



External Review of the Southern Ocean Observing System

3 May 2016



Table of Contents

SOOS External Review Process.....	1
Summary of Review and Recommendations...	2
External Reviews.....	5
SOOS Response to Reviews.....	16
SOOS Draft Implementation Plan.....	28

Background and Review Process

The Southern Ocean Observing System (SOOS) is an international initiative with the mission to facilitate the collection and delivery of essential observations on dynamics and change of Southern Ocean systems to all international stakeholders (researchers, governments, industries), through design, advocacy and implementation of cost-effective observing and data delivery systems. SOOS was established in 2011 and is sponsored by the Scientific Committee on Antarctic Research (SCAR) and the Scientific Committee on Oceanic Research (SCOR), both interdisciplinary bodies of the International Council for Science (ICSU).

In an effort to help shape the direction of SOOS' activities and to review its progress, SCAR and SCOR have facilitated a review of SOOS, mainly through its past achievements and the Implementation Plan released early in 2016. This review hopes to ensure that the SOOS strategy moves forward effectively and produces needed results, and also help to gauge the value of SOOS to the sponsoring organizations and identify areas for improvement.

The [SOOS Progress Report from 2012-2014](#) was sent along with the recent Implementation Plan to 4 external reviewers for feedback. Reviewers were reminded that SOOS is a relatively new project with limited resources (1.5 staff, and an annual budget of 60,000 AUD for expenditures, mainly travel) and that it heavily relies on contributions from individual scientists and country members. Their comments are summarized below, together with recommendations from SCAR and SCOR. Reviews received are attached to this document.

We would like to thank the reviewers for their time, efforts, and valuable insights.

The following is a summary of the received, followed by the actual reviews themselves.

The SOOS 2012-2014 Progress Report can be downloaded here:
<http://www.soos.aq/resources/reports?view=product&pid=29>

Summary of Review and Recommendations

Progress of SOOS

The SOOS International Project Office and the numerous distinguished researchers and managers who volunteer their time should be commended on the establishment of SOOS and development of its strong international visibility. The IPO in particular has demonstrated an incredible ability to mobilize the community and coordinate such a large and overarching activity with very limited resources.

The progress report is an attractive, impressive overview of the first three years of SOOS. It clearly shows how the original objectives have been approached and what progress has been made in each. Given the size of the budget, SOOS has done a great job in setting up and beginning to implement its objectives. However, resource limitations have hampered progress on some of the original objectives and the new implementation plan may be too ambitious given current resources. It would be in the best interests of the project to indicate what is feasible given current resources and what cannot be achieved without additional resources.

If successful, the SOOS Implementation Plan 2015–2020 will help to further increase our understanding of the globally important Southern Ocean. If developed as proposed, SOOS will be an important tool for supporting research, resource management, ocean policy and education. With much respect, and well wishes, the reviewers all support the growth and further development of SOOS.

The following are recommendations from SCAR and SCOR to SOOS as it considers the comments from the individual reviewers.

Setting Priorities

The SOOS vision is interesting and challenging, and would be ideal under unlimited funding. However, given the constraints of funding, it may be advisable for SOOS to identify a small number of core, long-term observations and mechanisms by which it could be sustainably managed. On top of that, one could build pieces of other important observations that would be great to have, if ideal conditions existed. It will likely be necessary to expand staff and/or partners to achieve all the important objectives. Unifying national objectives will perhaps be the biggest hurdle to achieving SOOS' plans.

As a proof of concept, SOOS should consider developing a 'demonstration project' where as many as possible of the ideal observations are collected together in a smaller area. Results may then help to upscale to the full Southern Ocean.

Making sure EOV sampling methods and standards on quality control are available should not take 5 years to achieve. Also in regards to the EOVs, it should be clarified that these have not been finalized and made available and incorporated into national and international efforts.

Objective KRA 3, although worthy and desirable, has not made much progress. Accomplishing this will require significant external support and administration, and additional resources will be needed. KRA 3 involves international collaboration and making sure that the international sampling methodologies and data quality control standards are used by the international community – not easy and definitely will need support (both financial and human).

KRA 5.3 may also need to be revisited as it appears to be quite a lofty goal for such a small coordination office. Data is a problem in almost every science activity; strong connections with partners and with individual investigators will be paramount.

It may also be good to mention in more detail what is envisioned beyond 2020.

Developing Strategic Partnerships

The success of SOOS very much depends on its partners and individuals involved and their relationships. It may be helpful to review these partnerships from time to time to make sure relationships are strong.

SOOS should identify strategic partnerships with other projects and organizations to help speed implementation of SOOS plans, create synergies, and reduce redundancies. SOOS should create specific ongoing activities with COMNAP and CCAMLR to strengthen SOOS activities and increase its relevance. SOOS has tried to develop joint activities with COMNAP, which have not been fully accepted, but attempts to build this relationship should continue. SOOS should develop good interactions with GOOS, while keeping focus on the observations needed to fulfill SOOS objectives, which may ultimately be different from some observations identified for GOOS.

SOOS cannot do everything on its own; it should be more proactive in partnering with other communities, such as climate and ocean modeling and those running research facilities. SOOS contributes updates to the Antarctic Treaty System, but it may also want to think about working through SCAR and SCOR to impact more ocean policy and economic decision-making on a broader scale.

Communication/Outreach

There may be some missed opportunities where better communication/outreach to individual researchers working on SOOS-related projects would help to increase connectivity from the local to international scale. SOOS is regularly mentioned in proposals as something that projects would contribute to, but there is often no direct connection made after projects are funded. It could be beneficial to SOOS to contact national funding agencies for a list of projects that mention SOOS. SOOS could then contact the PIs to make sure the link is actually developed and information is shared.

SOOS should consider convening a SOOS Open Science Meeting to discuss the implementation plan and progress on SOOS-related activities, and to plan implementation activities and integrate existing SOOS activities. Such a meeting could be held in conjunction with an annual SCAR science conference to reduce costs.

Integration of SOOS Activities

SOOS is a bottom-up initiative, but its goals require regional cooperation. Care should be taken so SOOS does not become a conglomeration of small projects which, if not tightly aligned, might not achieve the overarching goals of SOOS. All international science projects are driven by the ideas and energy of participating scientists, but it will be important for SOOS to remain more than an umbrella for

individual efforts, and to meet national and international needs for observations of the Southern Ocean.

Relationship of SOOS with SCAR and SCOR

Both SCAR and SCOR benefit greatly from the efforts of SOOS to the extent that it is clear that SOOS is part of both organizations. SOOS helps to demonstrate the increased value that two interdisciplinary bodies of ICSU can have when working together, both to each other as well as to helping ICSU fulfill its mission. To some individuals not so closely connected to international organizations, it may appear that SOOS is an independent entity and not connected to other more overarching organizations such as SCOR and SCAR. SOOS needs to help both sponsors connect closer to individual researchers, which is the benefit of the more 'bottom up' approach of SOOS. And SCOR and SCAR need to continue to help make SOOS visible, through SCOR and SCAR events, newsletters, Web sites, etc.

SCAR, through SOOS and other associated activities, should strengthen ties to global activities around risk management, modeling of impacts, and the impact of changes in service of society.

Funding

SCAR and SCOR greatly appreciate the funds provided by sponsors of the SOOS IPO, data management, and scientific activities. However, as noted earlier, the ability of SOOS to fulfill its plans is hindered by the relatively low level of funding for staffing and scientific activities.

It is imperative for the success of SOOS that the IPO continues. Both SCAR and SCOR, as well as member countries, should help to develop a long-term sustainable home for the SOOS IPO.

The funding currently available for SOOS has primarily been developed by the SOOS IPO. It will be important going forward for SOOS SSC members to increase their involvement in raising funds for SOOS from their national sources. SOOS should make contact with national funders either through individual meetings or a meeting with a group of existing and potential funders. It may also be helpful to identify specific funding sources for specific aspects of SOOS implementation.

Other

SOOS may want to consider keeping a 'lessons learned' document that might be shared with partners in the Arctic and elsewhere. A lot has been learned and perhaps others could avoid various pitfalls with advice from the SOOS process.

SCAR and SCOR would like to thank the Institute for Marine and Antarctic Studies and the Australian Research Council's Antarctic Gateway Partnership, at the University of Tasmania, Hobart, Australia, and Antarctica New Zealand for their contributions to the SOOS International Project Office.



External Review of the Southern Ocean Observing System



Review of Progress

In 2015, SOOS produced a review of its achievements. This document can be found here:
<http://soos.aq/images/soos/products/attachments/SOOS-Progress%20Report2015.pdf>

In reading this document, please provide a brief summary of your impression of how well SOOS has met its objectives. *Please keep in mind that SOOS is a relatively new project with limited resources (1.5 staff, and an annual budget of 60,000 AUD for expenditures, mainly travel). It heavily relies on contributions from individual scientists and country members.*

The point that the review question needed to remind me that the scale of resources was small relative to the massive costs of the activity being motivated, is sort of an answer to the question. There is only so much we can expect from the initiative in the scale of things.

This doesn't stop the plan having **4 key goals for addressing 2 key challenges through 6 core objectives**. Those 1.5 staff members must be kept busy. It seems to me that they have done a great job of getting a very ambitious set of objectives up and working. I could wonder if there hasn't been some scope-creep?

It may be semantics but the term "system", I think, is misleading for what the initiative seeks to do. Instead it seeks to facilitate advances, identify key metrics/data, enhances collaboration, and aids in data dissemination – and more. But it is not really a "system". I guess a system might result, but I suspect the owners of each of the components would be viewing their piece in a fairly scientifically proprietary way given the cost and effort.

I think individual perspectives on SOOS are geographically-dependent relating to how connected, motivated and well-supported local initiatives/committees are. For example, I've been working on a data stream that would be well-suited to SOOS once we have done further QA/QC. I'm sure SOOS got mentioned in the proposal yet I've not been approached by local representatives, either during design or once the data started coming in. Possibly the work was all so on-message that it is all in hand. However, in writing this commentary I found myself looking at pieces on-line that I'd not seen or thought about previously. I see the nice table with ticked boxes and it all makes sense but I don't particularly feel like I've been aware of this sequence and set of goals. Possibly I should get out more. I wonder if more effort

needs to be put in to seek out and engage with components that connect to the grand plan. Again this needs more resources and volunteer labour.

Also, I think investigator-led ideas will probably dominate the structure of work. This is a natural consequence of not having a large over-arching fund but instead expecting the “system” to be supported “bottom-up”. This is fine but you should expect bottom-up science goals to come with it. Another way of saying this is - unless specifically funded to “target the SOOS-identified key data”, I suspect I’m more likely to address specific questions that have evolved in my science ecosystem. I think SOOS might do well to have a more flexible framework around not so much “what is best to measure” (which of course is good to know and aspirational) but rather (also) “how can we use what is getting measured”.

Review of Implementation Plan

Please provide a short summary of your impression of the SOOS Implementation Plan. Include areas of strength, as well as areas that can be improved to better achieve the desired goals of SOOS.

The SOOS vision is interesting and challenging. It seems to present this very expensive work as monotonic – we gradually build the “system” until we have the wonderful utopian vision as shown in the diagram with gliders, landers, satellites, ship etc... all working together. As everyone working in the area will be aware, it is a challenge just keeping the status quo in terms of funding, let alone identifying a vision with sustained costs well in excess of present investment. Of course, this doesn’t make for particularly visionary or inspirational implementation plans. I think there needs to be identified time dimension to all this. The vision needs to identify core, long term observations and then process and higher frequency operations and their lifetimes.

I think the SOOS objectives as opposed to the actual “system” are spot-on and achievable with a lot of hard work - and a lot of donated time. The one that stands out though as problematic is Objective 4 – around unifying and enhancing efforts between nations etc. Good luck with this. Not because anyone is being obstructive but simply because getting international collaborations to work is a delicate weaving job between different funding models and different approaches to science and operations.

I wonder if there isn’t scope for a “demonstration project” – some focused activity where SOOS tries to apply all its ideas in a coherent fashion to demonstrate what is possible? I think this would be a worthy candidate for requesting more funds and perhaps having one of two Postdocs or PhD’s funded and tied to SOOS to better integrate the “System” with the activity.

Sponsorship Review

Both SCAR and SCOR sponsor SOOS, therefore it is important that SOOS contribute to the goals and outcomes of these organizations.

From your perspective, what are the benefits to SCAR in sponsoring SOOS?

From your perspective, what are the benefits to SCOR in sponsoring SOOS?

What can SOOS contribute to SCAR?

What can SOOS contribute to SCOR?

To my mind the answers to all the questions are the same. SOOS's contributions ARE the benefits to SCAR and SCOR. SOOS gets closer to motivating the targeted observational data so sorely needed. So SCAR and SCOR gain enhanced legitimacy by having a role in driving this process. It seems to me either SCAR or SCOR could have run the process themselves. But which one, and what would have been lost? So clearly there is an advantage in having SOOS sit in between (off to the side) of the two organisations. As an aside, you may have gathered I'm not so good at engaging with such organisations but SOOS brings the targets down to close enough to science questions, so much so that I can get motivated by its over-arching goals. I think SOOS engages with a not completely overlapping component of the science community.

I wish the activity well, it is important and needs support and debate. The recent CSIRO funding cuts are proof that these developments are not monotonically growing. We have to keep evaluating why we doing things and continue to make this clear to the political framework of the place and time.

=====

Review of Progress

In 2015, SOOS produced a review of its achievements. This document can be found here: <http://soos.aq/images/soos/products/attachments/SOOS-Progress%20Report2015.pdf>

In reading this document, please provide a brief summary of your impression of how well SOOS has met its objectives. *Please keep in mind that SOOS is a relatively new project with limited resources (1.5 staff, and an annual budget of 60,000 AUD for expenditures, mainly travel). It heavily relies on contributions from individual scientists and country members.*

The progress report is an attractive, impressive overview of the first three years of SOOS. It clearly shows how the original objectives have been approached and what progress has been made in each. In some areas progress has been good; the establishment of EOVs under Objective 1, for example (working alongside GOOS affiliated groups). Little progress has been made on Objectives 2 and 3 as yet, as expected in the early stages of the program. Progress has been hampered under Objective 5 by the delay in funding to bring about the launch of the Metadata Portal. This is a key Objective, however, so it is to be hoped that the program can get caught up soon.

What the document does make clear is the network of groups and personnel that have been gathered together, or at least connected together, in these initial 3 years. The success of the program will depend on these relationships and the value of this initial linking-up can't be over-estimated.

I would perhaps like to see more critical self-assessment in a progress-report. Of course successes should be promoted, but its also good to know what lessons have been learned, what approaches have been modified/abandoned (if any)? Just so other groups coming later could learn from SOOS, how a multi-national effort should be implemented.

Review of Implementation Plan

Please provide a short summary of your impression of the SOOS Implementation Plan. Include areas of strength, as well as areas that can be improved to better achieve the desired goals of SOOS.

Strengths:

The plan is very clear and broken down into manageable and likely effective tasks. There is a clear organizational structure and a strong network of external partners and communities, and internal components, to undertake it all.

Needs Improvement:

Other than the definition of EOVs, all the other activities are planned to continue until 2020. Its not clear if they are all to be on-going in perpetuity, or if some will be completed after 2020. It may be that SOOS is being realistic (pessimistic?) in how quickly activities will be progressed. If I look at Objective 3 for example, I can certainly understand that 3.2 "Use of international sampling method and data quality standards is widespread" would be a long-term, or ongoing, objective, but I would think that 3.1 "Information on international standards for EOVS sampling methods and data quality control protocols is made easily accessible" could be achieved before 5 years are up. In fact, if the EOVS have been identified (they have) and the intent is for a coordinated observing program, then it is critical that there be easy

access to the methods and protocols as soon as possible. Similarly, KRA 5.1. concerning the development of the metadata portal - while it is clear that development will be a continuous process the plan doesn't identify WHEN a first version will be up and running. I would like to see some objective/KRA completion targets revised, realistically, where they can be.

Sponsorship Review

Both SCAR and SCOR sponsor SOOS, therefore it is important that SOOS contribute to the goals and outcomes of these organizations.

I am not a member of SCOR or SCAR, and have not been part of their meetings, so my answers are only based on what I can determine from their outreach material.

From your perspective, what are the benefits to SCAR in sponsoring SOOS?

The Southern Ocean is part of SCAR's remit, therefore the SOOS is clearly addressing the SCAR goal to coordinate international research in the Antarctic, since observations will underpin that research.

From your perspective, what are the benefits to SCOR in sponsoring SOOS?

The Southern Ocean is a vital part of the global ocean so clearly supporting the observations that SOOS will coordinate will be useful to the goals of SCOR. It promotes interdisciplinary, international research efforts which the SOOS will be undertaking.

What can SOOS contribute to SCAR?

SOOS brings together experts in observing and understanding the Southern Ocean, expertise that may not be otherwise visible to SCAR. I would hope that it would be mutually beneficial, since SOOS members may benefit from the additional context of atmospheric and terrestrial Antarctic research that involvement with SCAR should bring.

What can SOOS contribute to SCOR?

As above really. With a larger focus on addressing research limitations than SCAR, SOOS could contribute to SCOR what it learns from the development of new observation technologies.

Review by Hong Kum Lee

Review of Implementation Plan

Please provide a short summary of your impression of the SOOS Implementation Plan. Include areas of strength, as well as areas that can be improved to better achieve the desired goals of SOOS.

As legacy of IPY 2007-2008, SOOS is an international framework for understanding Southern Ocean processes related with climate change, biogeochemical cycles, sea ice, and ecosystems. SOOS is a landmark effort for assessing the status of the Southern Ocean research programs. It is innovative in design, comprehensive and global. SOOS Implementation Plan 2015 – 2020 will win recognition of the importance of Southern Ocean. It will also strengthen the international network as basis for the long-term activities.

SOOS 20-year Vision summarized the role, mission, challenges and scientific themes excellently. 5-year strategic plan will bring integrated knowledge on many properties, processes, regions of Southern Ocean.

I can look at the key challenge areas summarized as 6 objectives that provide a baseline toward better understanding of past and future Southern Ocean processes.

In 6.5, the SOOS communication Strategy is implemented. I would recommend to implement mechanisms or policies whereby knowledge can effectively contribute to decision-making and policy communities. In comparison to GEC (IGBP, IHRD, WCRP, DIVERSITAS) in Future Earth, SCAR and SCOR have relatively weak research, monitoring, and assessment capacity for communicating with societies.

Sponsorship Review

Both SCAR and SCOR sponsor SOOS, therefore it is important that SOOS contribute to the goals and outcomes of these organizations.

From your perspective, what are the benefits to SCAR in sponsoring SOOS?

1. To foster coordinated research to understand the relationship between climate change and ecosystems.
2. To undertake work at the global scale. Global risk management, global modelling of the impact, the impact of changes in services on human well-being, etc.

From your perspective, what are the benefits to SCOR in sponsoring SOOS?

1. To enhance facilities and networks or excellence in observation of Antarctic ocean.
2. To change oceanographic data and information, such as integration of satellite data with oceanographic data, Argo, moored time-series.

What can SOOS contribute to SCAR?

1. To provide models simulating interactions of 6 themes listed in page 2.
2. To provided better research facilities: human resources, equipment(research vessels, ships, moorings, remote sensing, ROV, etc), sampling time and sites.

What can SOOS contribute to SCOR?

1. To contribute marine science to the development of ocean policies and economic development.
2. In regional and global governance: Participation of SCOR as a scientific organization in UN processes, i.e. SDGs.

Please provide any additional comments you would like to be considered as part of this review:

**Wishing SOOS be loved and fascinating programm as much as GEOSS.
Public infrastructure will be interconnecting systems for monitoring and forecasting global changes. It will also support science researchers, resource managers, decision-makers and other experts**

External Review of the Southern Ocean Observing System.

Reviewer:

Nicholas J P Owens

Director, Scottish Association for Marine Science

14th April 2016.

Introduction.

Firstly, I would like to say how much I enjoyed the task of reviewing SOOS. Whilst I have been involved, aware and connected with SOOS in various roles over a number of years, it was a pleasure to see the effort to date summarised in one place. Secondly, I would like to congratulate the IPO for the production of an easy to read and assimilate, and useful progress report. Furthermore, it was an engaging, informative and attractive document: it is a pity that all such documents are not of a similar standard.

However, somewhat more critically, I found the task of the review rather difficult because as I embarked on it I became unclear as to what exactly I was being asked to review: was it to comment on the performance of the IPO or was it to comment on the success of a major research/observation initiative? At one and the same time SOOS is: a philosophical and desirable idea; a major international research programme aspiring to achieve the ideal; a coordinating activity attempting pragmatically to do what it can towards contributing to the ideal. So what exactly was I being asked to do? My review perhaps reflects this uncertainty because it covers all aspects, although, rather like the documentation, the balance of my comments is towards the programme co-ordination.

Summary of success of SOOS in meeting its objectives.

1. SOOS is now a major programme on the international stage of oceanography. It is very clear this achievement is the result of the energy of many dedicated scientists who, having had the vision of what was needed, lobbied hard and for many years to attract sufficient interest and funding to support the necessary coordinating activity. Whilst this coordinating activity is not sufficient on its own to ensure success of SOOS, it is crucially necessary. I have no doubt that the activities of the IPO has 'breathed life' into SOOS as we know it today. The notion of a SOOS has been around for many years but it was always going to be the case that there would be no progress until an investment into establishing a coordinating body was made. The establishment of the IPO was a significant and positive step and has been a great success.
2. In a sense, the success of SOOS as it is today (governance, structure, work plans etc) has emerged from the successful creation of the IPO, which has been instrumental in creating the governance, work plans etc, one could

argue there is an element of tautology here. This comment perhaps reflects my difficulty in understanding what is being reviewed.

3. The objectives of SOOS have been established by the international community and, through the coordination of the IPO have been codified. There is no doubt the fact there is now a strong SOOS 'presence' and 'identity' is because of the presence and good offices of the IPO in marshalling the energy of the science community. The individuals involved, executive and non-executive are to be applauded for their efforts.
4. SOOS should be grateful for the considerable effort of the many distinguished and expert scientists who have given freely of their time, and continue to do so, to develop of SOOS.
5. I cannot argue with the objectives set by the SOOS community and nurtured by the IPO. However, I have some comments about some specific objectives.
 - a. KRA 1 – EOVS. The work done to date is in my view the most significant achievement of SOOS to date. However, it is a little unclear to me as to whether the EOVS have been finally agreed. It seems to me some (all?) remain at the candidate stage. The report indicates completion, with the Working Groups apparently having ended.
 - b. KRA 3. This is a very worthy and desirable objective, which together with KRA 4, perhaps could be considered the heart of SOOS: their success might be argued will define the overall success of SOOS. Yet, there appears to have been little progress or plans to drive KRA 3. forward. From previous experiences this will require significant external support and administrative effort to make much headway. I was also somewhat confused by what appears to be a mismatch between the implementation milestones and the operating plan for this KRA.
 - c. KRA 5.3: this seems destined to fail. To identify the 'orphan' datasets is challenge enough, but to make them available is surely too much of a challenge. Perhaps I have interpreted this inaccurately in that I understand this to mean the actual data are made available; perhaps it means simply to make available the existence of the data – the meta-data? If not I fear that 'volunteered expert input', which seems to be the approach advocated in the operating plan.

Review of the Implementation Plan.

1. The implementation Plan is a very clear document, which restates the background of SOOS, challenges, mission and values etc of SOOS. I cannot disagree with these. However, I wonder whether there has been any attempt to have a meeting of the SOOS community to take a top-down, strategic view of whether the approach being taken, tools of implementation etc remain appropriate or could be improved? There have been, and doubtless will continue to be, many technical meetings (the report details these) but I could not see anywhere a recent meeting to take a more existential view of SOOS. My sense is it would be unlikely that such a review would suggest a major change in direction but nevertheless I think it might be valuable.
2. The governance structure of SOOS seems entirely appropriate, having guided the programme well up to now. Similarly, the Working Groups and Task Teams have been shown to be highly effective.
3. The Operating plan is a clear roadmap for a number of years ahead. However, it highlights the major weakness of SOOS, that of the heavy dependence on volunteer contributions and the continuing existence of the IPO. I will address this point at the end of the review.

Sponsorship Review

I find it difficult to distinguish between benefits and contributions of SOOS to SCAR and SCOR, thus if I may I would like to consider these together for both SCAR and SCOR.

1. Given the respective positions of SCAR and SCOR, as interdisciplinary bodies of ICSU, it is useful to consider these questions in the light of the missions of ICSU and SOOS. I believe there is a large measure of overlap in the sense that both missions are concerned with, *inter-alia*: internationalisation; coordination; scientific question of major concern to society; and interaction with and influence of national and international policy.
2. Whilst SCOR and SCAR have 'personalised' the ICSU mission somewhat, their individual missions clearly have the same aspirations. Thus it is very clear that SOOS as a scientific programme sponsored by SCAR and SCAR demonstrates very clearly these bodies are fulfilling their own missions and thus of ICSU.
3. Explicit development of capability of developing countries is the one mission of SCOR and SCAR, especially SCOR, that does not appear to be well satisfied by SOOS. Regionalisation of the Southern Ocean is clearly part of the SOOS mission and thus by default could contribute to the development ambitions of SCOR and SCAR.

4. SCAR's specific role to provide scientific advice to the Antarctic Treaty System is particularly well served by its sponsorship of SOOS. (Also see below).

Additional Comments.

1. Reference was made in the report to the involvement of SOOS with The Antarctic Treaty System through the involvement with the ATCM, COMNAP and CCAMLR. Given the fundamental roles of the ATCM and COMNAP in facilitating the capability of even making any measurements at all in the Southern Ocean, let alone their extent and sustainability, I feel SOOS should have an explicit activity that identifies its connection with the ATCM, rather than rely on happenstance. Similarly, the connection between observations and CCAMLR is an important policy interface that relies on what SOOS is trying to achieve; thus another area that needs explicit SOOS activity to be identified in the Implementation Plan.
2. My key concern over the SOOS programme is the heavy reliance on one source of funding for the IPO and the continuing support of volunteer activities. This is not a criticism of SOOS, all similar multi-national science programmes have relied very heavily on this approach. Clearly, SCOR and SCAR endorsement of SOOS is important to help promote the value of SOOS. The specific actions of SCOR and SCAR in supporting enabling activities are also clearly of considerable value. Nevertheless, the apparent end of the current funding of the IPO in 2016 (if I interpret the table on p 37 correctly) is clearly of concern. I am certain this observation is not particularly helpful and all involved will be working tirelessly to ensure continuation of funding; however, I felt compelled to make this observation as part of the review. I wish I had the answer to the problem!



The Southern Ocean Observing System

Response to 2016 External Review by SCOR and SCAR

This document is a response to the external review of the SOOS 3-Year Progress Report and the SOOS 5-Year Implementation Plan, which was facilitated by the Scientific Committee on Oceanic Research (SCOR) and the Scientific Committee on Antarctic Research (SCAR).

The SOOS Executive Committee (EXCOM), Scientific Steering Committee (SCC), Data Management Sub-Committee and National Representatives discussed the review during the 2016 SSC meeting (Scripps Institution of Oceanography, USA, 12-14th May) and have produced the following response. In addition to this document, modifications will be made to the 5-Year Implementation Plan as a direct result of this review. The modified plan will then be made widely available to the community.

SOOS thanks SCAR, SCOR and the four reviewers for their insightful comments, recommendations and input, which come at a pivotal time of growth and increased momentum towards realizing the SOOS vision:

Sustained observations of dynamics and change of the physics, chemistry, geology and biology of the Southern Ocean system should be readily accessible to provide a foundation for enabling the international scientific community to advance understanding of the Southern Ocean and for managers to address critical societal challenges.

1. Response to Summary of Review and Recommendations

1.1 Progress of SOOS

Comment 1: “However, resources limitations have hampered progress on some of the original objectives and the new implementation plan may be too ambitious given current resources. It would be in the best interests of the project to indicate what is feasible given current resources and what cannot be achieved without additional resources”

An ambitious implementation plan is required to provide the physical, chemical and biological observations needed to respond to the core societal challenges that SOOS was developed to address. This requires entraining a diverse, distributed and interdisciplinary scientific community. This does not mean that we will spread ourselves too thin to be effective. We aim to keep the ambition in mind when taking a realistic step-wise approach to the development of SOOS. The broad vision will mean we will be ready to act on new opportunities and to respond to new challenges as needed. Nonetheless, the review comments have enabled us to identify issues within our objectives and better focus the SOOS mission. SOOS will make the following changes to streamline our objectives, and to better discriminate between what is possible now with current resource levels and technology, and what requires increased resourcing or technological advances to achieve the overall vision:

- The operating plan will be modified to include a roadmap of which KRA’s are tractable, near-term goals achievable with existing resources, and those that are not yet possible based on existing resources and current community participation.
- The operating plan will be modified to articulate priorities, to help maintain a clear path forward and focus funding efforts on key targets, with the view to filling remaining gaps as resource opportunities arise.
- KRA 1.1 will become KRA 1.2
- A new KRA 1.1 will be added “Establish criteria for adopting Essential Ocean Variables (EOVs) and communicate them”. This was previously implicit in the old KRA 1.1. However, it now needs stating clearly in order to include important work that was contained in objectives 3 and 4 (below).
- Objective 2 is removed because all KRA’s are implicit in other objectives: KRA 2.1 is encompassed by KRA 6.1; KRA 2.2 is encompassed by the new KRA 1.1; and KRA 2.3 will be carried out by regional and capability working groups and is therefore implicit in KRA 4.1.
- Objective 3 is removed because all KRA’s are implicit in other objectives: KRA 3.1 is part of the process of defining EOVs and is therefore implicit in the new KRA 1.2; KRA 3.2 is a core objective of the regional working groups and is therefore encompassed by 4.1; KRA 3.3 is a direct outcome of the new KRA 1.2, and development of new standards will be achieved through the working groups and task teams, thus this KRA is implicit in both KRA 1.2 and KRA 4.1.
- Objective 5 was streamlined, with KRA 5.2 and 5.3 now encompassed in KRA 5.1 to bring together all metadata portal activities.

The amended objectives and KRA’s are provided as Appendix 1 to this response.

1.2 Setting Priorities

Comment 2: “However, given the constraints of funding, it may be advisable for SOOS to identify a small number of core, long-term observations and mechanisms by which it could be sustainably managed”

The design of a system based on EVOs aims to prioritise observational activities to a set of core observations that can be sustained at the required level, independent of platforms and programs. Further, the EOV process will ensure that there is sound scientific basis for advocating for the continuation of an observation, with all EOVs required to contribute to estimating system properties that underpin key phenomena. SOOS has already made good progress towards developing regional working groups that will provide important coordinating mechanisms for sustaining the measurement of EOVs and propagating the priorities to other programs operating in the Southern Ocean. Further, SOOS is developing partnerships with important programs (examples include SOCCOM, NECKLACE, GO-SHIP, Argo, MEOP, CCAMLR, SO-CPR, ORCHESTRA, ROBOTICA, and many others) also undertaking measurements in the Southern Ocean. SOOS envisages that these two mechanisms will provide a network of sustained observations from across the broader scientific community.

Comment 3: “Unifying national objectives will perhaps be the biggest hurdle to achieving SOOS’ plans”

SOOS agrees that building effective coordination across all Antarctic research nations will be an important but difficult task. The aim of structuring the SOOS effort through regional working groups is to provide greater autonomy to the development of SOOS within regions and therefore provide greater opportunities for nations to participate in harmonising the needs of SOOS with their own capabilities and requirements. The strategy provides a grass roots approach to allowing scientists to operate and communicate with their own national programs. In this way, SOOS and individual nations will benefit from each other. An important partnership that needs to be strengthened is with the Council of Managers of National Antarctic Programs (COMNAP). Both the SOOS IPO and the COMNAP Secretariat have agreed to the mutual benefits, and now further arrangements are needed between COMNAP and SOOS to reinforce this connection.

Comment 4: “As a proof-of-concept, SOOS should consider developing a demonstration project where as many as possible of the ideal observations are collected together in a smaller area”

A number of working groups have been established to progress SOOS in different regions and capabilities. The region with the most time-series of observations and the greatest potential for coordinated activities is the West Antarctic Peninsula (WAP). Through outside funding (Royal Society of London) SOOS will hold a scientific workshop (May 2017) bringing together researchers from the WAP region, with the aim of building community connections and initiating the coordination of WAP activities in the coming years. SOOS agrees that this region could provide a demonstration of what SOOS can achieve and will give the working group for this region the impetus in this regard. Within capability working groups, efforts have also begun around planning multi-national, multi-disciplinary pilot studies that will make significant contributions to a proof-of-concept for SOOS, while at the same time enhancing new observing capabilities. SOOS envisions the experience and knowledge gain of these efforts will cumulate towards a fully functioning and effective observing system.

Comment 5: “Making sure EOVS sampling methods and standards on quality control are available should not take 5 years to achieve.”

Agreed. The operating plan will be modified to better reflect the time required for each KRA.

Comment 6: “...it should be clarified that these have not been finalised and made available and incorporated into national and international efforts.”

Many EOVS have been identified by different expert groups. The documentation for their standardisation and collection is yet to be finalised but this has a high priority within the different expert groups. It is worth noting that, in most cases, the standard methods have been developed by the international community and SOOS will adopt and champion those standards where appropriate and facilitate communities to develop standards only where such standards have not already been adopted. The regional working groups will be used to help advance their collection. SOOS will also be working with partners to achieve the coordinated collection of EOVS. These steps will be clarified in the implementation plan

Comment 7: “Objective 3 has not made much progress. Accomplishing this will require significant external support and administration, and additional resources will be needed. KRA 3 involves international collaboration and making sure that the international sampling methodologies and data quality control standards are used by the international community – not easy and definitely will need support (both financial and human).”

The following actions will be taken in response to this comment:

- Objective 3 has been removed as it was implicit in Objective 1 (see response to comment 1).
- In many cases, the development of standards will not be required by SOOS specifically because we will inherit the outcomes of already active international efforts (although there may still be a need for some consideration of whether standards will need to be adjusted to meet regionally-specific needs). The goal is to leverage off large-scale efforts being carried out by the international community for developing agreed upon standards that are ongoing. SOOS will work to ensure that the regional and capability working groups communicate the importance of uptake of international standards.

Comment 8: “KRA 5.3 may also need to be revisited as it appears to be quite a lofty goal for such a small coordination office. Data is a problem in almost every science activity; strong connections with partners and with individual investigators will be paramount.”

The following actions will be taken in response to this comment:

- KRA 5.3 has been re-worked as discussed in the response to comment 1. Nevertheless, SOOS will facilitate the curation in data repositories of key, *high-priority* datasets that are found to be orphans. We will not be working to house all orphan data.
- A statement on the role of the IPO will be added to the Implementation Plan to more clearly communicate that this activity (as with nearly all the KRAs) does not fall solely to the IPO to implement. The Data Management Sub-Committee was formed to carry out the majority of data activities, whilst the IPO role is focused on facilitation and brokering.

Comment 9: “It may also be good to mention in more detail what is envisioned beyond 2020.”

The following actions will be taken in response to this comment:

- The implementation plan will be amended to include a closing statement that articulates our plan beyond 2020.

1.3 Developing Strategic Partnerships

Comment 10: “The success of SOOS very much depends on its partners and individuals involved and their relationships. It may be helpful to review these partnerships from time to time to make sure relationships are strong. SOOS should identify strategic partnerships with other projects and organisations to help speed implementation of SOOS plans, create synergies, and reduce redundancies”

SOOS strongly agrees with this. Through this review it is apparent that SOOS has not articulated clearly enough the importance of our partnerships with programs and organisations in the broader community. The following actions will address this:

- A section on strategic partnership will be added to the implementation plan to highlight the importance of these connections.
- A schematic illustrating the core partnerships for SOOS will also be included.
- The implementation plan sections on “*Vehicles for Implementation*” and “*International Connections*” will be modified to better reflect that the internal SOOS community (e.g., the IPO, SSC) will not be the core implementers of the required activities. Rather, SOOS will 1) identify key communities already working towards addressing issues and build partnerships with these communities to facilitate their efforts; 2) Identify gaps in existing efforts and develop capability working groups or task teams from within the broader community to address these gaps; and 3) Develop strategies for the outcomes/outputs of the abovementioned efforts to be implemented through the regional working groups.

Comment 11: “SOOS should create specific ongoing activities with COMNAP and CCAMLR to strengthen SOOS activities and increase its relevance.”

COMNAP: SOOS is currently working with COMNAP on:

- COMNAP Antarctic Roadmap Challenge,
- Southern Ocean field project database.

CCAMLR: Input to CCAMLR on SOOS has been achieved through various papers to the working groups of the Scientific Committee of CCAMLR. Mechanisms for further interactions will be taken to SC-CCAMLR.

Comment 12: “SOOS should develop good international relationship with GOOS, while keeping focus on the observations needed to fulfil SOOS objectives, which may ultimately be different from some observations identified for GOOS.”

SOOS will continue to communicate and connect with GOOS expert panels and regional alliances through:

- joint sessions,
- dual involvement in workshops and meetings,
- collaborative efforts on specific products,
- involvement of SOOS in regional alliances meetings and email correspondence, and
- currently a member of SOOS EXCOM participates in the quarterly GOOS calls.

Comment 13: "...it should be more proactive in partnering with other communities, such as climate and ocean modelling and those running research facilities"

The modelling community is core to the SOOS vision and a stronger connection needs to be initiated. SOOS will develop a task team, with representatives from SOOS and the key modelling communities (e.g., ICED, CLIVAR-CLIC-SCAR SORP, WCRP, YOPP, SOCCOM, CCAMLR) to promote engagement and seek input on modelling requirements of observational data, to feed into EOVS development and statements on how EOVS meet the criteria for selection.

Comment 14: "...it may also want to think about working through SCAR and SCOR to impact more ocean policy and economic decision-making on a broader scale."

While it is within the SOOS mission to ensure that the data is available to support policy and economic decision-making (e.g., connection to CCAMLR), it is not within SOOS' remit to impact the policy outcomes directly. To more clearly articulate the role of SOOS:

- A schematic will be added to the Role of SOOS section of the implementation plan,
- Additional statements on what is in-scope and out of scope for SOOS will be added to the implementation plan to clarify the core responsibilities of SOOS in the broader community.

1.4 Communication and Outreach

Comment 15: "There may be some missed opportunities where better communication/outreach to individual researchers working on SOOS-related projects would help to increase connectivity from the local to international scale."

The IPO is currently unable to increase its communication with researchers. However, we acknowledge the importance of increasing the role of SOOS in the research and end-user communities. This will be facilitated through the field project database, the metadata portal and in the activities of endorsed projects and projects within the different working groups. The number of individual researchers involved makes it difficult to provide direct communication with researchers and also to record the uptake of SOOS within the community. SOOS is currently considering mechanisms for improving communication and uptake along with methods for tabulating performance in those areas. For example, it is considering putting in place a voluntary mechanism to provide a relative measure of project-based contribution to SOOS, such as the inclusion of citations and/or acknowledgements in all papers resulting from projects that are endorsed by SOOS or utilise SOOS products and services.

Comment 16: "SOOS should consider convening a SOOS Open Science Meeting to discuss the implementation plan and progress on SOOS-related activities, and to plan implementation activities and integrated existing SOOS activities."

The following actions will be taken in response to this comment:

- SOOS will consider organising a scientific meeting alongside Ocean Obs 2019. Organisation of SOOS-specific sessions at Ocean Sciences meetings is also an option being considered.
- A 2-year cycle variation to the annual SSC meeting will be implemented. Every second year, the SSC meeting will involve a 1-day science workshop bringing together representatives from all working groups and key SOOS partners. This will be initiated

for the 2017 SSC meeting if funding can be secured. SOOS takes cognisance in the importance of continually showcasing the scientific achievements of the Southern Ocean community – this being the key driver towards SOOS' remit.

1.5 Integration of SOOS Activities

Comment 17: "Care should be taken so SOOS does not become a conglomeration of small projects which, if not tightly aligned, might not achieve the overarching goals of SOOS."

Discussions on how to shift from project-focussed efforts to operational efforts need to be underpinned by a clear, quantifiable statement of observational requirements. This will only be possible after KRAs 1.1, 1.2 and 1.3 are completed. An important vehicle for this transformation will be the regional working groups. Further to this, the outcomes and outputs of SOOS capability working groups will feed into and be implemented by the regional working groups. Towards addressing this comment:

- A strong strategy for communication and alignment between SOOS efforts will be developed.
- Clear expectations of SOOS governance (IPO, EXCOM and SSC) to play a strong role in drawing together individual efforts into a cohesive community acting towards the SOOS long-term vision.

1.6 Relationship of SOOS with SCAR and SCOR

Comment 18: "SOOS needs to help both sponsors connect closer to individual researchers, which is the benefit of the more 'bottom up' approach of SOOS."

SOOS will work with SCAR and SCOR to achieve this, although additional communication loads are not possible with current capacity of the IPO.

1.7 Funding

Comment 19: "...the ability of SOOS to fulfil its plans is hindered by the relatively low level of funding for staffing and scientific activities."

Funding requirements and mechanisms were discussed at the 2016 SSC meeting, including new ideas on how funding may be leveraged. SOOS will develop a funding strategy to articulate steps towards a well-funded program and to help prioritise funding efforts.

2. Response to Specific Reviewer Comments

Reviewer 1

Paragraph 2:

The implementation plan was developed through the step-wise process shown in Figure 1; challenges define what the goals are, and the objectives are the actions required to achieve the goals. You cannot have objectives and goals without first defining what the challenges are that you are trying to address. We are unclear at which stage the reviewer believes that the scope may have crept, since the broad challenges were identified at the outset, and all SOOS activities are nested within these.

Paragraph 3:

SOOS is two overlapping concepts. It is simultaneously a vision of the complete system that we hope to ultimately develop, and it is the organisation (encompassing the IPO, SSC, DMSC, and our broader network of affiliates) that is working to lay the groundwork for the complete system. As the reviewer rightly identifies, it will be extremely challenging to build the entire vision, and so SOOS is explicitly not attempting to achieve this in one giant step. The implementation plan is focussed on actions that will lay the groundwork for developing the complete vision. Given the scale of the task, and the constantly shifting political and scientific environment, we consider it imprudent at this stage to attempt to identify all of the necessary steps to develop the complete vision. Thus, a system is not merely a side-effect of our current activities, it is the overall vision that we are working toward. We will amend the implementation plan to make this concept more explicit.

Paragraph 4:

SOOS IPO already engages in extensive communications activities and these are, for reasons of practicality, focussed on links with national, international, and domain-specific research collaborations, our regional working groups, and on mass communications such as our website and newsletters. The limited resources that SOOS have to dedicate to communication mean we rely on these channels to connect us with scientists. It is beyond the capacity of SOOS to individually contact every researcher collecting data relevant to SOOS. We invite Reviewer 1 to connect with the local SOOS representatives or the SOOS IPO. We also invite them to subscribe to the SOOS newsletter to be kept informed of activities and products.

Paragraph 5

SOOS agrees with this statement, and it will be an ongoing challenge for SOOS to build not only bottom-up efforts towards the “system”, but top-down support for the SOOS vision. The statement regarding a flexible framework is important, as is the distinction between “what is best to measure?” and “how can we use what is getting measured?”. It will be a core initial effort of the regional working groups to identify what is being measured in each region, and to then look at how best to integrate across the existing efforts, sustain existing funding levels, and identify and fill any key gaps. Additionally, considerations of practicality are embedded in negotiations about refining EOVS.

Paragraph 6

Addressed in summary statement above.

Paragraph 7

SOOS agrees Objective 4 will require significant effort to achieve but it is absolutely fundamental to the success of SOOS. There are also very good examples of what can be achieved with international integration, such as GO-SHIP, Argo, CCAMLR, and the Antarctic Treaty.

Paragraph 8

Addressed in summary statement above.

Reviewer 2*Paragraph 3*

This is an important suggestion and one that SOOS will look to include in future progress reports. A “lessons learned” section on the webpage or specific document may also be produced in the future.

Paragraph 5

The operating plan will be modified as discussed in section 1.1 to better reflect the time required to achieve each KRA, as well as highlight those KRAs that will involve ongoing efforts.

Reviewer 3*Paragraph 3*

See comment 14 in section 1.3

Paragraph 7

Suggestion 1 of potential SOOS contributions to SCAR falls outside of SOOS core priorities. Taken literally, suggestion 2 suggests SOOS should help to provide better facilities, and this also falls outside SOOS abilities. SOOS can, however, help people access information about facilities that other people provide, and this will be addressed by one of the key deliverable products that SOOS is developing – the Field Projects Database.

Reviewer 4*Paragraph 7a*

SOOS agrees with this statement and changes will be made to the operating plan to better reflect the status and expected timelines for completion of EOVS specifications.

Paragraph 7 b and c

Covered in the summary responses above.

Paragraph 8

The development of working groups and task teams, as well as the articulation of the SOOS mission and objectives are relatively new (2014-2015) and therefore no review of their progress has yet been done. That said, the SOOS Executive Committee and SSC consistently review specific activities and efforts towards key products. A full review of the tools of implementation and reflection on whether the plan remains fit-for-purpose will take place at the end of the period covered by the existing implementation plan, in preparation for the development of the future plan.

Paragraph 13

We acknowledge that capacity building is not explicitly cited as an objective of SOOS. However, SOOS actively promotes the involvement of developing country and early career scientists across all spheres of SOOS activities, including working groups, steering committee, workshops etc. As stated by the reviewer, the development of the regional working groups will, by default, require the involvement of many nations, and will therefore have a strong element of capacity building.

Paragraph 15

Clearer statements on key partnerships will be added to the implementation plan. Specific comments on connections to COMNAP and CCAMLIR are included in section 1.3 above.

Paragraph 16

A funding strategy is being developed to drive efforts towards securing longer-term funding from a range of sources for the SOOS IPO and for various projects.

APPENDIX 1

SOOS OBJECTIVES

Objective 1: Facilitate the design of a comprehensive and multi-disciplinary observing system for the Southern Ocean

- KRA 1.1: Criteria for adopting EOVS are established and communicated
- KRA 1.2: Southern Ocean Essential Ocean Variables are identified and the manner in which they satisfy the criteria are communicated
- KRA 1.3: Spatio-temporal, system-level EOVS sampling requirements are identified, documented and agreed, and strategies for implementation developed if needed
- KRA 1.4: A strategy for the uptake of EOVS within the regional working groups is developed

Objective 2: Unify and enhance current observation efforts and leverage further resources across disciplines, and between nations and programmes

- KRA 2.1: Working groups and task teams are developed to coordinate efforts across disciplines, programs, and nations boundaries to fill priority gaps
- KRA 2.2: Key products for the Southern Ocean that aid in information transfer and facilitate collaborative efforts are identified and produced
- KRA 2.3: Collaborative, multidisciplinary and multinational workshops and meetings are undertaken, to support the achievement of the SOOS mission

Objective 3: Facilitate linking of sustained long-term observations to provide a system of enhanced data discovery and delivery, utilising existing data centres and programmatic efforts combined with, as needed, purpose-built data management and storage systems

- KRA 3.1: A multidisciplinary metadata portal is developed and populated and continuously updated with records as new datasets become available. Achieving this includes facilitating the archiving of key orphan datasets in appropriate data repositories and with, comprehensive metadata records submitted to the SOOS metadata portal; data custodians are encouraged to provide direct links to the data in their metadata records.
- KRA 3.2: Up-to-date information on key Southern Ocean data programmes, centres, and repositories is provided.
- KRA 3.3: Web-based tools are explored and, as needed, developed to aid data discovery and delivery; the wider community is encouraged to adopt and enhance existing tools.
- KRA 3.4: Community-developed data synthesis tools and products for the Southern Ocean are accessible through the SOOS website

Objective 4: Provide services to communicate, coordinate, advocate and facilitate SOOS objectives and activities

- KRA 4.1: The need for sustained Southern Ocean observations is strongly articulated
- KRA 4.2: Engagement with international stakeholders, across all disciplines and nations, is maintained
- KRA 4.3: A SOOS community bibliography is developed

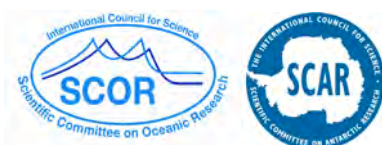
- KRA 4.4: A SOOS communication strategy is implemented
- KRA 4.5: Sustainable support for the SOOS International Project Office is maintained and enhanced
- KRA 4.6: SOOS administration, facilitation of strategic plan activities, and delivery of support services is maintained



SOOS
SOUTHERN OCEAN
OBSERVING SYSTEM

IMPLEMENTATION PLAN

2015 - 2020



CONTENTS

<u>PREFACE</u>	<u>3</u>
THE IMPLEMENTATION PLAN	3
<u>THE NEED FOR A SOUTHERN OCEAN OBSERVING SYSTEM</u>	<u>5</u>
SCIENTIFIC RATIONALE	5
KEY CHALLENGES	6
THE ROLE OF SOOS	7
MISSION AND VALUES	7
<u>VEHICLES FOR IMPLEMENTATION</u>	<u>9</u>
COMMITTEES	9
WORKING GROUPS	10
TASK TEAMS	10
<u>INTERNATIONAL CONNECTIONS</u>	<u>12</u>
<u>THE 5-YEAR STRATEGIC PLAN</u>	<u>13</u>
OVERALL GOALS	13
OBJECTIVES	13
<u>OPERATING PLAN</u>	<u>17</u>
<u>REFERENCES</u>	<u>19</u>

PREFACE

The Southern Ocean Observing System (SOOS) is an initiative of the Scientific Committee on Oceanic Research (SCOR) and the Scientific Committee on Antarctic Research (SCAR). SOOS was officially launched in August 2011 with the opening of the International Project Office (IPO), hosted by the Institute of Marine and Antarctic Studies at the University of Tasmania, Australia. This was preceded, however, by almost a decade of discussion and planning by the Southern Ocean community. This planning phase included the development of the SOOS [*Initial Science and Implementation Strategy*](#) (Rintoul et al., 2012), which provides a comprehensive overview of the scientific rationale for SOOS, the status of the international activities and programmes that are stakeholders in SOOS, and provides a framework of potential implementation avenues for SOOS to achieve its objectives.

Since 2011, SOOS has focussed on developing its governance and policies, international connections, and network building. In 2013, SOOS published its 20-year vision (Meredith et al., 2013), which articulated our ultimate objective, and allowed a trajectory of actions to be defined towards achieving this objective. What is now required is a detailed *Implementation Plan* that specifies these steps towards achieving the overall SOOS vision:

“Sustained observations of dynamics and change of the physics, chemistry, geology and biology of the Southern Ocean system should be readily accessible to provide a foundation for enabling the international scientific community to advance understanding of the Southern Ocean and for managers to address critical societal challenges”

The Implementation Plan

This document is intended to define actions of the SOOS community for the period 2015 – 2020. This plan is deliberately flexible, to enable SOOS to adapt as new demands and priorities are identified.

This Implementation Plan clarifies the SOOS mission by articulating the specific role of SOOS and its relationship to key communities; outlines the vehicles of implementation that are required to facilitate activities (including both field activities, and activities to enhance knowledge acquisition and capabilities). It also includes a Strategic Plan, which defines the goals, objectives, and key deliverables (described as Key Result Areas (KRAs) from here on). Furthermore, this Implementation Plan includes an Operating Plan that identifies the resources required to achieve each KRA.

The process used to develop this plan is illustrated in the Figure 1 below (modified from CIVICUS Strategic Planning Toolkit www.civicus.org/).

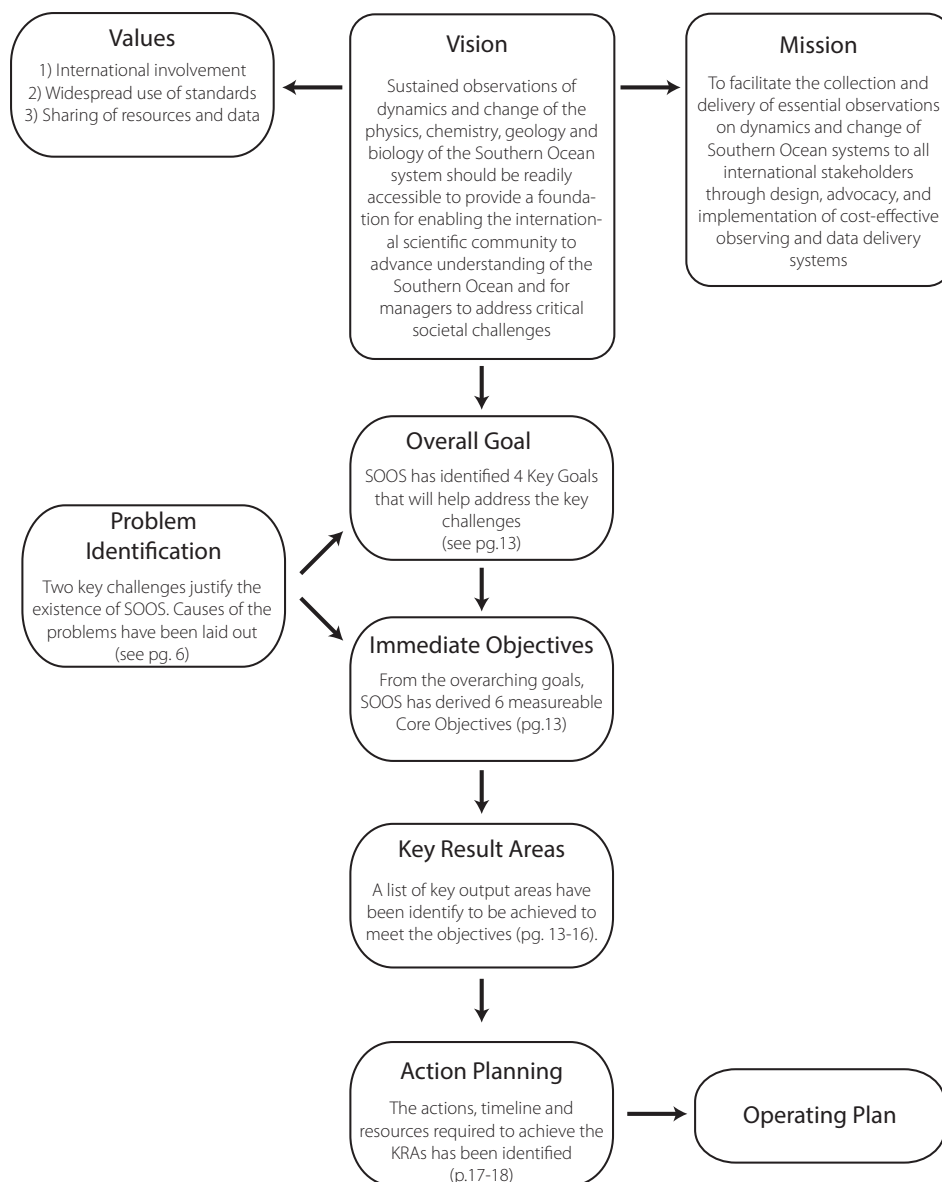


Figure 1: The CIVICUS Strategic Planning process as applied to the development of the SOOS Implementation Plan

THE NEED FOR A SOUTHERN OCEAN OBSERVING SYSTEM

Scientific Rationale

The Southern Ocean has a profound influence on global ocean circulation and the Earth's climate (Rintoul et al., 2012). The Southern Ocean provides the principal connections between the major ocean basins, and controls the connection between the deep and upper layers of the global overturning circulation, thereby regulating the capacity of the ocean to store and transport heat, carbon and other properties that influence climate and global biogeochemical cycles. The Southern Ocean contributes more to ocean storage of excess heat and carbon added to the Earth-atmosphere system by human activities than any other latitudinal band (Sabine et al., 2004; Purkey and Johnson, 2010), while export of nutrients by the upper limb of the overturning circulation ultimately supports 75% of the global ocean primary production north of 30°S (Palter et al., 2010).

Changes in the physical and biogeochemical state of the Southern Ocean are already underway, and will have global implications. The circumpolar Southern Ocean is warming more rapidly, and to greater depth, than the global ocean average (Purkey and Johnson, 2010; IPCC, 2013). The upper layers have freshened and widespread warming of the Antarctic Bottom Water has been observed (Böning et al., 2008; Durack and Wijffels, 2010; Purkey and Johnson, 2010). Since 1992, the satellite altimeter record shows an overall increase in sea level, with strong regional trends. Similarly, changes in sea ice extent are showing strong regional trends, with large increases in the Ross Sea sector contrasted with large decreases in the Bellingshausen Sea and around the Antarctic Peninsula (Parkinson and Cavalieri, 2012). The uptake of CO₂ by the ocean is changing its chemical balance, increasing the acidity and reducing the concentration of carbonate ions. The response of the Southern Ocean food web to changes in ocean chemistry remains largely unknown, but impacts on individual species are already being detected (e.g., Bednarsek et al., 2012; Constable et al., 2014).

Southern Ocean food webs rely on ice-associated intermediate trophic levels for the transfer of energy from primary producers to vertebrate predators. Generally speaking, the Southern Ocean food web is characterised by a keystone species, Antarctic krill, and this heavy dependence on a single species and aspects of the uniqueness of the Southern Ocean food webs and biogeochemical cycles make the system potentially vulnerable to climate variability and change (Murphy et al., 2012; Constable et al., 2014). There is evidence of changes in other components of the Southern Ocean food web, from phytoplankton to penguins and seals (e.g., Atkinson et al., 2004; Trivelpiece et al., 2011; Bost et al., 2015), however lack of long-term observations across large areas makes it difficult to assess long-term trends (Constable et al., 2014; Nymand Larson et al., 2014).

These recent changes underscore the importance of the Southern Ocean in the Earth system. Improved understanding of the links between Southern Ocean processes, global climate, biogeochemical cycles and marine productivity is needed to inform an effective response to the challenges of climate change, sea-level rise, ocean acidification and the sustainable use of marine resources. In particular, it is critical to understand how the Southern Ocean system will respond to changes in climate and other natural and human forcings, as well as the potential for feedbacks. To achieve this enhanced understanding, sustained multi-disciplinary observations are essential.

Derived from these imperatives, SOOS activities will be focused to address 6 interconnected Scientific Themes:

- 1) The role of the Southern Ocean in the planet's heat and freshwater balance
- 2) The stability of the Southern Ocean overturning circulation
- 3) The role of the ocean in the stability of the Antarctic Ice Sheet and its contribution to sea-level rise
- 4) The future and consequences of Southern Ocean carbon uptake
- 5) The future of Antarctic sea ice
- 6) The impacts of global change on Southern Ocean ecosystems

A more detailed scientific rationale on the imperative of SOOS is available in the SOOS [Initial Science and Implementation Strategy](#) (Rintoul et al., 2012) and the SOOS [20-Year Vision](#) (Meredith et al., 2014)

Key Challenges

The Southern Ocean Observing System has been established to overcome two important challenges for science and management in the region:

- 1) Southern Ocean observations are sparse, difficult, and expensive to obtain, and are often limited in space, time, quality, and variables measured.
 - Cause 1: Uncoordinated, short-term, single nation/discipline approach to observations leaves spatial and temporal gaps in observations.
 - Cause 2: Lack of continuous funding for sustained observations leaves gaps in observations in time and space.
 - Cause 3: Lack of strategic interfacing between nations, projects and disciplines on activities, plans, products and needs makes it difficult to streamline efforts and leverage investments for greater results.
 - Cause 4: Technological constraints have placed limitations on the type/amount of data that can be collected in an efficient and cost-effective way.
 - Cause 5: Variation in observational methodologies and protocols hamper intercomparability of measurements made by different systems in different locations.

2) Access to multidisciplinary, quality-controlled, observational data from the Southern Ocean is difficult and time consuming.

- Cause 1: Many fragmented, unconnected, mono-disciplinary or mono-platform data centres
- Cause 2: Lack of funding and/or action on data sharing and platform interoperability
- Cause 3: Variations in national/institutional data policies and data-sharing cultures
- Cause 4: Lack of general knowledge on the data that are being collected, are already available, and accessible

The role of SOOS

SOOS aims to deliver an integrated base-level set of observations needed to facilitate assessments of the multidisciplinary state of the Southern Ocean, by linking existing data streams and facilitating new ones. SOOS will provide an international interface for communication between nations and programs to streamline efforts and advocate for a consistent observation plan at an international level. SOOS will address the question “What do we need to measure to elucidate and explain fundamental system dynamics and change?”. Observations will be sustained, multi-disciplinary, standardised, quality-controlled and accessible. Traditional field process and targeted observational studies can then focus on more specific questions requiring additional/different measurements or more intensive data coverage.

SOOS focuses on 3 core elements:

- 1) Creating a set of best practices and requirements (e.g., system design, methodologies)
- 2) Coordination of international efforts towards enhanced collection of standardized observations
- 3) Data discovery/delivery

Mission and Values

The mission for SOOS is to facilitate the collection and delivery of essential observations on dynamics and change of Southern Ocean systems to all international stakeholders (researchers, governments, industries), through design, advocacy, and implementation of cost-effective observing and data delivery systems.

Underpinning this mission are values that are shared by SOOS and form the basis for our collaboration and connection with stakeholders.

- Open involvement of all interested nations, programmes, organisations and projects across all relevant disciplines, industries, and stakeholders
- Widespread adoption of international standards in data quality control and methodologies
- International sharing of resources and knowledge
- Open access to data and data products

VEHICLES FOR IMPLEMENTATION

Implementation of SOOS will be carried out by a combination of committees, working groups, and task teams.

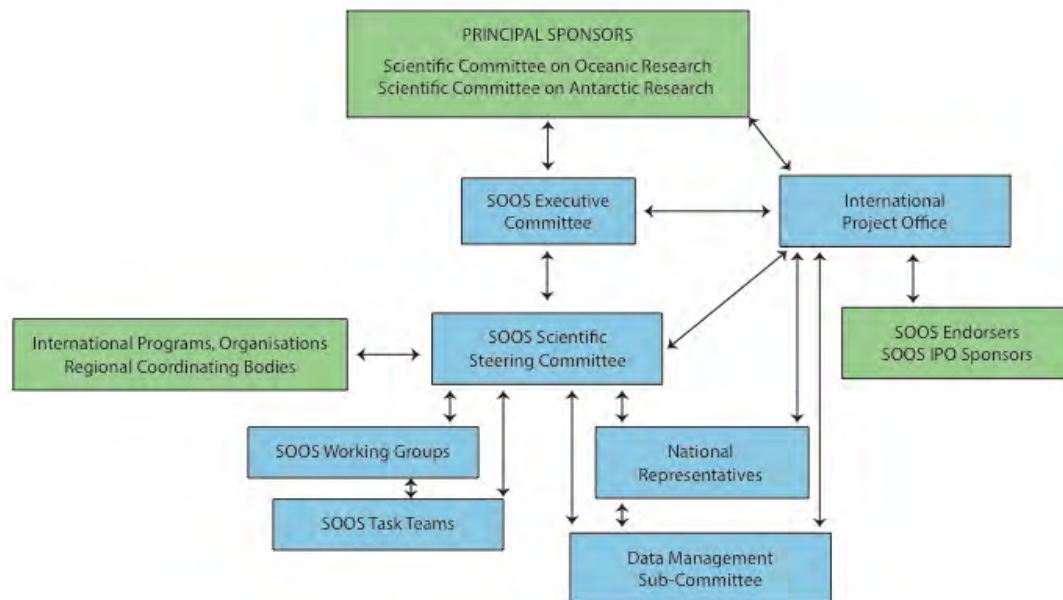


Figure 2: The governance and implementation structure of SOOS, including internal (SOOS-driven, blue) components, and links to external communities (green).

Committees

Executive Committee – www.soos.aq/about-us/ssc

The strategic vision and direction for SOOS is led by the Executive Committee (EXCOM) comprising a Biological Sciences Co-Chair and Vice Chair, a Physical Sciences Co-Chair and Vice Chair, and the Executive Officer. The EXCOM is in regular contact with sponsors and core stakeholders to ensure international input in the strategic governance of SOOS.

Scientific Steering Committee (SSC) – www.soos.aq/about-us/ssc

All SOOS activities are overseen by the international SOOS Scientific Steering Committee (SSC). The SSC meets annually and provides scientific direction for the SOOS in achieving its mission. The SSC comprises three organisational levels: EXCOM members, Scientific Members, and ex-officio representatives from key sponsors, nations and organisations.

Data Management Sub-Committee (DMSC) – www.soos.aq/data/dmsc

The SOOS Data Management Sub-Committee (DMSC) advises the SOOS SSC on the most effective collaboration mechanisms for managing and publishing observational data from the Southern Ocean. The DMSC comprises members who have professional data management expertise and who are affiliated with international and national data centres, networks, and programs.

Working Groups

Regional Working Groups – www.soos.aq/activities/regional-wg

SOOS will ultimately be implemented *regionally* based on interconnected sectors of national infrastructure and activities. The Southern Ocean community has identified five priority regions for development as Regional Working Groups (RWGs): The Southern Ocean Indian Sector (SOIS), the Ross Sea, the Weddell and Dronning Maud Land, the West Antarctic Peninsula, and the Amundsen/Bellingshausen Sea.

The Regional Working Groups will co-ordinate and implement the observing system in their region, including facilitating improved readiness and ability where needed. Development of Regional Working Groups allows identification of overlap in national areas of focus and observational activities that could be translated into better logistic coordination, scientific collaboration, and sharing of operational resources. It also allows the creation of joint funding proposals to progress SOOS in these regions, where such mechanisms exist.

Participation in any given RWG is flexible and defined by the location of national infrastructure, shipping routes, and involvement in regionally defined activities (e.g., any countries working in a region can be “member nations”). Although membership is flexible, there will be a small number of representatives responsible for the overall coordination of each Sector, and for communication of information to and from the SOOS SSC (and other relevant Stakeholders).

Capability Working Groups – www.soos.aq/activities/capability-wgs

The development and implementation of technologies, improvement in observational design, efficiency and coverage, as well as processes for information management and dissemination will be managed by *Capability Working Groups*. These working groups may take advantage of new developments in science and technology or be established to fill important gaps identified by RWGs or the SSC.

Task Teams – www.soos.aq/activities/task-team

Task Teams are short-term initiatives developed to produce a specific SOOS product (e.g., publication or document), scope out community needs and

readiness for actions on specific capabilities, or organise an activity. Task Teams are predominantly initiated and driven by SOOS IPO and SSC, but input from the greater scientific community is sought where required. Task Group products will be made freely available from the SOOS website and/or the SOOS [Zenodo Catalogue](#).

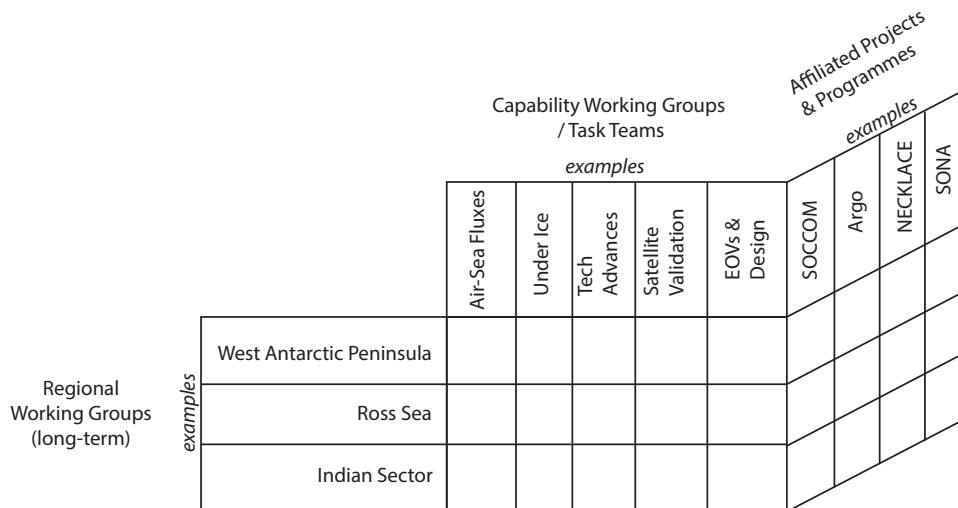


Figure 3: Existing national and international projects and programs contribute to SOOS and their efforts need to be identified and recognised as contributing regionally and/or to enhancing capabilities. This schematic visualises the relationship between Working Groups, Task Teams and affiliated activities in three dimensions.

INTERNATIONAL CONNECTIONS

SOOS has strong connections to many intergovernmental, international and national programs and initiatives. Efforts are made to extend our connections with these communities and to, where possible, work together to achieve common objectives, to avoid duplication, and to enhance impact and reach.

Further, several programmes exist that facilitate and coordinate the planning, organisation, collection, and management of observational data. National funding in support of these initiatives makes a significant contribution to the coverage of data required in an observing system. These coordination programmes also make enormous contributions to quality control and management of data, as well as ensuring the continuation and enhancement of funding for these observational activities. These programs make significant progress each year towards an integrated and sustained SOOS.

More information on specific programmatic connections is available at www.soos.aq/network/programmatic-connections

THE 5-YEAR STRATEGIC PLAN

SOOS has identified 4 key goals that will help address the key challenges (page 6), and from this, we have derived 6 Core Objectives and specific result areas that will address the causes (also page 6) of the key challenges.

Overall Goals

Goal 1: A coordinated, integrated, efficient, and sustained international program to deliver long-term, sustained observations of essential elements of Southern Ocean systems.

Goal 2: Regional implementation of long-term, sustained observations to achieve circumpolar coverage of Southern Ocean systems built upon existing efforts by national programs.

Goal 3: Facilitation and promotion of activities to improve observations of Southern Ocean systems, through international coordination and technological research and development, including the affiliation of projects and programs with this work.

Goal 4: Efficient and internationally integrated data management systems to enable stakeholders to access observations and synthesis products on the dynamics and change of Southern Ocean systems.

Objectives

SOOS Objectives are structured to follow a logical sequence of implementation:

- 1) Design of the System
- 2) Capabilities
- 3) Observations
- 4) Regional Implementation
- 5) Data Delivery
- 6) Support Activities

Objective 1: Design

Facilitate the design of a comprehensive and multi-disciplinary observing system for the Southern Ocean

Key Result Areas

1.1 Southern Ocean Essential Ocean Variables are identified using the process defined by the [Framework for Ocean Observing](#)

1.2 Spatio-temporal, system-level EOVS sampling requirements are identified, documented and agreed

1.3 A strategy for the uptake of EOVS within the Regional Working Groups is developed

Objective 2: Capability

Advocate and guide the development of new observation technologies

Key Result Areas

2.1 National and international projects that focus on aspects of technological advancement are advocated

2.2 Information on recommended accuracies and appropriate technologies is provided

2.3 Priority requirements for advances in observation technology are identified and articulated

Objective 3: Facilitating Observations

Compile and encourage use of existing international standards and methodologies, and facilitate the development of new standards where required

Key Result Areas

3.1 Information on international standards for EOVS sampling methodologies and data quality control protocols is made easily accessible

3.2 Use of international sampling methodologies and data quality control standards is advocated

3.3 Gaps in international standards are identified and, when required, new standards are developed

Objective 4: Regional Implementation

Unify and enhance current observation efforts and leverage further resources across disciplines, and between nations and programmes

Key Result Areas:

4.1 Working Groups and Task Teams that coordinate efforts across disciplines and programs, and between nations are developed

4.2 Key products that aid in information transfer and facilitate collaborative efforts are identified and produced:

4.2.1 The SOOS Field Project Database of existing and planned field activities is produced and used by the community

4.2.2 A SOOS-CliC-SCAR Community Report of Southern Ocean Satellite Data Requirements is produced

4.2.3 The SOOS National Capabilities webpages, database, and visualisation is produced and used by the community

4.2.4 SOOS Report Series is produced and provides the community with open access, citable literature

4.3 Collaborative, multidisciplinary, and multinational workshops and meetings are undertaken, resulting in the SOOS mission being achieved

Objective 5: Data Delivery

Facilitate linking of sustained long-term observations to provide a system of enhanced data discovery and delivery, utilising existing data centres and programmatic efforts combined with, as needed, purpose-built data management and storage systems.

Key Result Areas

5.1 A multidisciplinary metadata portal is developed, populated, and continuously updated with records as new datasets become available

5.2 An increasing proportion of metadata records in the SOOS portal have links that lead directly to the data

5.3 Key orphan datasets are identified, stored, and made available

5.4 Up-to-date information on key data programmes, centres, and repositories is provided

5.5 Web-based visualisation tools will be explored and developed to aid data discovery and delivery:

5.5.1 Visualisation tools available through NASA GCMD hosting are identified and explored

5.5.2 Options for mapping tools available via SOOS website that provide a direct link to data from key SOOS data streams are explored

5.6 Community developed data synthesis products are accessible through the SOOS website

Objective 6: Support Activities

Provide services to communicate, coordinate, advocate and facilitate SOOS objectives and activities

Key Result Areas

6.1 The need for sustained Southern Ocean observations is strongly articulated

6.2 Engagement with international stakeholders, across all disciplines and nations, is maintained and the SOOS Network grown.

6.4 A SOOS community bibliography is developed

6.5 The *SOOS Communication Strategy* is implemented

6.7 Robust and sustained support for SOOS International Project Office is maintained and enhanced

6.8 SOOS administration, facilitation of Strategic Plan activities, and delivery of support services (e.g., Working Groups, Task Teams, Committees and IPO activities) is undertaken

Operating Plan

The operating plan below outlines each of the KRAs and the proposed timeline, mechanism and resources required for their implementation. It should be noted that in many cases, a single working group or a single workshop will contribute to many KRAs. This table does not imply that each KRA requires a new working group or KRA-specific resources.

✔ Activity initiated/on-going

○ Activity completed

✓ Planned activity

* Resources not yet acquired

Implementation Activities		Planned Timeline of Implementation										Vehicle of Implementation	Required Resources
		2011	2012	2013	2014	2015	2016	2017	2018	2019	2020		
Objective 1:	Facilitate the design of a comprehensive and multi-disciplinary observing system for the Southern Ocean												
KRA 1.1	Southern Ocean Essential Ocean Variables are identified using the process defined by the Framework for Ocean Observing			✓	✓	✓	✓					SSC, Task Teams and Southern Ocean community	Workshop funding, IPO support, volunteered expert input
KRA 1.2	Spatio-temporal, system-level EOVS sampling requirements are identified, documented and agreed					✓	✓	✓	✓	✓	✓	Capability Working Groups	Dedicated project funding*, Workshop funding*, IPO support, volunteered expert input
KRA 1.3	A strategy for the uptake of EOVS within the Regional Working Groups is developed								✓	✓	✓	Regional Working Groups, Capability Working Groups, SSC	IPO support, volunteered expert input
Objective 2:	Advocate and guide the development of new observation technologies												
KRA 2.1	National and international projects that focus on aspects of technological advancement are advocated		✓	✓	✓	✓	✓	✓	✓	✓	✓	SSC, Capability Working Groups, IPO	IPO support, volunteered expert input
KRA 2.2	Information on recommended accuracies and appropriate technologies is provided						✓	✓	✓	✓	✓	Capability Working Groups	Workshop funding*, IPO support, volunteered expert input
KRA 2.3	Priority requirements for advances in observation technology are identified and articulated							✓	✓	✓	✓	Regional Working Groups, Capability Working Groups	IPO support, volunteered expert input
Objective 3:	Compile and encourage use of existing international standards and methodologies, and facilitate the development of new standards where required												
KRA 3.1	Information on international standards for EOVS sampling methods and data quality control protocols is made easily accessible						✓	✓	✓	✓	✓	Capability Working Groups	IPO support, volunteered expert input
KRA 3.2	Use of international sampling method and data quality standards is widespread								✓	✓	✓	Regional Working Groups, Capability Working Groups	IPO support, volunteered expert input
KRA 3.3	Gaps in international standards are identified and, when required, new standards are developed.						✓	✓	✓	✓	✓	Capability Working Groups, Task Teams	Workshop funding*, IPO support, volunteered expert input
Objective 4:	Unify and enhance current observation efforts and leverage further resources across disciplines, and between nations and programmes												
KRA 4.1	Working Groups and Task Teams that coordinate efforts across disciplines and programs, and between nations are developed				✓	✓	✓	✓	✓	✓	✓	Capability Working Groups, Regional Working Groups, Task Teams	Volunteered expert input, SSC, IPO support
KRA 4.2	Key products that aid in information transfer and facilitate collaborative efforts are identified and produced				✓	✓	✓	✓	✓	✓	✓	IPO, Task Teams	Volunteered expert input, Project-specific resources*, IPO support

KRA 4.3	Collaborative, multidisciplinary and multinational workshops and meetings are undertaken, resulting in the SOOS mission being achieved		✓	✓	✓	✓	✓	✓	✓	✓	✓	Working Groups, Task Teams, SSC, DMSC, IPO	Volunteered expert input, workshop-specific resources*, IPO support
Objective 5:	Facilitate linking of sustained long-term observations to provide a system of enhanced data discovery and delivery, utilising existing data centres and programmatic efforts combined with, as needed, purpose-built data management and storage systems												
KRA 5.1	A multidisciplinary metadata portal is developed, populated and continuously updated with records as new datasets become available			✓	✓	✓	✓	✓	✓	✓	✓	DMSC, IPO, Regional Working Groups	IPO support, volunteered expert input
KRA 5.2	An increasing proportion of metadata records in the SOOS portal have links that lead directly to the data						✓	✓	✓	✓	✓	DMSC, IPO, Regional Working Groups	IPO support, volunteered expert input
KRA 5.3	Key orphan datasets are identified, stored and made available					✓	✓	✓	✓	✓	✓	DMSC, IPO, Regional Working Groups	IPO support, volunteered expert input
KRA 5.4	Up-to-date information on key data programmes, centres and repositories is provided						✓	✓	✓	✓	✓	DMSC, IPO	IPO support, volunteered expert input
KRA 5.5	Web-based visualisation tools will be explored and developed to aid data discovery and delivery						✓	✓	✓	✓	✓	DMSC, IPO, Regional Working Groups	Product-specific resources*
KRA 5.6	Community-developed data synthesis products are accessible through the SOOS website								✓	✓	✓	Regional Working Groups, Capability Working Groups	IPO support, volunteered expert input
Objective 6:	Provide services to communicate, coordinate, advocate and facilitate SOOS objectives and activities												
KRA 6.1	The need for sustained Southern Ocean observations is strongly articulated	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	IPO, EXCOM, SSC, Regional Working Groups, Capability Working Groups, Task Teams	IPO support, volunteered expert input
KRA 6.2	Engagement with international stakeholders, across all disciplines and nations, is maintained		✓	✓	✓	✓	✓	✓	✓	✓	✓	IPO, EXCOM, SSC, Regional Working Groups, Capability Working Groups, Task Teams	IPO support, volunteered expert input
KRA 6.3	A SOOS community bibliography is developed							✓	✓	✓	✓	IPO, Endorsed projects, Regional Working Groups, Capability Working Groups, Task Teams	IPO support, volunteered expert input
KRA 6.4	<i>SOOS Communication Strategy</i> is implemented	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	IPO, EXCOM, SSC	IPO support, Resources for specific communication products*
KRA 6.7	Robust and sustained support for SOOS International Project Office is maintained and enhanced	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	IPO, EXCOM	IPO support
KRA 6.8	SOOS Administration, facilitation of Strategic Plan activities, and delivery of support services is undertaken	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	IPO, EXCOM	IPO support

REFERENCES

- Atkinson, A., Siegel, V., Pakhomov, E., Rothery, P., 2004: Long-term decline in krill stock and increase in salps within the Southern Ocean, *Nature*, 432, 100–103. doi:10.1038/nature02996
- Bednarsek, N., Tarling, G.A., Bakker, D.C.E., Fielding, S., Jones, E.M., Venebles, H.J., Ward, P., Kuzirian, A., Leze, B., Feely, R.A. and Murphy, E.J., 2012: Extensive dissolution of live Pteropods in the Southern Ocean, *Nature Geoscience*, 5, 881–885. Doi:10.1038/ngeo1635
- Böning, C.W., Dispert, A., Visbeck, M., Rintoul, S.R., and Schwarzkopf, F.U., 2008: The response of the Antarctic Circumpolar Current to recent climate change, *Nature Geoscience*, 1, 864–869.
- Bost, C.A., Cotte, C., Terray, P., Barbraud, C., Bon, C., Delord, K., Gimenez, O., Handrich, Y., Naito, Y., Guinet, C. and Weimerskirch, H., 2015: Large-scale climatic anomalies affect marine predator foraging behaviour and demography, *Nature Communications*, 6: 8220. Doi:10.1038/ncomms9220
- Constable, A.J., Melbourne-Thomas, J., Corney, S.P., Arrigo, K.R., Barbraud, C., Barnes, D.K.A., Bindoff, N.L., Boyd, P.W., Brandt, A., Costa, D.P., Davidson, A.T., Ducklow, H.W., Emmerson, L., Fukuchi, M., Gutt, J., Hindell, M.A., Hofmann, E.E., Hosie, G.W., Iida, T., Jacob, S., Johnston, N.M., Kawaguchi, S., Kokubun, N., Koubbi, P., Lea, M.-A., Makhado, A., Massom, R.A., Meiners, K., Meredith, M.P., Murphy, E.J., Nicol, S., Reid, K., Richerson, K., Riddle, M.J., Rintoul, S.R., Smith, W.O., Southwell, C., Stark, J.S., Sumner, M., Swadling, K.M., Takahashi, K.T., Trathan, P.N., Welsford, D.C., Weimerskirch, H., Westwood, K.J., Wienecke, B.C., Wolf-Gladrow, D., Wright, S.W., Xavier, J.C., Ziegler, P., 2014: Climate change and Southern Ocean ecosystems I: how changes in physical habitats directly affect marine biota, *Global Change Biology*, 20, 3004–3025.
- Durack, P. J., and Wijffels, S.E., 2010: Fifty-year trends in global ocean salinities and their relationship to broad-scale warming, *Journal of Climate*, 23, 4342–4362
- IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Murphy, E.J., Cavanagh, R.D., Hofmann, E.E., Hill, S.L., Constable, A.J., Costa, D.P., Pinkerton, M.H., Johnston, N.M., Trathan, P.N., Klinck, J.M., Wolf-Gladrow, D.A., Daly, K.L., Maury, O., and Doney, S.C., 2012: Developing integrated models of Southern Ocean food webs: Including ecological complexity, accounting for uncertainty and the importance of scale, *Progress in Oceanography*, 102, 74–92.
- Nymand Larson, J., Anisimov, O., Constable, A.J., Hollowed, A., Maynard, N., Prestrud, P., Prowse, T., Stone, J., 2014. Chapter 28: Polar Regions, in: Field, C.B., Barros, R.B. (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Report of Working Group II*. Intergovernmental Panel on Climate Change, San Francisco, p. 71 pp.
- Palter, J.B., Sarmiento, J.L., Gnanadesikan, A., Simeon, J., and Slater, R.D., 2010: Fueling export production: Nutrient return pathways from the deep ocean and their dependence on the meridional overturning circulation, *Biogeosciences*, 7, 3549–3568, doi:10.5194/bg-3547-3549-2010
- Parkinson, C.L., and Cavalieri, D.J., 2012: Antarctic sea ice variability and trends, 1979–2010, *The Cryosphere*, 6, 871–880, doi:10.5194/tc-6-871-2012.
- Purkey, S.G., and Johnson, G.C., 2010: Warming of global abyssal and deep Southern Ocean waters between the 1990s and 2000s: Contributions to global heat and sea level rise budgets, *Journal of Climate*, 23, 6336–6351.

Rintoul, S.R., Sparrow, M., Meredith, M.P., Wadley, V., Speer, K., Hofmann, E., Summerhayes, C., Urban, E., and Bellerby, R., 2012: *SOOS Initial Science and Implementation Strategy*. soos.aq/resources/science-strategies

Sabine, C.L., Feely, R.A., Gruber, N., Key, R.M., Lee, K., Bullister, J.L., Wanninkhof, R., Wong, C.S., Wallace, D.W.R., Tilbrook, B., Millero, F.J., Peng, T-H., Kozyr, A., Ono, T., and Rios, A.F., 2004: The oceanic sink for anthropogenic CO₂, *Science*, 305, 367–371.

Trivelpiece, W.Z., Hinke, J.T., Miller, A.K., Reiss, C.S., Trivelpiece, S.G., and Watters, G.M., 2011: Variability in krill biomass links harvesting and climate warming to penguin population changes in Antarctica, *Proceedings of the National Academy of Sciences*, 108, 7625–7628.
doi:10.1073/pnas.1016560108