

# **Performance Appraisal of Multibeam System — Hydrosweep at Different Seabed Provinces**

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## **ABSTRACT**

The performance of the multibeam sounding system (Hydrosweep system) has been assessed at three varying zones of the seabed — continental shelf, continental slope, and deepsea seamount areas. Statistical studies were performed on the beamwise time series depth profiles of 17 out of 59 beams. A program modification was made to obtain the time series depth profiles. Statistical evaluation shows that the standard deviation is prominent for slope and seamount areas of deeper waters. Unlike the slope area, the mean depth, mean depth errors, and standard deviations are higher for beams at edges compared to the centre beam in the seamount areas. At continental slope, the correlation coefficient is higher in comparison to that for values at the seamount area. The study at shelf area reveals minimum standard deviation and highest correlation coefficient of different depth values.

## **INTRODUCTION**

Accurate knowledge of water depth is of immediate concern in oceanographic research. Single beam echosounder replaced the lead line methods from 1920's onwards and with this continuous records of depths along each track of the ship became available [3]. Because of the improvement in transducer technology, this technique came into common usage around 1950's. The transducer beam widths were available around 30°- 60°. Narrow beam techniques for bathymetric use were introduced by 1950's and have been fully in operation with the phased array network for real time roll pitch correction since 1960's. Seabed relief from metres to kilometres can be recorded as a continuous profile. To have greater coverage as well as a high precision map, a multi-narrow beam concept was realised[16]. In 1970, the multibeam bathymetric system became commercially available with additional facilities like real time computation and data storage capabilities. Along with depth determination, this sonar system can be used for various objectives, such as geological surveys, to characterize the seabed, geotechnical properties and resource evaluation of polymetallic nodules [4]. Additionally, accurate knowledge

of water depth is of immediate concern in shallow water environment for navigational safety. High resolution, multibeam sounder system is found to be effective from the economic point of view as well as maintenance of higher accuracies and application in rough sea conditions [5,7,18]. Effective use of the above potentialities of the system is possible when a performance study is carried out. This paper presents the results of the performance evaluation of the multibeam system (Hydrosweep: M/S Krupp Atlas Elektronik, Germany) [6]. The Hydrosweep system is installed on *ORV Sagarkanya* and is designed for hydrographic surveying under shallow and deep sea conditions [13]. The National Institute of Oceanography (NIO) is presently using this system for detailed mapping of the manganese nodule rich areas in the Central Indian Basin [8]. It was also used in the central western continental margin of India [11]. Performance evaluation of the system was done using statistical techniques on the depth data collected at three different provinces (continental shelf, continental slope and deep sea seamount region). The statistical technique employed is known as the 'time series analyses', in which the sequence of data points logged for each beam is analysed. The bathymetric time series data for 17 of the 59 beams are presented with respect to the position surveyed for the three areas. This time series information is obtained by introducing modifications in the existing data post-processing software of the hydrosweep system.

### HYDROSWEEP SYSTEM

The first multibeam system was developed by M/s General Instruments Inc., USA under the trade name SEABEAM. It provided a coverage equal to 3/4th of the depth. Hydrosweep has the following advantages over SEABEAM: 1) wider coverage (twice the depth), 2) improved resolution, 3) wider depth range (10-10000 m), 4) maintenance of depth measurement efficiency at varying bottom conditions, and 5) real time sound velocity measuring capabilities [6,17].

The coverage of the hydrosweep system is 90°, and it provides 59 beams. It has identical transducer arrays mounted at right angles to each other, one of the arrays being parallel to the ship keel. Each array is a combination of three sub-arrays consisting of 96 elements, making a total of 288 elements. Since both the arrays are identical, they can be used for either transmission or reception. This facility incorporates a great advantage for calculating the mean sound velocity for the entire water column, which is further used for refraction correction. In the receiving mode, four elements in series form one group and in all 72 groups from 59 beams. The beams are 1.5° apart with average beam width being around 2.3° for deep water surveys (for shallow water, it is equivalent to 4.5°). The signals received are being preamplified, attenuation corrected and thereafter beamforming is performed using appropriate delays for 59 directions. These beamformed output signals are then tracked for bottom to know the exact depth from different directions. The sidelobe levels are 25 dB below the mainlobe, which is achieved

by using an appropriate shading technique. It is a matter of common knowledge that sidelobed suppression is necessary to avoid interference from sidelobes to mainlobes for the same beam or different beams.

Using the advantage of interchangeability of transmitting and receiving functions between the arrays, the system enters to a calibration mode for sound speed measurement. This technique is similar to the determination of root mean square velocity of the bottom layers with Normal Move Out (NMO) corrections in seismic. The comparison of the measured center-beam depth athwartship mode over successive pings with the 59 beams obtained in the fore-aft directions is made. The mean sound velocity is determined by least square residual comparison between the two profiles [17].

To provide a uniform ensonification pattern over  $90^\circ$  athwartship sector, this system performs in a sector scan mode. A transmit beam of beam width of  $45^\circ$  is step scanned in three directions. These beams are at angles of  $0^\circ$  and  $\pm 22.5^\circ$ . Hydrosweep operated in one of the three modes (shallow, medium or deep sea mode) based on the operational depths.

## AREA DESCRIPTION

The hydrosweep system installed onboard *ORV Sagarkanya* is operated in manganese nodule rich areas in the Central Indian Ocean Basin, and central part of the western continental margins of India. The present study was carried out in three selected areas - shallow continental shelf, continental slope and the deep sea seamount areas are the three selected areas.

The shallow shelf area in the Arabian Sea is located off the Mangalore Coast (Fig.1). This area on the western continental shelf lies between  $13.27^\circ$  —  $13.16^\circ$  N and long  $73.92^\circ$  —  $73.97^\circ$  E. The total distance covered is 12.88 nautical miles and the mean centre beam depth is 77.46 m. The seabed here is mainly sand [10]. A gradual change in sediment type to silty sand occurs towards the slope region.

Similarly, the second study area off the western continental margins (between lat.  $12.98^\circ$  —  $12.99^\circ$  N; long.  $73.47^\circ$  —  $73.55^\circ$  E) is a part of the continental slope. Though the mean depth is 634.5 m, the maximum and minimum depths are 1435 m and 282 m, showing large variations. Here, the bottom is of silty sand type. The amount of data chosen for study is 8.78 nautical miles long.

Performance study of the system was also carried out in the deep sea seamount area of the nodule bearing Central Indian Ocean Basin. The mean centre beam depth is 5342 m. The area lies between lat.  $11.75^\circ$  —  $11.64^\circ$  S; long.  $78.58^\circ$  E, covering a length of 9.48 nautical miles. The bottom consists of siliceous sediments [14].

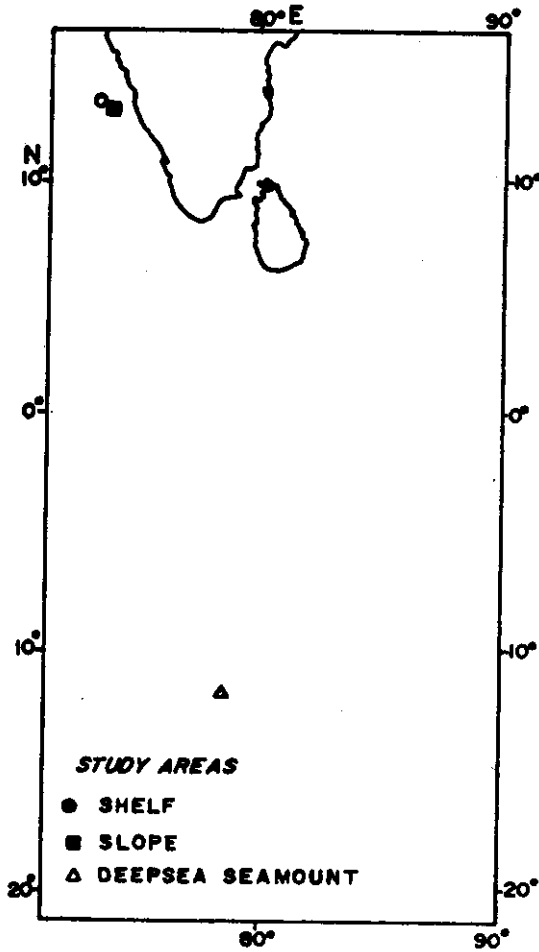


Fig. 1 — Map showing different locations of the study

### PERFORMANCE STUDY

For a bathymetric system operated for depth data acquisition, there are many factors which have direct and indirect implication on the accuracy. Some of the factors are timed depth measurement error, heave, roll and pitch errors, sound velocity measurement errors [12]. Several parameters are responsible for the particular type of error source. For example, range measurement is dependent on the beam angle, depth, bottom composition and roughness, and slope of the bottom. Similarly, error occurs due to the ship's attitude, beam angle, seastate,

depth, heading, ship's speed and platform position. The sound velocity errors are dependent on the beam angle, depth sound velocity at the transducer face, sound velocity structure and gradient.

Capt. W Mobley (NOAA) identified the principal sources of errors in the depth sounding system and estimated a budget for a standard deviation [1]. Capt. Mobley's suggestion imposes a lower bound 68% (1.0 sigma) and upper 90% (1.64 sigma) on the error results. The most practical proposal was made by National Ocean service (NOS), which suggests use of only the 90% depth measurements falling within a specified bound. This means the standard deviation should not exceed 1.64 sigma. The standard deviation  $\sigma_e$  is expressed as:

$$\sigma_e = 0.18 d + 0.006 \quad \dots(1)$$

where  $d$  is the depth,  $\sigma_e$  and  $d$  are expressed in metres. The value of  $\sigma_e$  is computed for different study area to set the maximum possible error limit (goal).

In the statistical technique devised to analyse the system performance, known as 'time series analysis', the sequence of data points logged from each beam is analysed. The bathymetric time series data for 17 of the 59 beams are plotted with respect to the position surveyed (Fig.2). Programs were developed to obtain different beam wise depth data from the Hydrosweep, and to calculate statistical parameters of depth data.

*Shallow shelf area* — The mean centre beam depth on the shallow shelf area is 77.46 m and the general topography of the area is flat and plain. Depth variation from centre to extreme beams is not more than 8 m throughout the area. From Fig.3, it is observed that the beam-wise standard deviation for the centre beam is only 0.26 m. This value is significantly low compared to the upper bound standard deviation computed using Eq.(1). For this depth range, it is equivalent to 0.63 m. All standard deviation values for different beams are low compared to values obtained using Eq.(1). No variation in beam-wise data is observed. Similarly, there is no variation in the mean depth and mean depth difference as seen in Figs 4 and 5.

The seabed in this area consists of coarse grain sediments (calcareous sands), coral and algal reefs and algal hard grounds [10,15]. The performance of the Hydrosweep system operated in this shallow shelf area is different from the performance of Bathymetric Swath Survey System (BSSS, M/S General Instruments, USA) in Bellingham Harbor area. For BSSS, the beam wise standard deviation is much higher than the goal value (upper bound error) [12]. Since the beam widths of these two systems are almost similar, it may be understood that the main reason for such an effect is the type of the bottom and the operating frequency. Bellingham area consists of soft mud and the operating frequency of BSSS is 36 kHz. The higher values of standard deviation are due to the interaction of the soft mud bottom with the relatively high frequency returns. On the other hand, in the shelf bottom condition where the Hydrosweep is operated, the bottom consists of compact sand and the frequency of operation is low (15.5 kHz).

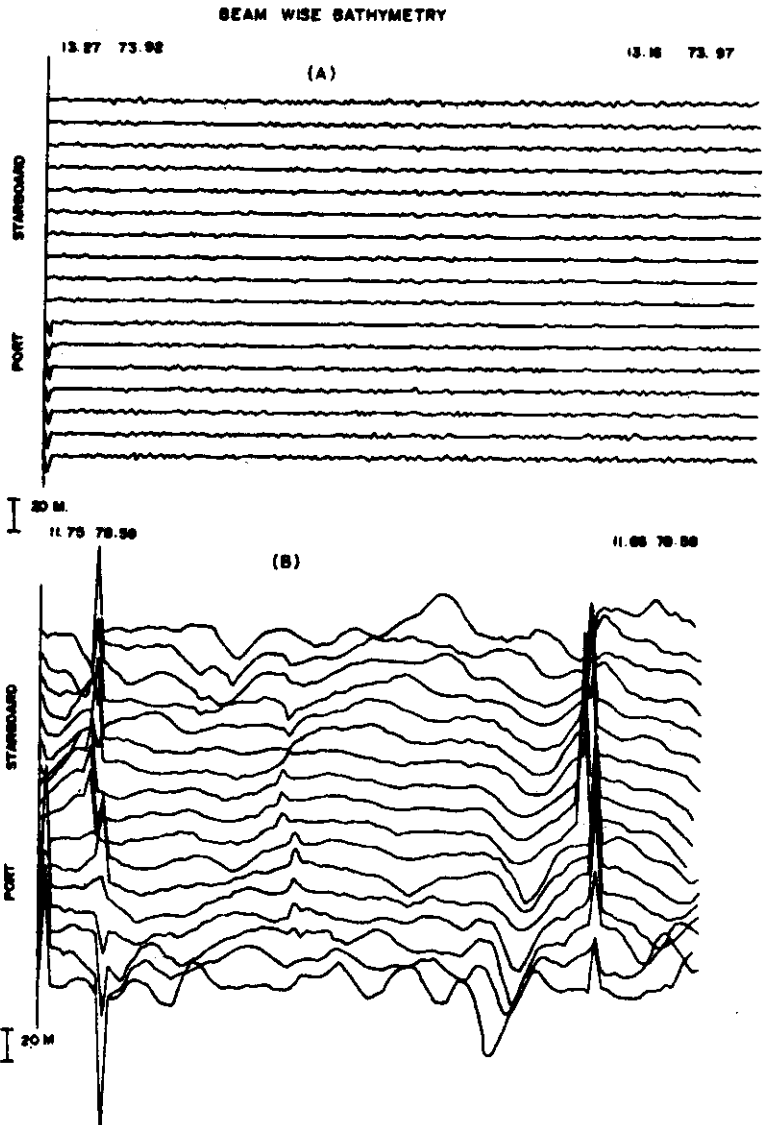


Fig.2 — Beamwise time series output of the shallow shelf (A) and the deep sea seamount area (B)

The cross-correlation coefficient between two random functions provides the inter-relationship between the two sets of data. A critical view at the correlation matrices reveals that the correlation coefficient between the two different depth

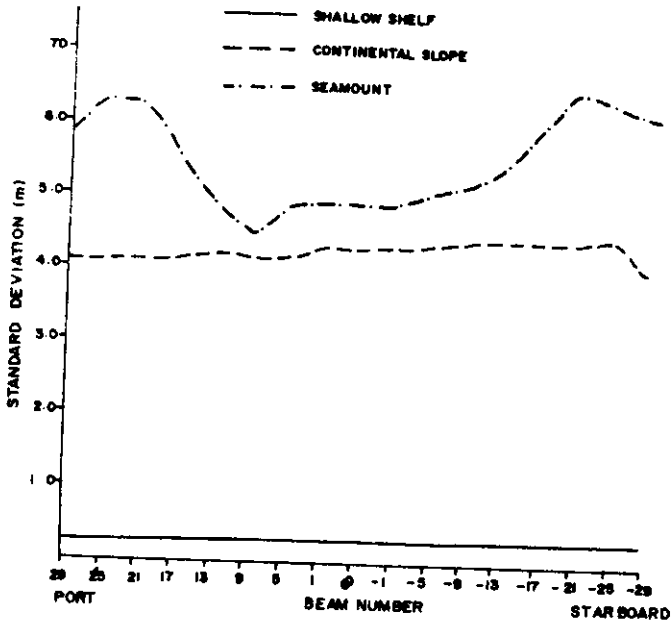


Fig.3 — Standard deviation errors with respect to the beam numbers

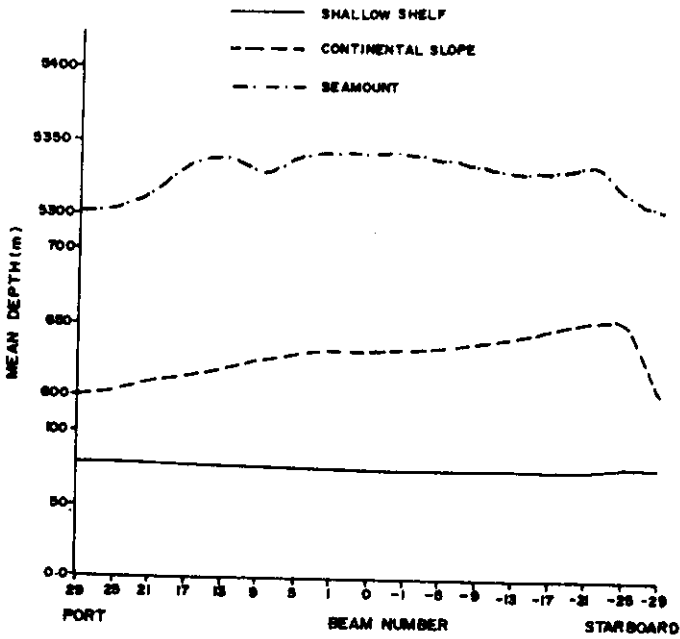


Fig.4 — Mean depth with respect to the beam numbers

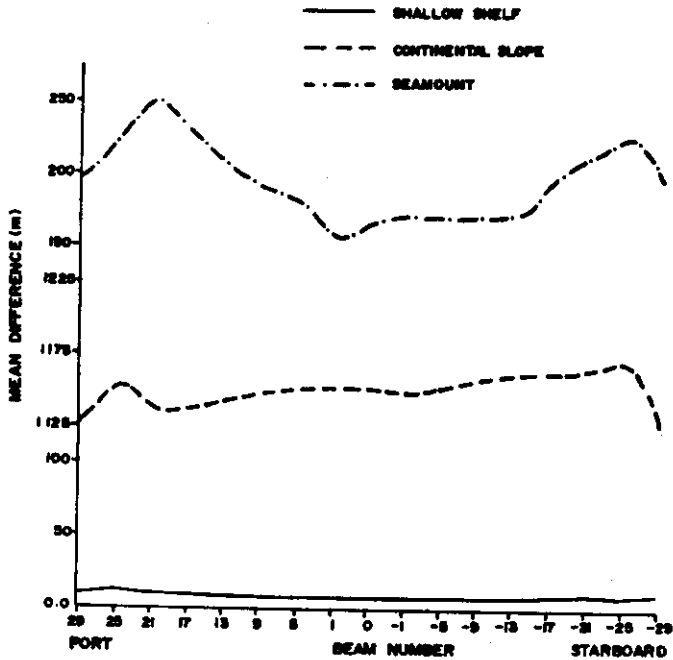


Fig.5 — Mean depth difference with respect to the beam numbers

data varies between 0.92 and 1.0, indicating a strong correlation (Table 1). Depth distribution study in this area is carried out for the centre beam data based on Krause and Meanard [9]. The probability density function (PDF) gives the density of depth distribution of the depth values [2] to find the PDF of the depth, the profiles are divided into depth intervals of 5m. All these values are normalised with respect to PDF information for the shallow shelf region which falls in the range 75-80 m. PDF (Fig. 6) reveals that the distribution is normal, i.e., Gaussian type. This mode of distribution appears to match with the idea of having low standard deviation of the centre depth.

*Continental slope* — The beam-wise time series data for the continental slope area is not presented here because of the difficulty in adjusting its range within the same scale. The standard deviation for the centre beam depth is 4.31 m. The standard deviation values are constant over different beams. The computed upper bound error value (goal) for the centre beam data based on Eq.(1) is found to 3.98 m, slightly higher than the standard deviation in Fig.3. The variation in mean depth is observed to be more in starboard direction than on the port side (Figs 4 and 5), the ship movement being upslope. The initial depth for the centre beam is measured to be 1423 m, which slowly decreases to 294 md. The higher standard





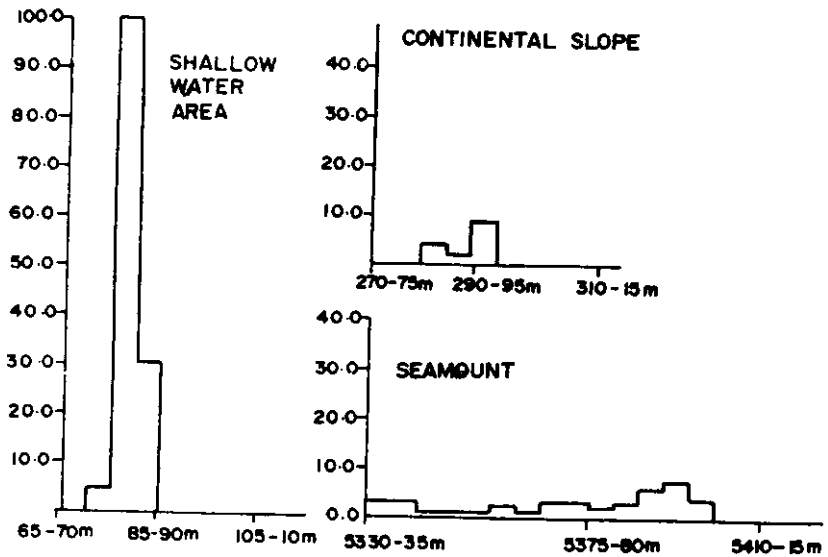


Fig.6 — Probability density functions of the depth data of 3 different study areas

deviation in variation of mean depth is because of the upslope run of the ship. The upslope ship traverses produce second bottom returns and the position of the bottom tracking gate may sometimes be tracking the second return. It was realised [5,12] that these errors are possible artifact effects and are prominent when the ship is in upslope traverse because of the inability of the system to cope up with a sudden depth change when moving upslope. Moustier and Klienrock [5] emphasised the point that the practical way is to run the ship parallel to the slope. Apart from the operational part of the bottom gate, the difficulty may also lie with sidelobe insonification of the slope when upslope traverse is made. A drop in the acoustic signal backscattering strength for other than normal incidence angle is common in comparison to normal incidence. Under this condition the bottom tracking gate may not be able to differentiate between the sidelobe of the normal incidence and the main lobe of the other than normal incidence beams coinciding with the sidelobe.

Comparison of various beam depth data for this area shows that though the area is sloping (Table 1), the correlations are quite good. This ensures that the performance of different beams is very much in relation, though the mean depth difference in the area is quite significant.

The PDF of the centre beam data is found to be non-Gaussian P type (Fig.6). In this study, the available data points beyond the depth 310-315 m are limited and hence have been neglected.

*Deep sea seamount area* — Seamount area is selected to represent the deep sea region, as it is the extreme case where maximum depth variation between the beams is expected. Beamwise plot for deepsea seamount area in the Central Indian Ocean Basin is shown in Fig.2B. The depth range for the centre beam is 5233-5406 m. The data chosen is only a part of a big seamount encountered, which is about 1200 m high. The mean depth for the centre beam is 5342 m. Within the survey line, different seamount peaks are seen in the figure. The standard deviation for the centre beam data is found to be 4.84 m (Fig.3). Also, the standard deviations are higher on the port and starboard side beams. The upper bound error value (goal) is computed (Eq.1) to be 32.23, which is much higher than the values obtained. Though the values for the outer beams are higher, these are still low compared with the goal value. Again, the above observations are seen to be matching with the plots of mean depth and mean depth error with beam numbers (Figs 4 and 5).

A relatively low correlation coefficient of depth data for different beams shows that the variations are maximum in this area compared to the other two study areas (Table 1). The PDF of the centre beam data also supports the fact that the seabed depth distribution is non-Gaussian type, which shows a pronounced skewness of the depth distribution (Fig.6). The features add a segment of shallower depth to a possible symmetrical depth distribution of a uniform province [9].

## CONCLUSION

Beamwise time series analyses establish that the Hydrosweep system performs effectively in the shallow shelf region, where the beamwise standard deviation is very low and the correlation coefficient is high. For the slope area and seamount area of deeper waters, beamwise standard deviation error is higher, though in the seamount area it is significantly less than the goal. The standard deviation, mean depth and mean depth errors are higher for beams at edges compared to the centre beam in the seamount area. For continental slope, correlation coefficient is higher. But the correlation coefficient value in the seamount region is low. However, these variations in the correlation coefficients and standard deviations are within the allowed error limit of the system.

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