Evaluation of fisheries sonar's for whale detection in relation to seismic survey operations

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Preface

The International Association of Oil and Gas Producers (OGP) have initiated and funded this report. Responsible for this report has been Dr. Frank Reier Knudsen and M.Sc. Ole Bernt Gammelsæter, Simrad AS, Dr. Petter Helgevold Kvadsheim, Norwegian Defense Research Establishment and Dr. Leif Nøttestad, Institute of Marine Research. The purpose of the report has been to evaluate if commercial fisheries sonar's can be used to detect whales in relation to seismic survey operations.

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Contents

Summary

The ability of a low frequency (20-30 kHz) and high frequency (110-122 kHz) fisheries sonar to detect killer whales has been evaluated. A fishing vessel equipped with the Simrad SP90 (low frequency) and SH80 (high frequency) sonar's were used to survey an area with large numbers of killer whales in the northern part of Norway in November 2006. Whales appeared as distinct echoes on both sonar's. Visual observations were used for confirmation of whale detections. Detection range on the SP90 sonar was at least 1500 m and for the SH80 reliable detections was obtained up to 400 m range. In addition to the direct echo from the whale, vocalization (whistles and clicks) and wakes from swimming whales (surfacing) were picked up on both sonar's providing strong criteria for positive detection and classification of the target. Whales were detected during dives without any effect of water depth. No apparent behavioral reactions were observed during sonar operation.

An acoustic target with echo strength similar to killer whales was suspended at 10 m water depth in the Oslo fjord in January 2007. The plan was to position the target at different water depths from the surface to the bottom and evaluate detection at different ranges. However, due to cold surface water a strong surface sound channel had developed making it impossible to complete this experiment. Detection range for the target was up to 2000 m.

Ray tracing, sound propagation (transmission loss) and detection probability were simulated for both sonar's based on actual sound speed profile (CTD) measurements from the field work using the software Lybin. It was good agreement between actual observations and simulations. Simulations were also made based on CTDs collected from an area relevant for seismic surveys. It is recommended that simulations are performed of sound propagation and detection probability based on CTD profiles, surface and bottom conditions and predicted echo strength of whales in the actual survey area, as a supplement to sonar observations.

Introduction

Effects on man-made noise on marine mammals have been subject to much concern. A comprehensive review is given in the book “Marine mammals and noise” by Richardson et al. (1995). A more recent review with focus on noise exposure criteria is found in Southall et al. (2006). One particular activity receiving much attention is marine geophysical explorations based on air guns and its impact on marine mammals. There is a concern that air gun exposure may adversely affect marine mammals by direct injury and behavioral disruption and ultimately lead to death (Richardson et al., 1995; Southall et al., 2006). Therefore, establishing safety zones for seismic surveys has high priority. Visual observations and passive listening using hydrophones are relevant methods for whale detection in relation to seismic surveys and marine mammal research. Both methods have limitations. Visual detection is dependent on daylight, good visibility and low sea state. Passive acoustics is only useful when the whales are vocalizing and is sensitive to factors like port/starboard ambiguity, range and bearing accuracy and operator experience. Availability of these methods alone, therefore limit the time a seismic vessel can operate, and thus, increases the duration and cost of the surveys. Methodology that can reliably detect marine mammals within the established safety zone during all operational weather conditions for seismic surveys, and which is independent of visibility and the vocal behavioral state of the animals, is thus required for cost efficient operations and to secure that marine mammals are not injured or strongly affected by seismic surveys. Physical constraints in the marine environment make active sonar detection the only means which has the potential to fulfill these requirements

Negative attention has been directed towards active sonar’s and stranding of whales, but this is related to military tactical sonar’s operating at a 2-10 kHz (Frantzis, 1998; Balcomb and Claridge, 2003; Hildebrand, 2005). Sonar’s used to locate fish operate at higher frequencies and have been used for decades throughout the world, including areas occupied by whales. The operating frequencies of fisheries sonar’s can be detected by whales (e.g. Au et al, 2000), but fishermen have reported that whales are seemingly unaffected by these sonar’s, even close to the fishing vessels. This is also in agreement with actual studies reporting only few and weak reactions to higher frequency sonar’s (see Richardson, et al., 1995). Fisheries sonar’s have major advantages compared to existing whale detection methods. They are not limited by light, visibility and weather conditions, or dependent on whale vocalization. Fisheries sonar's typically operate at frequencies between 20 and 30 kHz. Higher frequency sonar's are also available operating at frequencies above 100 kHz. Most whales can detect frequencies in the 20-30 kHz range, but only smaller whales like dolphins will detect frequencies above 100 kHz (e.g. Au et al., 2000). The source level of fisheries sonar's does typically not exceed 220 dB re. 1 μPa. Sound pressure levels of 180 dB re. 1 μPa is set as a "do not exceed" criterion for seismic air gun arrays (NMFS, 1995) and has become a generally accepted level also for other sources. This sound pressure level is reached within a few tens of meters range from most fisheries sonar's.

Although whales occasionally have been observed on fisheries sonar's in many different locations, the recordings have not been collected and few experiments have been conducted to assess how well sonar's are suited for marine mammal monitoring.

In this study we have evaluated the Simrad SP90 (20-30 kHz) and SH80 (110-122 kHz) sonar's ability to detect killer whales. Due to its high frequency the SH80 is detected only by a limited number of marine mammals, and is thus attractive. However, the high frequency will limit the detection range and the SP90 sonar might be a better choice although it can be detected by most whales. The study has been divided into three parts:

1. A practical survey to investigate the ability of the SP90 and SH80 to detect killer whales. Particular attention was given to detection ranges and depths, criteria for whale identification, and effects on whale behavior.
2. A practical survey to investigate the ability to detect an artificial whale target under controlled conditions at different water depths and ranges.
3. Modeling of sonar sound transmission: ray tracing, sound propagation and probability of detection based on actual recordings of sound speed profiles and estimated whale echo strength.

Materials and methods

Field experiment 1: Using conventional fisheries sonar’s to detect killer whales

Vessel

FV “Inger Hildur”. A 56 m long, 11 m wide purse seiner (figure 1) is equipped with both the SP90 and the SH80 sonar.

Figure 1. The fishing vessel “Inger Hildur” used during the whale survey

Survey area

This survey took place in the Vestfjord, Ofotfjord, and Tysfjord in Norway (68°-69ºN: 13º-17°E) (figure 2) during one week in late November 2006. The herring stay over winter in this area as part of its annual migratory cycle. Large numbers of killer whales traditionally visit the area to feed on the herring providing a cost-effective opportunity for whale observations. Whale tourism is also popular in the area. Weather conditions varied during the survey from calm winds to storm with periods of rain. Wind speeds during whale observations were 3-7 ms^{-1}. Sea surface temperature was 6-7º C.

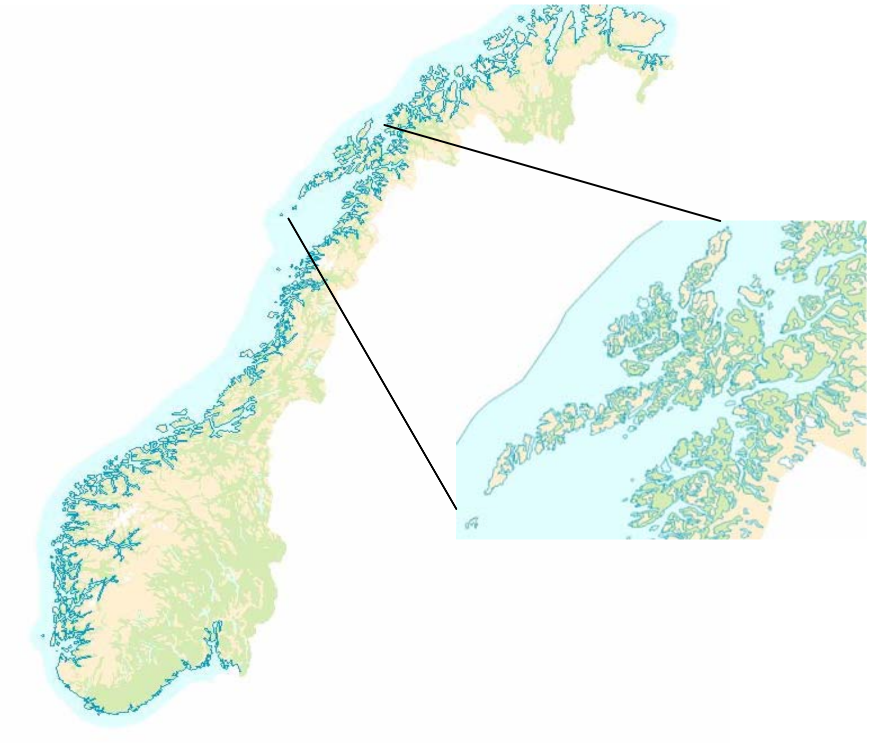


Figure 2. Map of Norway showing the geographical area for the whale survey (Vestfjord, Ofotfjord and Tysfjord).

Sonar sound transmission

Sonar's have two transmit modes: horizontally (omni-directionally) and vertically. In omni-directional mode the acoustic beam is like a horizontal disc with a narrow vertical opening angle of 8-10º depending on frequency. The horizontal transmission is used to detect targets around the vessel, typically fish schools at ranges up to several kilometers. The horizontal beam can be tilted from the surface towards the bottom and thus cover the whole water column. In vertical mode the acoustic beam is shaped like a narrow 180° degrees fan pointing from the surface towards the bottom. This fan can be rotated 360º and targets in the water column and near the bottom will be detected. Figure 3 is an illustration of both horizontal and vertical sound transmission.

Figure 3. Illustration of horizontal and vertical sonar transmission.

The sonar can be set to alternate between horizontal and vertical sound transmission and recordings from both transmissions are displayed on the sonar screen (figure 4).

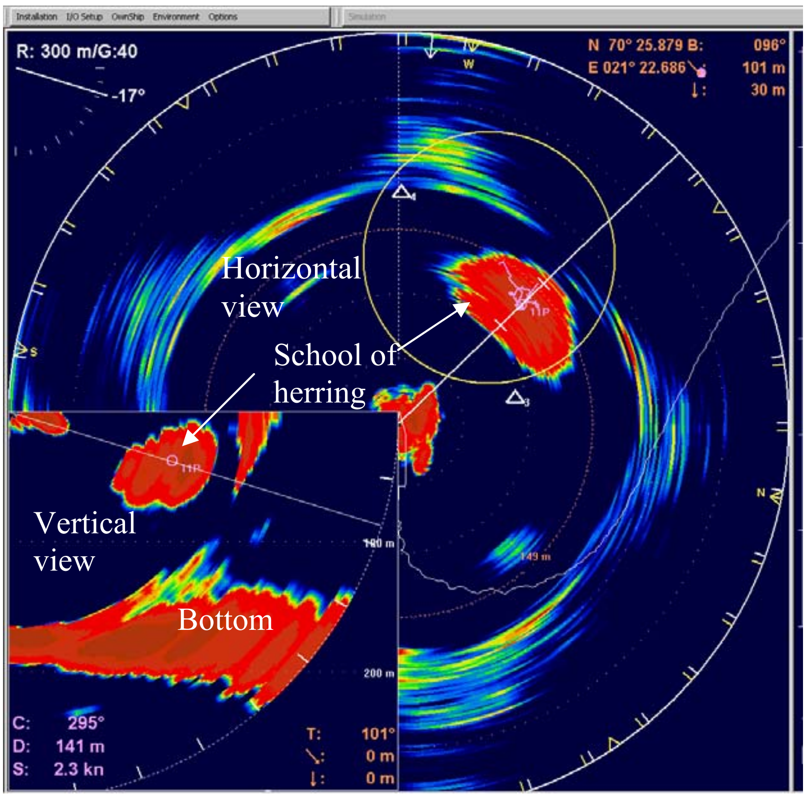


Figure 4. Classical sonar picture showing a school of herring both in the horizontal and vertical view. Range is 300 m and horizontal tilt is -17°.

The sonar's

SP90 and SH80 sonar's operating at 20-30 kHz and 110-120 kHz, respectively. The sonar's were not transmitting simultaneously. There are three source level settings on the SP90: low (206 dB re. 1 μPa), medium (212 dB re. 1 μPa) and high (218 dB re. 1μPa) and one source level on the SH80: medium (211 dB re. 1 μPa). Source levels are RMS values. Pulse form of the SP90 was 16-64 ms (bandwidth 1 kHz, FM) and on the SH80 it was 13-26 ms (5 kHz bandwidth, FM) depending on sonar range. The horizontal beam can be tilted from +10º to -60° on both the SP90 and SH80 sonar. Sonar's were operated throughout the day. The lowest power settings on the sonar's were mostly used. No sonar transmission was started when whales were in the vicinity of the research vessel. The National Marine Fisheries Service (NMFS) set an underwater "do not exceed" criterion for use of a seismic air gun array of 180 dB re. 1 μPa (sound pressure level) for marine mammals (NMFS, 1995) to guard against injury. In table 1 the 180 dB sound pressure level range is calculated for the 3 different power settings of the SP90 and the one power setting of the SH80 sonar based on simple geometrical spreading (20 log r +2αr, r=range, α=absorption coefficient).

	Low	Medium	High
SP90	20	40	80
SH80		35	

Table 1. Ranges in meters were 180 dB re 1 μPa sound pressure level is reached for the SP90 and SH80 sonar's at the different source level settings.

Observation procedure

FV "Inger Hildur" was searching randomly in the survey area during the day with a speed of 6-8 knots. Sonar recordings were only collected during daylight hours, when visual observations of whales were possible, giving an effective operation period of 6 hours day^{-1}. When encountering whales, the vessel slowed down or stopped. Data were collected throughout the observation period either as screen dumps or as raw data recordings. Only recordings verified by visual observations are used for analysis and reporting.

To establish sound speed profiles, CTD profiles were collected several times ever day using a SAIV SD204 sensor (www.saivas.no).

Field experiment 2. Estimating detection efficiency and ranges using an artificial whale target

Vessel

RV Simrad Echo (figure 5) equipped with the SP90 and SH80 sonar's. Length and with of vessel is 20 and 7 m, respectively.

Figure 5. Research vessel "Simrad Echo" used during the artificial whale target survey.

Survey area

The experiment took place in the Oslo fjord in January 2007. Water depth in the survey area is about 250 m.

Procedure

A triplane sonar target reflector (figure 6) was suspended at 10 m water depth. The intention was to use 5 different water depths from 10 to 200 m. However, due to cold surface water a strong sound channel with a lower boundary at about 20 m had developed making tests at deeper water impossible. Target strength of the sonar reflector is -5 dB re 1 µPa at 110 kHz and -15 dB re 1 µPa. RV "Simrad Echo" was approaching the sonar reflector with a speed of 5 knots starting at 2 km distance. Sonar screen dumps and raw data were continuously collected. CTD profiles were collected at three locations (ranges 0, 500 and 1500 m from the sonar reflector).

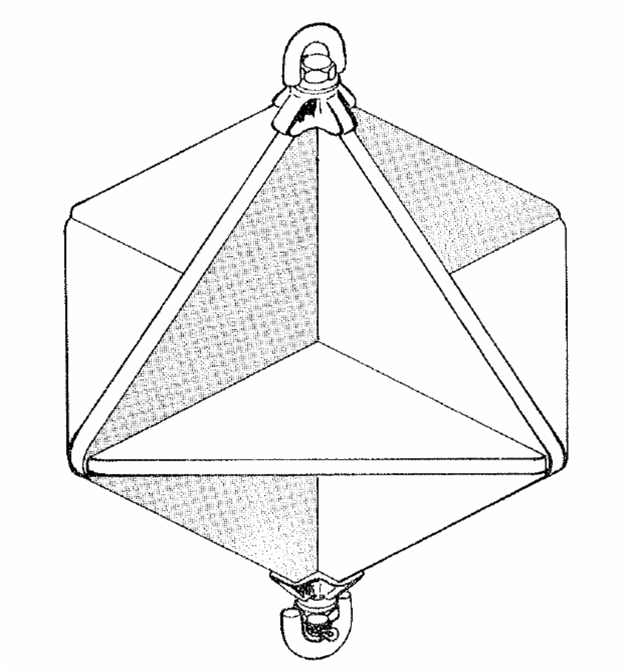


Figure 6. Triplane target reflector (50x50 cm). Echo strength at 25 and 110 kHz is – 15 and -5 dB re. 1 uPa, respectively.

Theoretical assessment. Modeling of sound transmission.

The CTD profiles collected in field experiment 1 and 2 were used to model ray traces, sound propagation (transmission loss), and probability of detection under the actual experiments using the Lybin software program developed by the Norwegian Navy and the Norwegian Defense Research Establishment. Wind speed in all simulations is set to 4 ms^{-1} as this was considered an average wind speed during the surveys.

Experiment 2 could not be completed as planned due to the strong surface channel. As a substitute, we used actual CTD profiles from the Institute of Marine Research database (Tindor) collected in an area off the west coast of Norway (59°-60ºN: 5º-6°E) in
i) winter/spring, ii)spring/summer and iii) fall/winter 2006 to simulate sound propagation and detection probability of a -5 dB re 1 µPa target on the SP90 sonar.

Results and discussion

Field experiment 1: Using conventional fisheries sonar's to detect killer whales including sound transmission modeling.

Killer whales were encountered every day. They were either found as groups of animals staying in one area or swimming at high speed (3-8 knots) from one location to another. Figure 7 is a typical recording from the SP90 sonar. The position of the ship is in the centre. Behind the vessel, echoes from the ship wakes are seen. Several whales are detected between 2-700 m and one whale is detected at approximately 1000 m. Whales were visually observed in the surface at the same location as they appear on the sonar screen. However, fewer whales were typically observed in the surface than on the sonar. This is reasonable since the surfacing of the whales is not synchronous.

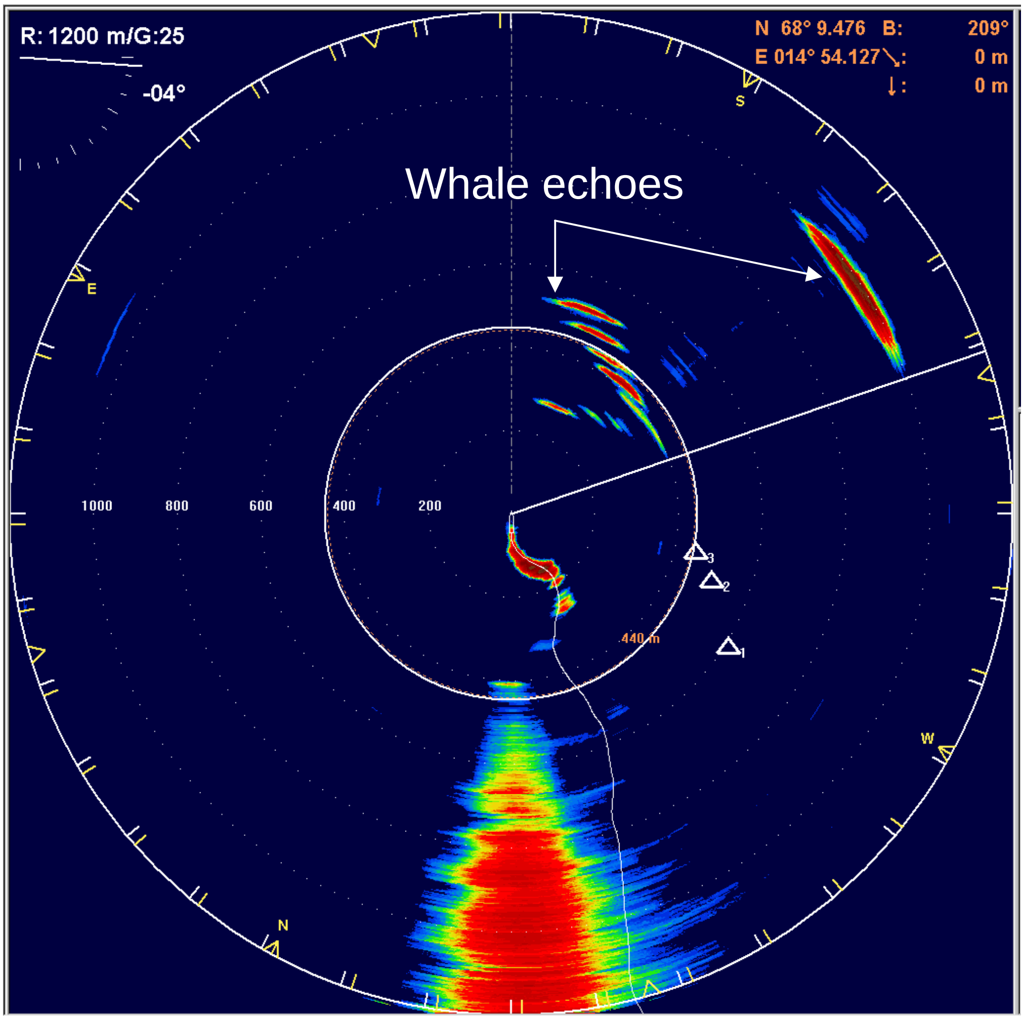


Figure 7. Sonar picture from SP90 showing a group of 7 killer whales between 200-600 m. One whale is detected at 1000 m range. Only two whales were visually observed in the surface. Total range is 1200 m and vertical tilt is-4°.

Figure 8 is a recording from the SH80 during the same time period showing echoes from a few whales between 2-300 m and one animal between 4-500 m. Both the SP90 and the SH80 detected whales equally well at the relatively short ranges in these examples.

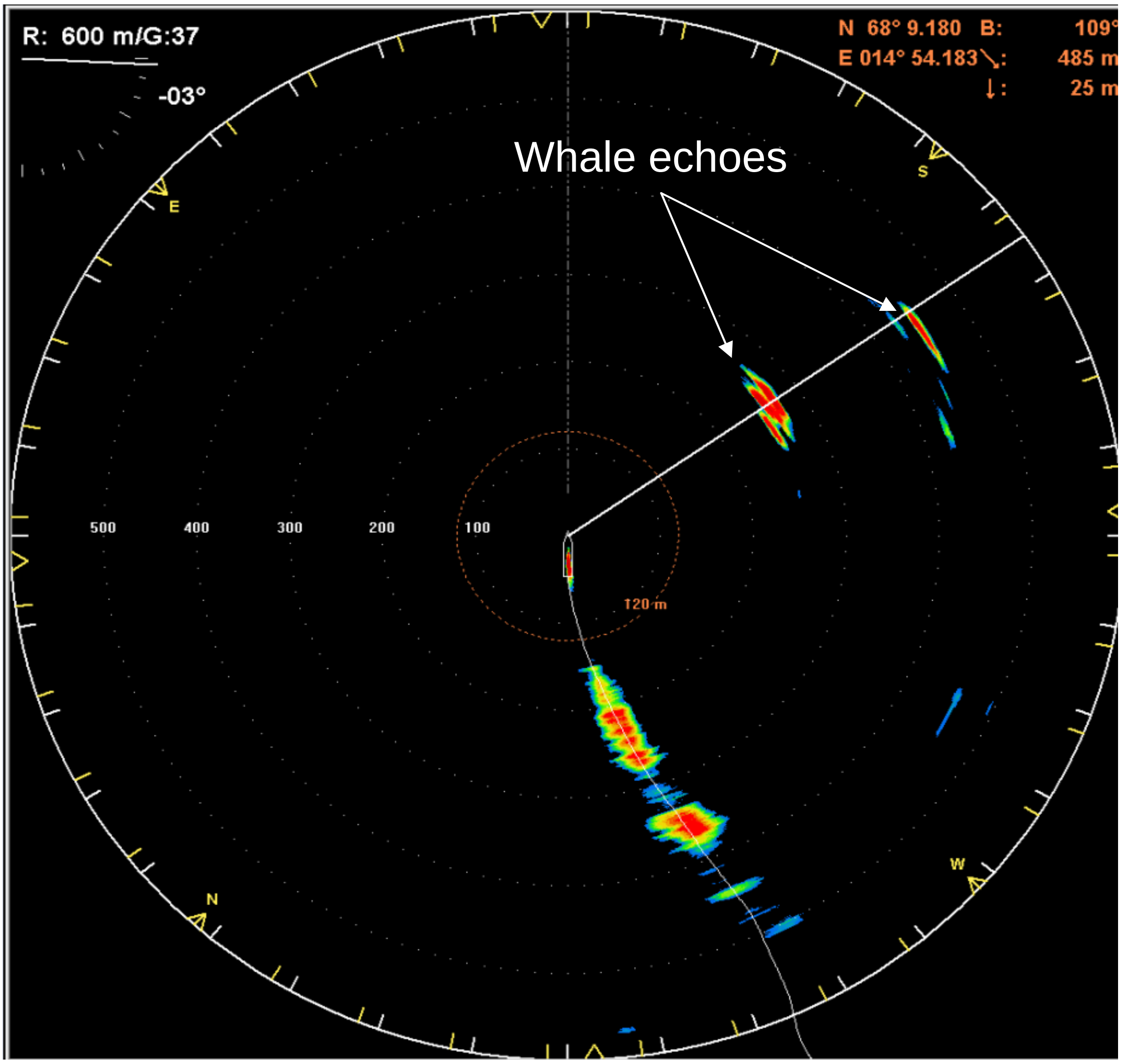


Figure 8. Sonar picture from SH80 showing echoes from several whales. Range is 600 m and vertical tilt is -3º.

A direct comparison of the detection performance between the two sonar's was difficult since sound transmission was not synchronized. However, in Figure 9 the same whale is detected on both sonar's almost at the same time. On the SP90 sonar the whale is detected at 200 m (fig. 9 a) and at 250 m on the SH80 sonar (fig 9 b). The vertical view of both sonar's shows that the whale is in the surface. Tilt angle is -8° on the SP90 and -6° on the SH80. The echo of the whale is strongest at the SP90 sonar, but detection is good at both sonar's at these short ranges. At longer ranges (>500 m), the SP90 sonar was superior to the SH80. One reason is the much higher sound absorption at the SH80 operating frequency (~37 dB km^{-1}) compared to the SP90 (~5 dB km^{-1}). Maximum detection range on the SP90 sonar was 1500 m, but this will depend on many factors were the sound speed profile and background noise are the most important.

(a) (b)

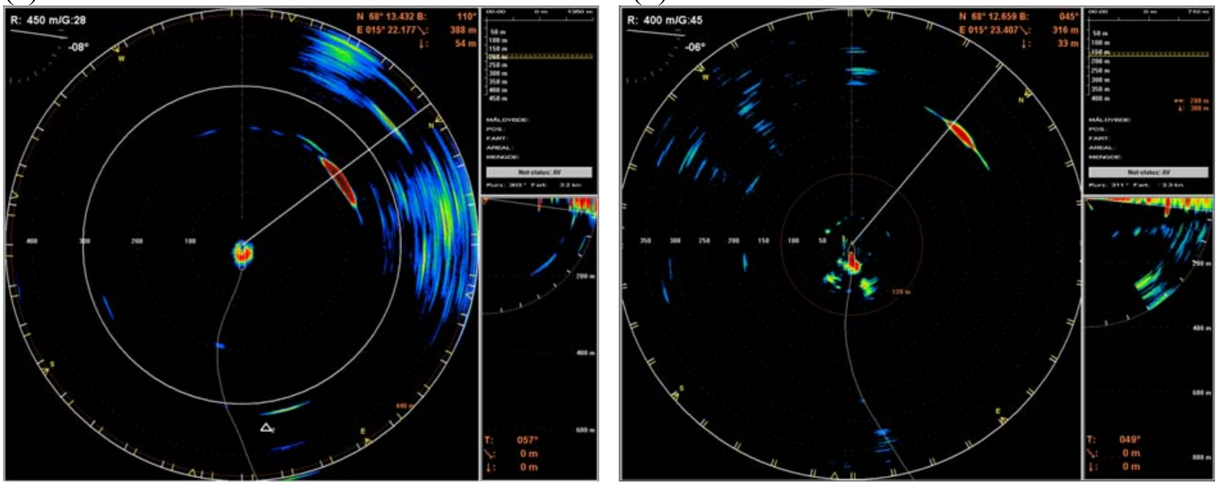


Figure 9. Echo from the same whale is detected on both sonar's almost at the same time. SP90 (a) and SH80 (b). Range on the SP90 sonar is 450 m and on the SH80 it is 400 m. The lower right display in both (a) and (b) is the vertical view.

No apparent reaction to sonar transmissions or the vessel was observed. When encountering a group of whales, we typically slowed down or stopped the vessel. The whales were swimming calmly around and dives were occasionally observed. Within a group it was easy to distinguish between males, females and calves. The group typically stayed in the same area for a long while and was most likely feeding on herring. Once, after a group of whales have been observed at close range for some time, the animals left the area. Whether this has anything to do with our presence, is not known. On a few occasions transmitting power on the SP90 was increased from low to medium to high. This had no observable effect on the whales. The survey area is a fishing ground for many vessels using the sonar to locate herring schools. Whales in this area should therefore be well habituated to active sonar's. It is expected that whales being naive to sonar transmissions would show behavioral reactions (see Richardson et al., 1985).

Positive whale identification can be difficult based on the echo from a target alone. In addition to the direct echo from the whale, weaker echoes were frequently picked up from the wake of the whale during swimming and surfacing, producing a pattern of repeated echoes (figure 10). It is likely that both air release from whales and air mixed into the water during surfacing are sources of the observed echoes. The surface interval in this example is about 25

m. It is reason to believe that the surface interval will depend on both whale swimming speed and species and could be used for recognition of both species and behavioral state. The SP90 and SH80 sonar's have target tracking functions for estimation of swimming speed and bearing.

During many of the observations, whale vocalization could be heard on the sonar sound channel (unfortunately, the sonar has no option to record sound). It was easy to discriminate between whistles (long tones) and clicks, the two fundamental social sounds in odontocetes (Popper, 1980) and killer whales specifically (Thomsen et al., 2001). The vocalization was also picked up on the sonar screen. In figure 10 the vocalization, as clicks, can be seen at longer ranges than the whale echo. The echo strength of the vocalization apparently increases in strength with range. This is due to the range (time) dependent amplification of detected signals built into all sonar's to compensate for sound spreading (geometrical and cylindrical).

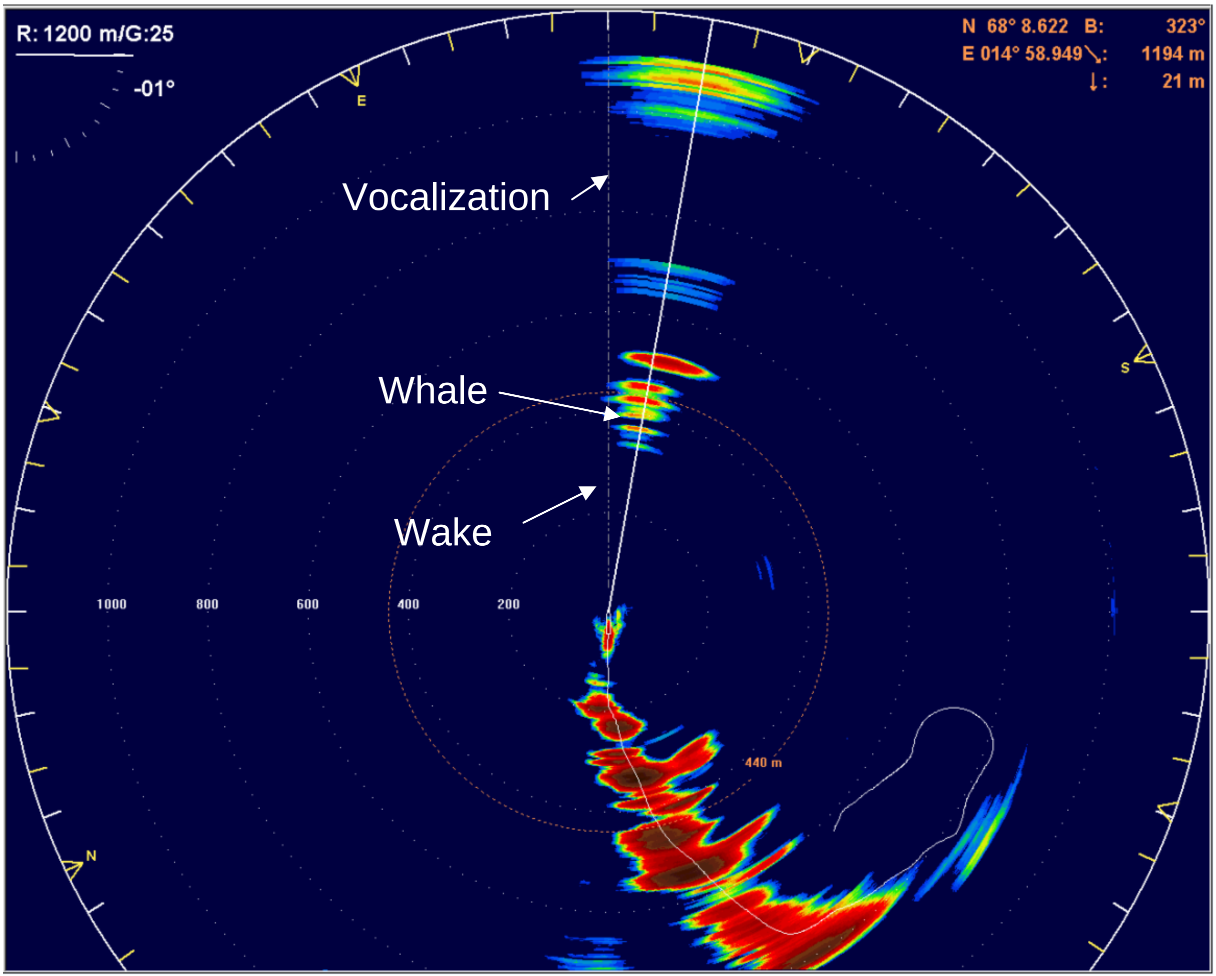


Figure 10. Sonar picture from SP90 showing one whale echo and wake echoes produced when during surfacing. In addition, killer whale vocalization, as clicks, can be seen on the screen. Range is 1200 m and vertical tilt is -1°.

Vocalization, as both clicks and whistles, was also picked up on the SH80 sonar (figure 11).

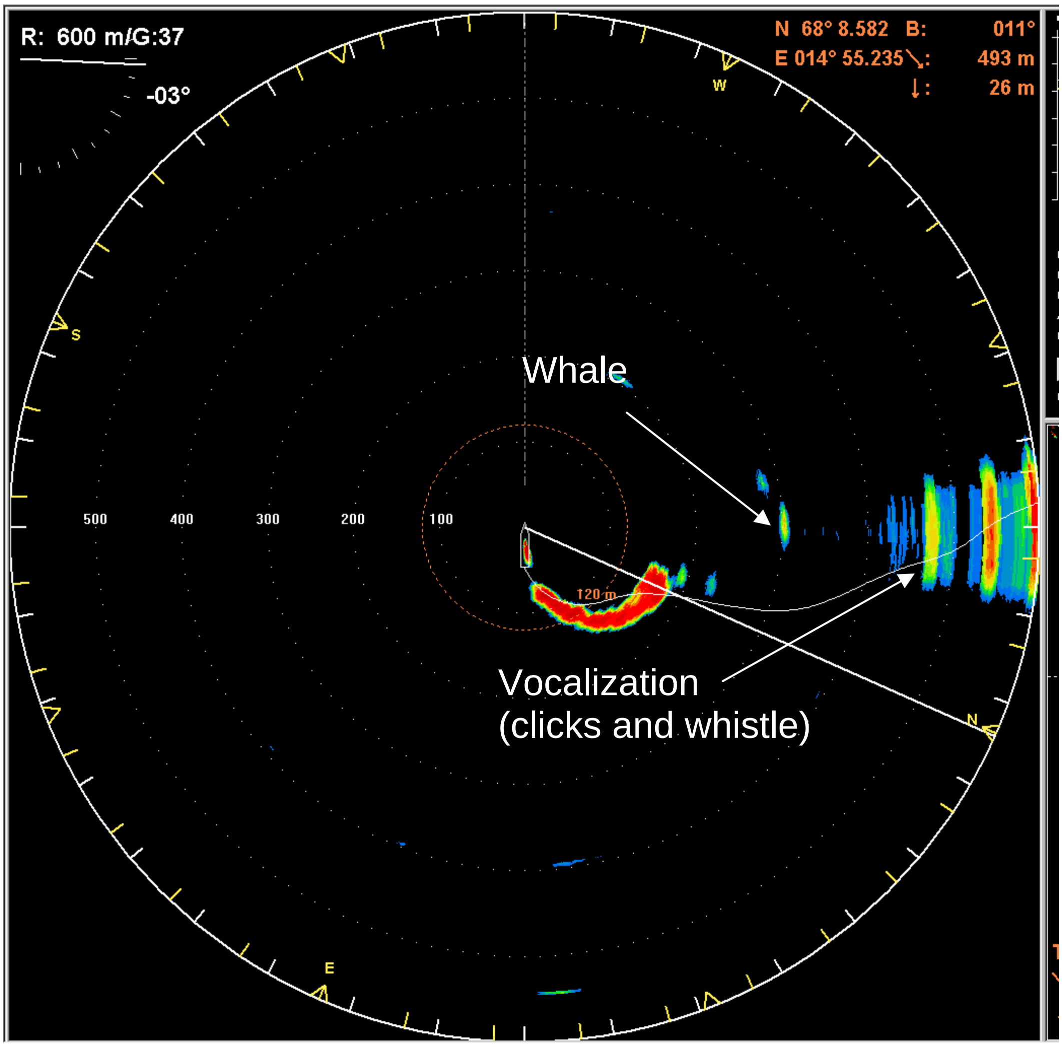


Figure 11. Sonar picture from SH80 showing a whale echo and vocalization as both clicks and whistles. Range is 600 m and vertical tilt is -3°.

Figure 12 is from the SP90 sonar showing many whales around the vessel at ranges up to 700 m. Figure 12 (a) shows detection of vocalization, as clicks. Figure 12 (b) is again the same group of whales, and in this example the vocalization is a continuous whistle. The dominant frequency of killer whale vocalization has been reported to be 8.3 kHz with a frequency bandwidth of 4.5 kHz (Thomson et al., 2001), but is also know to be within the SP90 sonar operating frequency range (>20 kHz) (Diercks et al., 1971). The pick up on the sonar's should therefore be both the fundamental vocalization frequencies and the harmonics. In any case, detection of vocalization is a strong criterion for whale identification in addition to the direct echo and the wakes from surfacing animals. During our survey, killer whales were the only species encountered, but it is reasonable to believe that the detected vocalization pattern can be used to discriminate between different species of whales and behavioral states. Baleen whales produce only low frequencies of sound, typically below 1 kHz, that can not be picked up on our sonar’s and used for identification and classification (see Richardson et al., 1995; Au et al., 2000).

(a) (b)

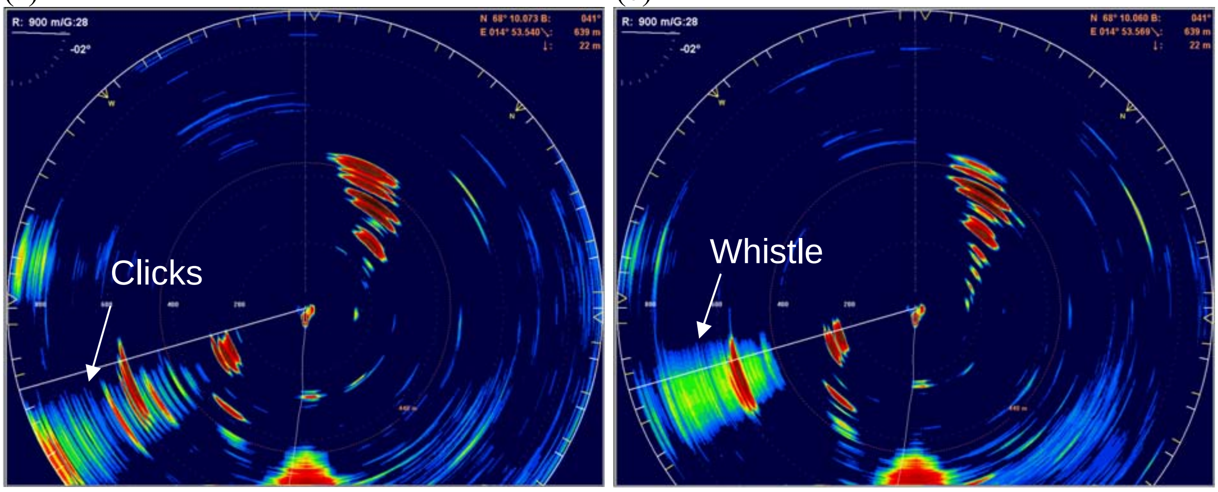


Figure 12. Sonar picture from the SP90 showing a group of whales and vocalization as both clicks (a) and whistle (b). Range is 900 m.

Several sonar observations were made of whales during dives. Whether increased pressure reduces whale detect ability due to lung collapse is not known. In fish, the swim bladder is responsible for more than 95% of the reflected acoustic energy (Foote, 1980). Some fish are incapable of filling the swim bladder when submerged and the echo strength of these fish decreases with depth according to Boyles law (Alexander, 1966). The same will apply to the lungs of the whale. In figure 13 the SP90 sonar is tilted -14 degrees and shows a clear echo in the horizontal view in front of the vessel at about 300 m range. In the vertical view the same echo is seen at around 100 m water depth. A similar recording is shown in figure 14 for the SH80. Objects are detected around the vessel in the horizontal view. In the vertical view one object is detected near 200 m water depth. It is likely to assume that these objects are whales since whales doing dives were observed in the surface in the same time period. It is not possible from our observations to say that the echo strength of the whales is reduced with water depth. Even at water depths of 200 m, the whales are easily detected on both sonar’s. Although we made no observations, there is good reason to believe that whales will be detected at deeper water than 200 m, and at long horizontal distances from the vessel during dives.

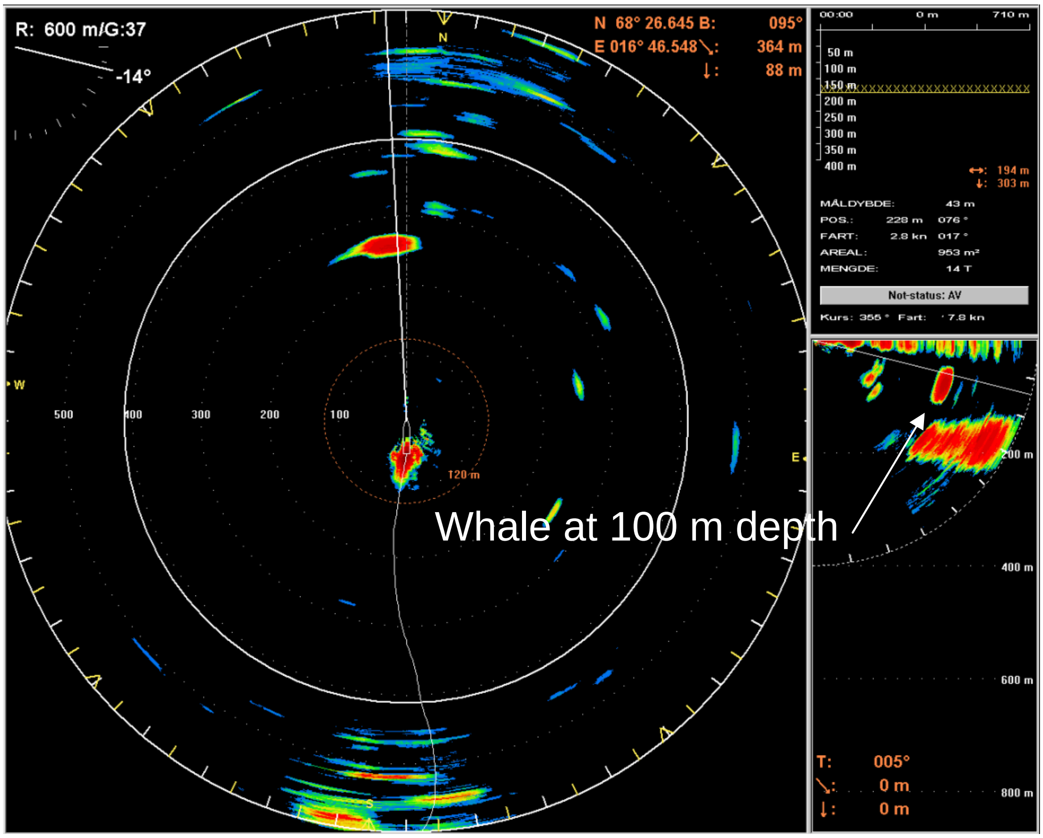


Figure 13. Sonar picture from SP90. In the horizontal view the whale is detected in front of the vessel at about 300 m. In the vertical view the whale echo is seen at about 100 m. Range is 600 m.

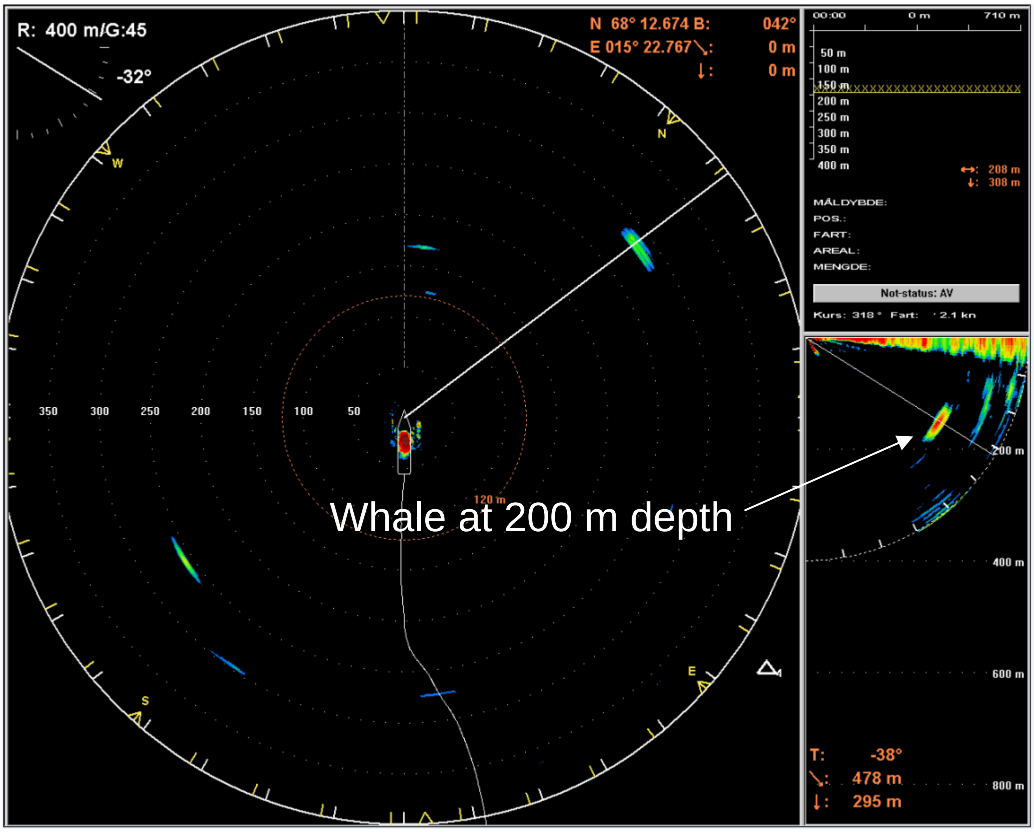


Figure 14. Sonar picture from SH80. In the horizontal view whales are detected around the vessel. In the vertical view one whale echo is seen close to 200 m. Range is 400 m.

The echo strength of the whales was difficult to quantify from the sonar recordings during this field experiment. Tracking of whales on the SH80 sonar confirmed that the echo strength is higher than -10 dB re. 1 μPa. On the SP90, the echo from a whale was always stronger than on the SH80, and a reasonable assumption is that the echo strength is higher than -5 dB re. 1 μPa. However, large variation in measured echo strength from a whale is expected due to on the size of the animal, lung filling and orientation (aspect) relative to the sonar. Target strength of dolphins varies with 21 dB between side and tail aspect and maximum target strength was -11 dB re. 1 μPa and dependent of frequency (Au, 1996). Love (1973) reported target strength of humpback whales of +7 dB re. 1 μPa near side aspect and -4 dB re. 1 μPa near head aspect at 20 kHz. Killer whale size is between the dolphin and the humpback whale and a reasonable assumption is that this apply also to target strength. This is in agreement with our results. However, actual measurement of echo strength of whales depending on size, orientation and depth are sparse and is needed to establish a reliable methodology for whale detection and classification based on active acoustics.

It is likely that echoes from strong non-whale targets like large swim bladder fish can be confused with the echoes from whales. In some instances were no whales were visually observed, strong echoes were seen on the sonar screen, but without vocalization and the characteristic surfacing pattern from swimming whales (figure 15). Fishermen suggested that these detections could be echoes from big cod and saithe as large individuals of these species are frequently caught in the survey area.

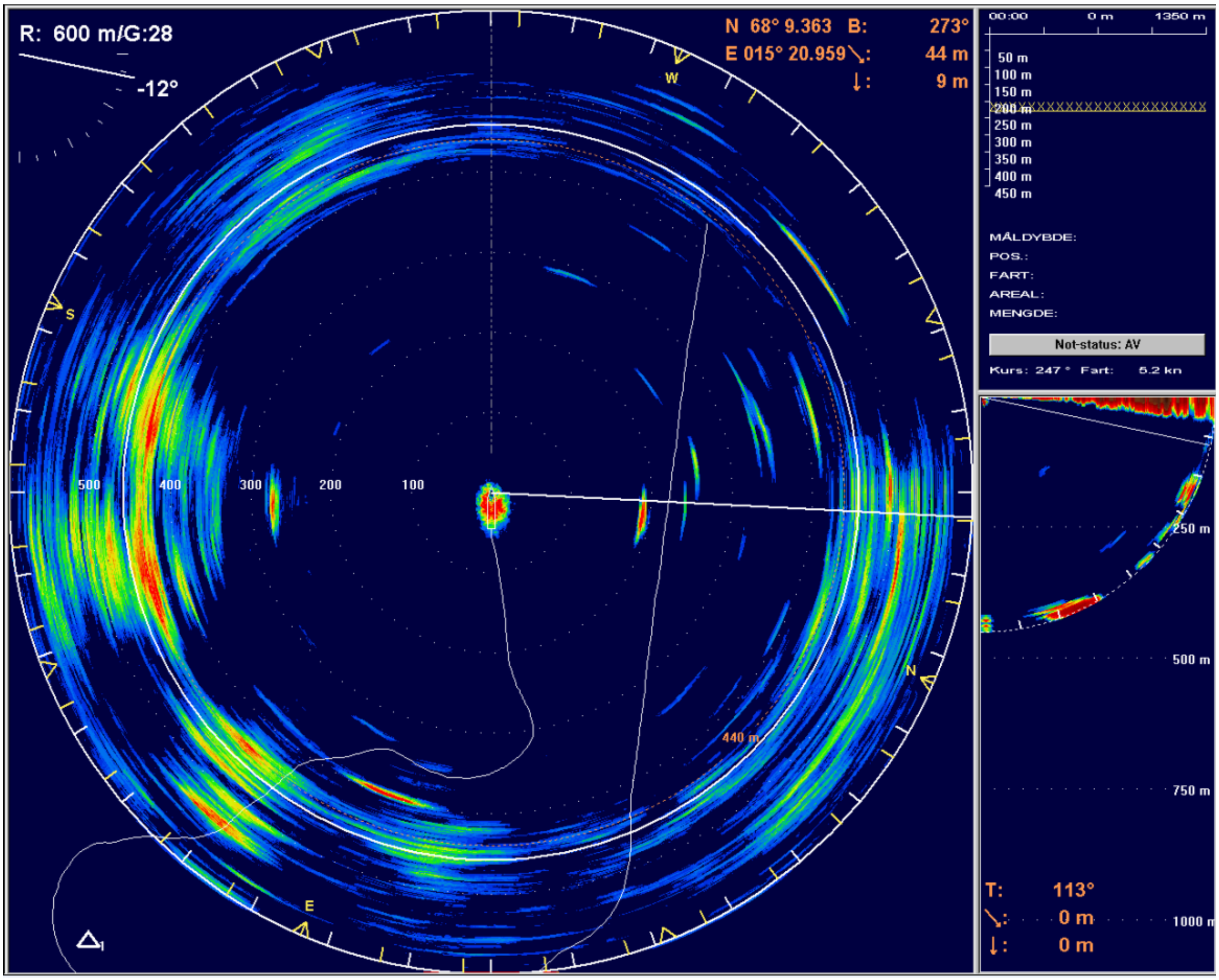


Figure 15. Sonar picture from SP90 showing objects detected without vocalizing or wakes. The objects can be big cod or saithe.

From the CTD measurements in the survey area, Lybin was used to simulate ray tracing, sound propagation and detection probability. The sound speed profile is shown in figure 16 (a) together with the ray-tracing. The surface water is cold, with gradually increasing temperature apart from distinct warmer layer around 100 m. Figure 16 (b) is a comparison of sound propagation between the SP90 and SH80 sonar. Detection probability for both sonar's is simulated in figure 16 (c). Echo strength of the target is set to – 5 dB re. 1 μPa. The color scale is detection probability in percent showing that a killer whale close to the surface should be detected with more or less equal probability to about 400 m, but at longer ranges the detection probability is higher on the SP90 sonar. Detecting whales at deeper water is obtained by tilting the sonar. Figure 17 is an example where the sonar is tilted to -20 degrees. Figure 17 (a) is the ray-tracing. Figure 17 (b) is the sound propagation for the SP90 and the SH80. In figure 17 (c) detection probability is shown for the two sonar's. Again, detection probability is not too different for the two sonar's to about 400 m, but at longer ranges the SP90 is superior. This is in agreement with the actual sonar observations.

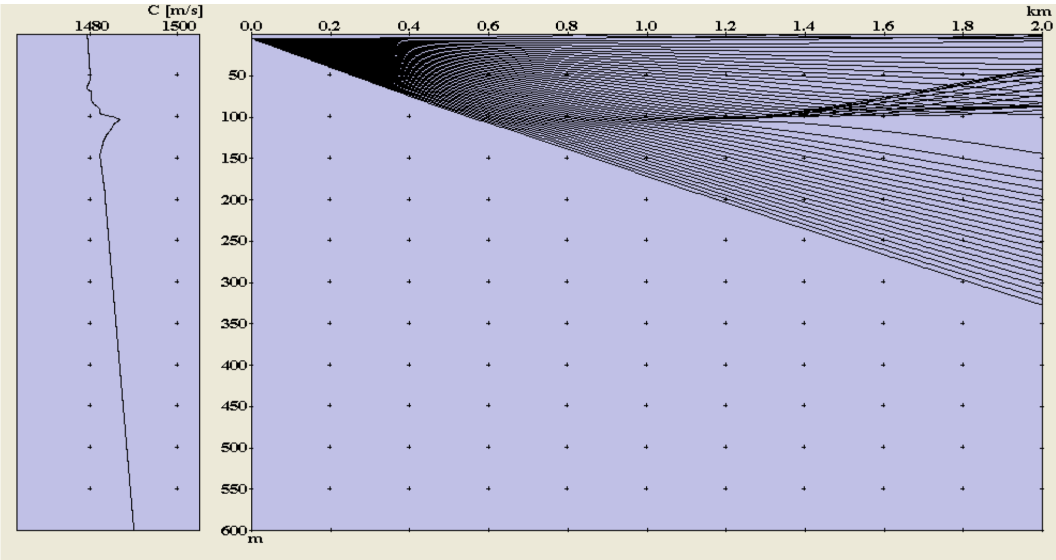


Figure 16 (a) Sound speed profile and ray trace simulation based on CTD measurements collected during the whale survey. Sonar horizontal tilt is -5 degrees. Water depth is 600 m and horizontal range is 2 km.

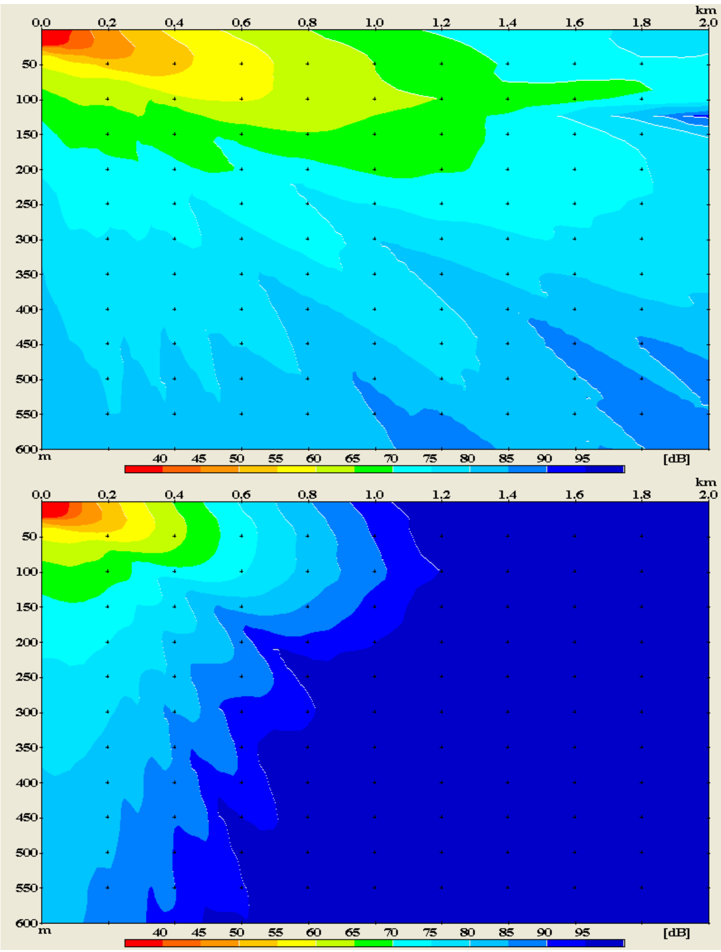


Figure 16 (b) Simulation of SP90 (upper) and SH80 (lower) sound propagation. Colors are transmission loss in dB according to color scale.

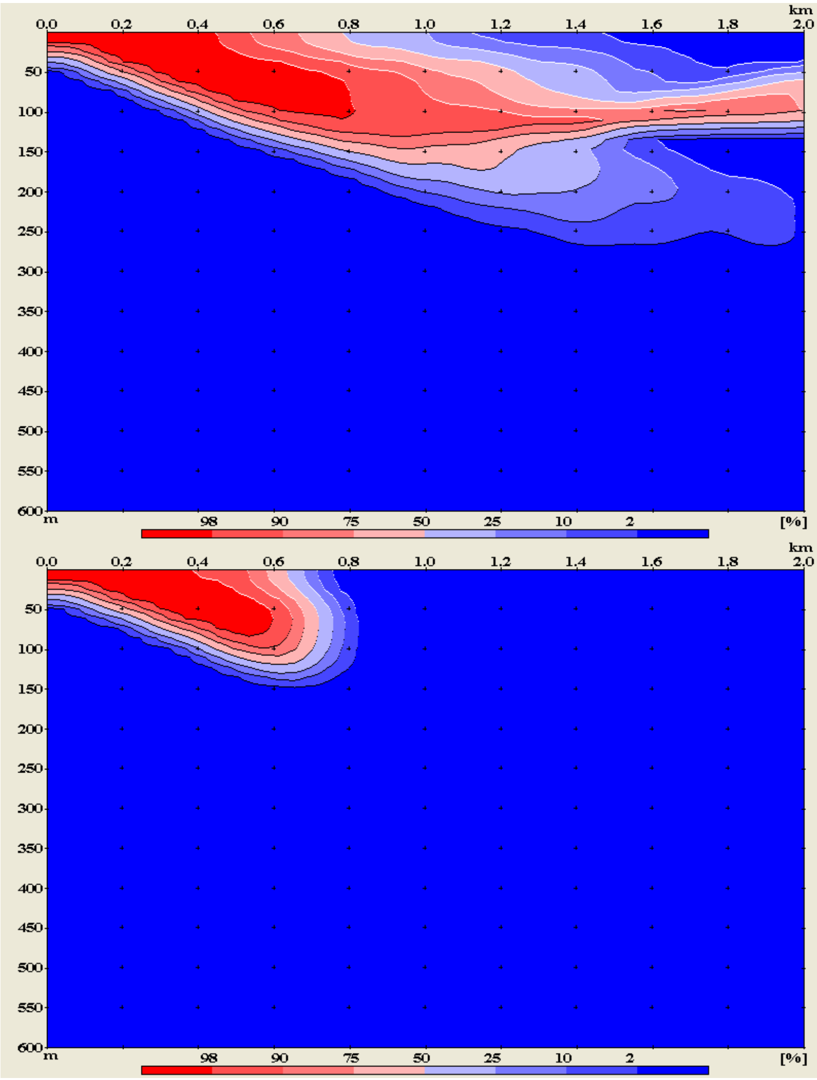
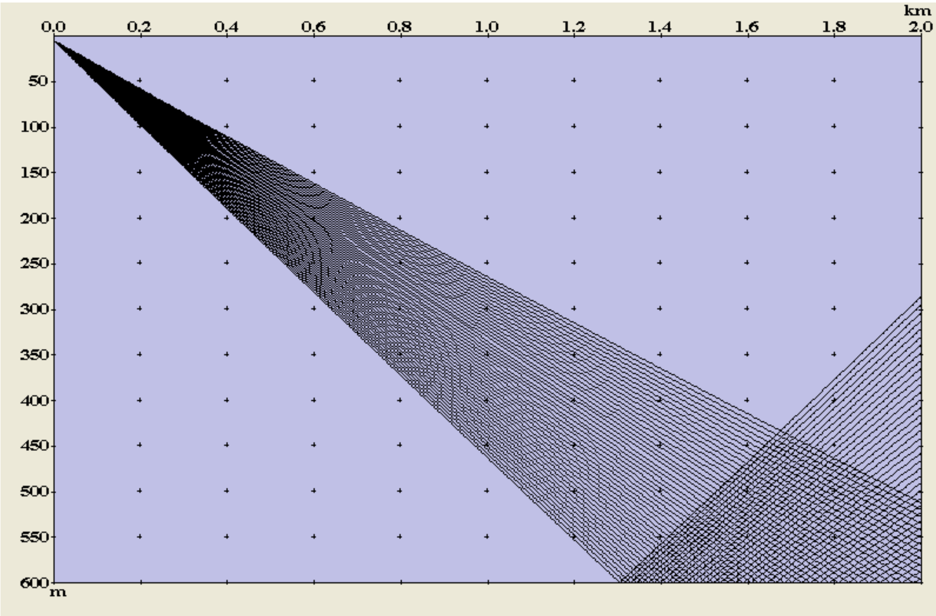


Figure 16 (c) Detection probability of a – 5 dB target at different ranges for the SP90 (upper) and SH80 (lower) sonar. Colors are % detection probability according to color scale.



17 (a). Simulation of ray tracing when sonar's are tilted -20 degrees.

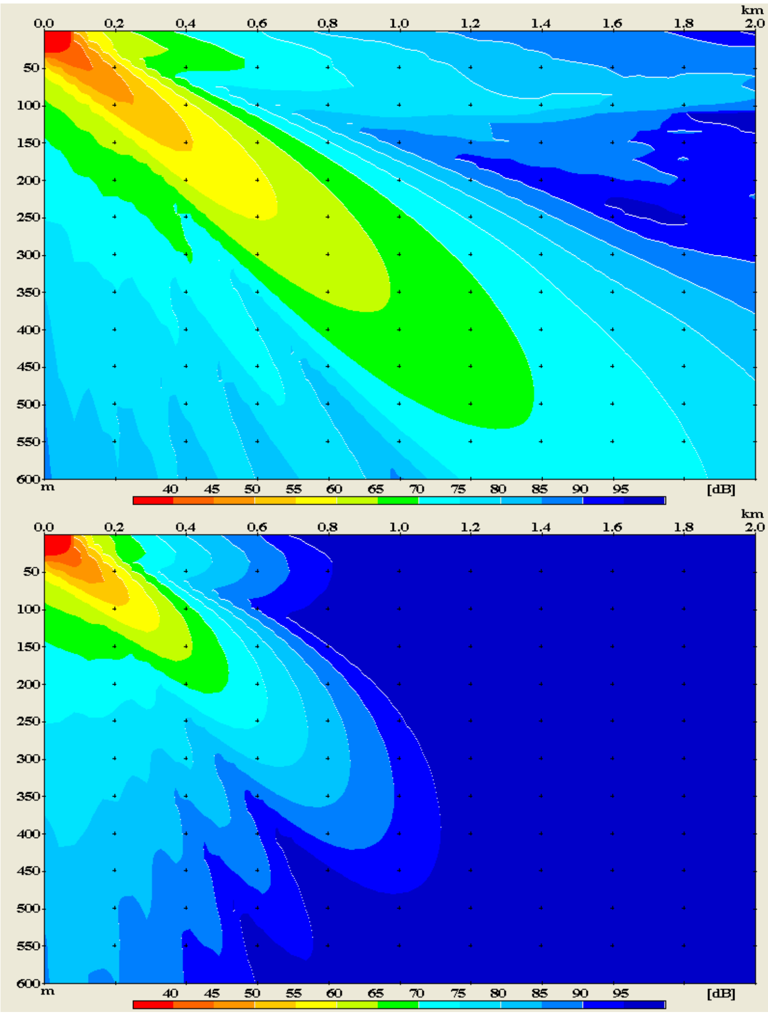


Figure 17 (b) Simulation of SP90 (upper) and SH80 (lower) sound propagation.

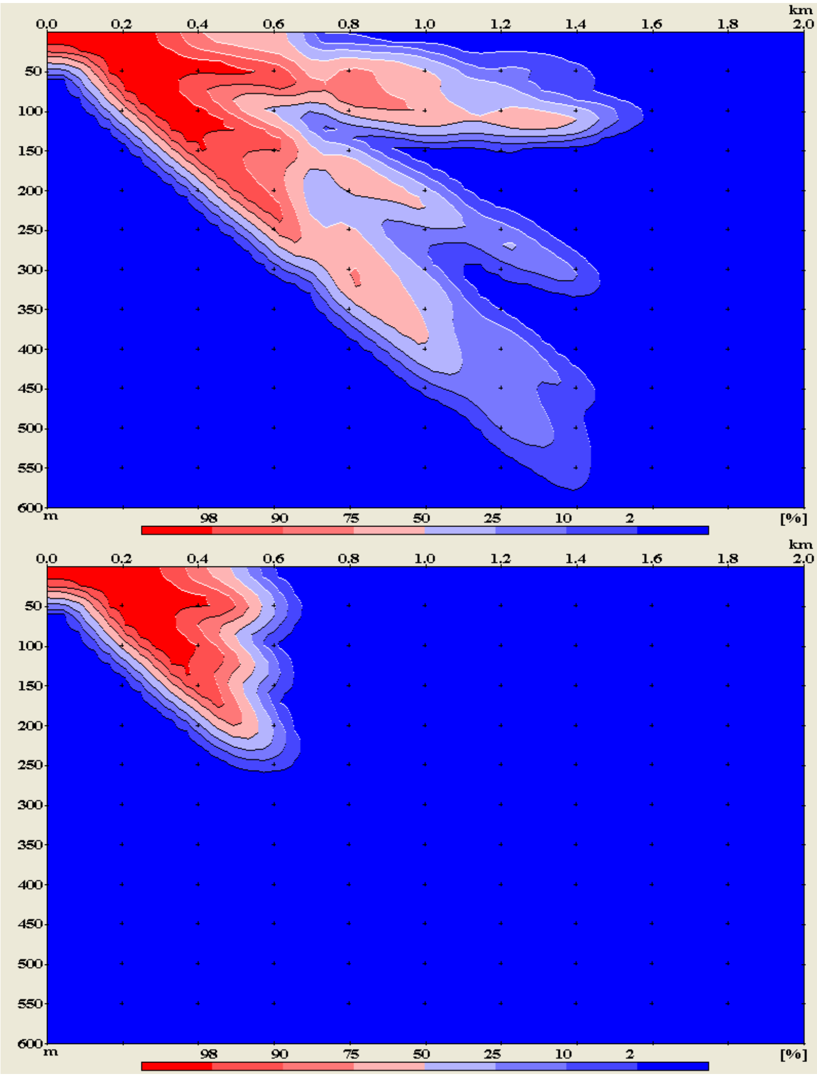


Figure 17 (c) Detection probability of a – 5 dB target at different ranges for the SP90 (upper) and SH80 (lower) sonar.

Field experiment 2. Estimating detection efficiency and ranges using an artificial whale target including sound transmission modeling.

Figure 18 (a) is the sound speed profile and the ray-tracing based on the measured CTD in the Oslo fjord in January 2007. Typical winter conditions are encountered with cold surface water producing a strong sound channel with a lower boundary at about 20 m water depth. Sound was entrapped in this channel and sound spreading was likely cylindrically rather than spherically, giving long detection ranges for the triplane sonar reflector. Maximum detection range was near 2000 m for the SP90 sonar. The SH80 was not used in at this stage, but we want to repeat this experiment under different sound speed profile conditions and include the SH80 sonar. Sound propagation and detection probability for a -15 dB re. 1 µPa target is given in figures 18 (b) and (c), respectively. Actual detection range seems longer that obtained from the simulation.

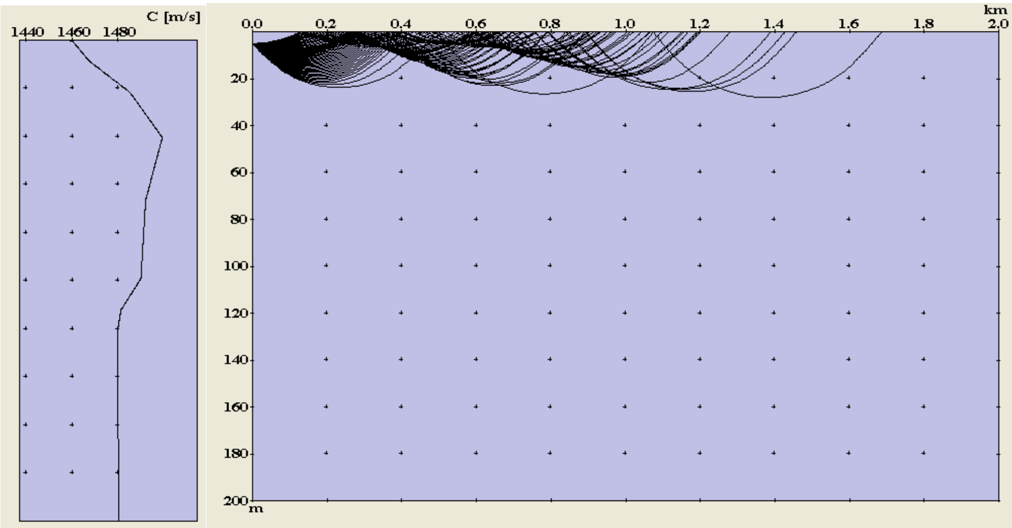


Figure 18 (a) Sound speed profile and ray trace simulation based on the CTDs collected during the survey.

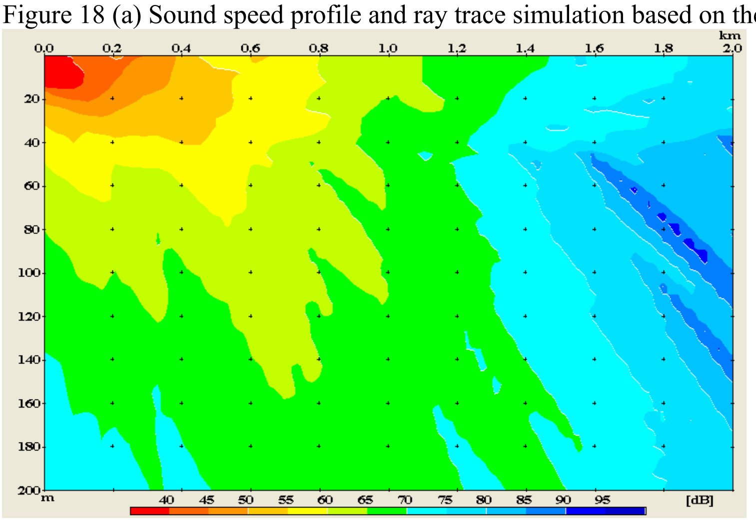


Figure 18 (b) Simulation of SP90 sound propagation loss. Colors are transmission loss in dB according to color scale.

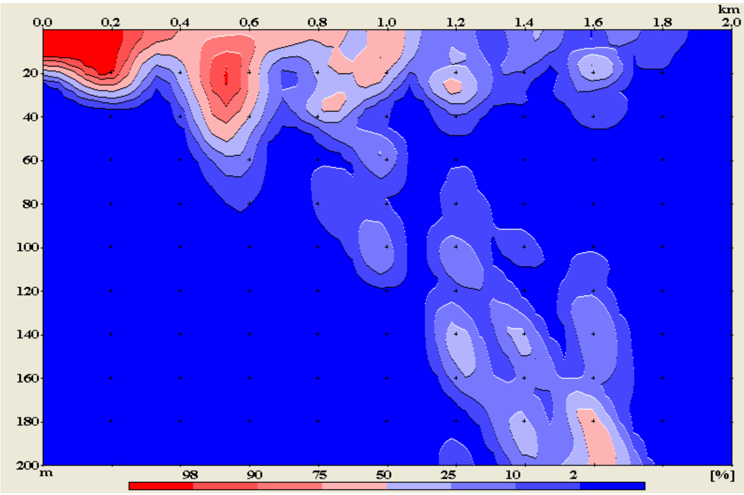


Figure 18 (c) Detection probability of a -15 dB target. Colors are % detection probability according to color scale.

Ray-tracing and detection probability for the SP90 sonar were simulated based on CTDs collected during winter/spring, spring/summer and fall/winter in an area relevant for seismic explorations outside the west coast of Norway. Water depth in the area is ~100m. The winter/spring sound speed profile show a gradual increase in water temperature with depth causing upward deflection of the sound beam. Sound propagation loss and probability of detection is shown in figure 19. Detection probability is high (>90%) at ranges up to 400 m for a -5 dB re. 1 μPa target but is reduced to 50% at about 800 m (figure 19 c). In spring/summer the sound speed profile is more even throughout the water column improving probability of detection at longer ranges and deeper water (figure 20). In the fall, the sound speed is even more stable with increasing water depth (figure 21) further improving probability of detection. Water column coverage in all above examples is good and can be improved by proper adjustment of the sonar tilt angle. Seen from the simulations, blind zones are present, but they are reduced when a ship is sailing. It is recommended that CTD profiles for the actual area are available during a seismic survey and that simulations of sound propagation and detection probability are performed as input to sonar settings and improved understanding of sonar recordings. Factors causing large variation in simulated detection probability are surface conditions (wind speed) and bottom. E.g. in the fall/winter example, at wind speed 0 ms^{-1} detection probability near surface with -2° tilt is >98% up to 1.4 km range, while at wind speed 4 ms^{-1}, >98% detection probability is dramatically reduced (<200 m).

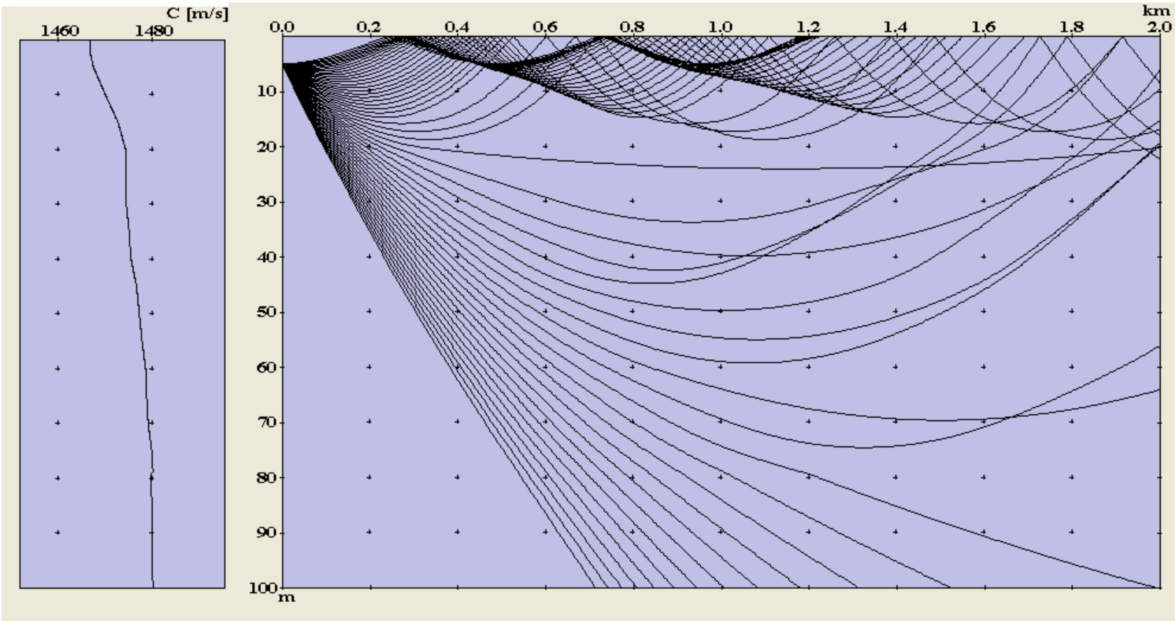


Figure 19 (a). Sound speed profile and ray trace simulation based on CTDs collected during winter/spring. Sonar tilt is -5 degrees.

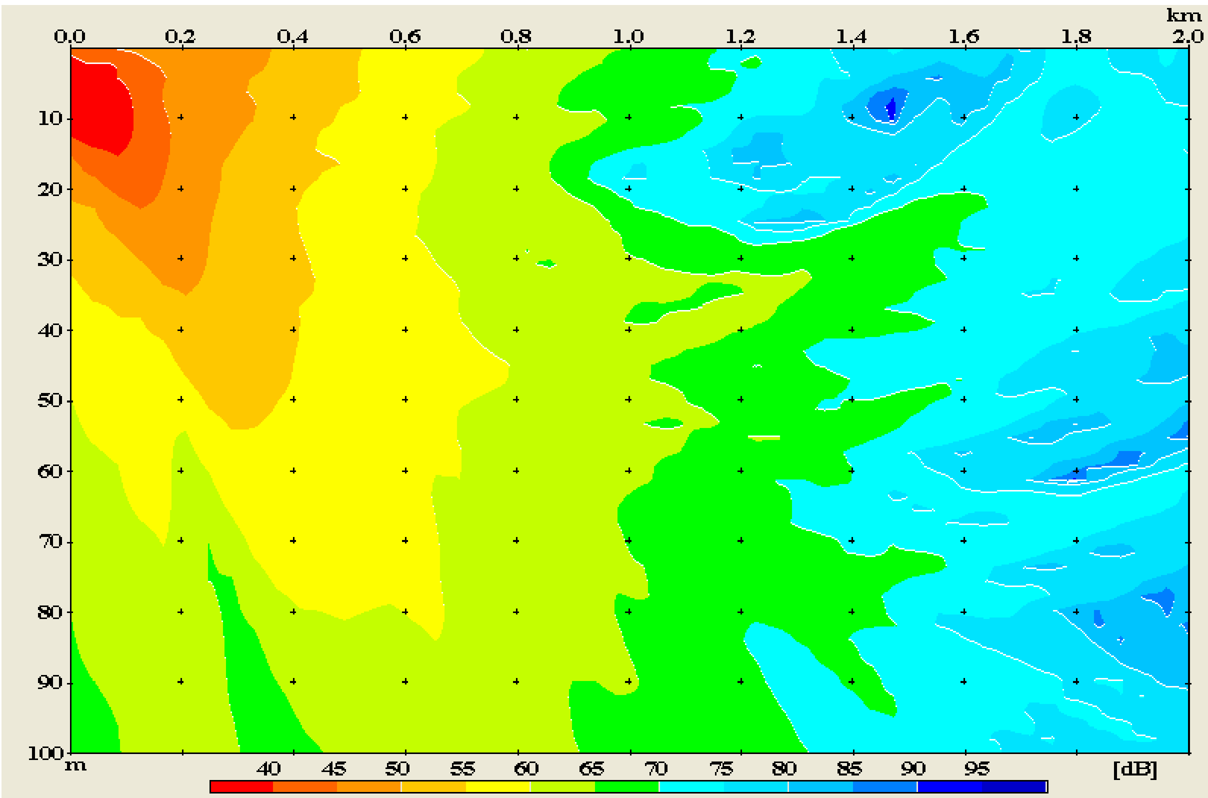


Figure 19 (b) Sound propagation simulation winter/spring for the SP90 sonar.

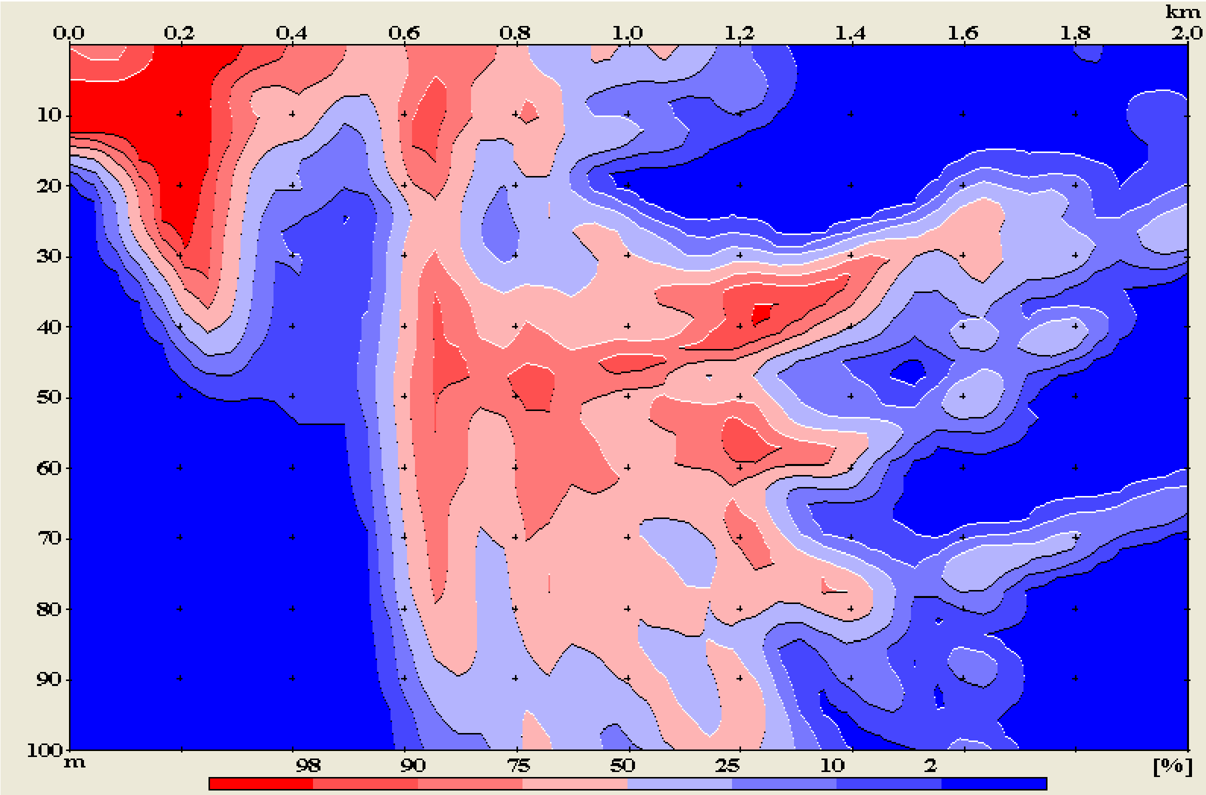


Figure 19 (c) Detection probability of a -5 dB target at different ranges and water depths winter/spring for the SP90 sonar.

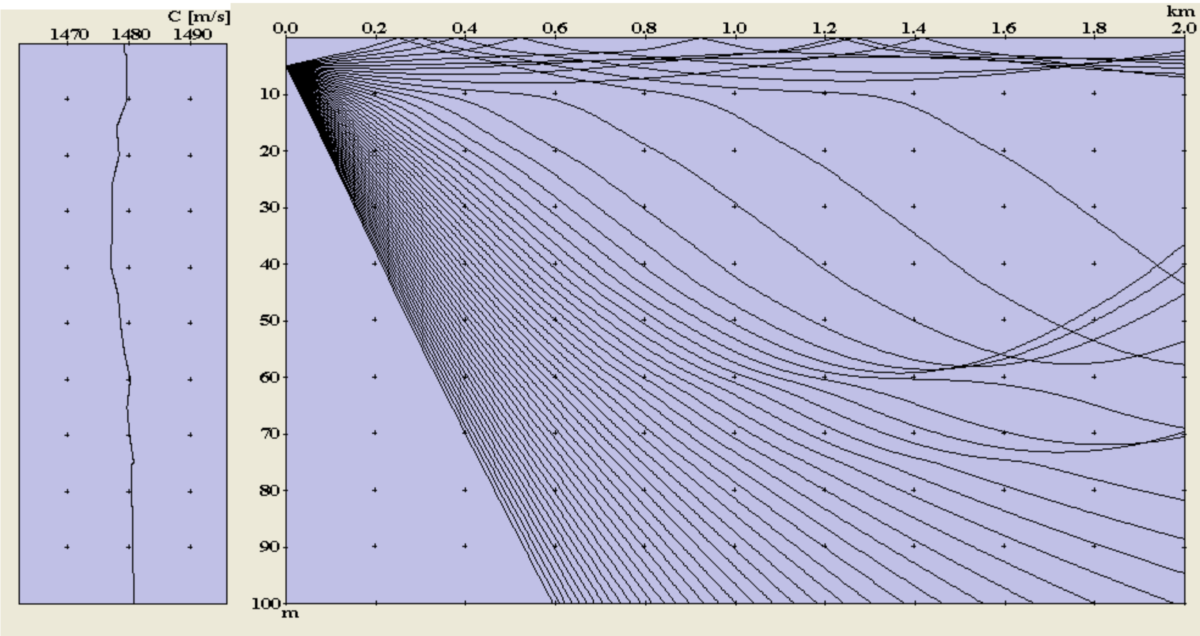


Figure 20 (a) Sound speed profile and ray trace simulation based on CTDs collected during spring/summer. Sonar tilt is -5 degrees.

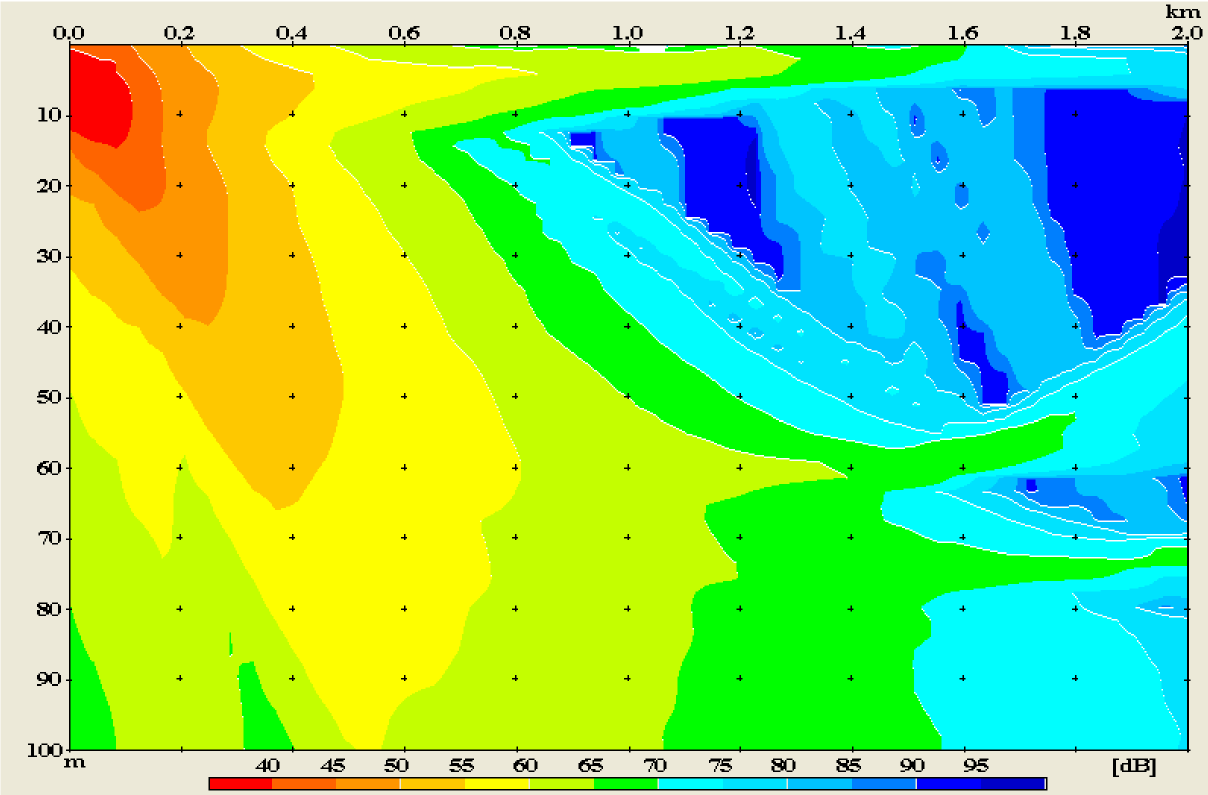


Figure 20 (b) Sound propagation simulation spring/summer for the SP90 sonar.

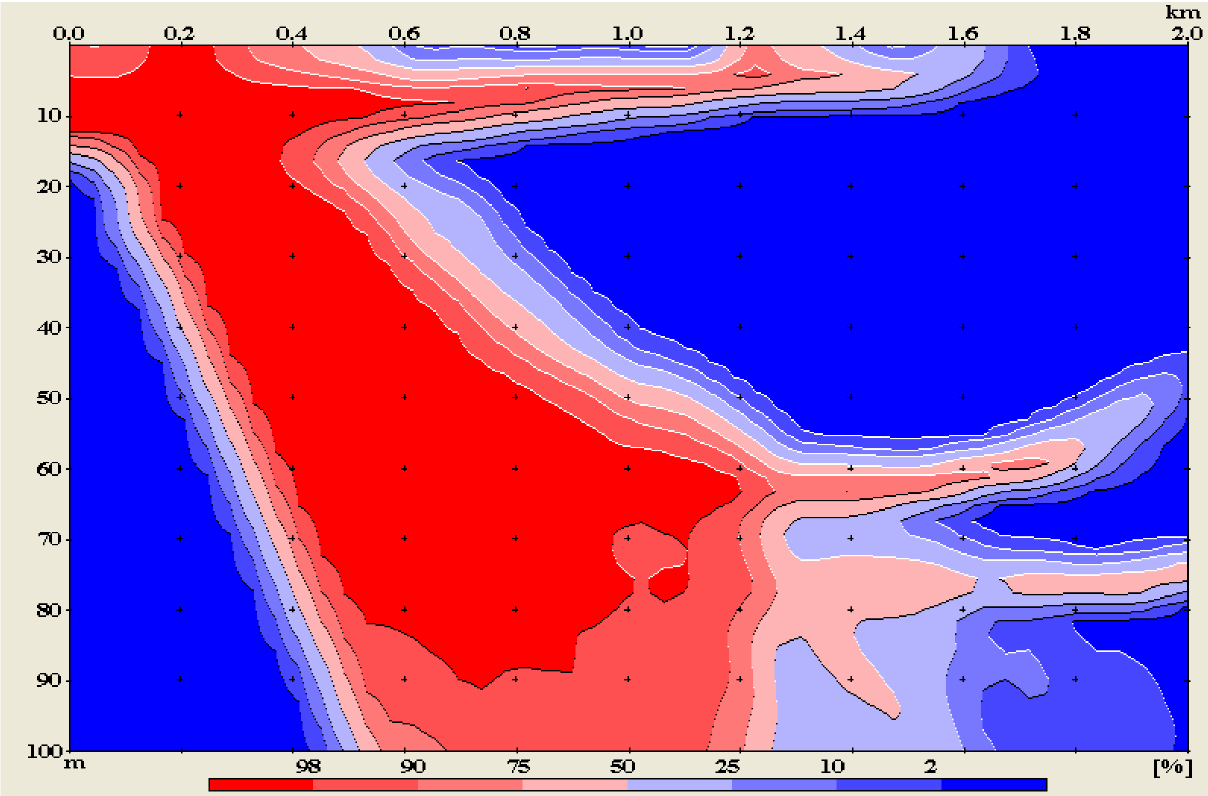


Figure 20 (c) Detection probability of a -5 dB target at different ranges and water depths spring/summer for the SP90 sonar.

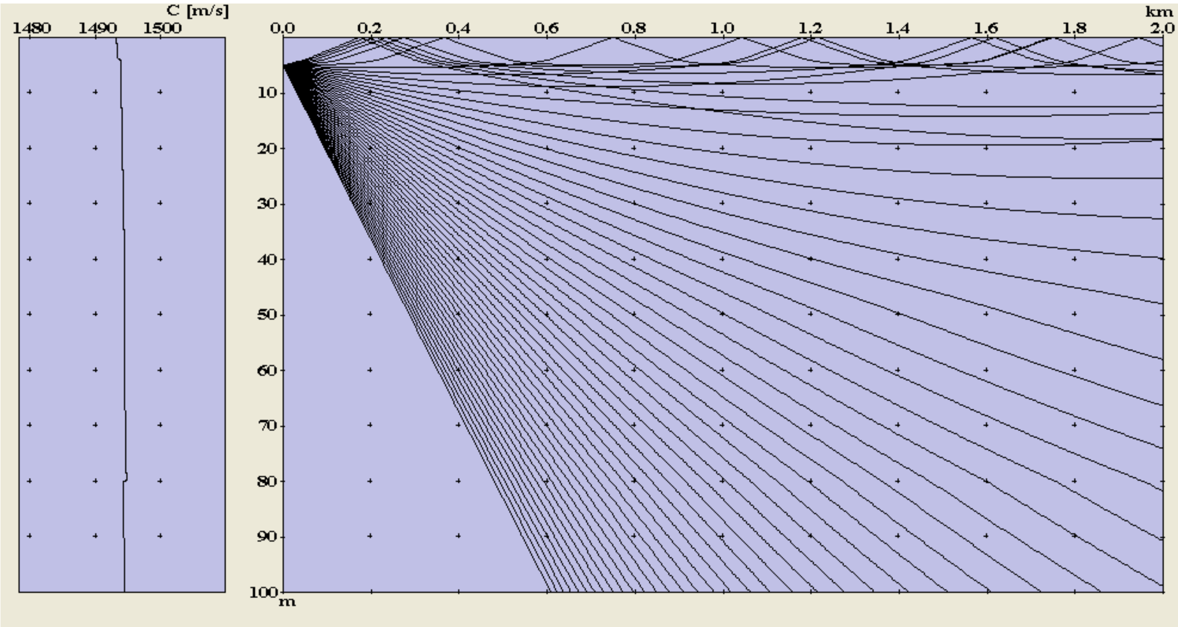


Figure 21 (a) Sound speed profile and ray trace simulation based on CTDs collected during fall/winter. Sonar tilt is -5 degrees.

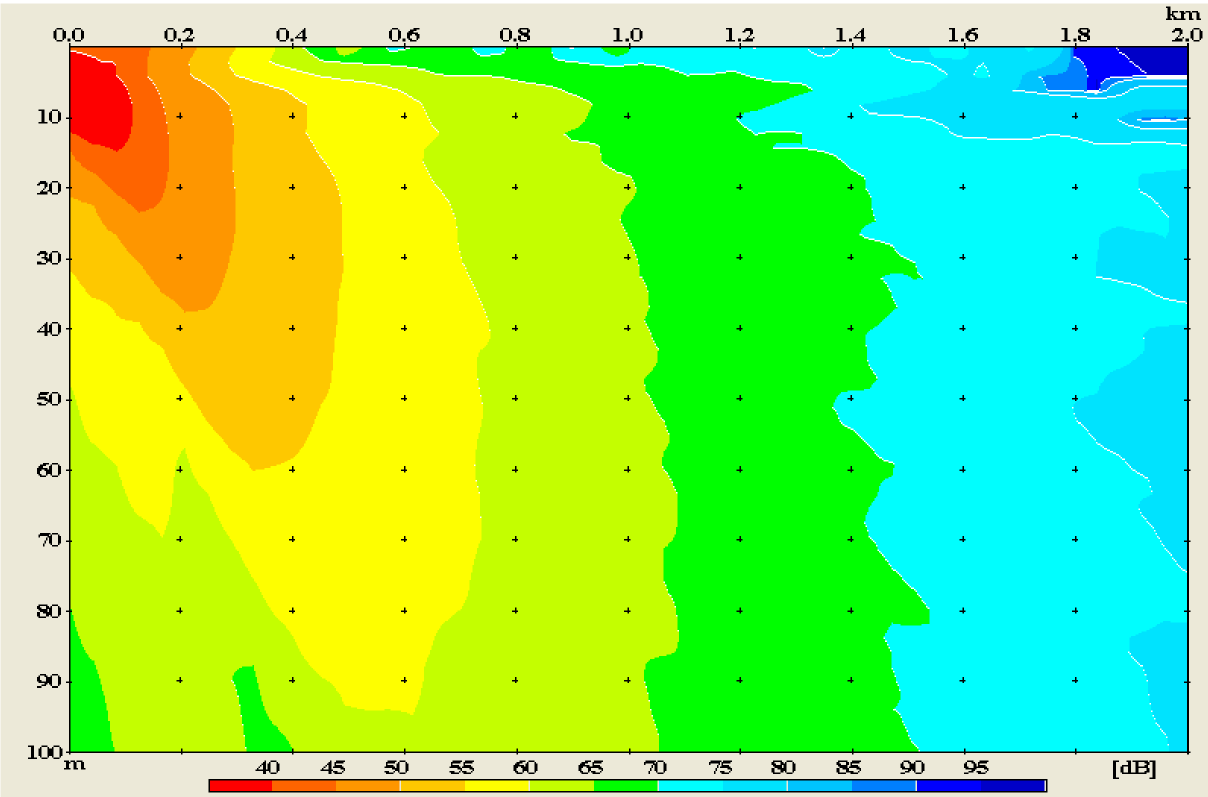


Figure 21 (b) Sound propagation simulation fall/winter for the SP90 sonar.

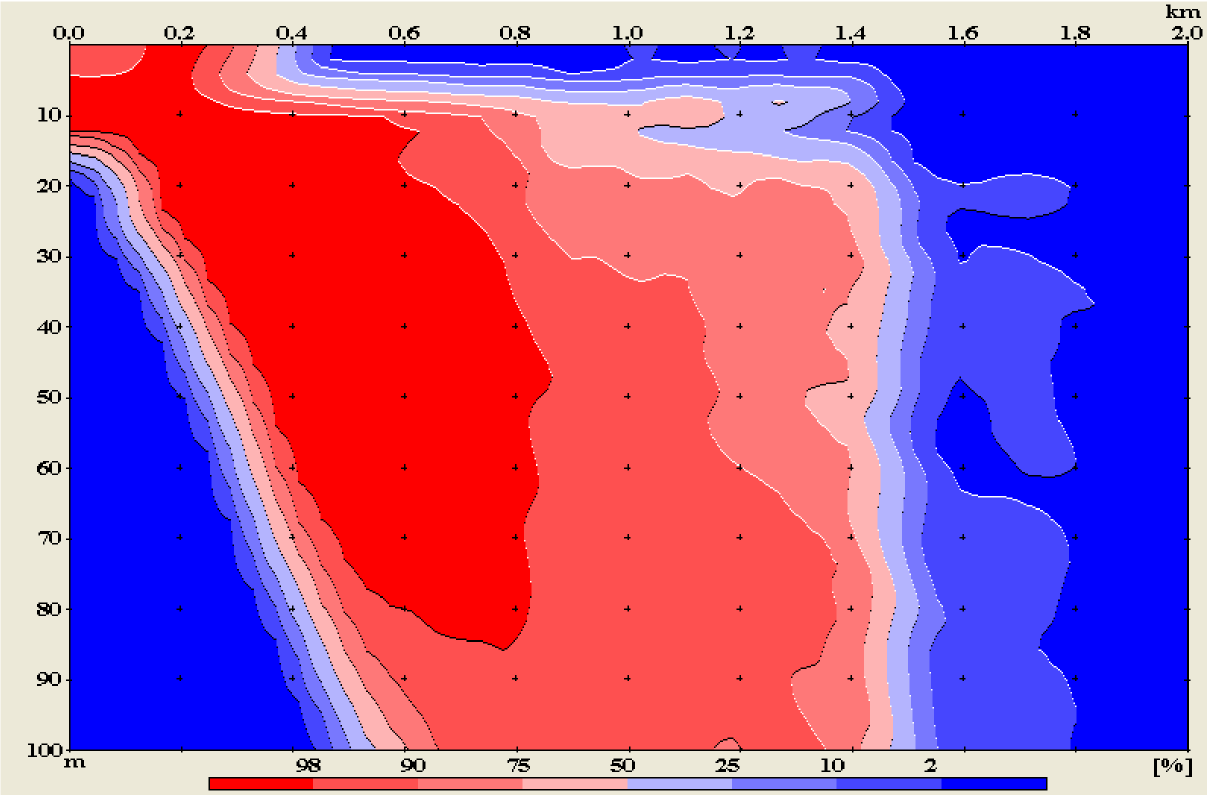


Figure 21 (c) Detection probability of a -5 dB target at different ranges and water depths fall/winter for the SP90 sonar.

Conclusions

- The SP90 sonar detected whales up to at least 1500 m range. The SH80 sonar did not give reliable detection at ranges > 400 m.
- Whale echo strength was higher at the SP90 sonar than at the SH80 sonar.
- In addition to the direct echo from the whale, both vocalization (whistles and clicks) and echoes from wakes of the swimming whale were seen on the sonar screen.
- There was no indication that the echo of the whale was reduced with depth. Animals were clearly detected to 200 m water depth.
- The whales showed no apparent reaction to sonar transmissions, even near the vessel.

Uncovered matters

- Only sparse information about killer whale echo strength and how it depends on water depth was obtained in the present study. Thus, more data is needed on target strength of marine mammals, and how target strength varies with water depth.
- More information about actual sound speed profiles in relevant areas and how this affect the sonar's ability to detect whales should be obtained.
- The study was conducted in an area were the killer whales are well adapted to sonar transmissions. The lack of behavioral reactions might therefore not be the case under other conditions. Sonar exposure experiments on a few species of whales should therefore be executed.

Short term follow up

High priority should be given to investigate the echo strength of whales and how it depends on the size of the animal, species, aspect and depth. A cost efficient experiment could be conducted outside Andenes, Norway during the summer 2007 using FV "Inger Hildur" or a similar vessel equipped with both sonar's and echo sounders. Several species of whales are found in this area during the summer, in particular sperm whales. They are doing foraging dives down to more than 1000 m, giving a good opportunity to study echo strength as a function of all above mentioned factors. Including the echo sounder in addition to the sonar will provide and opportunity to obtain quantitative measurements of whale echo strength. In addition, both baleen whales and other toothed whales occupy the area, so knowledge about more species can be obtained. Scientist and whale observers that have studied whales in this area for many years, are interested to participate in such an experiment.

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