2021 2030 United Nations Decade of Ocean Science for Sustainable Development

Southern Ocean Action Plan

2021 – 2030

In support of the United Nations Decade of Ocean Science for Sustainable Development

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Prologue

In 2017, the United Nations proclaimed a Decade of Ocean Science for Sustainable Development (hereafter referred to as the UN Ocean Decade) from 2021 until 2030 to support efforts to reverse the cycle of decline in ocean health. To achieve this ambitious goal, this initiative aims to gather ocean stakeholders worldwide behind a common framework that will ensure ocean science can fully support countries in creating improved conditions for sustainable development of the world's oceans. The initiative strives to strengthen the international cooperation needed to develop the scientific research and innovative technologies that can connect ocean science with the needs of society at the global scale.

Based on the recommendations in the Implementation Plan of the United Nations Decade of Ocean Science for Sustainable Development (Version 2.0, July 2021), the Southern Ocean community engaged in a stakeholder-oriented process to develop the Southern Ocean Action Plan. The Southern Ocean process engaged a broad community, which includes the scientific research community, the business and industry sector, and governance and management bodies.

As part of this global effort, the Southern Ocean Task Force identified the needs of the Southern Ocean community to address the challenges related to the unique environmental characteristics and governance structure of the Southern Ocean. Through this community-driven process, we identified synergies within the Southern Ocean community and beyond in order to elaborate an Action Plan that provides a framework for Southern Ocean stakeholders to formulate and develop tangible actions and deliverables that support the UN Ocean Decade vision.

Through the publication of this Action Plan, the Southern Ocean Task Force aims to mobilise the Southern Ocean community and inspire all stakeholders to seek engagement and leverage opportunities to deliver innovative solutions that maintain and foster the unique conditions of the Southern Ocean. This framework provides an initial roadmap to strengthen links between science, industry and policy, as well as to encourage internationally collaborative activities in order to address existing gaps in our knowledge and data coverage.

The Southern Ocean Action Plan will, as part of the UN Ocean Decade, deliver in achieving the UN Agenda 2030 and its Sustainable Development Goals in a polar context.

Scope

The term Southern Ocean refers generally to the water surrounding the Antarctic continent; however, the northern boundary has different limits, depending on the scientific or political context. The Southern Ocean Task Force takes a broad definition which includes both political and scientific considerations, and recognises that this ocean region is unique in its connectivity to other major oceans and its properties across latitudes and longitudes.

Furthermore, given the strong societal focus of the UN Ocean Decade, the geographical scope of this Action Plan also takes into account the socio-economic connection of Antarctic gateway cities with the Southern Ocean in order to recognise the wider socio-ecological implications of the Southern Ocean within the Earth system. Given all of the above, this Action Plan will include consideration of the sub-Antarctic region.

The Southern Ocean Task Force recognises that the scope of this Action Plan might be wider than expected, however, it rightfully reflects the relevance of the Southern Ocean to the world and its disproportionate role in regulating the Earth system. Not only does the Southern Ocean have a central position in global ocean circulation and ocean productivity, it also acts as a strong yet exhaustible buffer against climate change by storing some of the excess carbon and heat from the atmosphere. Beyond influencing global biogeochemical cycles, the Southern Ocean also affects sea-level rise through its influence on the Antarctic ice sheet.

"The Southern Ocean is home to unique biodiversity and large productive ecosystems that are at risk from global change."

The Need for a Southern Ocean Action Plan

In the Southern Ocean, human presence and the combined effects of various forms of pollution, transport, infrastructure, and the pursuit of living resources, together with accelerated climate change at high latitudes, are exerting increasing pressures on the environment. These changes have the potential to alter the role of the Antarctic and Southern Ocean in regulating global climate and other systems, as well as impacting a host of other important ecosystem services. Being well adapted to stable environmental conditions, with unique traits, Antarctic species are considered more vulnerable to environmental perturbations and pollutants, compared to species from more northerly latitudes.

The vast, remote and harsh environment of the polar regions means that no single nation can develop and implement a research and data strategy to understand and manage these regions. The twelve nations involved in Antarctic research during the 1957-1958 International Geophysical Year (IGY) recognised the need for international collaboration in this remote region of the world and created the Special Committee on Antarctic Research (now the Scientific Committee on Antarctic Research, SCAR) in 1958 through the International Council of Scientific Unions (ICSU) (now the International Science Council, ISC). Today, SCAR has 45 member countries and nine ISC unions. The political and legal regulatory framework for human activities in Antarctica was first established the following year by the Antarctic Treaty, which was signed on 1 December 1959 and came into force in 1961. Currently signed by 54 member countries (29 Consultative Parties), the Treaty indicates that both terrestrial and marine areas south of 60°S are exclusively reserved for peaceful purposes and international scientific research collaborations. As part of the Antarctic Treaty System (ATS), the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), established in 1982, is responsible for conserving Antarctic marine life and managing fisheries in its Convention area (the area south of 60°S latitude, as well as the area between that latitude and the Antarctic Convergence, also referred to as the Polar Front), by ensuring an ecosystem-based management approach for the conservation and rational use of marine living resources. Later, in 1998, the Protocol on Environmental Protection to the Antarctic Treaty (the Environmental Protocol, also known as the Madrid Protocol) came into force to provide a comprehensive framework to protect the Antarctic environment and manage human activities in Antarctica.

Since the Southern Ocean community of stakeholders is globally unique in its operation within the Antarctic Treaty System, which is based entirely on scientific understanding and environmental protection, it is imperative to strengthen international collaborations to increase scientific understanding of the Antarctic region. Underlying the UN Ocean Decade is the need for data management to align itself with the FAIR (Findable, Accessible, Interoperable, Reusable) (Wilkinson *et al.* 2016) principles to achieve the ambitious data objectives of the UN Ocean Decade (Tanhua *et al.* 2019).

The UN Ocean Decade Societal Outcomes align strongly with the remit of the Antarctic Treaty and its Committee for Environmental Protection. The Southern Ocean community therefore recognises the need to develop and implement a coordinated, international plan that builds on our existing understanding of how human interaction with the Southern Ocean can benefit people and societies in ways that will also contribute to the protection and conservation of the unique characteristics of these regions.

The Southern Ocean Action Plan will, as part of the UN Ocean Decade, deliver in achieving the UN Agenda 2030 and its Sustainable Development Goals (SDGs) in a polar context.

The Southern Ocean Process

As the Southern Ocean community progresses through the United Nations Decade of Ocean Science for Sustainable Development (2021 – 2030), this is a significant time to reflect on the achievements of the Southern Ocean Task Force towards achieving the UN Ocean Decade vision during its first year.

Based on the recommendations in the global Ocean Decade Implementation Plan (Version 2.0, July 2021), the Southern Ocean community engaged in a stakeholder-oriented process to develop the Southern Ocean Action Plan (Figure 1). The Southern Ocean process was launched in February 2020, at the First Southern Ocean Regional Workshop at the Ocean Sciences Meeting in San Diego (USA), where key research priorities were identified for three of the seven UN Ocean Decade Societal Outcomes.

During the northern spring of 2021, the Southern Ocean Task Force conducted an extensive exercise to collect information from the implementation plans of partner organisations [Scientific Committee on Antarctic Research (SCAR), 2017; Southern Ocean Observing System (SOOS), 2016; European Polar Board (EPB), 2017; Integrating Climate and Ecosystem Dynamics in the Southern Ocean (ICED), 2008; and World Climate Research Programme (WCRP), 2018], as well as previous polar and Antarctic initiatives, including the SCAR Horizon Scan (Kennicutt *et al.* 2014, 2015) and its subsequent Southern Ocean-focused paper (Xavier *et al.* 2016), the Antarctic Roadmap Challenges led by the Council of Managers of National Antarctic Programs (COMNAP) (Kennicutt *et al.* 2016), and the outputs of the EU-PolarNet consortium (EU-PolarNet, 2016a,b, 2019, 2020a,b). This exercise generated a review of identified strategic and scientific priorities for the Southern Ocean, published in May 2021 (Southern Ocean Task Force, 2021).

The next step consisted of engaging stakeholders in an open survey to gather insights on the review. Participants provided input on the activities and contributions that should be developed in the context of the Decade. Working Groups were set up for each of the Ocean Decade Societal Outcomes. Each Working Group is chaired by key experts from academia, government or industry, with working group participation open to all interested parties to ensure the broadest representation. Southern Ocean challenges and ensuing actions were identified to develop concrete strategies (see Annex 1). The input from each Working Group was synthesised into separate Working Group reports which served as a basis for the Southern Ocean Action Plan.

The process culminated in the organisation of the Second Southern Ocean Regional Workshop during the Southern Ocean Decade & Polar Data Forum Week 2021 (20 – 24 September 2021), which aimed to communicate to the broad Southern Ocean community on the development process of the Southern Ocean Action Plan and to seek further engagement from diverse stakeholders. This week-long online event gathered 400+ participants and combined a conference style meeting in support of knowledge exchange, with a public consultation approach to identify the needs of the Southern Ocean community to address the challenges related to the unique conditions in the Southern Ocean.

The UN Ocean Decade Societal Outcomes are the following:

1.	2.	3.	4.	5.	6.	7.
A clean ocean where sources of pollution are identified and removed	A healthy and resilient ocean where marine ecosystems are mapped and protected	A sustainably harvested ocean ensuring the provision of food supply	A predictable ocean where society has the capacity to understand current and future ocean conditions	A safe ocean where people are protected from ocean hazards	A transparent and accessible ocean with open access to data, information, and technologies	An inspiring and engaging ocean where society understands and values the ocean

Through this community-driven effort, Working Groups – each dedicated to one of the UN Ocean Decade's Societal Outcomes – gathered valuable input on what needs to be improved and developed for the Southern Ocean stakeholders to fulfil the central vision of the UN Ocean Decade to conduct "the science we need for the ocean we want" in the Southern Ocean region. By identifying synergies within the Southern Ocean community and beyond, the Southern Ocean Task Force was well-equipped to elaborate an Action Plan that provides a framework for Southern Ocean stakeholders to formulate and develop tangible actions and deliverables for the Decade.

Furthermore, the Workshop shed light on the cross-cutting nature of constraints affecting the management of, and activities within, the Southern Ocean, such as (i) the lack of coordinated research facilities, (ii) limited access to data, infrastructure, and resources, and (iii) the scarcity of effective mechanisms for collaborations between different sectors (academia, government, industry, etc.) and the resulting mismatch between the needs of society and research interests and outputs.

The development process of the Southern Ocean Action Plan engaged a broad community spanning the scientific research community, industry, infrastructure (national Antarctic programmes, logistics coordinators), policy and management, operational service providers and Antarctic scientific and policy governing bodies (see Annex 2). This inclusive approach is a key pillar of the Southern Ocean contribution to the UN Ocean Decade, and will be prioritised throughout its implementation.

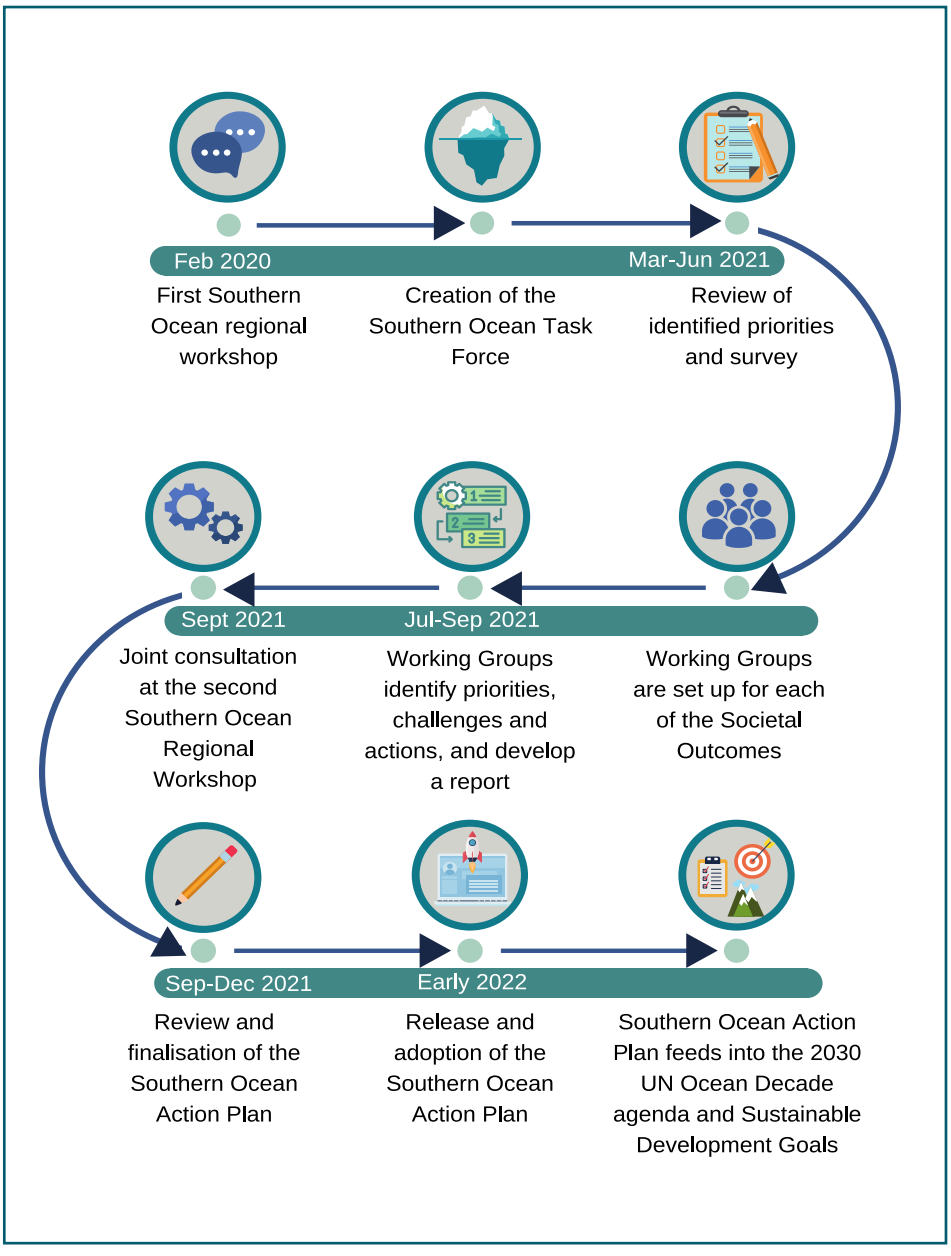


Figure 1. The Southern Ocean process

Developing the Southern Ocean Action Plan

Where we come from...

The Southern Ocean contribution to the UN Ocean Decade builds on synergistic efforts that have been taking place since the early 2000s. The Southern Ocean process to develop the Southern Ocean Action Plan aims to represent the diversity of stakeholders through an open and transparent process. By including experts from science, policy and business, the composition of the Southern Ocean Task Force has already crossed several boundaries, whether they be geographical or disciplinary, thus reflecting many different voices. In this way, the Southern Ocean Task Force is a good example of how a community can work together to collectively deliver innovative solutions to maintain and protect the unique environments of the Southern Ocean. The Southern Ocean process builds on many previous successes across the international community, including those led by members of the Task Force. For example, the Southern Ocean Observing System (SOOS) is an international initiative developed in 2011 by the Scientific Committee on Antarctic Research (SCAR) and the Scientific Committee on Oceanic Research (SCOR). By gathering and sharing Southern Ocean data to national and international stakeholders, SOOS has facilitated the establishment of a strong network of researchers, governments and industries that work together to achieve objectives framed around different society's needs.

Although the Southern Ocean process has already been successful in reaching out to various stakeholders, the Ocean Decade will also provide opportunities for further engagement to broaden representation, competence and accessibility to overcome Southern Ocean challenges related to research, logistics and uptake. Efforts to promote an inclusive network of racial and ethnic minorities are already being undertaken at the polar level, such as the Polar Impact Network founded in 2019, together with initiatives of Task Force members. The goal to attain gender equality and suppress sexual orientation discrimination is also well established by initiatives like Women in Polar Science (WiPS) and Pride in Polar Research, which have been active since 2014 and 2018, respectively. Furthermore, efforts to strengthen the fresh perspectives of new generations of Southern Ocean professionals are continuously improving. The

Association of Polar Early Career Scientists (APECS) is an important legacy of the International Polar Year (IPY) in 2008, which fosters engagement in education, outreach and communication. The mission of APECS is to ensure the knowledge transfer between generations by offering opportunities for training, networking, leadership and skills development.

...Where we are going

The Southern Ocean is underrepresented at the international level, despite playing an important role in regulating climate and many other systems at the global scale. The Southern Ocean Task Force will use the Ocean Decade to provide a platform to underline the importance of the Southern Ocean and highlight its relevance in the Earth System. Owing to its well-established operation, the Southern Ocean community is uniquely placed to join the United Nations Decade of Ocean Sciences for Sustainable Development.

Following the publication of the Southern Ocean Action Plan, the Southern Ocean Task Force anticipates that the Southern Ocean community will find inspiration and seek engagement to deliver innovative solutions to maintain the unique conditions of the Southern Ocean. This framework aims to provide an initial roadmap to strengthen links between science, industry, and policy, develop global capacity in Southern Ocean related topics, and encourage internationally collaborative activities in order to tighten knowledge and data gaps.

The bridges we need to achieve the Southern Ocean we want

The bridges we need to achieve the Southern Ocean we want

The review published in May 2021 (Southern Ocean Task Force, 2021) shed light on the highly cross-cutting nature of constraints affecting research in and management of the Southern Ocean. Some of these challenges are not unique to the Southern Ocean and could be considered at a wider geographical scale. Other challenges were cross-cutting in nature when considered with regards to individual UN Ocean Decade Societal Outcomes. This is because the Societal Outcomes of the Ocean Decade are all closely interdependent and interwoven (Box 1).

To tackle the connectivity of the Outcomes, the Southern Ocean Task Force identified five bridges that need to be built, reinforced and/or maintained to achieve the Southern Ocean we want (Figure 2). These include the lack of sustained long-term funding, insufficient capacity within the Southern Ocean community, limited access to data, infrastructure, and resources, the scarcity of effective mechanisms for collaborations between different sectors and regions, and the resulting mismatch between the needs of society and research interests and outputs.

These bridges represent the most pressing challenges that need to be overcome to preserve and restore marine ecosystems and support the people who depend on them. In this way, the UN Decade of Ocean Science for Sustainable Development will be able to create synergies with the UN Decade on Ecosystem Restoration to protect oceans and their resources.

Realising that these challenges are not limited to the Southern Ocean, but have a global scope, is crucial. Addressing these challenges and building those 'bridges' across disciplines and regions then also requires a global approach, under the auspices of the UN Ocean Decade.

BOX 1:
The interdependence of the Societal Outcomes of the Ocean Decade

Access to data and infrastructure (Outcome 6) is essential to successfully understand the current and future states of the Southern Ocean (Outcomes 2 and 4). Achieving these will allow informed decisions to be made in view of attaining a clean (Outcome 1), resilient (Outcome 2), and sustainably productive ocean (Outcome 3). All of these will ensure a safer ocean where fewer extreme events occur (Outcome 5) and where forecast systems allow for timely responses (Outcome 4). The success of all the above will steer the transition to the sustainable development of ocean activities by inciting behaviour change, engagement and innovation (Outcome 7), which will in turn influence the next generation to invest in ocean science (Southern Ocean Task Force, 2021).

1. Funding

Designing research projects and/or management plans for future human activities requires funding (Box 2). Beside the inevitable seed funding necessary to develop such activities, long-term investment that goes beyond the typical lifespan of a project/programme is needed to expand meaningful interactions between research groups, communities and other stakeholders. Sustained collaborations not only enable stakeholders to share knowledge and build trust amongst all parties, but also to join efforts in designing more integrative and multidisciplinary projects.

Furthermore, some scientific questions, such as evaluating the impacts of environmental change, require long-term monitoring and data acquisition which cannot be addressed without long-term funding. This is particularly crucial for the Southern Ocean, as many areas are inaccessible throughout the winter season. Therefore, there is a need to coordinate calls to improve the technological capabilities to (i) operate in and observe inaccessible areas year-round, (ii) to transport, maintain and rapidly analyse samples, and (iii) to support the establishment of a sustained collaborative network of long-term observatories.

BOX 2:
Funding diversity in polar research

The funding mechanisms for polar research around the world are as diverse as polar research itself. To truly achieve the mission of the UN Ocean Decade to develop "Transformative ocean science solutions for sustainable development, connecting people and our ocean" in the polar regions will not only require a high level of cooperation, it will also call for an improved understanding of the policy making process, and the polar research funding landscape. Even with a comparatively much advanced regional and international collaboration in the Southern Ocean, the funding mechanisms remain very diverse, at all levels. Some examples given here should increase insight into various funding regimes/schemes around the globe for Southern Ocean research. Polar researchers of most nations can benefit from more than one of the funding regimes given below:

1) Dedicated National Polar Research Programmes: several nations run large national polar research programmes that provide dedicated funding and maintain polar infrastructure for Antarctic and Southern Ocean research activities. There are two basic models for federal support of Antarctic research activities.

a) Some nations have polar research programmes that include staff scientists as federal employees who can initiate new research projects and be tasked with working on specific initiatives of national interest. These programmes also provide funding calls for competitive grants for non-federal researchers.

b) Other countries have dedicated polar funding available primarily from competitive grants. Therefore, research priorities are strongly driven by the science community.

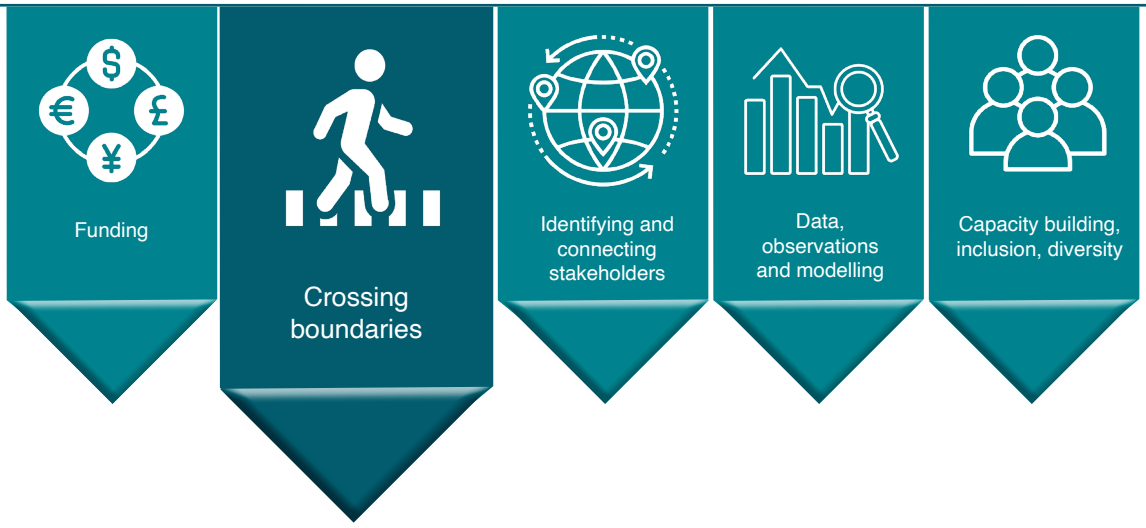
2) Polar research falls within the Research & Innovation agenda of national science funding agencies: several national funding agencies do not run a dedicated polar, Arctic or Antarctic funding programme, instead they include polar research within the overall competitive research and innovation funding calls.

3) Regional funding agencies, e.g. European Commission (EC). The EC funds research through ambitious programmes like Horizon 2020, within which there is a mixture of dedicated polar research calls, and broad science calls that polar researchers can apply for. The Joint Programming Initiatives (JPI) are another successful regional funding initiative.

4) Other collaborative intergovernmental organisations like the Belmont Forum.

5) International organisations like the Southern Ocean Observing System - SOOS (a joint initiative of SCAR and SCOR): providing very important seed funding to set up research initiatives in the Southern Ocean.

6) Funding and/or in-kind support through charities, foundations, NGOs, business and industry groups and many more: this includes funding and/or in-kind support of research, research-related activities and logistics such as dedicated ship time for polar research.



2. Crossing boundaries

a. Blurring national and regional borders

Expanding the international collaborative community in the Southern Ocean region is required to create synergies in competence and knowledge to improve our scientific understanding of the Southern Ocean region. To achieve efficient transnational cooperation, aligning national and international research programmes and implementing standardised data management is required. This first step was taken over 60 years ago with the creation of SCAR. Since then, SCAR and other organisations have worked to effectively coordinate international collaborations in Southern Ocean research and to establish data repositories. International cooperation increases the dissemination of quality controlled and reliable Southern Ocean knowledge, and encourages co-production of knowledge and co-design of projects. This is particularly essential for the Southern Ocean as its harsh conditions make it difficult for single nations to develop and implement a long-term and integrative research strategy. Building on the current framework of international collaborative programmes will require identifying already-existing effective co-design methods and improving current methodologies in collaborative research, planning and management. The anticipated increase in research innovation resulting from such a cohesive community will strengthen the relevance of the Southern Ocean region at the international level.

b. Linking disciplines

Facilitating transdisciplinary cooperation and complementarity is essential to generate and deliver relevant and integrative knowledge to the scientific community, governments, the business and industry sector as well as the general public. This Action Plan hopes to build on the existing base and deepen strategic integrated collaboration in order to develop holistic and integrative research projects. The current lack of effective communication between disciplines should be addressed by allocating time and effort to improve the dialogue within different communities and disciplines in order to bridge the various branches of natural sciences more effectively, and include social sciences and humanities and arts from the outset.

c. Co-designing global polar research priorities

Many organisations at national, regional and international levels are identifying and prioritising the most pressing global polar science and support needed in terms of infrastructure, funding and other needs. These include but are not limited to the various initiatives of the Southern Ocean community such as the SCAR Antarctic and Southern Ocean Horizon Scan (Kennicutt *et al*. 2014, 2015, Xavier *et al*. 2016), the Antarctic Roadmap Challenges led by COMNAP (Kennicutt *et al*. 2016), the European Polar Research Programme (EU-PolarNet, 2016a,b, 2019, 2020a,b), the SOOS Science and Implementation Plan (SOOS, 2016; Newman *et al*. 2022), and the Integrating Climate and Ecosystem Dynamics in the Southern Ocean (ICED) Science Plan and Implementation Strategy (ICED, 2008). These concerted international actions to establish coordinated research prioritisation, and subsequent science-based and scenario-based advice provides fast and effective avenues for policy-related actions for policy makers. Recent examples of large and globally coordinated programmes to identify and respond to global research priorities are the MOSAiC Expedition, The Year of Polar Prediction (YOPP), and the Thwaites Glacier programme. These very large scale initiatives bring together the global community and are successful when resources are pooled.

3. Identifying and connecting stakeholders

The Antarctic Treaty System, and the multitude of other organisations involved in the Antarctic and Southern Ocean promote strong collaborations between academia, research, government, industry, and other relevant stakeholders. Such collaborations are required to enhance conservation and management, safe operations, sustainable economies (transport, fisheries, tourism, others), and capacity building in the Southern Ocean Region. The Southern Ocean Task Force has identified several areas of improvement:

a. Improving dialogue at the science-policy interface

In polar research, there already exists a constructive and iterative engagement between science and policy-makers. For example, in the Southern hemisphere between the many national (e.g. national Antarctic Programmes), regional (European Polar Board, Asian Forum for Polar Sciences, Reunión de Administradores de Programas Antárticos Latinoamericanos, and the All Atlantic Ocean Research Alliance) and international science organisations (e.g. SCAR, WCRP) and associated policy fora. The latter includes the Antarctic Treaty System, including CCAMLR, and UN bodies (e.g. the World Meteorological Organisation (WMO), and the International Hydrographic Organisation (IHO)) and activities such as the United Nations Framework Convention on Climate Change (UNFCCC), the United Nations Convention on the Law of the Sea (UNCLOS), and the UN SDGs. Linkages between researchers and policy- and decision-makers in international and national governments, non-governmental bodies, and governmental organisations already exist and are remarkably strong in the Antarctic and Southern Ocean region. However, an improved dialogue would help to not only further support conservation and management, and also to determine research priorities for the science community. In particular, it will be important to highlight the important role played by the Southern Ocean in a changing climate to policy makers, and by focusing on the existing and likely future threats to the Southern Ocean.

Development of Decision Support Tools (DSTs) is essential to improving dialogue at the science-policy interface. The key challenges that have been identified for their successful implementation include the long term funding for operating and maintaining a continuous delivery of accurate and up-to-date information. The use of participatory techniques such as scenario analysis further improves the understanding and illustrates the added value of using evidence-based knowledge for decision-making. There is a need to further identify methods that have proven effective in communicating between science and policy globally, and determining how these apply to the Southern Ocean and the wider polar regions. One example is the Antarctic Environments Portal, that includes summaries of the current state of knowledge on issues of relevance to Antarctic managers and policy-makers, and on environmental pressures likely to cause change into the future. Such science-policy information brokering products that have been developed with, and are directly relevant to stakeholders, will illustrate the potential of available knowledge and can incentivise the uptake by stakeholders.

b. Ensuring societal needs are reflected and addressed through research

Addressing societal needs through research requires supporting and strengthening communities that bridge the gap between science and societal stakeholders, while communicating the

transdisciplinary nature of the Southern Ocean issues. Optimisation of the chain of information linking research outcomes to society requires adequate brokering of scientific information, identification of relevant indicators of baseline states and changes, improved access to knowledge, including the FAIR data management requirements, and the design and maintenance of relevant tools for different stakeholders. Prototypes or proofs of concept for such information brokering products that are user-relevant, will illustrate the potential of available knowledge.

There is a need for an analysis of governance and management systems for steering human activities in nature, and their capacity to integrate and employ diverse knowledge to inform choices, and to make rapid adjustments as new knowledge is made available. Further, we need to emphasise the importance of identifying available sources for environmental and socio-economic data that are required to assess systematic impacts upon the Antarctic environment and related human activities. A holistic framework to assess the impacts of, and possible solutions for coping with environmental change and its socio-cultural consequences should be developed to:

I. improve human well-being and resilience of communities anticipating that the rate of change may be faster than social systems' adaptation capabilities,

II. support a sustainable approach to new economic activities and addressing new potential pressures, and

III. enable sound, informed and effective decision-making by policy-makers.

To be able to identify and reach the desired future states envisioned by stakeholders for the Southern Ocean, it is important to first identify the relevant stakeholders themselves, and secondly receive advice and guidance on optimal pathways towards the desired states ensuring a just transition. These transitions require a strong foundation, achieved by building knowledge and skills needed for sustainability, sustainable growth, employment, and participation of the communities and society at large. It is imperative to release policy advice and educational information at different levels of complexity in order to engage across the full spectrum of society and to provide maximal societal benefit from the use of research results in decision-making.

c. Linking the industry with research, infrastructure and logistics

Strengthening engagement with, and input from, industry partners and business operators working in the Antarctic and Southern Ocean region is necessary for broadening and maintaining collection of long-term time series of data relevant for ecosystem monitoring. These partnerships could provide greater spatial and temporal coverage, while engaging operators in using mobile, comparative, and complimentary measurement platforms. It is important to underpin co-design and consultative processes with industry stakeholders to help ensure meaningful engagement for all, raise awareness of ecosystem impacts, and collection of data relevant for protecting the fragile Southern Ocean ecosystem. To help stakeholders make informed decisions, development of communication and interaction platforms with information at different levels of complexity is important. Focusing on topical areas such as tourism, transport, science and fishing, can strengthen interaction and knowledge integration between research, industry, infrastructure and logistics stakeholders. These strengthened interactions lead to better management practices, and to strengthened protection of the fragile Southern Ocean region.

4. Data, observations and modelling

Informed decision making to achieve the oceans that we want relies upon appropriate scientific input, which itself relies upon scientific data. Therefore, data, observations and modelling are closely intertwined and integral parts of all societal outcomes for the Ocean Decade. In the polar regions, the remoteness and harsh environment pose considerable logistical challenges for making such observations. The rapid changes occurring in these environments mean these observations are especially valuable and need to be sustained over long timeframes. Collaboration can reduce the cost of making such observations. Widespread use of standards and protocols allows increases in both the quality and interoperability of the observations as well as of the data created from those observations. SCAR, SOOS, and the Arctic Data Committee have developed recommendations for principles that will advance an alignment of Polar Data Policies (Tronstad *et al.* 2021), and these have already been adopted in the SOOS Data Policy (SOOS Data Management Sub-Committee, 2022).

a. Improving spatial and temporal coverage

This Action Plan has identified the cost and environmental challenges of fieldwork in the Southern Ocean that limit the community's ability to collect sufficient observing data to meet the Ocean Decade's priorities. To address this, it is important to optimise the utility of observing assets and other polar infrastructure by coordinating their use internationally. Coordination can be achieved at the level of large internationally organised observing campaigns, as well as through the routine sharing of information about polar infrastructure, observing assets and logistics. This is further elaborated in the section 'How to achieve - a Transparent and Accessible Southern Ocean'.

b. Ensuring data and information are fully utilised

The full utilisation of data and the resulting information, in the form of publications, requires the data to be FAIR and the information to be Open Access. This way the data and information are available to be (re)used by science, but also by the public and society at large.

The FAIR data principles (Findable, Accessible, Interoperable, Reusable) (Wilkinson *et al.* 2016), are a set of community-agreed guiding principles and practises developed to support the reusability of digital assets. The community's capacity to ensure that a given piece of data is fully FAIR varies according to the data type, the methods used by observing scientists, and the resources available for documenting and standardising the data.

Open access can be defined as the practice of providing online access to scientific information that is free of charge to the end-user and reusable.

For data that describe widely agreed variables and that are collected using standardised protocol, including many of those collected through long-term observing programmes, it is achievable for the data to be shared in standardised formats, having undergone standardised quality control and quality assurance processing, so that they may be aggregated, subsetted, and merged with other datasets for maximum reusability. The Argo programme is an example of how this process can work.

However, many Southern Ocean datasets cannot be realistically expected to be processed through such uniform channels and processes. Historical datasets of considerable value were collected through idiosyncratic methods and with varying degrees of documentation that may

or may not support standardisation. Additionally, data collected through process studies or with new observing technologies are often collected using bespoke sampling methods and stored in non-standardised formats. These datasets are often small and highly variable, and they are often referred to as the "long tail" of data. Standardising these datasets may well be either unachievable or prohibitively expensive. However, these datasets may well have value to multiple users and so should be findable and accessible, even if it is not possible to standardise and serve them up in ways that make them interoperable and easily reusable.

The Southern Ocean Action Plan requires the community to work with existing relevant initiatives within the polar and the oceanographic data communities to develop the tools and systems to support the aggregation and federation of standardised datasets as well as to discover long tail datasets. A further elaboration can be found in the section 'How to achieve - a Transparent and Accessible Southern Ocean'.

c. Long term sustainability of observatories and data stewardship

The FAIR data principles are designed to be implemented in the context of long-term data stewardship, where data centres have ongoing funding to ensure that datasets are maintained and continually made available to new generations of researchers, even as the sharing technology changes. It is important that contributing nations and programmes ensure that data management is supported for the long term.

d. Modelling

In order to fully understand the Southern Ocean, Earth system models and blended model-observation systems are needed across different disciplines and on different length and time scales. This includes large scale climate activities such as the WCRP Model Intercomparison Projects (MIPs) covering everything from scenario runs for the IPCC Assessments to more focussed MIPs on e.g. sea ice, ice sheets and oceans, to regional downscaling (e.g. Antarctic CORDEX) as well as focussed modelling efforts in the Southern Ocean (national and international), and finally process-based models that simulate species-level or ecosystem responses to changing drivers. Activities such as SCAR's AntClimNow are already working on the best use of modelling and observational data. Added to this, the use of new and novel techniques such as the Digital Twins/Digital Earths concepts, Artificial Intelligence, and Machine Learning techniques will be critical in the future.

5. Capacity building, inclusion, and diversity

a. Ensuring diversity of voices at the table, at all stages of planning, research, funding and data sharing

The current capacity of the Southern Ocean community is not sufficient to address all of the issues that are now being faced, many of which have important societal implications. It is imperative that programmes be developed to engage research communities around the world, at all career stages in Southern Ocean activities, and to build a community with true transdisciplinary capability. This is an important challenge that can be addressed through national, regional and international programmes that focus on diversity and equity, education and training, and capacity building. The UN Decade of Ocean Science provides the opportunity to coordinate across these programmes to ensure a diversity of voices at all stages. Transformations like these require the whole spectrum of activities, both short and long term, from tackling individual issues to changing overall mindsets and attitudes to ensure true diversity at the table. Learning from and collaborating with organisations that have expertise in issues related to diversity in the polar regions will only help ensure a richly diverse and welcoming Southern Ocean and polar community. Ensuring a diverse Southern Ocean and Polar community must be a priority. Grassroots networks and organisations like Women in Polar Science (gender diversity), Polar Impact (network of racial & ethnic minorities based mainly in UK and Europe), Pride in Polar Research (network of LGBTQIA+ polar researchers), amongst many other national, regional and global diversity initiatives draw attention to issues that require ongoing attention from the Southern Ocean community.

b. Capacity building

With global inequity of research funding, and polar research capabilities, for Southern Ocean research (and polar research in general) to thrive requires developing and strengthening the skills, abilities, processes and resources for researchers and organisations globally. Capacity-building provides for a transformation that is generated and sustained over time - the Antarctic and Southern Ocean community has many successful capacity building initiatives that may be expanded to reach a wider audience. Current initiatives include Fellowship programs run by international organisations like SCAR, COMNAP, IAATO, CCAMLR in the Southern Ocean, and also fellowships and ambassador programs from global organisations like POGO, SCOR and the All Atlantic Ocean Research Alliance. There are also further initiatives targeted to specific capacity building requirements that are coordinated at regional, national and organisational levels as required. Running a capacity building initiative for targeted skill building activities is also feasible, for example for Polar Ocean observation could be requested of the currently ongoing polar ocean observation programs.

Circumstances unique to Antarctic and Southern Ocean socio-ecological research systems may create a need for particular kinds of skills, organisational structure or leadership. These can be provided by developing innovative education and training systems that integrate different knowledge sources and contribute to building the skills needed for sustainability, enhanced participation of society and strengthened public understanding and awareness of the value of the Southern Ocean and the Polar Regions. Organisations like the Polar Educators International and APECS have led dialogue and collaboration between educators, and researchers,

thus highlighting and sharing the global relevance of the polar regions. Use of participatory methods develops and maintains the capacity for effective & sustainable management and informed decision-making in the Southern Ocean and polar regions. Innovative training systems developed for the Southern Ocean will contribute to both the Ocean Best Practices and may also be compiled within the Ocean Teacher Global Academy (OTGA), which has been endorsed as a UN Ocean Decade Action.

c. Improving technology for better access (open access to knowledge, data and science)

Technological improvements enhance both the quality and quantity of information, through expanded observations, and improve community knowledge by identifying the mechanisms for integration of different knowledge systems and knowledge co-production. New technologies such as autonomous platforms carrying sensors, automated distributed sampling hubs, increased use of emerging remote sensing capabilities, and advances in bandwidth capacity, can support safe and sustainable operations, reducing the need for human presence, and increasing the availability of knowledge. Enlarging the spatial coverage of autonomous platforms in air, ground, and water builds capacities and capabilities for exploration within the Southern Ocean, and also informs global research. Provision of virtual access to the Southern Ocean and the polar regions for researchers, and digital twinning activities will improve access to the research, the ensuing data and our knowledge of the polar systems.

The Southern Ocean Action Plan

THE SOUTHERN OCEAN ACTION PLAN

How to achieve a clean Southern Ocean

where sources of pollution are identified, reduced or removed

Ocean Decade Definition of the Outcome

Society generates a vast range of pollutants and contaminants, including marine debris, plastic, excess nutrients, anthropogenic underwater noise, hazardous chemicals, organic toxins and heavy metals. These pollutants and contaminants derive from a wide variety of land- and sea based sources, including point and non-point sources. The resulting pollution is unsustainable for the ocean and jeopardises ecosystems, human health and livelihoods. It will be critical to fill urgent knowledge gaps and generate priority interdisciplinary and co-produced knowledge on the causes and sources of pollution and its effects on ecosystems and human health. This knowledge will underpin solutions co-designed by multiple stakeholders to eliminate pollution at the source, mitigate harmful activities, remove pollutants from the ocean and support the transition of society into a circular economy.

Relevance

The Southern Ocean plays a key role in regulating global climate and other systems, as well as impacting a range of other important ecosystem services. It is thus imperative to address urgent knowledge gaps and generate interdisciplinary and co-produced knowledge on the causes and sources of pollution and its effects on ecosystems and human health and livelihoods. Finding innovative solutions to eliminate pollution at the source, mitigating harmful activities, and removing pollutants from the ocean, is critical to attain a clean ocean and support the transition of society into a circular economy. This includes finding solutions to pollutants and contaminants including marine debris, plastic, excess nutrients, anthropogenic underwater noise, hazardous chemicals, organic toxins, and heavy metals.

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Challenges Identified by the Working Group

Achieving a Clean Southern Ocean will require working jointly on four main areas:

Evaluating the extent of pollution in the Southern Ocean by implementing pollutant data coverage and monitoring. This includes assessing the distribution and concentration of pollutants generated from both internal and external sources and defining the behaviour of pollutants across the food chain as well as their response to specific environmental conditions in the Southern Ocean.

Improving our understanding of current and future effects of pollution on the Southern Ocean biota and ecosystems. This challenge will be achieved by identifying critical pollutant hotspots in the Southern Ocean, determining individual and cumulative toxicity thresholds and, identifying biological and genetic adaptation strategies that may provide resilience to potential impacts of different pollutants. Furthermore, it is important to set these challenges in the context of climate change by taking into account the interaction between pollutants and climatic stressors (i.e. see Box 3).

The achievement of the first two challenges will facilitate the accomplishment of the last two:

Preventing, mitigating, and recovering from environmental damages by identifying methods to prevent contaminants mobilisation and investigating how to facilitate the remediation of contaminated sites.

Developing strategies for a transition to greener practices. In terms of pollution, what happens in the Southern Ocean does not stay only in the Southern Ocean (and vice-versa). To achieve a Clean Southern Ocean, it is fundamental to promote a systematic and integrated global strategy and scale up from a regional to global scale approach. This challenge will include evaluating current practices for the supply of goods and material to the in situ Southern Ocean community, improving waste management, and reducing greenhouse gas emissions.

Overview

The table below displays the cross-cutting nature of specific research challenges related to Working Group 1.

Clean | Healthy and resilient | Productive | Predicted | Safe | Transparent and accessible | Inspiring and engaging

Challenges		Societal Outcomes
1 Evaluating the extent of pollution in the Southern Ocean		
1.1	Determine baseline knowledge of distribution and concentrations of current marine pollutants in polar species and the abiotic environment and identify data gaps (including potential presence of pollutants not yet detected).	
1.2	Increase data coverage to better understand the spatial (vertical and horizontal) and temporal distribution of pollutants of interest or concern in order to identify sources, processes, and accumulation “hotspots”.	
1.3	Identify local sources (e.g. around research stations) and external sources (e.g. ocean currents and atmospheric transport) of pollutants.	
1.4	Investigate processes involved in the remobilisation of contaminants in the marine environment (e.g. sea ice, ice shelves, or marine sediments).	
1.5	Understand the effect of the specific Antarctic environmental conditions (e.g. physical isolation caused by the Antarctic Circumpolar Current, low temperatures, seasonal light regime, sea ice, seasonal ozone depletion and UV radiation) on the distribution, degradation and sinking rates of contaminants.	

1.6	Develop interactive 3D model of pollutants distribution and movements to predict future scenarios.	
1.7	Understand how climate change impacts (changing wind patterns, currents and weather) may affect transfer, degradation and transformation of contaminants in the SO.	

2 Improving our understanding of current and future effects of pollution on the Southern Ocean biota and ecosystems

2.1	Identify the main pollutant pathways (e.g. POPs, heavy metals, microplastics) subject to trophic transfer and evaluate potential bioaccumulation and biomagnification in upper trophic levels.	
2.2	Understand which of these pollutants present the greatest threat and identify toxicity thresholds for key species.	
2.3	Investigate the multi stressors impact of different types of pollutants: how/ if interaction of pollutants generate additive, antagonist or synergistic stressors, which are the most sensitive species, and what does it mean for population dynamics?	
2.4	Address how pollutants can combine with other climatic stressors (e.g. climate change, other - ocean acidification, etc.) to produce lower biological thresholds in vulnerable species and ecosystems.	
2.5	Understand how increased anthropogenic noise from vessel operations, aircraft, construction, and other marine based scientific research affects marine life.	
2.6	Use ecotoxicogenomic approaches to identify biological and genetic adaptation strategies that may provide resilience to environmental contaminants.	
2.7	Determine levels of antimicrobial resistance in areas of high impact and understand the potential implications for Antarctic species. Understand the extent and mechanisms by which diseases spread between Antarctic species (e.g. cholera in penguins, SARS transmission).	
2.8	Assessing the main health risks for humans and animal populations of pollution in Antarctic environments (e.g. accumulation in commercially fished species, black water and waste from stations).	
2.9	Investigate what is the role of / if contaminants have a role in the decreasing trends for populations/ species (e.g. what is the role of contaminants in the total impacts on marine species?).	
2.10	Understand what impacts, if any, natural and anthropogenic pollution has on long-term Antarctic research activity, including monitoring.	
2.11	Assess the impacts, if any, pollution has on Southern Ocean krill harvesting, fisheries and tourism activity.	

3 Preventing, mitigating, and recovering from environmental damages

3.1	Develop a comprehensive inventory of existing sites and sources of contamination.	
3.2	Work with Antarctic operators to understand how waste materials (such as packaging) including plastics and microplastics) are being managed. Identify ways to share knowledge and best practice that will promote the reduction of waste at source, before loading onto Antarctic vessels and deployment to the Antarctic Treaty regions.	

3.3	Investigate how to facilitate remediation of contaminated sites at a large scale and low cost (e.g. improved understanding of microbial/fungal bioremediation of pollutants under conditions of low temperature and limited oxygen and water availability).		
3.4	Work with national programmes to inform further development of response plans for emergencies, including drift models that take into account ice-oil interactions.		
3.5	Assess how physical and social changes at the global scale (e.g. strengthening westerlies, increased urban development in the southern hemisphere) will change the distribution and concentrations of pollutants within the Southern Ocean.		
3.6	Identify best practice containment technologies and methodologies for Southern Ocean conditions to prevent mobilisation of contaminants.		
3.7	Investigate how fuels used in Antarctic vessels, including research vessels, can best be transitioned to cleaner, more environmentally friendly alternatives.		
3.8	Identify best practice remediation of contaminated sites technologies and methodologies, especially for at a large scale requirements and at low cost.		

BOX 3:
Hotspots of impact for Southern Ocean biota due to the concomitant presence of pollutants and climate-related stress.

Addressing pollutants as potential stressors in the Southern Ocean in isolation will not give the insight required to determine their true impact in years to come. Instead, it is fundamental to account for potential cumulative effects with other pollutants. Further, in the Southern Ocean pollution occurs concomitantly with other global environmental changes such as ocean acidification and ocean warming. The interaction between climate change and pollutants might influence the potential for pollutants interactions, as well as lead to enhanced susceptibility of biota to pollutants and/or climate change.

Being well adapted to extreme but stable environmental conditions, with unique phenotypic traits, Antarctic species are considered more vulnerable to environmental perturbations and pollutants, compared to species from lower latitudes. Keystone species that support Southern Ocean ecosystems already under threat by human-driven perturbations might be the best target to determine more realistic pollutants toxicity thresholds, where the biological thresholds to stressors can be lower in combination compared to in singularity.

To target specific mitigation actions it is fundamental to identify the critical hotspots area of impact for marine biota due to potential cumulative impact between pollutants and/or with climatic stressors (i.e. by the production of a multilayered environmental risk map)

Nevertheless, to expand pollutant study from single to multiple stressors is challenging when testing for two or more environmental stressors and there is a risk that evidence becomes more conflicting. This level of complexity will involve interdisciplinary efforts and encompassing empirical, experimental, and modelling approaches.

THE SOUTHERN OCEAN ACTION PLAN

How to achieve a healthy and resilient Southern Ocean

where marine ecosystems are understood and managed

Ocean Decade Definition of the Outcome

Degradation of marine ecosystems is accelerating due to unsustainable activities on land and in the ocean. To sustainably manage, protect or restore marine and coastal ecosystems, priority knowledge gaps of ecosystems, and their reactions to multiple stressors, need to be addressed. This is particularly true where multiple human stressors interact with climate change, including acidification and temperature increase. Such knowledge is important to develop tools to implement management frameworks that build resilience, recognise thresholds, and avoid ecological tipping points and thus ensure ecosystem functioning and continued delivery of ecosystem services for the health and well-being of society and the planet as a whole.

Relevance

The Southern Ocean is home to unique and iconic biodiversity and provides a range of important ecosystem services, including fisheries, wildlife tourism, nutrient cycling and climate regulation. It is thus imperative to address urgent knowledge gaps and generate interdisciplinary and co-produced knowledge on the key drivers of change and their impacts on Southern Ocean species, ecosystems and processes.

Challenges Identified by the Working Group

Achieving a Healthy and Resilient Southern Ocean will require working jointly on four main areas (Figure 2):

Improving our understanding of key drivers of change and their impacts on Southern Ocean species and ecosystems. This challenge requires fundamental information on Southern Ocean biodiversity, their biology and ecology, and the structure and functioning of Southern Ocean ecosystems across a range of spatial and temporal scales. It also requires an assessment of the impacts of climate change and other stressors (such as ocean acidification, plastic pollution, trace metals, and invasive species) on Southern Ocean biota and ecosystems and their vulnerability to these pressures. For the latter, it is also crucial to improve our understanding of cryo-pelago-benthic coupling processes and refine monitoring and modelling tools to predict future changes.

Highlighting the relevance of Southern Hemisphere ice (sea ice, land ice and subsea permafrost) in ecological processes of the Southern Ocean. This includes understanding the effects of ice on atmospheric and oceanic circulation as well as its impacts on marine ecosystems (i.e. food webs) and its contribution to climate change (i.e. carbon uptake, greenhouse gases, aerosols fluxes, sea level rise).

Improving our understanding of biogeochemical processes of the Southern Ocean linked to sea ice, glaciers, ice shelves and air. This challenge requires understanding the impact of ice retreat on carbon and sulphur fluxes into the Southern Ocean, including the distribution of climate-active gases and halogens. Understanding ocean-cryosphere-atmosphere interactions will not only enable us to improve our understanding of the biological carbon pump, it will also enable us to identify the key drivers of primary production.

Improving our understanding of the Southern Ocean's role within the global climate system by evaluating impacts of the ozone hole and its recovery on marine ecosystems, and by improving our understanding of natural modes of climate variability, and investigating how greenhouse gases will be released and how they will affect climate and ecosystems.

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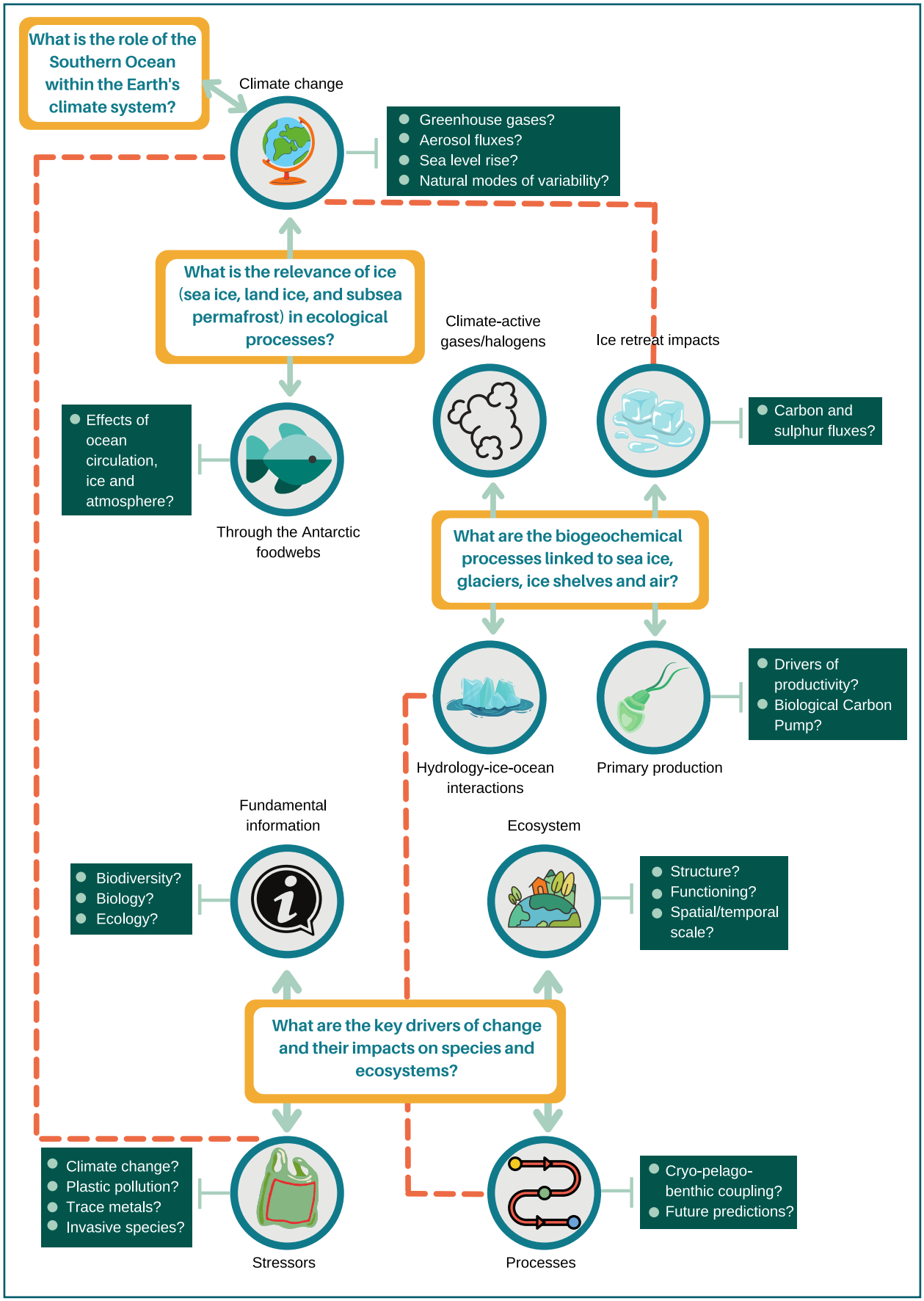


Figure 2. Conceptual diagram illustrating the challenges and specific topics within each challenge that should be addressed to achieve a Healthy and Resilient Ocean. Dashed lines represent transdisciplinary connections between challenges.

Overview

The table below displays the cross-cutting nature of specific research challenges related to Working Group 2.

Clean | Healthy and resilient | Productive | Predicted | Safe | Transparent and accessible | Inspiring and engaging

Challenges		Societal Outcomes
1 Improving our understanding of key drivers of change and their impacts on Southern Ocean species and ecosystems		
1.1	Improve our fundamental knowledge of the biodiversity, physiology and ecology of Antarctic marine organisms across a range of spatial and temporal scales (e.g. ice associated, mesopelagic, deep-sea and benthic communities at the regional and circumpolar scales).	
1.2	Determine life histories and their strategies (including habitat use) of key species.	
1.3	Understand the interactions of various life stages of plankton species with other food web components (including microzooplankton and phytoplankton, ice algae, migrant and resident predators and benthic communities) and the potential consequences for energy flow and biogeochemical cycling.	
1.4	Determine the structure and functioning of Southern Ocean ecosystems.	
1.5	Determine the key drivers of change and their impacts on Southern Ocean species and ecosystem structure and functioning. This should include emphasis on the effects of changing sea ice conditions on key species (e.g. Antarctic krill, upper trophic level species).	
1.6	Distinguish the impacts of physical climate change due to anthropogenic processes/stressors on Southern Ocean food web structures from natural variability.	
1.7	Investigate the potential changes in Southern Ocean systems occurring from influences of climate change and direct and indirect human activities (e.g. marine traffic, tourism, fishing, pollutants (including emerging pollutants and plastics), invasive species, parasites and diseases).	
1.8	Understand the impacts of invasive species and range shifts of native species on ecosystems and human well-being.	
1.9	Identify which pathways for alien species introductions present the greatest risks and which locations are most vulnerable to invasion.	
1.10	Assess the origin, fate and effects of Southern Ocean pollution (e.g. plastics, trace metals, POP´s) in Antarctic ecosystems.	
1.11	Identify biosecurity techniques to reduce introduction risk and develop methods to respond to existing invasions and a programme of disease surveillance/detection.	
1.12	Understand the role of microbiomes in Antarctic ecosystems.	

1.13	Improve our understanding of cryo-pelago-benthic coupling and the impacts of multiple drivers on different ecoregions (e.g. shallow, deep, off- and in-shore, high and low latitudes, bays, canyons, exposed shelf areas etc.).	
1.14	Understanding bacteria-algae coupling under potential future impacts scenarios.	
1.15	Identify marine biogeographic regions of biodiversity and related processes and their importance in maintaining ecosystem structure and functioning, ecosystems services and conservation.	
1.16	Understand how changes in environmental factors will manifest in population-, community- and ecosystem-level changes (e.g. persistence or emergence of pathogenic forms of microbial species in future conditions).	
1.17	Understand the impacts of changing ocean circulation and water mass properties on early life history stage dispersal and colonisation.	
1.18	Understand co-evolution between species or disruption of key marine interactions.	
1.19	Determine the key factors for speciation.	
1.20	Assess the spatio-temporal impacts of ocean acidification and deoxygenation on upper ocean biogeochemical processes and food web dynamics.	
1.21	Understand the role of iron (and other trace metals) in shaping the environment: address sources (e.g. hydrothermal, sedimentary, glacial, sea-ice), role on microbial and micro-algal growth and in food web recycling, the impact of microbial ligands-EPS, siderophores, and microbes in regulating trace metal availability for biogeochemically important processes like nitrification, denitrification and silica assimilation.	
1.22	Understand how deep-sea ecosystems respond to modifications of deep-water formation, and their interactions with shallow water ecosystems.	
1.23	Investigate the physiological limitations, thresholds and tipping points of Antarctic marine organisms and their consequences in Antarctic ecosystems.	
1.24	Determine the resilience of zooplankton species to change.	
1.25	Identify the potential of biological and genetic adaptation of organisms to environmental change that may provide resilience.	
1.26	Determine thresholds leading to extinction & collapse.	
1.27	Assess the vulnerability of Southern Ocean ecosystems to combined, multi-stressor human and natural influences.	
1.28	Identify key marine species as biomonitors of trophic interactions, food web structure and environmental change, and develop a system of “ecosystem health”.	
1.29	Evaluate long-term trends of change in Southern Ocean ecosystems (e.g. using use of long-term monitoring programmes and historical data).	
1.30	Impact of changes in the Southern Ocean physical characteristics on the functioning and adaptations of the microbial loop, and the coupled rates of carbon transfer across trophic levels.	
1.31	Improve modelling tools to predict future change in the Southern Ocean in the context of the IPCC framework.	

1.32	Identify how the uniqueness and endemism of Southern Ocean species and ecosystems (and their intrinsic value) respond to global change and other stressors.	
1.33	Determine how fast mutation rates are and how extensive gene flow is.	
1.34	Identify and develop metrics or indicators to monitor the status and resilience of Antarctic social-ecological systems.	
1.35	Identify molecular and cellular adaptations and understand the functioning of cells at low temperatures.	
1.36	Understand how proteins function at low temperatures and how they interact differently with other cell components (e.g. water, osmolytes) from warmer water species.	
1.37	Assess genetic/genomic biodiversity status of Antarctic marine organisms in relation to their resilience and adaptation.	
1.38	Evaluate how Antarctic marine food webs compare to other food webs elsewhere in terms of resilience and adaptation.	
1.39	Promote the future development of conservation of Southern Ocean ecosystems under different protection scenarios, including ecologically connected and climate smart networks of Marine Protected Areas, assess actual strategies and propose new concepts, being eventually more efficient and being adapted to recent and future developments.	
1.40	Assess how changes in Southern Ocean biodiversity will affect global marine biodiversity (at both the species and functional level), fisheries and foodwebs.	
1.41	Improve understanding of the high benthic patchiness (hot and cold spots in terms of biodiversity, endemism and ecosystem functions) to identify key processes and vulnerable communities and support ecosystem management and conservation.	
1.42	Determine anti-microbial resistance levels in Antarctic marine organisms.	
1.43	Understand how diseases spread between Antarctic invertebrate and vertebrate species.	

2 Highlight the relevance of Southern Hemisphere ice (sea ice, land ice and subsea permafrost) in ecological processes of the Southern Ocean

2.1	Understand the differences between various ice types for ecosystem structure and functioning.	
2.2	Evaluate the impact of sea-ice variability on the base of the Antarctic food web and the consequences for ecosystem structure and functioning.	
2.3	Define the uniqueness of sea-ice species in terms of their intrinsic value and role in ecosystem services (e.g. genetic and medicinal resources).	
2.4	Understand ocean circulation, properties and processes beneath Antarctic sea ice and ice shelves.	
2.5	Understand how the sea-ice ecosystem is linked to the pelagic and benthic ecosystem.	
2.6	Understand influences of changes in freshwater fluxes from iceberg melting, sub-ice shelf melting, subglacial discharge and sea ice on ocean circulation, biogeochemistry and marine ecosystems.	

2.7	Quantify sea ice-ocean-atmosphere characteristics and biological processes including floe-size distribution, wave-ice interaction and deformation processes at the ice edge/marginal ice zone. This is critical to understand processes that drive change and variability in the volume, properties, floe-size and distribution of Antarctic sea ice and consequent impacts on atmospheric and oceanic properties, and circulation in marine biogeochemistry and ecosystems.	
2.8	Understand dynamics of the Antarctic fast-ice belt and its role in protecting glacier/ice shelf fronts, polynya formation/maintenance and water-mass modification.	
2.9	Evaluate the contribution of seasonally ice-covered areas to greenhouse gases and aerosols fluxes, carbon uptake and export.	
2.10	Assess the spatial, seasonal and interannual distribution of essential climate variables in the sea-ice-impacted Southern Ocean to decrease uncertainty on air-sea-ice fluxes.	
2.11	Evaluate the contribution of seasonal variability of sea ice to heat budgets, considering turbulent fluxes at the ocean-atmosphere interface.	
2.12	Explore the differences in sea ice processes between the Arctic and Antarctic.	
2.13	Understand the role of fast ice for the ecosystem at the end of winter/start of summer and if there is environmental risk if broken out early by shipping.	
2.14	Understand ocean circulation properties and processes beneath Antarctic sea ice and ice shelves.	
2.15	Understand dynamics of the Antarctic fast-ice belt and its role in protecting glacier / ice shelf fronts, polynya formation/maintenance and water-mass modification relevant to Antarctic ecosystems.	
2.16	Assess the spatial, seasonal and interannual distribution of essential climate variables in the sea ice-impacted Southern Ocean to decrease uncertainty on air-ice- sea fluxes.	

3 Improving our understanding of biogeochemical processes of the Southern Ocean linked to sea ice, glaciers, ice shelves and air

3.1	Evaluate how sea level rise may provide changes or create new habitats.	
3.2	Understand the importance of sea ice for the life history of polar species.	
3.3	Understand the wider impact of ice retreat on carbon and sulfur fluxes (and dissolved organic matter [DOM] chemistry) into the ocean (e.g. in microbiome and microbial loop) and the atmosphere and how these may vary according to actions/management decisions.	
3.4	Understand influences of changes in freshwater fluxes from iceberg melting, sub-ice shelf melting, subglacial discharge and sea ice on ocean circulation and marine ecosystems.	
3.5	Improve subglacial and continental shelf bathymetry to understand how it affects Antarctic ice sheet, and related ecosystems, response to climate change.	
3.6	Understand the impact of climate change on Antarctic subsea permafrost and its effects on ecosystems and biogeochemical cycles.	
3.7	Develop a comprehensive approach to study the hydrology-ice-ocean interactions.	

4 Improving our understanding of the Southern Ocean's role within the global climate system

4.1	Understand patterns and variations in nutrient dynamics and biogeochemical processes at various spatial and temporal scales, and their interactions with physical and biological processes.	✓	
4.2	Understand the role of metabolic diversity and evolution in Southern Ocean biogeochemical cycling and ocean ecosystem processes.	✓	
4.3	Understand the feedbacks between Southern Ocean circulation, water masses, biogeochemical cycling and the cryosphere, including the role of coastal and open ocean polynyas.	✓	
4.4	Assess the spatial, seasonal and interannual distribution of climate-active gases (e.g. dimethylsulfide) and halogens in ice-covered and ice-free waters.	✓	
4.5	Understand the fluxes of climate relevant components (e.g. aerosols, gases) between the ocean, ice and atmosphere.	✓	✓
4.6	Determine the key drivers of primary productivity and the Biological Carbon Pump - light, predation and nutrient supply - and assess ongoing changes in these parameters.	✓	
4.7	Quantify the impact of recycling and remineralisation, including via the Microbial Carbon Pump, on nutrients and carbon cycling in the water column and by macro- meio- as well as microbenthic communities.	✓	
4.8	Understand the role of physical processes such as upwelling, mixing and lateral oceanic advection on nutrient and CO_2 distributions and fluxes.	✓	
4.9	Understand impacts of the combined changes in ocean physics and marine ecosystems on the Southern Ocean sink for CO_2.	✓	
4.10	Identify the effects of Westerly winds on ocean circulation, carbon uptake and global teleconnections.	✓	
4.11	Prioritise understanding of the role of Antarctic krill, salps, and other organisms, such as cetaceans, in the role of carbon uptake, storage and long-term sequestration.	✓	
4.12	Estimating the efficiency of biological pump of C, S and N using sediment traps, being an insight into microbes associated with sinking particles and composition of aggregates.	✓	
4.13	Understand how the recovery of the ozone hole will affect regional and global atmospheric circulation, climate and ecosystems.	✓	
4.14	Understand the processes controlling the polar ecosystems (i.e. Antarctic and Arctic), including the climate system, the socio-ecological system structure and functioning, and the different knowledge systems and their multiple interactions.	✓	
4.15	Understand the ocean's role in determining/modulating natural modes of climate R4.16 variability at both global and regional scales.	✓	
4.16	Understand the specific role of sea-ice (dominated) areas in determining climate variability.	✓	
4.17	Determine and understand the mechanisms of regional variation in climate regulation.	✓	
4.18	Enhance understanding of processes controlling, and feedbacks resulting from, the interactions between the polar climate system components using data acquisition and long-term observation.	✓	
4.19	Identify key interaction and feedback processes across spatio-temporal scales and improve the description of these processes in coupled earth system models and in coupled regional models.	✓	

4.20	Improve understanding of greenhouse gas climate sensitivity and climate forcing, through improved inclusion of interactions between atmosphere, ocean, cryosphere and biogeochemical cycles in models.	●	●
4.21	Understand the role of human impacts on the Southern Ocean, particularly the impact of anthropogenic heat and carbon on water mass properties, formation and circulation, and the changes in surface fluxes and freshwater input from the cryosphere.	●	
4.22	Understand what the regional and coastal impacts of a changing climate are upon sea level, ocean heat content, ocean-cryosphere interactions and the water cycle.	●	
4.23	Understand what processes control coastal dynamics and upwelling systems, including the impacts of a changing climate.	●	
4.24	Understand what the oceanic constraints on transient climate sensitivity are, including air-sea exchange, ocean heat uptake and transport, and the Earth's energy budget.	●	
4.25	Understand how volcanic activity affects the global atmosphere, the stability of cryospheric components (i.e. glaciers and ice sheets) and marine ecosystems.	●	
4.26	Investigate whether greenhouse gases stored in Antarctic and Southern Ocean clathrates, sediments, soils, and permafrost will be released as climate changes.	●	
4.27	Understand how the Southern Ocean regulates Southern Hemisphere clouds and climate.	●	●
4.28	Advance the understanding of ecological feedbacks in the Earth System.	●	●
4.29	Quantify the contribution of Southern Ocean ecosystems to global carbon cycle.	●	●

THE SOUTHERN OCEAN ACTION PLAN

How to achieve a productive Southern Ocean

supporting sustainable food supply and a sustainable ocean economy

Ocean Decade Definition of the Outcome

The ocean is the foundation for future global economic development and human health and well-being, including food security and secure livelihoods for hundreds of millions of the world's poorest people. Knowledge and tools to support the recovery of wild fish stocks, deploy sustainable fisheries management practices and support the sustainable expansion of aquaculture, while protecting essential biodiversity and ecosystems, will be essential. The ocean also provides essential goods and services to a wide range of established and emerging industries, including extractive industries, energy, tourism, transport and pharmaceutical industries. Each of these sectors has specific, priority needs in terms of increased knowledge and support to innovation, technological development and decision support tools to minimise risk, avoid lasting harm and optimise their contribution to the development of a sustainable ocean economy. Governments also require information and tools, for example via national accounts that incorporate ocean indicators, to guide development of sustainable ocean economies and promote marine sectors.

Relevance

The ocean provides essential resources and services that are key to the global economic development, human health and wellbeing. Ensuring the sustainable expansion of marine activities such as deploying ecosystem-based fisheries management practices and developing greener tourism approaches is not only necessary to protect the unique biodiversity and ecosystems of the Southern Ocean, it will also secure food supply and livelihoods for millions of people around the globe.

Challenges Identified by the Working Group

Achieving a Sustainable and Productive Southern Ocean will require working jointly with key stakeholders including those responsible for the conservation and management of the region (ATS, CCAMLR) and the industry (fishing, tourism) on four main areas:

Improving our assessment of the current status of the ecosystems supporting essential services. Achieving this challenge would require identifying and developing relevant ecological indicators to evaluate risks to the Southern Ocean; improving our understanding of the consequences of human-induced change on polar ecosystem services; developing new guidelines for ecosystem monitoring and assessment. All the former would allow assessing how much ecosystem services the Southern Ocean ecosystem contribute to the global budget and whether they will change in space and time.

Achieving sustainable management of fisheries based on an ecosystem approach, including the recovery of overexploited species and the effect of climate change on ecosystems. This challenge is a pivotal requirement, needing substantial collaboration with other working groups (i.e. see Box 4). Crucial steps include improving understanding of Antarctic species sustainability and resilience; developing new methods to effectively integrate both quantitative and qualitative data, and analysing the expected effects of crossing thresholds that are likely to be irreversible in the near term; developing integrated stock assessments that take into consideration the ecosystem where the fishery operates; developing Decision Support Tools (DSTs) for time-effective delivery of advice; and developing recovery strategy plans for overexploited species, considering their ecological role and current and future status of the ecosystem.

Ensuring science-based and effective spatial planning process, including MPAs, with consideration of sustainable fisheries and tourism management. This challenge will require assessing the effectiveness of existing Southern Ocean Marine Protected Areas, as well as conducting new research to support monitoring and management of new and existing MPAs. This should consider effects on ecosystem processes, sustainable use of resources, historical changes, future projections on species distribution, and climate-driven change.

Ensuring a sustainably harvested and productive Southern Ocean by working towards a stronger interface between science, industry and policy. Essential to the success of this programme is the connection between scientific and policymaking processes. Identified challenges include determining how complexity and uncertainty in our understanding of the functioning of these ecosystems should be reflected in the preparation and delivery of management advice; discussing the need for sustainable use of resources in light of changing environments and expanding human needs; investigating what ways research and policy can effectively tackle the whole extraction cycle, from exploration to the final stage of closure of operations, and related remediation and reclamation activities, among others.

Overview

The table below displays the cross-cutting nature of specific research challenges related to Working Group 3.

Clean | Healthy and resilient | Productive | Predicted | Safe | Transparent and accessible | Inspiring and engaging

Challenges		Societal Outcomes
1 Improving our assessment of the current status of the ecosystems supporting essential services		
1.1	Identify and develop relevant ecological indicators to evaluate risks to the Southern Ocean and services it provides and to monitor health and rates of ecosystem change and its interactions with human activities.	
1.2	Improve the understanding of the consequences of human-induced change on polar ecosystem services.	

1.3	Create guidelines for sustainable monitoring and regular assessments that enable us to assess our progress towards the desired states.		
1.4	Improve our understanding of key mechanisms regulating the ecosystem in the winter.		
1.5	Assess how much ecosystem services of the Southern Ocean ecosystem contribute to a global budget, and whether they will change in space and time.		
2 Achieving sustainable management of fisheries based on an ecosystem approach, including the recovery of overexploited species and the effect of climate change on ecosystems			
2.1	Improve understanding of fish stock sustainability and resilience integrating oceanographic, climate, ecosystem structure and functioning, connectivity and harvesting interactions.		
2.2	Identify new methods to effectively integrate both quantitative and qualitative data, identify critical data gaps, and analyse the likely effects of crossing thresholds that are likely to be irreversible in the near term.		
2.3	Develop integrated stock assessments which take into consideration the ecosystem where the fishery operates.		
2.4	Develop models considering the functional connectivity among ecosystem elements, including drivers in all cardinal directions (e.g. circumpolar, Subtropical effect on polar regions).		
2.5	Identify thresholds or abrupt or irreversible changes.		
2.6	Develop Decision Support Tools (DSTs) for the timely management of fishing quotas.		
2.7	Develop recovery strategy plans for overexploited species, considering the ecological role and current and future status of the ecosystem (which may affect their realised recovery abundance).		
2.8	Understand the role of Myctophid for consumers, producers and as an extractable resource.		
2.9	Understand the role of Mackerel icefish for consumers, producers and as an extractable resource.		
2.10	Progress on the understanding and managing of toothfish species.		
2.11	Progress on the understanding and managing of Antarctic krill.		
3 Ensuring science-based and effective spatial planning process, including MPAs, with consideration of sustainable fisheries and tourism management			
3.1	Assess the success of existing Southern Ocean Marine Protected Areas in meeting their conservation objectives, including as scientific references areas, and determine additional requirements for the achievement of regional conservation and research objectives.		
3.2	Contribute to the delivery of effective Southern Ocean spatial planning, including new research and monitoring to support new and existing MPAs, considering effects on ecosystem processes, sustainable use of resources, historical changes and future projections on species distribution, and climate-driven change.		

3.3	Develop informed strategies for management adaptation and conservation priorities at different time-scales.		●		
3.4	Identify mechanisms to harmonise Southern Ocean conservation priorities and the sustainable management of human activities.		●		●
3.5	Develop a framework to assess responsible and sustainable marine transport and tourism industries in harmony with the spatial planning of the Southern Ocean.	●	●		
4 Ensuring a sustainably harvested and productive Southern Ocean by working towards a stronger interface between science, industry and policy					
4.1	Determine how the complexity and uncertainty in our understanding of the functioning of these ecosystems should be reflected in the preparation and delivery of management advice.		●	●	●
4.2	Assess the need for sustainable resource utilisation in light of changing environments and expanding human needs.		●		●
4.3	Determine how the Southern Ocean can contribute to blue growth and a low carbon energy transition.		●	●	
4.4	Investigate what ways research and policy can effectively tackle the whole extraction cycle, from exploration to the final stage of closure of operations, and related remediation and reclamation activities.		●		●
4.5	Identify the institutional, political and practical obstacles challenging the decision-making process at CCAMLR.		●		●
4.6	Assess how external pressures and changes in the geopolitical configurations of power affect Antarctic governance and science.		●		●
4.7	Knowledge enabling Antarctic operators to be leading contributors in developing a responsible strategy for achieving economic gains with sustainable solutions and inclusive benefit from a green economy.	●	●	●	●

BOX 4:
Improving the management of Antarctic krill

Antarctic krill Euphausia superba is one of the most abundant organisms on the planet, playing a critical role in the Antarctic food web by connecting lower and upper trophic levels, recycling organic iron and sinking significant amounts of carbon to the aphotic zone. It also supports the largest fishery in the Southern Ocean, with over 400,000 tonnes caught in 2020. Despite its abundance, increasing demand by recovering baleen whales, growing fishing interests, coupled with decreasing productivity associated with climate change, pose concerns regarding its future sustainability. Yet, the interaction among these factors remains poorly understood.

An improved management regime for Antarctic krill is being developed by CCAMLR. Still, its successful implementation will require extensive data and capabilities yet to be developed. Ongoing interaction with other research groups, such as the Scientific Committee on Antarctic Research Krill Action Group (SKAG), will help in bringing the necessary expertise.

Targeted research is needed to understand, among others, the Antarctic krill's resilience to climate change, the effects of sea-ice on population dynamics, stock-recruitment relationship, connectivity among regional stocks. All the above will require extensive research and modelling efforts, including targeted surveys and expanding monitoring during winter amid a dwindling availability of at-sea research platforms.

The main challenges for this Ocean Decade Societal Outcome include expanding monitoring programs and the development of robust, integrated assessments capable of integrating available data, combining individual and ecosystem models to understand population variability, for informing fishery management decisions.

The above will require solving practical issues, such as developing tools capable of collecting data autonomously, over extended periods under harsh Antarctic conditions. New partnerships for collecting data will be crucial for achieving some of these objectives, including from fishing and tourist industries, which have demonstrated capacity for sampling Antarctic krill, predators (i.e. albatrosses, penguins, seals, whales) and the environment. In addition, data will need to be transmitted in nearly real-time for analysis and use on feedback-management decisions.

THE SOUTHERN OCEAN ACTION PLAN

How to achieve a predicted Southern Ocean

where society understands and can respond to changing ocean conditions

Ocean Decade Definition of the Outcome

The vast volume of the ocean is neither adequately mapped nor observed, nor is it fully understood. Exploration and understanding of key elements of the changing ocean, including its physical, chemical and biological components and interactions with the atmosphere and cryosphere, are essential, particularly under a changing climate. Such knowledge is required from the land-sea interface along the world's coasts to the open ocean and from the surface to the deep ocean seabed. It needs to include past, current and future ocean conditions. More relevant and integrated understanding and accurate prediction of ocean ecosystems and their responses and interactions will underpin the implementation of ocean management that is dynamic and adaptive to a changing environment and changing uses of the ocean.

Relevance

The Southern Ocean has a critical role in global climate, the uptake and sequestration of carbon dioxide, global warming mitigation, and global ocean productivity. The current models implemented for Southern Ocean systems are useful for accessing scenarios of change and future states, but are limited by our current understanding of key biological, chemical, and physical drivers of change and consequent impacts. An integrated view of the Southern Ocean, including its connectivity to global climate and sea level, is critical for predictions of its future states. Predictions at decadal time scales will enable decision makers to develop holistic and timely management responses to a changing environment.

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

Challenges Identified by the Working Group

Achieving a Predicted Southern Ocean will require working jointly on three main areas:

Improving understanding of fundamental processes and responses to change. This challenge highlights the need for integrated studies of physical, biogeochemical and ecological processes and interactions across multiple scales in the three-dimensional ocean and of responses to changes to multiple drivers. In particular, improved understanding of seasonal dynamics and variation in regional systems throughout the circumpolar Southern Ocean is critical to developing scenarios of change and projections of future states. This challenge requires coordination and support of existing observing programs, inclusion of a broader community and wider stakeholders in observing efforts, open data sharing (FAIR data, joint with working group 6), and data collection using standardised methods. It is critical that data collection and quality be sufficient to support high-resolution models implemented for regional, circumpolar and climate studies.

Enhancing and expanding observational capability to support predictions. This challenge recognises that sustained observational networks with sampling resolution sufficient to provide a framework of essential ocean variables data, initial conditions, boundary forcing, and parameterisation are crucial for model calibration, intercomparison, and verification which in turn are critical to advancing predictive capability. In addition to regional observational programs, implementation of coordinated, international, circumpolar observational programs provide important observations of the three dimensional connectivity and flows into and out of the Southern Ocean including physical and chemical interactions with the atmosphere and cryosphere and changes in species diversity, abundance, and distribution. Continuation and expansion of regional observations to encompass a wider range in systems will allow quantification of life histories of key species, development of a total carbon budget, coverage of the annual production cycle, and quantification of the role of sea ice in regulating ecosystem production; all are integral to predictions relevant to policy and management.

Improving and enhancing Southern Ocean modelling capability. This challenge recognises that modelling needs vary depending on the time and space-scales of the desired prediction. Continued development of high resolution regional circulation models and their inclusion in circumpolar and global models are critical for prediction of ocean-ice sheet and air-sea interactions, water mass formation, and freshwater fluxes. Integrated models with end-to-end integration across ecological and biogeochemical processes, coupled life histories of key species, food webs and biogeochemical cycling and incorporating projections of carbon cycling and fluxes and Southern Ocean impacts on global productivity are needed to elucidate the effects of multiple stressors on Southern Ocean ecosystems and are crucial to inform decision making for conservation and management.

Overview

The table below displays the cross-cutting nature of specific research challenges related to Working Group 4.

Clean | Healthy and resilient | Productive | Predicted | Safe | Transparent and accessible | Inspiring and engaging

Challenges		Societal Outcomes
1 Improving spatial and temporal coverage of observations		
1.1	Year round observations.	
1.2	Observations in more regions.	
1.3	Characterising regional seasonal variation/variability.	

1.4	Expanding observations of under ice environments.	
1.5	Characterisation of vertical fluxes.	
	2 Better measurements of sea ice volume	
2.1	Accurate estimates of volume crucial to understand thermodynamics.	
2.2	Antarctic-calibrated sea ice models.	
2.3	Improved knowledge of snow-ice ratios and densities.	
2.4	New approaches for measuring thickness.	
	3 Observing and modelling across trophic levels	
3.1	Primary productivity and fate of carbon throughout the water column.	
3.2	Improved observation and modelling of mesopelagic species and ecosystems.	
3.3	Improved models of higher predator movement and distributions.	
3.4	Improved knowledge and models of changes in behaviour and distributions of species at different trophic levels in a range of habitats.	
	4 Improving regional environmental models	
4.1	Improved Southern Ocean specific model parameterisation.	
4.2	Detailed modelling of carbon cycling including improved representation of biological processes.	
4.3	Analyses and models of three-dimensional fluxes (biogeochemical and ecological).	
4.4	Development of high resolution models for the Southern Ocean and approaches to downscaling from global models to improve projections.	

THE SOUTHERN OCEAN ACTION PLAN

How to achieve a safe Southern Ocean

where life and livelihoods are protected from ocean-related hazards

Ocean Decade Definition of the Outcome

Hydro-meteorological, geophysical, biological and human-induced hazards create devastating, cascading and unsustainable impacts for coastal communities, ocean users, ecosystems and economies. The changing frequency and/or intensity of weather- and climate- related hazards is exacerbating these risks. Mechanisms and processes for assessing priority risks, mitigating, forecasting and warning of these hazards and formulating adaptive responses are required to reduce short- and longer-term risks on land and at sea. Higher density ocean data and improved forecast systems – including those related to sea level, marine weather and climate – are needed from near real time through to decadal scales. When these enhancements are linked to education, outreach and communication, they will empower policy and decision-making and they will mainstream individual and community resilience.

Relevance

The changes in frequency and intensity of ocean-related hazards are a reflection of the relentless environmental and anthropogenic pressures that oceans are experiencing today. Because there are additional constraints related to the unique conditions of the Southern Ocean, ensuring a safe Southern Ocean will require stronger collaborative efforts, especially given the unique political context of Antarctica.

The Southern Ocean presents very particular challenges to those operating in and transiting through its waters. Along with the extreme conditions there are specific hazards including those related to sea ice formation and the issues related to how sparsely sensed and accessed the Southern Ocean is in general. Given this background, it is clear that for the Southern Ocean it is imperative to coordinate risk mitigation measures amongst operators, both national and commercial, and provide the best possible information on which to make safety related decisions. The opportunity exists to consider engagement with the Southern Ocean in a broader context to include perceptions of those impacted by the Southern Ocean, e.g. in near shore environments, more widely and over longer time scales.

Further, inflow of relatively warm waters into the ice-shelf cavities of the Antarctic ice sheet poses a less perceivable though very real risk. Ocean-forced instability of the Antarctic ice sheet is a major tipping point under global warming and will cause significant sea level rise posing a threat to coastal areas across the globe. It is of eminent importance to both enhance awareness of this remote, slowly progressing, hardly stoppable threat and improve our capabilities to observe current and future warming and ice melt in the Southern Ocean.

Challenges Identified by the Working Group

Achieving a Safe Southern Ocean will require working jointly on four main areas:

Improving forecasting capabilities to produce outputs that are matched to the needs of the users and reflect the changing activities in the Southern Ocean and the influence of climate change. Co-design in this process will be essential to produce information and services that have operational relevance but feed into longer term development in areas such as governance. Southern Ocean climate prediction suffers from regional biases in global climate models, which are mostly due to a lack of knowledge of regional key processes demanding a tighter network of observations and enhanced community efforts across disciplines. The outcomes of the WMO Year of Polar Prediction should feed into improving predictability at weather and shorter climate timescales.

Understanding the impacts of changing environmental conditions on risk and vulnerability. Building on the state of the art research available there is a need to develop trans-disciplinary projects to: communicate research findings around changing environmental conditions and impacts to Southern Ocean stakeholders and communities; enhance

engagement, education and services; and investigate ways to build resilience and adaptability and reduce risks to human safety.

Improving emergency response competences by working with partners including the Marine Rescue Coordination Centres to identify risks, vulnerabilities and knowledge gaps to enhance existing operations. Identify those technologies and institutional mechanisms that are appropriate to support the flexibility and capabilities required to build future resilience.

Engaging with policy-makers. Work collaboratively with policy-makers to ensure that awareness of threats and associated thresholds with regard to risks and hazards are understood and the benefit of supporting research to address these is widely communicated and achieves the broadest support possible.

Overview

The table below displays the cross-cutting nature of specific research challenges related to Working Group 5.

Clean | Healthy and resilient | Productive | Predicted | Safe | Transparent and accessible | Inspiring and engaging

Challenges		Societal Outcomes
1 Improve forecasting capabilities		
1.1	Understand how the probability of extreme events (thermal, hydrological etc.) changes under global warming and natural low-frequency variability and how this affects our ability to predict such events.	
1.2	Develop the techniques that will allow downscaling from global to regional and local-scale environmental forecasts.	
1.3	Understand how extreme events affect the Antarctic cryosphere and Southern Ocean.	
1.4	Develop more detailed risk maps of storm surges.	
1.5	Quantify, forecast and determine vulnerabilities to severe space weather events.	
1.6	Understand how Antarctic processes affect mid-latitude weather and extreme events.	
2 Understand the impacts of changing environmental conditions on risk and vulnerability		
2.1	Understand how physical changes, and resulting biological effects ultimately cascade and lead to unpredictable, compounded contingencies, risks and impacts for economic and societal actors.	
2.2	Assess which communities, economic sectors and activities that base their livelihoods in/around the Southern Ocean are most vulnerable in the face of emergencies, and why (e.g. is it due to a policy issue, systemic injustices, etc.).	
2.3	Understand how the changing conditions and changing dimensions of human activities in the Southern Ocean impact the type and level of risk and vulnerability, as well as determine where these risks and vulnerabilities are.	
2.4	Identify risks and vulnerabilities in the Southern Ocean in order to define adaptation and mitigation actions in response to climate change.	

2.5	Identify the processes controlling the stability and equilibrium of glaciers and ice sheets and how they will affect future global sea level.	
2.6	Understand how the characteristics of the ice sheet bed, such as geothermal heat flux and sediment distribution, affect ice flow and ice sheet stability.	
2.7	Estimate CO_2 equivalent thresholds that may foretell collapse of all or part of the Antarctic Ice Sheet.	
2.8	Understand the tsunami hazard resulting from instability on Antarctic continental margins.	
2.9	Understand the extensive dissociation of gas hydrates in submarine and subglacial sediments.	
3 Improve emergency response competences		
3.1	Understanding user needs and human behaviour. Through co-production of knowledge, information services, trans-disciplinary projects, and research that empirically examines user perceptions, decisions, and responses to forecasts (environmental predictions) and hazard warning messages we can enhance services and increase human safety and resilience.	
3.2	Enhance care of the environment and the security of navigation by ensuring all vessels are required at their ports of departure to comply with the Polar Code, SOLAS and MARPOL before entering the Southern Ocean.	
4 Engage with policy-makers		
4.1	Understand how communities and Southern Ocean operators perceive the risks of a changing environment, how they may be impacted, how they may adapt and their future environmental information needs. Develop trans-disciplinary projects to: communicate research findings around changing environmental conditions and impacts to Southern Ocean.	
4.2	Work with operators and National programmes to understand Antarctica as a workplace, including workers' perceptions of safety, workforce makeup, and the training and capabilities needed for the future polar workforce.	
4.3	Work proactively with with governance bodies to ensure the most recent and relevant research informs updated guidance and regulations.	
4.4	Work to include an emphasis on the co-creation of policy that safeguards the health and well-being of the Southern Ocean socio-ecological system (which includes human use).	

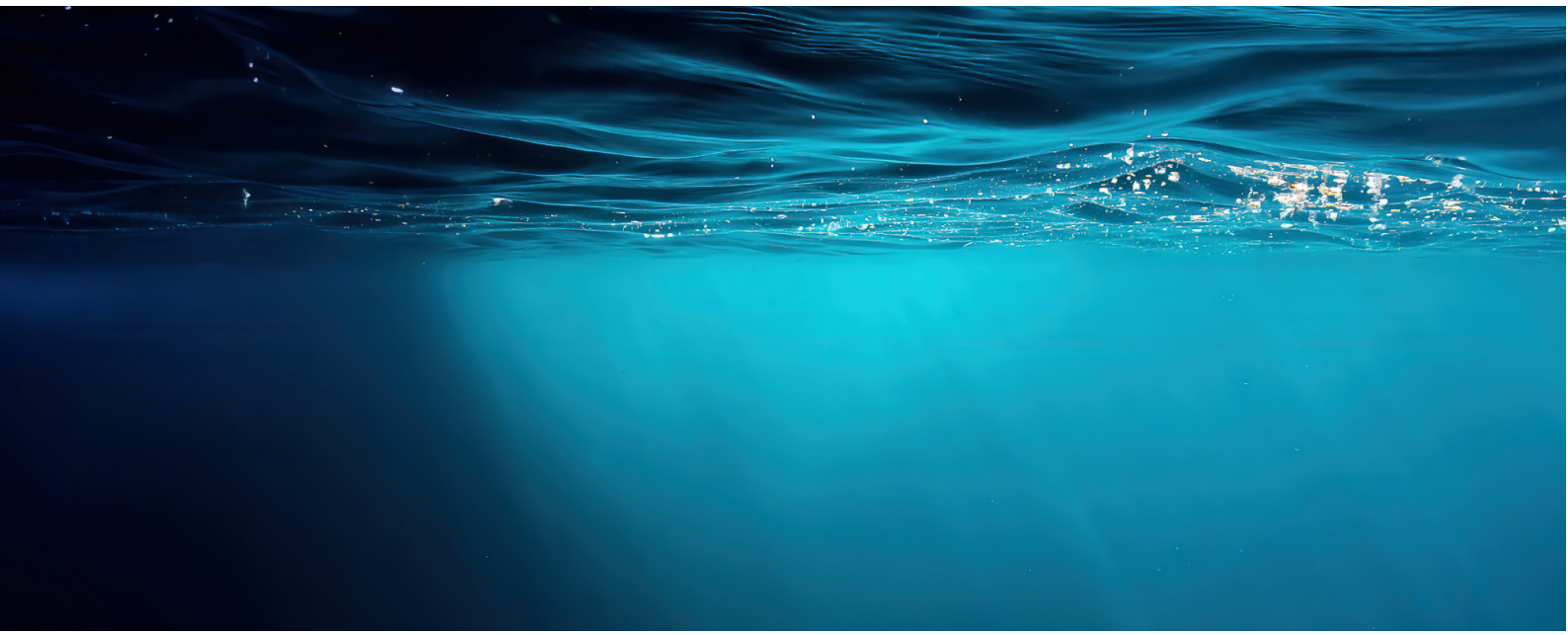
THE SOUTHERN OCEAN ACTION PLAN

How to achieve a transparent and accessible Southern Ocean

with open and equitable access to data, information and technology and innovation

Ocean Decade Definition of the Outcome

Inequalities in ocean science capacity and capabilities need to be eradicated through simultaneously improving access to and quality control of data, knowledge and technology. This needs to be coupled with increased skills and opportunities to engage in data collection, knowledge generation and technological development, particularly in Least Developed Countries (LDCs), Small Island Developing States (SIDS) and Landlocked Developed Countries (LLDCs). Increased dissemination of quality controlled and relevant ocean knowledge to the scientific community, governments, educators, business and industry and the public, through relevant and accessible products, will improve management, innovation and decision-making, contributing to societal goals of sustainable development.



Relevance

Inequalities in opportunity and access are common in ocean sciences. Capacity and capability must be rebalanced across the globe with a fair approach, to achieve real inclusivity for the benefit of all and for the progress of science and society. Achieving a transparent and accessible ocean is therefore needed at all levels. For this reason, this Outcome is considered as being cross-cutting with all other Outcomes.

Challenges Identified by the Working Group

Achieving a Transparent and Accessible Southern Ocean will require working jointly on five main areas:

Improving access to Southern Ocean infrastructures, including to computing infrastructure outside of the Southern Ocean. The Southern Ocean is remote and logistically challenging to work in, so optimising access to and the

use of existing and new infrastructures will have benefits for improving equity in research as well as for the Decade objectives. The main challenges and actions in this space are focussed on improving the sharing of information about what data, infrastructures, platforms, and logistical capabilities are available, so that stakeholders can assess their suitability and capacity to support their planned activities. Existing tools such as DueSouth and Polardex provide a mechanism for international sharing of logistical information for fieldwork but will become considerably more effective with the development of standards and best practices for making such information available by disparate sources. The Southern Ocean community is already taking a lead role in defining these standards for the broader polar community but there is a need to work with similar information sharing mechanisms globally, to avoid future siloing of polar logistical information. It is important to involve all relevant stakeholders such as the Antarctic Treaty Consultative meetings (ATCM), COMNAP, SCAR, SOOS, EPB, CCAMLR, IAATO, POGO, POAwg, etc. Special emphasis should be on making computing infrastructure accessible to scientists from countries without Southern Ocean research programmes.

Building the Southern Ocean digital ecosystem for data and information access and exchange as part of the global Decade digital ecosystem (Box 5). For the Southern Ocean, there are two key approaches to data sharing, which will need to develop in parallel, to maximise the Findability, Accessibility, Interoperability, and Reusability (the FAIR Principles) (Wilkinson *et al*. 2016) of Southern Ocean data. Making Southern Ocean data broadly accessible supports researchers and citizen scientists with limited access to fieldwork (e.g. because of cost, the size of their nation's Southern Ocean research program, caring responsibilities, or disability) to be productive and engaged Southern Ocean researchers.

For data that are collected through observing programs - i.e. data that describe commonly agreed variables and that use standardised and agreed methods of observation, processing, and documentation, it is appropriate to develop systems (such as SOOSmap, biodiversity.aq) that aggregate the data in portals that allow users to subset and explore the data in a browser before downloading the data in a range of formats. Work is needed to better document the holdings of source data centres and the harvesting relationships between them and centralised portals, to improve transparency for users and to help administrators identify gaps and duplications in their data holdings, but the core systems are in place to allow this approach to expand during the Decade.

However, much ocean science does not and likely will not meet the requirements for inclusion in such data aggregating efforts. Historical datasets, as well as those from process studies, new observing methods, and from research communities that have not gone through standardisation efforts, are often referred to as "long-tail" data in that they constitute a large volume of highly variable datasets. For such datasets, the only feasible approach to making them Findable and Accessible (the first two of the FAIR Principles) is to make metadata records easily discoverable. Given that metadata records about the Southern Ocean are stored in dozens of metadata catalogues around the globe, it is critical to develop tools that will allow federated search of all these catalogues simultaneously.

This situation is well acknowledged by the Decade which calls in its Implementation Plan for the development of a digital ecosystem.

BOX 5:
The Decade digital ecosystem

"No single or central digital infrastructure or system will be sufficient to meet the needs of the Decade. Implementation of the digital ecosystem will require inclusive and outward-facing co- design and co-construction of a distributed, integrated and interoperable set of digital solutions that will form components of the overall ecosystem. The Decade digital ecosystem will catalyse cooperation between data generators and users from diverse stakeholder groups including governments, UN entities, scientists, planners, decision-makers, as well as industry and the public. The digital ecosystem and its component parts will support users in accessing, understanding, assessing, and providing impactful feedback on raw and processed data, information and knowledge so that these better meet their specific needs."

- IOC-UNESCO, 2021

The Polar Data Discovery Enhancement Research (POLDER) working group (which is a body of SOOS, the SCAR Standing Committee of Antarctic Data Management, and the IASC/SAON Arctic Data Committee) is actively working on several of the problems needed to support the development of federated search for metadata from polar regions, in close collaboration and co-design with broader global groups working in this space, such as DataONE and the Ocean

InfoHub/Ocean Data and Information System (OIH/ODIS) project as well as the Decade Coordination Office for data (DCO) and the Data Coordination Platform (DCP). POLDER has identified schema.org as the most feasible interchange language for a polar federated search, as it allows individual data centres to crosswalk key fields from their metadata standards to shared standard of information that can be harvested by a federated search tool. It is developing best practice guidance on how to implement schema.org for polar data centres. It has also identified existing metadata harvesting relationships in a complex landscape, in order to minimise duplications and omissions in a federated search, and is supporting the development of a pilot polar federated search tool by the World Data System International Technology Office. Making federated search a reality for the polar regions will require ongoing development of best practice guidance, implementation of schema.org by polar data centres, the development of indexing and searching tools, and ongoing financial and technical support by the community.

Promoting and Implementing the Polar Data Policy Recommendations. Since 2019, polar data committees linked to the Scientific Committee on Antarctic Research (SCAR), the International Arctic Science Committee (IASC), the Sustaining Arctic Observing Networks (SAON) initiative, and the Southern Ocean Observing System (SOOS), have developed principles for alignment of their data policies (Tronstad *et al*. 2021). These recommended principles have been implemented in the SOOS Data Policy (SOOS Data Management Sub-Committee, 2022) and a new SCAR data policy is under development. The principles also informed the revision of the IOC Data Policy.

These data policy principles should underpin all data collection efforts in the Southern Ocean for the duration of the UN Ocean Decade and the community will need to promote the use of the SOOS and SCAR data policies to ensure broad uptake of these principles.

Developing and Promoting Data Best Practices. Making data truly FAIR requires standardisation of sampling methods, observing methods, data processing, and data dissemination methods. As discussed above, this may not be feasible or desirable for all kinds of Southern Ocean data but for observing programs, it is critical. To achieve this, it is important to identify, document and share best practice approaches for each step of the data lifecycle, and for all participants to apply those best practices. Some members of the Southern Ocean community have begun working with the Ocean Best Practices System, which hosts a library of best practices documentation and assists communities to develop and improve best practice guidance on a range of topics. To make the Southern Ocean decade a success, it is critical that those collecting, processing, and developing tools to manage ocean data engage with best practices. All Southern Ocean decade programmes and projects are advised to connect with the Ocean Practices for the Decade Programme ("OceanPractices").

Promoting Data Literacy. Data literacy is important for researchers who both collect and reuse data but also for policy makers and community members, who rely on knowledge products based on that data and for science coordinators and funders, who need to decide how best to direct resources to maximise the societal benefit from scarce resources. The IOC Capacity Development programme aims to build that required capacity globally.

As part of the Decade, it is important to develop education material aimed at a wide array of audiences on topics including, but not limited to, where to find relevant data; how to publish data effectively; how data are aggregated or federated from many organisations; the obligations and norms documented in data policies; and understanding quality assurance and quality control methods for particular data streams. For training courses on all of these, and more, topics a reference is made to the Ocean Teacher Global Academy (OTGA) with its network of Regional Training Centres (RTC).

Overview

The table below displays the cross-cutting nature of specific research challenges related to Working Group 6.

Clean | Healthy and resilient | Productive | Predicted | Safe | Transparent and accessible | Inspiring and engaging

Challenges	Societal Outcomes
1 Improve access to Southern Ocean infrastructures, including to computing infrastructure outside of the Southern Ocean	
1.1 Availability of and access to research infrastructure, ships, equipment, computational power.	
1.2 Access to data (e.g. through web services).	
1.3 Development of discovery tools for logistical information.	
1.4 Costs of ships and shipping time prohibits participation of researchers from many nations, waste of talent.	
2 Build the Southern Ocean digital ecosystem for data and information access and exchange as part of the global Decade digital ecosystem	
2.1 Spatial and temporal coverage of samples and data, especially in remote & inaccessible areas.	
2.2 (Near) real-time availability of observational data for model input and decision making, including decision-making for catastrophe/calamity mitigation.	
2.3 Findability of data and research infrastructures.	
2.4 Interoperability of data, standards and research infrastructures.	
2.5 Traceability (provenance) and quality of data.	
2.6 Enhancement of cross-disciplinary research and integration of social sciences and humanities with other branches of research.	
2.7 Long-term financial sustainability of data resources and infrastructures including maintenance, upgrading and adaptation to new technology.	
2.8 Need to allow time for the community to adopt the use of existing and new resources (maintenance of the resource, education and capacity building) (Global issues).	

3 Promote and Implement the Polar Data Policy Recommendations

3.1 Ensure ethical sharing and use of data.

3.2 Implementation of standardised, machine actionable Data Management Plans (DMPs).

4 Develop and Promote Data Best Practices

4.1 Development and uptake of best practices to describe and annotate data, quality and provenance.

4.2 Availability of reproducible workflows.

5 Promote Data Literacy

5.1 Improved data literacy (the ability to read, understand, create, and communicate data and information) among data managers, researchers, policy makers, and stakeholders.

5.2 Availability of education resources.

THE SOUTHERN OCEAN ACTION PLAN

How to achieve an inspiring and engaging Southern Ocean

where society understands and values the ocean in relation to human wellbeing and sustainable development

Ocean Decade Definition of the Outcome

In order to inspire behaviour change and ensure the effectiveness of solutions developed under the Ocean Decade, there needs to be a step change in society's relationship with the ocean. This can be achieved through ocean literacy approaches, formal and informal educational and awareness-raising tools, and through measures to ensure equitable physical access to the ocean. Together, these approaches will build a significantly broader understanding of the economic, social and cultural values of the ocean by society and the plurality of roles that it plays to underpin health, well-being and sustainable development. This Outcome will highlight the ocean as a place of wonder and inspiration, thus also influencing the next generation of scientists, policy-makers, government officials, managers and innovators.

Relevance

The Southern Ocean plays an important role in global climate systems, yet remains a remote place for most people, experienced vicariously by those living far away. Ocean literacy approaches and improved access to the oceans and ocean discourse will help build a significantly broader understanding of the environmental, economic, social, and cultural values of the ocean by society; highlight the plurality of roles that the Southern Ocean plays in underpinning human health, wellbeing and sustainable development; and emphasise the intrinsic values associated with the Southern Ocean and its associated marine ecosystems. Key priority areas include recognising the values of the Southern Ocean; promoting appreciation of global climate connections; building an inclusive Antarctic Region; engaging the Southern Ocean industry in knowledge production; fostering cultural connections with Antarctica; supporting ocean education; and highlighting the Southern Ocean across policy agendas.

Despite being the last of the UN Ocean Decade's Outcomes, changing society's relationship with the ocean and supporting behaviour change are probably the most important and most challenging objectives to reach over the next ten years. Together with the Societal Outcome - Achieving a Transparent and Accessible ocean - the achievement of this last Outcome underpins the success of all the other Outcomes and more importantly, it lays the foundation to accomplish and deliver the Decade's ambitious vision.

Challenges Identified by the Working Group

Achieving an Inspiring and Engaging Southern Ocean will require working jointly across six main areas:

Recognising the values of the Southern Ocean. To achieve a sustainable socio-ecological future, it is important to recognise the role of the Southern Ocean and its connection to human and planetary wellbeing. The achievement of this challenge will require research projects and programmes to be developed to evaluate (i) the status of knowledge of subsets of global societies about the Southern Ocean, and (ii) the linkages between knowledge about these regions and pro-environmental decision-making and behaviour.

Identifying the different ways in which the Southern Ocean is valued and engaged with. This includes recognising types of rational use (science, tourism, transport, and fishing) as focal areas for research. This knowledge will not only strengthen human engagement, but it will also set a regulatory framework for management practices in the Southern Ocean. It also invites consideration of the Southern Ocean as a more-than-human space and reflexive positioning of researchers in each project.

Supporting Ocean Education. This includes assessing the role of education in achieving a sustainable socio-ecological future. Achieving this challenge will require the development of innovative education and training systems that integrate different knowledge sources. These will contribute to (i) building the skills needed for sustainability, (ii) enhancing participation of society and, (iii) strengthening public understanding and awareness of the value of Polar Regions.

Fostering cultural connections with Antarctica. This recognises that while the Southern Ocean is geographically remote for many, it can also be a place of ecocultural importance and a powerful imaginative force. This therefore includes supporting the arts to engage with and share stories about the Southern Ocean. Securing funding for communication and engagement issues related to the Southern Ocean will help to increase the quality of engagement.

Building an inclusive Antarctic region. This includes establishing the best ways of engaging with targeted Southern Ocean communities and drawing on expertise from scholars specialising in science communication, as well as listening to the voices of youth and local people who live with the Southern Ocean. This is required to maximise the engagement of broad groups, including researchers at various stages of their careers, policy-makers, the business and industry sector, and other Southern Ocean stakeholders. Meaningful communication is key to the success of building an inclusive Southern Ocean region.

Facilitating co-production of new knowledge about the Southern Ocean region by engaging Southern Ocean industry in knowledge production and nurturing stronger and sustainable collaborations between researchers, industry, policy and decision-makers in international and national governments, non-governmental bodies, and governmental organisations. This includes bringing Southern Ocean issues to the fore across a range of policy agendas.

Overview

The table below displays the cross-cutting nature of specific research challenges related to Working Group 7. As this Working Group is inherently cross-cutting, most of the Challenges identified here are relevant for other Working Groups too.

Clean | Healthy and resilient | Productive | Predicted | Safe | Transparent and accessible | Inspiring and engaging

Challenges	Societal Outcomes
1 Recognising the value of the Southern Ocean	
1.1 Develop and facilitate research projects and programmes that examine the status of knowledge of subsets of global societies about the Southern Ocean and dependent ecosystems as well as its central role for global planetary health.	

1.2	Develop and facilitate research projects and programmes that examine the linkages between knowledge about these regions and pro-environmental decision-making and behaviour.	
1.3	Acknowledge existing expertise in Southern-Ocean and Antarctic-related decision-making, in particular the knowledge and experience held by the Antarctic Treaty System and CCAMLR, as well as organisations such as COMNAP, SCAR and IAATO.	

2 Identifying the different ways in which the Southern Ocean is valued and engaged with

2.1	Recognise types of rational use (science, tourism, transport, fishing) as focal areas for research on human engagement with and management of the place. Strengthening knowledge integration can be incorporated into strengthened management practices.	
2.2	Recognise the ethical dilemma posed by an anthropocentric approach to researching, valuing and utilising the Southern Ocean and Antarctica and acknowledge the agency of non-human life forms and the importance of respecting their rights as well as humanity's adverse impacts on their habitats - in the past, present and future.	
2.3	Develop Decision Support Tools (DSTs) to support informed decision-making related to Southern Ocean challenges.	
2.4	Ensure DSTs draw on the wide range of disciplinary expertise available across the Southern Ocean research community.	

3 Supporting Ocean Education

3.1	Develop innovative education and training systems that integrate different knowledge sources and will contribute to building the skills needed for sustainability, enhanced participation of society and strengthened public understanding and awareness of the value of polar regions.	
3.2	Facilitate transnational cooperation and complementarity.	
3.3	Promote the continuity of education and outreach opportunities in conjunction with commercial operators in the Southern Ocean.	
3.4	Improve societal understanding of Southern Ocean issues and appreciation of Southern Ocean for its intrinsic values, as a unique environment, and global values, for its role in Earth systems and regulating climate change.	
3.5	Encourage participation of citizens in Southern Ocean relevant projects through citizen science.	
3.6	Facilitate communication, cooperation and engagement between Antarctic Treaty Parties on education and outreach on the Southern Ocean.	
3.7	Draw on evidence-based findings to prioritise activities that lead to long term impact.	

4 Fostering cultural connections with Antarctica

4.1	Secure funding for communication and engagement issues related to the Southern Ocean, in order to increase the quality of engagement.	
4.2	Channel the arts' ability to challenge and inspire a diverse range of audiences.	

4.3	Incorporate arts into science strategies at a National level.	
4.4	Connect people remotely to the Southern Ocean through the celebration and promotion of cultural production.	

5 Building an inclusive Antarctica

5.1	Emphasise the role of young people of all backgrounds as the inheritors of the changing planet.	
5.2	Identify demographic groups and knowledge systems that are being missed out of key conversations and take action to address these in meaningful and respectful ways.	
5.3	Engage meaningfully with audiences both close to and far away from the Southern Ocean.	
5.4	Foreground the long standing connections of Indigenous populations in Gateway or Southern rim countries with Antarctica and the Southern Ocean.	
5.5	Use participatory techniques such as scenario analysis to improve understanding and illustrate the added value of using evidence-based knowledge for decision-making	

6 Facilitating co-production of new knowledge about the Southern Ocean region

6.1	Develop stronger linkages between researchers, industry, and policy and decision-makers to contribute to co-design of projects and facilitate co-production of new knowledge about the Southern Ocean region.	
6.2	Identify the time, effort and logistical requirements that come with learning to effectively communicate between natural sciences, social sciences, arts and humanities and actively provide support to facilitate this inter-disciplinary engagement.	
6.3	Expand the role of tourism in citizen science and as platforms of opportunity.	
6.4	Expand the concept of the “Antarctic Ambassadors” within the context of a wider polar community, emphasising joint ownership of the IAATO-led campaign.	
6.5	Ascertain how successful the current engagement is, noting that many tourists are very well engaged with the region before/when and after visiting Antarctica and the Southern Ocean.	
6.6	Engage with tour operators to make Antarctic tourism as sustainable as possible thus inspiring industry in other parts of the world.	

Conclusion

This Action Plan represents a community effort: A framework for Southern Ocean stakeholders to formulate and develop tangible actions and deliverables that support the UN Ocean Decade vision, whilst allowing for wider community engagement throughout the decade. This framework aims to provide an initial roadmap to strengthen links between science, industry, and policy, as well as to encourage internationally collaborative activities in order to tighten knowledge and data gaps, and to globally improve capacity in Southern Ocean related topics.

The development of the Southern Ocean Action Plan has been a community-driven process and aims to represent the diversity of stakeholders. By including experts from science, policy and business, the composition of the Southern Ocean Task Force has already crossed several boundaries, whether they be geographical or disciplinary, thus reflecting many different voices. In this way, the Southern Ocean Task Force is a good example of how a community can work together to collectively deliver innovative solutions to maintain and protect the unique environments of the Southern Ocean.

Following the publication of the Southern Ocean Action Plan, the Southern Ocean Task Force anticipates that the Southern Ocean community will find inspiration and seek engagement to deliver innovative solutions to maintain and foster the unique conditions of the Southern Ocean. We hope that the Southern Ocean Action Plan will leverage opportunities and bring communities together to implement the priorities and overcome the challenges that have been recognised within the Plan. The Southern Ocean Task Force hopes that the UN Ocean Decade will act as a platform to underline the importance of the Southern Ocean and highlight its relevance in the global Earth System. Although the Southern Ocean process has already been successful in reaching out to various stakeholders, the Ocean Decade is an opportunity to bring any missing voice to the table in order to broaden representation and expertise to overcome Southern Ocean challenges related to research, logistics and uptake.

The Southern Ocean contribution to the UN Ocean Decade will be updated over the course of the UN Ocean Decade and the Southern Ocean Task Force will make sure to keep the same approach and keep the process open to the entire Southern Ocean community.

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Appendices

Annex 1: Guiding documents for Working Groups

To deliver a uniform and curated process across the multiple Working Groups, the following guiding documents and agendas were provided. This was provided to enable better preparation for participants to Working Group meetings and to prepare for the 2nd Southern Ocean Regional Workshop held in September 2021.

The documents included:

A. Guidelines to Working Group chairs
B. Guidelines to Working Group members
C. Reporting template for Working Groups

A: Guidelines to Working Group chairs

Background

Based on the recommendations in the global implementation plan of the United Nations Decade of Ocean Science for Sustainable Development (2021-2030), members of the Southern Ocean community set up a Task Force to develop the Southern Ocean Action Plan. This Action Plan will provide a framework for Southern Ocean stakeholders to formulate and develop concrete activities that support the Decade vision.

Together with outputs from the First Southern Ocean Workshop, the Southern Ocean Task Force collated strategic and scientific priorities from our individual implementation plans, together with those outlined in previous polar and Antarctic initiatives, including the SCAR Horizon Scan (2014), COMNAP Antarctic Roadmap Challenges (2016) and EU-PolarNet (2016). This synthesis generated a report of identified strategic and scientific priorities for the Southern Ocean, which served as a basis for the Southern Ocean survey, launched in May 2021. This stakeholder-oriented consultation aimed to identify gaps within the report and prioritise Southern Ocean objectives to ensure the well-representation of all groups. Additionally, stakeholders provided input on the activities and contributions that should be developed in the context of the Decade.

Working Groups are now being established for each of the Decade's Societal Outcomes. Through a series of meetings, the Working Groups will identify the needs of the Southern Ocean community in view of addressing the Southern Ocean priorities identified through the survey. The input from each Working Group will be synthesised into a Draft Southern Ocean Action Plan, which will then be jointly reviewed and discussed by all stakeholders at the 2nd Southern Ocean Regional Workshop. This workshop will be held online from 20-22 September 2021 and will bring forward a community consensus on how the Southern Ocean community will engage within the Ocean Decade Framework. Following the 2nd Southern Ocean Regional Workshop, the Task Force will review and finalise the Southern Ocean Action Plan.

All working group meetings will be held online. The chair of your WG will contact you by email with a link to meetings. Key dates include 9 July 2021 for the Kick-off meeting for all groups, followed by two closely-related online events, the 2nd Southern Ocean Regional Workshop (20-22 September 2021) and Polar Data Forum IV (22-24 September 2021).

Expectations for WG input

Each Working Group (WG) should work on completing the objectives below during WG meetings while covering as many perspectives as possible, i.e. scientific, policy, management, industry, etc. How the WG undertakes the writing of their WG report is determined by the WG chairs.

Each WG member is expected to contribute to the reporting of their appointed WG meetings. A template for reporting will be made available for each WG to fill in. All WG members will be granted editing access to their dedicated WG documents and will have commenting access to the report of other WGs.

WG meeting objectives:

1. Quick presentation of WG members, their position and ongoing/future activities and needs.
2. Identify regional challenges that need to be overcome to achieve Southern Ocean priorities (cfr report) over the next 10 years in the context of your appointed Societal Outcome. This includes :
   - Research challenges (purely scientific)
   - Logistical challenges (funding, infrastructure, data accessibility, etc.)
   - Uptake challenges (effective communication between stakeholders, engaging the public)
3. Identify tangible actions that would be able to address these challenges.
4. Delineate the scope of suggested actions (leading organisation, involved stakeholders, funding, timeline, implementation).
5. Identify (and describe in a few words) already-existing activities and stakeholders who are presently working towards resolving these challenges.
6. Rank suggested actions in order of priority while taking into account feasibility and timeline. The highest ranking actions will be included in the Southern Ocean Action Plan and will most likely require additional notes.

As a Working Group Chair, you are expected to:

1. Prior to WG meetings
   - Get an overview of:
     - The Southern Ocean Process
     - The composition of your WG, flag us if an important actor is missing
   - Read WG Guidelines for Chairs.
   - Plan the organisation and reporting approach for your WG.

2. During WG meetings
   - Stick to your agenda plan (see point 1.).
   - Describe your approach towards achieving your WG objectives.
   - Take notes for the WG report.
   - Work towards achieving the meeting objectives.

3. Between meetings
   - Be aware that meeting duration is limited to two hours. If required, you and the members of your WG may need to provide additional comments in your appointed shared document.
   - Contribute to the writing of the WG report.
   - Comment on other WG draft reports if needed.
   - Review comments on your own report.
   - Collaborate with chairs and contact points from other WGs to identify cross-cutting themes.

4. After WG meetings
   - WG chairs must submit their final WG report to Annemie R. Janssen by 13th September. WG reports will serve as a basis for the Draft Southern Ocean Action Plan to be presented at the 2nd Southern Ocean Regional Workshop (20-22 September 2021).
   - Each WG chair must prepare a recap video to present the work of their WG (to be released on 14 September) and a short 3-min presentation for the 2nd Southern Ocean Regional Workshop (20-22 September 2021).

5. Collaborate with the Chairs of other WGs to discuss cross-cutting themes.

Important dates

9 July	Kick-off plenary
13 September	Deadline for the submission of WG report
14 September	Release of WG recap videos
20-22 September	2nd Southern Ocean Regional Workshop
22-24 September	Polar Data Forum IV

B: Guidelines to Working Group members

Background

Based on the recommendations in the global implementation plan of the United Nations Decade of Ocean Science for Sustainable Development (2021-2030), members of the Southern Ocean community set up a Task Force to develop the Southern Ocean Action Plan. This Action Plan will provide a framework for Southern Ocean stakeholders to formulate and develop concrete activities that support the Decade vision.

Together with outputs from the First Southern Ocean Workshop, the Southern Ocean Task Force collated strategic and scientific priorities from our individual implementation plans, together with those outlined in previous polar and Antarctic initiatives, including the SCAR Horizon Scan (2014), COMNAP Antarctic Roadmap Challenges (2016) and EU-PolarNet (2016). This synthesis generated a report of identified strategic and scientific priorities for the Southern Ocean, which served as a basis for the Southern Ocean survey, launched in May 2021. This stakeholder-oriented consultation aimed to identify gaps within the report and prioritise Southern Ocean objectives to ensure the well-representation of all groups. Additionally, stakeholders provided input on the activities and contributions that should be developed in the context of the Decade.

Working Groups are now being established for each of the Decade's Societal Outcomes. Through a series of meetings, the Working Groups will identify the needs of the Southern Ocean community in view of addressing the Southern Ocean priorities identified through the survey. The input from each Working Group will be synthesised into a Draft Southern Ocean Action Plan, which will then be jointly reviewed and discussed by all stakeholders at the 2nd Southern Ocean Regional Workshop. This workshop will be held online from 20-22 September 2021 and will bring forward a community consensus on how the Southern Ocean community will engage within the Ocean Decade Framework. Following the 2nd Southern Ocean Regional Workshop, the Task Force will review and finalise the Southern Ocean Action Plan.

All working group meetings will be held online. The chair of your WG will contact you by email with a link to meetings. Key dates include 9 July 2021 for the Kick-off meeting for all groups, followed by two closely-related online events, the 2nd Southern Ocean Regional Workshop (20-22 September 2021) and Polar Data Forum IV (22-24 September 2021).

Expectations for WG input

Each Working Group (WG) should work on completing the objectives below during WG meetings while covering as many perspectives as possible, i.e. scientific, policy, management, industry, etc. How the WG undertakes the writing of their WG report is determined by the WG chairs.

WG members are expected to contribute to the reporting of their appointed WG. A template for reporting will be made available for each WG to fill in. All WG members will be granted editing access to their dedicated WG documents and will have commenting access to the documents for other WGs.

WG meeting objectives:

1. Quick presentation of WG members, their position and ongoing/future activities and needs.
2. Identify regional challenges that need to be overcome to achieve Southern Ocean priorities (cfr report) over the next 10 years in the context of your appointed Societal Outcome. This includes :
    - Research challenges (purely scientific)
    - Logistical challenges (funding, infrastructure, data accessibility, etc.)
    - Uptake challenges (effective communication between stakeholders, engaging the public)
3. Identify tangible actions that would be able to address these challenges.
4. Delineate the scope of suggested actions (leading organisation, involved stakeholders, funding, timeline, implementation).
5. Identify (and describe in a few words) already-existing activities and stakeholders who are presently working towards resolving these challenges.
6. Rank suggested actions in order of priority while taking into account feasibility and timeline. The highest ranking actions will be included in the Southern Ocean Action Plan and will most likely require additional notes.

As a Working Group member, you are expected to:

1) Prior to WG meetings
- Get an overview of the Southern Ocean Process
- Read Guidelines for WG members

2) During WG meetings
- Take notes for the WG report
- Work towards achieving the meeting objectives

3) Between meetings
- Be aware that meeting duration will be limited. If required, you may need to provide additional comments in your appointed shared document.
- Contribute to the writing of the WG report
- Comment on other WG draft reports if needed.
- Review comments on your own report

4) After WG meetings
- WG chairs must submit their final WG report to Annemie R. Janssen by 13th September. WG reports will serve as a basis for the Draft Southern Ocean Action Plan to be presented at the 2nd Southern Ocean Regional Workshop (20-22 September 2021).
- Each WG chair must prepare a recap video to present the work of their WG and a short 3-min presentation for the 2nd Southern Ocean Regional Workshop (20-22 September 2021).

Important dates

9 July	Kick-off plenary
13 September	Deadline for the submission of WG report
14 September	Release of WG recap videos
20-22 September	2nd Southern Ocean Regional Workshop
22-24 September	Polar Data Forum IV

C: Reporting template for Working Groups WG number :

WG number :

Targeted Societal Outcome :

WG chair(s) :

Ocean Decade Definition of the Outcome :

Identify regional challenges that need to be overcome to achieve Southern Ocean priorities (cfr report) over the next 10 years in the context of your appointed Societal Outcome.

● Research challenges (purely scientific)
Challenge R1:
Challenge R2:
...

● Logistical and technical challenges (funding, infrastructure, data accessibility, etc.)
Challenge L1:
Challenge L2:
...

● Uptake challenges (effective communication between stakeholders, engaging the public)

Challenge U1:
Challenge U2:
...

Identify tangible actions that would be able to address these challenges. Delineate the scope of suggested actions (leading organisation, involved stakeholders, funding, timeline, implementation).

Action 1

Name of Action	
Related challenge	ex: R1, U2, … (see above)
Short description	
Key stakeholders to consider	
Timeline	
Potential resources	
Other comments	

Action 2

...

Describe already-existing activities and stakeholders who are presently working towards resolving these challenges.

Name of Action	
Related challenge	ex: R1, U2, … (see above)
Short description	
Leading organisation	
Key stakeholders	
Timeline	
Resources	
Other comments	

Rank suggested actions in order of priority while taking into account feasibility and timeline. The highest ranking actions will be included in the Southern Ocean Action Plan and will most likely require additional notes.

Order of priority	Action number & name
1	ex: Action 2
2	
3	
...	

If you have any further comments/suggestions, please describe them below.

Annex 2: Southern Ocean Task Force members and Working Groups

Southern Ocean Task Force

Scientific Committee on Antarctic Research (SCAR)
- Eoghan Griffin
- Deneb Karentz
- Susie Grant

Royal Belgian Institute for Natural Sciences & SCAR Antarctic Biodiversity Portal (Biodiversity.aq, Regional node for OBIS)
- Anton Van de Putte
- Annemie Rose Janssen

Southern Ocean Observing System (SOOS)
- Mike Williams
- Eileen Hofmann
- Sian Henley

European Polar Board (EPB)
- Renuka Badhe
- Joseph Nolan
- Pjotr Elshout

Polar Data Discovery Enhancement Research (POLDER)
- Pip Bricher

International Oceanographic Data and Information Exchange (IODE) of IOC/UNESCO
- Taco de Bruin

Scientific Committee for Oceanic Research (SCOR)
- Patricia Miloslavich

Integrated Climate and Ecosystem Dynamics of the Southern Ocean (ICED)
- Eugene Murphy
- Eileen Hofmann
- Rachel Cavanagh
- Nadine Johnston

The WMO/IOC-UNESCO/ISC World Climate Research Programme (WCRP)
- Mike Sparrow

CLIVAR/CliC/SCAR Southern Ocean Region Panel (SORP)
- Elisabeth Sikes
- Torge Martin

International Association of Antarctica Tour Operators (IAATO)
- Amanda Lynnes

Royal Netherlands Institute for Sea Research (NIOZ)
- Taco de Bruin
- Marten Tacoma

Pew Charitable Trusts
- Nicole Bransome

World Wide Fund for Nature (WWF)
- Emily Grilly
- Rhona Kent

Working Group chairs

Working Group 1 – A clean ocean
- Clara Manno - British Antarctic Survey
- Cath Waller - University of Hull
- Jeff Bowman (until November 2021) - Scripps Institution of Oceanography, University of California San Diego

Working Group 2 – A healthy and resilient ocean
- José C. Xavier - University of Coimbra and British Antarctic Survey
- Maria A. van Leeuwe (until December 2021) - University of Groningen
- Sally Lau (from February 2022) - James Cook University

Working Group 3 – A sustainably productive ocean
- Javier A. Arata - Association of Responsible Krill harvesting companies

Working Group 4 – A predicted ocean
- Stuart Corney - Institute for Marine and Antarctic Studies, University of Tasmania

Working Group 5 – A safe ocean
- Eoghan Griffin - Scientific Committee on Antarctic Research

Working Group 6 – A transparent and accessible ocean
- Anton Van de Putte - Royal Belgian Institute of Natural Sciences and SCAR Antarctic Biodiversity Portal
- Taco de Bruin - International Oceanographic Data and Information Exchange of IOC/UNESCO and NIOZ Royal Netherlands Institute for Sea Research

Working Group 7 – An inspiring and engaging ocean
- Hanne Nielsen - Institute for Marine and Antarctic Studies, University of Tasmania
- Rahul Mohan - National Centre for Polar and Oceanic Research, Ministry of Earth Sciences, India

Working Group 8 – Cross-cutting themes
- Renuka Badhe - European Polar Board
- Taco de Bruin - International Oceanographic Data and Information Exchange of IOC/UNESCO and NIOZ Royal Netherlands Institute for Sea Research
- Annemie Rose Janssen - Royal Belgian Institute of Natural Sciences

A few numbers…

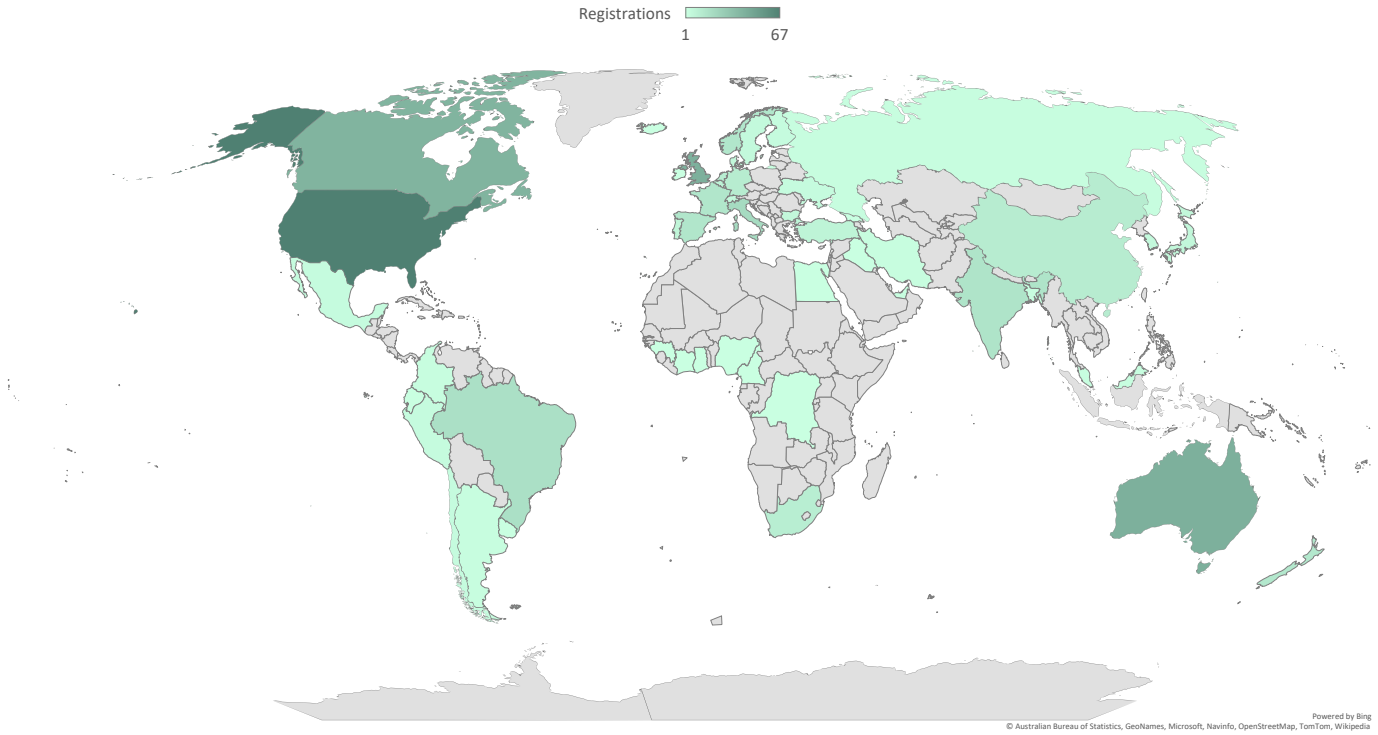
The development process of the Southern Ocean Action Plan engaged a broad community spanning the scientific research community, the business and industry sector, infrastructure, operational service providers and policy and management bodies.

The Southern Ocean Task Force was successful in reaching all continents of the globe. In the Working Group phase of the Southern Ocean process, individuals and representatives of diverse organisations from 26 countries took part in the WG meetings.

Working Group	Number of Participants (excluding internal Southern Ocean Task Force members)
WG1: Clean Ocean	32
WG2: Healthy & Resilient Ocean	80
WG3: Sustainably Productive Ocean	42
WG4: Predicted Ocean	63
WG5: Safe Ocean	21
WG6: Accessible Ocean	50
WG 7: Engaging Ocean	30

**Note that several participants were involved in multiple Working Groups.*

The Southern Ocean Decade & Polar Data Forum Week 2021 (20 – 24 September 2021) gathered 434 participants from 53 countries. See geographic distribution map below.



Annex 3: List of acronyms

ADC	Arctic Data Committee
APECS	Association of Polar Early Career Scientists
ATCM	Antarctic Treaty Consultative Meeting
ATS	Antarctic Treaty System
CCAMLR	Commission for the Conservation of Antarctic Marine Living Resources
CEP	Committee for Environmental Protection
CliC	Climate and Cryosphere (WCRP core project)
CLIVAR	Climate and Ocean: Variability, Predictability and Change (WCRP core project)
COMNAP	Council of Managers of National Antarctic Programs
DCO	Decade Coordination Office for data
DCP	Data Coordination Platform
DST	Decision Support Tools
EC	European Commission
EPB	European Polar Board
FAIR	Findable, Accessible, Interoperable, Reusable
IAATO	International Association of Antarctica Tour Operators
IASC	International Arctic Science Committee
ICED	Integrated Climate and Ecosystem Dynamics of the Southern Ocean
ICSU	International Council of Scientific Unions (now ISC)
IGY	International Geophysical Year
IOC-UNESCO	Intergovernmental Oceanographic Commission of UNESCO
IODE	International Oceanographic Data and Information Exchange of IOC/UNESCO
IPCC	Intergovernmental Panel on Climate Change
IPY	International Polar Year
ISC	International Science Council
LDC	Least Developed Countries
LGBTQIA+	Lesbian, Gay, Bisexual, Transgender, Queer or Questioning, Intersex, Asexual or Ally
LLDC	Landlocked Developed Countries
NGO	Non Governmental Organisation
NIOZ	Royal Netherlands Institute for Sea Research
OBPS	Ocean Best Practices System
OIH/ODIS	Ocean InfoHub/Ocean Data and Information System
OTGA	Ocean Teacher Global Academy
POAwg	Polar Observing Assets working group
POGO	Partnership for Observation of the Global Oceans
POLDER	Polar Data Discovery Enhancement Research
SAON	Sustaining Arctic Observing Networks
SCAR	Scientific Committee on Antarctic Research
SCOR	Scientific Committee for Oceanic Research
SIDS	Small Island Developing States
SO	Southern Ocean
SOOS	Southern Ocean Observing System
SORP	CLIVAR/CliC/SCAR Southern Ocean Region Panel
UN	United Nations
UN SDG	United Nations Sustainable Development Goals
UNESCO	United Nations Educational, Scientific and Cultural Organisation
WCRP	World Climate Research Programme
WiPS	Women in Polar Science
WMO	World Meteorological Organisation
WWF	World Wide Fund for Nature
YOPP	Year of Polar Prediction

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SCAR

SOOS SOUTHERN OCEAN OBSERVING SYSTEM

European Polar Board

Integrating Climate and Ecosystem Dynamics ICED

IODE

International Science Council SCOR Scientific Committee on Oceanic Research

NIOZ

WCRP World Climate Research Programme

CLIVAR

INTERNATIONAL ASSOCIATION ANTARCTICA TOUR OPERATORS IAATO

WWF

THE PEW CHARITABLE TRUSTS

belspo

museum NATURALSCIENCES.BE