SUB-BOTTOM IMAGING WITH VARIABLE BEAM WIDTHS

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1 INTRODUCTION

For a sub-bottom profiler (SBP) narrowing the beam typically improves the image quality. However, the performance of narrow beam SBPs is known to be susceptible to sloping sediments. The SBP 120/300 sub-bottom profilers are narrow beam SBPs, designed with the capability to operate with increased beam width. This has proved to be a useful feature for imaging of complex sediment structures where sediment slope angles exceed the most narrow beam width[1].

Recently a new operating mode has been added to the SBP 120/300 systems that allow cyclic variation of the beam widths. This enables sub-bottom imaging with narrow beams and wide beams in a single pass. In this paper some of the first results obtained using this mode is presented. Additionally one example showing echograms over a fan of narrow receiver beams is given, demonstrating separation of backscatter from the specular returns.

2 ECHO FORMATION

To allow discussion of the differences in sub-bottom imaging using wide and narrow beams, a rough model for the formation of SBP echoes is presented. A more thorough description of SBP echo formation can be found elsewhere[2].

The primary application of an SBP is imaging of sediments, in which case the desired signals are the specular reflections from sediment interfaces. SBPs are monostatic systems; i.e. the location of the transmitter (TX) and the receiver (RX) is practically the same. Picturing a beam as a bundle of rays, a specular reflection implies that only the ray hitting an interface at normal incidence will be reflected back in direction of the RX. This illustrates one advantage of wide-beam SBPs over narrow-beam ones: The wider the beam the more tolerant the system will be to slopes.

The part of a sediment interface contributing to a specular return is typically much smaller than the footprint of an SBP and to a fair approximation independent of the SBP beam width[2]. The specular return is from a disk of size given by the 1st Fresnel zone which has a radius of

$$r_S = \sqrt{\frac{w * h}{2}}$$

where *w* is the wavelength of the signal and *h* is the height of the transmitter over the surface[3]. This disk gives the horizontal resolution of an SBP[2] provided it is smaller than the area illuminated by the sonar, something which is usually the case.

Backscatter is different in that an incident ray is scattered in all directions; i.e. the wider the beam the more backscatter is received. When the pulse is in the sub-bottom sediment layers the amount of backscatter is proportional to a disk (neglecting the curvature of the spherical wavefront) of approximate radius

$$r_R = h * \tan\frac{\theta}{2}$$

where θ is the beam width of the SBP. When the imaging of sediments is limited due to backscatter the only way to improve the imaging is to reduce the beam width while keeping the sediment interface surface normal within the SBPs main lobe. As can be seen from the above expressions, the size of the footprint increases more rapidly with depth h than the 1st Fresnel zone does, thus the specular reflection to backscatter ratio will decrease with increasing depth.

Figure 1 shows the 1st Fresnel zone and the footprints of 3, 6 and 12 degrees SBPs at depths ranging from 200 m to 1000 m. The specular return to backscatter ratio is maximized when the footprint is equal to or smaller than the 1st Fresnel zone.

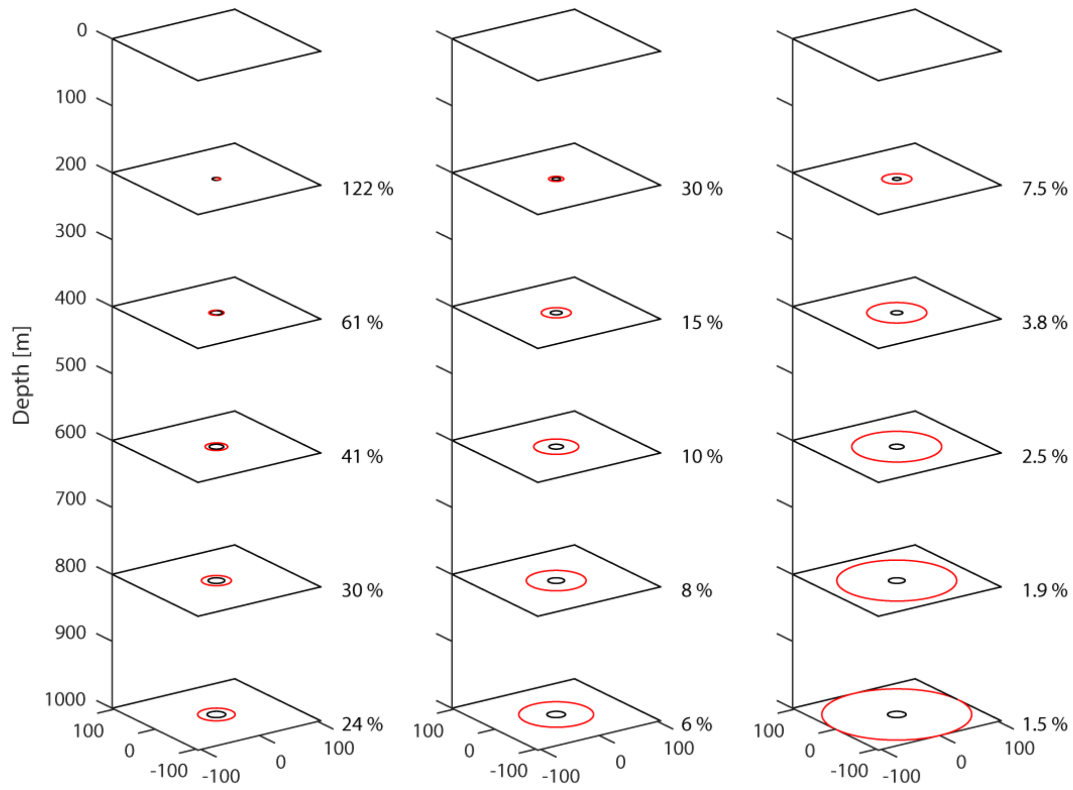

Figure 1: From left to right the red circles illustrate the footprints of SBPs with opening angles 3, 6 and 12 degrees, respectively. The black circles illustrate the 1st Fresnel zone. The ratio of the 1st Fresnel zone to the footprint is given in per cent.

3 THE SBP 120/300 INSTRUMENTS

The sub-bottom profilers SBP 120 and SBP 300 from Kongsberg Maritime are add-ons to the bathymetric multi-beam echo sounders EM 122 and EM 302, respectively. They have a dedicated TX array and share the RX array and a preamplifier with an EM system. Like the EM systems these SBPs employ the Mills cross principle to obtain narrow beams using two orthogonal line arrays for TX and RX with the TX array mounted parallel to the vessel keel. Within the TX beam that is wide across-ship a fan of RX beams can be formed per ping making them multi-beam SBPs. Apart from being integrated to different EM systems, which imply minor differences, the SBP 120 and SBP 300 are identical systems that are offered in three base models having minimum TX beam widths 3, 6, or 12 degrees. The RX beam width is determined by the size of the RX antenna and for a typical installation it is comparable to the TX beam width. The source signature most frequently used are chirp pulses of length 2 to 100 milliseconds (ms) spanning the sweep range 2.5 kHz to 6.5 kHz. The maximum source level is frequency dependent and typically well above 220 dB re 1 uPa @ 1m.

With increasing system size (decreasing beam width) the challenge constituted by sloping sediments becomes more severe. Sediments sloping acrosstrack can be covered using a fan of narrow receiver beams. Up until now there have been two ways of dealing with alongtrack slope angles exceeding the TX beam width: 1) The TX beam can be tilted to obtain normal incidence. This is awkward as the sediment slope angle in general changes not only with position but also with range. 2) The TX beam width can be increased using one half or one quarter of the TX array. Neither is this option very satisfactory as increasing the beam width implies more backscatter and hence reduced image quality; data quality is traded in for slope robustness.

Recently, a new operating mode has been added with cyclic variation of the TX beam width allowing sub-bottom profiling with different beam widths in a single pass. This enables near simultaneous acquisition of wide beam and narrow beam data at the expense of reduced alongtrack sampling interval for a given survey speed/ping rate. This new mode with cyclic variation of transmit beam width is well suited to observe the impact of beam width on SBP imaging.

4 EXPERIMENTAL RESULTS

All data presented in this paper are collected with the largest SBP 120 system available; i.e. the TX and RX arrays each have a 3 degrees opening angle at 4 kHz and the combined beampattern of the two orthogonal line arrays is mainly a symmetric beam of 3 degree beam width.

For all examples shown here the processing applied to the raw beam data is the following: matched filtering, compensation for spherical divergence, calculation of the signals envelope, and starting at the sea floor a time variable gain of 0.5 dB per millisecond (ms) is added.

The echograms are presented using a logarithmic color scale proportional to the intensity of the signal. The vertical scale of all echograms is the two-way travel time in milliseconds. When the TX beam width is increased a smaller part of the TX antenna is used and the source level decreases. To simplify comparison with a fixed color scale, the source level reduction is compensated for by adding a fixed gain of 6dB and 12 dB to the 6 degree TX and 12 degree TX results, respectively.

4.1 Variable TX and RX beam widths

In this example the SBP 120 is configured to run in a transmit cycle mode of three pings with beam width cycling through 3, 6 and 12 degrees. The RX beam width is set to follow the beam width of the TX; i.e. the footprints (the two-way beam patterns) are kept symmetric. The ping rate of the system was 4.2 Hz, which means the ping rate for each TX beam width was 1.4 Hz. The resulting echograms for the vertical RX beam are shown in Figure 2. Most evident is the improved data quality of the more narrow beams well below the surface, but note that also very close to the seabed sediment interfaces are imaged using the 3 degree beams that cannot be detected using the 12 degree beams. With increasing footprint the strength of the specular return is practically unchanged while the amount of surface backscatter increases which obscures the shallowest specular returns.

4.2 Variable TX and fixed RX beam widths

Instead of keeping the footprints symmetric as in the previous section, it is possible to operate with a fan of narrow RX beams in combination with varying TX beam width. In this mode each echogram using a wider TX than RX beam will be more susceptible to the acrosstrack slope angle than the alongtrack slope angle, but as long as the correct combination(s) of TX and RX beams are chosen this mode provide better signal to noise ratio (SNR) and better specular return to backscatter ratio for the wider TX beams than what is obtained with the symmetric footprints.

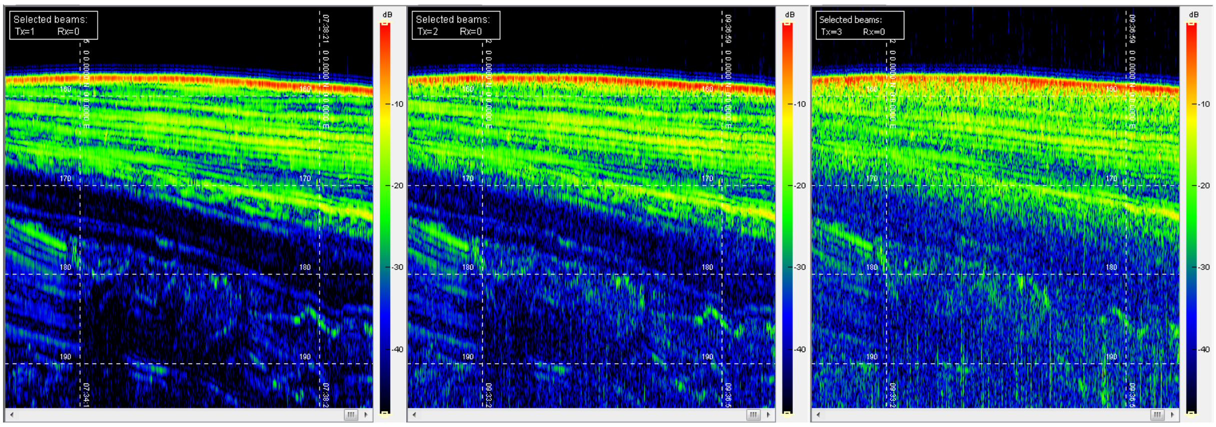

Figure 2: From left to right the beam widths used are (TXxRX) 3°x3°, 6°x6° and 12°x12°, respectively. Data were collected at vessel speed 6.75 m/s using a ping rate 4.2 Hz. The signal used is a linear chirp of duration 10 ms sweeping from 2.5 to 6.5 kHz. Depth was 120 meters and the distance covered in the images shown above is around 2.3 kilometer.

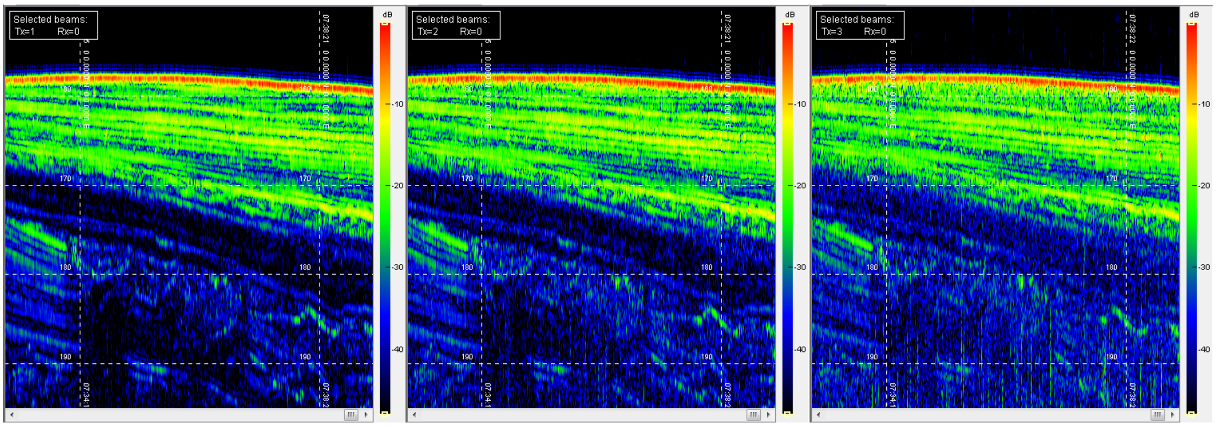

Figure 3: Same data as in Figure 2 except the RX beam width has been changed. From left to right the beam widths are (TXxRX) 3°x3°, 6°x3° and 12°x3°, respectively.

In a standard operational SBP 120 system one has to set the RX beam width either to “follow TX beam width” or to operate with a fixed beam width. However, during collection of the results presented in the previous section the individual raw hydrophone signals were recorded which enabled reprocessing of that data set to see what the resulting imaging would be if the system had been operated with a fixed RX beam width of 3 degrees. These reprocessed results are shown in Figure 3. The leftmost image is identical to the leftmost image of Figure 2 since the RX beam width in this case is unchanged. For the other images we see an improvement in imaging narrowing the RX beam width. Most of this improvement is due to reduced backscatter but there is also an improvement due to a reduction of ambient noise.

4.3 Narrow beams and sensitivity to slopes

While testing the new mode of alternating beam width we did not encounter an area where the benefit of having the wider TX beam echograms available was striking. During collection of the data presented in section 4.1 a fan of RX beams spaced by 3 degrees were generated per ping. For purpose of illustration we look at the echograms where the RX beams are pointing six degrees to the port; the geometry is then roughly the same as with vertical RX beams and sediments sloping six degrees acrosstrack. These echograms are shown in Figure 4. Using the narrowest beam it is hard to identify any layering, whereas for the widest beam we see the layering almost as well as with the vertical beam (cf. Figure 2). This illustrates the vulnerability of narrow beams to slopes and shows why the wide beam results can sometimes be a useful supplement.

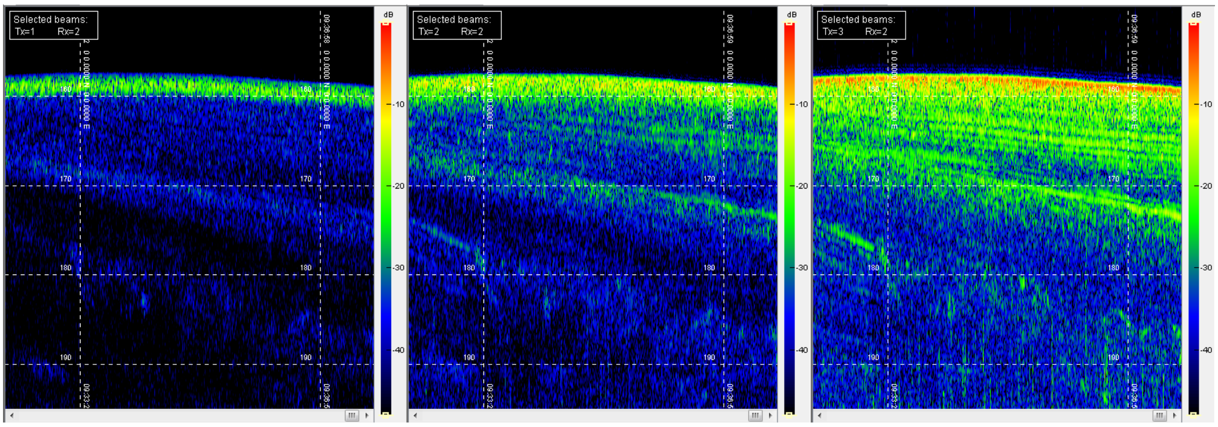

Figure 4: Same pings as in Figure 2 except the RX beams are pointing 6 degrees to the port. From left to right the beam widths are (TXxRX) 3°x3°, 6°x6° and 12°x12°, respectively

4.4 Backscatter over a fan of RX beams

Although the desired signal (i.e. normally the specular reflections) is in the echogram(s) most of the time in which the incidence angles are closest to zero, it can be informative to look at the complete fan of RX beams. Sometimes there is little to see except for pickup of the specular returns due to the sidelobes of the RX beam pattern, other times there are significant amount of backscatter as in the examples selected for this paper.

One example from an area with significant backscatter is shown in Figure 5. The system is pinging with a vertical TX beam 3 degrees wide, and per ping a fan of eleven RX beams 3 degrees wide is generated. These RX beams are spaced by three degrees and the fan is symmetric about the vertical. Consider the first echo from the seabed: in the standard echogram (left side) it appears to be a smooth surface. This observation is supported by the acrosstrack echogram of the last ping (right side) where backscatter associated with the sea floor return is invisible in the side beams; only the undesired sidelobe pickup of the specular reflection is seen. Then there are less well-defined interfaces for about 7 ms before what seems to be a rougher sediment layer is reached. Associated with this layer we observe in the sidebeams backscatter at ranges increasing with increasing incidence angle. One more region of increased backscatter is evident in the acrosstrack echogram. Backscatter is typically easier to observe comparing the alongtrack echograms of the different RX beams. This is illustrated in Figure 6 where a shorter segment of the data shown in Figure 5 is replayed six times, consecutively displaying how the imaging changes as the RX tilt angle is decreased from 15 degrees port to the vertical in steps of 3 degrees.

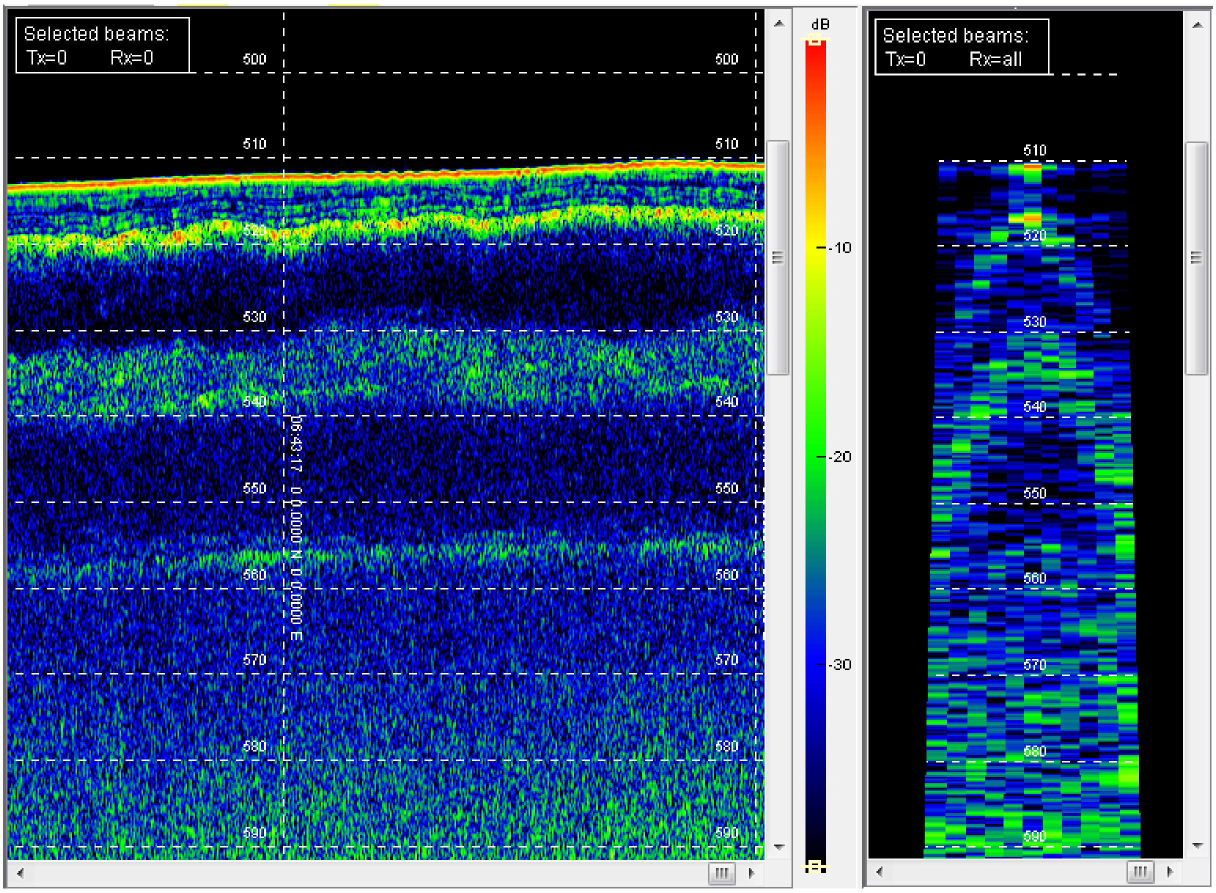

Figure 5: To the left a standard alongtrack echogram from the combination of the vertical TX beam and the vertical RX beam, both beams 3 degree wide. To the right is shown the acrosstrack fan of RX beams for the last ping; port beams to the left, starboard beams to the right. The pulse was a 30 ms linear chirp sweeping 2.5 to 7 kHz, the ping rate was 1.1 Hz, and the survey speed was about 3 m/s. The depth is about 370 meters and the horizontal distance in the alongtrack echogram is about 1.5 kilometer.

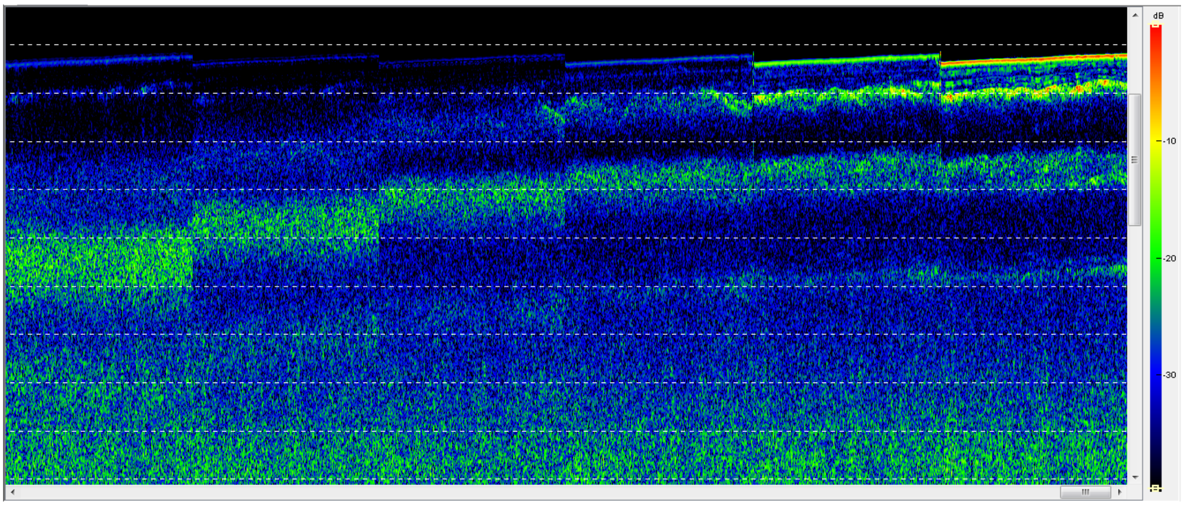

Figure 6: Segment of the same data shown in Figure 5 observed with a 3 degree beam pointing port by (left to right) 15, 12, 9, 6, 3, and 0 degrees relative to the vertical.

5 DISCUSSION

The optional cyclic variation of the transmit beam width is primarily intended as a tool for application when sediment slope angles constitute a problem for the most narrow beams. With this new mode SBP profiles can be acquired in a single pass using both narrow and wide beams. The narrow beams typically provides the best data, however in those parts of the mapped area where the specular returns are fading out in the narrow beam data, one will also have wide beam data available to complete the picture.

For a given ping rate and survey speed there will be a reduced alongtrack sampling interval when the transmit cycle mode is applied compared to normal operation. A reasonable requirement might be that the ship movement from trace to trace in an echogram should not exceed the horizontal resolution given by the size of the 1st Fresnel zone. During collection of the data presented in sections 3.1-3.3 the movement from trace to trace is less than 5 meters for each of the three echograms, and at the sea floor depth of 120 m the diameter of the first Fresnel zone is in the range 7.5 to 12 meters for the chirp signal; i.e. there is some overlap from trace to trace even at the fairly high vessel speed used during this acquisition. It is possible that the new mode can be put to use as a default operating mode under many conditions without increasing the survey time. This can free the operator from the sometimes challenging task of selecting the “best” transmit beam width when surveying an unknown area.

Although primarily intended as a tool for deployment during regular SBP profiling in cases where the narrow beams become a nuisance, the transmit cycle mode may also be of interest for detailed studies of the impact of beam widths on sub-bottom imaging since it allows comparison of using different beam widths under near identical conditions.

The primary purpose of the fan of RX beams is to provide robustness to acrosstrack slopes. It can also be useful for detection of buried objects. The ability to separate backscatter from the specular return is perhaps mainly interesting for purpose of illustration. It is possible that having the fan of RX beams available can make it easier to give a rapid assessment of sediment “roughness”. Also, at higher frequencies there is an interest in backscatter from the sea floor and it might be that low frequency backscatter from the sea floor can provide additional valuable information. The transmit sector of the SBP 120/300 systems can be tilted forward (or backward) by up to 15 degrees. In combination with a fan of RX beams data with oblique incidence angle covering a swath up to 30 degrees wide can be recorded, providing a set of data in which the backscatter is separated from the specular reflections.

6 REFERENCES

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