Observing High Latitudes:

extending the core Argo array

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Why observe the polar oceans?

Polar regions play a critical role in setting the rate and nature of global climate variability through their moderation of the earth's heat, freshwater and carbon budgets. Recent studies suggest that some of the strongest climate change signals are already occurring in the high latitudes (Fig 1). The Southern Ocean is warming more rapidly than the global average (Gille 2008, Böning *et al.*, 2008). Both the Arctic and Southern Oceans are experiencing widespread changes to water mass properties, circulation and sea ice extent (Aoki *et al.*, 2005, Polyakov *et al.*, 2005, Turner and Overland 2009). Routine, sustained observations are required in order to detect, interpret and understand global climate change (Rintoul *et al.*, 2009, Lee *et al.*, 2009).

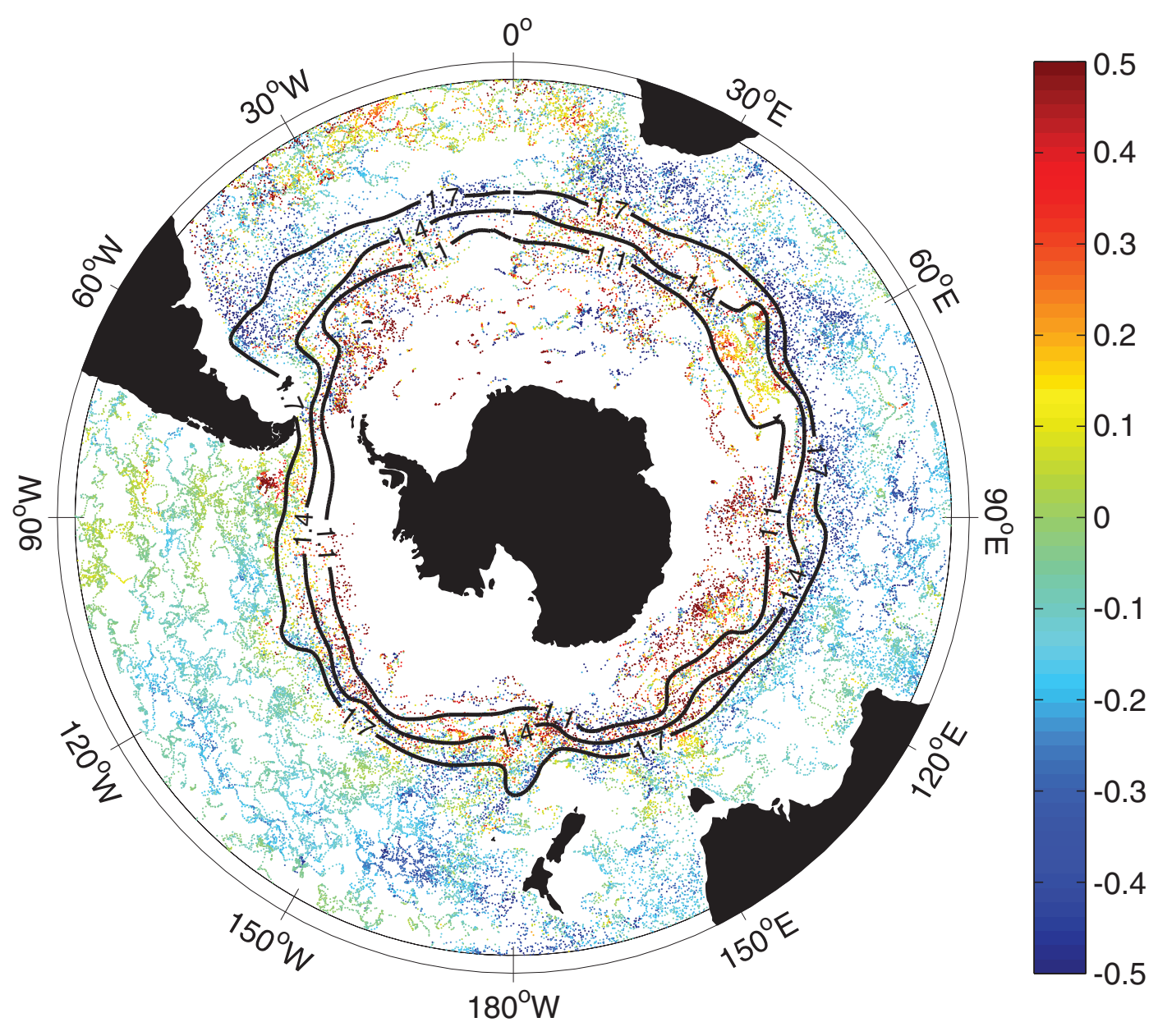


Figure 1: Southern Ocean warming (temperature anomalies from the climatological mean) observed from 52447 Argo profiles (from Böning *et al.*, 2008).

High latitude observations

In the past, the high latitude oceans have been drastically under-sampled, particularly in winter. Over the last decade, the Argo program has already provided more profiles in the Southern Ocean than that collected by over 100 years of ship-based hydrography (Fig 2). Indeed, autonomous, ice-capable profiling floats are already beginning to extend Argo monitoring into the logistically-difficult seasonal ice zone.

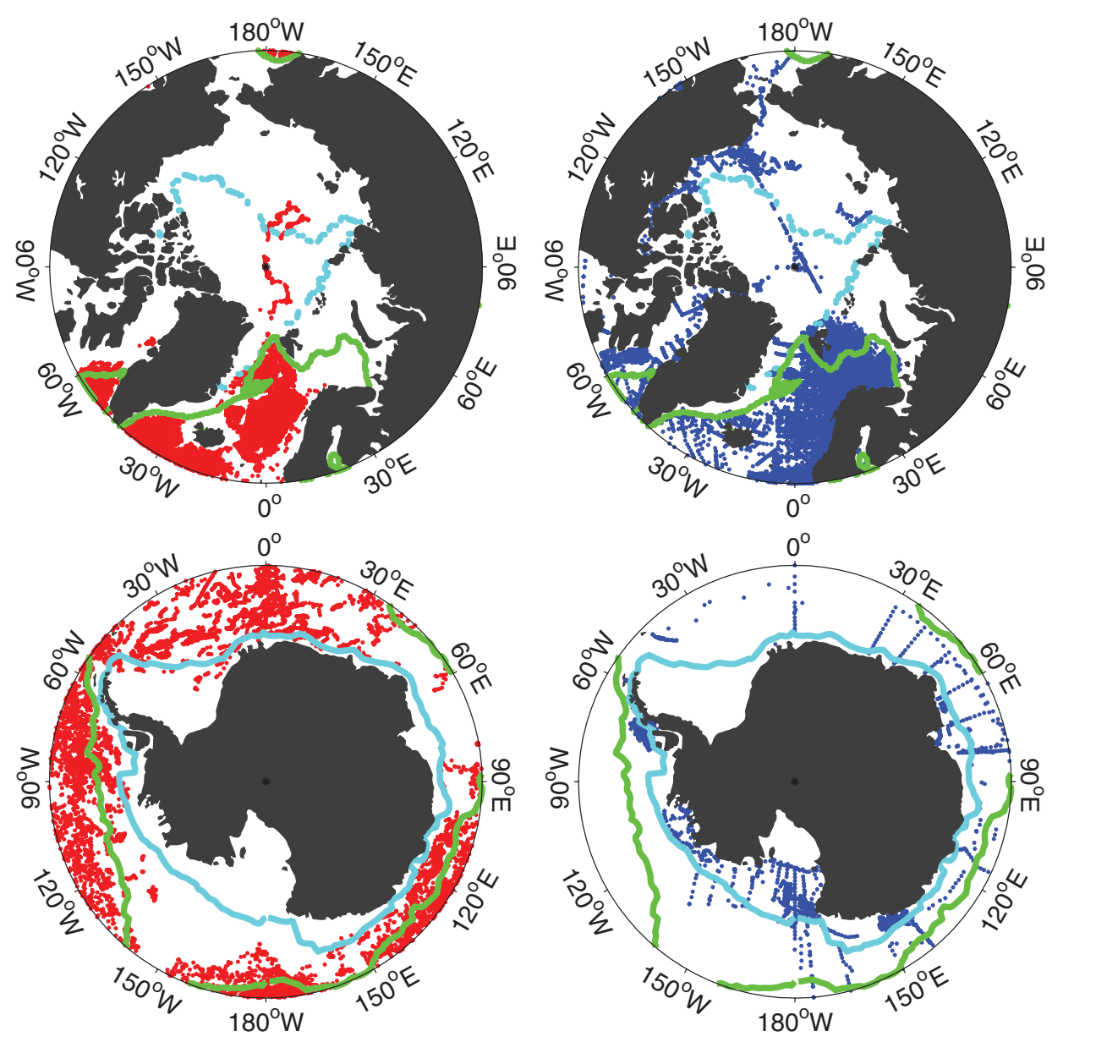


Figure 2: Data coverage from Argo (red dots) and hydrography (blue dots) over the past decade in the Arctic (top panels) and Antarctic (bottom panels). The late summer ice edge (cyan line) and late winter ice edge (green line) in 2007 is shown. The number of Argo profiles in the Antarctic (6586) far surpasses the number from hydrography (1977). In the Arctic, profiles from ship-based hydrography (19517) still outnumber those from Argo (8359).

Argo core mission excluded the ice zone

The original Argo mission excluded the high latitudes due to the inability of early floats to sample under sea ice (Argo Steering Team *et al.*, 2009). Technological advances in float design in recent years now give us this capability.

Ice-capable float technology

Advancements have come through:

- hardware – polar profiling floats with ice-hardened antennae (Fig 3)
- software – open-water test (Fig 4) and ice-avoidance algorithms (Fig 5)
- communications (Iridium), allowing the transmission of stored winter profiles

Figure 3: Woods Hole Oceanographic Institute researcher Luc Rainville prepares to deploy a Polar Profiling Float (PPF) in the seasonal ice zone of the Beaufort Sea. The ice-strengthened Iridium antenna and hardened outer casing protect the float from damage as it ascends under ice.

As of December 2008, over 100 floats had been deployed north of 60° N and over 200 floats south of 60° S. Ice-capable floats have successfully survived multiple winters in seasonal ice zones through the use of ice avoiding algorithms (Fig 6).

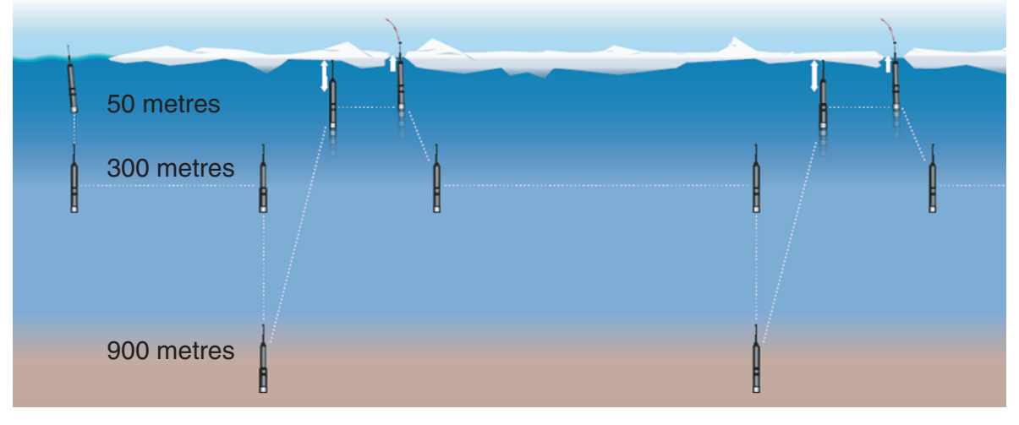
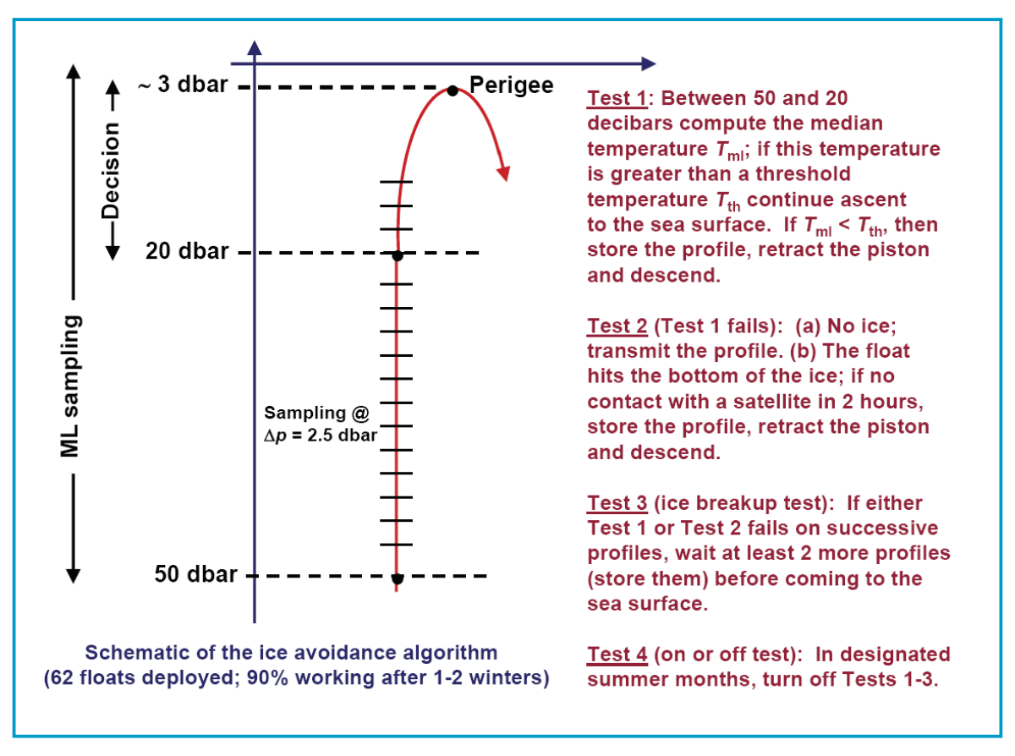


Figure 4: Polar Profiling Floats use the open-water test and Iridium communications to determine the presence of ice. If the float surfaces it establishes a link with the satellite and transmits the profile. If it cannot connect, it assumes it is under ice, stores the profile and descends 50 m, waiting an hour before trying again. In heavy ice, the float repeatedly tries to surface (up to 50 times) before descending and starting a new cycle. In this way, floats will bump along under the ice until they can surface and telemeter data.



Test 1: Between 50 and 20 decibars compute the median temperature T_{ml}; if this temperature is greater than a threshold temperature T_{th} continue ascent to the sea surface. If $T_{ml} < T_{th}$, then store the profile, retract the piston and descend.

Test 2 (Test 1 fails): (a) No ice; transmit the profile. (b) The float hits the bottom of the ice; if no contact with a satellite in 2 hours, store the profile, retract the piston and descend.

Test 3 (ice breakup test): If either Test 1 or Test 2 fails on successive profiles, wait at least 2 more profiles (store them) before coming to the sea surface.

Test 4 (on or off test): In designated summer months, turn off Tests 1-3.

Schematic of the ice avoidance algorithm
(62 floats deployed; 90% working after 1-2 winters)

Figure 5: University of Washington floats use an algorithm (modified from the AWI ice sensing algorithm) that relates the probability of sea ice presence to the temperature of the water column below. The float aborts the ascent and descends if the median water temperature between 20 and 50 m depth is less than -1.79° C, close to the freezing point of sea water at the surface. If this test fails and the float hits ice but fails to connect to the satellite within two hours, the profile is stored and the float descends. If either test fails on successive profiles, then the two profiles are stored before attempting another ascent.

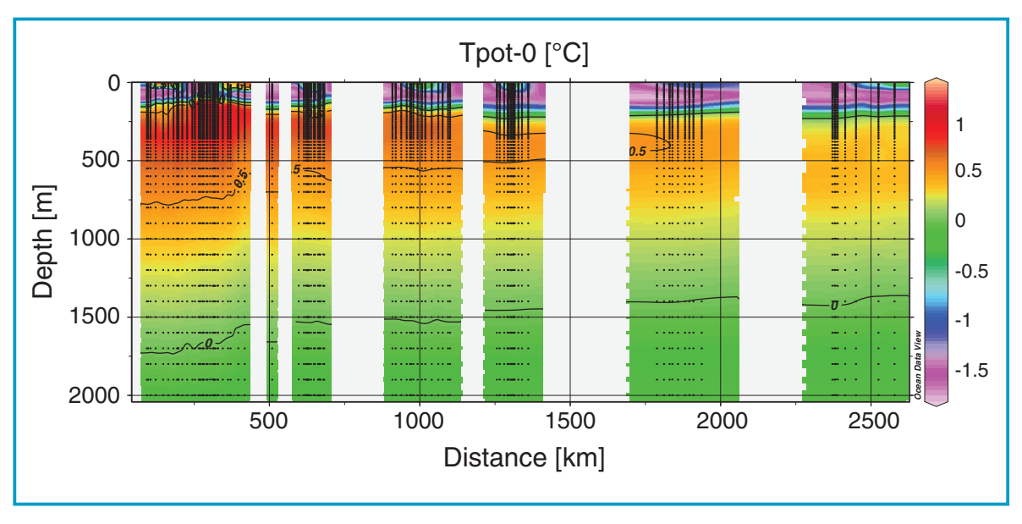


Figure 6: Temperature measurements from a float using the AWI ice sensing algorithm that has survived for more than 6 years in the seasonal ice of the Weddell Sea.

Under-ice positioning

Argo float profiles can only be geo-located using satellite systems when the float surfaces. In heavy ice however, floats may not be able to find leads through which to surface and establish communications. Geolocation can also be achieved without surfacing, via an array of moored sound sources and floats carrying acoustic receivers.

A RAFOS sound source array and acoustically-tracked floats in the Weddell Sea are already yielding valuable information on ocean circulation and structure beneath the sea ice (Figs. 7 and 8). Fourteen moored sound sources are required for complete coverage of the Weddell Gyre. Currently, 10 active sources are in place (Fig 7).

The effective RAFOS tracking range is at least 900 km with the sources presently in use (Fig 9). Signal range and quality is reduced by under-ice reflections over winter (~ 600 km). In the Arctic, an array of low frequency (<100 Hz) sound sources would be required to provide basin-wide geolocation.

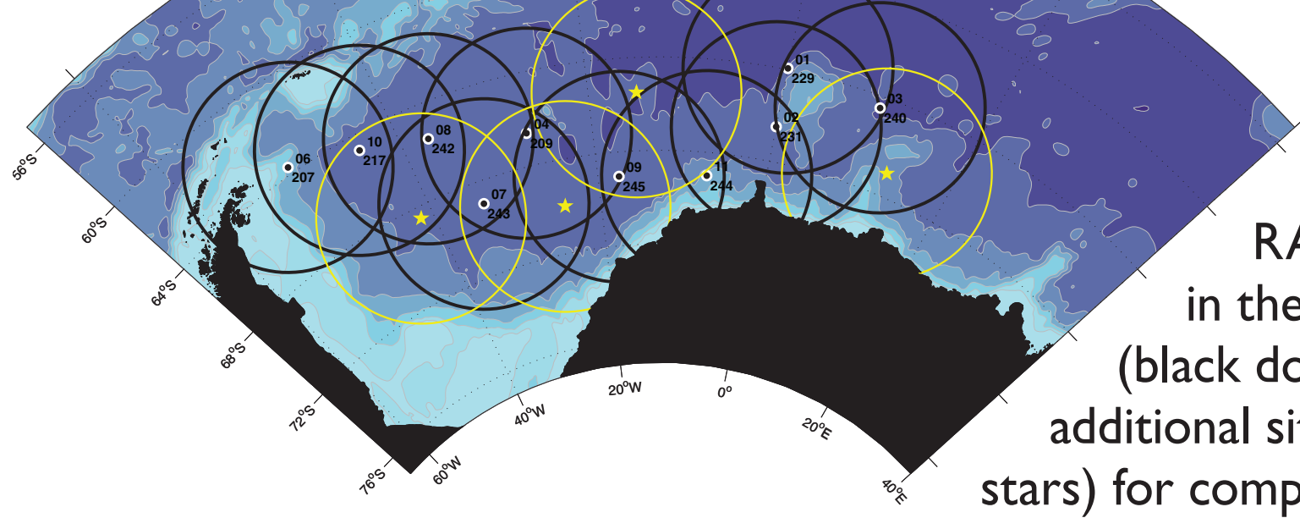


Figure 7: Existing RAFOS sound sources in the Weddell Sea (black dots) and proposed additional sites (yellow stars) for complete coverage of the Weddell Gyre. Circles indicate approximate signal range.

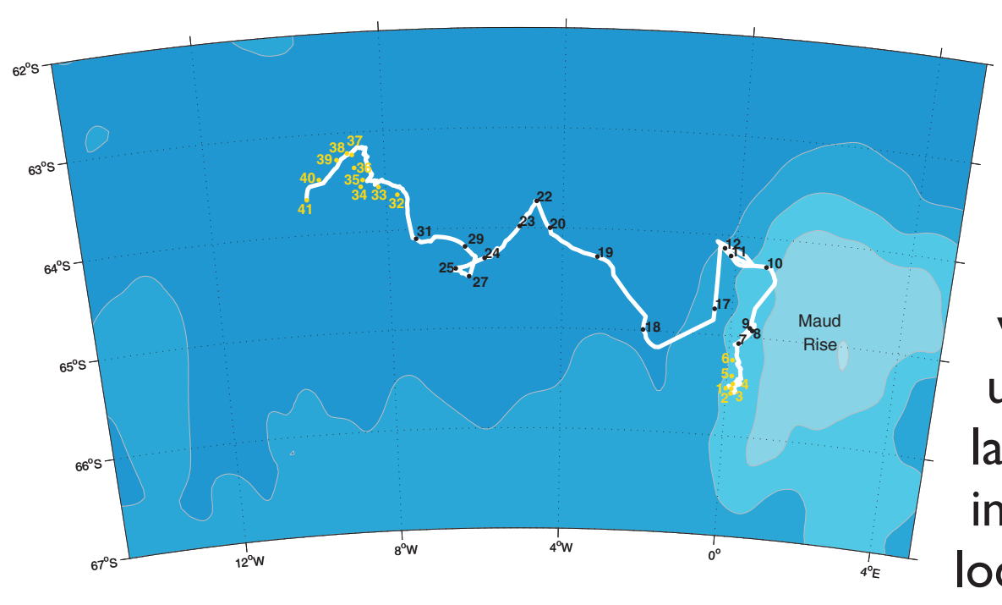


Figure 8: The trajectory (white line) of an AWI float (with RAFOS receiver) in the Weddell Gyre. The float was deployed in open water (yellow labels), then drifted under ice for 240 days (black labels). Under-ice profiles were interim-stored over winter and geo-located using the RAFOS array.

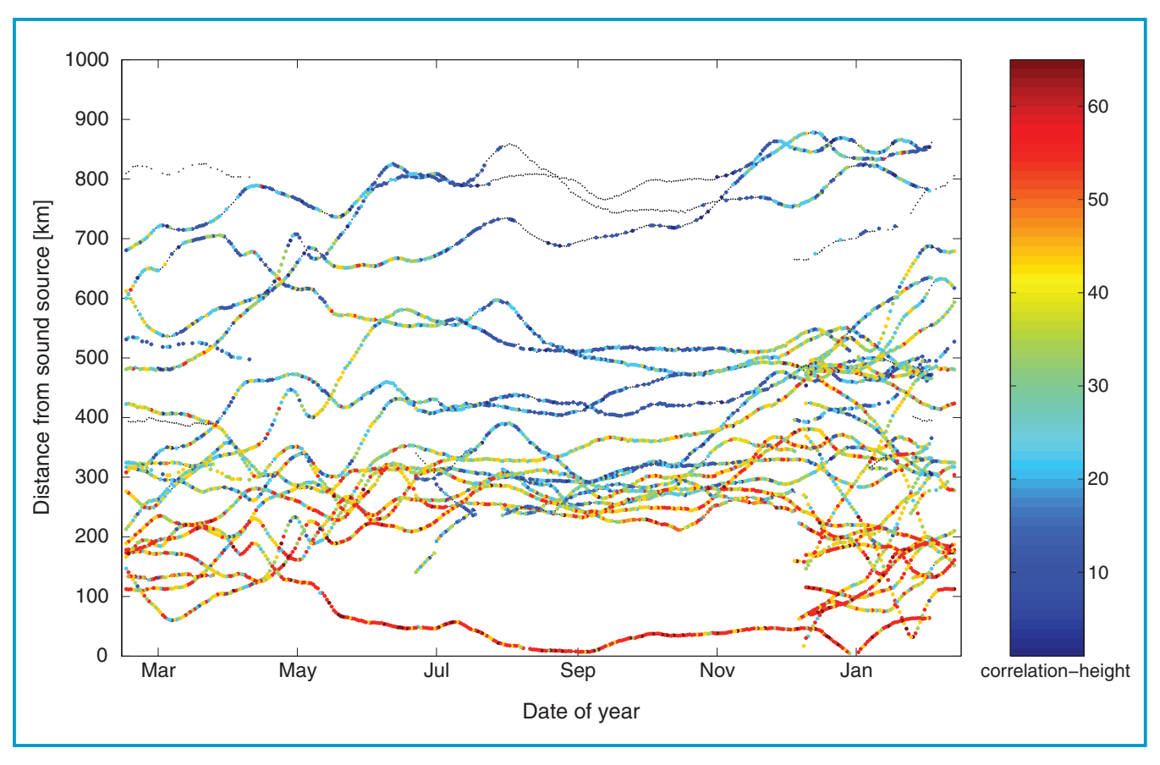


Figure 9: Transmission quality with time of year and distance from the sound source. The colour of the dot represents signal quality, the higher the correlation height, the better the transmission. Black dots indicate that the float was too far from the source to receive a useful signal.

Extending Argo to the seasonal ice zone

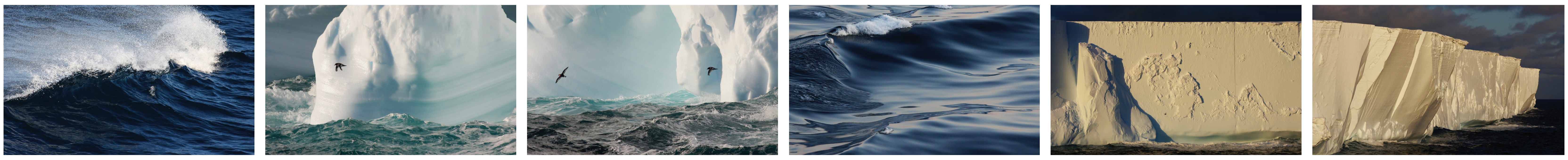
Based on the nominal 3×3 degree density, 300 floats are required in the seasonal ice zone (60° to fast ice edge) in the Arctic (depths > 900 m) and 360 floats in the Antarctic (depths > 2000 m). Incremental costs include the ice-hardened antenna (€850) and RAFOS receiver (€1000), software revisions are available at no extra cost. Sound sources currently in use are €60,000 each with a lifespan of 6 years. Other commercially available sound sources with greater range have not yet been tested in this context but should also be considered. Deployment opportunities in the high latitudes are constrained by reduced ship traffic and higher charter costs. Developing links with Antarctic tourist vessels may provide further opportunities. Additional investment over and above core Argo funding is required.

Conclusions

Sustained, comprehensive observations of the polar oceans can only be achieved in a broad-scale and cost-effective way by using autonomous platforms like Argo floats. It is thus imperative that a commitment is made to enhance and maintain an array of ice-capable floats and sound sources in the high latitudes. The extension of the core Argo network beyond 60 degrees in both hemispheres will ensure that it remains one of the most important and truly global components of the earth observing system.

Key recommendations:

- Complete and maintain the existing Argo array at the original design density.
- Extend Argo to the seasonal ice zone, through a combination of ice-capable floats and acoustically-tracked floats.
- Maintain and extend the array of sound sources and acoustically-tracked floats in the Weddell Gyre. Establish a similar array in the Ross Sea Gyre.
- Design and implement a low frequency (10-100 Hz) basin-scale array of sound sources and acoustically-tracked floats in the Arctic.



Antarctic photos by Esmee van Wijk; Argo photo by Alicia Navidad

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