The Southern Ocean Hydrophone Network (SOHN)

Circum-Antarctic passive acoustic monitoring of Antarctic blue and fin whales

The SORP Antarctic blue and fin whale acoustic trends working group (ATW)
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Executive Summary

The Acoustic Trends Project of the Southern Ocean Research Partnership (SORP) is an international effort to implement a long term acoustic research program that aims to examine trends in Southern Ocean blue (*Balaenoptera musculus intermedia*) and fin whale (*B. physalus*) abundance, distribution, and seasonal presence through the use of passive acoustic monitoring techniques. To achieve this goal, the Acoustic Trends Working group aims to create the Southern Ocean Hydrophone Network (SOHN). The SOHN will consist of a network of autonomous underwater acoustic recording stations surrounding the Antarctic continent.

The SOHN aims to achieve a circumpolar distribution of acoustic recording sites with each site remaining active throughout the 10 year duration of the project. While logistical constraints may prevent uniform distribution of SOHN recording sites around the continent, the Acoustic Trends Project aims to have at least one recording site in each of the six IWC management areas (i.e., one per 60° longitudinal wedge). In addition to circumpolar coverage, high priority will also be given towards achieving simultaneous temporal coverage, especially in the early years of the project. While the goals of the SOHN are ambitious, the increasing cost of marine research in Antarctic waters makes the SOHN an increasingly cost-effective way to monitor Antarctic blue and fin whales over the coming decades.

Due to the high cost of Antarctic research as well as the broad spatial and temporal scales over which the SOHN will span, international collaboration and coordination are imperative to achieve the project goals. To facilitate international participation in the SOHN, this document provides practical recommendations to increase the efficiency of passive acoustic data collection in Antarctic waters. We first outline the requirements of SOHN acoustic recorders, and then discuss the potential for integration with oceanographic data collection efforts as well as the potential for servicing of SOHN stations from ships of opportunity. Finally we discuss the benefits and limitations of different types of moorings, acoustic recorders, and recovery aids as well protocols for servicing of SOHN stations.

In addition to providing recommendations that may reduce the cost of data collection, we also provide recommendations regarding standardization of recording locations, devices, and metadata. Standardization of data is paramount for accurate and efficient analysis and interpretation of SOHN data, and will facilitate future comparisons with baseline data collected from the SOHN. By introducing efficient and standardized data collection methods we aim to increase participation by partner nations and organizations in the SOHN and Acoustic Trends Projects.

Methods for data processing allowing standardized, integrative, and circumpolar analyses of the SOHN data base will be the focus of a separate document which is currently in preparation by the Acoustic Trends Working group.

Introduction

Sighting surveys are traditionally the means by which cetacean population abundance estimates are obtained. In the Southern Ocean however, these surveys are increasingly few and far between due to the particularly difficult working environment and the costs of surveys, and are also restricted by the inherent limitations of visual surveys (e.g., daylight, weather, sea ice, visual detection range, etc., Branch 2007; Hammond et al 2013). From 1978 to 2010 the International Whaling Commission (IWC) supported first the International Decade of Cetacean Research (IDCR, 1978-1996) and then the Southern Ocean Whale Ecosystem Research (SOWER, 1996-2010) programs. Auxiliary data from over 30 of these annual sighting surveys (three circumpolar sets of cruises over 27 years from 1978-2004) were used to estimate the abundance of Antarctic blue whales (*Balaenoptera musculus intermedia*; Figure 1) (Branch et al. 2004). Only two of the recent cruises focused on fin whales (*Balaenoptera physalus*; Figure 2) and did not result in abundance estimates (Ensor et al. 2006; 2007). It is unlikely that the circum-Antarctic effort of IDCR/SOWER will be repeated in the near future. Nevertheless, the IWC is interested in monitoring the recovery of Antarctic blue and fin whales. Given the long-range propagation of blue and fin whale vocalizations, passive acoustic monitoring is a robust means of monitoring these species over long time periods in remote areas, including the Southern Ocean (Mellinger et al., 2007; Van Opzeeland et al. 2008; Van Parijs et al., 2009; Samaran et al., 2013).

Passive acoustic recordings at individual locations or regions provide information about how the presence and properties of whale calls change over time (Širović et al. 2004; Samaran et al. 2010; Gavrilov et al. 2012). At a minimum, acoustic data reveal when a species occurs in a region (but only when animals are acoustically active). With additional parameters such as the probability of detecting produced calls in the study area and the average call production rate, trends in Antarctic blue and fin whale abundance can be monitored using acoustics-based methods. Furthermore, spatial patterns of calling activity can be assessed using networks of widely spaced recorders, potentially providing information about broad-scale movements of animals (Stafford et al. 2004; Morano et al. 2012; Nieukirk et al. 2012; Samaran et al. 2013). Depending on the configuration, networks or arrays of recorders may even be used (with appropriate caveats and assumptions) to estimate the density of populations (Thomas and Marques 2012; Marques et al. 2013).

The SORP blue and fin whale Acoustic Trends Working group (hereinafter referred to as ATW) aims to implement a long-term research program that will examine trends in Southern Ocean Antarctic blue and fin whale behaviour, seasonal presence, distribution and abundance through the use of passive acoustic monitoring techniques (SORP Workshop, Seattle 2009). Using passive acoustic instruments to record calls of Antarctic blue and fin whales provides a valuable and cost-efficient method to gather data on these species (Mellinger et al. 2007) which are relatively rarely observed during visual surveys (Williams et al. 2006; Branch et al. 2007; Gedamke and Robinson 2010; Kaschner et al. 2012). Furthermore, the ATW proposes monitoring of the same areas, simultaneously, over relatively long time scales. Such coordinated spatio-temporal monitoring effort will strengthen the eventual analysis of the data, allowing more robust conclusions to be made about the observed patterns in calling activity.

Figure 1. Antarctic blue whale, *Balaenoptera musculus intermedia* (Picture: B. Miller, Austrialian Antarctic Division).

Figure 2. Fin whale, *Balaenoptera physalus* (Picture: NOAA).

The SOHN project

Long-term passive acoustic recorders deployed for up to a year or more were first utilized to study baleen whales in the Southern Ocean in 2002 (Širović et al. 2004), and to date are used still relatively sporadically in this region. A review of the available passive acoustic data from the Southern Hemisphere revealed that coverage differs strongly between areas, with some areas being monitored continuously over several years (e.g., at CTBTO sites, PALAOA), whereas others (e.g., IWC area 1 and 6) had no passive acoustic monitoring effort (Samaran et al. 2012). Furthermore, the currently available (long-term) records comprise widely varying time frames, ranging in duration from several months to years (Sirović et al. 2009; Samaran et al. 2012). The fact that these passive acoustic data were collected at changing locations over the past decade with a range of different passive acoustic recording equipment types further complicates comparisons among areas or time periods.

To initiate a long-term structured monitoring program and the gathering of baseline acoustic data, we propose the implementation of a passive acoustic monitoring network consisting of a 'necklace' of Acoustic Recorders (ARs) surrounding the Antarctic continent: the Southern Ocean Hydrophone Network (SOHN). One of the core objectives driving the SOHN project is to understand geographic and temporal variation in distribution patterns of animals through their calling behavior. Passive acoustic monitoring therefore needs to occur at a number of fixed locations over the complete duration of the SOHN project. International collaboration and coordination will be essential for the SOHN project to succeed given the scale of effort that is envisioned both in terms of data collection and processing. The low density of shipping in the Southern Ocean combined with limited access to Antarctic-going vessels requires international collaboration among various national research programs and institutes in order to efficiently share logistical assets and minimize the costs of data acquisition.

With this whitepaper, the ATW aims to encourage and guide nations participating in the SOHN project with a set of recommendations to standardize the data that will be collected. We discuss deployment and recovery options for ARs, and investigate tradeoffs among different hardware, software, and mooring systems that comprise available ARs. We then provide recommendations regarding recording locations, hardware, and specifications (e.g., sample rate, duty cycling recordings), as well as recommendations with respect to data formats, calibration, and metadata required by the project. Finally, the ATW proposes that the data acquired by the SOHN ARs are archived in a central data base, allowing integrative processing of the circum-Antarctic data.

Timeframe

The recommended operational period for the SOHN is 10 years as this represents the time span over which the population of Antarctic blue whales should double, assuming a population growth of 7% (Branch et al. 2004). Furthermore, continuous operation of ARs at each site, especially early in the life of the SOHN, is highly recommended in order to facilitate simultaneous coverage, which is required to address questions regarding the spatial distribution of calling whales within a season.

After the initial 6 years, the need for continuous data collection at each location will be re-evaluated. If non-continuous data collection is deemed sufficient, close temporal coordination between sites will be essential, as it is only through such a coordinated effort that the aims of the SOHN program can be met.

Spatial coverage

To best assess trends in distribution and relative abundance of blue and fin whales, an understanding of spatio-temporal distribution patterns, including knowledge of where animals are not found, is required. Ideally, the SOHN would therefore have dense circum-Antarctic coverage with equal monitoring effort in all sectors. However, logistical limitations make achieving such coverage very difficult. For example, scant shipping routes in the central Pacific sector of the Southern Ocean provide limited cost-effective opportunities for AR deployments, in contrast to the Atlantic sector of the Southern Ocean which is transited by ships relatively frequently due to ongoing research programs (Figure 3). Acknowledging these practical concerns, the SOHN project aims to have at least one AR station in each of the six IWC management areas (Figure A1, Appendix). ARs are recommended to be placed within 200 km of the edge of the maximum summer extent of sea ice, to maximize the chances that ARs can be retrieved by non-ice breaking vessels. ARs that form part of the SOHN are required to be placed south of the Antarctic Convergence as this zone may act as a barrier in sound propagation. In order to further compare data collected by the SOHN with historic data sets from the Antarctic, SOHN stations should be established, where practical and appropriate, at the locations of historic recordings (see Table 1, Appendix). Presently, France, Germany, Australia and South Africa have deployed, or have plans in the near future to deploy hydrophones in Antarctic waters that may be used as first nodes of the network (green circles, Figure 3).

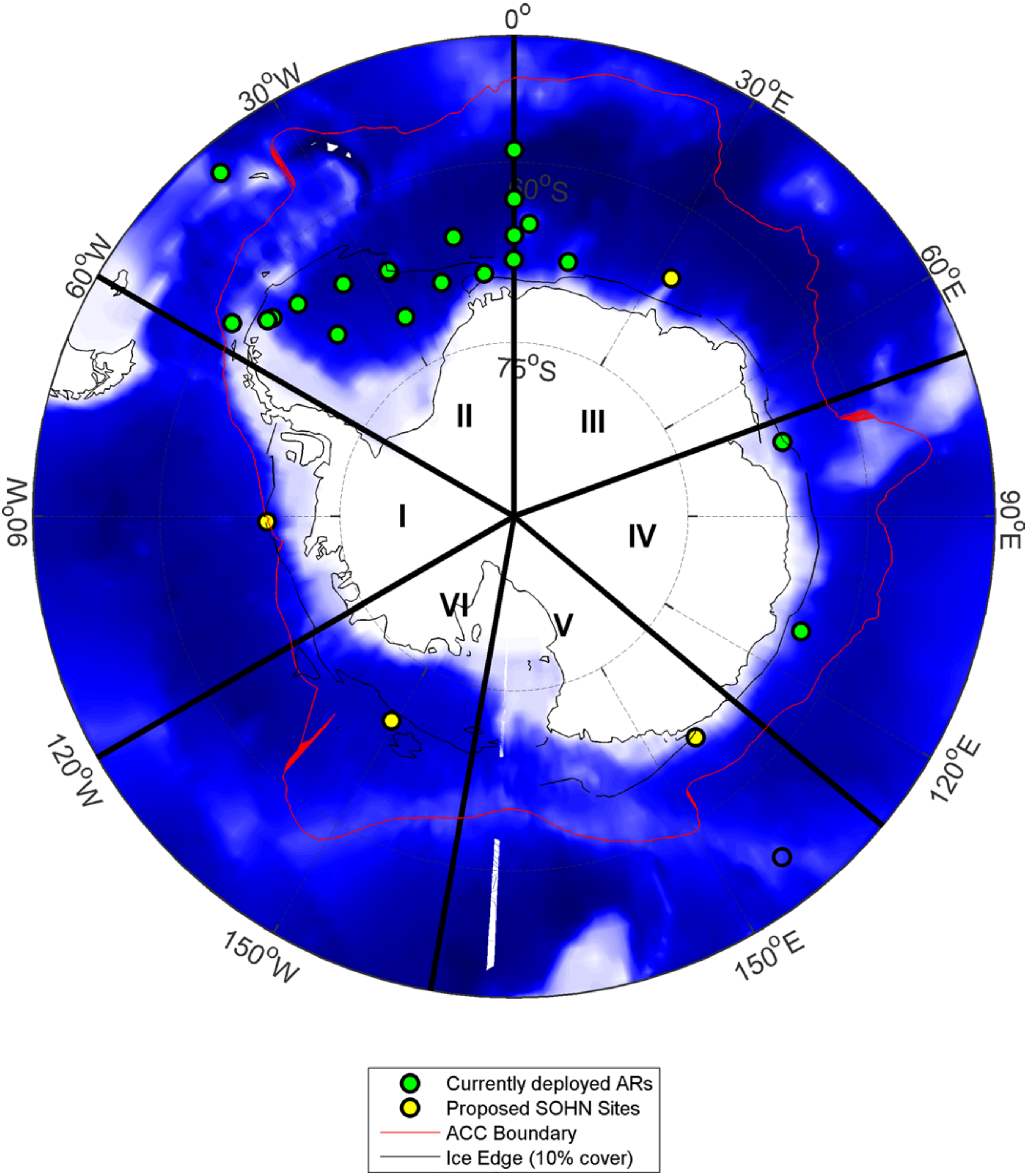

Figure 3 - Locations of current recording sites that may be used as part of SOHN (green circles) and proposed SOHN recording sites (yellow circles). Thick black lines indicate IWC management areas I-VI. Contours indicate 300 m (light blue), 3000 m (light purple) and 6000 m (dark purple). The red line shows the northern boundary of the Antarctic Circumpolar Convergence (Sokolov & Rintoul 2009a). The thin black line is indicative of the edge of the sea ice and corresponds to the monthly average sea-ice cover of 10% in February from 2000-2012 (Maslanik & Stroeve 1999).

Logistical issues

In addition to the limited ship time for Antarctic work, the spatial and temporal coverage of the SOHN may be further restricted by the cost of ARs. Fixed costs include the cost of purchase of ARs and training of technicians, while ongoing costs of ARs include the cost of servicing, calibration, and the ship time required for deployment and recovery. The cost of electronic components of ARs is likely to decrease with the recent and continuing proliferation of efficient, low-powered purpose-built computers and affordable data storage. Ongoing costs, especially those arising from shipping, are therefore likely to represent the major costs of AR stations in the SOHN. This requires international collaboration among different institutes in order to efficiently share logistical assets and minimize the costs of data acquisition and processing.

Standardization

For this multi-national large scale passive acoustic monitoring program to achieve the goal of compiling a circum-Antarctic data set spanning 10 years, standardization of acoustic and meta data acquisition methods and data processing is an important prerequisite. The definition of data acquisition and processing standards will allow data from the ARs that compose the SOHN to be merged into a pan-Antarctic database, freely available to participating members, from which large scale patterns in distribution and habitat usage can subsequently be extracted. A blueprint for SOHN passive acoustic data processing will be the focus of a separate document which is currently in preparation by the ATW group.

As emphasized in previous sections, it is paramount that recording efforts are coordinated both spatially and in time, but also ideally with respect to the type of recording equipment that is used, how ARs are programmed (e.g., sample rate, duty cycle) and the type of acoustic data analyses that are used to extract the relevant information. Provided that a proper funding source can be identified, the ATW aims to create and stock a "library" of calibrated instruments that could be checked out by participating partners for deployments either in an extant mooring or as a stand-alone instrument. In the meantime, below we provide details on instruments, moorings and deployments that might be used for opportunistic mooring of instruments that can become part of the SOHN.

Deployment and recovery considerations

Here, we adopt the definition from the recent review on fixed autonomous PAM recorders by Sousa-Lima et al. (2013) that an acoustic recorder (AR) is defined as "any electronic recording device or system that acquires and stores acoustic data internally (i.e., without cable or radio links to a fixed platform or receiving station) on its own, without the need of a person to operate it; it is deployed semi-permanently underwater (i.e., usually via a mooring, buoy, or attached to the sea floor); and is archival (i.e., must be retrieved after the deployment period to access the data)."

We hereby stress that this definition therefore excludes recordings collected with ship-towed arrays, gliders, sonobuoys or cabled observatories. While in-situ recordings from towed arrays and sonobuoys are likely to be highly complementary to long-term recordings made by ARs, collection and analysis of these short-term recordings are presently outside of the scope of the SOHN project. The same applies to long-term data sets from cabled observatories such as CTBTO and PALAOA – these will also provide important complementary data to the SOHN but, based on their location, are not considered direct nodes of the hydrophone network.

In this section we offer recommendations regarding deployment and recovery of ARs. Often tradeoffs must be made between best-practices and efficient-practices in order to accommodate logistical constraints and costs. While there is no single "best-practice" for all deployment and recovery scenarios, we attempt to consider the scenarios that are most likely to occur.

Deployment depth

Long-range propagation of underwater sound is highly dependent on the stratification of the water column. Hence reception of Antarctic blue and fin whale calls may display complex depth and distance dependent patterns depending on the relative location of the whale and the receiver. Thus accurate knowledge of the environmental conditions (e.g., depth, salinity, temperature profile) as well as the precise location of the ARs is required in order to maximize the utility of the acoustic data.

The Southern Ocean has a relatively uniform hydrographic regime, at least in the open ocean environment, and stratification is generally stable without strong fluctuations. However, the oceanographic regime can display substantial variation throughout time in areas where circumpolar Antarctic currents have strong interactions with large-scale topography (Sokolov and Rintoul, 2009a,b). Most of the energy from sounds produced in shallow waters in the Antarctic are likely to be retained in a surface duct due to a relatively shallow sound-speed minimum and an upward refracting sound-speed profile found in most Antarctic waters (Hall, 2005; Miller unpublished data; Figure 4). However, logistical, bathymetric, and sea-ice related constraints may prohibit deployment and recovery of ARs in these shallow waters (see next section). In order to ensure similar sound-propagation at each of the initial sites comprising the SOHN it is recommended that ARs be deployed deeper than 1000 m.

Ultimately, the relationships between signal strength, background noise contribution, and deployment depth will be re-evaluated based on data from experimental moorings with multiple ARs at different recording depths (which are currently in deployment, Van Opzeeland et al. 2013) to choose a deployment depth that minimizes variability in the detection range and detection probability among sites for Antarctic blue and fin whale acoustic signatures. For deployments where instrument depth might not be known, or may vary (e.g., on an oceanographic mooring), an integrated or external (e.g., microcat) pressure/depth sensor should be incorporated.

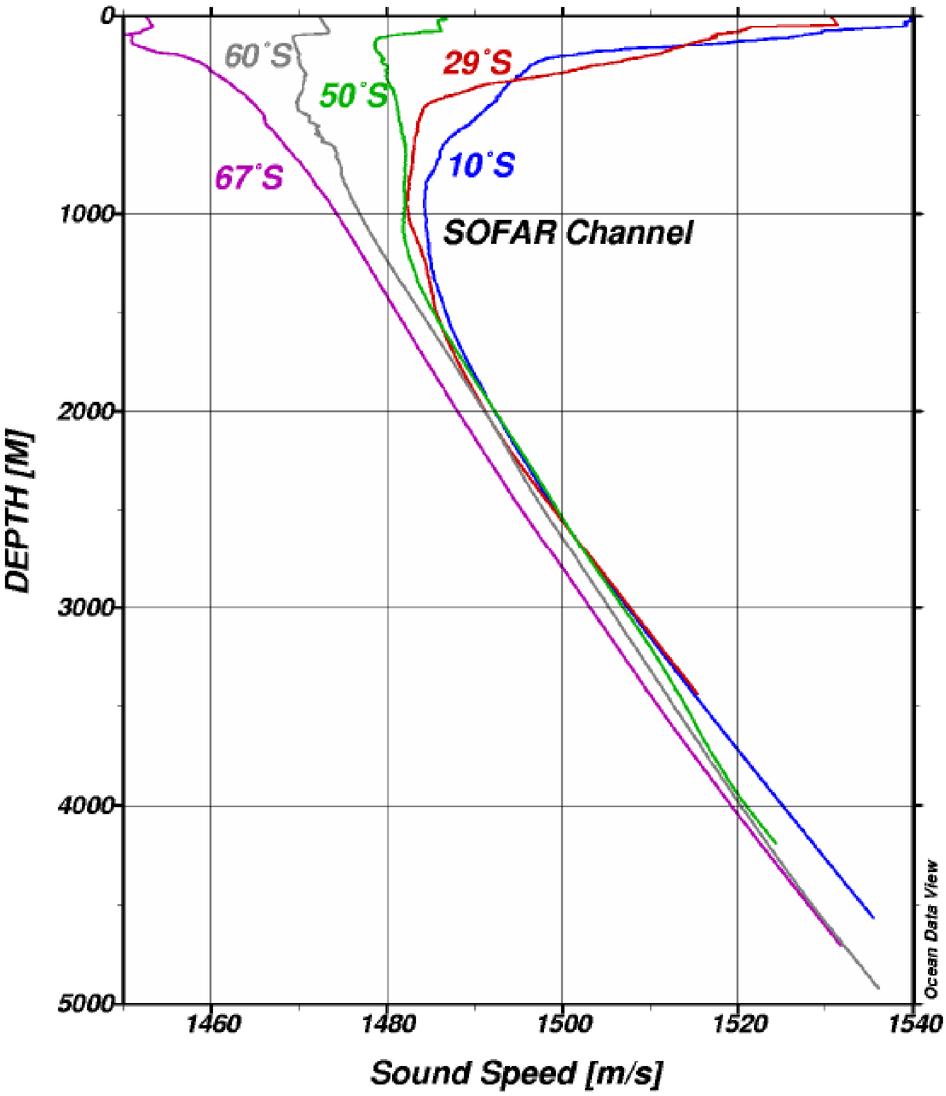

Figure 4. Sound velocity profiles from hydrographic stations (CTD) across the Pacific Ocean. The deep sound channel is observed as a minimum in sound-speed for the 10'S and 29'S profiles. The sound-speed minima shift towards the surface creating a surface duct at 50'S 60'S and 67'S (From Boebel et al. 2009).

Moorings

ARs can be deployed as part of existing scientific (e.g., oceanographic) moorings, or they may be independently anchored to the sea floor (Figure 5). In the Southern Ocean, moorings are generally designed with the top flotation not shallower than 200 m below sea-surface to avoid entrapment and subsequent displacement by passing icebergs). ARs within the SOHN are recommended to be deployed >1000 m to ensure low ambient noise floors and consistent sound propagation among recording sites. Care needs to be taken that ARs are not positioned directly below flotation as these could acoustically shield the AR and cause turbulence and hence low-frequency noise in the recordings. Hydrophones should be located at least 10 m, ideally 50 m, below floats.

In the frequency band of Antarctic blue and fin whale vocalizations (10-100 Hz), recordings might be heavily affected by strumming noise if the mounting of the hydrophone is too rigid. Strumming noise can be reduced by introducing flexibility in the AR mounting. ARs can be attached to the mooring line with swivels on both ends so that they can rotate or move along the mooring line with so-called eddy-grips (http://www.nautilus-gmbh.de/files/vitrovex_floatation_housings.pdf), so as to move with currents. Any combination of metals (e.g. of shackles and mooring frames) needs to be evaluated for compatibility and isolators must be used when necessary to prevent corrosion which can eventually lead to instrument loss. Taping of shackles or other actions that can introduce O2-rich or -poor regions should also be avoided to prevent crevice corrosion. Insulated wire or cable ties, rather than tape, have been used successfully to keep shackle bolts held fast. Previous long-term deployments of ARs in the Southern Ocean suggest the prevalence of corrosion and biofouling appears to be relatively low. Galvanized shackles and rings as mooring hardware have proved to work well.

When deploying ARs in areas that are known to have some degree of ice cover at the time of retrieval, short moorings may not be as readily detected on the surface as a longer mooring. While the mooring length must be balanced with additional costs and operational ease of deployment and recovery, longer moorings are easier to relocate and are recommended in areas with dense ice fields during retrieval. This does not apply in areas with open water, where short moorings can be used with more confidence of a successful relocation. Figure 6 is a flowchart intended to help determine which type of mooring, deployment and recovery strategy is suitable for some common scenarios.

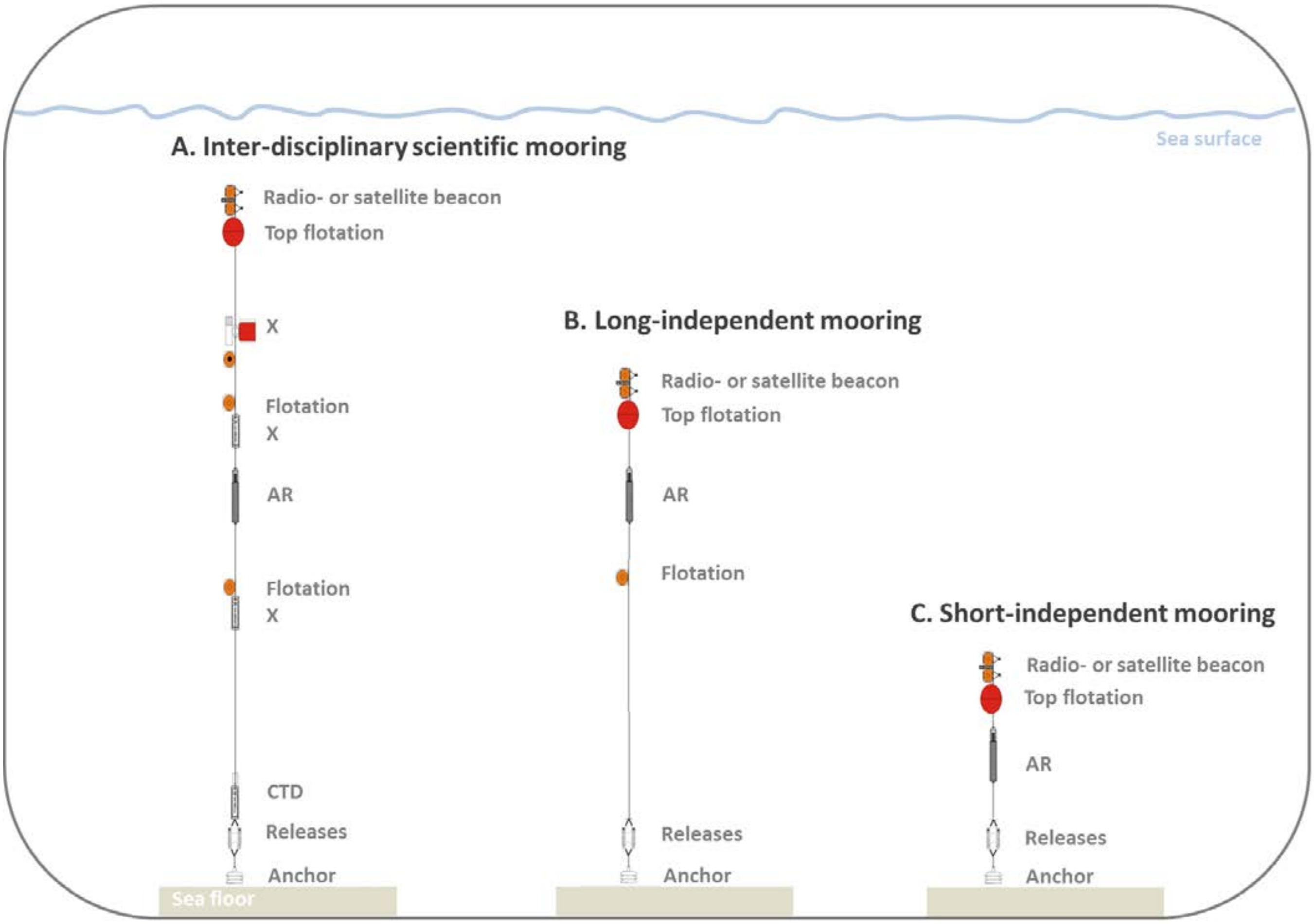

Figure 5. Exemplary mooring set-up for ARs in A) interdisciplinary moorings, B) long-independent moorings, and C) short-independent moorings. X indicates other scientific measurement instruments (e.g., ADCP, current meter, sediment traps). Note that depicted mooring length is not to scale, e.g. short independent moorings may be only 20 – 30 m off the sea floor, whereas long and inter-disciplinary moorings can be 10 or more times as long, depending on their set up and location.

ARs in scientific moorings

Using oceanographic mooring infrastructure can help to significantly reduce the cost and logistic effort of deployment and recovery of ARs, particularly in the Southern Ocean. In the context of integrating ARs in oceanographic moorings, it needs to be stressed that ARs do not affect oceanographic measurements, have little hydrodynamic drag and are similar in deployment and recovery operation to standard oceanographic instrumentation such as current meters and acoustic releases. ARs only need a little additional flotation to be added to compensate for their weight (e.g. 2 additional benthos spheres for a 30 kg AR). When ARs are deployed with eddy grips, mounting of the AR occurs out of the mooring line and is therefore independent of overall mooring forces. Examples of studies that had ARs included in existing scientific moorings are Miksis-Olds et al. (2010), Royer et al. 2010, Moore et al. (2012), Stafford et al. (2012), Rettig et al. (2013).

When using existing scientific moorings to deploy ARs, deployment duration will be dependent on the frequency with which the oceanographic moorings are serviced. This projected deployment duration should be factored into decisions on the hardware (e.g., hard drive size, battery life) and software programming (e.g., duty cycle, sample rate) for the instrumentation. Furthermore, deployment locations of ARs are of course dependent on the purpose of the oceanographic measurements.

A further advantage of including ARs in inter-disciplinary moorings is that in some cases additional in-situ environmental information can be obtained from measurement instruments on the same mooring, such as time series data on temperature, currents and local biomass in the water column from ADCPs and sediment traps (e.g., Cisewski et al. 2010) which may be useful to derive information on spatio-temporal association patterns of whales with prey as well as species-specific habitat preferences.

Independently moored ARs

There are two possible means to independently moor ARs: as bottom-mounted (i.e., sitting on the sea-floor or on a very short tether) instruments or as part of longer mooring lines that are anchored to the sea-floor but extend up into the water column.

Compared to oceanographic moorings, independently moored ARs may provide greater flexibility in terms of deployment location and duration (i.e., frequency of service). However, this flexibility may come with extra costs mainly due to the need for dedicated time for deployment and recovery as well as the need for relatively specialized systems and shipboard equipment to deploy and recover moorings. For moorings with heavy anchors (long moorings, bottom-mounted moorings), a crane or A-frame is generally required to safely lift and deploy the float, instrument and particularly the anchor from on deck. For long moorings, a winch for spooling out line is ideal - however, on deck on- and off-spooling using a simple stand is feasible. Specialized recovery systems are typically comprised of acoustically-activated release mechanisms. These systems are costly, but especially important for moorings anchored in deep waters.

In the sections below, we briefly discuss several ways in which the additional costs that apply to independently moored ARs may be mitigated, explore the tradeoffs between costs of shipping vs. the costs of moorings, and discuss AR designs that may exemplify these tradeoffs.

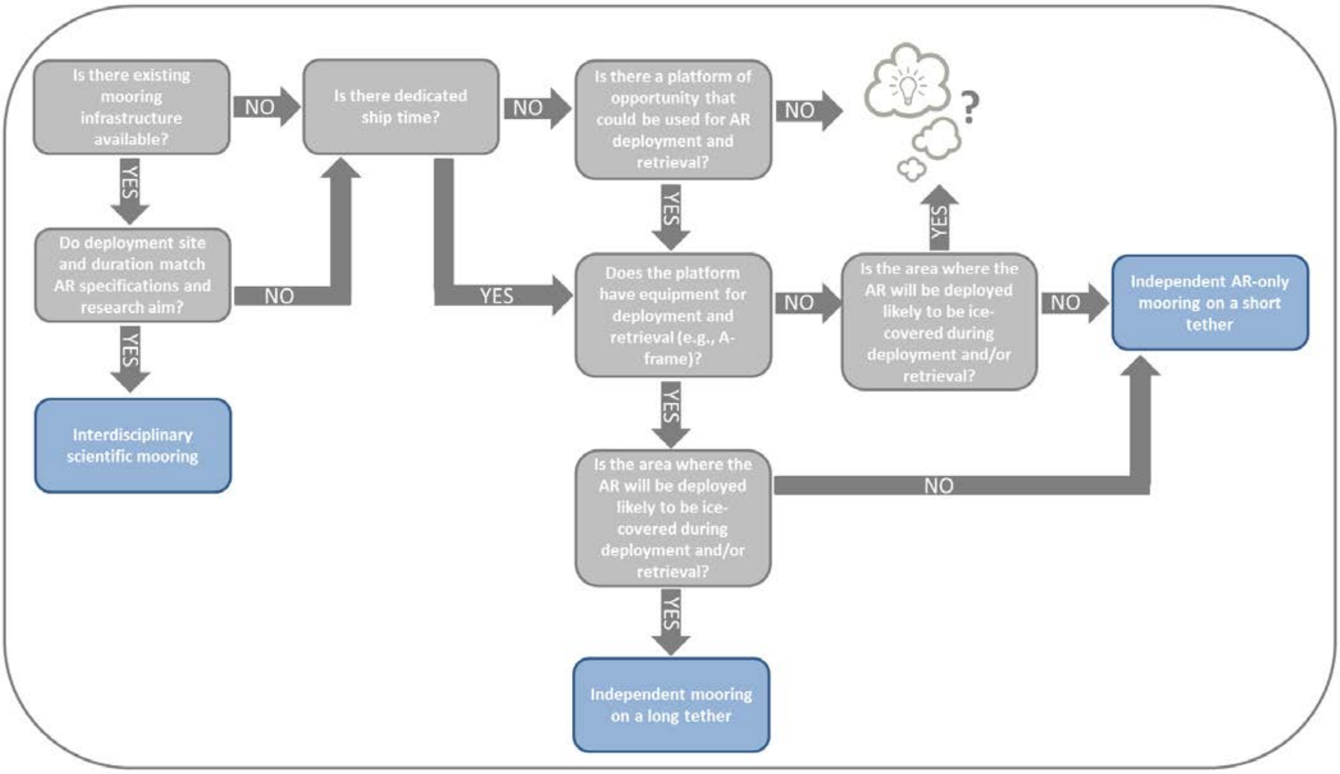

Figure 6. Flow-chart of different mooring designs to guide decisions on deploying in interdisciplinary moorings, long-independent moorings, and short-independent moorings. The cloud with the light bulb indicates that AR deployment may be unfeasible or other options to deploy an AR need to be explored.

Mitigating the high costs of ship time

Opportunistic deployments

To minimize the amount of dedicated ship time required for independent mooring deployments, mooring locations may be selected along existing supply routes for Antarctic stations (e.g., Gedamke et al. 2007). Apart from reducing the time to reach the deployment location, this also facilitates regular (i.e., often annually in the case of Antarctic station supply ships) servicing of the mooring. However, as is the case when using existing scientific mooring infrastructure, deployments are restricted to locations along supply routes. This should not be problematic so long as the requirements for preferred latitude and concurrent deployment with instruments at other longitudes are met.

When no dedicated ship time is available, some AR types may allow deployment off platforms of opportunity, such as cruise ships. It is paramount in this case that the dimensions and weight of the AR unit allow deployment from the platform of opportunity (for example when no crane and winch are available). Mooring set-up needs to be simple (e.g. have short tethers) and instruments ready for deployment with any consideration of additional instrumentation for in-situ measurements carefully weighed against increasing the complexity of deployments.

Retrieval of moorings often requires substantial maneuverability of the ship to remain on station, particularly in the case of strong winds and heavy seas. Even for dedicated platforms it is not unusual for retrieval maneuvers to take more than an hour from first sighting the mooring until it is hauled on deck. It is furthermore recommended that someone with sufficient technical experience and knowledge of ARs is on board the ship to take responsibility for the instrument, e.g. to secure lithium batteries if necessary and provide a time signal for later synchronization of the AR. Platforms of opportunity such as cruise ships are therefore less suitable for mooring retrieval, but research ships with personnel that have experience with oceanographic instrumentation should be able to opportunistically recover ARs. Attempts to find or communicate with lost or unresponsive instruments may be restricted if there is limited or no dedicated ship time available.

Deployment/recovery efficiency

There are several practical steps that can be taken in order to maximize the efficiency of AR deployments and minimize the amount of dedicated ship time required. For example deployments may be optimized by preparing the AR and mooring on shore and before arriving on station. In cases when ARs are prepared long before deployment, AR status checks and clock-synchronization are recommended prior to deployment if feasible. Final checks may be facilitated by an externally visible infrared diode that provides an internal clock and life beat (i.e., indicating the device is operational).

Simplifying the mooring design will also reduce the amount of dedicated ship time required, e.g., by using bottom-mounted instruments that require no spooling of cable. For bottom-deployed instruments or ARs moored close to the sea floor, pressure measurements (e.g., by means of additional microcats) can be omitted, provided that the bathymetry is known. A more compact and less complex instrument type has the further advantage that deployments minimize personnel requirements.

Recovery efficiency on the other hand, may be increased by maximizing the ascent rate, which can be achieved by increasing buoyancy and minimizing drag forces. Where possible, acoustic releases with a 'push-off' release mechanism may be used as these are typically more time-efficient than "burn-wire" release mechanisms. To facilitate locating the AR on the water surface, recovery aids such as strobes to allow recovery in darkness, and increase visibility in daylight, are recommended. A VHF locator can be used for detection of surfacing and bearing to the mooring even when it has not been sighted. Furthermore, satellite telemetry (i.e., short-burst iridium/GPS) is bidirectional and may be considered to efficiently locate the mooring and thereby overcome the cost of a ship-time consuming grid search for instruments. Finally, although these additions increase overall instrument cost, they both reduce ship time for recovery, and reduce the likelihood of instrument loss.

All instruments should have contact information printed on the outside so that lost or detached instruments can be returned in case they are found.

Care should furthermore be taken that should a permanent loss of instrumentation occur, any impact to the environment is minimized.

Maximizing the likelihood of instrument recovery

To minimize the chances of instrument loss due to malfunction of the release mechanism or fouling with the ocean bottom, it is recommended where possible to include redundancy in the release mechanism, either by including dual releases in parallel in case of failure of the primary release and by carrying multiple transponders onboard for activating acoustic releases. This too adds substantially to the cost of the mooring and is therefore not a prerequisite for SOHN ARs as many oceanographic moorings worldwide rely on a single release.

Depending on seabed characteristics, it may be advantageous to include buffers between weights, acoustic releases and AR electronics in bottom-deployed ARs. These buffers absorb the motion of the recorder and release upon the impact of the weights with seabed, thereby reducing the chances of releases or instrument becoming embedded in soft sediment.

Instrument preparation pre-deployment

Given the high cost of time at-sea and limited number of berths on many Antarctic voyages, there are many instances in which it may be most cost-effective to perform all servicing of ARs on shore. This trade-off will minimize amount of time and personnel required at-sea, but comes at the cost of efficient use of instruments as instruments will not be redeployed on the same voyage in which they are recovered. Furthermore, depending on how long an instrument will be underway on board a ship, steps should be taken to minimize the time that the instrument is not yet in the water but already recording (e.g. through a scheduled start time for recording when the instrument is expected to be deployed), and to ensure the overall in-water recording duration is sufficient for the project goals. These scenarios are most likely to occur on platforms of opportunity that may have the capability to recover moorings, but lack the technical personnel to fully service and refurbish an AR. To best facilitate continuous occupation of locations, it is recommended that rather than re-deploying the same instrument that was recently recovered, a pre-programmed, replacement instrument be provided. This will require a larger “library” of instruments but will reduce time on board and the need for a dedicated technician.

Data and metadata storage

Recording capacity

Generally, the logistic complexity and high costs of deploying and maintaining ARs in the Southern Ocean (and polar oceans in general) are often balanced by relatively long deployment periods. Large parts of the Southern Ocean are seasonally ice-covered and hence only allow ships to access these regions to retrieve or deploy ARs during austral summer. Recording capacity with respect to power and data storage therefore needs to cover at least one year for most areas, but preferably 2 to 3 years to keep logistics of recovery and deployment as flexible and cost-effective as possible. To meet these capacity requirements, low power consumption and high power-storage capacity are a prerequisite for long-term deployments in polar oceans. Some of the currently available ARs already allow collection of continuous records over up to three years. Moreover, the pace with which developments in acoustic recording technology are progressing promises that AR recording capacities will soon no longer restrict deployment periods in polar oceans. ARs that form nodes in the SOHN are recommended to collect continuous acoustic records, as currently too little is known about Antarctic blue and fin whale vocal behavior to decide on subsampling schemes that form a reliable basis to e.g., extrapolate hourly call rates (Thomisch et al. in prep).

However, efficiency of data collection should be balanced by minimizing the risk of data loss. In the harsh marine environment that comprises the Southern Ocean there is a very real risk that an AR might fail to deliver data. Failures can occur due to misconfigured ARs, electronic or mechanical failure within an AR, or failure to recover an AR (Dudzinski et al. 2011). Thus, while we recommend the capability for continuous data collection over 2-3 years, we also recommend servicing ARs as frequently as possible in order to minimize potential gaps in data collection that might arise due to AR failures.

AR sample frequency

Blue and fin whales produce the lowest frequency sounds of any cetacean, thus sample rates can be low for passive acoustic monitoring, which in-turn relaxes storage capacity requirements for long-term records. In addition, such sample rate requirements also make it possible to explore the possibility of opportunistically including both ocean-bottom seismometers and hydrophones (OBH/OBS) data in the pan-Antarctic data set, in particular for data sparse areas. Assuming that the calls of interest for passive acoustics monitoring are Z-calls for Antarctic blue whales and 80-100Hz downsweeps for fin whales, a sample rate of at least 250 Hz and an appropriate anti-aliasing filter (ensuring clean data up to at least 100Hz) should be used. This sample rate represents the lower limit of recordings that could contribute towards the SOHN.

ARs that are not bottom-mounted (i.e., in the water column), should be programmed to have a steep high-pass filter (~10Hz corner-frequency) to attenuate low frequency strumming noise from the mooring.

If recording capacity allows, instruments programmed to higher sample rates (e.g., 4 kHz) can capture a much wider range of calls produced by whale and seal species in Antarctic waters (e.g., Gedamke and Robinson 2010; Van Opzeeland 2010). Additionally, higher sampling rates may allow investigation of hypotheses regarding associations and interactions among whale species or large scale comparisons of acoustic habitats/soundscapes (e.g., Boyd et al. 2011). As mentioned previously, the recent and continued advances in digital storage make power, rather than storage capacity, the limiting factor when considering a sample rate.

Data format

To allow processing with various analytical tools, ARs should as their primary function record a lossless encoded waveform of raw acoustic pressure, in addition to any on-board processing providing spectrogram image files or derived data (e.g., event detections). While perceptual-based encoding of data, such as MP3, may allow for increased data storage, encoding schemes based on human perception may yield unpredictable performance when most of the sound energy occurs at frequencies below that which a human listener would likely be able to perceive, as is the case with most Antarctic blue and fin whale sounds.

Pre-processing of data within the recorder may be a viable approach for future studies e.g. triggering recording only when specific acoustic events are detected or saving only the detection information (e.g. event logging). However, for the purpose of the SOHN project, in particular the collection of baseline acoustic information, full, original acoustic records are required. In addition to baseline data on whale vocalizations, full original acoustic records provide important information on the ambient noise spectrum, which, as also addressed earlier, is of interest to evaluate the role of biotic and abiotic contributions to local soundscapes.

Given that WAV is the most commonly used data format for virtually all sound analysis software, we recommend WAV as the primary user-facing data format for acoustic data from ARs. However, knowledge of sample rate and bit depth can be used to convert almost any lossless encoded data to WAV files prior to data processing. Furthermore, certain recording systems allow storage of metadata (such as instrument serial number, location, time stamps, temperature and depth) throughout the recording in archival file formats (Johnson et al. 2013). Where possible, recording in these formats is desirable, but not a prerequisite, for SOHN ARs.

Calibration of ARs

Periodic (e.g., biennial) calibration of ARs over the full bandwidth of whale sounds is very useful in order to ensure accurate measurements of the amplitude of the pressure waveform recorded by each AR. Without full system calibration, it will not be possible to extract some meaningful physical units (e.g., absolute amplitude in Pascals, intensity in dB re 1 uPa) from the recorded data which may prohibit meaningful comparisons among ARs. Calibrations should not be limited to amplitude, but also comprise frequency and absolute time.

Full system calibration can consist of a single frequency-dependent response function and distortion limits for the entire recording chain, or it may be derived from independent calibration factors from each component. A typical recording chain consists of hydrophones, amplifiers, digitizers, and storage. Hydrophones typically function as transducers, converting pressure waveforms into analog voltages. These voltages are then amplified and digitized by the recording chain. Finally, digitized signals are scaled and encoded before being written to digital media. Thus, the frequency-response of the entire recording system (i.e., preamplifiers, anti-aliasing filters, gain of analog-to-digital converters) should also be calibrated periodically. The purpose of a full system calibration is to allow measurement of absolute levels of sound. Additionally, a calibrated system allows for more robust assessment should distortion of sound occur due to overloading of some component of the recording chain.

When possible, the frequency response of hydrophones should be calibrated over the entire recording bandwidth and amplitude range at a dedicated calibration facility. The frequency response of the remainder of the recording chain can be calibrated by connecting a signal generator in place of the hydrophone and allowing the instrument to record several calibrated frequency sweeps (i.e., measured frequency and RMS amplitude). Frequency calibration should cover the entire recording bandwidth. Amplitude calibration should include the noise floor (i.e., zero root-mean-square (RMS) amplitude) up to the amplitude at which clipping/distortion begins to occur.

As an alternative, nations participating in the SOHN project may in the future obtain calibrated instruments through the ATW's "library" of instruments.

Metadata requirements

To archive important metadata to the sound recordings, the ATW recommends that the following information be logged on instrument forms upon deployment and recovery of SOHN ARs. The metadata that can be logged will depend on the platform that deploys/recovers the AR as platforms of opportunity may not have personnel and expertise to perform more complex tasks e.g., open ARs and measure battery voltage. The first list ('Metadata form for platforms of opportunity') therefore represents the metadata that are to be logged for SOHN ARs **in all cases** independent of the platform that is used. Research teams responsible for the AR should make sure that in cases when platforms of opportunity are used, the required metadata can be logged by the ship's crew as efficiently as possible (e.g., provide instrument forms, serial number visible on the outside of the instrument).

The second list ('Metadata form for dedicated platforms') provides a more elaborate list of important metadata that the ATW recommends is logged when SOHN ARs are deployed from dedicated (research) vessels. These documents will also be (made) available through the SORP website.

Metadata form for platforms of opportunity

- AR metadata
  - Serial number
  - Start date and time of recording
- Acoustic Release (in most cases provided by responsible research team)
  - Type
  - Serial number
  - Operating frequency
  - Activation codes
  - Type of deck box required
- Deployment metadata
  - Deployment time, date, and position (UTC, latitude, longitude)
  - Depth/bathymetry of instrument and sea floor
  - Number and (approximate) location of any whales in the vicinity
- On Recovery
  - Date and time of acoustic release
  - Date and time of recovery
  - Any leaks or obvious problems with the AR?
  - AR clock offset synchronized (time of signal and type of signal, e.g. could be as simple as banging on a pipe at a known time next to the hydrophone)
  - Number and location of any whales sighted in the vicinity of the AR
- Additional information
  - Mooring ID
  - Name of ship
  - Summary of ice conditions at recording location
  - Additional information from recovery aids (e.g., GPS/Iridium location at surface)

Additional metadata to be collected by dedicated platforms

- AR metadata
  - Instrument type
  - Data format (e.g., wav, bin, raw)
  - Sample rate, bit depth, header information
  - Duty cycle used (settings)
  - Hydrophone type, serial number, calibration date
  - Calibration factors (including frequency response)
  - Types of additional data streams
- Deployment metadata
  - AR clocks initially synchronized to UTC
  - Additional geolocation (post-deployment survey)
  - SSP (sound speed profile if available)
- On Recovery
  - Battery voltage
  - Did the instrument record? # GB recorded
  - Backup the recorded data
- Additional information
  - instruments on mooring
  - Point of contact

Review of ARs for deployments in the Southern Ocean

Sousa-Lima et al. (2013) provided an inventory of fixed autonomous passive acoustic recording devices. Not all recording systems listed in their review meet the requirements of SOHN ARs as listed in previous sections of this document. However, given the rapid development of AR hardware, adaptations and new hardware development are likely to deem any recommendation with respect to specific hardware for the SOHN out of date. The ATW therefore refers to the SORP website (http://www.marinemammals.gov.au/sorp/projects/) where an up-to-date list will be kept on recommended AR systems currently on the market with links to their manufacturers.

If the AR "library" comes to fruition, it is anticipated that the instruments will be managed i.e., programmed, calibrated and managed by one of the SOHN partners. This is presently under discussion and will also be announced on the SORP website.

Archival and management of the SOHN data base

All acoustic data collected as part of SOHN will be archived so that partner collaborators will have access to the data. Presently, two options are being explored: archiving at PANGAEA (http://www.pangaea.de/about/) which is managed by the Alfred Wegener Institute (AWI) and the Australian Ocean Data Network (AODN, http://portal.aodn.org.au/aodn/). Each of these institutions has experience serving and maintaining large, global databases. We anticipate that if data are collected under the direct aegis of SOHN (versus current deployments undertaken independently by partners such as South African National Antarctic Programme (SANAP) and the AWI), the data will be available online after they have been quality checked. Data collected independently by partners that have agreed to be part of SOHN will be embargoed for a mutually agreeable time by those partners before being made available.

As part of the archiving, long-term spectral averages (LTSAs) will be produced and available to provide a rapid assessment of data quality (particularly with regards to noise) and for the seasonal occurrence of blue and fin whales (see Samaran et al. 2012).

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Appendix

Instrument Name	Depth	Latitude	Longitude	Start Date	End Date	Instrument type	Initial Contact
Drake	350	-60.5	-61	2005-01-01	2006-01-01	HARUphone	Dziak/Park
Bransfield1	350	-62.9	-59.5	2005-01-01	2007-01-01	HARUphone	Dziak/Park
Bransfield2	350	-62.5	-58.9	2005-01-01	2007-01-01	HARUphone	Dziak/Park
Bransfield3	350	-62.5	-58	2005-01-01	2007-01-01	HARUphone	Dziak/Park
Bransfield4	350	-62.3	-57.9	2005-01-01	2007-01-01	HARUphone	Dziak/Park
Bransfield5	350	-62.2	-57.1	2005-01-01	2007-01-01	HARUphone	Dziak/Park
Bransfield6	350	-62.9	-60.2	2005-01-01	2007-01-01	HARUphone	Dziak/Park
Scotia1	350	-57.5	-41.4	2007-01-01	2009-01-01	HARUphone	Dziak/Park
Scotia2	350	-58.9	-37	2007-01-01	2009-01-01	HARUphone	Dziak/Park
Scotia3	350	-57.4	-36.6	2007-01-01	2009-01-01	HARUphone	Dziak/Park
Scotia4	350	-56.4	-33.9	2007-01-01	2009-01-01	HARUphone	Dziak/Park
WAP1	1600	-62.3	-62.2	2001-03-01	2003-02-01	ARP	Sirovic/Hildebrand
WAP2	3000	-63.8	-67.1	2001-03-01	2003-02-01	ARP	Sirovic/Hildebrand
WAP3	3000	-65	-69.1	2001-03-01	2003-02-01	ARP	Sirovic/Hildebrand
WAP4	3000	-66	-71.1	2001-03-01	2003-02-01	ARP	Sirovic/Hildebrand
WAP5	3000	-66.6	-72.7	2001-03-01	2003-02-01	ARP	Sirovic/Hildebrand
WAP6	3000	-67.1	-74.2	2001-03-01	2003-02-01	ARP	Sirovic/Hildebrand
WAP7	450	-65.4	-66.1	2001-03-01	2003-02-01	ARP	Sirovic/Hildebrand
WAP9	870	-67.9	-68.4	2001-03-01	2003-02-01	ARP	Sirovic/Hildebrand
DGN	0	-6.3	71	2002-01-01	2003-12-01	CTBT	Stafford
DGS	0	-7.6	72.5	2002-01-01	2003-12-01	CTBT	Stafford
DGS	0	-7.6	72.5	2004-01-01	2005-12-01	CTBT	Gedamke
CL	0	-34.9	114.1	2002-01-01	2012-06-01	CTBT	Gedamke
Crozet	300	-46	51	2003-05-01	2004-04-01	CTBT	Samaran
MAD	1300	-26.1	58.2	2006-11-01	2008-12-01	HARUphone	Royer/Samaran/Guinet

Instrument Name	Depth	Latitude	Longitude	Start Date	End Date	Instrument type	Initial Contact
MAD	1300	-26.1	58.2	2009-12-01	2014-12-01	UBOphone	Royer/Samaran/Guinet
NCRO-1	1100	-41	52.8	2009-12-01	2014-12-01	UBOphone	Royer/Samaran/Guinet
NCRO-2	1100	-41	53.2	2009-12-01	2012-12-01	UBOphone	Royer/Samaran/Guinet
NCRO-3	1100	-41.2	53	2009-12-01	2012-12-01	UBOphone	Royer/Samaran/Guinet
WKER-1	500	-46.6	60.1	2009-12-01	2014-12-01	UBOphone	Royer/Samaran/Guinet
WKER-2	500	-46.6	60.5	2009-12-01	2014-12-01	UBOphone	Royer/Samaran/Guinet
WKER-3	500	-46.8	60.4	2009-12-01	2014-12-01	UBOphone	Royer/Samaran/Guinet
SWAMS	1000	-43	75.6	2006-10-01	2008-01-01	HARUphone	Royer/Samaran/Guinet
SWAMS	1000	-43	75.6	2010-02-01	2014-01-01	UBOphone	Royer/Samaran/Guinet
NEAMS	1200	-31.6	83.2	2006-10-01	2008-04-01	HARUphone	Royer/Samaran/Guinet
NEAMS	1200	-31.6	83.2	2010-02-01	2014-01-01	UBOphone	Royer/Samaran/Guinet
Casey2004	3000	-63.8	111.8	2004-02-01	2005-01-01	ARP	Gedamke
Prydz2005	1800	-62.6	81.3	2005-01-01	2006-02-01	ARP	Gedamke
Kerg2005	2700	-66.2	74.5	2005-02-01	2006-02-01	ARP	Gedamke
Kerg2006	2680	-66.2	74.5	2006-02-01	2007-03-01	ARP	Gedamke
Prydz2006	1900	-62.6	81.3	2006-02-01	2007-03-01	ARP	Gedamke
44S.2006	1866	-44	144.7	2006-03-01	2007-01-01	Curtin Logger	Gedamke
65S.2006	1100	-65.6	140.5	2006-02-01	2007-01-01	Curtin Logger	Gedamke
54S.2006	1600	-53.7	144.8	2005-12-01	2006-10-01	Curtin Logger	Gedamke
54S.2008	2078	-53.7	141.8	2007-12-01	2009-02-01	Curtin Logger	Gedamke
Kerg2009	587	-56.1	77.8	2009-02-01	2010-01-01	Curtin Logger	Gedamke
Casey2010	2770	-64.6	108.3	2009-12-01	2010-12-01	Curtin Logger	Gedamke
PALAOA	180	-70.3	-8.1	2005-12-27	ongoing	PALAOA (2 hydrophones)	AWI/van Opzeeland
MARU#1	4798	-59.1	0.0	2008-12-12	2010-12-12	MARU	AWI/van Opzeeland
MARU#2	5144	-64.1	0.1	2008-12-14	Not recovered	MARU	AWI/van Opzeeland
AWI 230-6	200	-66.0	0.0	2008-03-08	2010-12-16	aural	AWI/van Opzeeland
AWI 232-9	216	-68.6	0.0	2008-03-11	2010-12-19	aural	AWI/van Opzeeland

Instrument Name	Depth	Latitude	Longitude	Start Date	End Date	Instrument type	Initial Contact
AWI 227-11	1007	-59.0	0.1	2010-12-11	2012-12-11	sonovault	AWI/van Opzeeland
AWI 229-9	969	-63.6	0.0	2010-12-15	2012-12-14	sonovault	AWI/van Opzeeland
AWI 230-7	934	-66.0	0.0	2010-12-16	2012-12-15	sonovault	AWI/van Opzeeland
AWI 231-9	1083	-66.3	0.0	2010-12-23	2012-12-16	sonovault	AWI/van Opzeeland
AWI 232-10	987	-69.0	0.0	2010-12-19	Left on position (2015)	sonovault	AWI/van Opzeeland
AWI 244-2	1003	-69.0	-7.0	2010-12-27	2012-12-26	sonovault	AWI/van Opzeeland
AWI 245-2	1051	-69.0	-17.2	2010-12-27	2012-12-28	sonovault	AWI/van Opzeeland
AWI 209-6	207	-66.4	-27.1	2010-12-29	2013-01-01	aural	AWI/van Opzeeland
AWI 207-8	219	-63.4	-50.5	2011-01-06	Left on position (2015)	aural	AWI/van Opzeeland
AWI 206-7	909	-63.3	-52.1	2011-01-06	Left on position (2015)	sonovault	AWI/van Opzeeland
AWI 227-12	1020	-59.0	0.0	2012-12-11	2015-01	sonovault	AWI/van Opzeeland
AWI 229-10	969	-63	0.0	2012-12-14	2015-01	sonovault	AWI/van Opzeeland
AWI 230-8	949	-66.0	0.0	2012-12-15	2015-01	sonovault	AWI/van Opzeeland
AWI 232-11	958	-68.0	-0.1	2012-12-18	2015-01	sonovault	AWI/van Opzeeland
AWI 244-3	998	-69.0	-7.0	2012-12-25	2015-01	sonovault	AWI/van Opzeeland
AWI 248-1	1081	-65.6	-12.2	2012-12-27	2015-01	sonovault	AWI/van Opzeeland
AWI 245-3	1065	-69.0	-17.2	2012-12-28	2015-01	sonivault	AWI/van Opzeeland
AWI 249-1	1051	-70.5	-28.5	2012-12-30	2015-01	sonovault	AWI/van Opzeeland
AWI 209-7	226 1007 2516	-66.4	-27.1	2013-01-01	2015-01	sonovault	AWI/van Opzeeland
AWI 208-7	956	-65.4	-36.3	2013-01-03	2015-01	sonovault	AWI/van Opzeeland
AWI 250-1	1041	-68.3	-44.1	2013-01-05	2015-01	sonovault	AWI/van Opzeeland
AWI 217-5	960	-64.2	-45.5	2013-01-09	2015-01	sonovault	AWI/van Opzeeland
AWI 207-9	219, 1012, 2489	-63.4	-50.5	2013-01-12	2015-01	sonovault	AWI/van Opzeeland
AWI 206-8	277 907	-63.2	-51.5	2013-01-04	2015-01	aural sonovault	AWI/van Opzeeland
AWI-251-1	212	-61.0	-55.6	2013-	2015-01	sonovault	AWI/van Opzeeland

Instrument Name	Depth	Latitude	Longitude	Start Date	End Date	Instrument type	Initial Contact
	210			01-06		aural	
AWI K02	235	-52.25	-40.5	2013-10-01	2015-01	aural	AWI/van Opzeeland
Davis2013	2000	-66.2	74.5	2013-01-01	2014-01-01	aad	AAD
Maud Rise	300	-65	3	2014-01-01	2015-01-01	aural	SABWP
Astrid Ridge	300	-67.75	12	2014-01-01	2015-01-01	aural	SABWP
SWAMS	1000	-43	75.6	2013-01-01	2014-01-01	UBOphone	Royer/Samaran/Guinet
NEAMS	1200	-31.6	83.2	2013-01-01	2014-01-01	UBOphone	Royer/Samaran/Guinet
DumontDurville	1100	-65.6	140.5	2013-01-01	2015-01-01	Aural	AAD
HobartDumont44	1866	-44	144.7	2014-01-01	2015-01-01	Aural	AAD
HobartDumont54	2078	-53.7	141.8	2014-01-01	2015-01-01	Aural	AAD
Casey2014	2770	-63.7	111.8	2013-12-21	2015-01-01	AAD Logger	AAD
WalvisBay	300	-34.2	17.7	2014-01-01	2015-01-01	aural	SABWP
Cape	300	-26.8	14	2014-01-01	2015-01-01	aural	SABWP
CL	0	-34.9	114.1	2013-06-01	2020-06-01	CTBT	AAD
WKER-1	500	-46.6	60.1	2013-12-01	2016-12-01	UBOphone	Royer/Samaran/Guinet
NCRO-1	1100	-41	52.8	2013-12-01	2016-12-01	UBOphone	Royer/Samaran/Guinet

Table 1. List of known AR deployments in the Southern Ocean.

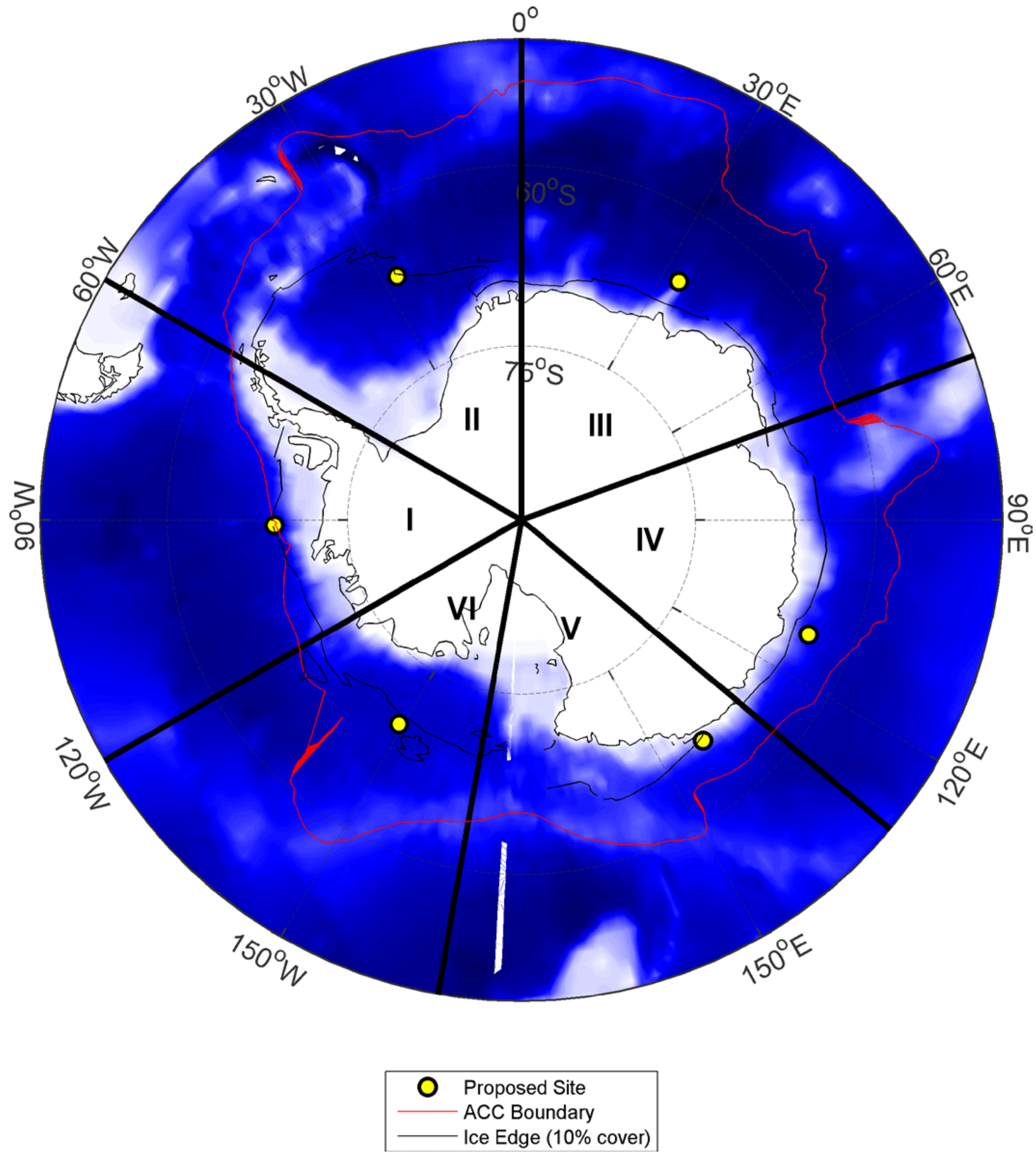

Figure A1. Locations of proposed SOHN recording sites (yellow circles). Thick black lines indicate IWC management areas I-VI. Contours indicate 300 m (light blue), 3000 m (light purple) and 6000 m (dark purple). The red line shows the northern boundary of the Antarctic Circumpolar Convergence (Sokolov & Rintoul 2009a). The thin black line is indicative of the edge of the sea ice and corresponds to the monthly average sea-ice cover of 10% in February from 2000-2012 (Maslanik & Stroeve 1999).

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