Risk Assessment of ATLAS HYDROSWEEP DS-2 Hydrographic Deep Sea Multi-beam Sweeping Survey Echo Sounder

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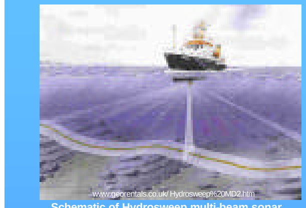
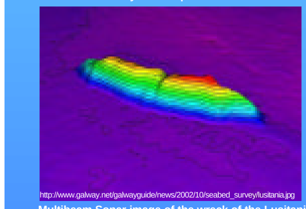
✍ Why at all? Applications of multi-beam sonar:



Schematic of Hydrosweep multi-beam sonar



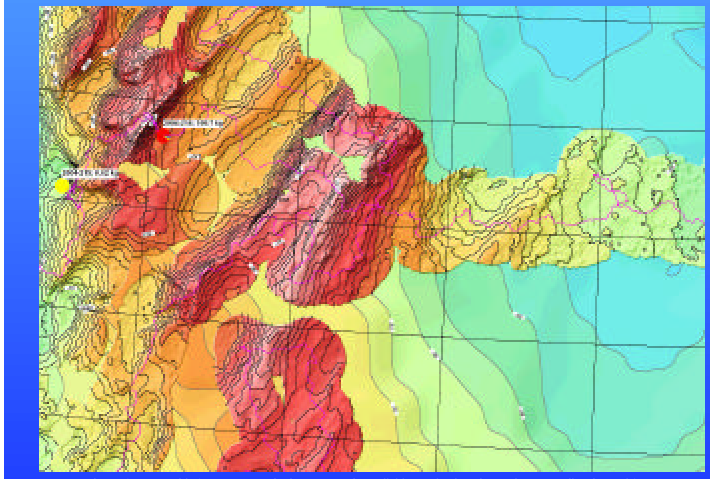
Multibeam Sonar image of the wreck of the Lusitania

Hydrosweep is used to map the topography of the ocean's floor in 2-D and at a high resolution. Such data is crucial for several research fields and environmental studies within the oceanic environments:

✍ To identify and map sites of environmental importance such as cold water coral reefs or seamounts.

✍ To determine *in-situ* the exact site for oceanographic, geophysical, climatological or biological studies, such as deep water passages, sediment layers or ice-berg grounding tracks.

✍ To develop reliable navigational charts, particularly in remote areas, for commercial navies and tourism.



Comparison of topographic from IBCAO - the best currently available Arctic chart (smooth contour lines) - and from a RV Polarstern Hydrosweep survey (wiggly contour lines) near Gakkel Ridge/Lena trough (83°N, 3°W). Contour lines every 100m.

Abstract

The hull-mounted *Atlas Hydrographic* multibeam deep-sea echosounder *Hydrosweep DS-2* is installed on several research vessels (e.g. *R/V Maurice Ewing, R/V Meteor, R/V Polarstern*) to carry out bathymetric surveys of the sea floor. At full ocean depth (3000 to 11000m water depth), the instrument usually operates in "Deep Sea II" mode. In this mode, three short (24, 12 and 24ms) sound pulses of 15.5 kHz are successively emitted, ensonifying a port-, centre- and starboard beam, respectively. This pattern repeats itself at regular intervals of typically 15 seconds. The resulting swath covers an area of approximately twice the local water depth along the profile line.

The sound pressure level (SPL) capable of causing a temporary threshold shift (TTS) is calculated on the basis of the 3-dB exchange rate criterion, resulting in a critical SPL of 203.2 dB$_{RMS}$ rel. 1µPa. For this calculation, a conservatively estimated effective pulse length of 60 ms, i.e. the sum of the three pulses, is used. Then the corresponding region is derived from the *Hydrosweep DS-2* beam pattern. Again a conservative approach selects the maximum SPL of each of the three consecutive pulses for every direction. The resulting critical region is heart-shaped and bounded by a box of 43 m depth, 46 m width athwartship and 1 m (sic!) width fore-and-aft.

Subsequently, regions where reception of multiple pings could lead to a TTS are determined for increasing numbers of assumed ensonifications. Finally the region where potential critical behavioural responses may occur is determined, assuming a sound pressure level commensurate with results from the Bahamas 2001 stranding event.

Conclusion

For cruising ships (*R/V Polarstern* particularly), the study concludes that the risk of causing a TTS to marine mammals is conservatively estimated to be less then 1% of the risk of a collision between the ships-hull and the animal by comparing the relevant volumes and cross-sections. The risk of causing a permanent threshold shift (PTS) will be smaller, though quantification thereof is difficult. For ships on station (zero velocity), the non-zero risk of ensonifying a marine mammal at TTS levels obviously exceeds the risk of collision, as the latter becomes zero. In this later situation, mitigation methods such as a shut down of *Hydrosweep* on station when whales are observed within a certain mitigation radius could serve to eliminate any remaining risks.

✍ How to assess the risk? The Approach:

TTS by single ensonification:

✍ First, the Hydrosweep signal parameters, i.e. signal repetition rate and signal length, were determined from the manual and verified independently by acoustic measurements.

✍ Second, based on the dual criterions proposed by the Noise Exposure Criteria Group [*N.E.C.G.*, 2004], a critical sound pressure level SPL is determined at which – for the given signal length – a TTS could occur.

✍ Third, for this critical SPL, the geometry of the volume with critical or higher SPL is determined, defining the critical volume.

✍ Fourth, the critical volume is compared to the volume displaced by the ship, defining a relative risk.

TTS by multiple ensonifications:

The same approach is repeated successively for increasing numbers of assumed ensonification, causing decreasing values of critical TTS thresholds and increasing critical volumes. Again, a relative risk is calculated for each case.

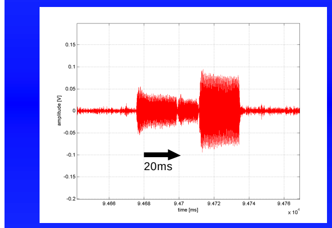
The risk of behaviourally induced damage

Detached from the above study based on TTS criterions, the risk of causing a behaviourally response capable of causing damage is compared to the use of military, mid-frequency sonars as presented in the Bahamas stranding report.

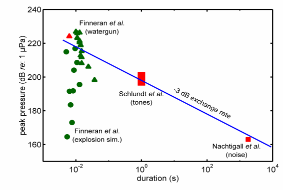
✍ Known deficiencies

The principal deficiency of this study is the unknown inter-species applicability of the 3-dB exchange rate presented below to the species of primary concern (with regard to Antarctic research), i.e. blue-, fin-, sei- and sperm whales. By contrast, the TTS study involved data from captured bottlenose dolphins and a beluga whale. However, both size (the concerned species are significantly bigger than the ones tested) and assumed hearing spectrums of these species (at least for the three mysticetes, with presumed lower susceptibility at the Hydrosweep frequency of 15.5 kHz) suggest that the application of this curve to the four endangered species is rather conservative choice than not. Nevertheless, this issue remains as one of the scientific questions to be addressed in future research.

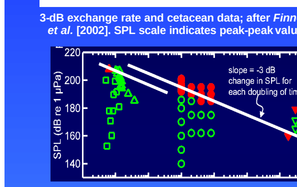
✍ Pulse lengths and the dual criterions: The critical Sound Pressure Level (SPL)



Recording of a single Hydrosweep signal.



3-dB exchange rate and cetacean data; after *Finneran et al.* [2002]. SPL scale indicates peak-peak values



3-dB exchange rate and cetacean data; after Noise Exposure Criteria Group [*N.E.C.G.*, 2004]. Time axis scaled to figure above, SPL scale indicates RMS values.

Hydrosweep (HS) consecutively ensonifies three slightly overlapping lobes (port, centre, starboard) with 15.5kHz signals of 24, 12, and 24ms duration. Hereinafter a cumulative signal length of t = 60ms is assumed. While Hydrosweep signals are short in time, they must not be confused with pulses, which are broadband and carry the bulk of their energy in the first period. HS signals behave like tones, with a multi-period onset and offset and sinusoidal behaviour throughout.

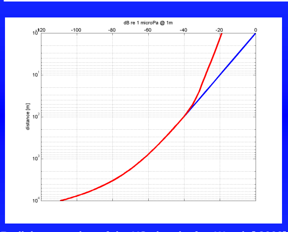
Finneran et al. [*Finneran et al.*, 2000; 2002] proposed to use the 3-dB exchange rate to describe the onset of a temporary threshold shift (TTS) as a function of signal length. Most recently, the "Noise Exposure Criteria Group" adopted these curves, with the additional distinction between tones and pulses. Note the use of different SPL reference systems (RMS and P-P in the two graphs). The 3-db exchange rate curves shifted somewhat with time:

TTS critical [dB$_{P\text{-}P}$] = -10 log10(t) + 208.8 [*Finneran et al.*, 2000]
TTS critical [dB$_{P\text{-}P}$] = -10 log10(t) + 198.6 [*Finneran et al.*, 2002]
TTS critical [dB$_{P\text{-}P}$] = -10 log10(t) + 204.3 tones, [*N.E.C.G.*, 2004]
TTS critical [dB$_{P\text{-}P}$] = -10 log10(t) + 200.0 (this study)

This study uses a curve close to the conservative estimate of Finneran et al. [2002]. Based thereon, the assumed HS signal length of 60 ms implies a critical sound pressure level of 212.2 dB$_{P\text{-}P}$, or, in terms of RMS levels, of 203.2 dB$_{RMS}$. The additional peak pressure criteria of 224 dB$_{RMS}$ re 1µPa, as proposed by the "Noise Exposure Criteria Group", is less stringent and can hence be disregarded hereinafter.

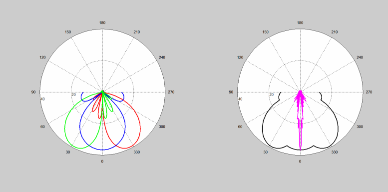
The critical SPL for 60ms long HS tones is 203.2 dB$_{RMS}$

✍ Beam Pattern and 203.2-dB contour



Radial attenuation of the HS signal, after Wendt [2002].

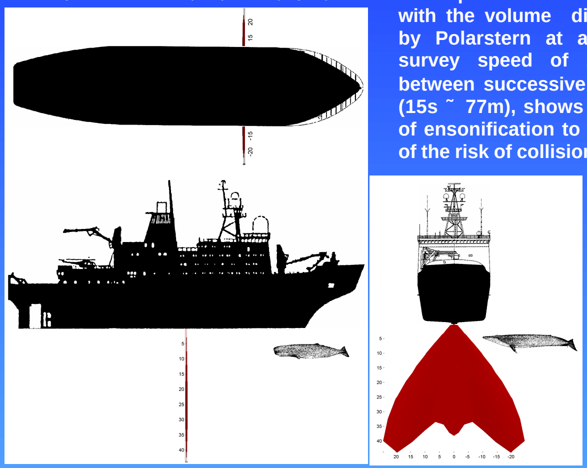
What is the size of the 203.2 dB contour? For this evaluation we used the radial attenuation function of the entire field, i.e. including the near-field the far field and the transitional region between, as well a the 3-D far-field beam pattern to obtain the full 3-D SPL field. Note that the nominal SPL is 239 dB$_{RMS}$ re 1µPa @ 1m (blue), while the real SPL at 1 m is 220 dB$_{RMS}$ re 1µPa (red).



Beam pattern of the HS signal, kindly provided by Atlas Hydrographic. Left: frontal view, with starboard (green), centre (blue) and port (red) lobes. Right: Max. SPL in frontal (black) and side (magenta) views.

The resulting SPL = 203-dB region is heart-shaped and bounded by a box of 43m depth, 46m width athwart ship, and 1m width fore-and-aft. Within this region, the reception of a single pulse would suffice to cause a TTS to mid-frequency cetaceans.

A comparison of this volume with the volume displaced by Polarstern at a typical survey speed of 10kn in between successive signals (15s ˜ 77m), shows the risk of ensonification to be 1.2% of the risk of collision.



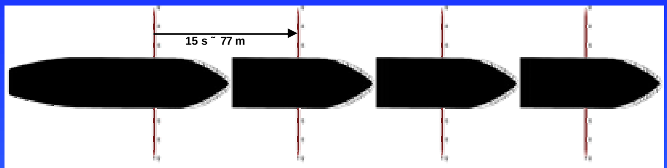
Three views of the HS 203.2-dB contour in comparison with RV Polarstern and a Sperm and Blue whale.

The critical region for TTS is of 43 m depth, 46 m width athwartship and 1m (sic!) width fore-and-aft.

The risk of ensonification amounts to 1.2% the risk of collision.

✍ Multiple ensonifications

At SPL lower than 203.2 dB, reception of a single ping will not cause a TTS. However reception of several pings may accumulate enough energy to finally cause a TTS. This has been described by a 5 dB decrease in TTS threshold for a 10-fold increase of the number of signals received Assuming increasing numbers of received pings (col. 1), [Turnbull and Terhune, 1993]. we here calculate the respective critical SPL (col. 2) and exposure times (col. 3) necessary to causing a TTS. The limits of the corresponding dB-contour (col. 4-6) is determined and the corresponding volume is compared to the volume displaced by the ship during the exposure time, resulting in an estimate of relative risks (col. 7). The later calculation overestimates the rel. risk, as it does not include the probability of the whale actually following the (intermittently occurring) sound beam.

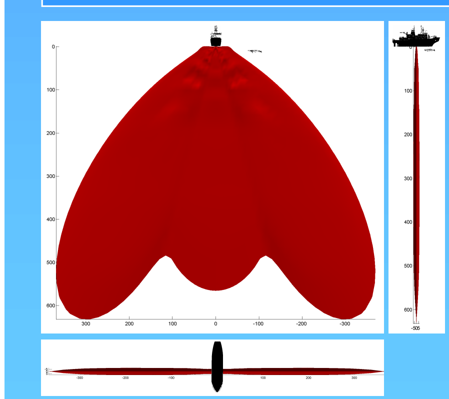


Displacement of RV Polarstern at 10 kn, with four HS signals transmitted every 15s. The corresponding 200.2-dB contour is shown in red.

number of pings	contour [dB$_{RMS}$]	minimum exposure time	width athward	width fore-and-aft	depth	relative risk [%]
1	203.2	60 10^{-3}s	46 m	1 m	43 m	1.2
2	201.7	15 s	62 m	1 m	56 m	1.0
4	200.2	45 s	78 m	1 m	70 m	0.8
8	198.7	105 s	97 m	1 m	85 m	0.6
16	197.2	225 s	117 m	1 m	103 m	0.4
32	195.7	7 min	140 m	2 m	122 m	0.6
64	194.2	15 min	165 m	3 m	145 m	0.7
128	192.7	31 min	196 m	3 m	171 m	0.5
256	191.2	63 min	232 m	4 m	201 m	0.4
512	189.7	> 2h	273 m	5 m	237 m	0.4
1024	188.2	> 4h	322 m	6 m	278 m	0.3
2048	186.7	>8 h	376 m	7 m	325 m	0.2
4086	185.2	> 17h	440 m	9 m	380 m	0.2
43652	180.0	> 7 day	738 m	15 m	632 m	0.1
4.3 10^8	160.0	> 200 yrs	3458 m	189 m	2818 m	$2\cdot10^{-7}$

For multiple ensonifications, the relative risk remains less than 1 %

✍ Behaviorally induced damage risk



Three views of the HS 180-dB contour in comparison with RV Polarstern and a Sperm and Blue whale.

Recently proposed scenarios describing the underlying mechanisms of stranding events concordant with usage of military tactical mid-frequencies sonar require the concurrent occurrence of a number of environmental conditions and sonar characteristics that are inconsistent with typical Antarctic conditions and the HS sonar, which are:

- ✍ presence of a shelf
- ✍ significant surface sound channel
- ✍ horizontal sound emission of sonar
- ✍ wide opening angle of sonar emission
- ✍ long sonar pulses
- ✍ high doses / duty cycle

	Takt. Mid-Freq. Sonar AN SQS 53C [NOAA and U. S. Navy, 2001]	Hydrosweep
pulse length	1500 ms	60 ms
repetition rate	24 s	15 s
duty cycle	6.3%	0.4 %
frequency	2 – 8 kHz	15.5 kHz
Extent of 160 dB contour	Ø ca.68 km (obere 200 m) Ø ca.20 km (unterhalb 200 m)	3458 m (T) x 189 m (X-beam) x 2818 m (A-beam)
volume	820000·10^6 m^3	2300·10^6 m^3
dose	52000·10^6 m^3	1·10^6 m^3

The above table shows that the dose emitted by AN SQS 53C is 52'000 times higher than the dose emitted by Hydrosweep.

Hence we consider such a scenario unlikely to occur when using HS in the Antarctic.

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