Article

Testing Multibeam Echo Sounders versus IHO S-44 Requirements

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The aim of this trial of the multi-beam echo sounders was to ascertain whether the echo sounders EM 1002 and EM 3000 Dual, manufactured by Kongsberg Simrad AS in Horten, Norway, were able to meet the International Hydrographic Organization's standards for Special Order surveys and Order 1 surveys with regards to object detection as given in Special Publication No. 44, 4th edition. The scope of this test included designing and building cubic objects of different sizes to be launched and recovered from the seabed for testing at several different water depths. Also a specially designed EM 3000 dual mounting frame with the sonar heads tilted horizontally (at zero degrees) was designed. Both the EM 1002 and the two EM 3000 dual systems were able to detect objects on the seafloor to within the specifications for Special Order surveys.

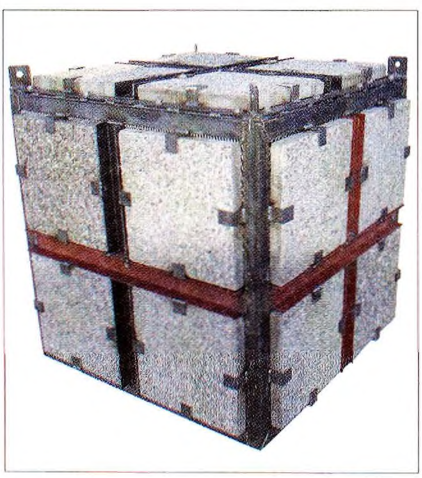


Figure 1: The 1x1x1m cube. Steel frame with rock tiles mounted

This article gives the results of the EM Evaluation trials performed in March 2003 in Horten, Norway, on the multi-beam echo sounders EM 1002, and EM 3000 Dual 40 degrees sonar head tilt angle and EM 3000 Dual with the two sonar heads mounted with a zero degree tilt angle.

These tests show the EM 1002 EM 3000 D/40 and EM3000 D/0 to be in compliance with the IHO S-44 standard, Special Order, as stated in the 4th edition of April 1998, for water depths less than 31m and speeds up to 5 knots.

Maximum water depth for object detection for Special Order surveys is described by the IHO for safety of navigation purposes. The maximum water depth for Order 1 surveys is 40 metres. It was decided to work in water depths shallower than 40 metres in order to limit the scope of this test. For safety of navigation purposes, water depths below 40 metres will be sufficient for most cases.

This test included designing and building objects for detection according to Special Order and Order 1 surveys. The cubic objects defined in the IHO S-44 specifications were interpreted to mean cubic objects with all sides equal to the given measurements of 1 m or 2

Figure 2: Close up of one of the rock tiles on the 1m cube

m. That is the 1m cube was designed with sides 1m x 1m x 1m.

In addition, a mounting frame for the two sonar heads on the EM 3000 Dual at zero degree horizontal tilting angle was designed and built. The

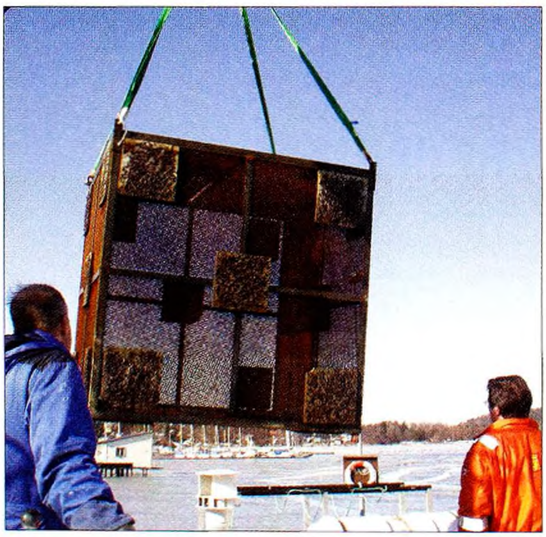


Figure 3: Lifting the 2m cube aboard MK Simrad Echo. The tiles are the five squares on each side of the cube. Note that you can see through the cube

cubes were built in co-operation between Kramek Ltd. in Horten, and the Kongsberg Simrad mechanical engineering shop in Horten, Norway.

The survey part of this test took three weeks, and finished 19th March 2003. Some preliminary tests were carried out in December 2002, mainly to make sure that it was possible to recover the objects once they had been submerged at sea for some time. The coming of winter conditions, particularly the freezing of the sea, in the Autumn of 2002, caused postponement of the main surveying until March of the following year.

Equipment

The multi-beam echo sounders used in this test were an EM 1002, a 95 kHz echo sounder with a maximum ping rate > 10 Hz and 111 beams per ping, and 2 x 2 degree beam width, pulse length 0.2 ms and an EM 3000 Dual / which has the sonar heads tilted at 40_degrees, a 300kHz max ping rate of 40Hz and 254 beams per ping and 1.5 x 1.5 beam width.

The EM 3000 Dual with a specially designed mounting rack has horizontally mounted sonar heads with a 0 degree tilt. This dual EM 3000 was made for better overlap of the sonar swathes.

There have been some previous trials done with object detection, and it was decided to make the cubes of rock, or rock tiles. Previous studies have shown that steel frame cubes may not be the most suitable. Also rock provides a realistic target face, and also easier to handle in somewhat rough conditions. The downside to choosing rock is its weight.

The four cubic objects made were 2m, 1m, 0.5m, and 0.25m cubes. All sides of these cubes were equal, except where size made it impossible to fit the rock tiles to the hinged top on the 0.25m cube. The 1m cube in the figure shows four rock tiles on each side and a steel frame. Both the top and the bottom also have rock tiles, and all the cubes are hollow inside. This makes it easier, if heavier, to handle the cubes. It does not matter if they are drifting when they are lowered as can happen, especially with the smaller cubes.

The three smallest objects were made of commercially available rock tiles. The entire cubic surface was covered with tiles for the 1 m and smaller objects. The rock tiles measured 0.4m x 0.4m x 0.05m, and the frame was steel. The tops were hinged, in case it was decided to fill the cubes during later tests. All sides were equal, except the top which was hinged, and the weight of the 1m cube was 650kg.

The largest object (2 m cube) was made with tiles made of rock mounted on a double steel frame. Weight restrictions limited surface area covered by rock tile. Only about 0.8m of the cubic area for the 2m cube was covered with rock tiles. These rock tiles measured 0.4 x 0.4 x 0.03m, and were hand made especially for this project. Between the tiles covering parts of the surface of the 2m cube, was a sandwich layer of two steel frames. The frames had holes, and they measured 1.5cm x 3.0cm at the widest. The weight of the 2m cube was 650kg.

Two different vessels were used in the trial, the MK *Simrad Echo* for the launch and recovery operations of the cubes, and *Pingeline* for the surveying. *Pingeline*, the Hydrographic Department's own 30 feet vessel, is equipped with EM 1002, EM 3000D/40, EM 3000D/0, Seapath 200, Starfix, UPS, GPS, and a Workstation Sunblade 100. Top survey speed for *Pingeline* is 7 knots in good weather. It would have been desirable to have done a few runs at higher speeds, but it was not possible to go beyond 5 knots for this test.

Software used was Kongsberg Simrad Subsea's new 5.2 release for the EM 1002, and for EM 3000 both systems the 5.1u29 release was used. Neptune 4.10 post-processing software from Kongsberg Simrad Subsea, Hydrographic Development Department was used.

Requirements

The requirements of the IHO, S-44 specifications are given in the table below. These requirements are for Special Order, Order 1 through 3. The test concerned Special Order surveys and Order 1 surveys with regards to object detection. The 1m cube was used for Special Order surveys, and the 2m cube was expected to be used for Order 1 surveys.

International Hydrographic Organization, Special Publication No. 44, 4th Edition, April 1998, Summary of Minimum Standards

ORDER	SPECIAL	1	2	3
Horizontal accuracy	2m	5m + 5 per cent of depth	20m + 5 per cent of depth	150m + 5 per cent of depth
Depth accuracy	a=0.25m b=0.0075	a=0.5m b=0.013	a=1.0m b=0.023	Same as order 2
100 per cent bottom search	Compulsory	Required in selected areas	May be required in selected areas	Na Na
System detection capability	Cubic features >1m	Cubic features >2mup to 40m	Same as order 1	
Line spacing	Na, 100 per cent search	3 x ǀdepthǀ or 25m	3-4xǀdepthǀ, or 200m	4xǀdepthǀ

Test

One limiting factor of this test was the time schedule. Only three weeks in March were available for the whole launch, recovery and surveying. This meant there was a restriction in terms of test site, as valuable time for travel had to be limited, and we were forced to stay within a short distance of the office in the Oslo fjord .

Initially it was hoped to test at 10m, 20m and 40m water depth, on relatively flat seabeds. But due to ice conditions, the test ended up placing the objects at approximately 15 m and 30 metres water depth. Unfortunately there was no suitable site available at this time of the year close to Horten with 40 metres water depth. The four cubic objects were placed in a straight line with distances between them of around 30 metres.

The seabed at both chosen locations was relatively flat with mainly sand and mud. None of the cubes were buried more than 15cm in the sea floor.

At both the 15m site and the 30m site a minimum of 20 survey lines were run at up to three different distances/angles from the cubes. The surveys were run at two different speeds, 3 knots and 5 knots for each echo sounder at each depth. The survey lines were run in a North-South direction and vice versa.

The areas finally selected were Bastoeyrenna (15m), and an area north of Mefjordbaaen and south of Bastoeya (31m). Both sites are a short travel time from the office and vessel harbour.

Accuracy

Seapath 200 was used for horizontal positioning in all tests. The positioning accuracy for the Seapath 200 is 1.5m at 95 per cent confidence level, as given by the manufacturer. The requirements for S-44 Special Order surveys are that the positioning accuracy should be better than 2m, and for Order 1 surveys the positioning accuracy should be better than 5m + 5 per cent water depth. The Seapath 200 thus satisfies the requirements.

For 95 per cent confidence level depth accuracy is given by

$$\sqrt{(a^2 + bd^2)}$$

Where a = 0.25m, b = 0.0075m for Special order surveys, and a = 0.5m and b = 0.013m for Order 1 surveys.

For Gaussian error distribution this corresponds to twice the standard deviation.

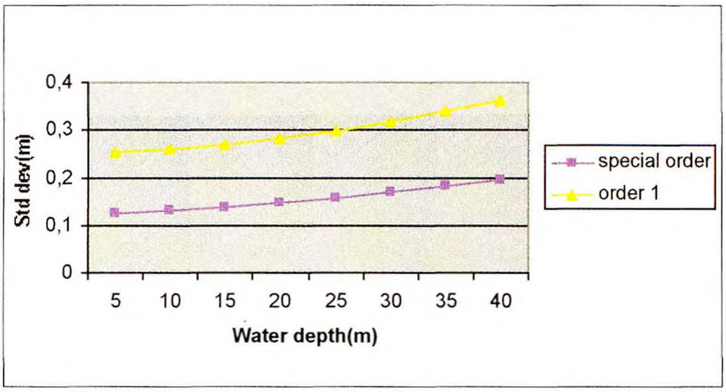


Figure 4: Std Dev of sounding errors

For Special Order surveys, 100 per cent bottom search is compulsory. This is an ambiguous term, and not a precise definition. Later editions of the S-44 might change or clarify this. The number of pings per target could be a better definition. Land Information New Zealand (LINZ) has a better defined requirement for object detection. To ensure target detection a minimum of three strikes along and three strikes across the object is required. As shown by Hammerstad (3) the EM 3000 dual will meet LINZ special order accuracy within its calculated coverage. EM 1002 will meet LINZ special order accuracy to beam pointing angles to 75 degrees for depths less than 25m, and will have to be limited to 70 degrees for deeper waters. This test was done at 15m and 31m, and the coverage used for the EM 1002 was 60 degrees.

Line spacing for Special order surveys is not applicable according to the S-44 4th Edition, as 100 per cent search is compulsory. For Order 1 surveys in our test at 15 m water depth, maximum line spacing would be 45m. For 35m depth the maximum line spacing would be 105m.

Results

All four cubic objects for detection were placed on the seafloor, and 20 survey lines for each dis-

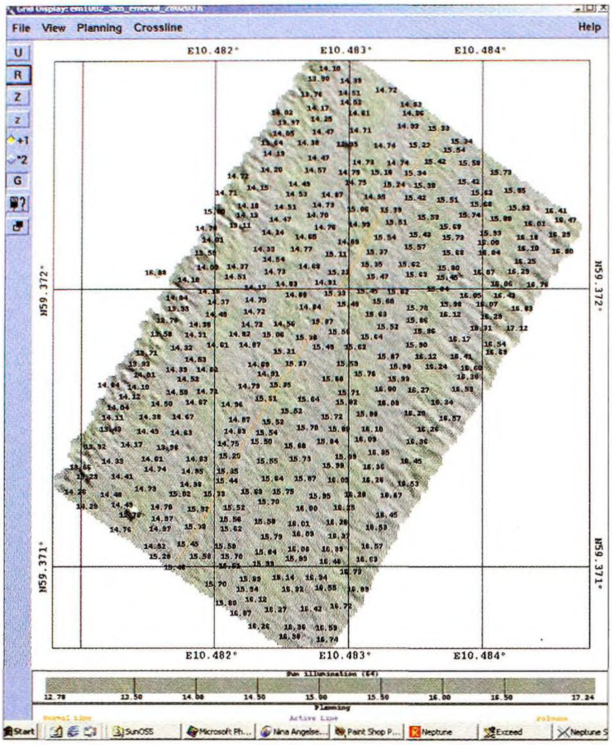


Figure 5: EM 1002, 15m water depth, 3 knots speed. GridDisplay. Depth points included

tance/angle for each echo sounder were run.
2 survey speeds, 3 knots and 5 knots for 15m depth and 31m depth for each echo sounder were used.

The coverage used was ±65 degrees for EM 1002, 70/10 – 10/70 for the EM 3000 Dual / 40 and ±65 degrees for both sonar heads for the EM 3000 Dual with zero degrees horizontally tilted sonar heads.

Below is an example of the EM 3000 Dual / 40 system, water depth 15m and speed 3knots. The figure shows Grid Display with Sun Illumination, and the grid cell size is adjusted to show 10 – 15 points, thus the grid cells varied between 0.5m and 1.5m.

It was also found that depth data was better for detecting objects than side scan.

Results for all survey lines are given in the table below. They are given as detection percentages based on whether or not the object was visible to the operator in the Grid Display. Some of the surveys were done with more than 20 survey lines.

It is important to remember that 100 per cent detection means that the object was detected 20 out of 20 times. Detection percentage of 95 per cent simply means the object was visible 19 out of 20 times. There is not much room for error, human or otherwise with this setup. Ideally one would have the time to do several tests to get a more statistical significant number of results. It can be argued that with as few as 20 results this is not enough. It was considered important to test both

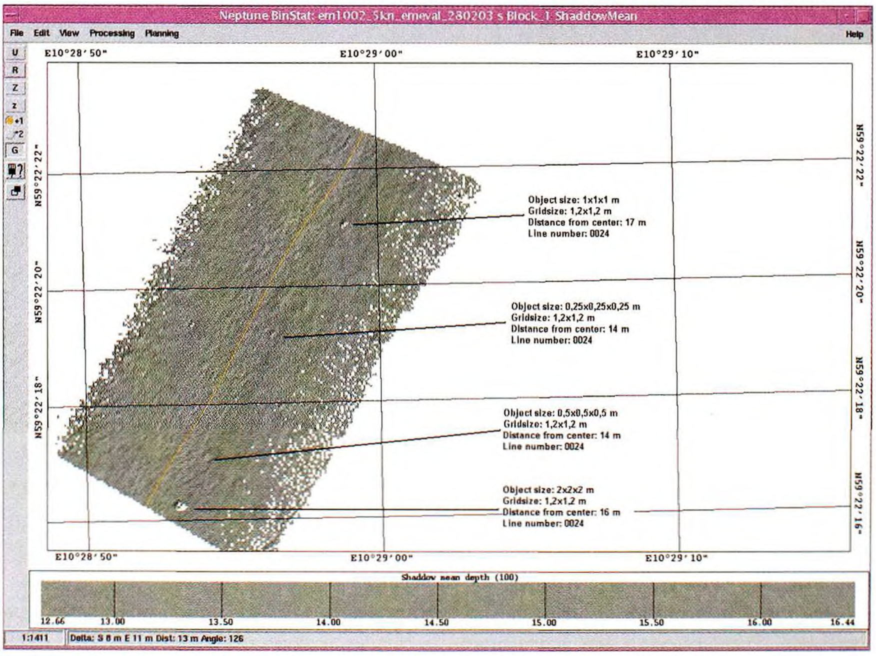


Figure 6: EM 1002. 15m water depth, 5 knots speed. Neptune Binstat

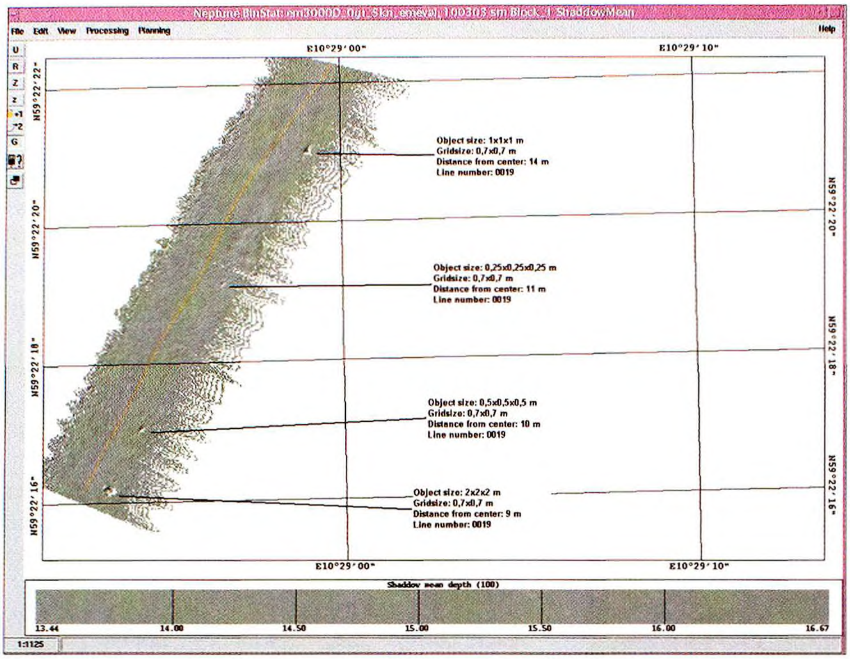


Figure 7: EM 3000 Dual/0 degrees. 15m water depth, 5 knots speed. Neptune BinStat

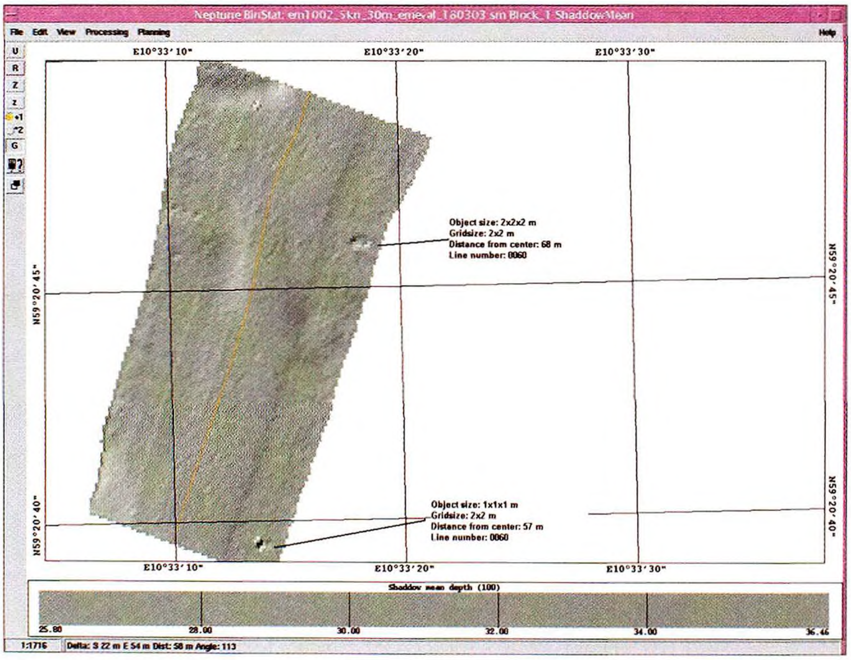


Figure 8: EM 1002. 31m water depth, 5 knots speed. Neptune Binstat

at 3 knots and 5 knots to see if there were any differences depending on boat speed, but in hindsight it might have been as valuable to increase the number of results per depth and angle and echo sounder.

Clearly the EM 1002 has no problem detecting the 1m cube. The 2m cube was not so well detected, but this can be explained by the fact that the 2m cube is not really a 2m cube. Also the holes in the 2m cube's steel frame allow the EM 1002 soundings at 95 kHz to pass right through with a wavelength smaller than 1.5cm.

As expected, the better overlap of the EM 3000 Dual / 0 degrees gives slightly better results in

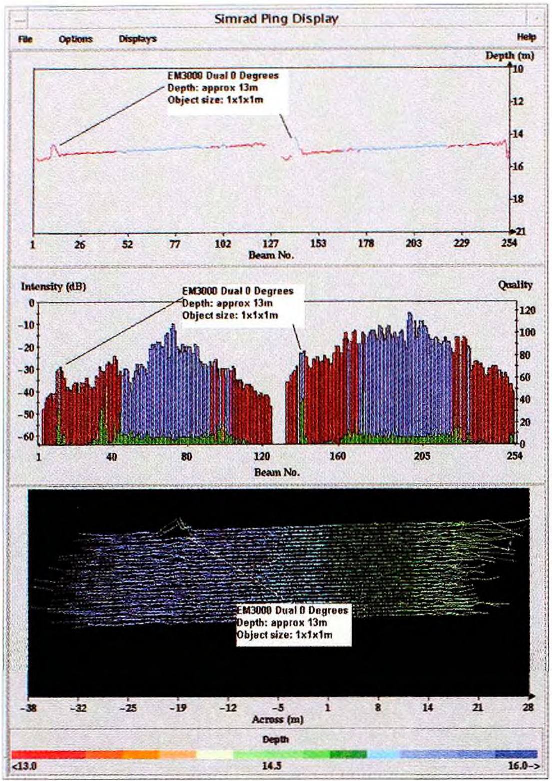


Figure 9: EM 3000 Dual / 0 degrees. Ping Display. 13m water depth

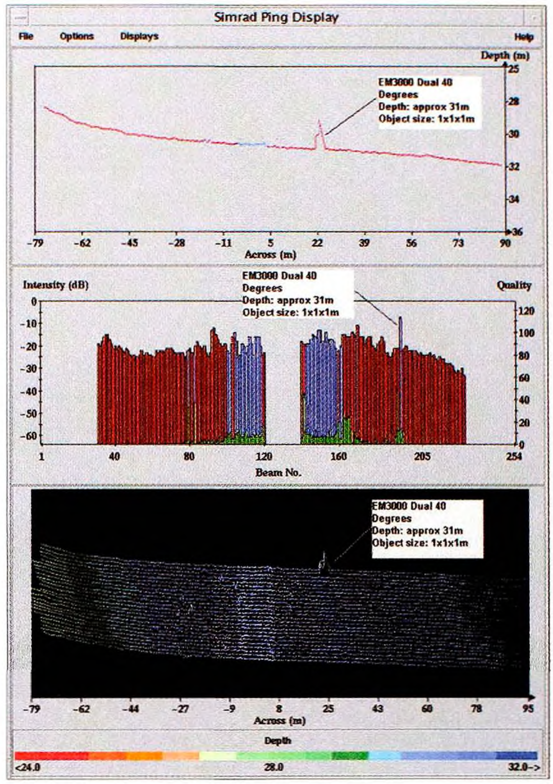
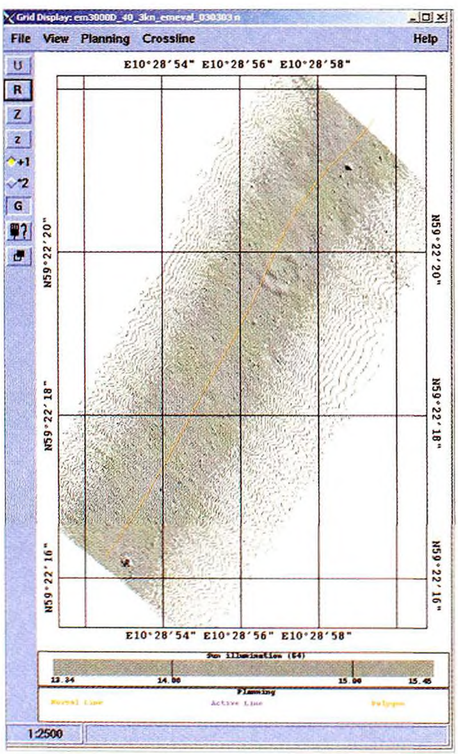


Figure 10: EM 3000 Dual / 40 degrees. Ping Display. 31m water depth



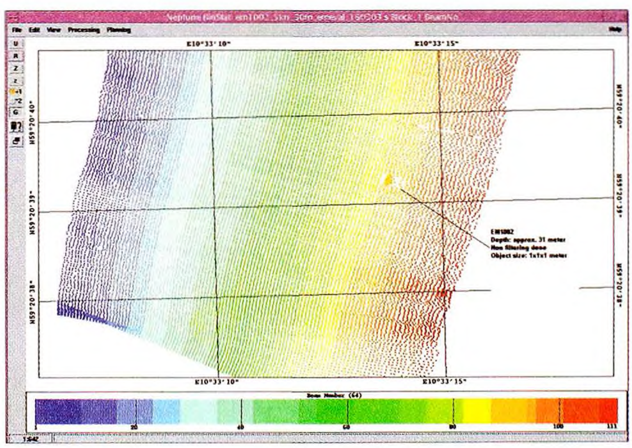


Figure 12: EM 1002 Beam numbers from Neptune. 1m cube

Figure 11: EM 3000 dual/40 degrees. 15m water depth, 3 knots speed. GridDisplay

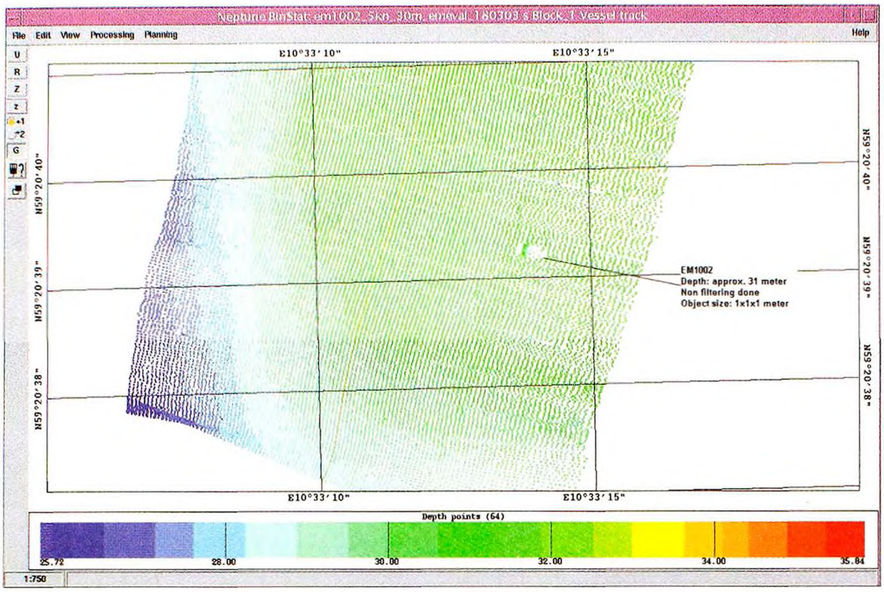


Figure 13: EM 1002 Depth points from Neptune. 1m cube

EM 1002				
15m water depth, 3 knots				
	1m cube	2 m cube	0.5m cube	0.25m cube
10m/34deg	100 per cent	85 per cent	40 per cent	10 per cent
25m/53deg	100 per cent	100 per cent	81 per cent	10 per cent
35m/67deg	100 per cent	100 per cent	81 per cent	5 per cent

EM 1002				
15m water depth, 5 knots				
	1m cube	2 m cube	0.5m cube	0.25m cube
10m/34deg	95 per cent	75 per cent	35 per cent	0 per cent
25m/53deg	100 per cent	100 per cent	80 per cent	25 per cent
35m/67deg	95 per cent	100 per cent	70 per cent	0 per cent

EM 1002				
31m water depth, 5 knots				
	1m cube	2 m cube	0.5m cube	0.25m cube
10m/18deg	100 per cent	80 per cent	0	0
25m/39deg	100 per cent	100 per cent	0	0
35m/48deg	100 per cent	100 per cent	10 per cent	0

EM 3000 dual/40 degrees				
15m water depth, 3 knots				
	1m cube	2 m cube	0.5m cube	0.25m cube
10m/34deg	100 per cent	100 per cent	100 per cent	85 per cent
25m/53deg	100 per cent	100 per cent	100 per cent	75 per cent
35m/67deg	100 per cent	100 per cent	62 per cent	11 per cent

detecting the smaller cubes, but with an exception at 31m water depth at 5 knots speed.

Some beam numbers and depth points showing the coverage for the EM 1002 is given below.

Conclusion

The EM 1002, EM 3000D/40 and EM 3000D/0 detected the 1m cube to within a confidence level of 95 per cent or better. This is within the specifi-

EM 3000 dual/40 degrees				
15m water depth, 5 knots				
	1m cube	2 m cube	0.5m cube	0.25m cube
10m/34deg	100 per cent	100 per cent	100 per cent	65 per cent
25m/53deg	100 per cent	100 per cent	95 per cent	45 per cent
35m/67deg	100 per cent	100 per cent	79 per cent	26 per cent

EM 3000 dual/40 degrees				
31m water depth, 5 knots				
	1m cube	2 m cube	0.5m cube	0.25m cube
10m/18deg	95 per cent	95 per cent	10 per cent	0
25m/39deg	100 per cent	100 per cent	35 per cent	5 per cent
35m/48deg	100 per cent	100 per cent	0 per cent	0

EM 3000 dual/0 degrees				
15m water depth, 3 knots				
	1m cube	2 m cube	0.5 cube	0.25 cube
10m/34deg	100 per cent	100 per cent	80 per cent	100 per cent
20m/53deg	100 per cent	100 per cent	40 per cent	95 per cent

EM 3000 dual/0 degrees				
15m water depth, 5 knots				
	1m cube	2 m cube	0.5m cube	0.25m cube
10m/34deg	100 per cent	100 per cent	85 per cent	100 per cent
20m/53deg	100 per cent	100 per cent	100 per cent	25 per cent

EM 3000 dual/0 degrees				
31m water depth, 3 knots				
	1m cube	2 m cube	0.5m cube	0.25m cube
10m/18deg	100 per cent	100 per cent	50 per cent	15 per cent
25m/39deg	100 per cent	100 per cent	25 per cent	5 per cent
35m/48deg	100 per cent	100 per cent	5 per cent	0

EM 3000 dual/0 degrees				
31m water depth, 5 knots				
	1m cube	2 m cube	0.5m cube	0.25m cube
10m/18deg	100 per cent	95 per cent	20 per cent	0
25m/39deg	100 per cent	100 per cent	20 per cent	0
35m/48deg	100 per cent	100 per cent	0	0

cations for Special order from IHO S-44. This was tested for survey speeds up to 5 knots, and with water depths of 15m and 31m.
All tests were at 3 or 5 knots speed however a few test runs were done at 7 knots, and they indicate similar results. The 1m cube seems to be clearly visible at all times.
Weight restrictions limited the size of the rock tiles on the surface of the cube, resulting in a rock tiling area corresponding to a 0.8m cube. Thus the design of the 2m cube is not ideal, and we cannot expect the Order 1 survey to be verified with this test. Thus the test is inconclusive for Order 1 surveys because of the design of the cube.

Further Work

It will be interesting in the near future to compare the EM 3000 Dual with the new EM 3002 that is being put on the market from Kongsberg Simrad in the fall of 2003.

Acknowledgements

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References

International Hydrographic Organization (1998), 'IHO Standards for Hydrographic Surveys', *Special Publication No. 44,* 4th Edition, International Hydrographic Bureau, Monaco

Wells, D.E., Monahan, D.(2002), 'IHO S-44 Standards for Hydrographic Surveys and the Variety of Requirements for Bathymetric Data', *The Hydrographic Journal,* No 104

Hammerstad, E. (2001), 'EM Technical Note', *Internal Kongsberg Simrad Publication,* Horten

Pøhner, F. (2002), 'Kongsberg Simrad Shallow Water Mapping Solutions', *Internal Kongsberg Simrad Publication,* Horten

Biographies

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Freddy Pøhner was born in Drammen in 1944. He Graduated from the Technical University of Norway, dept of Engineering Cybernetics, in 1967, and was awarded the Dr. Ing. Degree at the same department in 1974. Dr. Pøhner joined the private company Norcontrol the same year, where he stayed for 10 years – working on product developments mainly in the field of radar detection and target tracking. In 1984 he joined Simrad A/S, where he has contributed to the development mainly of hydrographic instruments and systems. Dr. Pøhner is presently responsible for sales and marketing of hydrographic solutions for Kongsberg Simrad.

Kjell Nilsen is Product Manager for Multbeam Echosounders. He has been working with hardware development of fishery and naval sonars (1977 to 1990), and has been occupied with system design and signal processing for multibeam echosounders since 1990.

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