Review of identified priorities for the Southern Ocean in the context of the UN Ocean Decade

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About this review

The following document attempts to place existing scientific priorities in the context of the United Nations Decade of Ocean Science for Sustainable Development. However, there is a lack of clarity with regard to the relationship that links the Decade Outcomes. Since the connectivity of the Outcomes is not explicitly represented, reviewing the scientific priorities and classifying them according to the Decade Outcomes is a complex matter. Consequently, it could be wise to highlight the interdependency of these Outcomes to emphasize how to get from science to tangible strategies aimed at preserving and restoring ecosystems as well as supporting the people who depend on them. In this way, the UN Decade of Ocean Science will be able to create synergies with the UN Decade of Ecosystem Restoration to protect oceans and their resources.

The guiding thread could be presented as follows:

Access to data and infrastructure **(Outcome 6)** is essential to successfully understand the current and future states of the Southern Ocean **(Outcomes 2** and **Outcome 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 which will ensure a safe 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.

In light of this, three types of challenges can be identified:

- Research challenges (purely scientific)
- Logistical challenges (funding, infrastructure, data accessibility, etc.)
- Uptake challenges (effective communication between stakeholders, engaging the public)

For the time being, six cross-cutting challenges have been identified:

- Ensure capacity development and access to knowledge
- Improve interdisciplinary capacity and knowledge integration
- Facilitate transnational cooperation and complementarity
- Ensure long-term funding
- Frame Southern Ocean questions and issues in terms of social needs
- Create synergies with the Arctic community

Contents

Cross-cutting themes

1. Ensure capacity development and knowledge access

The current Southern Ocean community capacity is not sufficient to address the issues that are now being faced, many of which have important societal implications. It is imperative that programs be developed to engage new research communities and early career researchers in Southern Ocean activities and to build a community with transdisciplinary capability. This is an important challenge that can be addressed through national and international programs that focus on education, training and capacity building. The UN Decade of Ocean Science provides the opportunity to coordinate across these programs.

Priorities include:

Sharing data and infrastructure

- Promote the FAIR principles (Findable, Accessible, Interoperable and Re-usable) for data management
- Develop data and accounts to make them more complete and more user-friendly
- Improve semantic annotation of data and the web services providing these, and provide information on how to document quality and provenance
- Improve the support of new data acquisition through future multi-year fieldwork programmes and observatories
- Develop dedicated and comprehensive frameworks for coordination and collation of research that will strengthen and make available the knowledge base required for society and governance to measure and regulate the "footprint" of operational activities
- Identify resources, traceability of data, to support knowledge-based management, sustainable development, and policy decisions
- Invest in low-cost, low-energy and clean communication systems for real-time transmission of observational data from the Southern Ocean to better link observations and models
- Coordinate research vessels at sea with compatible instruments and communication protocols
- Take advantage of shared logistics and organisation to conduct transect-based coordinated large-scale targeted programmes
- Consider Social License to Operate (SLO) as a part of the Impact Assessment process. SLO might also play a role in social justice considerations, referring to, among others, the rights of ethnic minorities, youth, and those marginalised on gender, sexual orientation or other grounds
- Anonymise and contextualise quantitative social and health data on large and small spatial scales to simplify integration with other data and re-use

Technological improvements

- Develop new technological solutions for generation, treatment, long-term preservation and sharing of scientific data. This will require a truly Big Data approach addressing volume, heterogeneity, and speed in data
- Better and more integrated platforms for high-performance computing (HPC) to handle the rapidly growing Big Data requirements that are needed
- Enhanced measurement infrastructures, and new advanced technologies, supercomputing facilities
- Enhance the infrastructure capacity in support of more efficient and sustainable research
- Enhance the quality and quantity of information, through expanded observations, and knowledge by identifying the mechanisms for integration of different knowledge systems and knowledge co-production
- Deploy new technologies such as autonomous platforms carrying sensors, automated distributed sampling hubs, increased use of emerging remote sensing capabilities, and advances in bandwidth capacity, supporting not only safe and sustainable operations
- Deploy advanced sensor and platform technologies to perform measurements compliant with relevant standards under harsh, cold, and remote conditions

- Enlarge the spatial coverage of autonomous platforms in air, ground, and water
- Improve capabilities for exploration within the ocean, ice and solid earth
- Enhanced and integrated observing systems building upon existing and new environmental research infrastructures including near-real time data transmission

Capacity building

- Determine whether circumstances unique to Antarctic socio-ecological systems research create a need for particular kinds of skills, organizational structure or leadership
- Use participatory methods to develop and maintain the capacity for effective & sustainable management and informed decision-making
- 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

2. Improve transdisciplinary capacity and knowledge integration

Strong collaborations between academia, government, and industries are required to enhance technology developments, new jobs, safer operations, better sustainable economies (transport, fisheries and industry), and capacity building in the Southern Ocean Region.

Priorities include:

Science

- Improve communication and personal relationships within different communities and disciplines to effectively bridge natural and social sciences and to establish a common understanding of data and information content
- Identify the time and effort requirements that come with learning to effectively communicate between natural sciences, social sciences and humanities

Policy

- Lead concerted international actions to establish coordinated research and subsequent science-based and scenario-based advice for fast and effective action in management and international policies
- Engage constructively and iteratively with policy-makers at all stages of the research, with a focus on the existing and likely future threats to polar ecosystems, stake- and right-holders
- Use of participatory techniques such as scenario analysis to improve understanding and illustrate the added value of using evidence-based knowledge for decision-making

Develop Decision Support Tools (DSTs). Key challenges for their implementation include the logistics of operating and maintaining the continuous delivery of information

- Develop stronger linkages with policy and decision-makers in international and national governments, non-governmental bodies, and governmental organizations
- Identify methods that have proven effective in communicating between science and policy, and determine how these apply to the unique treaty-governed Antarctic Region (>60°S).

Business & Industry

Engage business operators in the collection of long time series of ecosystem monitoring data. These should be utilised to their maximum and expanded with greater spatial coverage, engaging operators in using mobile, comparative, and complimentary measurement platforms

Use topical areas involving resource conservation and use (tourism, transport, fishing, resource extraction) as focal areas for research on strengthening knowledge integration that can be incorporated into strengthened regulatory and management practices

Underpin co-design and consultative processes to help ensure meaningful engagement, local benefits and proper attention to ecosystem impacts

Develop equitable platforms to help stakeholders make informed decisions

Release policy advice and educational information at different levels of complexity in order to engage across the full spectrum of society and

to directly benefit from use of research results in decision-making

3. Facilitate transnational cooperation and complementarity

A collaborative international scientific collaborative community is required to create synergies with education, capacity building and policy.

- Coordinate and standardise observation protocols, especially for the design and implementation of standardised data management to make the best use of existing and accumulating data sets
- Identify already-existing effective methods that employ co-design approaches in research, planning and management
- Improve methodologies for co-design and co-production of data, which may also alter initial classic research questions and drive greater innovation in research approaches
- Expand our understanding of existing international regimes in the context of internationally governed regions
- Map the national, international, and commercial stakeholders in the different regions
- Align with international research programmes and collaborations with relevant research project initiatives
- Contributions to International conventions, protocols and agreements
- Raise participation and importance of the Southern Ocean through the UN Decade of Ocean Science by increasing visibility in activities such as OceanObs and other international ocean efforts

4. Ensure long-term funding

Funding is required to increase the ways of meaningful interaction between research groups, communities and other stakeholders when designing research projects and management plans for future human activities. A mix of joint pilot and feasibility studies could be a way forward. However, it should be noted that long-term investment, beyond the 3-5 years of the normal lifespan of research projects, is needed to ensure that there is a possibility to build trust amongst all the parties.

Priorities include:

Publish coordinated calls for seed money to implement new polar research programmes and long-term observation sites
Coordinate calls to improve the technological capabilities to operate in and observe inaccessible areas year-round, to transport, maintain and rapidly analyse samples, and to support the establishment of a sustained network of long-term observatories (super-sites) and collaborative networks, devoted to performing a well-integrated multidisciplinary observing programme and to validate remote sensing products.

5. Frame Southern Ocean questions and issues in terms of societal needs

This requires the development of a community that bridges the gap between science and the public and can communicate the transdisciplinary nature of the Southern Ocean issues.

Priorities include:

- Identify the desired future states envisioned by stakeholders and 'right—holders' for the Southern Ocean
- Provide guidance on optimal pathways towards the desired states ensuring a just transition
- Provide a holistic framing for assessing impacts of, and possible solutions for coping with environmental change and its socio-cultural consequences 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
- Identify available sources for environmental and socio-economic data that are needed to assess systematic impacts upon the Antarctic environment as well as related human

activities

- Build the knowledge and skills needed for sustainability and sustainable growth, employment, and participation of the communities and society at large
- Develop prototypes or proofs of concept for user-relevant products or services illustrating the potential of available knowledge. Such tools can incentivise the uptake of knowledge by stakeholders and pave the way towards a possible operational use
- Conduct a comprehensive analysis of governance and management systems for steering human activities in nature, their capacity to integrate and employ diverse knowledge to inform choices, and to make rapid adjustments as new knowledge is made available
- Optimise the chain of information linking research outcomes to decision-making through 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 of relevant tools for the different stakeholders

6. Create synergies with the Arctic community

- Implement a coordinated, international, circumpolar observational [and next steps too… (analysis of results, etc.)] program to elucidate processes that 1) allow life histories of key species in the Southern Ocean ecosystem to be quantified, 2) allow a total carbon budget to be developed, 3) provide coverage of the annual cycle, and 4) quantify the role of sea ice in regulating ecosystem productivity. The UN Decade of Ocean Science may provide a platform for engaging national programs in such an effort
- Conduct interdisciplinary research on polar climate effects and feedbacks based on stronger circumpolar and interdisciplinary collaboration, as well as an enhanced sharing of access to polar infrastructures
- Develop further analysis and evaluation of indicators and processes to support effective and strategic implementation of measures aimed at achieving Agenda 2030 and the UN SDG's in a Polar context
- Determine how the relevant insights of both "sustainability science" and the study of collaborative science be operationalized in polar research

Societal Outcome 1: How to achieve - A clean 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.

Identified priorities

1. Understand the extent of pollution

- Identify the sources, sinks, dynamics and impacts of increased bioavailability of natural and anthropogenic pollutants
- Identify the available methods to help determine the extent of contamination
- Understand the effect of the polar conditions on the distribution and lifetime of contaminants

2. Understand the effects of pollution on the natural world

- Understand how natural and anthropogenic pollutants and contaminants currently affect Southern Ocean biota and ecosystems and what the future scenarios are
- Understand how anthropogenic noise (caused by vessel operations, marine-based energy extraction and production operations, etc.) affects marine life
- Identify biological and genetic adaptation strategies of organisms to environmental contaminants that may provide resilience to the accumulation of trace metals and metalloids and persistent organic contaminants in marine food webs
- Determine the exposure and response of Antarctic organisms and ecosystems to atmospheric contaminants, and whether the sources and distributions of these contaminants are changing
- Assessing the main health risks for human and animal populations in the changing Southern Ocean environment

3. Prevent and recover from environmental damages

- Identify the methods to prevent mobilisation of contaminants
- Develop more accurate methodologies and procedures to prevent and recover from environmental damages caused by accidents and failures in Antarctic operations
- Investigate how to facilitate remediation of contaminated sites at a large scale and low cost

4. Transition to a greener industry

- Investigate how fuels used in shipping can best be transitioned to cleaner, more environmentally friendly alternatives
- Identify the drivers, conditions, requirements and consequences of Polar mineral and petroleum extractive industrial activities

Societal Outcome 2: How to achieve - A healthy and resilient 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 filled. 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 wellbeing of society and the planet as a whole.

Identified priorities

1. Improve understanding of key drivers of change and their impacts on Southern Ocean species and ecosystems

Food webs

- Assess the key drivers of change and their impacts on Southern Ocean ecosystems (food webs and biogeochemical cycling) at circumpolar and regional scales, with emphasis on the effects of changing sea ice conditions on key species (e.g., Antarctic krill, upper trophic level species)
- Understand Southern Ocean biodiversity at benthic and pelagic scales, by investigating the potential changes accruing from influences of climate change and human activities, e.g., marine traffic, tourism, fishing, pollutants (including emerging pollutants and plastics), invasive species and diseases
- Distinguish the impacts of physical climate change due to anthropogenic processes on Southern Ocean food web structures from natural variability
- Determine the structure and dynamics of Southern Ocean food webs, including pathways other than krill
- Determine spatio-temporal variations in food webs, including the vertical migrations of mesozooplankton and their changing availability to predators, and the role of ocean circulation in the transport and retention of organisms
- Understand links between biogeochemical processes and food web structure, including the identification of key functional groups and interactions, and the role of depth-related links in food webs in influencing biogeochemical cycles
- Understand the role of life histories (including vertical movement, interaction with ice biota and over-wintering strategies) of lower trophic level species of zooplankton on microzooplankton and phytoplankton dynamics, and the potential consequences on nutrient dynamics
- Determine life histories and interactions of linked food web components, especially mid and upper trophic level species
- Understand co-evolution between species or disruption of key interactions
- Determine the key factors for speciation in the Southern Ocean
- Understand impacts of ocean acidification on upper ocean biogeochemical processes and food web dynamics
- Understand the role of iron on phytoplankton growth and the importance of iron recycling in food webs in high-nutrient low-chlorophyll regions
- Assess the extent and impact of ocean acidification across the Southern Ocean
- Understand how deep-sea ecosystems respond to modifications of deep-water formation, and how deep-sea species interact with shallow water ecosystems
- Assess the extent to which the “greening” of the Southern Ocean is changing phytoplankton biodiversity, distribution and abundance, investigating the impact of these changes on CO2 uptake, and zooplankton grazers

Invasive Alien Species

- Understand the impacts of invasive species and range shifts of native species on ecosystems and human well-being
- Identify which pathways for alien species introductions present the greatest risks and which locations are most vulnerable to invasion
- Identify biosecurity techniques to reduce introduction risk and develop methods to respond to existing invasions
- Investigate how the coming orders of magnitude change in the Antarctic intertidal will impact the likelihood of alien invasion?

Resilience & Adaptation

- Determine which species are most threatened by physiological limitations, and how physiological plasticity can offset abiotic stress
- Identify species/ecosystem response to global change: Adaptation & resilience or Extinction & collapse
- Identify biological and genetic adaptation strategies of organisms to environmental change that may provide resilience
- Determine how fast mutation rates are and how extensive gene flow is in the Southern Ocean
- Identify and develop metrics or indicators to monitor the status and resilience of social-ecological systems
- Assess the vulnerability of polar ecosystems to combined human and natural influences

2. Improve understanding of sea ice, including its role in ecological processes of the Southern Ocean

- Understand ocean circulation, properties and processes beneath Antarctic sea ice and ice shelves
- 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
- Quantify sea ice-ocean-atmosphere characteristics and processes including floe-size distribution, wave-ice interaction and deformation processes at the ice edge / marginal ice zone 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 circulations
- Understand dynamics of the Antarctic fast-ice belt and its role in protecting glacier / ice shelf fronts, polynya formation/maintenance and water-mass modification
- Evaluate the contribution of seasonally ice-covered areas to carbon uptake and export
- Improve subglacial and continental shelf bathymetry to understand how it affects Antarctic ice sheet response to climate change
- Understand how subglacial hydrology affects ice sheet dynamics
- Understand the impact of climate change on Antarctic subsea permafrost and its effects on ecosystems and biogeochemical cycles
- 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
- Evaluate the contribution of seasonal variability of sea ice to heat budgets considering turbulent fluxes at the ocean-atmosphere interface

3. Improve understanding of Southern Ocean biogeochemical cycling. The Southern Ocean plays a key role in biogeochemical cycling, particularly in regulating air-sea exchange of carbon dioxide in the global carbon cycle

- Understand patterns and variation in nutrient dynamics and biogeochemical processes at various temporal and spatial scales and their int with physical and biological processes
- Understand the feedbacks between Southern Ocean circulation and water masses and the cryosphere, including the role of coastal and open ocean polynyas
- Assess the spatial, seasonal and interannual distribution of climate-active gases and halogens in ice-covered and ice-free waters
- Determine the key drivers of primary productivity and the Biological Carbon Pump - light,

stratification, circulation, and nutrient supply - and assess ongoing changes in these parameters

- Quantify the impact of recycling and remineralization, including via the Microbial Carbon Pump, on nutrients and carbon cycling
- Understand the role of physical processes such as upwelling, mixing and lateral oceanic advection on nutrient and CO2 distributions and fluxes
- Understand impacts of the combined changes in ocean physics and marine ecosystems on the Southern Ocean sink for CO2
- Identify the effects of Westerly winds on ocean circulation, carbon uptake and global teleconnections

4. Improve understanding of the Southern Ocean's role within the Earth Climate System (Cross-cuts Outcome 4)

- Understanding the processes controlling the different polar systems, including the climate system, the socio-ecological system structure and functioning, and the different knowledge systems and their multiple interactions
- Understand what the ocean's role is in determining or modulating natural modes of climate variability at both global and regional scales
- Enhance the understanding from data acquisition and long-term observation of processes controlling, and feedbacks resulting from, the interactions between the polar climate system components
- Identify key interaction and feedback processes and improve the description of these processes in coupled earth system models and in coupled regional models
- Better understanding of greenhouse gas climate sensitivity, climate forcing, through better inclusion of interactions between atmosphere, ocean, cryosphere and biogeochemical cycles
- Understand the role of human impacts on the Southern Ocean, notably 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
- 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
- Understand what processes control coastal dynamics and upwelling system and how upwelling systems change will with a changing climate
- 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
- Understand how volcanic activity affects the global atmosphere and the stability of cryospheric components, particularly glaciers and ice sheets
- Investigate whether greenhouse gases stored in Antarctic and Southern Ocean clathrates, sediments, soils, and permafrost will be released as climate changes
- Understand how will the ozone hole recovery affect regional and global atmospheric circulation, climate and ecosystems
- Contribute to IMBeR's Innovation Challenges (including I. The role of metabolic diversity and evolution in Southern Ocean biogeochemical cycling and ocean ecosystem processes, II. The development of a global ocean ecosystem observational and modelling network that provides ecosystem ocean variables (eEOVs) and to improve marine data and information management, III. To advance the understanding of ecological feedbacks in the Earth System, and IV. To advance and improve the use of social science data for ocean management, decision making and policy development).

Societal Outcome 3: How to achieve - A productive ocean supporting sustainable food supply and a sustainable ocean economy

Ocean Decade Definition of the Outcome

The ocean is the foundation for fuure global economic development and human health and wellbeing, 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.

Identified priorities

1. Increase the suite, types and reliability of measurements, including those focused on ecosystem change, needed to inform management and policy

- Determine what principles are required to utilise data from ecosystem monitoring programmes as part of management
- 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
- Assess the need for sustainable resource utilisation in light of changing environments and expanding human needs
- Improve the understanding of the consequences of human-induced change on polar ecosystem services
- Create guidelines for sustainable monitoring and regular assessments that enable us to assess our progress towards the desired states
- 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. Ensure a sustainably harvested and productive Southern Ocean by working towards a stronger interface between science and policy

- Identify thresholds or abrupt or irreversible changes
- 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
- Provide relevant and timely scientific advice to decision-makers for sustainable management of the Southern Ocean under a changing climate
- 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
- Knowledge enabling Antarctic operators to be frontrunners in developing a circular economy achieving economic gains with sustainable solutions and benefit commercially from a green economy
- Identify the institutional, political and practical obstacles to adopting and implementing ecosystem-based management on a larger scale
- Assess how external pressures and changes in the geopolitical configurations of power affect Antarctic governance and science
- Develop models that incorporate direct and indirect impacts of human activities to inform

decision making and the evaluation of management strategies

- Understand cumulative effects and extended causal relationships that play out over temporal and spatial scales, particularly interactions between people and nature
- Better knowledge of the effects of operations on natural and social environments, with a focus on integrated effects, involving different environmental and social factors

3. Ensure science-based and effective MPAs and uphold sustainable fisheries management and tourism development

- Evaluate the distribution of species in relation to CCAMLR, MPAs and climate change, considering historical changes and future projections
- Assess the success of Southern Ocean Marine Protected Areas in meeting their protection objectives, and determine how they affect ecosystem processes and resource extraction
- Develop informed strategies for adaptation and priorities at different time-scales
- Investigate how transport and other marine activities can be developed to avoid disturbing current and future networks of marine protected areas
- Improve understanding of fish stock sustainability and resilience integrating data on oceanographic, climate, ecosystem and harvesting interactions
- Investigate how mining and even hydrocarbon extraction can be pursued to ensure they are informed and guided by Agenda 2030 goals
- Identify what social and environmental risks cruise ships and infrastructure development pose
- Determine the scope for consistent and dedicated monitoring of tourism impacts, particularly at highly visited sites
- Determine how the Southern Ocean can contribute to blue growth and a low carbon energy transition
- Identify new methods to effectively integrate both quantitative and qualitative data, fill critical data gaps, and analyse the likely effects of crossing thresholds that are likely to be irreversible in the near term

Societal Outcome 4: How to achieve - A predicted 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.

Identified priorities

1. Understand the likely change of fundamental processes in the Southern Ocean in the future

- Assessing baseline state, changes, and future threats concerning polar ecosystems and their relation to the socio-ecological systems and society
- Quantify sea ice-ocean-atmosphere characteristics and processes including floe-size distribution, wave-ice interaction and deformation processes at the ice edge / marginal ice zone to understand changes in sea-ice area and volume over seasonal, annual, decadal, and millennial timescales
- Understand changes in the Antarctic Ice Sheet and its impact on global sea level
- Determine dynamics of interannual, decadal and longer-term temporal changes in the distribution and abundance of key species in relation to climatic variability, including the effects of changes in temperature, sea ice extent and ocean circulation patterns
- Identify gaps in knowledge and initiate or enhance monitoring activities to strengthen future predictions of environmental impacts and trends
- Use paleo-records of polar climate and environmental conditions to provide insight into present and future states
- Assess changes in:
    - Interior water mass transformation due to iso/diapycnal mixing
    - Processes and forcing mediating upwelling/subduction from the mixed layer
    - The role of mesoscale and submesoscale eddies in setting water mass properties and mediating the overturning circulation
    - The stability of the upper ocean overturning circulation in response to changes in winds, increased ice melt and surface warming
    - The stability, variability and future trends in frontal positions

2. Enhance and expand observational capability to support predictions

- Undertake planning for remote sensing capability that will improve capability to measure winds, backscatter for biomass, chlorophyll, salinity, temperature, sea ice, and land ice, in the Southern Ocean. Improved remote sensing capability will significantly enhance the ability to forecast and project circulation, ecosystems and their interactions over a range of space and time scales
- Increase air-sea flux observations with emphasis on:
    - Varying conditions imposed by storms, and sea state and katabatic winds
    - Regions and times (winter) of high uncertainty in reanalysis products
    - Areas covered by sea ice and influenced by polynyas/leads
- Enhance and pursue efforts to observe from space and ground-truth the retrieved information

- Improve satellite flux capabilities to:
    - Develop reliable retrievals of turbulent heat fluxes, especially in high winds and sea state
    - Improve freshwater flux retrievals for regions with variable ice-induced freshwater inputs
- Increase spatial and temporal coverage of assessments measuring the air-sea-ice fluxes of other climate relevant gases (e.g., N2O, CH4, DMS, halogens, Isoprene)
- Expand the spatial scale of existing long time-series of ecosystem monitoring data
- Advance the settings of observation systems and fully coupled climate models in order to improve assessments of regional climate change impacts
- Address the inability to assimilate existing and future observations into Earth System models and weather and climate prediction

3. Improve and enhance Southern Ocean modelling capability

- Decrease uncertainty in atmosphere and ocean dynamics and boundary-layer thermodynamic processes, aiding improvements in weather and climate models
- Constrain variability in Southern Ocean carbonate system and ocean-atmosphere CO2 fluxes over seasonal and annual temporal scales
- Understand how predictive skill can be improved at subseasonal-to-multidecadal time scales, and what the predictability limits are, if any, at these scales
- Determine how the structure and dynamics of Southern Ocean ecosystems should be represented in ecosystem models used in resource management
- Improve ecosystem models to test hypotheses
- Determine how we can best use modelling and records of past conditions (e.g. proxies) to understand ocean- atmosphere-ice-land interactions and global teleconnections
- Develop Earth System Models development
- Understanding the limits of predictability of coupled Earth System Models
- Understand how long-term changes in the climate mean state affect climate variability and its predictability
- At policy-relevant spatial and temporal scales, integrate available environmental and societal knowledge to model future scenarios
- Improve modelling and molecular techniques need to link broad-scale effects of drivers in socio-ecological systems to predict consequences for society and the natural environment at multiple scales. This will advance interdisciplinary and collaborative analyses of marine and terrestrial systems. The outcome will create plausible future trajectories of socio-ecological systems that allow for effective adaptation and decision-making
- Develop novel model development and innovative approaches. At a variety of scales, from processes to regional climate prediction, models, data assimilation, Machine Learning and Artificial Intelligence should be applied and developed in close conjunction with the improved measurement capabilities as well as through use of emerging long-term observational datasets for validation
- Investigate how to coherently integrate climate and food web models in order to represent the ecosystem response to global change processes
- Enhance predictive skill across climate, circulation, cryosphere, and ecosystems. The Southern Ocean community can add scenarios, such as freshwater inputs in the Southern Ocean, to understand climate sensitivity. End-to-end integration across ecosystems is needed to improve estimations of carbon fluxes, understand the effects of multiple stressors on ecosystems, identify biological hotspots, and evaluate the effects of living resource extraction on biological productivity.

Societal Outcome 5: How to achieve - A safe 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 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.

Identified priorities

1. Improve forecasting capabilities

- 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
- Understand how the changing polar conditions and changing operations impact the type and level of risk and vulnerability, as well as determine where these risks and vulnerability are
- Develop the techniques that will allow downscaling from global to regional scale forecasts
- Develop more detailed risk maps of storm surges
- Quantify, forecast and manage the risk of severe space weather events

2. Understand the impacts of changing environmental conditions on risk and vulnerability

- Identify the processes controlling the stability and equilibrium of polar glaciers and ice sheets and how they will affect future global sea level
- Understand how the characteristics of the ice sheet bed, such as geothermal heat flux and sediment distribution, affect ice flow and ice sheet stability
- Understand how Antarctic processes affect mid-latitude weather and extreme events
- Estimate CO2 equivalent thresholds that may foretell collapse of all or part of the Antarctic Ice Sheet

3. Improve emergency response competences

- Identify risks and vulnerability in the Polar Regions in order to define adaptation and mitigation actions in response to climate change
- Develop appropriate responses in case of accidents to protect life, the environment and community values. There is a need to develop emergency response capacities to mitigate consequences of accidents and natural disasters
- Understand how extreme events affect the Antarctic cryosphere and Southern Ocean
- Investigate how search and rescue operations can be prepared and organized more effectively
- Underpin the development of technologies as well as institutional mechanisms and operational competences to meet the challenges associated with increasing and changing risks and vulnerabilities

4. Engage with policy-makers

- Increase policy awareness of threshold of changes and hazard
- Engage iteratively with policy-makers to develop a focus on the existing and likely future threats to polar ecosystems and communities.

Societal Outcome 6: How to achieve - An accessible 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 LDCs, SIDS and 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.

Identified priorities

1. Ensure knowledge access and capacity building

See-cross cutting 1

2. Facilitate transnational cooperation and complementarity

See-cross cutting 3

3. Promote stakeholder participation

See-cross cutting 2

Societal Outcome 7: How to achieve - An inspiring and engaging 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 incite behaviour, change and ensure the effectiveness of solutions developed under the 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, wellbeing 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.

Identified priorities

1. Recognize the value of the Southern Ocean

- Nurture public education and outreach initiatives to demonstrate the relevance of Southern Ocean biology in the World's ecosystems
- Designing education and training systems for better information of stake- and right-holders and increased awareness of the society on the value of the Southern Ocean.
- Strengthen the public understanding of the relevance of Polar Regions in the global weather and climate system, and for the development and preservation of biodiversity
- Improve societal understanding of Southern Ocean issues and appreciation of the Southern Ocean for its global value in Earth systems and unique environment
- Determine the role of the educational system in achieving a sustainable socio-economic future
- Recognize the importance of conservation of the Southern Ocean to preserve its intrinsic value, for humanity, including for future generations

2. Increase stakeholder engagement

See cross-cutting 2

Summary

Cross-cutting themes

1. Ensure capacity development and access to knowledge
   - Sharing data and infrastructure
   - Technological improvements
   - Capacity building
2. Improve interdisciplinary capacity and knowledge integration
   - Science
   - Policy
   - Business & Industry
3. Facilitate transnational cooperation and complementarity
4. Ensure long-term funding
5. Frame Southern Ocean questions and issues in terms of social needs
6. Create synergies with the Arctic community

Societal Outcome 1: How to achieve - A clean ocean where sources of pollution are identified, reduced or removed

1. Understand the extent of pollution
2. Understand the effects of pollution on the natural world
3. Prevent and recover from environmental damages
4. Transition to a greener industry

Societal Outcome 2: How to achieve - A healthy and resilient ocean where marine ecosystems are understood and managed

1. Improve understanding of key drivers of change and their impacts on Southern Ocean species and ecosystems
   - Food webs
   - Invasive Alien Species
   - Resilience & Adaptations
2. Improve understanding of sea ice, including its role in ecological processes of the Southern Ocean
3. Improve understanding of Southern Ocean biogeochemical cycling. The Southern Ocean plays a key role in biogeochemical cycling, particularly in regulating air-sea exchange of carbon dioxide in the global carbon cycle
4. Improve understanding of the Southern Ocean's role within the Earth Climate System (Cross-cuts Outcome 4)

Societal Outcome 3: How to achieve - A productive ocean supporting sustainable food supply and a sustainable ocean economy

1. Increase the suite, types and reliability of measurements, including those focused on ecosystem change, needed to inform management and policy

2. Ensure a sustainably harvested and productive Southern Ocean by working towards a stronger interface between science and policy

3. Ensure science-based and effective MPAs and uphold sustainable fisheries management and tourism development

Societal Outcome 4: How to achieve - A predicted ocean where society understands and can respond to changing ocean conditions

1. Understand the likely change of fundamental processes in the Southern Ocean in the future

2. Enhance and expand observational capability to support predictions

3. Improve and enhance Southern Ocean modelling capability

Societal Outcome 5: How to achieve - A safe ocean where life and livelihoods are protected from ocean-related hazards

1. Improve forecasting capabilities

2. Understand the impacts of changing environmental conditions on risk and vulnerability

3. Improve emergency response competences

4. Engage with policy-makers

Societal Outcome 6: How to achieve - An accessible ocean with open and equitable access to data, information and technology and innovation

1. Ensure knowledge access and capacity building - See-cross cutting 1

2. Facilitate transnational cooperation and complementarity - See-cross cutting 3

3. Promote stakeholder participation - See-cross cutting 2

Societal Outcome 7: How to achieve - An inspiring and engaging ocean where society understands and values the ocean in relation to human wellbeing and sustainable development

1. Recognize the value of the Southern Ocean

2. Increase stakeholder engagement - See cross-cutting 2

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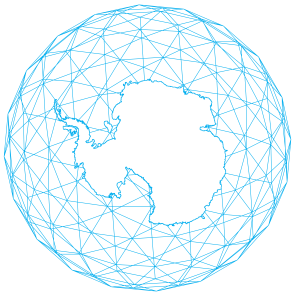

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