

Theme 1:

Antarctica InSync

Antarctica International Science &
Infrastructure for Synchronous Observation

Southern Ocean Physical and Biogeochemical Cycles in a Changing Climate

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Motivation and Background

1. **Climate regulation and global coupling**

The Southern Ocean dominates planetary heat and carbon uptake, couples all major ocean basins via the ACC and subpolar gyres, and exerts first-order control on sea level rise through ice–ocean interactions.

2. **Rapid physical, chemical, and biological change with large uncertainties**

Subsurface warming, CDW shoaling, sea ice variability, shifting freshwater balance, and micronutrient-limited ecosystems are changing fast, but key budgets (heat, freshwater, carbon, nutrients) remain poorly constrained and sometimes contradictory.

3. **Observational insufficiency as the core limiting factor**

Major uncertainties in carbon uptake, freshwater sources, ecosystem function, and gas fluxes stem from sparse, seasonally biased observations, especially in winter and under ice, blocking reliable understanding of trends and extremes.

Knowledge gaps

- **Air-sea fluxes:** Direct heat, carbon and momentum flux measurements (including turbulent components) are urgently needed, particularly at high latitudes and all seasons; bulk parameterizations inadequate and often disagree
- **Deep water upwelling and transformation:** Winter/shoulder season observations absent; CDW upwelling mechanisms, sea ice-driven transformations, and mesoscale/submesoscale processes poorly quantified
- **AABW formation and export:** Dense shelf water production, polynya convection, and off-shelf export processes remain uncharacterized during critical autumn and winter months
- **Cross-shelf exchange mechanisms:** Cross-shelf transport, eddy roles, and topographic interactions poorly characterized due to sparse current and turbulence measurements
- **Freshwater budget unconstrained:** Precipitation, ice melt variability, sea ice thickness, and internal salt redistribution all poorly quantified
- **Carbon and trace gases:** Autumn/winter/spring data gaps prevent understanding CO₂ flux, carbon cycling, biological carbon fixation; CH₄ and N₂O observations almost entirely absent

High level key recommendations

- 1. Long-Term Time Series Maintenance:** Secure the critical multi-decadal ship/land-based monitoring, mooring, and Argo programs (including biogeochemical and deep) that have been essential for detecting climate and biogeochemical trends in the past decades.
- 2. Air-Sea Flux Measurements:** Use underway systems on as many vessels and in situ platforms as possible, ensuring standardised practices, to routinely measure key variables to derive air-sea fluxes of heat, momentum, moisture, CO₂, methane (CH₄), and nitrous oxide (N₂O).
- 3. Marginal Ice Zone Process Studies:** Fund interdisciplinary autumn-to-spring ship campaigns in Southern Ocean subpolar regions characterised with large-scale upwelling to capture critical atmosphere-ocean-ice interactions driving the ocean distribution of heat, carbon, (micro)nutrient, and climate-relevant gases, as well as the biological carbon pump.

High level key recommendations

4. Year-Round Continental Shelf Observations: Deploy an internationally coordinated network of ice-capable floats, autonomous platforms, and moorings to observe processes that drive the global ocean circulation and affect global biogeochemical cycles, as well as the southward ocean heat transport threatening ice-sheet stability.

5. Critical Region Monitoring: Establish internationally coordinated observation arrays at regional choke points, controlling bottom water export, meridional and vertical transport of heat and other tracers, meltwater pathways and constrain biogeochemical consequences.

6. Ocean-Ice Interface Observations: Fund observations at the interface between ocean and sea-ice, and ocean and ice shelves, develop open-source ice-capable technology, such as acoustic positioning and navigation, and implement coordinated infrastructure that can operate with those, to observe critical processes year-round

High level key recommendations

7. Enhanced Earth Observation Capabilities: Ensure the development of new and consistent satellite observation products tailored for Southern Ocean regions to retrieve salinity, temperature, sea level, ocean mass, ice volume, and ocean color for process understanding, integrating these remote observations with in situ where needed.

8. Process-Based Model Development and evaluation: Utilize the expanded observational capabilities and process understanding immediately for development and validation of numerical model parametrisations for ice-ocean interactions, ocean mixing, key processes of the biological carbon pump and water mass formation to evaluate and reduce future climate projection uncertainties

9. International Resource Sharing: Formalise shared ship berths, support data sharing and international data portals, coordinated platform deployments, platform sensor hosting, sharing of sampling equipment and other common equipment to maximize coverage and cost-efficiency

List of relevant InSync WG

Physical oceanography	<ul style="list-style-type: none">Ice shelf–ocean interactionsSouthern Ocean air-sea fluxesHotspots of atmosphere-ice-ocean interactionImproving Southern Ocean surface salinity knowledge through satellite–in situ synergyAABW (formation, export and variability)
Biogeochemistry	<ul style="list-style-type: none">Carbon cycleCoastal connection and hydrographic drivers of Antarctic biogeochemistry and carbon cyclingBiogeochemistry of other GHGs (e.g. CH₄ and N₂O) in the Southern OceanSeasonal cycle of micronutrients and microbial interactions in the Southern Ocean (M&Ms)Trace elements
Platforms	<ul style="list-style-type: none">Coordinated profiling float deploymentsSOBIS: Survey of spatial Southern Ocean biodiversity
Connections with other themes	<ul style="list-style-type: none">Past ocean-ice-earth interactionsAntarctic buoy program = distributed networkEnergy budgets, boundary layer turbulent fluxes (albedo, and stability over ice sheets and sea ice)Past, Present and Future Surface Mass Balance of the Antarctic Ice SheetCircumpolar Whale DistributionAtmospheric Monitoring in the Northern Antarctic Peninsula: Understanding the Drivers of Climate Extremes