A Perennial Acoustic Observatory in the Antarctic Ocean

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Abstract. In December 2005 the Perennial Acoustic Observatory in the Antarctic Ocean (PALAOA, Hawaiian word for “whale”) was set up on the Ekström ice shelf, Antarctica near the German Neumayer Station (Boebel et al., 2006). Since then, it almost continuously records the underwater soundscape in the vicinity of the ice shelf edge and is intended to do so over the duration of several years. These long-term recordings allow studying the acoustic repertoire of whales and seals in an environment almost undisturbed by humans. The data is analyzed to detect species specific vocalizations, infer the approximate number of animals inside the measuring range, calculate their movements relative to the observatory, and examine possible effects of the sporadic shipping traffic on the acoustic and locomotive behaviour of marine mammals. Underwater sound is recorded by means of four hydrophones located through boreholes below the 100 m thick floating ice sheet. They are attached to an autonomous, wind and solar powered station, which can record at 192 kHz / 24 Bit. A compressed data stream is transmitted in real time via wireless LAN from PALAOA to the German Neumayer Base at 15 km distance. From there, a permanent satellite link transmits an even more compressed stream to the AWI in Germany. It can be accessed live from our webpage at http://www.awi.de/acoustics. So far, Weddell seals, crabeater seals, Ross seals, leopard seals, killer whales, blue whales, fin whales and minke whales have been identified in the recordings along with several vocalizations which could not be assigned with certainty to species level yet. Additionally, many non-biological sounds were recorded, mostly generated by ice and some anthropogenic events like ships passing by and human activities on the ice. Difficulties have arisen from the sheer size of this constantly growing dataset, which consists of more than 10.000 hours so far. We develop interfaces and setups to process this stream in real time and analyze it both interactively and by means of batch processes running in parallel on a workstation cluster, for example applying detectors specific to single species, based on hidden Markov models. These recordings, which are largely free of anthropogenic noise, provide also a base to set up passive acoustic mitigation systems used on research vessels by developing automatic pattern recognition procedures to be used in the presence of interfering sounds, e.g. propeller noise.

Introduction

Antarctica is one of the last areas on earth which is to a large extent untouched by human activities and it is granted a special protection status. The continent is by international agreements dedicated to nature and science. The Madrid Protocol of the Antarctic Treaty System requires a permit for all operations in the Antarctic territory beyond 60° South, to be issued by an authority of one of the respective contracting states. Applications for research permits do require a proof of the environmental soundness of the planned activities. Potential risks of the field work to marine mammals in particular must be evaluated in terms of the possible impact on species or population level. Therefore it is necessary to take into account the presence of the respective species at the proposed time and location of the operation. However, little is known about the abundances and migration patterns of many species due to the inaccessibility of this remote area which can only be assessed by ice-strengthened vessels during the austral summer months. Knowledge about the total number of animals and their spatio-temporal distribution is usually gained on ship surveys where observers count the sightings of animals and extrapolate abundance estimates from these numbers. However, marine mammals spend most of their lifetime submerged, and the probability of spotting them in the open ocean is influenced by factors such as light conditions, weather, sea state and the observer himself. Hence the results strongly depend on assumptions on detectability and behaviour. Reliable data exist only for areas which are visited by ships frequently enough to provide sufficient statistics. Recently, satellite transmitters attached to individual animals allow following their migration paths for substantial periods of time, extending the knowledge to locations and seasons where direct observation is not possible.

But in general, estimations of the number of animals in a given area at a given time still suffer from a high degree of uncertainty.

As most marine mammals are vocal under water, the methods for passive acoustic monitoring which have been developed in the recent years provide a convenient and efficient way to detect marine mammals. Autonomous systems allow to record for extended periods of time without the necessity of human presence and can be deployed at sites of interest. However, the Antarctic environment imposes extraordinary demands on material and operations, so special equipment and procedures are needed here. Germany operates the year-round manned Neumayer research base on the Ekström Ice Shelf, at 70°39'S, 008°15'E, close to the shelf ice edge at the north-eastern entrance of Weddell Sea. Many species of seals and whales have been observed to inhabit this area. As this is a focal point of Germany’s Antarctic activities, it is of great interest to study the influence of human operations to the marine environment at this location. Lastly, the base also provides the necessary logistics to set up and maintain a hydroacoustic observatory, that otherwise would go far beyond the operational and financial scope of such a project. In 2005 we deployed a hydrophone array near Neumayer Base, which since then provides continuous online access to the underwater soundscape of Antarctic waters.

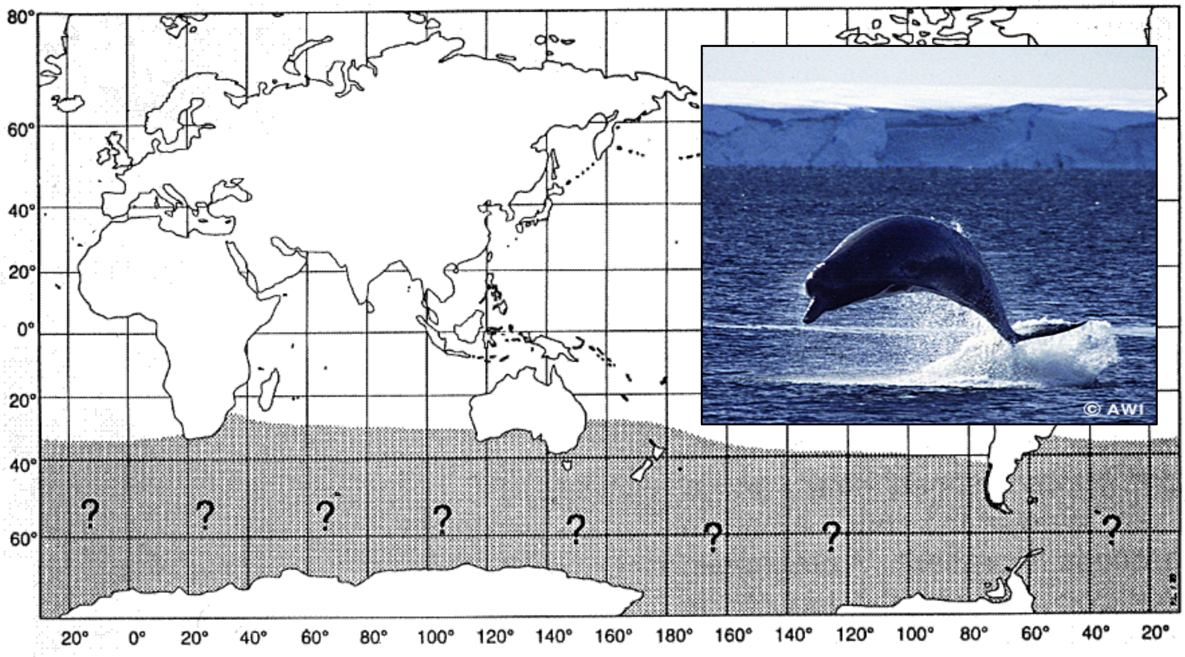

Figure 1: Proposed distribution of the Arnoux beaked whale, as given in the United Nations FAO species identification guide.

Ice Shelf Edge Habitat

Antarctica is almost completely covered by ice which can reach heights of up to 4000 metres in the inland of the continent. From this ice mass, glaciers and ice streams form which slowly move towards the coast. Reaching the ocean, the glaciers and ice streams float on top of the water and can extend hundreds of kilometres to the north, forming large ice shelves. At the edge, ice breaks off, either by calving or releasing giant table icebergs which can reach a size of hundreds of square kilometres. In austral winter the ocean is covered by sea ice, either drifting *pack ice* or *fast ice* attached to the ice shelf. However, the predominant katabatic winds drive this ice mass northwards and frequently create a stripe of open water, the coastal polynia. In summer, the sea ice disappears mostly and leaves an open ocean. This area is habitat to several species of penguins, whales and seals, year-round or seasonal. Only the Weddell seals stay in the coastal shelf waters all the year, while Ross, leopard and crabeater seals are summer guests only. It is unclear, which whale species are present here in wintertime, taking advantage of the open waters provided by the polynia.

Figure 2: Ice shelf edge with crabeater seals on sea ice floes and penguins on an iceberg (top left), Weddell seals on fast ice (top right), a group of minke whales (bottom).

Station Location

Traditionally, hydrophones are deployed in the ocean either on anchored or drifting buoys or sea bottom moorings. In the Antarctic Ocean, buoys will be destroyed by drifting ice floes. In shallow, coastal waters moorings will be destroyed by big icebergs ploughing the seafloor. There is no way to route a cable safely from an underwater station towards the shore, like in hydrophone stations deployed at many places elsewhere in the world. The only safe place is provided by the ice itself. The massive floating ice shelf, with a thickness of up to hundreds of meters provides a perfect shelter. 15 km north of Neumayer Base, west of Atka Bay the Eckström Ice Shelf spreads to a typical, finger like structure. Under the most prominent of these ice fingers, called the *North Pier*, surrounded by the ocean on the north-west, north and east side, we were expecting to have excellent acoustic reception from the surrounding ocean. In general it is extremely dangerous to move on the ice due to crevasses pervading the glacier, but this area is safe to access on a secured way, marked with flags. It leads to the base because ships use this site as a pier to unload the Neumayer supplies.

Figure 3: The PALAOA site ●, photographed from a helicopter (left) and from the spot marked ● (right).

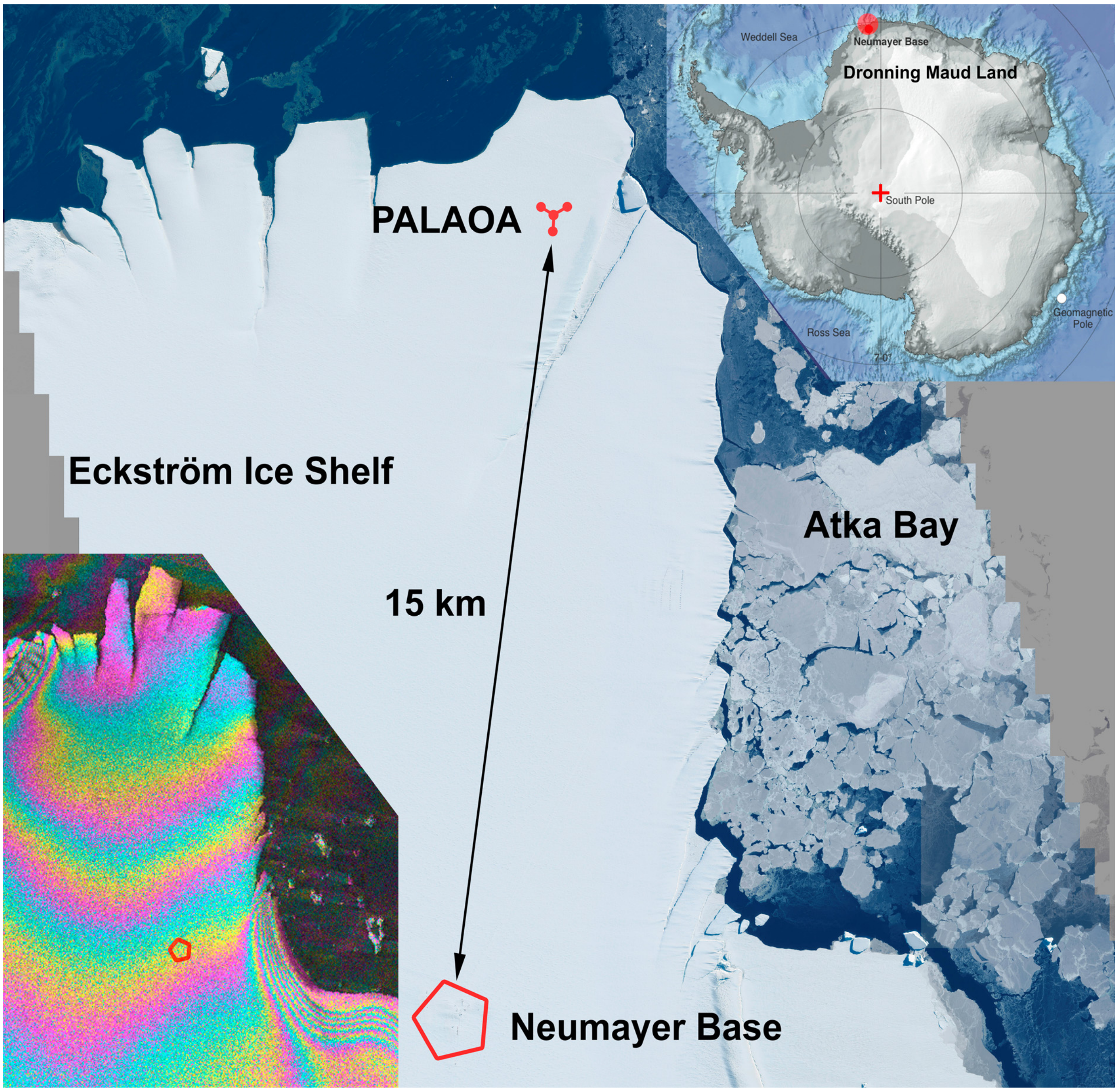

Figure 4: Location of PALAOA with an IKONOS satellite image underlay and a radar interferometer picture, showing the physiograpy of the area.

Hydrophone Deployment

Holes were drilled through the 100 m thick ice shelf to get access to the water body underneath. This was achieved by a hot water drilling system developed by AWI, which is capable to melt through the ice in about 12 hours per hole. Energy consumption is enormous, requiring about 750kW to melt the ice and heat the water to 95°C.

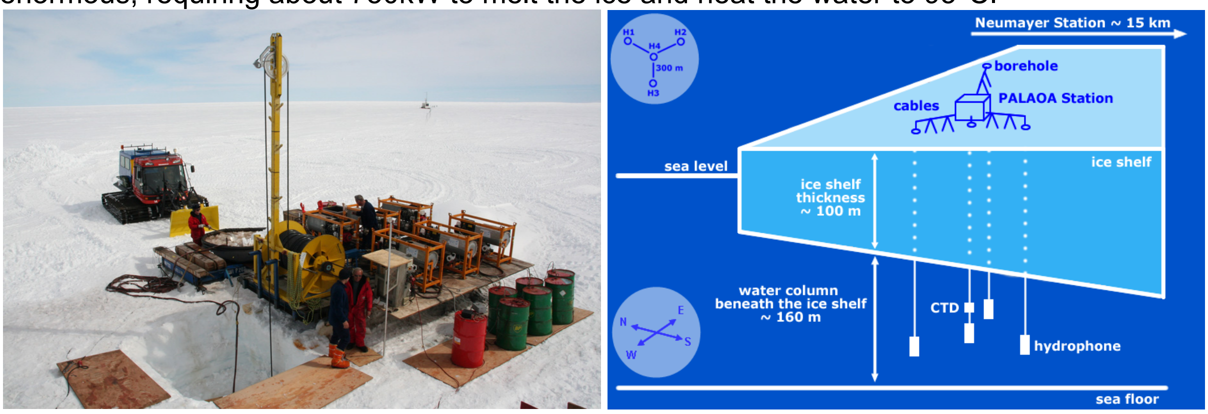

Figure 5: Hot Water drilling equipment and hydrophone array layout.

Energy and Networking

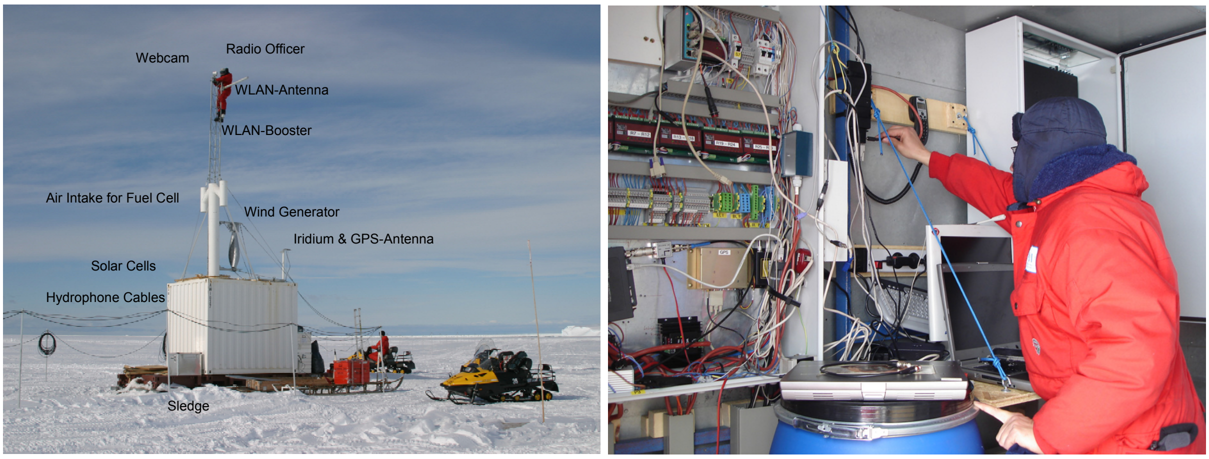

Figure 6: The PALAOA container and the electronics inside.

Energy is crucial for any autonomous system. PALAOA is equipped with solar cells, a wind generator, a large battery bank and a methanol fuel cell. Energy consumption can be tuned according to the available supply by switching devices on or off on demand. This energy management is implemented as a BASIC program on a BARIX Barionet PLC, equipped with relays and I/O modules. Almost all devices in the observatory are switchable via a relay.
Hydrophone amplifiers have a very high input impedance, about 100 MOhm. This implies that they pick up interference easily which induces noise and artefacts in the audio recordings. Charge controllers, on the other hand, and DC-DC converters emit a lot of electronic noise. Attempting to power the hydrophones directly from a circuit connected to the charge controllers, results in horrible sound quality. We set up a power bus system with a main energy circuit and two audio circuits for the hydrophones. Each of 6 battery packs can be attached either to the main, charging bus or one of the audio busses. In this way it is possible to separate the audio system galvanically which reduces interference drastically. In addition, all hydrophones were also completely separated from each other. After deployment of the first hydrophone through its borehole, we received a very good signal quality. However, after attaching the second hydrophone, the signal of both channels was disturbed by spikes with higher amplitude than the audio signal. The spikes appeared immediately when any connection between the hydrophone was made. Connecting the ground of another hydrophone cable was enough. After a lot of investigations and tests we are confident now, that we accidently built an extremely large and powerful antenna. The hydrophone cables form 3 legs of a 600 x 180 m rectangle and the seawater closes the loop. Such a giant closed loop is the ideal geometry for a VLF ring antenna which picks up electromagnetic frequencies in the audible range. Lightning strikes are known to produce such signals, known as *sferics* or *whistlers*, which can travel around earth. We were listening to all the thunderstorms in the world at once. Especially during noon in Amazonas and Congo areas the spikes increased. The only solution was to completely separate every hydrophone channel galvanically from each other. However, during the built-up period we did not have the necessary equipment with us at that time and we decided to connect only one hydrophone and bring the necessary equipment to connect the other hydrophones one year later. It is not a trivial task to set up a multi-channel audio system without any wires between the components. Also each hydrophone had to be powered separately which increased the complexity of the energy system enormously. We developed an audio system with separate AD converters for each hydrophone channel which were connected via optical fibre to a digital sound card, in the PC. However when we returned one year later we discovered that two of the four hydrophones were defect. Only the central and the north eastern hydrophones were still operational. There is no chance to find out what caused this defect, as the boreholes had frozen again. With only two channels left, is was much easier to achieve galvanic separation. Standard studio DI boxes did the job for the audio signals and the power wiring could be modified to have two separate battery packs and two power

busses for the hydrophone amplifiers. In minimal mode, only sending a stream it consumes 20 watts, mainly for the wireless LAN bridge, which connects the container to the local network at Neumayer Base. Data rate on this 15 km wireless link is about two MBits/s. This set up has worked flawlessly in any weather condition so far, allowing permanent access to the acoustic data and station control via the internet.

Satellite Stations

Figure 7: Single hydrophone deployment through sea ice.

In January 2007 when the sea ice was still accessible, we set up another mobile recording station, PALAOA-S. A RESON 4032 hydrophone was deployed through a hole in the sea ice which was about two meters thick at this location. This hole was excavated with a chainsaw until the seawater flooded in and finished with a core drill. Because the sea ice was already receding and it was unpredictable when this ice floe would drift away, we decided to install the electronic box on top of the ice shelf, about 200 meters away and tied it securely. It contained a portable Microtrack 2496 (24 Bit, 96 kHz) recorder, powered by external batteries. It recorded the hydrophone along with GPS signals on the second channel. The 1pps signal, a better than microsecond precise pulse once every second was mixed by a small self made circuit with the serial NMEA data, containing ASCII timestamps and positions. As the main PALAOA station has the same capability, it is possible to synchronize the recordings later at sample precision for long baseline sound source localisation. In this way we could compensate temporarily for the lost hydrophones of PALAOA.

Data Handling

PALAOA can generate data at an enormous rate. Two audio channels and the synchronization signal at 24 Bit and 192 kHz will produce 140 GB per day. We are not able to stream this amount continuously through the wireless link to Neumayer, instead there is a portable 500 GB USB disk attached locally, which has to be replaced by the radio officer periodically. However, single files of interest can be downloaded by FTP at any time. We record only sporadically at this quality, particularly when PALAOA-S is active too and the GPS channel is required at high precision. This mode is quite energy consuming as PC, MOTU sound interface, external hard disk and GPS consume together about 25 W. If such data needs to be transmitted online to Neumayer at a reasonable rate, a WLAN booster is required. This increases the effective data rate of the wireless link from 500 kBit/s to 2 MBit/s, but requires additional 25 W. This setup can only be activated during austral summer when the solar cells are 24 hours operational. For the continuous streaming of audio we use a BARIX Instreamer device. It only requires 7 W and generates a stereo 16 Bit, 32 kHz MP3 stream at 192 kBit/s, which can be transferred via the WLAN without booster. Time stamping of the data happens at Neumayer Base, which allows only for about one second accuracy - which is not a problem as long as synchronizing with other audio sources is not required. An improved version of this device is announced and will allow to mark up the audio stream via a serial input with GPS data. It will have 24 Bit / 96 kHz capabilities and can buffer locally on an USB device in case of network congestion. We hope to deploy the improved device in January 2009. On a workstation within the Neumayer Base the audio stream is stored locally, cut down into one minute MP3 files. Thus there are 1440 files generated per day, each has a size of about 1.25 MB. Every day 1.7 gigabytes accumulate, per year up to 620 GB in half a million files. The autonomous webcam on top of the mast takes one 1280 x 960 Jpeg picture every minute, size ~300 kB, and transfers it via FTP to the Neumayer PC where it is stored along with the audio files, adding another 150 GB. In addition, we continuously collect oceanographic data from the CTD probe, temperatures and technical operating data of the meteorological readings from the Neumayer observatory, and network statistics from the satellite link. This is only 1 MB per day which is sent and logged via the standardized syslog protocol and online available at PALAOA, Neumayer, and in the Alfred Wegener Institute in Bremerhaven. Data is regularly backed-up on 200 GB LTO2 tapes which are shipped twice a year to Bremerhaven, in November when the first transport after the 8 month overwintering period is available and in February or March when the last ship leaves Neumayer just before access to the base is cut off from the rest of the world again. During the rest of the year, Neumayer is accessible only via a 128 kBit/s IntelSat link to the AWI in Bremerhaven, of which 24 kBit/s are assigned to the PALAOA project. We transmit a continuous OGG-Vorbis recompressed audio stream using the open source IceCast system and a small webcam picture every ten minutes. The data is presented and analyzed online in our lab and kept until the high quality from the tapes arrives. In total, we collected about 4 TB during the first two years of operation which are kept in our data silo in Bremerhaven with one petabyte capacity. There the data is held on LTO2 tapes in two redundant copies which are automatically loaded on demand by tape robots. To the network the system transparently appears as a simple network drive. It conforms to the requirements for reliable scientific data storage. The online audio stream and webcam pictures are publicly accessible via the internet (icecast.awi.de). Datasets are published with an open access license through the PANGAEA database (www.pangaea.de), and the World Data Centre for Marine Environmental Data, hosted by AWI. This satisfies the conditions of the Berlin Declaration on "Open Access to Knowledge in the Sciences and Humanities" as required by the AWI data policies.

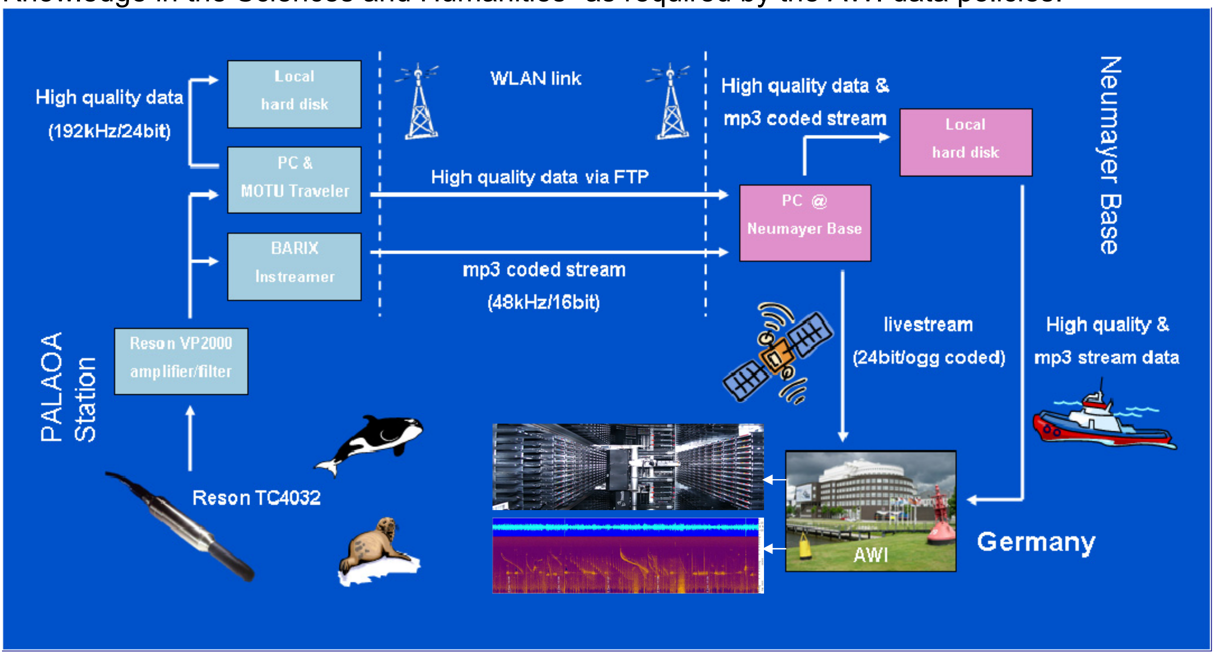

Figure 8: Audio data streams, from the water to long term archival and web broadcasting

Data Processing

All the PALAOA recordings consist of standard multimedia files (Wav, Flac, Mp3, Ogg, and Jpeg) and the additional metadata is stored in text files. As they are kept transparent on a network drive, it is possible to use standard software to easily access the dataset. However, the sheer amount of files makes it hard to analyze longer periods; no software can load a million sound files at once. We assembled an application in MATLAB, “PALAOAdb” to allow easy access to the dataset from a timeline or event oriented view. It periodically updates its database, by analyzing the recent online recordings to provide an up to date display. The initial view is a plot of several selectable parameters for the whole recording period, which is currently 2 years. Available are sound specific measures like RMS or peak sound level, external observations like air and water temperature or tidal current. Also the results of analyses like pattern recognition algorithms can be selected. One can zoom in and click to open single files, either with a built in player and spectrogram view or any external program or media player like XBAT, Ishmael, Audacity or Adobe Audition. PALAOAdb provides displays to visualize parameters and results from the whole data set.

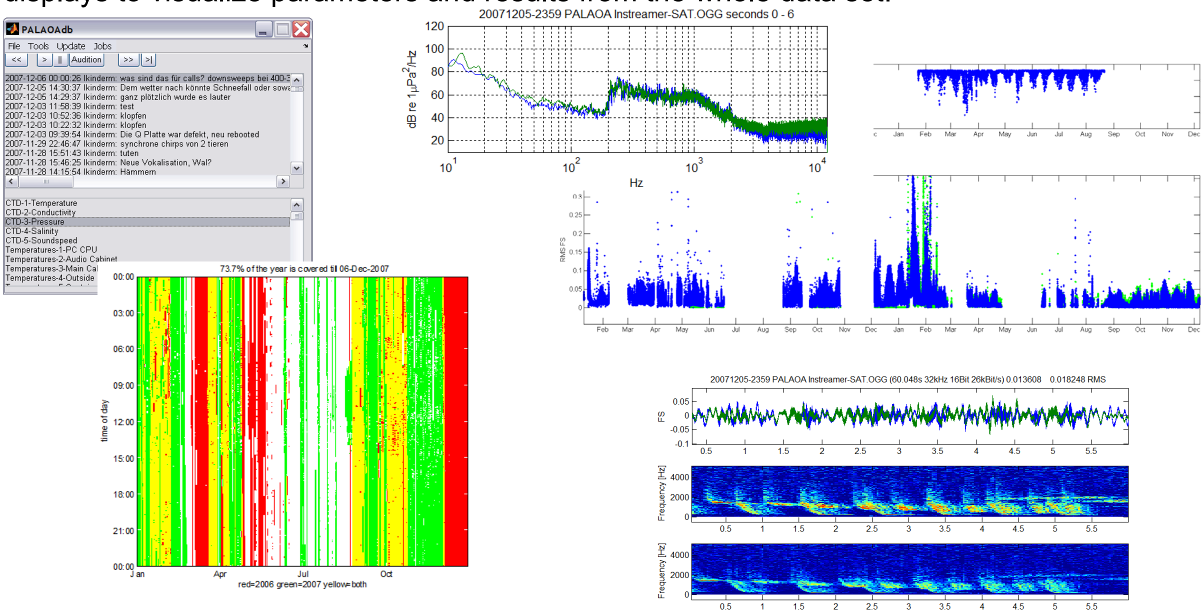

Figure 9: PALAOAdb software tool to handle long audio time series.

It takes about one second to load and process a single mp3 file with the basic procedures, additional modules will add to this. So an offline analysis can be done in up to 60 times real time speed. New algorithms have to be implemented as MATLAB functions that take a one-minute waveform array and a file information structure as arguments and deliver a structure containing the result. PALAOAdb will create timeline views from the results. To speed up processing of long-term periods like a whole year of recordings, we implemented a distributed computing system that allows sharing this task between multiple computers. PALAOAdb will compile a "worker" executable (no MATLAB licenses needed for the workers!) split the whole task into smaller jobs (defined by m-files) and just place everything into a network directory. All communication occurs via the file system: any computer in our institute network only needs to start the worker program and the computer will start to operate on a selection of the sound files. Finally, PALAOAdb collects all the results and generates a single structure array that can be accessed easily in the same way as performing all analyses on a single machine. As there is no interprocess communication between the workers, the speed scales linearly with the number of nodes as long as the network and the file server are not saturated by fetching the audio files. With a size of 1.35 MB per one-minute mp3 file, a 100 MBit network can handle up to 10 files per second, thus 500 times real time should be possible employing 10 PCs, scanning a year in less than a day. If the algorithm needs much longer than a second to analyze 60 seconds of data it will take proportionally more time.

First Results

Currently we host two years of recordings in the database, from December 2005 to December 2007 high quality files (192 kBit/s MP3 and/or 192 kHz, 24 Bit WAV), and since then compressed 24 kBit/s Ogg-Vorbis files. While we are presently developing automated pattern recognition modules for the PALAOAdb system, a first analysis of the data was done by hand, which is a necessary preparatory work also for evaluating the pattern recognition algorithms. We concentrated on seals in this phase as their vocalizations are within the human hearing range and can be analysed without further transformation of the recordings.

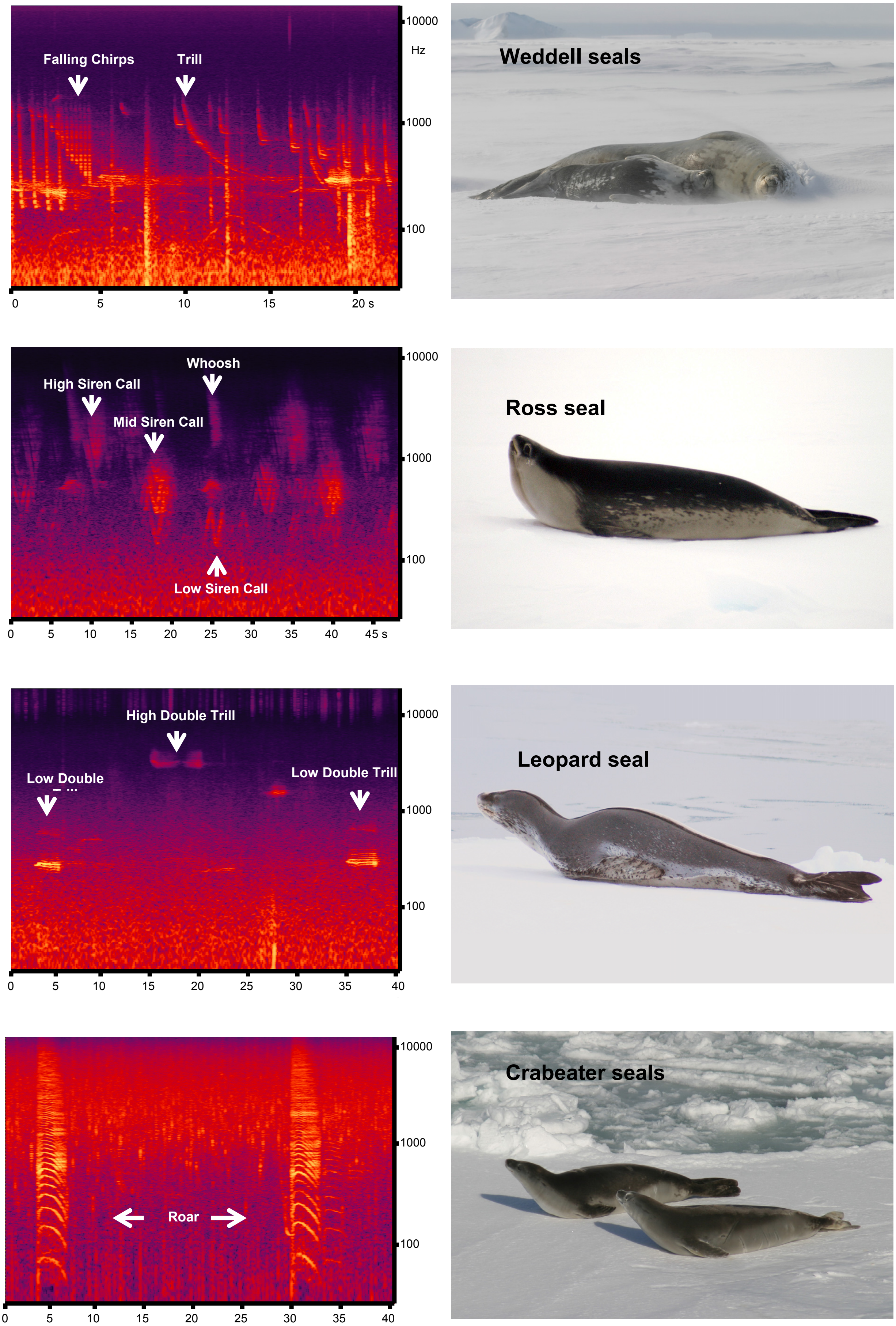

Figure 10: Spectrograms of different seal vocalizations

Seal Presence

Four species of seals are present in the vicinity of PALAOA, Weddell, Ross, leopard and crabeater seals. They can be distinguished by their underwater calls (Fig 10). Each of the species uses different sounds. A first manual scan through the recordings of 2006 shows the cycle of the presence of Weddell, Ross, crabeater and leopard seals.

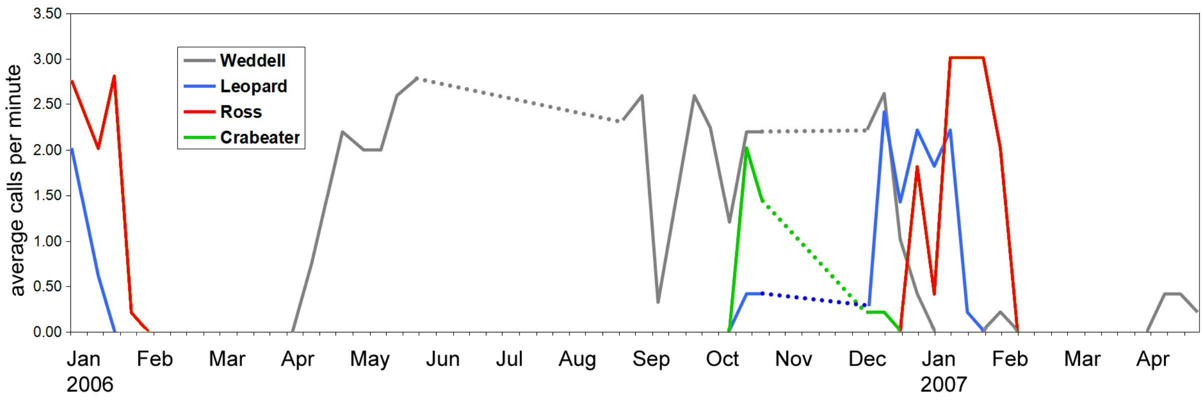

Figure 11: Seal calling activity during the year. Dotted lines bridge data gaps.

All four species show very different patterns in their acoustic presence. While it is not a priori clear that calling activity corresponds directly to the number of animals, at least recent data on the migratory behaviour of Ross seals, satellite tagged at a coastal site south-west of Atka Bay show, that their seasonal presence in this area coincides exactly with the detection of their calls.

Bioacoustics of Ross seals

The vocalizations of Ross seals, the rarest of all Antarctic pinnipeds, were analyzed for the first time in detail using the PALAOA recordings, revealing that their repertoire consists of three distinct siren like calls and a whoosh like sound. The four call types are clearly distinct from each other (Fig 13). However, the function of the different sounds remains unclear.

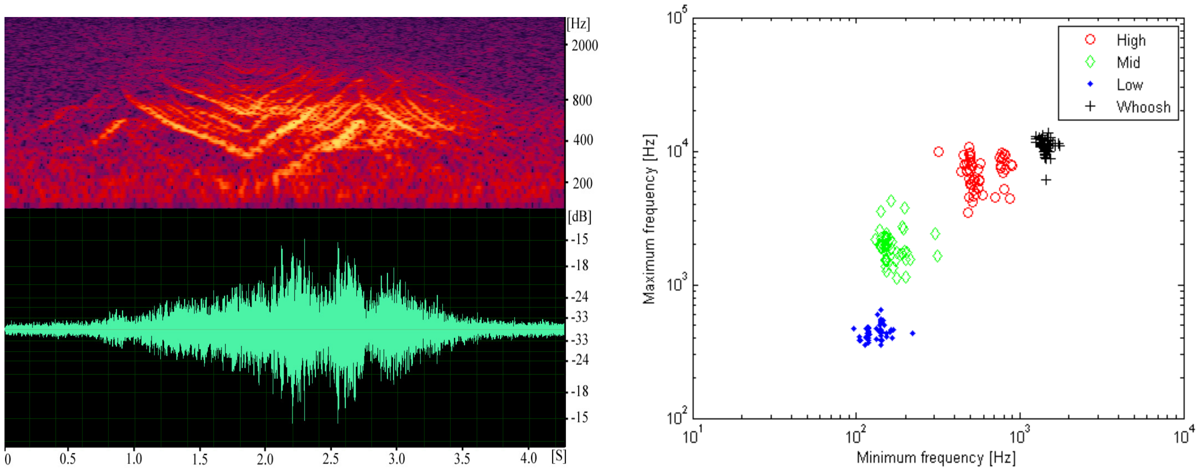

Figure 12: Spectrogram and waveform of the Ross seal high siren call (left), scatterplot of the frequency limits of all four calltypes (right)

Localization techniques allow to separate single animals from the recordings, a two-hydrophone system can reveal the bearing of an incoming sound while more hydrophones allow to detect the distance and position too. By this method we are able to count the animals in acoustic range of PALAOA. In addition, individual movements of calling animals can be tracked, which enables investigation of spatial distribution of callers in relation to their vocal characteristics.

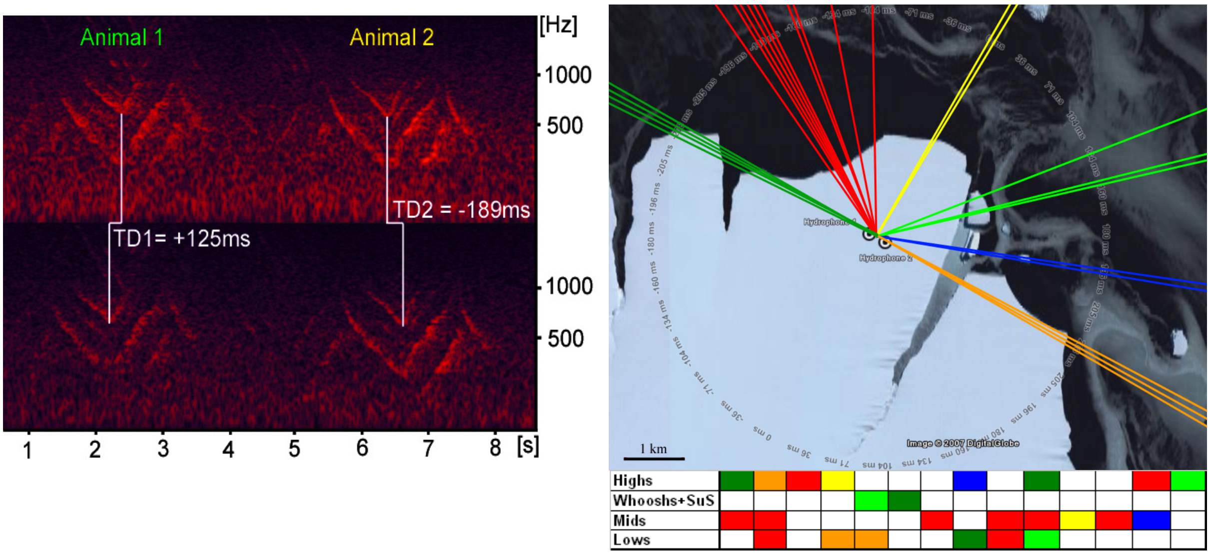

Figure 13: Localizing animals. Sounds arrive at different times at the two hydrophones (left). At least 6 or 7 individuals are vocalizing from different directions (right). The temporal structure of their “conversation” (bottom right).

Natural Sound Background

The loudest event we recorded with PALAOA so far occurred on March, 19th 2006 at 8:15. For more than 10 minutes the hydrophone input was completely overdriven, and we had to estimate the peak amplitudes from the steepness of the signal at zero crossing. From ENVISAT-ASAR satellite pictures we determined that two icebergs had collided about 20 km offshore. One of them stuck on the ground for some days while the other was approaching with the speed of the ocean current. The estimated source level of this event were well above 200 dB re 1 µPa @ 1 m and, with 10 minutes continuous duration, a sound exposure level of 228 dB SEL, this marks an iceberg collision as one of the loudest events in the oceans.

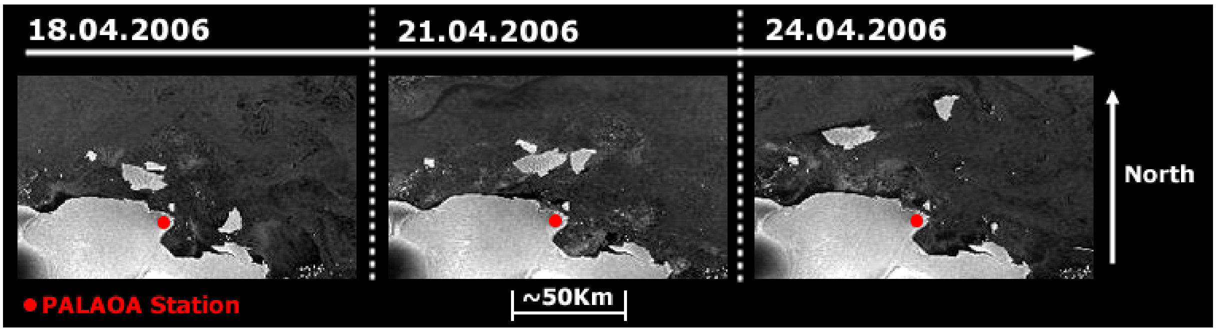

Figure 14: ENVISAT-ASAR images of an iceberg collision, provided by ESA. The large iceberg has a length of about 20 kilometers.

Perspectives

PALAOA is intended to work for several years to provide a long time series of acoustic data to look out for long term trends eventually induced by climate change. Also Atka Bay is an interesting place for studying the biology of marine endotherms. There is a local Weddell seal population of around 300 animals and an emperor penguin colony with 8000 breeding pairs, attracting predators like leopard seals and killer whales. Biologists from AWI plan to combine acoustic recordings from PALAOA with on site observations and satellite tagging programs to study the behaviour and ecology of these animals. To infer from passive acoustic recordings to real abundances of a species is a difficult task that also requires additional field work for gauging. We plan to deploy seals with acoustic tags to derive the vocal behaviour of diving

individuals. Information on individual at-sea and haul-out activities, depending on time and weather and ice conditions is necessary to estimate the percentage of animals which are and which are not in the water at a given time. Then, from the calls recorded by PALAOA in a period, together with the calling rate of an individual and the percentage of animals that are in the water it will be possible to get estimates of the total number of animals in the PALAOA vicinity.
A problem in generalising the data is the question whether the location is typical for the ice shelf edge, or even for other parts of the Southern Ocean. In order to investigate this we are preparing to set up additional, smaller autonomous recorders at other locations for shorter periods to obtain acoustic recordings from other sites.

The future of PALAOA is thrilling. We intend to run the observatory for as long as possible to obtain the long time series which is necessary to detect changes and trends, both in the physical noise background and in the marine mammal presence which might be induced by changes in the Antarctic environment. However, while PALAOA is not standing on thin ice, its fate might well lie in the depth of the ocean. The break-off of the ice shelf is not predictable, and a journey on an iceberg around Antarctica might start any day. We took precautions to recover the PALAOA container in this case by equipping it with a GPS/Iridium phone, however, the chances of such a rescue operation are in the air.

Further Readings

ACKLEY S.F., BENGSTON J.L., BOVENG P., CASTELLINI M., DALY K.L., JACOBS S., KOOYMAN G.L., LAAKE J., QUETIN L., ROSS R., SINIFF D.B., STEWART B.S., STIRLING I., TORRES J., YOCHEM P.K. (2003) A top-down, multidisciplinary study of the structure and function of the pack-ice ecosystem in the eastern Ross Sea, Antarctica. Polar Record **39**(210): 219-230.

BESTER M.N., FERGUSON J.W.H., JONKER F.C. (2002) Population densities of pack ice seals in the Lazarev Sea. Antarctica. Antarctic Science **14**(2): 123-127.

BLIX A.S., NORDØY, E.S. (2007) Ross seal (Ommatophoca rossii) annual distribution, diving behaviour, breeding and moulting, off Queen Maud Land, Antarctica., Polar Biology **30**(11): 1449-1458.

BOEBEL O., KINDERMANN L., KLINCK H., BORNEMANN H., PLÖTZ J., STEINHAGE D., RIEDEL S., BURKHARDT E. (2006) Acoustic Observatory Provides Real-Time Underwater Sounds from the Antarctic Ocean. EOS **87**: 361-372.

BOEBEL, O., KLINCK, H., KINDERMANN, L., EL NAGGAR, S. (2008).PALAOA: Broadband recordings of the Antarctic coastal soundscape, Bioacoustics, **17**, 19-21.

GREEN K., BURTON H.R. (1988) Annual and diurnal variations in the underwater vocalizations of Weddell seals. Polar Biology **8**: 161-164.

HALL-MARTIN A.J. (1974) Observations on population density and species composition of seals in the King Haakon VII Sea, Antarctica. South African Journal of Antarctic Research **4**: 34-39.

KLINCK, H., KINDERMANN, L., BOEBEL, O. (2007).Detection of Leopard seal (Hydrurga leptonyx) vocalizations using the Envelope-Spectrogram Technique (tEST) in combination with a Hidden Markov Model, Canadian Acoustics, in Print.

MIRHAJ M., PLÖTZ J., BORNEMANN H., KINDERMANN L., KLINCK H., BOEBEL O. (2004) Underwater calls of Weddell seals in the Weddell sea, Antarctica. SCAR Open Science Conference “Antarctica and the Southern Ocean in the Global System”, 25-31 July 2004, Bremen, Germany. Terra Nostra, Schriften der Alfred-Wegener-Stiftung 2004/4 p 138.

ROUGET P.A., TERHUNE J.M., BURTON H.R. (2007) Weddell Seal underwater calling rates during the winter and spring near Mawson Station, Antarctica. Marine Mammal Science **23**(3): 508-523.

SEIBERT, A.-M., KLINCK, H., KINDERMANN, L., BORNEMANN, H., VAN OPZEELAND, I., PLÖTZ, J., BOEBEL, O. (2007). Characteristics of underwater calls of the Ross seal, 17th Biennial Conference on the Biology of Marine Mammals, 29 November - 3 December 2007, Cape Town, South Africa.