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D4.4.12 Improving under-ice positioning methods in the high-latitude Southern Ocean

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[2] Integers correspond to submitted versions.

Table of Contents

Table of Figures

1. INTRODUCTION

This document describes the efforts made by the British Oceanographic Data Centre (BODC), which is part of the National Oceanography Centre (NOC), to improve the positioning of Argo floats that spend part of their life under sea ice around Antarctica. This includes floats that only have ice avoidance software, like some of the MOCCA fleet, and floats that have acoustic 'RAFOS' receivers for triangulating position based on fixed sound sources on moorings in the Weddell Sea.

The original objective was to work on improving or developing methods, but this after initial research switched to engaging researchers and infrastructure experts already engaged in this work to make existing approaches more readily available to the wider Argo community. However, after initial investigation it became apparent that there were others actively engaged in this field of research and operational activity, and the key challenge and achievement was to bring these people together, and formulate plans for the future, rather than attempt to duplicate effort.

This work was undertaken as part of BODC's role as the coordinating partner of the Southern Ocean Argo Regional Centre (SOARC). SOARC is responsible for ensuring the sustainability of the Argo array in the Southern Ocean and the reliability of the data available in this dynamic, complicated and under-sampled region of the global ocean. In doing so, BODC has enhanced European leadership in the region, and has improved the sustainability of the array in the Southern Ocean beyond the life of the MOCCA project.

2. DEVELOPING COLLABORATIONS

2.1. The challenge of under-ice operations

The Arctic Ocean and Southern Ocean are subjected to large seasonal variability in sea-ice cover resulting from seasonal warming and cooling of these regions. In the Southern Ocean this results in most of the surface ocean south of the Antarctic Circumpolar Current (ACC) becoming ice-covered, and in some regions this sea-ice persists throughout the year. Figure 1 shows an indicative annual minimum sea-ice extent, with multi-year sea-ice present east of the Antarctic Peninsula in the Weddell Sea and at high latitude in the Ross Sea. Figure 2 shows an indicative annual maximum sea-ice extent covering the ocean up to a latitude of ~50°S throughout much of the Southern Ocean.

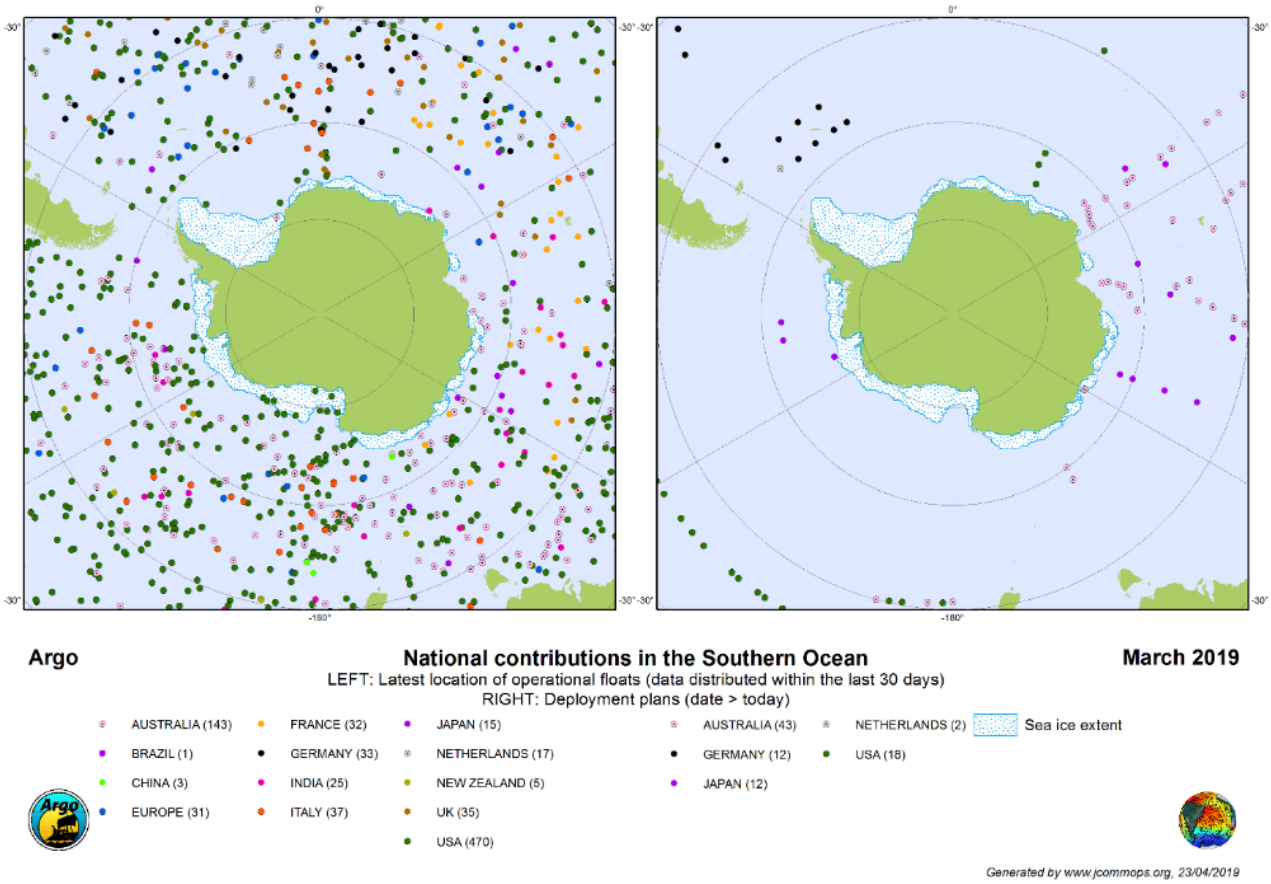

Figure 1 – Southern Ocean indicative annual minimum sea-ice extent, with the locations of active Argo floats (left) and planned Argo float deployments (right) during March 2019, from www.jcommops.org

Whilst an Argo float is operational under sea-ice it must first be able to avoid surfacing to prevent damage to the communications antennae and sensor payload. Argo floats operating in seasonally sea-ice covered regions have been routinely equipped with ice avoidance software for several years, and have the capability to store profiles sampled whilst under-ice for transmission when the float is able to surface. Floats with these capabilities are available from multiple manufacturers. More information about the challenges of operating Argo floats is available from the international Argo Project Office *Polar Argo webpages*.

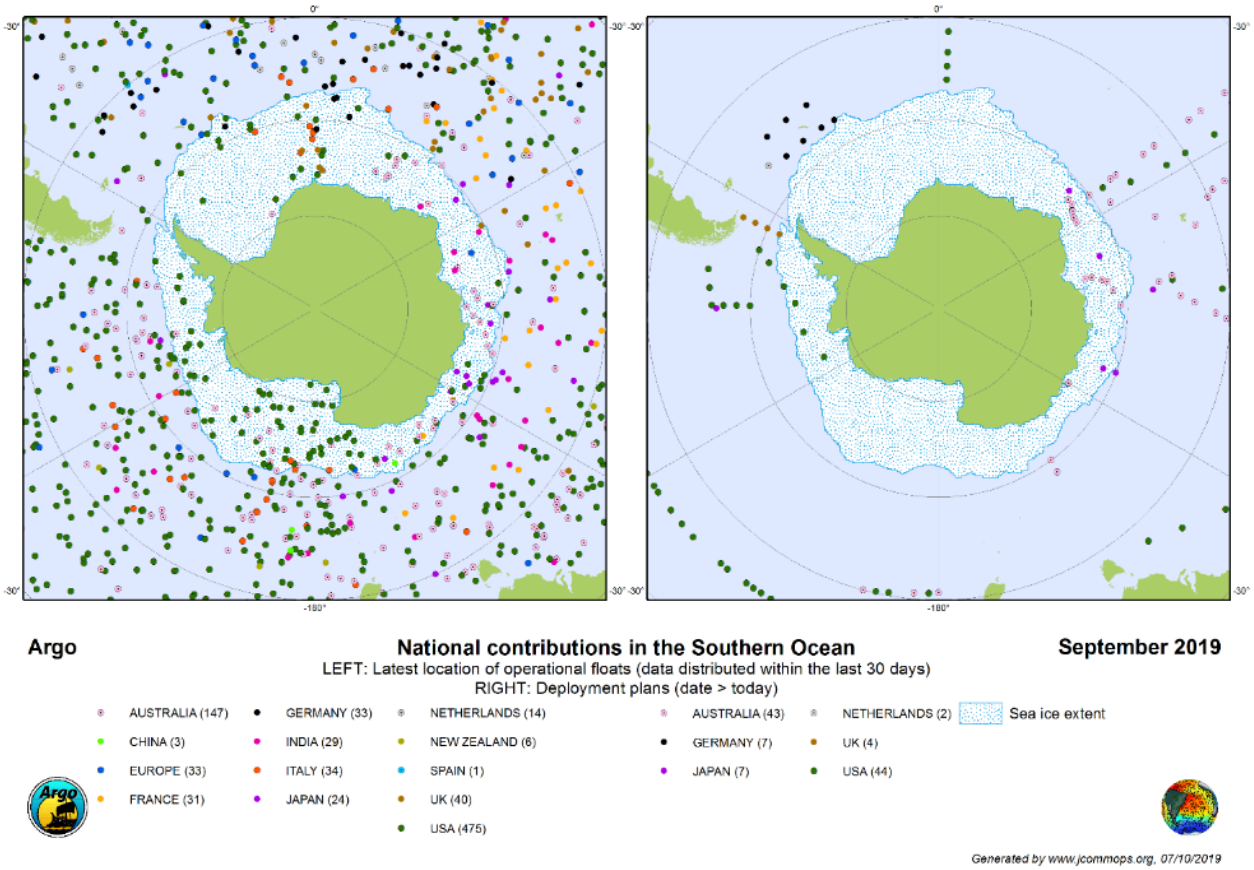

Figure 2 - Southern Ocean indicative annual maximum sea-ice extent, with the locations of active Argo floats (left) and planned Argo float deployments (right) during September 2019, from www.jcommops.org

2.2. Under-ice positioning techniques

The key challenge that remained in operating under-ice is determining the position of the float to an acceptable level of accuracy when satellite determined GPS locations are not available due to sea-ice cover. Initially BODC had sought to develop techniques in this area itself in support of MOCCA floats and other European floats deployed in the high latitude Southern Ocean. However, it became clear after initial research that much progress had already been made on this topic (e.g. *Chamberlain et al. 2018*) and focus shifted to improving coordination, knowledge sharing and promotion of existing efforts.

Investigation of existing efforts has shown that there are 4 main under-ice positioning techniques to consider:

1. Basic linear interpolation between points where floats could surface, but which is of limited value, especially close to complex bathymetry where an interpolated position could place a float profile below the sea-floor. This is the default approach used by the Argo Data Assembly Centres (DACs) in lieu of the application of more advanced techniques;

2. Interpolation based on contours of bathymetry and the Coriolis effect resulting from the Earth's rotation, which has proven very effective in close proximity to steeply sloping bathymetry such as in the Weddell Sea close to - but not on - the Antarctic continental shelf, and also near seamounts such as Maud Rise (*Chamberlain et al., 2018*);

3. Under-ice positioning using the RAFOS (Ranging And Fixing Of Sound) sound source mooring array (see figure 3) deployed and maintained by AWI in the Weddell Sea (*Klatt et al., 2007*). This is particularly important in the abyssal plains of the Weddell Sea where deep and flat bathymetry renders no. 2 less reliable. This requires expertise and specialist software (which has just been redeveloped outside of the MOCCA project) to be able to process RAFOS data received by the float. It has also been identified that this approach is best applied to the Argo fleet as a whole and would benefit from a coordinated effort rather than individual Argo programmes carrying out this analysis. Additionally, further research has been undertaken to further refine RAFOS positioning with a Kalman filter which can be integrated into existing analysis software (*Chamberlain et al., 2018*);

4. Under-ice positioning whilst on the continental shelf which requires specialist approaches to managing a float's mission and inferring under-ice positions using coastal bathymetry (*Wallace et al., 2020*).

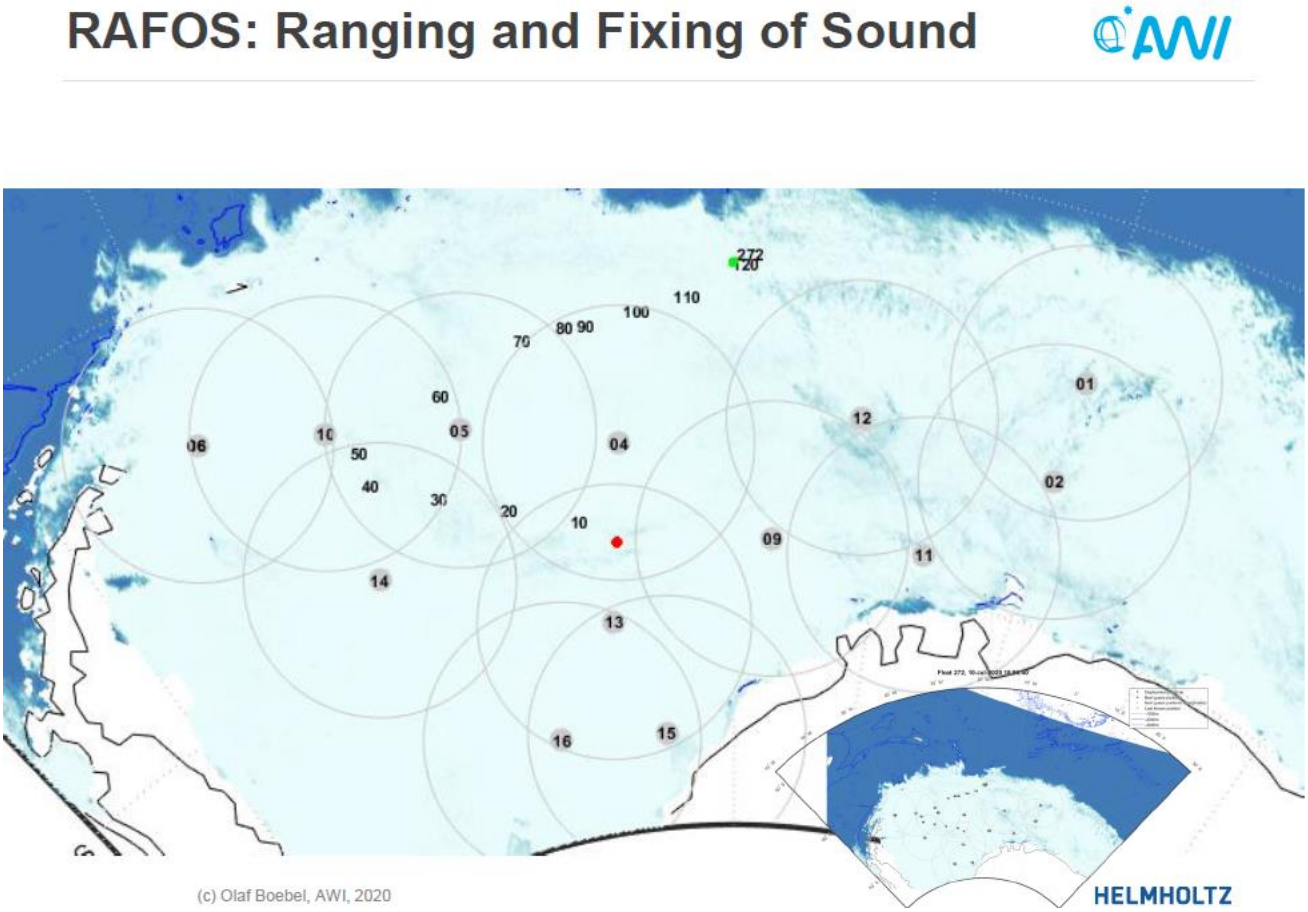

Figure 3 - RAFOS (Ranging And Fixing Of Sound) sound source mooring locations (numbered grey dots) and indicative effective range (grey cicles) in the Weddell Sea, courtesy of Olaf Boebel, AWI

2.3. Developing the SOARC Partnership

At the start of the MOCCA project, various different institutions within the Argo community were engaged in operational activity and research in the seasonal sea-ice zone of the Southern Ocean, but these efforts were not coordinated to a common plan. BODC has focused on identifying keys partners, introducing them to the role of SOARC (*www.soarc.aq*) and inviting them to share their knowledge and expertise.
At the start of the MOCCA project in 2015 the SOARC partnership included only BODC and CSIRO (Australia, *www.cmar.csiro.au/argo/*), the latter of which has experience of operating Argo floats under-ice on the Antarctic continental shelf south of Australia. In 2016 the partnership grew to include MOCCA project partner BSH (*www.bsh.de*), who lead the German Argo programme. This was followed in 2017 by MBARI joining to represent the USA SOCCOM project (*soccom.princeton.edu*) who are world leaders in biogeochemical Argo in the Southern Ocean.

This still left a gap regarding under-ice positioning expertise, so later in the MOCCA project, during 2019 and 2020, the focus shifted specifically onto expanding the partnership to include the AWI (Germany, *www.awi.de*) who maintain the RAFOS mooring array and further representatives from the SOCCOM project from Scripps Institute of Oceangraphy (*scripps.ucsd.edu*) with expertise in under-ice positioning methods and the University of Washington (*www.ocean.washington.edu*) with expertise in quality control.

As a result of this developing partnership, pursued as part of the MOCCA project, SOARC is now well-positioned to meet the challenges of operating under-ice, and under-ice positioning.

3. FUTURE

The next step for the SOARC partnership is to raise the profile of existing technologies and techniques, emphasizing their maturity, to encourage more widespread adoption in the Argo community and ultimately increase the number of deployments into the seasonally sea-ice covered regions of the Southern Ocean. This is particularly the case with using the RAFOS array in the Southern Ocean for acoustic positioning, which until now has been largely used only by the German Argo programme. As Argo develops towards full implementation its global, full-depth, multi-disciplinary mission, it is essential that existing mature technologies can be made available to contributing programmes. BODC will continue to coordinate these efforts and plans to make use of some of these under-ice positioning techniques and approaches as part of establishing regional data quality assessments in the Southern Ocean as part of the EU H2020 project Euro-Argo RISE WP5.

4. REFERENCES

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