

Opinion: Status, Plans and Needs of Southern Ocean Modelling

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Abstract. In preparation for the *SOOS/OCEAN:ICE Workshop on ice-ocean observation harmonization and future priorities agenda*, a survey targeting the modelling community was conducted to assess research priorities for the Southern Ocean and Antarctica. [While this initiative was tailored mostly towards physical ocean and ice modelling, its outcome](#) specifically supports the design of field activities from the open Southern Ocean to the Antarctic shelf for the forthcoming *Antarctica InSync* campaign and is aligned with broader strategic planning efforts ahead of the next International Polar Year (IPY). The survey results are a useful basis to further communication between modeling and observing science communities. We believe this is crucial for optimizing campaign planning, achieving enhanced data usage and improving numerical experiments.

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1 Background

The Southern Ocean is responsible for 83% of the global ocean heat [content increase over the historical period](#) and more than 40% of global ocean anthropogenic carbon uptake (Frölicher et al., 2015; Williams et al., 2024). [Ocean](#) heat is a major driver of the current Antarctic ice sheet mass imbalance (Adusumilli et al., 2020; Bell & Seroussi, 2020; Noble et al., 2020). Nevertheless, this part of the world ocean features some of the most severe and long-standing biases present in state-of-the-art climate models with far reaching implications for climate projections (Stouffer et al., 2017; Beadling et al., 2020; Moreno-Chamarro et al., 2022; Zhang et al., 2023).

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Full understanding of the processes and feedbacks of climate change in the Southern Ocean and Antarctica can only be gained by combining in-situ observations, satellite reconnaissance and numerical modelling. The region is difficult to access, especially where ice covered, and direct observations thus remain sparse. Remote sensing is limited to the surface, at least for the ocean. And models are valuable tools but never perfect. The upcoming Antarctica InSync and the IPY programs are centered around field campaigns, which [is natural considering](#), the need for strategically planning ship schedules and equipment acquisition years in advance.

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53 [Satellite missions and model development follow again different cycles and routines, partly](#)
54 [on even longer schedules. Dedicated numerical experiments can be accomplished on a much](#)
55 [shorter time scale though.](#) Nevertheless, coordinating efforts across these science
56 communities and intensifying exchange between them from early on in these major programs
57 will be crucial for turning advanced process understanding into improved projections of the
58 future climate in and beyond the southern high latitudes. Therefore, the survey initiative
59 documented here supports a push for early integration of and engagement by the modeling
60 community in these observation-driven efforts.

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64 [As](#) a rather spontaneous effort, [the survey was](#) of ad hoc design. Despite being launched just
65 before the northern hemisphere summer break, it received a relatively large number of
66 completed responses (98), representing a broad cross-section of the ocean and climate
67 modeling community. This great turnout is also owed to the endorsement by [SOOS](#)
68 (<https://www.soos.aq/>), the Southern Ocean Observing System and [CLIVAR](#)
69 (<https://www.clivar.org/>), Climate and Ocean Variability, Predictability, and Change offices
70 and Scientific Steering Groups, who spread the call in the SOOS Update (Issue 31) and the
71 CLIVAR Bulletin, respectively, in August 2025 as well as the sharing of the call across
72 mailing lists of [Antarctica InSync](#) (<https://www.antarctica-insync.org/>), [APECS](#)
73 (<https://www.apecs.is/>), [ASPeCt](#) (<https://aspectssouth.org/>), [BEPsII](#)
74 (<https://sites.google.com/site/bepsiwg140/home>), [BioEcoOcean](#) (<https://bioecoocean.org/>),
75 [Polar-CORDEX](#) (<https://climate-cryosphere.org/polar-cordex/about/>), [Cryolist](#)
76 (<https://lists.cryolist.org/mailman/listinfo/cryolist>), the [EU Polar Cluster](#)
77 (<https://polarcluster.eu/>), [ICED](#) (<https://www.iced.ac.uk/>), [IMBeR](#) (<https://imber.info/>),
78 [IMECaN](#) (<http://imecan/>), [MISOMIP2](#) (<https://misomip.github.io/misomip2/>), [ObsSea4Clim](#)
79 (<https://obssea4clim.eu/>), [Ocean & Carbon Biogeochemistry](#) (<https://www.us-ocb.org/>),
80 [OCEAN:ICE](#) (<https://ocean-ice.eu/>), CLIVAR's [Ocean Modeling Development Panel](#)
81 (<https://www.clivar.org/clivar-panels/omdp>) and [Southern Ocean Region Panel](#)
82 (<https://www.clivar.org/clivar-panels/southern>), [POGO](#) (<https://pogo-ocean.org/>), [SCAR](#)
83 (<https://scar.org/>), [SCOR](#) (<https://scor-int.org/>), [SOCCOM](#) (<https://soccocom.org/>), the
84 CLIVAR task team and Community-MIP [SOFIA](#) (<https://sofiamip.github.io/>), and [TipESM](#)
85 (<https://tipesm.eu/>). This positive engagement yielded a valuable and unprecedented dataset
86 that offers quantitative insights into current priorities and gaps in Southern Ocean research
87 and modeling. It provides a robust foundation for ongoing and future strategic discussions
88 regarding the alignment of modeling and observational efforts.

Deleted: The survey was designed with a primary focus on the ocean modeling community. Although particular attention was initially given to realistic regional Southern Ocean configurations and CMIP-class global climate and Earth system models, input was solicited from modelers working across a range of spatial and temporal scales, and model complexities. While the survey emphasized physical oceanographic processes, coupled interactions with other components of the climate system, for example, sea ice, ice shelves and atmospheric dynamics were considered as well. Contributions related to biogeochemical processes and ecosystem modeling were also encouraged though not covered comprehensively. For pragmatic reasons, we defined the Southern Ocean as the region south of approximately 50°S in the survey context.

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90 [The survey was designed with primarily the physical ocean modeling community in mind and](#)
91 [thus pre-defined answers often highlight physical oceanographic processes \(see Appendix\).](#)
92 [Although leaning towards such processes, coupled interactions with other components of the](#)
93 [climate system, such as sea ice, ice shelves, and the atmosphere were considered as well.](#)
94 [Contributions related to biogeochemical processes and ecosystem modeling were also](#)
95 [encouraged though not covered comprehensively. It turns out that a more careful selection of](#)
96 [the pre-defined answers would have been advantageous and likely beneficial for a broader](#)
97 [coverage of these coupled processes. Relatively little use was made of the “Other” free text](#)
98 [option by the respondents. Similarly, the survey started out with an emphasis on probing](#)
99 [modelling groups using realistic regional Southern Ocean configurations and CMIP-class](#)
100 [global climate and Earth system models to study the historical period and maybe 21st century](#)
101 [projections. But it evolved into covering a much broader range of spatial and temporal scales,](#)
102 [and model complexities, for which the respondents did make use of the free text comment](#)

126 [fields. For pragmatic reasons, we limited the geographical region and defined the Southern](#)
127 [Ocean as the area south of approximately 50°S in the survey context.](#)

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129 The following summary presents key findings of the survey. While the [dataset](#)
130 (<https://doi.org/10.5281/zenodo.17289776>) (Martin et al., 2025) can be further explored, a
131 first look already holds significant potential for informing cross-disciplinary planning and
132 collaborative program development in the Southern Ocean and Antarctic research landscape.
133

134 **2 Who participated?**

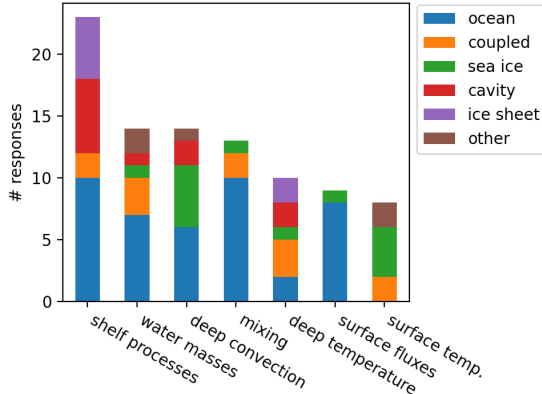
135
136 About half of the 98 survey participants [48%] identified as oceanographers, others see
137 themselves as experts in coupled climate [13%], sea ice [12%], ice shelf cavity [10%] and
138 land ice [8.2%] modelling. Colleagues studying processes at basin to global scales and from
139 annual to centennial scales contributed two-thirds of the replies; less than a quarter indicated
140 a research focus on mesoscale (10-100 km) processes with periods of months to seasons.
141

142 **3 Survey results and discussion**

143 **3.1 Model status and evolution**

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145
146 We asked the participants for the most problematic ocean model bias allowing a single choice
147 only aiming for a clear emergence of the most pressing issue from the survey. About a
148 quarter identified processes of the Antarctic continental margin (shelf seas, slope current, ice
149 shelf cavities) as requiring most attention (Figure 1). Further, open ocean deep convection
150 and water mass transformation [both 14.3%] and mixing were highlighted. Individual free
151 text answers mentioned deep ocean circulation, modeling of biogeochemical cycles and the
152 carbon pump, planetary boundary layer of ice-covered seas, and impacts on benthic
153 ecosystems as other major model biases, which are not displayed in Figure 1. The
154 respondents related such biases in particular to global coupled climate [38%] and ocean
155 models [28%] in general such as those used for the Climate Modelling Intercomparison
156 Project (CMIP); this may reflect the dominant area of expertise of the participants however.
157 Moreover, the respondents identified a dozen specific ocean models and state estimates as
158 well as specifically high resolution model versions that include some of these major biases
159 (see published survey data for details; Martin et al., 2025). We emphasize that moving
160 towards finer grid resolution alone may yield individual improvements but will not solve all
161 the biases—as is documented in Moreno-Chamarro et al. (2022).
162

ocean model biases by expert group

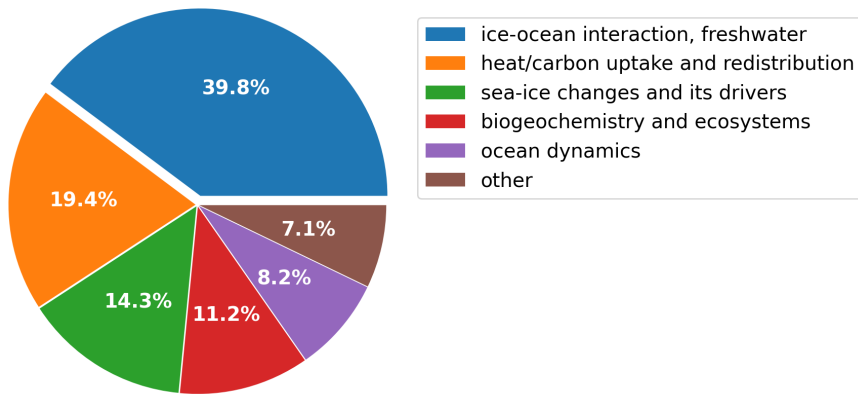


163
 164 Figure 1: “What is the most problematic ocean model bias?” Eight well-known issues were listed as pre-
 165 defined, single-choice answers to ensure emergence of the most pressing problems. In this distribution of the
 166 responses we merged seasonality of surface fluxes and air-sea CO₂ flux into surface fluxes. The 91 responses (of
 167 98 in total) are color-coded with respect to the area of expertise provided by the respective respondents. Here,
 168 “other” refers to all areas of expertise not explicitly listed, e.g. atmosphere and ecosystem.
 169

170 It is important to understand that open ocean deep convection—while physically not
 171 unrealistic (Gordon, 1978)—is dramatically overestimated in many climate models,
 172 specifically those of coarse resolution, with consequences for ocean to atmosphere heat
 173 redistribution, sea ice coverage, bottom water characteristics, and eventually also internal
 174 climate variability (Reintges et al., 2017; Heuzé et al., 2021). In reality, Antarctic bottom
 175 water (AABW) is formed on the continental shelf where sea ice formation and ice shelf melt
 176 play key roles in the transformation of upwelled deep water (Silvano et al., 2023) and so does
 177 mixing for its transformation into Antarctic intermediate water (AAIW) further equatorward
 178 (Li et al., 2022). To this end, nearly three-quarters of all participating experts pointed out
 179 biases that are inter-connected and play an imminent role in the formation of water masses,
 180 such as AABW and AAIW, crucial for the global overturning circulation and for the natural
 181 sequestration of heat and anthropogenic carbon.
 182

183 Hence, it is no surprise that implementation of ice shelf cavities [20%], convection
 184 parameterization [18%], scale aware (mixing) parameterizations [15%] and overflow
 185 parameterization [13%] were listed as most urgent model development targets. There has
 186 been remarkable advancement in these directions over the past two decades (e.g., De Rydt et
 187 al., 2024; Legg et al., 2009; Bruciaferri et al., 2024). And it has been demonstrated that these
 188 new developments can mitigate model biases in the Southern Ocean even at relatively coarse
 189 resolution despite remaining issues (e.g. for ice shelf cavities see Hutchinson et al., 2023).
 190 However, we believe there is often significant delay or inaction in implementing such
 191 advancements, as model development is rarely funded directly by dedicated research projects.
 192 The push for rapid research outcomes tends to favor easily implemented targets — the 'low-
 193 hanging fruit' — over more complex, long-term efforts.
 194

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196 Figure 2: “What is in your view the singular key science topics in the Southern Ocean?” The five most frequent
 197 answers were provided as part of seven examples and could be simply ticked. Pre-defined answers less picked
 198 were air-sea exchange and extreme events. Additional topics were given by the respondents as free text input.
 199 These include, amongst others, [air-sea exchange](#), [cloud-radiation processes](#), [extreme events](#), [nutrient](#)
 200 [redistribution](#) and [cross-disciplinary topics](#), and are collated as ‘other’.

Deleted: carbon uptake and storage.

203 This behavior is evident in the responses on near-term model evolution. Among those,
 204 increasing model complexity [27%] and spatial resolution [24%] stand out. Other goals such
 205 as improving or developing novel parameterizations and including artificial intelligence
 206 based modules are only considered by 11-13% of the participants. In this case multiple
 207 answers were possible and participants ticked or listed 2-3 responses on average. It [appears](#),
 208 that preference is given to model complexity—evolving climate models into Earth system
 209 models by coupling more components, for example, ice sheets or biogeochemistry modules—
 210 over improving model physics. However, [we think](#) this could also be a sign of a more
 211 diversified, cross-disciplinary science landscape. As compute power keeps growing,
 212 resolving model issues by enhancing grid resolution appears to be a possible avenue to reduce
 213 biases (e.g., Rackow et al., 2022). But this is a costly option and impractical for applications
 214 on centennial time scales since proper representation of mesoscale dynamics in the high
 215 latitudes of the Southern Ocean requires grid spacing of 1/8°-1/20° (and finer on the
 216 continental shelf), to properly resolve the Rossby radius (Hallberg, 2013, their Fig. 1). [We](#)
 217 [suggest that new](#) observations supporting model development could thus lead to improved
 218 and yet affordable simulations on a large range of spatial and temporal scales.

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220 3.2 Scientific focus

221 Reducing the major model biases and advancing ocean and climate models as laid out above
 222 will be essential to address the key research topics identified in the survey responses.
 223 Freshwater, heat and carbon budgets are high on the scientific agenda of the modelling
 224 community (Figure 2). Questions on process understanding and future evolution of the
 225 Antarctic ice sheet, its ice shelves and their interaction with the ocean through heat and
 226 meltwater dominate the results [40%]. While this is research at the continental margin, heat
 227 and carbon uptake where the low latitude Southern Ocean plays a major role was named
 228 second [19%], followed by interest in the recent and future sea ice trends [14%]. On the one
 229 hand, these results are somewhat biased by the research areas of the participants. On the other
 230 hand, scientific interest has migrated poleward in the Southern Ocean, where major
 231 challenges have been identified, such as knowledge gaps in ice-ocean interaction affecting
 232

237 global sea level rise projections, and where new observational techniques for under-ice
238 sampling and mesoscale ocean simulations have become available.

239
240 The results suggest that oceanic processes themselves, such as dynamics from mesoscale
241 eddies to large-scale circulation, tides, waves and mixing are not “big questions” by
242 themselves anymore despite remaining issues and their important role in current “grand
243 challenges” like ice-ocean interaction, warm water intrusion onto the continental shelf and
244 biogeochemical modeling. Further, we assume that the underrepresentation of
245 biogeochemical and ecosystem research as well as atmospheric process understanding, most
246 prominently clouds and aerosols, is likely a consequence of questionnaire design and the
247 focus group addressed.

248 3.3 Observations used and needed

249
250
251 Before diving into a discussion on the observational needs of the modelling community, we
252 would like to call attention to the data sources actually used. There is an unbroken preference
253 by modellers to use gridded data products [28%], i.e. statistically interpolated fusions of
254 observations from various sources, and reanalysis or state estimates [21%], which are based
255 on a numerical model and incorporate observations through, e.g. assimilation techniques.
256 Likely also due to their extensive spatial coverage, satellite-borne remote sensing products
257 are favored as well [15%]. Data from ship-borne instruments, moorings, and floats appear to
258 be used less often directly, [10-13%]. We acknowledge that observational data of all kinds, in
259 particular including in-situ data, feed into the gridded products though. Nevertheless, it is
260 important to note that modelers tend to validate their simulations against these kind of
261 “observations”, which in fact are advanced data products and rather not viewed as actual
262 observations by the observing, sea-going science community. Further, any in-situ data that is
263 not included in such gridded products is likely less used or even overlooked by modelers and
264 thus does not contribute as much to the improvement of models.

265
266 Based on our personal experience, modelers tend to lean on derived products, such as
267 reanalyses and state estimates, because (1) observations are typically sparse and direct
268 comparisons require complex subsampling of model output, (2) formats and platforms used
269 to share observational data are still not unified and easily accessible to users despite ongoing
270 efforts, and (3) original measurements require advanced background knowledge and
271 interpretation for use in model validation. These issues can be mitigated by, for instance,
272 providing open-source validation packages along with the measurements and the
273 development of virtual instruments, i.e. tool boxes allowing for the subsampling of model
274 output in ways emulating specific observational instruments. Further, we suggest that
275 communication between the science communities should be strengthened and educational
276 programs, such as summer schools, could introduce instruments, proper data handling and
277 aforementioned tool boxes to the next generation of modelers.

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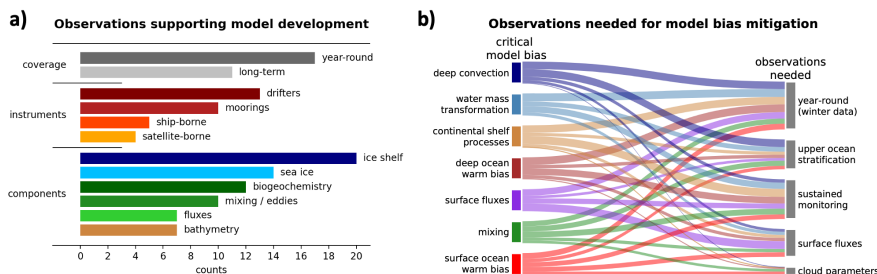


Figure 3: (a) “Which kind of observations would further this [model] development?” (without pre-defined answers). Free text responses were grouped by key words (right hand side bar labels) and sorted into groups of temporal coverage, instrumentation/sensors/platform and Earth system components (left hand side labels). In total 130 responses were identified. (b) Linking the two questions “What is the most problematic ocean model bias?” and “Which observations could help understanding biases or further the process understanding?” by the same respondent. In both cases pre-defined answers were provided but free text replies were also possible; multiple choice was allowed. Overall 200 responses were cross-linked. The number of responses on the left side are normalized, see Fig. 1 for specific numbers.

For reducing observational gaps, especially with mitigating model biases in mind, modelers should be given and take the opportunity to provide input to evolving observational programs early in the planning phase. This would ensure multiple use of the data collected in the end. Figure 3a shows observations desired for bias mitigation with in-situ observations clearly dominating over remote sensing data. This preference can be interpreted as a need for better process understanding in which in-situ data are considered actual “ground truth” and often provide higher resolution in space and time, which is useful in several aspects, such as model validation, identifying of processes resolved at a given grid spacing, improving model parameterizations, etc. Another interpretation is that modellers are well aware of in-situ measurements being crucial for better quality gridded products. And while such products are preferred in the actual validation process, the dire need for more ground truth data in a changing climate is acknowledged and its collection valued.

Moreover, the scientific goals and observational plans of Antarctica InSync appear to be very much in line with the needs of the modelling community wishing for year-round data especially in ice-covered seas and combining physical and biogeochemical measurements (Figure 3a). The strong desire for winter observations and year-round monitoring in the Southern Ocean [29%] is linked nearly equally to all major biases identified (Figure 3b). As is already discussed by the Antarctica InSync community, building capacity for sustained monitoring in preparation for the International Polar Year in 2032/33 and beyond would also strongly support model improvement and advancement [25%]. Observations of the upper ocean stratification and surface fluxes would enable a better process understanding of the mixed layer and help to constrain vertical/diapycnal mixing parameterizations in models. Interestingly, the role of other climate system components causing biases in the ocean, for example, sea ice and snow, clouds and radiative processes, was not highly considered. This is likely owed to the limited choice of pre-defined answers we provided and the behavioral bias of the respondents preferring to tick one of those rather than entering individual answers. Nevertheless, we take this as an opportunity to point out the need for improved fundamental understanding and acknowledgement of coupled mechanisms and feedbacks within and beyond the focus group. Having better records of magnitude and variability of Southern Ocean surface fluxes of both physical and chemical quantities will help this significantly.

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366 Similarly, any observations in support of heat and freshwater budgets especially with a focus
367 on ice-ocean interaction will be instrumental in advancing models and improving climate
368 projections. And last but not least, high-resolution bathymetry data of the Southern Ocean
369 from the Antarctic Circumpolar Current to the continental margin and into the ice shelf
370 cavities is urgently needed. Topography is a key ingredient for realistic simulations of the
371 ocean circulation, specifically the import of warm deep water and the export of dense bottom
372 waters, and therefore crucial for reliable projections of ice shelf melting.

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374 4 Conclusions and Outlook

375 In conclusion, surveys like this provide a valuable overview of the current status, plans, and
376 data needs not only for the Southern Ocean but also for the global modeling community.
377 There are also some experiences to take away from this exercise, in particular how the pool
378 of respondents shapes the usefulness of the survey, how to ask targeted questions without
379 being exclusive, how pre-defined multiple-choice answers simplify the analysis but reduce
380 the variety of responses, and which metainformation really is instrumental for interpreting the
381 responses. All of this is well known and demonstrates the importance to involve experts on
382 questionnaire design rather than constructing an ad hoc survey. Nevertheless, the feedback by
383 the community to our survey has been very positive indicating that such surveys can be a
384 valuable tool for future international program planning.

385
386 With the Antarctica InSync program in active planning and IPY approaching, we hope the
387 results presented—with additional data available (Martin et al., 2025)—will inform both the
388 scientific community and stakeholders to advance observations and models. The findings
389 already contributed to the *SOOS/OCEAN:ICE Workshop* discussions and conclusions.
390 Research priorities include ice–ocean interactions, Southern Ocean heat and carbon uptake,
391 and the recent major changes in sea ice. Addressing these challenges requires model
392 developments such as ice-shelf–ocean coupling, biogeochemistry, and higher resolution,
393 alongside improved understanding of continental shelf processes and upper-ocean
394 stratification. This, in turn, requires new observations in key regions with ice shelves most
395 vulnerable to warm water intrusions and ocean circulation choke points. Further, the survey
396 results call for stronger communication between the modeling and observing communities
397 and dedicated data-use training for modelers. Antarctica InSync offers a major opportunity to
398 advance such efforts.

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402 Data availability

403 The survey results are available through Zenodo (Martin et al., 2025),
404 <https://doi.org/10.5281/zenodo.17289777>.

406 Author Contributions

407 TM conceived the original idea of conducting the survey, led the analysis and produced all
408 figures. All authors contributed to the survey design, its content and writing of this
409 manuscript. AMH explored different survey platforms and distributed the survey call.

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411 Competing Interests

412 The authors declare to have no competing interests.

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420 Acknowledgement

421 The authors thank [three anonymous reviewers for their positive, useful comments leading to a](#)
422 [more careful interpretation of the survey](#). We specifically thank SOOS and CLIVAR for their
423 support and endorsement of the survey facilitating this study. We [are grateful to](#) all the
424 scientific networks and coordinators for widely spreading the survey call and all the
425 participants for responding yielding such great turnout. Helpful comments on the
426 questionnaire design by Chris Danek, Ivy Frenger, Alexander Haumann, Qian Li, Lavinia
427 Patara, Ariaan Purich, David Stevens were much appreciated. The survey was conducted
428 using Google Forms and we made use of the initial visualization of the statistics provided by
429 this platform in material provided by Martin et al. (2025). AJSM was supported by Ocean
430 Cryosphere Exchanges in Antarctica: Impacts on Climate and the Earth system, OCEAN
431 ICE, which is funded by the European Union, Horizon Europe Funding Programme for
432 research and innovation under grant agreement Nr. 101060452, 10.3030/101060452; OCEAN
433 ICE contribution number 50; he was also funded by UK Research and Innovation (UKRI)
434 under the UK government's Horizon Europe funding Guarantee [grant number 10048443].
435 SOOS is a joint initiative of the Scientific Committee on Oceanic Research (SCOR) and the
436 Scientific Committee on Antarctic Research (SCAR). SOOS sponsors include SCAR and
437 SCOR, the Tasmanian State Government, CSIRO, the Australian Antarctica Program
438 Partnership (AAPP), the Alfred Wegener Institute (AWI), OCEAN:ICE, the Swedish Polar
439 Research Secretariat and the TÜBİTAK MAM Polar Research Institute. The SOOS
440 International Project Office is hosted by the Institute for Marine and Antarctica Studies,
441 University of Tasmania.

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523 **Appendix**

524 [Here we repeat for convenience the survey introduction and questions along with the](#)
525 [response options. A screenshot of the original questionnaire website is available at](#)
526 <https://doi.org/10.5281/zenodo.17289777>.

527

528 **Southern Ocean modelling: status, plans and needs**

529 In preparation of the *SOOS/OCEAN:ICE/Antarctica InSync workshop* on ice-ocean
530 observation harmonisation and future priorities agenda, which will be held in Copenhagen in
531 September this year and also serves for the planning of [Antarctica InSync](#) activities, we
532 kindly ask for your input.

533 All of the 12 questions below focus on the Southern Ocean region (south of ~50°S), physical
534 ocean processes are prioritised but immediate interaction with other system components can
535 be addressed (atmosphere, sea ice, ice shelves, biogeochemistry, ecosystem etc.), and the
536 applications we have in mind range from realistic regional models in the Southern Ocean to
537 CMIP-type global climate models (with or without further coupled components like ice
538 shelves or biogeochemistry).

539 **Please select from the multiple choice items or add an alternative item as "other".**
540 **This should not take more than 10 minutes.**

541 Note, the first three questions on expertise and scales may help to "set the stage" for the
542 answers of the other questions. If you work on very different scales, you may consider
543 answering the questionnaire twice for different cases. A link for another response is provided
544 after submitting the first one.

545 ***Please respond until September 15. (deadline extended)***

546 Thank you for your time and effort.

547 Torge Martin (OMDP), Carolina Dufour (SORP), Andrew Meijers (SOOS), Alyce Hancock
548 (SOOS)

549 *This questionnaire is supported by SOOS and CLIVAR panels SORP and OMDP. The*
550 *anonymous(!) data may be used by these panels for planning of further activities beyond the*
551 *above mentioned workshop.*

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552 <https://www.soos.aq>, <https://www.clivar.org/clivar-panels/southern>,
553 <https://www.clivar.org/clivar-panels/omdp>

554

555 **1) What is your primary area of expertise?**

556 This is independent of a focus on physical, biological or other processes.

- 557 Ocean
558 Sea ice
559 Ice-shelf cavity
560 Ice sheet/ice shelf/icebergs
561 Atmosphere
562 Coupled climate modelling
563 Other: _____
564

564

565 **2) What spatial scales do you work on?**

- 566 Submesoscale (<10 km)
567 Mesoscale (10-100 km)
568 Basin-scale (>100 km)
569 Global impacts
570

570

571 **3) What temporal scales do you work on?**

- 572 Days to weeks
573 Months to seasons
574 Years to decades
575 Decades to centuries
576 Beyond centuries
577

577

578 **4) What is in your view the singular key science topic in the SO?**

- 579 Ocean dynamics (sub-/mesoscale eddies to large-scale circulation)
580 Ice sheet/shelf–ocean interaction, fresh water
581 Heat and/or carbon uptake and redistribution
582 Sea-ice change and drivers/consequences thereof
583 Air-sea exchange, incl. carbon/trace gasses
584 Marine biogeochemistry and ecosystems
585 Extreme events
586 Other: _____
587

587

588 **5) What kind of observational data do you preferably use?**

589 *[multiple answers allowed]*

- 590 Campaign based data (e.g. ship transects, gliders, ...)
591 Stationary, year-round data (e.g. moorings)
592 Varied spatial and temporal coverage (e.g. Argo-Floats)
593 Gridded data products integrating various data sources
594 Reanalysis/ocean state estimate products
595 Remote sensing data (please specify below)
596 Other: _____
597

597

598 **If you selected "Remote sensing data" above, please specify the variable and**
599 **product here:**

600 _____

601
602 **6) What is the most problematic ocean model bias?**

- 603 ○ Surface warm bias, too small sea ice extent
- 604 ○ Deep warm bias
- 605 ○ Mixing
- 606 ○ Seasonality of surface fluxes
- 607 ○ Air-sea CO2 flux
- 608 ○ Water mass formation and characteristics (AABW, AAIW, ...)
- 609 ○ Open-ocean convection (polynyas)
- 610 ○ Shelf processes (e.g. slope current, ice shelf cavities, overflows, ...)
- 611 ○ Other: _____

612
613 **7) Which type of model did you have in mind when answering the last question**
614 **on biases?**

615 For example, list model complexity, grid resolution, application case, or anything
616 else.

617 _____

618
619 **8) Which observations could help understanding biases or further the process**
620 **understanding? [multiple answers allowed]**

- 621 ○ Winter data (year-round observations)
- 622 ○ Upper ocean stratification
- 623 ○ Surface fluxes
- 624 ○ Cloud observations
- 625 ○ Sustained monitoring
- 626 ○ Other: _____

627
628 **9) Where do mismatches exist between traditionally observed quantities and**
629 **model diagnostics (e.g. mixed layer depth)?**

630 _____

631
632 **10) What is the most pressing ocean model development?**

633 *[multiple answers allowed]*

- 634 ○ Implementation of ice shelf cavities
- 635 ○ Overflow parameterization, vertical coordinates
- 636 ○ Convection parameterization, vertical mixing
- 637 ○ Scale-aware parameterization, e.g. for eddies
- 638 ○ Biogeochemistry module
- 639 ○ Coupled ecosystem module
- 640 ○ Surface waves and/or tides
- 641 ○ Sea ice dynamics
- 642 ○ Other: _____

643

644

645 **11) Where will you or your collaborators evolve ocean models towards over the**
646 **next decade?**

647 *[multiple answers allowed]*

- 648 ○ Coupling more Earth system components (ice sheets, biogeochemistry, ...)
- 649 ○ Including more processes (tides, waves...)
- 650 ○ Novel parameterizations (submesoscale, scale-aware...)
- 651 ○ Higher resolution (horizontal and/or vertical)
- 652 ○ Unstructured grids, variable topography (wetting/drying, ice shelf cavity
- 653 shape)
- 654 ○ AI-based model components (parameterizations, emulators, ...)
- 655 ○ Other: _____

656 **12) Which kind of observations would further this development?**

657 _____

658

659

660

661 **Voluntary option:** provide your contact details for further discussion regarding Antarctica

662 InSync modeling activities: **name, affiliation, e-mail** (comma delimited please).

663 _____

664

665

