collection of *in situ* measurements of GHF and bedrock radiogenic heat production. SERCE articulated the need for individual scientists to make seismic and geodetic data freely and openly available within data repositories. SERCE successfully recommended to SCAR that geodetic monuments be maintained, and not removed at the end of individual studies, to enable long-term mm-level monitoring of the crust.

Finally, we would like to note that SERCE has been well supported through the SCAR office and particularly the work of Eoghan and Chandrika most recently. The funding level of $20k/yr has enabled targeted and well considered support and we remain convinced that ECRs in particular have benefited as a result. This is borne out in the testimony we have received from many individual researchers who replied to our call for input to this report.

Main report

Original rationale and objectives

The Solid Earth Response and influence on Cryospheric Evolution (SERCE) scientific research program aims 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 overarching objective is being addressed through integrated analysis and incorporation of geological, geodetic and geophysical measurements into models of glacial isostatic adjustment (GIA) and ice sheet dynamics.

The program is designed to synthesize and integrate the extensive new geological and geophysical data sets obtained during and subsequent to the International Polar Year with modelling studies, in a timeframe to contribute to IPCC AR6. SERCE aims to 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.

Indicative areas of interest to SERCE include GIA modelling (including validation of models), geodetic observation of bedrock deformation, models of elastic deformation, geothermal heat flow, influence of GIA on ice sheet dynamics, seismological inferences of Earth's crust and mantle, and bedrock erosion by the ice sheet, etc. This list should not be seen as definitive and we welcome focus on other in-scope research topics.

Main scientific achievements

The achievements of SERCE over its full period can be categorised at the highest level as being:

1. SERCE has helped *transform* GIA science.
2. SERCE has *accelerated and broadened research* on GIA modelling, ice sheet modelling (notably the feedbacks with the solid Earth), glacial seismology, and other related fields, by training new cohorts of researchers through co-sponsored Schools.
3. SERCE has *advanced understanding* of Antarctic geothermal heat flow and its impact on ice sheet dynamics.
4. SERCE has *elevated global understanding* of the role of Antarctic ice mass balance in future sea-level change.
5. SERCE has provided the overarching science framework for *collection of new data* by projects which are funded by national Antarctic programmes, including internationally coordinated projects.

SERCE can reasonably lay claim to facilitating the accelerated transformation of GIA science over its lifetime. Prior to SERCE, Antarctic GIA was still being treated as a forward modelling problem with few data constraints, solid Earth properties were considered largely to only vary radially, and the response to ice mass change was assumed to take place over millennia. We now know that spatial variation in Earth rheological structure varies by 2-3 orders of magnitude and that the solid Earth could be an important brake on ice sheet retreat in West Antarctica on centennial time scales. SERCE-led community building and training resulted in the community working on these problems quadrupling in size since the commencement of SERCE.

Although at an earlier stage, SERCE can likewise lay claim to beginning to accelerate research into Antarctic geothermal heat flow through multiple approaches and inter-disciplinary discussions. This community has revealed major differences in GHF estimates, which present the basis for future fieldwork and modelling activities.

These developments were deliberate and targeted by SERCE leadership, with substantial funding directed to training and workshops in these domains.

Contributions of SERCE leaders and participants to international science initiatives have ensured that data-driven, state-of-the-art science on Antarctic GIA, solid earth – ice sheet feedbacks, ice mass balance, and sea level fingerprinting, are strongly represented in the membership of, e.g., SCAR Horizon Scan, the NASA/ESA Ice Sheet Mass Balance Intercomparison Exercise, IPCC, PALSEA, and the WCRP Grand Challenge on Regional Sea-Level Rise.

Delivery against original implementation plan

The (reviewed and updated) SERCE implementation plan is shown below with summary of delivery against it

YEAR	WORKSHOP/SYMPOSIA	THEME SESSION	TRAINING	OUTREACH
2012	Earth Structure/Modelling (SCAR OSC)	Earth–Cryo Interactions SCAR OSC AGU		Logo Web site plan
2013	"Reconciling Observations and Models of Elastic and Viscoelastic Deformation due to Ice Mass Change" *(w/* IAG, Ilulissat, Greenland)			Complete Web site
2014		Earth–Cryo Interactions SCAR OSC	GIA Training School *- postponed to 2015*	Complete Web site
2015	"Ice load changes and Earth deformation" (Fairbanks, Alaska) with IAG Sub-commission 3.4 (support from TU Denmark, EGU and UAF) Data archiving & exchange (ISAES)	Earth–Cryo Interactions EGU IUGG ISAES	GIA Training School Autonomous Systems-ISAES	Training School Videos on web Complete Web site
2016	"The Antarctic ice sheet from past 2 future" (w/ AntClim[21], ISMASS, PAIS at SCAR OSC)	Earth–Cryo Interactions EGU SCAR OSC AGU	Cryoseismology Training School *- postponed to 2017*	Complete Web site
2017	"Glacial Isostatic Adjustment and Elastic Deformation" (w/ IAG, Reykjavik, Iceland)	EGU thematic session AGU/JpGU joint session "Cryoseismology - a new proxy for detecting surface environmental variations of the Earth",	Cryoseismology Training School	

		Chiba, Japan, May 2017 IAG-IAPSEI thematic session, Kobe, Japan		
2018	Antarctic Heat Flow (Hobart, Australia)	Earth–Cryo Interactions EGU SCAR OSC AGU	Polar Geodesy Summer School (led by SCAR Expert Group GIANT)	Preliminary metadata catalogue and GPS velocity dataset uploaded to website *- replaced by GIANT REGAIN program*
2019	"Glacial Isostatic Adjustment, Ice Sheets, and Sea-level Change – Observations, Analysis, and Modelling" (w/ Polar Knowledge Canada & NRCan, Ottawa, Canada)	Earth–Cryo Interactions EGU IUGG ISAES AGU	GIA Training School	Training School Videos on web Geothermal Heat Flow White Paper
2020	SERCE wrap-up meeting, SCAR OSC Geothermal Heat Flow workshop at SCAR OSC PALSEA workshop "Improving understanding of ice sheet and solid earth processes driving paleo sea-level change" at Columbia University, USA *- postponed to 2021*	EGU thematic session – *took place online* SCAR OSC – *took place online* AGU thematic session – *took place online*		Geothermal Heat Flow White Paper
2021	PALSEA workshop "Improving understanding of ice sheet and solid earth processes driving paleo sea-level change" at Columbia University, USA			

denotes completed. denotes delayed.

Main education, outreach and capacity building achievements

SERCE has invested considerably in capacity building activities. These have focused on co-funding and organising training schools, with funds directed almost universally to support the attendance of ECRs and those from countries with developing Antarctic programs, or to support the attendance of globally leading lecturers.

Namely, the schools were:

- 2x 5-day GIA training schools in USA (2015) and Sweden (2019)
- A 6-day cryo-seismology training school in USA (2017)

Between the three schools, 130 on-site students from dozens of countries attended, as well hundreds of participants who viewed lectures virtually from around the globe.

The GIA training schools emerged from earlier training schools funded by COST Action ES0701, which brought together leading experts in seismology, GIA modelling, geodesy, and ice sheet change to train scientists in the field of GIA. The SERCE-funded and -coordinated training schools, in collaboration with the NSF-funded POLENET project, built on this successful model. 87 students attended the SERCE GIA training schools with predominantly 90% ECRs in attendance from more than 30 nationalities. These students were given hands-on experience in the use of open-source GIA model code.

Lectures from the GIA 2015 and 2019 schools were recorded and are available as an enduring legacy. In both cases, up to 60 students attended online in real time across multiple continents and the 2019 training school videos have received 1,297 views to date [September 2020]. Reports on the training schools were circulated via the SCAR Newsletter and website. All training schools included field trips to provide further understanding of relevant physical phenomena.

The cryo-seismology training school was coordinated by world-leading seismologists and focused on delivering training in new techniques used in this emerging sub-discipline. The school was attended by 44 students from 15 countries. In particular, the workshop focused on developing understanding of the ice-bed interface, basal hydrology and iceberg calving using seismic methods. Both theoretical and practical aspects were considered, with students undertaking exercises in data analysis. The school was featured in an EGU blog and a report was published in Ice, the news bulletin of the International Glaciological Society.

The feedback from all training schools has been overwhelmingly positive, with post-school surveys including the following quotes:

- “The course was great. International participants enriched the experience with local point of view and different scientific backgrounds.”
- “My favorite part of the course was being able to interact with each of the instructors outside of their lectures. I think some of the best discussions occurred while at lunch or dinner or even during the coffee breaks.”
- “Thanks for all the organization, things were really great and I learned a lot. Actually in terms of both organization and content/lecture quality this was the best summer school I've visited so far.”

The far-reaching success of these schools would not have been possible without SERCE resources and support, which leveraged funding from many international science organisations to reach a larger audience and maximize course impact for early career researchers.

Outreach activities to the broader scientific community have focused on the SERCE website. Resources include the training school recordings and SERCE publications.

Partnerships made and support received

The aims of SERCE align strongly with cryosphere-facing branches of bodies such as the International Union of Geodesy and Geophysics (IUGG), the US National Science Foundation (NSF), and the European Geosciences Union (EGU). We are fortunate to have been able to secure significant funding from these bodies, as well as a large number of local organisations, that has enabled us to deliver the range of activities detailed above.

We estimate the total contribution from partner organisations to be ~$195,000 over the lifetime of SERCE. We would specifically like to acknowledge funding from: NSF-POLENET, International Association of Cryospheric Sciences (IACS), International Associated of Geodesy (IAG), DTU Space (Denmark), DynaQlim (funded by the International Lithosphere Program), University of Alaska Fairbanks, International Glaciological Society, European Space Agency, University of Tasmania, Antarctic Gateway Partnership (Australia), ACE CRC (Australia), Polar Knowledge Canada, and the Geological Survey of Canada. The PALSEA-SERCE workshop planned for September 2021 is supported by PAGES and INQUA.

In addition to support received from partner organisations, SERCE has been able to provide support to other ventures. Specifically, we have provided letters of support to strategic research proposals that seek to address research goals identified in our horizon-scanning exercises (see next section) and we have provided input to the WCRP Grand Challenge on Regional Sea-Level Rise.

Finally, there is no way to quantify the number of new research collaborations that have been facilitated through attendance at SERCE workshops or training schools, but we are confident that our strategy of bringing diverse communities together to discuss common interests has played a significant role in forging new research partnerships, leading to the development of new research areas.

Other legacies

Beyond the legacy of scientific outputs and outcomes and communities of researchers described above, other SERCE legacies include:

- Shift to more open data sharing

Prior to the commencement of SERCE much Antarctic geophysical data pertaining to the solid Earth was slow to be released. From its commencement SERCE vocalised the need for datasets to be immediately freely available. While culture change is not yet complete, major changes in standard practice are occurring, leading to recent GPS networks funded by UK and Australian agencies with the investigator-led proposal for data provision to be immediately free and open.

- Horizon Scan of strategic research goals

During our 2017 GIA workshop we invited the research community to compile a list of ‘top 10 questions’ that are currently at the forefront of GIA research. These questions were revisited and updated during the 2019 GIA workshop and a similar activity was carried out during the 2018 workshop on geothermal heat flow (see workshop reports for details). It is hoped that the knowledge-gaps identified through these exercises will set the agenda for SERCE-related research in the coming decade.

- Ongoing training resources

The two GIA training schools funded by SERCE were recorded and these remain available as an enduring legacy of the research program. In the year following the 2019 GIA training school, the online lectures were viewed ~1,300 times.

Draft final Budget summary

	2019	2020
	Spent	Allocated
(US$)	$34,504	$24,174

- Total allocation over SERCE lifetime: **$168,000 (8yrs x $21,000)**
- Total expenditure to date: **$143,826**
- Total direct support received from other sources: approx. **$195,000**
- Total budget used to support ECRs: **$142,800** (projected total amount used to support ECRs, estimated as 85% of total allocated budget)
- Total budget used to support countries with developing programmes: **$25,200** (estimated as 15% of all allocated funds, noting there is significant overlap with ECR support in this category)

We request carry over to 2021 of $20,000. Of this $10,000 is to support the attendance of ECRs and researchers from countries with developing Antarctic programs at the postponed PALSEA meeting and $10,000 is to facilitate an interdisciplinary meeting of national researchers to review and report on the benefits of long-term geophysical observing networks in Antarctica and potential future pathways to funding them.

Final future research recommendations to Delegates

Below, we identify key areas for future research of high value. These are not exhaustive, however. We expect many or all of these will be the focus of the INSTANT SRP.

- 3D Earth rheology

During SERCE, understanding of spatial variations in the rheological structure of Antarctica has advanced considerably. Nonetheless, absolute constraints on mantle viscosity remain accurate to the level of ~1 order of magnitude at best – the difference between major and negligible mantle feedback on ice sheet retreat.

- New GIA models

GIA model corrections for GRACE and GRACE Follow-On data have received only limited updates since ~2013. Low viscosity mantle in West Antarctica means that knowledge of ice loading changes through the Late Holocene, in combination with Earth models with 3D rheological structure, are required for accurate modelling of the GIA signal. Ice history of this period is generally poorly understood.

- GHF white paper summary

Little is known about subglacial environments, despite them having a primary role in glacial dynamics over a wide range of timescales. Areas of ongoing need include mapping geothermal heat flow, groundwater, subglacial melt, erosion and deposition, and sediment flux into the ocean.

The geothermal heat flow community has been established through SERCE, forming from individual and dispersed researchers. That community recently produced a white paper highlighting differences between individual techniques and ways to progress this field. Two immediate recommendations are available from the GHF working group. They were proposed at SCAR 2018 and are relevant to SCAR and National Operators:

SERCE recommends scientists support the measurement of thermal gradients and conductivities in crystalline bedrock and sediments.

SERCE recommends scientists derive and make available radiogenic heat production rates for Antarctic archive rock samples and outcropping lithologies.

- Coordination of long-term observing networks

There is an urgent need to review the sustainability of long-term observational networks in Antarctica, networks which cannot be maintained by individual nations but require long-term funding and logistics support. Amongst those relevant to SERCE, continent-wide GPS and seismic networks have emerged in the last decade as new networks of this kind. Forthcoming satellite communications advances may substantially reduce data download logistics costs, but improvements to power generation are further required.

- New magnetotelluric observations

To date, magnetotelluric observations have been used only sparsely in Antarctica but recent research has suggested that these data may offer new constraints on mantle rheology, in particular, constraints on mantle water content.

Final procedural recommendations

We have faced very few operational challenges thanks to the relative simplicity of SCAR's internal procedures and excellent support from SCAR Secretariat. The reimbursement process is very straightforward, and we appreciate the flexibility we have had in choosing how to spend SERCE funds. SCAR guidance to focus on early career researchers and researchers from countries with emerging Antarctic programs has paid dividends - the SERCE community has grown significantly over the past 8 years and we are now in a position where former ECRs are world-leading scientists and SERCE-facing research is taking place in an ever-increasing number of countries. In the early stages there were some barriers to updating our website but support from the Communications Officers over the past couple of years has made the process much simpler. Similarly, guidance from the Executive Director and Executive Officer has been excellent in recent years.

Notable Papers

1. Whitehouse, P.L., Gomez, N., King, M.A., Wiens, D.A., 2019. Solid Earth change and the evolution of the Antarctic Ice Sheet. *Nat Commun* **10**, 1-14.

This invited review paper in Nature Communications summarises the current state-of-the-art in research associated with SERCE activities and interests and provides a review of future research priorities that will feed into future SCAR Scientific Research Program activities.

2. Nield, G.A., Barletta, V.R., Bordoni, A., King, M.A., Whitehouse, P.L., Clarke, P.J., Domack, E., Scambos, T.A., Berthier, E., 2014. Rapid bedrock uplift in the Antarctic Peninsula explained by viscoelastic response to recent ice unloading. *Earth Planet. Sci. Lett*. **397**, 32-41.

   Barletta, V.R., Bevis, M., Smith, B.E., Wilson, T., Brown, A., Bordoni, A., Willis, M., Khan, S.A., Rovira-Navarro, M., Dalziel, I., Smalley, R., Kendrick, E., Konfal, S., Caccamise, D.J., Aster, R.C., Nyblade, A., Wiens, D.A., 2018. Observed rapid bedrock uplift in Amundsen Sea Embayment promotes ice-sheet stability. *Science* **360**, 1335.

These studies document the use of GNSS observations to identify a viscous solid Earth response to contemporary ice loss. This was unexpected and is one strand of evidence that has been used to identify the presence of weak mantle material beneath West Antarctica.

3. Lloyd, A.J., Wiens, D.A., Zhu, H., Tromp, J., Nyblade, A.A., Aster, R.C., Hansen, S.E., Dalziel, I.W.D., Wilson, T.J., Ivins, E.R., O'Donnell, J.P., 2020. Seismic Structure of the Antarctic Upper Mantle Imaged with Adjoint Tomography. *J Geophys Res-Solid Earth* **125**, 33.

This study is one of many studies that have emerged during the lifetime of SERCE that document variations in mantle properties using seismic methods.

4. van der Wal, W., Whitehouse, P.L., Schrama, E.J.O., 2015. Effect of GIA models with 3D composite mantle viscosity on GRACE mass balance estimates for Antarctica. *Earth Planet. Sci. Lett*. **414**, 134-143.

   Hay, C.C., Lau, H.C.P., Gomez, N., Austermann, J., Powell, E., Mitrovica, J.X., Latychev, K., Wiens, D.A., 2017. Sea-level fingerprints in a region of complex Earth structure: The case of WAIS. *J Climate* **30**, 1881-1892.

   Powell, E., Gomez, N., Hay, C., Latychev, K., Mitrovica, J.X., 2020. Viscous Effects in the Solid Earth Response to Modern Antarctic Ice Mass Flux: Implications for Geodetic Studies of WAIS Stability in a Warming World. *J Climate* **33**, 443-459.

Building on evidence for spatial variations in mantle rheology beneath Antarctica, a suite of studies has sought to model the impact of these 3D variations when investigating the solid Earth response to ice sheet change.

5. Bradley, S.L., Hindmarsh, R.C.A., Whitehouse, P.L., Bentley, M.J., King, M.A., 2015. Low post-glacial rebound rates in the Weddell Sea due to Late Holocene ice-sheet readvance. *Earth Planet. Sci. Lett*. **413**, 79-89.

Kingslake, J., Scherer, R.P., Albrecht, T., Coenen, J., Powell, R.D., Reese, R., Stansell, N.D., Tulaczyk, S., Wearing, M.G., Whitehouse, P.L., 2018. Extensive retreat and re-advance of the West Antarctic Ice Sheet during the Holocene. *Nature* **558**, 430-434.

These studies document emerging evidence for ice sheet readvance during the Holocene. They hypothesise that this process was triggered by solid Earth rebound in response to earlier ice mass loss.

6. Gomez, N., Pollard, D., Mitrovica, J.X., 2013. A 3-D coupled ice sheet-sea level model applied to Antarctica through the last 40 ky. *Earth Planet. Sci. Lett*. **384**, 88-99.

Adhikari, S., Ivins, E.R., Larour, E., Seroussi, H., Morlighem, M., Nowicki, S., 2014. Future Antarctic bed topography and its implications for ice sheet dynamics. *Solid Earth* **5**, 569-584.

Konrad, H., Sasgen, I., Pollard, D., Klemann, V., 2015. Potential of the solid-Earth response for limiting long-term West Antarctic Ice Sheet retreat in a warming climate. *Earth Planet. Sci. Lett*. **432**, 254-264.

Gomez, N., Pollard, D., Holland, D., 2015. Sea-level feedback lowers projections of future Antarctic Ice-Sheet mass loss. *Nat Commun* **6**, 8798.

Pollard, D., Gomez, N., DeConto, R.M., 2017. Variations of the Antarctic Ice Sheet in a coupled ice sheet-Earth-sea level model: sensitivity to viscoelastic Earth properties. *Journal of Geophysical Research: Earth Surface* **122**, 2124-2138.

Larour, E., Seroussi, H., Adhikari, S., Ivins, E., Caron, L., Morlighem, M., Schlegel, N., 2019. Slowdown in Antarctic mass loss from solid Earth and sea-level feedbacks. *Science* **364**, 969

The recognition that there are two-way feedbacks between solid Earth deformation and ice sheet dynamics has triggered a new area of research during the lifetime of SERCE. This research has revolved around the development of coupled ice sheet-solid Earth models.

7. Gomez, N., Latychev, K., Pollard, D., 2018. A coupled ice sheet-sea level model incorporating 3D Earth structure: Variations in Antarctica during the last deglacial retreat. *J Climate* **31**, 4041-4054.

The culmination of research into the effect of 3D mantle rheology and feedbacks between ice sheet dynamics and solid Earth deformation is this paper that documents a new model that accounts for both effects.

8. Shepherd, A., Ivins, E., Rignot, E., Smith, B., van den Broeke, M., Velicogna, I., Whitehouse, P., Briggs, K., Joughin, I., Krinner, G., Nowicki, S., Payne, T., Scambos, T., Schlegel, N., Geruo, A., Agosta, C., Ahlstrom, A., Babonis, G., Barletta, V., Blazquez, A., Bonin, J., Csatho, B., Cullather, R., Felikson, D., Fettweis, X., Forsberg, R., Gallee, H., Gardner, A., Gilbert, L., Groh, A., Gunter, B., Hanna, E., Harig, C., Helm, V., Horvath, A., Horwath, M., Khan, S., Kjeldsen, K.K., Konrad, H., Langen, P., Lecavalier, B., Loomis, B., Luthcke, S., McMillan, M., Melini, D., Mernild, S., Mohajerani, Y., Moore, P., Mouginot, J., Moyano, G., Muir, A., Nagler, T., Nield, G., Nilsson, J., Noel, B., Otosaka, I., Pattle, M.E., Peltier, W.R., Pie, N., Rietbroek, R., Rott, H., Sandberg-Sorensen, L., Sasgen, I., Save, H., Scheuchl, B., Schrama, E., Schroder, L., Seo, K.W., Simonsen, S., Slater, T., Spada, G., Sutterley, T., Talpe, M., Tarasov, L., van de Berg, W.J., van der Wal, W., van Wessem, M., Vishwakarma, B.D., Wiese, D., Wouters, B., Team, I., 2018. Mass balance of the Antarctic Ice Sheet from 1992 to 2017. *Nature* **558**, 219-222.

Understanding the contemporary pattern of solid Earth deformation in response to past ice sheet change is a crucial step in being able to quantify present-day ice sheet change. Many SERCE-facing scientists were involved in this high-profile study.

9. Gunter, B.C., Didova, O., Riva, R.E.M., Ligtenberg, S.R.M., Lanaerts, J.T.M., King, M., van den Broeke, M.R., Urban, T., 2014. Empirical estimation of present-day Antarctic glacial isostatic adjustment and ice mass change. *The Cryosphere* **8**, 743-760.

Martin-Espanol, A., Zammit-Mangion, A., Clarke, P.J., Flament, T., Helm, V., King, M.A., Luthcke, S.B., Petrie, E., Remy, F., Schon, N., Wouters, B., Bamber, J.L., 2016. Spatial and temporal Antarctic Ice Sheet mass trends, glacio-isostatic adjustment, and surface processes from a joint inversion of satellite altimeter, gravity, and GPS data. *Journal of Geophysical Research: Earth Surface* **121**, 182-200.

Sasgen, I., Martin-Espanol, A., Horvath, A., Klemann, V., Petrie, E.J., Wouters, B., Horwath, M., Pail, R., Bamber, J.L., Clarke, P.J., Konrad, H., Drinkwater, M.R., 2017. Joint inversion estimate of regional glacial isostatic adjustment in Antarctica considering a lateral varying Earth structure (ESA STSE Project REGINA). *Geophys J Int* **211**, 1534-1553

The contemporary pattern of solid Earth deformation in response to past ice sheet change can also be determined via the inversion of complementary satellite data sets.

10. Burton-Johnson, A., Dziadek, R., Martin, C., Halpin, J.A., Whitehouse, P.L., Ebbing, J., Martos, Y., Martin, A., Schroeder, D., Shen, W., Ritz, C., Goodge, J., Van Liefferinge, B., Pattyn, F., Reading, A., Ferraccioli, F., Sub-Group, a.t.S.G.H.F., 2020. Antarctic Geothermal Heat Flow: Future research directions. *SCAR/SERCE White Paper*.

An emerging strand of SERCE research is the role of geothermal heat flow (GHF) in controlling ice sheet dynamics. The distribution of GHF is poorly constrained – this recent SERCE White Paper documents our current state of knowledge on quantifying GHF across Antarctica.

11. Austermann, J., Pollard, D., Mitrovica, J.X., Moucha, R., Forte, A.M., DeConto, R.M., Rowley, D.B., Raymo, M.E., 2015. The impact of dynamic topography change on Antarctic ice sheet stability during the mid-Pliocene warm period. *Geology* **43**, 927-930.

On a longer timescale, dynamic topography change will impact ice sheet dynamics. This novel article documents the impact on ice sheet stability during a climatic warm period ~3 million years ago.

12. Aster, R.C., Winberry, J.P., 2017. Glacial seismology. *Rep Prog Phys* **80**, 39.

Another emerging strand of SERCE research is the field of Glacial Seismology. This article documents the development and potential applications of this field.

Budget

Planned use of remaining funds

Year (YYYY)	Purpose/Activity	Amount (in USD)
2021	PALSEA workshop support on "Improving understanding of ice sheet and solid earth processes driving paleo sea-level change" at Columbia University, USA	10,000
2021	Workshop on long-term geophysical observing networks	10,000

Membership

Leadership

Role	First Name	Last Name	Affiliation	Country	Email	Date Started
Joint Chief Officer	Matt	King	University of Tasmania	Australia	matt.king@utas.edu.au	2016
Joint Chief Officer	Pippa	Whitehouse	Durham University	UK	pippa.whitehouse@durham.ac.uk	2016
Chief Officer (2012-2016)	Terry	Wilson	Ohio State University	USA	wilson.43@osu.edu	2012-2016
*ECR Rep	Nadya	Yanakieva	Bulgarian Antarctic Institute	Bulgaria	nadya.yanakieva@gmail.com	2017
*Sub-group co-leader	Alex	Burton-Johnson	British Antarctic Survey	UK	alerto@bas.ac.uk	2017
Sub-group co-leader	Jacqui	Halpin	University of Tasmania	Australia	Jacqueline.Halpin@utas.edu.au	2017

*Please identify early-career researchers with * in first column*

Other members

First Name	Last Name	Affiliation	Country	Email
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Rene	Forsberg	Danish Technical University	Denmark	rf@space.dtu.dk
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