

THE INTERNATIONAL HYDROGRAPHIC REVIEW



**INTERNATIONAL HYDROGRAPHIC BUREAU
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Editorial



When I joined the Australian Hydrographic Service as a trainee nautical cartographer in 1979, it didn't take long to find the collection of International Hydrographic Review (IHR) journals in the office library. Over many years, the editions of the IHR have been a major source of knowledge about the international hydrographic community. It is my hope as the new Editor, along with the assistance of the Editorial Board, that the IHR maintains its high standard in providing timely and relevant material to our industry.

This is my first edition as the new Editor and it is appropriate to thank Adam Kerr for his contribution as the previous Editor. I first met Adam in 1990 at an IHO working group meeting in Sydney and I was very fortunate to have worked with Adam on several IHO meetings that he led. His contribution to hydrography and his leadership and mentorship during this period cannot be underestimated. It has been a privilege to know Adam and I am grateful for his friendship over many years.

This Edition comprises six articles covering a wide range of topics. The first article delves into the use of wavelet analysis and artificial neural networks to recover a vessel's 3D position when data gaps from GPS/INS exist. The second paper investigates the characteristics of sea water in tropical regions to determine the requirement for sound velocity measurements for equipment calibration. The continued critical need to ensure hydrographic surveyor training meets industry expectations is covered in our third paper which describes the IHO Cat. A training course in France.

Closer to my home, the fourth paper discusses the complex tidal interactions through Torres Strait. This narrow stretch of water is a critical waterway for shipping transiting through the northern waters of Australia. The organisation structure of hydrographic offices is a continual challenge as HO's face the challenges of tighter budgets, often conflicting priorities between Defence and civil responsibilities and new responsibilities and expectations from a growing public awareness of global issues. Our fifth paper describes the transformation of the French organisation SHOM into a new entity to address these responsibilities and the author looks back on the last 3 years to describe outcomes of the transformation. Our final paper presents quantitative methods and statistical measurements to analyse and evaluate multibeam performance and behaviour to improve data quality and detect artefacts.

This edition includes Notes relating to the launch of the new survey vessel for the Faculty of Maritime Studies, King Abdulaziz University, Saudi Arabia; an advertisement for the upcoming HYDRO2011 being held in Fremantle, Australia in November 2011; and a copy of the opening address given by the Indian Chief of Navy at the recent Hydrographic Symposium held in India.

One publication has been reviewed and deals with Electronic Charting technology for safe navigation and planning. The book provides a thorough discussion on all aspects of the technology and reinforces the need for comprehensive training in order to maximise the use of the technology.

On behalf of the Editorial Board, I hope that this edition provides information of interest to you. If you have any comments, please do not hesitate to contact me. Thank you to all of the authors for your contributions. Your ongoing support of the IHR is much appreciated. Finally, I would like to express thanks to my colleagues who provided peer reviews for the Articles in this edition. Your feedback and encouragement to the authors is much appreciated.

Ian W. Halls
Editor

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BRIDGING GPS OUTAGES USING SPECTRAL FUSION AND NEURAL NETWORK MODELS IN SUPPORT OF MULTIBEAM HYDROGRAPHY.

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Abstract

In classical hydrographic surveying, the use of GPS is limited to providing horizontal control for survey vessels. More recently, an alternative practice has evolved, which determines depth values relative to a geodetic datum and then relate them to tidal datums through a series of vertical datum transformations. Although it has a number of advantages over classical hydrographic surveying, this practice requires accurate 3D positioning information. Unfortunately, accurate 3D positioning solution may not always be available as a result of communication link problems, GPS outages, or unsuccessful fixing for the ambiguity parameters. This paper examines the use of wavelet analysis to spectrally combine the GPS/INS height data series and the heave signal to bridge the height data gaps. In addition, a neural network-based model is developed to precisely predict the horizontal component of the survey vessel.



Résumé

Dans les levés hydrographiques classiques, l'utilisation du GPS est limitée à la fourniture d'un contrôle horizontal pour les bâtiments hydrographiques. Plus récemment, une autre pratique est apparue et celle-ci détermine les valeurs de profondeur par rapport à un système géodésique puis les rapporte au niveau de référence des marées par le biais d'une série de transformations du système géodésique vertical. Bien que ceci offre un certain nombre d'avantages par rapport aux levés hydrographiques classiques, cette pratique nécessite des informations exactes sur la détermination de la position en 3D. Malheureusement, une solution exacte de détermination de la position en 3D n'est pas toujours disponible à cause de problèmes de liaison en matière de communications, de défaillances GPS, ou de réparation infructueuse des paramètres d'ambiguïté. Le présent article examine l'utilisation d'une analyse des ondelettes pour combiner de manière spectrale les séries de données de hauteur GPS/INS et le signal de pilonnement afin de combler les lacunes en données de hauteur. En outre, un modèle inspiré d'un réseau neuronal est en cours de développement en vue d'une prédiction précise de la composante horizontale du bâtiment hydrographique.



Resumen

En los levantamientos hidrográficos clásicos, el uso del GPS está limitado al suministro de control horizontal para los buques hidrográficos. Más recientemente, se ha desarrollado una práctica alternativa, que determina los valores de la profundidad relativos a un datum geodésico y los relaciona posteriormente con los datums de mareas a través de una serie de transformaciones del datum vertical. Aunque tiene una serie de ventajas con respecto a los levantamientos hidrográficos clásicos, esta práctica requiere una información precisa del posicionamiento en 3D. Desgraciadamente, puede que una solución de posicionamiento preciso en 3D no esté siempre disponible como resultado de los problemas de enlaces de datos, los cortes GPS, o un ajuste infructuoso de parámetros de ambigüedad. Este artículo examina el uso de un análisis de ondas pequeñas para combinar espectralmente la serie de datos de altura GPS/INS y la señal de oleaje para superar las deficiencias de datos de alturas. Además, se ha desarrollado un modelo basado en la red neural para predecir con precisión la componente horizontal del buque hidrográfico.

Introduction

The current state of technology in hydrographic surveying makes use of multibeam echo-sounding systems, which provide digital hydrographic data with near-full coverage of the seabed. Traditionally, in multibeam hydrography, the use of GPS has been limited to providing horizontal positioning of the survey vessel. Depth values relative to tidal datum were obtained using the bathymetric data corrected for a number of vertical translations including vessel's draft, squat, settlement, heave and tide. Unfortunately, however, not all vertical translations can be accurately measured or modelled, which affects the accuracy of the final hydrographic products. An alternative practice has recently evolved, which takes advantage of the improved 3D positioning, attitude and heave solutions through the use of RTK-based GPS/INS systems. With this practice, depth values are determined relative to a geodetic datum and then are related to tidal datums through a series of vertical datum transformations. Unlike classical hydrographic surveying, vertical translations such as vessel's draft, squat, settlement and heave are not required with this practice. Unfortunately, although has a number of advantages over classical hydrographic surveying, this practice requires accurate 3D positioning information, which may not always be available as a result of communication link problems, GPS outages, or unsuccessful fixing for the ambiguity parameters. This paper examines the use of wavelet analysis to spectrally combine the GPS/INS height and heave data to obtain continuous, precise high-rate height information. It is shown that the maximum error in the case of a 60-second data gap is 9 cm, which indicates that the height data can be recovered with high accuracy even when relatively long data gaps are encountered. To recover the horizontal positioning component, a neural network-based prediction method was developed. A three-layer feedforward neural network trained with the back-propagation algorithm was employed for this purpose. It is shown that, for an outage period of 60 seconds, the maximum absolute errors in the easting and northing components are in the order of 2.1 cm and 4.3 cm, respectively.

Vessel Positioning and Orientation

Traditionally, the vessel's heading (yaw) was measured by a mechanical gyrocompass (or a magnetic compass), while the roll, pitch and heave information were obtained from a motion sensor. Gyrocompasses provide heading measurements with an accuracy level of 0.75° or better. However, accuracy degradation can be expected under dynamic conditions or with the increase in the vessel's latitude. Magnetic compasses provide heading measurements at a relatively lower accuracy level (about 1-2 degrees or less). The first generation motion sensors employed a two-axis damped pendulum to obtain the pitch and roll information and a vertical accelerometer to obtain the heave information. That series of motion sensors was succeeded by another series, which used the

measurements of a strapdown array of tri-axial linear accelerometers and three angular rate gyros to estimate the pitch, roll and heave. Unfortunately, both generations of motion sensors suffered from accuracy limitations. The most noticeable limitation is the incapability of those sensors to adequately measure the roll component in the presence of strong horizontal acceleration, as a result of, for example, sharp turns (Dinn and Loncarevic, 1994). Multi-antenna GPS systems were also developed in early 90s for the purpose of vessel attitude determination (Lachapelle et al., 1994). These systems have the advantage that they sense the attitude in a purely kinematical mode, which means that they are immune to external forces. This is particularly important when the survey vessel makes a sharp turn. They suffered, however, from some accuracy limitations; with the noise due to the short distances between the GPS antennas being the most challenging. According to Kleusberg (1995), the noise level increases by a factor of 10 if the distances between the antennas are reduced from 10 meters to one meter. Therefore, this method did not find wide acceptance within the hydrographic community.

More recently, a GPS-aided inertial navigation system was developed, which aimed at improving the positioning, attitude and heave solutions by taking advantage of the complementary nature of the GPS and the INS systems. This integration improved the accuracy and reliability of positioning, roll and pitch solutions significantly. However, the accuracy of the heading and heave solutions were relatively low. As shown by Skalous (1995), the accuracy of the heading solution is limited by both the horizontal accelerometer biases and the gyro biases. To overcome this limitation, some manufacturers have recently developed integrated GPS/INS systems that utilize two GPS receivers and antennas, e.g., Applanix POS/MV systems and Seapath 200 RTK. The two GPS receivers are used to determine the initial GPS-based heading of the survey vessel, which is then blended with the inertial data to produce smoothed final heading information. Reported heading accuracy is in the order of 0.01° (1s) for a 4m antenna separation, which is about one order of magnitude better than that of the single GPS-aided INS system. A newer version of Applanix system, POS/MV Elite, was recently introduced, which does not require a second GPS receiver to obtain high-accuracy heading (Applanix, 2009). To achieve this, the POS/MV Elite system uses a higher grade inertial measurement unit (IMU) than predecessor.

Unfortunately, although state-of-the-art RTK-based GPS/INS systems meet the IHO specifications under normal operation conditions, they may not do so under GPS outages. For example, although the recently developed Applanix POS/MV Elite provides sub-decimeter-level accuracy under normal operation conditions, its accuracy is reported to deteriorate to 0.5m (1s) after a 60-second GPS outage (Applanix, 2009).

In fact, the accuracy deteriorates at a much higher rate with longer GPS outage as a result of the INS drift. Considering a 60-second GPS outage and given that the vertical positioning component is always worse than the horizontal positioning component, the POS/MV Elite system may not meet the vertical uncertainty requirements of IHO Special Order. In addition, depending on the water depth and the accuracy of other vertical translations, the vertical uncertainty requirements of IHO Order 1 may not be met as well. Other systems on the market are expected to have a similar or a poorer performance.

Wavelet Analysis

A wavelet is a waveform of finite interval and zero mean (Mathworks, 2002). Wavelet analysis is a relatively new way of modeling and processing signals, which have traditionally been done by Fourier analysis. While Fourier analysis breaks up a signal into sine and cosine functions, wavelet analysis breaks up a signal into translated (i.e., shifted) and scaled versions of the original wavelet. Translating a wavelet means shifting it forward (or backward) in time. Scaling a wavelet, on the other hand, means stretching (or compressing) it to obtain low and high frequency wavelets. Smaller scale factors correspond to more compressed (or high frequency) wavelets and vice versa. There exist many wavelet families that can be used for various purposes, including Daubechies, Haar, Meyer, Morlet, and others. In this paper, we used the Daubechies (db) family of wavelets. There are some advantages of wavelet analysis over Fourier analysis, including the ability of the former to analyze non-stationary signals and signals with more localized features (Bogges and Narowich, 2001; Mathworks, 2002).

A wavelet-based filtering is accomplished by first decomposing the signal to obtain the wavelet coefficients, both approximations and details. The approximations constitute the low-frequency constituents of the signal, while the details constitute the high-frequency constituents. It should be pointed out that a suitable decomposition level must be used, which would depend on the signal characteristics (Mathworks, 2002). Once the wavelet coefficients are obtained, the unwanted coefficients (i.e., details in the case of POS altitude and approximations in the case of heave) are removed or modified. The last step is to re-construct the signal using the approximation coefficients of the POS altitude data and the details coefficients of the heave signal.

Artificial Neural Network Model Development

Artificial Neural Networks (ANN), or simply neural networks, are computational models that imitate the human brain in performing a particular task (Haykin, 1999). They have the capability to solve complex problems through learning, or training, and then generalizing

the network outputs for other inputs. A neural network consists of processing elements, or neurons, that are massively interconnected. Each of the connecting links is characterized by its own weight, or strength. Figure 1 represents a block diagram of a simple model of a neuron showing the weights of the various links. An activation function, such as a sigmoid function or a hyperbolic tangent function, is applied to limit the amplitude of the neuron. The sigmoid function is an s-shaped function, which is used widely in the construction of the neural networks (Haykin, 1999). The logistic function represents an example of the sigmoid function, which is defined as:

$$\phi(v) = [1 + \exp(-av)]^{-1} \quad (1)$$

where the parameter a represents the slope of the sigmoid function. Finally, an external bias, b_k , is applied to increase or lower the net input of the activation function. The neural network is trained to find the optimal values for the weights and the biases.

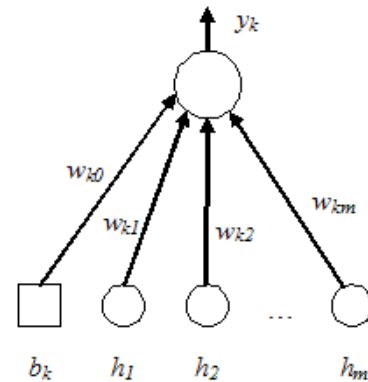


Figure 1. Simple neuron model

The above structure for a neuron k can be represented mathematically as:

$$v_k = \sum_{j=1}^m w_{kj} h_j + b_k = \sum_{j=0}^m w_{kj} h_j \quad (2)$$

$$y_k = \phi(v_k) \quad (3)$$

where $h_0, h_1, h_2, \dots, h_m$ are the input signals; v_k is the activation potential of neuron k ; y_k is the output signal, and $w_{k0}, w_{k1}, w_{k2}, \dots, w_{km}$ are the weights of neuron k . It should be noted in (2) that the values of $h_0 = +1$ and $w_{k0} = b_k$, respectively.

Neural networks can be designed in various ways, depending on how the neurons are structured and the learning algorithms, or rules, used. Network architectures may be classified as single-layer feedforward, multi-layer feedforward, and recurrent networks (Haykin, 1999).

Recurrent neural networks are similar to the feedforward networks, with the exception that the former have at least one feedback loop. According to Schuh et al. (2002), feedforward networks have better prediction capabilities than recurrent networks. In our prediction model, we used the feedforward neural networks. In this case, the output signal at a neuron j (either a hidden neuron or an output node) can be written as:

$$y_j(n) = \varphi(v_j(n)) \quad (4)$$

where $v_j(n)$ is the activation potential of neuron j , which is defined by:

$$v_j(n) = \sum_{i=0}^m w_{ji}(n) y_i(n) \quad (5)$$

where m is the total number of inputs (without the bias) applied to neuron j ; $w_{ji}(n)$ represents the weight connecting the output of neuron i to the input of neuron j at iteration n (n^{th} training example); and $y_i(n)$ is the output signal of neuron i (i.e., the input signal of neuron j). It should be clear that $y_i(n) = h_i(n)$, the i^{th} element in the input vector, if neuron j is in the first hidden layer.

Training a neural network is accomplished through iterative adjustments of the free parameters, i.e., the weights and bias, of the network till we obtain the optimal values. There exist various learning algorithms, which are fundamental to the design of neural networks. Of these, the back-propagation-learning algorithm is the most widely used for feedforward neural networks (Schuh et al., 2002), which is discussed here.

With the back-propagation-learning algorithm, the output signal of a neuron j , $y_j(n)$, is compared to a desired (target) output, $d_j(n)$. The error signal at the output of neuron j , $e_j(n)$, is defined as:

$$e_j(n) = d_j(n) - y_j(n) \quad (6)$$

where n represents the n^{th} training example (i.e., n^{th} pattern). The objective of the iterative adjustments is to make $y_j(n)$ as close as possible to $d_j(n)$, which can be achieved by minimizing a cost function (total instantaneous error energy over all neurons in the output layer) defined as:

$$\mathcal{E}(n) = \frac{1}{2} \sum_{j \in C} e_j^2(n) \quad (7)$$

where C represents all neurons in the output layer. The weight correction $\Delta w_{ji}(n)$ can now be defined according to the delta rule as (Haykin, 1999):

$$\Delta w_{ji}(n) = -\eta \frac{\partial \mathcal{E}(n)}{\partial w_{ji}(n)} = \eta \delta_j(n) y_i(n) \quad (8)$$

where η is the learning rate parameter; and $\delta_j(n)$ is the local gradient defined by:

$$\delta_j(n) = -\frac{\partial \mathcal{E}(n)}{\partial v_j(n)} = e_j(n) \phi_j'(v_j(n)) \quad (9)$$

where $\phi_j'(v_j(n))$ is the derivative of the associated activation function. This means that for $\delta_j(n)$ to exist, the activation function must be continuous, which is satisfied by both the sigmoid and hyperbolic tangent functions presented above.

The selection of the learning rate parameter η affects the rate of learning of the neural network. The smaller the value of η is, the smaller the changes in the weights and network rate of learning. Smaller η values result in smaller changes to the weights in the network, and consequently slower rate of learning. If, on the other hand, the η values are too large, the network may become unstable (i.e., oscillatory) and the algorithm diverges. To overcome this problem, the generalized delta rule is used, which introduces an additional term to (8) known as the momentum constant (see Haykin, 1999 for details).

The weights will be adjusted iteratively by presenting new epochs of training examples to the neural network. Unfortunately, there is no clear-cut criterion to decide when to stop the training, i.e., to consider that the back-propagation algorithm has converged (Haykin, 1999). If the training is not stopped at the right point, an over-fitting of the training data (i.e., model does not interpolate well between the points) might occur. One approach to address this problem is to create a test dataset, which tests the neural network for its generalization performance (NeuralWare, 2001).

Under certain circumstances, for example when encountering a prediction problem, it might be better to use the modular neural networks (NeuralWare, 2001). A modular neural network has the capability of dividing a problem into sub-problems and resolving each sub-problem rather well. It consists of a group of back-propagation networks, sometimes referred to as “local experts”, each has the same architecture. This group of networks compete to learn the various aspects of the problem, which is then controlled by a “gating network”. The number of local experts is determined by the number of output neurons of the gating network. In this work, a modular three-layer feedforward neural network trained using the back-propagation algorithm was selected to predict the horizontal position of the survey vessel during GPS outages.

Results and Discussion

To verify the proposed spectral fusion and neural network techniques, we used the 2005 Common Dataset, which was collected in Plymouth Sound, UK, in August 2004. POS/MV 320 RTK with a 4m antenna separation was used to provide reference positioning, attitude and heave data. A total of eight tracklines were used to verify the proposed technique. The results of one trackline are presented in this section as an example. Similar results were obtained for the other tracklines.

To ensure adequate results, preprocessing of the data was necessary. While the POS altitude data was sampled at approximately 0.1 sec, the heave data was sampled at approximately 0.02 sec (so were the roll and pitch). As such, we used the Matlab toolbox to interpolate the above data sets, along with the heading data, to bring them at exactly 0.02 sec sampling rate. It should be pointed out that the interpolated POS altitude data are only initial values for the high-rate altitude data. Obtaining precise high-rate altitude data, however, is dealt with at a later stage of processing as shown below. As well, gaps in the POS altitude data, which essentially result from the GPS outages, are left without interpolation. The second preprocessing step involved a time offset correction, which was detected between the POS altitude and heave data sets. To determine the time offset, we performed a cross-correlation analysis between the POS altitude and heave data sets. Figure 2 shows the correlation function for trackline 56. As can be seen in Figure 2, the peak of the cross-correlation function is shifted by 0.84 seconds, which indicates that there is a time shift between the two data sets. Table 1 shows the time shifts for all tracklines. Once determined, a time shift correction was applied to the POS altitude data. The final preprocessing step determined the altitude of the IMU reference point (RP) in the North-East-Down (NED) reference frame. This was achieved based on the WGS84 coordinates of the master shipboard GPS antenna, the sensor offsets (lever arm) and the vessel attitude parameters. This step enables the combination of the IMU RP altitude data and the heave signal.

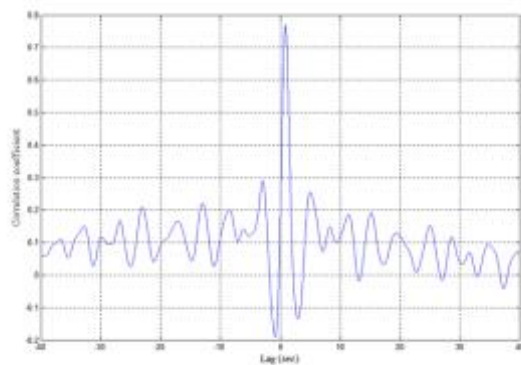


Figure 2. Cross-correlation function showing time shift

Trackline	56	57	58	59	69	70	72	73
Time shift (sec)	0.84	0.00	0.22	0.46	0.24	0.92	0.20	0.06

Table 1. Time shift for all tracklines

a. Height Recovery Results:

Artificial outages of 15, 30 and 60 seconds, respectively, were introduced to the continuous IMU RP altitude data series obtained above. As the heave signal represents the

vertical translation relative to a local mean water level, we considered the line connecting the last point before an outage and the first point after the same outage as the heave datum. The recovered altitude value at any time during an outage is then obtained by adding the heave datum value, relative to WGS84, to the heave value at that time. Table 2 shows the minimum and maximum residual values (i.e. recovered minus reference) and the standard deviations for the various outages. As can be seen, the maximum residual values are less than 3cm and 9cm for outages of 30 and 60 seconds, respectively. This means that the altitude data can be recovered with high accuracy even for data gaps of up to 60 seconds.

Altitude data gap (seconds)	Residuals		Standard deviation (cm)
	Minimum value (cm)	Maximum value (cm)	
15	1.0	2.1	0.7
30	2.5	2.6	1.1
60	2.1	9.0	2.6

Table 2. Altitude residuals for various outage periods

To obtain a precise high-rate altitude data we spectrally combined the heave data with the no-gap altitude data obtained above. In principle, this can be done by applying a high-pass filter to the heave data and a matching low-pass filter to the original (no-gap) altitude data. Adding the two filtered data sets produces the required high-rate altitude data. Traditionally, the Fourier transform is used for this purpose. However, since the heave signal is non-stationary, wavelet analysis might be a better choice. In this research we used the db1 wavelet family with a decomposition level of 3 for filtering both of the original altitude and heave data sets. The final high-rate, precise altitude data was then obtained through signal reconstruction using the approximations coefficients of the original altitude data and the details coefficients of the heave signal. Figures 3 and 4 show a comparison between the recovered high-rate altitude data obtained with the wavelet method and the correct (without the artificial gaps) altitude data. As can be seen in Figures 3 and 4, the two data sets match each other very closely, which proves that the wavelet method can effectively be used to recover the vessel altitude at a high rate.

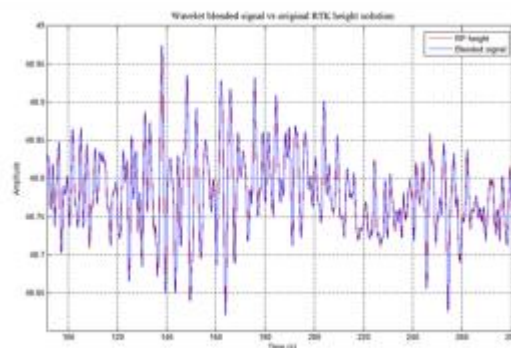
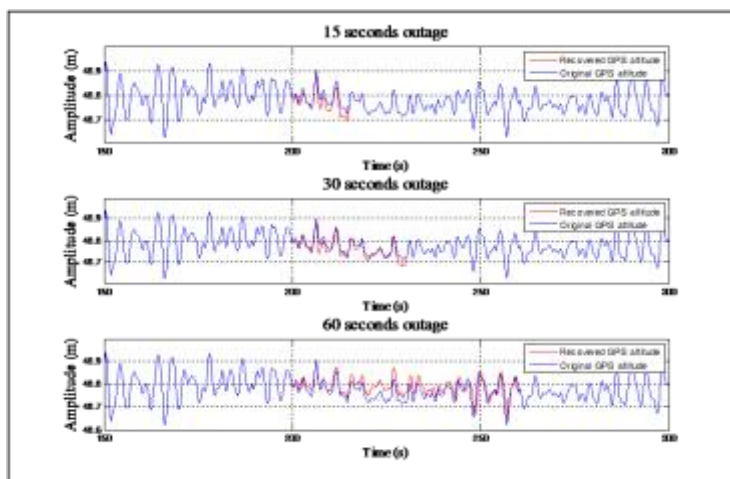


Figure 3. Recovered wavelet-based altitude

Figure 4. :
Recovered
wavelet-based
altitude for
various outage
periods.



b. Horizontal Position Recovery Results:

In principle, predicting the horizontal position can be carried out using differential distance (i.e. distance travelled between two consecutive epochs) and heading data. However, examining the differential distance data series showed that it contains too many spikes, which result from missing values. This can confuse the neural network, which leads to incorrect results. To overcome this problem, we replaced the distance with the vessel speed, which is always uniform, and the time difference. The heading data were used as the third input to the neural network.

As indicated above, we used a modular three-layer feedforward neural network trained using the back-propagation algorithm to predict the horizontal position of the survey vessel during GPS outages. The structure of the neural network was built using the Matlab neural network toolbox.

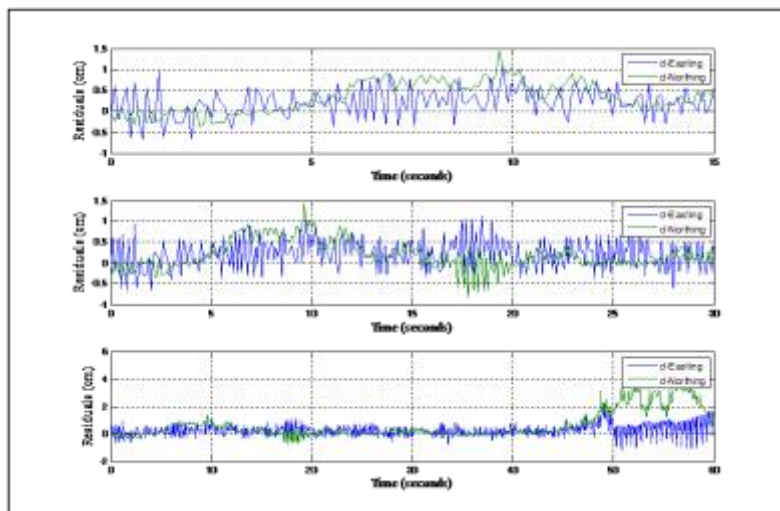
Several tests were conducted to optimize the structure of the network.

It was concluded that the modular neural network with the structure 3-20-2] gives the best results, i.e., has the lowest root-mean-square (RMS) error. Similar to the height data, artificial outages of 15, 30 and 60 seconds, respectively, were introduced to the speed, differential time, and heading data sets. We used a 100-epoch segment of the speed, time difference, and heading data sets for training the neural network, while the network output was the easting and northing increments. Table 3 shows the ANN prediction results for the easting and northing components for the three artificial gaps. Figure 5 shows the northing and easting residuals for the various outages. As can be seen, the designed neural network was capable of predicting the northing and easting components at the centimeter level regardless of the outage duration.

Table 3. Horizontal position residuals for various outage periods

Horizontal Position data gap (seconds)	Easting Residuals		Northing Residuals	
	Mean value (cm)	Maximum value (cm)	Mean value (cm)	Maximum value (cm)
15	0.2	0.7	0.3	0.4
30	0.2	1.1	0.2	1.4
60	0.3	2.1	0.6	4.3

Figure 5.
Easting and
northing
residuals for
various outage
periods



Conclusions

This paper examined the potential use of wavelet analysis and artificial neural networks to recover the vessel's 3D position. It has been shown that the 3D position can be recovered with high accuracy even for data gaps of up to 60 seconds. This allows for a number of applications to be developed, including the development of a seamless vertical reference system and coastal zone management.

Acknowledgments

The 2005 common dataset was made available by the Shallow Survey 2005, which was jointly organized by the UK Hydrographic Office (UKHO) and the Maritime and Coastguard Agency (MCA).

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Biographies

Ashraf El-Assal is the Head of the H.GIS and digital cartography division in the Egyptian Hydrographic office. He is a CAT A hydrographer and has 10 years experience in hydrographic field work and data processing. He took over the responsibility of the Digital cartography division and ENC production in parallel with hydrographic work since 2004. He holds a PhD degree from the Arab Academy for Science and Technology and Maritime Transport, Alexandria, Egypt in hydrographic surveying. Dr. El-Assal is a national expert on the law of the sea and has published several papers in the fields of Hydrographic surveying and digital cartography.

Prof. Dr. Saad M. Abdelrahman is currently the Dean of Education Affairs and Scientific Research in Arab Academy for Science and Technology and Maritime Transport, Alexandria, Egypt. He joined Nautical Department, College of Maritime Transport and Technology as a professor of Physical Oceanography, since 1998. He worked in Faculty of Marine Science, King Abdulaziz University (KAAU), Saudi Arabia from 1989 until 1998 during which he was appointed as a chairman of Marine Physics department. In U.S.A., he worked as an adjunct research professor at Naval Postgraduate School (NPGS), CA during (1986-1987). He joined the Civil Engineering Department, faculty of Engineering, Alexandria University as a lecturer (part time) and also the Institute of Coastal Research in Alexandria as a visiting researcher from 1987 to 1989.

He received his M. Sc. and Ph.D. degrees in 1983 and 1986 from the Naval Postgraduate School (NPGS), California, U.S.A. in Oceanography, with emphasis on coastal processes. In 1980, he received a diploma from NAVOCEANO, U.S.A. in Hydrographic Surveying and Coastal Oceanography. He earned B. Sc. in Civil Engineering, Alexandria University, Egypt in 1973.

Dr. Abdelrahman has specialized in hydrodynamics, coastal processes Oceanography and hydrographic surveying.

Prof. Ahmed El-Rabbany's obtained his Ph.D. degree in GPS from the Department of Geodesy and Geomatics Engineering, University of New Brunswick, Canada. He is currently a full professor and Graduate Program Director at Ryerson University, Toronto, Canada. He also holds an Honorary Research Associate position at the Department of Geodesy and Geomatics Engineering, University of New Brunswick. Prof. El-Rabbany's areas of expertise include satellite positioning and navigation, integrated navigation systems, and hydrographic surveying. He authored an easy-to-read GPS book, which received a 5-star rating on the Amazon website and was listed as a bestselling GPS book. He also published and presented over 180 journal and conference papers and presentations. Prof. El-Rabbany received a number of awards in recognition of his academic achievements, including three merit awards from Ryerson University.

UNDERWATER ACOUSTICS AND DEPTH UNCERTAINTIES IN THE TOPICS

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Abstract

Acoustic velocity is known to vary with temperature, depth and salinity (TDS). Calibration of acoustic systems is required at the beginning and end (and sometimes midway) of each hydrographic operation, in order to correct for these velocity variations. Estuarine waters in the tropics were investigated employing wide combinations of temperature, depth and salinity to verify the relationships between these parameters and the acoustic velocity. A maximum error in depth of 0.2m was obtained. Consequently, in the absence of other sources of errors, acoustic systems may need to be calibrated only once in the cause of a full day bathymetric survey operation in the tropics.



Résumé

L'on sait que la vitesse des ondes acoustiques varie en fonction de la température, de la profondeur et de la salinité (TDS). L'étalonnage de systèmes acoustiques est requise au début et à la fin (et parfois au milieu) de chaque opération hydrographique, afin de corriger ces variations de la vitesse. Les eaux d'estuaires dans les zones tropicales ont été l'objet d'investigations à l'aide d'une large combinaison de températures, de profondeurs et de salinité afin de vérifier la relation entre ces paramètres et la vitesse des ondes acoustiques. Une erreur maximum de profondeur de 0,2m a été obtenue. Par conséquent, en l'absence d'autres sources d'erreurs, les systèmes acoustiques peuvent devoir être étalonnés une fois seulement pour la cause d'une opération de levés bathymétriques d'une journée entière dans les zones tropicales.



Resumen

Se sabe que la velocidad acústica varía con la temperatura, la profundidad y la salinidad (TDS). Se requiere la calibración de los sistemas acústicos al principio y al final (y a veces a mitad de camino) de cada operación hidrográfica, para corregir estas variaciones de velocidad. Se estudiaron las aguas de las zonas de estuarios de los trópicos, empleando amplias combinaciones de temperatura, profundidad y salinidad para comprobar las relaciones entre estos parámetros y la velocidad acústica. Se obtuvo un error máximo de 0,2 m en la profundidad. Por consiguiente, en ausencia de otras fuentes de errores, los sistemas acústicos pueden necesitar ser calibrados sólo una vez a causa de una operación hidrográfica de un día entero de duración en los trópicos.

Introduction

Estuaries represent one of the most ecologically important habitats on earth. An estuary is a semi-enclosed coastal body of water with one or more rivers or streams flowing into it, and with a free connection to the open sea, where freshwater from inland is mixed with saltwater from the sea (US Environmental Protection Agency, 2007a, 2007b; Pritchard, 1967; Stewart, 2005).

It has generally been established that the speed of propagation of sound in water varies with salinity, temperature, and pressure of the water body through which the sound propagates (Mackenzie, 1982; US Naval Academy, 2007). In order to compensate for the effect of the error in acoustic velocity introduced by this variation, acoustic systems are usually calibrated at the beginning, and end of bathymetric operations, and at times in between operations (US Army Corps of Engineers, 1998). The use of sound velocity profilers is also recommended for the determination of the speed of sound, at regular intervals, throughout the duration of survey (Canadian Hydrographic Service, 2005, 2008). These recommendations have been universally practiced for several years in both temperate and tropical regions. This practise has been found necessary for operations in temperate regions where variation in the speed of sound can cause an error as high as 0.7m in measured depth (Osada et al., 2003). However, the need for this practice in tropical regions, with relatively low variation in basic underwater acoustic parameters appears not to have been properly investigated.

The research is intended to determine the degree of variation of acoustic velocity in tropical estuaries, ascertain how it might affect bathymetric operations, and based on deduced facts, suggest appropriate instructions for bathymetric operations in similar environments.

Study Area

The rivers and creeks investigated in this study are all located in the Niger Delta region of Nigeria. This represents a densely populated region in Nigeria, and constitutes the hub of oil and gas industry in the country. The Niger Delta, as officially defined presently by the Nigerian Government, extends over about 70,000 km² and makes up 7.5% of Nigeria's land mass, and includes Bayelsa, Delta, Rivers, Edo, Akwa Ibom, Imo, Abia, Cross River, and Ondo States (see Figure 1).



Figure 1. Map of Niger Delta region MSN Encarta,

The Niger Delta region is characterised by wetlands, and water bodies made up of creeks and rivers traversing the entire region and endowed with enormous natural resources. Apart from being the main source of large deposits of hydrocarbons in the country (Tuttle et al, 1999), it is home to the third largest mangrove forest, with the most extensive freshwater swamp forests, tropical rain forests, and rich biological diversity, in the world (Niger Delta Awareness, 2007).

Acoustic Velocity

Underwater acoustics is of great interest to mariners involved in underwater communication, mapping of the ocean floor and seabed topography. In saltwater, sound travels at speed of between 1,420 m/s and 1,560 m/s or above. As shown in Figure 2, the principal factor influencing the speed of sound in seawater is temperature, with salinity and depth having lower effects. A change of 1°C will result in approximately 4 m/s, while a change of 1 parts per thousand (ppt) in salinity will result in about 1.3 m/s, and a depth of 100m will result in 1.7m/s variation in sound velocity (Dushaw et al. 1993, Hall, 2000). The average value of underwater acoustic velocity has been found to be approximately 1500m/s in seawater (US Naval Academy, 2007; Pike, 1998).

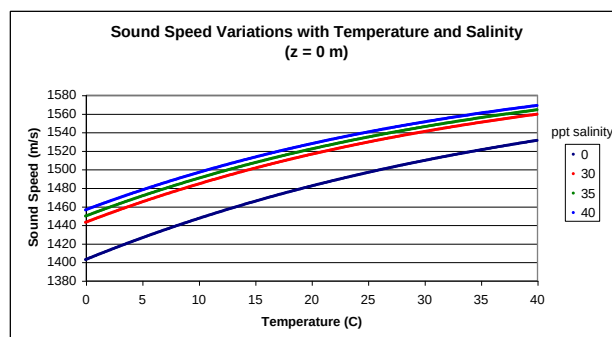


Figure 2. Effects of temperature and salinity variations on sound velocity (After Lurton, 2002).

There are numerous empirical relationships that have been developed for the computation of acoustic velocity from the three basic parameters (temperature, salinity, and pressure). Some of the prominent ones include Woods equation, Wilson equation, Del Grosso expression, Medwin formula, Chen and Millero formula, and Mackenzie formula (Pike, J.M. and Beiboer, 1993)

The various equations have different accuracy specifications, and are employed at different acoustic conditions. Consequently, depending on the expected accuracy, care is usually taken, in the choice of an appropriate model for the computation of acoustic velocities of different water bodies.

Estuaries

This project was developed from evaluation of series of hydrological and acoustic data captured in the course of field work in estuaries.

Estuaries are specialized environments and are usually calm, sheltered and shallow, and may vary greatly in temperature, salinity, and turbidity (murkiness). Thus, average acoustic velocities in estuaries are different from those of the oceans.

Estuaries are defined by tides, as they are washed either daily or twice daily with seawater. At high tide the salinity of the estuary will rise as seawater (20 – 35 ppt of salt dissolved in the water) enters the estuary mixing with freshwater (0 - 0.5 ppt) flowing downstream. The reverse takes place during low tide. Estuarine salinity can thus vary from 0 - 35 ppt depending on the tide and amount of freshwater input. The meeting of seawater and freshwater implies that a range of different temperatures, water levels, currents, and levels of oxygen are also possible.

Estuaries in the Study Area

The estuaries considered in this study are characterised by significant spatial and temporal variations of salinity. This is as a result of the mixing of the fresh waters and the sea waters, and the effect of rainfall in the area. At any given time of the year, a longitudinal salinity gradient exists from the upper reaches to the lower reaches of the estuaries (Dublin-Green, 1990).

The lower reaches (close to the seas) have higher salinity values than the upper reaches. Seasonal (temporal) variations in salinity of the river system are related to the rainfall regime. Maximum salinity values were normally recorded during the late dry season while minimum salinity values are recorded in the late wet season. There also exists slight vertical variation in salinity in the estuaries. Bottom water salinities were observed to be higher than those of the surface. There is also salinity variation over tidal cycles. The estuary waters were more saline during the high waters than the low water periods, due to the influx of sea water during high water (Dublin-Green, 1990).

Temperatures in most of the rivers of the estuaries were almost uniform (Dublin-Green, 1990). But despite the uniformity, water temperature varies seasonally, with maximum values during the late dry season and early wet seasons; and minimum values during the late wet seasons. There is also slight variation of temperature with depth. The temperatures tend to decrease with increasing depth.

The rivers and creeks considered in this study include: Bonny River in the eastern flank of the Niger Delta (see Figure 3), Forcados River, Escravos River, Ramos River, Ethiopie River, Benin River, Jones Creek, Odidi Creek, Staurt Creek, Odimodi Creek, Ahigbo Creek, Keremo Creek, and Iyeye Creek, all in the western flank (see Figure 4).



Figure 3: Study Locations on Eastern Niger Delta, A = Bonny; B=New Calabar River, C=Sambreiro River; D=Buguma Creek; E=Krakrama Creek, F=Cawthorne Channel; and G=Andoni River



Figure 4. Study Locations on Western Niger Delta: A = Forcados River, B = Escravos Rivers, C= Odidi Creek, D= Egwa Creek, E = Jones Creek, Benin Creek, G = Ethiopie River, H= Warri River, I = Staurt Creek, J= Odimodi Creek, and K= Iyeye Creek.

Data Acquisition

The data used in this project were temperature, salinity, and depth values, obtained at 30 minutes interval, from the rivers and creeks in the Niger Delta region of Nigeria. Table 1 shows sample data from the Forcados River while Figures 5 and 6 show the plots of the deferent parameters. Almost all the data considered in the study were observed over a 25 hour period for the various rivers and creeks.

The data were mostly acquired by Geosite Surveys Nig. Ltd, who was commissioned by the Shell Petroleum Development Company of Nigeria (SPDC) to undertake site surveys of all pipelines within the Western Division, on the site of the then proposed Liquefied Natural Gas Loading Jetty (Osuagwu, 1989), in Bonny River. Some data were equally obtained from Zenith Niger Group, who carried out a hydrographic survey of a section of the Forcados River and around a rig site in the Benin Estuary for SPDC.

Location : Forcados River			Water Depth : 10 metres			
Position : 153000mN 327000mE			Date : 12/05/93			
05 23' 2.33" N 05 22' 4.89"E						
TIME	SURFACE SECTION		MIDDLE SECTION		BOTTOM SECTION	
	Temp. (°C)	Salinity (‰)	Temp. (°C)	Salinity (‰)	Temp. (°C)	Salinity (‰)
13:30	27.29	16.54	26.66	22.45	26.62	25.1
14:00	27.47	16.8	26.74	24.4	26.63	25.45
14:30	27.26	18.33	26.67	25.65	26.61	25.4
15:00	27.06	18.9	26.69	24.6	26.58	25.16
15:30	26.88	17.81	26.63	24.3	26.55	25.13
16:00	26.82	18.06	26.6	24.26	26.54	24.92
16:30	26.74	18.02	26.69	23.82	26.52	24.27
17:00	26.45	16.98	26.65	22.5	26.52	23.96
17:30	26.3	16.12	26.63	22	26.53	23.5
18:00	26.12	15.95	26.57	21.16	26.52	23.06
18:30	26.3	15.03	26.5	19.5	26.45	23.02
19:00	26.69	14.64	26.57	19.4	26.5	23.1
19:30	26.4	17.55	26.48	19.22	26.4	21.32
20:00	26.48	16.42	26.45	18.9	26.45	22
20:30	26.55	16.14	26.45	18.5	26.38	20.6
21:00	26.57	15.9	26.5	18.4	26.45	22.4
21:30	26.58	16.81	26.48	18.8	26.45	23.4
22:00	26.59	16.91	26.49	19.3	26.46	23.3
22:30	26.6	16.72	26.48	19.38	26.45	23.55
23:00	26.62	16.7	26.5	20.3	26.48	24.04
23:30	26.7	16.45	26.51	21.5	26.5	24.5
00:00	26.8	16.66	26.62	21.7	26.58	24.9
00:30	27.18	16.97	26.65	23.08	26.56	25.13
01:00	27.29	16.5	26.66	23.4	26.62	25.1
01:30	27.44	16.8	26.75	24.4	26.6	25.45
02:00	27.26	17.3	26.67	24.75	26.61	25.4
02:30	27.1	17.8	26.7	24.6	26.58	25.2
03:00	26.88	17.8	26.63	24.1	26.55	25.13
03:30	26.85	17.7	26.58	23.55	26.5	24.92
04:00	26.74	15.9	26.69	21.23	26.52	24.2
04:30	26.7	15.5	26.64	20.2	26.52	23.65
05:00	26.69	15.1	26.66	19.8	26.5	23.45
05:30	26.64	15.95	26.58	19.2	26.52	23.3
06:00	26.57	15.05	26.53	19.07	26.49	23.02
06:30	26.21	14.32	26.4	20.51	26.42	22.8
07:00	26.32	14.57	26.43	20.76	26.48	22.83
08:00	26.43	17.55	26.46	19.22	26.45	21.32
08:30	26.48	16.45	26.45	19.9	26.45	22
09:00	26.52	16.14	26.47	19.85	26.45	21.9
09:30	26.57	15.94	26.5	18.77	26.45	22.4
10:00	26.57	16.81	26.5	18.8	26.48	23.45
10:30	26.59	16.7	26.49	19.26	26.46	23.3
11:00	26.61	16.72	26.49	19.38	26.48	23.55
11:30	26.62	16.72	26.5	20.22	26.48	24.04
12:00	26.69	16.45	26.54	21.9	26.55	24.54
12:30	26.8	16.64	26.62	21.72	26.58	24.92
13:00	27.14	16.97	26.66	23.08	26.6	25.13
13:30	27.2	17.1	26.78	23.1	26.7	25.2
14:00	27.35	17.23	26.95	23.23	26.67	25.12
14:30	27.1	17.2	26.87	23.13	26.8	25.2

Table 1. Forcados River Salinity, Temperature, Depth Values



Figure 5. Plot of sectional temperature values against time, for the Forcados River.

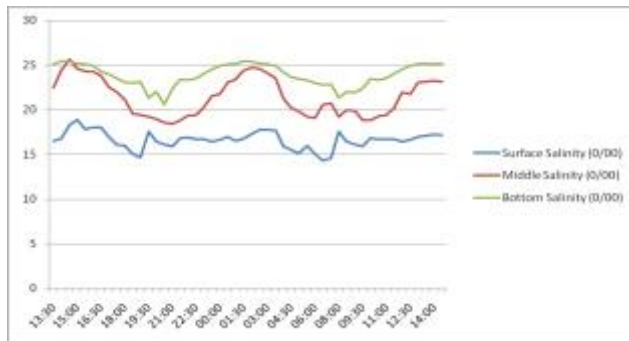


Figure 6. Plot of sectional salinity values against time, for the Forcados River.

Data Processing

To compute the maximum variation in acoustic velocities of the rivers and creeks, the velocities of the water bodies for a particular period were initially computed from the temperature, salinity, and depth (pressure) values, obtained from the rivers. The acoustic velocities were computed using the Chen and Millero formula. The prevalent conditions in the estuaries of the tropics fall within the ranges of the parameters contained in the Chen and Millero algorithm.

The Chen and Millero expression is based on the comprehensive observation of sea waters in the ranges of :

$$0 < T < 40^{\circ}; 0 < S < 40; 0 < P_b < 1000.$$

where:

$$P_b = \text{Hydrostatic Pressure in bars}$$

From the validity matrix of Del Grosso formula, it was observed that the Del Grosso formula, which compares with Chen and Millero in precision and accuracy, is only suitable for deeper waters (depth > 1000m). In addition to this, the valid temperature and salinity ranges are outside the temperature and salinity ranges of the rivers and creeks considered.

The same applies to the Medwin formula. Furthermore, the Mackenzie formula that could have approximated the Chen and Millero formula has a valid salinity range above those encountered in the estuary of study.

Chen and Millero Equation

This formula, developed in 1977 and adopted by UNESCO in 1983 is given by:

$$C = C_w(t,p) + A(t,p)*S + B(t,p)*S^{3/2} + D(t,p)*S^2$$

where :

$$C_w(t,p) = (C_{00} + C_{01}*T) + (C_{02} * T^2 + C_{03}*T^3 + C_{04}*T^4 + C_{05}*T^5) + (C_{10} + C_{11}*T + C_{12}*T^2 + C_{13} * T^2 + C_{14}*T^4) * P_b + (C_{20} + C_{21}*T + C_{22}*T^2 + C_{23} * T^2 + C_{24}*T^4) * P_b^2 + (C_{30} + C_{31}*T + C_{32}*T^2) * P_b^3$$

$$A(t,p) = (A_{00} + A_{01}*T) + (A_{02} * T^2 + A_{03}*T^3 + A_{04}*T^4 + A_{05}*T^5) + (A_{10} + A_{11}*T + A_{12}*T^2 + A_{13} * T^2 + A_{14}*T^4) * P_b + (A_{20} + A_{21}*T + A_{22}*T^2 + A_{23} * T^2 + A_{24}*T^4) * P_b^2 + (A_{30} + A_{31}*T + A_{32}*T^2) * P_b^3$$

$$B(t,p) = (B_{00} + B_{01}*T) + (B_{10} + B_{11}*T)*P_b$$

$$D(t,p) = D_{00} + D_{10}*P_b$$

Computation was however truncated at the 2nd term of the above expressions (i.e. for C_w , $A(t, p)$, $B(t,p)$ and $D(t,p)$) since this is adequate for the accuracy requirement in this investigation.

The coefficients in the above expressions to the 2nd term are defined in Table 2.

Table 2. Definition of coefficients in Chen and Millero Equation

SUBSCRIPT	A	B	C	D
00	+ 1.389	-1.922E-2	1402.388	1.727E-3
01	-1.262E-2	-4.42E-5	5.03711	*
02	+7.164 E-5	*	-5.80852E-2	*
03	2.006E-6	*	3.3420E-4	*
04	-3.21E-8	*	-1.4780E-6	*
05	*	*	3.1464E-9	*
10	9.4742E-5	7.3637E-5	0.153563	-7.9836E-6
11	-1.258 E-5	1.7945E-7	6.8982E-4	*

Computation of acoustic velocities of the rivers

A program was developed based on the Chen and Millero formula for the computation of the acoustic velocities. The depth values, where appropriate, were converted to pressure values using Medwin Depth/Pressure relationship given by:

$$D = 9.7153 \cdot P_k$$

where;

$$D = \text{Depth}$$

$$P_k = \text{Hydrostatic Pressure (kg.cm}^{-2}\text{)}$$

It should be noted that $1\text{ bar} = 10^5 \text{ Pa} = 10/g (\phi) \text{ Kg.Cm}^{-2}$ where:

g = Acceleration due to gravity at latitude ϕ

The acoustic velocities of the surface, middle, and bottom sections of each column of rivers were computed, and the mean of these sectional velocities were taken as the velocity of each column of water, for the particular time interval. The initial velocities computed were based on the original raw data captured directly from the field. To ascertain the effect of variation of any of the three basic parameters (temperature, salinity, depth) on the acoustic velocities; and to simulate all possible conditions in the entire estuary, the parameters were subsequently varied from the lowest to the highest expected range in tropical estuaries. *Table 3* shows the various combinations of the parameters employed in the computations for all the rivers. Salinity was varied between $0\text{‰} - 35\text{‰}$, temperature was varied between $15^\circ\text{C} - 35^\circ\text{C}$, and depth, from $3\text{m} - 15\text{m}$. These values represent the extreme ranges that can be encountered in estuaries in Nigeria.

The mean velocities for the rivers were computed from the acoustic velocities already computed, using the moving averages.

That is:

$$\text{Mean Velocity} = \frac{(v_1 + (2 \cdot v_2) + v_3))}{4}$$

where v_1, v_2, v_3 represent velocities at the surface, middle and bottom respectively.

Computation of maximum variation of acoustic velocity

Proceeding from the previous section, the maximum and minimum variation in acoustic velocities of the rivers and creeks for all the considered conditions were determined. The maximum velocity variation was computed as the difference between the highest mean velocity value and the lowest mean velocity value of any particular river.

Modelling the effect of acoustic velocity variation

Having computed the maximum velocity variation from the different models, the effects of the variations on sounded depths were computed. The two-way travel time of the acoustic wave is given by:

$$t = \frac{2 \cdot d}{v}$$

where:

v and d represent the acoustic velocity and the sounded depth respectively.

The effect ' μ ' of the variation of the acoustic velocity on depth ' d ' were computed from the computed velocity variations, and the mean time of travel in the river. This was done for all the combinations of the temp, depth and salinity for the rivers and creeks considered.

That is:

$$\partial = \frac{\mu \cdot t}{2}$$

where:

μ = Variation of acoustic Velocity (Maximum Mean Velocity – Minimum Mean Velocity)

t = Mean time of travel

∂ = error in d due to μ

Results and discussion

Table 4 shows the velocity computations for the observed combination of parameters, whilst *Figures 7 to 9* show plots of velocities for the original data obtained from the Forcados River, Odidi Creek and the Bonny River. *Table 5* shows the maximum and minimum values of the velocities for the various models, while *Figure 10* shows the velocity variation plot for all the chosen combinations of temperature, salinity, and pressure.

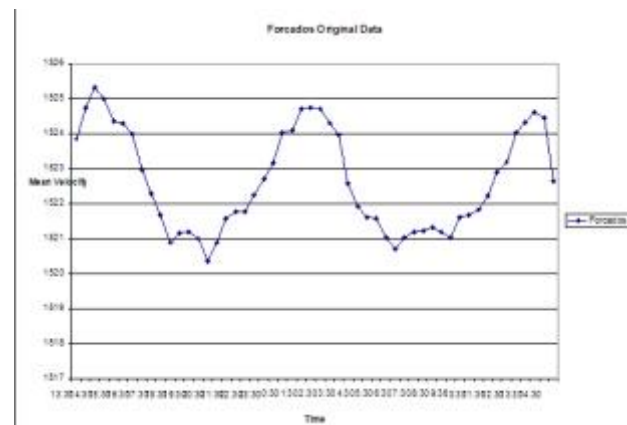


Figure 7. Forcados River mean velocity vs time (original data)

S/N	Model	Temperature ($^{\circ}\text{C}$)	Salinity (‰)	Depth (m)
1	Original Data	Original value	Original value	Original value
2	0- Salinity model	Original value	0	Original value
3	0-Salinity-3m Depth	Original value	0	3
4	0-Salinity-15m Depth	Original value	0	15
5	3m Depth	Original value	Original value	3
6	15m Depth	Original value	Original value	15
7	15- Salinity	Original value	15	Original value
8	15- Salinity-3m Depth	Original value	15	3
9	15- Salinity-15m Depth	Original value	15	15
10	15- Salinity model	Original value	35	Original value
11	15- Salinity-3m Depth	Original value	35	3
12	15- Salinity-15m Depth	Original value	35	15
13	15 Degree Temp	15	Original value	Original value
14	15 Degree - 3m Depth	15	Original value	3
15	15 Degree - 15m Depth	15	Original value	15
16	15 Degree - 3m Depth-0 Sal	15	0	3
17	15 Degree - 15m Depth-0 Sal	15	0	15
18	15 Degree -0 Salinity	15	0	Original value
19	15 Degree -15 Salinity	15	15	Original value
20	15 Degree -35 Salinity	15	35	Original value
21	15 Degree Temp	35	Original value	Original value
22	15 Degree -0 Salinity	35	35	Original value
23	15 Degree -15 Salinity	35	15	Original value
24	15 Degree -0 Salinity	35	0	Original value
25	15 Degree - 3m Depth-35 Sal	35	35	3
26	15 Degree - 15m Depth-35 Sal	35	35	15

Table 3: Matrix of models

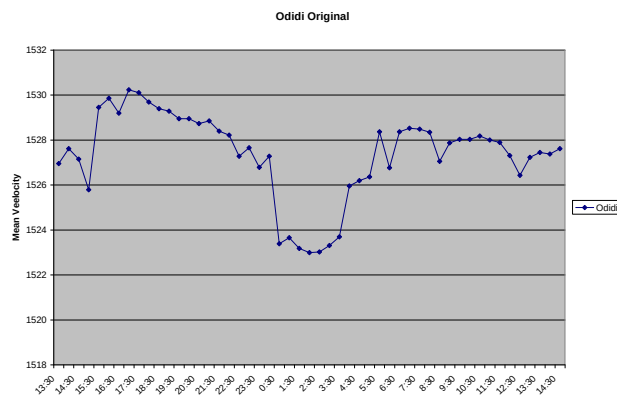


Figure 8. Odidi Creek mean velocity per time (original data)

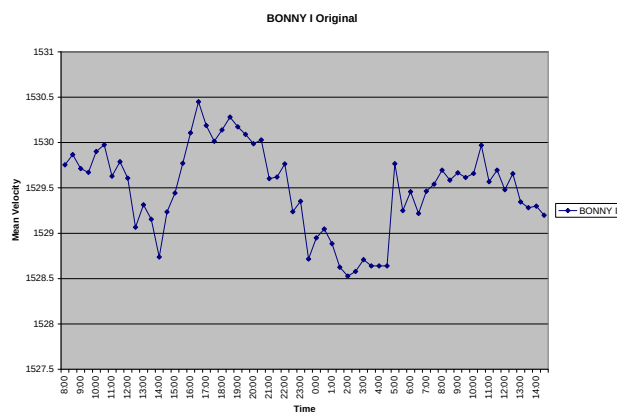


Figure 9. Bonny River mean velocity per time (original data)

The error in depth introduced by the maximum velocity variation in Figure 10 was compared with the allowable errors for the various orders of bathymetric surveys.

The International Hydrographic Organisation (IHO) classified hydrographic operations into four different orders (special, first, second and third order) for the purpose of evaluating depth/bathymetric uncertainties. (IHO S44, 1998, Wells and Monahan, 2002).

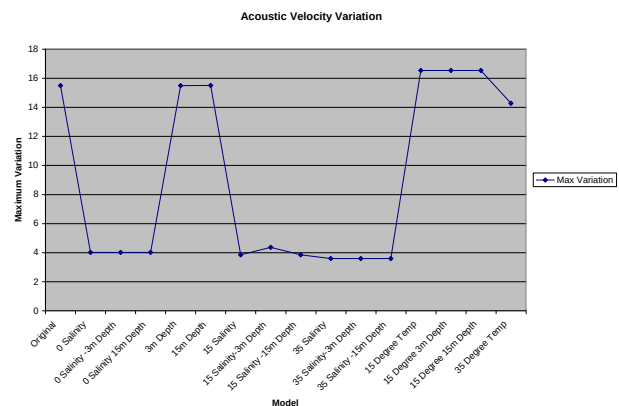


Figure 10. Maximum Acoustic Velocity Variation Plot

TIME	Jones Crk	TIME	Ethiopia	TIME	Benin Cr	TIME	Escravos	TIME	Bonny	TIME	BONNY T
10:30	1515.25	8:00	1526.21	11:00	1519.01	7:30	1521.35	8:40	1515.64	6:40	1528.70
11:00	1515.22	8:30	1526.79	11:30	1519.00	8:00	1520.78	9:30	1516.12	6:30	1528.60
11:30	1514.57	9:00	1526.88	12:00	1520.66	8:30	1520.61	9:00	1515.25	6:00	1528.71
12:00	1514.26	9:30	1526.21	12:30	1520.67	9:00	1520.60	9:30	1515.49	5:30	1528.65
12:30	1514.17	10:00	1526.01	13:00	1520.27	9:30	1520.77	10:00	1515.54	10:00	1528.9
13:00	1515.95	10:30	1526.43	13:30	1520.25	10:00	1520.8	10:30	1515.8	10:30	1528.02
13:30	1515.96	11:00	1526.17	14:00	1520.44	10:30	1520.97	11:00	1515.7	11:00	1528.63
14:00	1514.2	11:30	1526.89	14:30	1520.7	11:00	1520.70	11:30	1515.75	11:30	1528.3
14:30	1514.0	12:00	1526.77	15:00	1520.26	11:30	1521.25	12:00	1515.89	12:00	1528.61
15:00	1514.7	12:30	1526.6	15:30	1520.29	12:00	1520.88	12:30	1515.97	12:30	1528.02
15:30	1515.25	13:00	1526.21	16:00	1520.61	12:30	1521.01	13:00	1516.05	13:00	1528.29
16:00	1515.70	13:30	1526.89	16:30	1520.84	13:00	1521.41	13:30	1516.31	13:30	1528.38
16:30	1515.4	14:00	1526.81	17:00	1520.66	13:30	1521.88	14:00	1516.37	14:00	1528.72
17:00	1515.39	14:30	1526.8	17:30	1520.82	14:00	1521.30	14:30	1516.11	14:30	1528.23
17:30	1515.21	15:00	1526.66	18:00	1520.66	14:30	1521.21	15:00	1516.61	15:00	1528.43
18:00	1515.43	15:30	1526.88	18:30	1520.66	15:00	1521.1	15:30	1517.77	15:30	1528.77
18:30	1515.30	16:00	1526.62	19:00	1520.81	15:30	1521.32	16:00	1517.85	16:00	1528.09
19:00	1515.27	16:30	1526.66	19:30	1520.67	16:00	1521.17	16:30	1517.8	16:30	1528.46
19:30	1515.22	17:00	1526.73	20:00	1520.77	16:30	1521.32	17:00	1517.81	17:00	1528.13
20:00	1515.09	17:30	1526.77	20:30	1520.75	17:00	1520.64	17:30	1517.35	17:30	1528.02
20:30	1515.32	18:00	1526.29	21:00	1520.68	17:30	1520.79	18:00	1516.8	18:00	1528.13
21:00	1515.22	18:30	1526.17	21:30	1520.72	18:00	1520.90	18:30	1516.8	18:30	1528.27
21:30	1515.39	19:00	1526.2	22:00	1520.96	18:30	1521.15	19:00	1516.59	19:00	1528.17
22:00	1515.29	19:30	1526.48	22:30	1521.2	19:00	1521.36	19:30	1516.88	19:30	1528.08
22:30	1514.88	20:00	1526.44	23:00	1520.75	19:30	1521.07	20:00	1516.59	20:00	1528.88
23:00	1514.27	20:30	1526.88	23:30	1520.66	20:00	1521.01	20:30	1516.7	20:30	1528.02
23:30	1515.3	21:00	1526.22	0:00	1520.84	20:30	1521.77	21:00	1526.74	21:00	1528.61
0:00	1515.25	21:30	1526.74	0:30	1520.65	21:00	1521.42	21:30	1526.94	21:30	1528.62
0:30	1515.64	22:00	1526.84	1:00	1520.20	21:30	1521.70	22:00	1526.92	22:00	1528.77
1:00	1515.32	22:30	1526.4	1:30	1520.48	22:00	1521.55	22:30	1526.82	22:30	1528.27
1:30	1515.25	23:00	1526.42	2:00	1520.82	22:30	1521.30	23:00	1526.87	23:00	1528.38
2:00	1515.19	23:30	1526.44	2:30	1520.19	23:00	1521.04	23:30	1526.85	23:30	1528.68
2:30	1515.29	0:00	1526.38	3:00	1520.29	23:30	1521.02	0:00	1526.82	0:00	1528.35
3:00	1515.39	0:30	1526.31	3:30	1520.2	0:00	1520.81	0:30	1526.84	0:30	1528.02
3:30	1515.06	1:00	1526.33	4:00	1520.8	0:30	1521.1	1:00	1526.87	1:00	1528.79
4:00	1515.01	1:30	1526.32	4:30	1520.3	1:00	1520.85	1:30	1526.87	1:30	1528.61
4:30	1515	2:00	1526.4	5:00	1520.37	1:30	1521.15	2:00	1526.76	2:00	1528.35
5:00	1515.08	2:30	1526.48	5:30	1520.29	2:00	1521.11	2:30	1526.82	2:30	1528.57
5:30	1515.2	3:00	1526.41	6:00	1520.47	2:30	1521.7	3:00	1526.88	3:00	1528.67
6:00	1515.31	3:30	1526.22	6:30	1520.51	3:00	1521.4	3:30	1526.27	3:30	1528.62
6:30	1515.36	4:00	1526.61	7:00	1520.72	3:30	1521.8	4:00	1526.32	4:00	1528.62
7:00	1514.79	4:30	1526.03	7:30	1520.81	4:00	1522.78	4:30	1526.43	4:30	1528.62
7:30	1514.8	5:00	1526.84	8:00	1520.27	4:30	1524.36	5:00	1526.47	5:00	1528.65
8:00	1515.01	5:30	1526.38	8:30	1520.66	5:00	1523.83	5:30	1526.34	5:30	1528.28
8:30	1514.77	6:00	1526.28	9:00	1520.92	5:30	1524.48	6:00	1526.2	6:00	1528.21
9:00	1514.77	6:30	1526.17	9:30	1520.88	6:00	1524.69	6:30	1526.61	6:30	1528.23
9:30	1515.07	7:00	1526.97	10:00	1520.81	6:30	1524.38	7:00	1526.47	7:00	1528.47
10:00	1515.29	7:30	1526.61	10:30	1520.33	7:00	1525.74	7:30	1526.3	7:30	1528.3
10:30	1514.88	8:00	1526.8	11:00	1520.31	7:30	1525.01	8:00	1526.7	8:00	1528.71
11:00	1514.27	8:30	1526.71	11:30	1520.2	8:00	1525.44	8:30	1526.25	8:30	1528.35
11:30	1515.3	9:00	1526.02	12:00	1520.09	8:30	1525.09	9:00	1526.88	9:00	1528.68
mean	1514.68		1525.24		1520.29		1523.06		1526.12		1528.48

Table 4. Mean Velocities (Moving Averaging) from Jones Creek, Ethiop, Benin, Escravos and Bonny Rivers (Original Data).

Model	Maximum Variation Velocity (m/s)	River/Creek	Minimum Variation Velocity (m/s)	River/Creek
Original Data	15.4903	Benue	1.5056	Egwa
0-Salinity model	4.011	Odidi	0.7802	West Kereku
0-Salinity-3m Depth	4.011	Odidi	0.7802	West Kereku
0-Salinity-15m Depth	4.011	Odidi	0.7803	West Kereku
3m Depth	15.489	Benue	1.5056	Egwa
15m Depth	15.489	Benue	0.5056	Egwa
15-Salinity	3.843	Odidi	0.748	West Kereku
15-Salinity-3m Depth	4.362	Odidi	0.7479	West Kereku
15-Salinity-15m Depth	3.844	Odidi	0.748	West Kereku
35-Salinity model	3.591	Odidi	0.6996	West Kereku
35-Salinity-3m Depth	3.591	Odidi	0.6997	West Kereku
35-Salinity-15m Depth	3.591	Odidi	0.6998	West Kereku
15 Degree Temp	16.530	Benue	0.4395	Odiodi
15 Degree-3m Depth	16.529	Benue	0.4395	Odiodi
15 Degree-15m Depth	16.529	Benue	0.4395	Odiodi
35 Degree Temp	14.277	Benue	0.0214	Egwa

Table 5. Results of maximum and minimum acoustic velocity variation

The expression for the bathymetric uncertainty is given by:

$$S = \pm \sqrt{[a^2 + (b \cdot d)^2]}$$

where:

S = uncertainty

a = sum of depth independent errors, i.e. the sum of all constant errors

b = sum of depth dependent errors,

d = depth of water column in metres

The values of these factors are given in *Table 6* below.

ORDER	Special	First	Second	Third
Reduced depth Accuracy Factors (IHO, 1998)	a = 0.25m b = 0.0075	a = 0.5m b = 0.013m	a = 1.0m b = 0.023m	a = 1.0m b = 0.023m
Depth	15m / 40m	100m	200m	250m
Allowable Error	0.274m / 0.391m	1.391m	4.707m	5.836m

Table 6 Depth Accuracy Factors (IHO, 1998) and Allowable Depth Error

Using the above equation and the factors in *Table 6*, the following allowable depth errors were computed for each of the categories of hydrographic survey (see also *Table 6*).

Figure 11 shows the plot of the errors in sounded depth due to the different velocity variation in all the models and the plots the allowable error for a 15m and 40m depth estuary. It was found in this study that for the maximum velocity variation of 16.5296m/s in the study area, an error of 0.0819m in the sounded depth, will result. But as seen from the computation presented in *Table 6* and *Figure 11*, special order bathymetric surveys will have an allowable depth error of 0.274m for a 15m depth estuary, and 0.391m for a 40m depth estuary.

It can therefore be inferred that the effect of the variations in acoustic velocity on the sounded depth is insignificant for most practical purposes for bathymetric surveys in estuaries in the tropics. Consequently, for such surveys in the tropics, and in the absence of other sources of errors, the initial calibration (start of sounding calibration) will be sufficient for the whole duration of the survey.

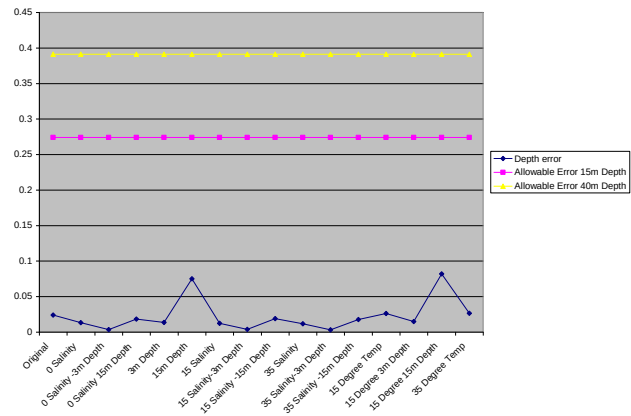


Figure 11. Maximum Depth Error Plot

Conclusion

The studies have shown that even under extreme combinations of temperature and salinity, the maximum velocity variation obtained in the tropics, and particularly in Nigeria, was 16.53m/s and this introduced a depth error of 0.082m for a depth 15 meters, which is greater than the maximum depth in the area. Computation of errors for bathymetric uncertainty for a depth of 15m is 0.274m while the error for the maximum depth of 40m in special order surveys is 0.391m.

It is therefore obvious that the error introduced by the variation of acoustic velocity in tropical estuaries is below the allowable error and can be regarded as having insignificant effect to the sounded depth.

It can therefore be inferred that whilst carrying out a bathymetric survey in these locations, the initial calibration (start of sounding calibration) will suffice for the duration of the survey and the variation in the acoustic velocity will be assumed to be negligible for all practical purposes. Consequently, when providing hydrographic survey instructions, it is recommended to make a distinction between tropical and temperate environments.

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HYDROGRAPHY AT MASTER AND IHO CAT-A LEVEL AT ENSTA-BRETAGNE¹

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Abstract

This paper aims at analyzing the requirements for the education of surveyors acting at the IHO Cat A level, namely those who will manage independently hydrographic fieldworks. We also propose an analysis of the educational capacity in hydrography, with regards to both the professional demand of hydrographers and the required level in the industry. This paper is the fruit of a work conducted for four years at the ENSTA-Bretagne, the French IHO Cat A course. We use the results of a complete redesign of our course that occurred in 2006 and from our three years of feedback from the industry.



Résumé

Cet article vise à analyser les besoins en matière d'enseignement d'hydrographes qui interviennent au niveau de cat A de l'OHI, à savoir ceux qui gèreront de façon indépendante les travaux hydrographiques sur le terrain. Nous proposons également une analyse des capacités d'enseignement en hydrographie, à la fois eu égard à la demande professionnelle en hydrographes, et au niveau requis dans l'industrie. Cet article est le fruit de travaux menés pendant quatre années à l'ENSTA-Bretagne, dans le cadre du cours français de cat A de l'OHI. Sont utilisés les résultats d'un réaménagement complet de notre cours effectué en 2006 et de trois ans d'informations en retour de l'industrie.



Resumen

El objetivo de este artículo es analizar los requerimientos para la enseñanza de los hidrógrafos que actúan a nivel de la Categoría A de la OHI, a saber aquellos que manejan de forma independiente estudios hidrográficos sobre el terreno. Proponemos también un análisis de la capacidad educativa en hidrografía, con respecto a ambas cosas, la solicitud profesional de los hidrógrafos y el nivel requerido en la industria. Este artículo es el fruto de una labor llevada a cabo durante cuatro años en el ENSTA de Bretaña, el Curso Francés de la OHI en Categoría A. Utilizamos los resultados de un nuevo diseño completo de nuestro curso, que tuvo lugar en el 2006 y de nuestros tres años de retroinformación de la industria.

¹ ENSTA-BRETAGNE was formerly ENSIETA

1 Introduction

The International Hydrographic Organization (IHO), together with the Federation Internationale des Géomètres (FIG) and the International Cartographic Association (ICA) have defined since the early 1970's a standard of competence for hydrographic surveyors, known as the M5 norm. The main aim of this norm is to "provide guidance whereby individual surveyors may be trained and qualified in accordance with internationally accepted levels of competence". The IHO M5 norm defines the minimum knowledge and experience that are considered necessary for hydrographic surveyors, for essential subjects (bathymetry, water levels and flows, positioning, hydrographic practice, hydrographic data management, environmental science, legal aspects), as well as for optional units (nautical charting, hydrography to support port management and coastal hydrography, offshore seismic surveying, offshore construction hydrography, remote sensing, military hydrography, and inland waters hydrography). The essential fact of the S5 norm is that each item is *defined in details in terms of competence, but not in terms of ability to set-up a methodology in response to a global surveying problem*. The aim of this paper is to present how, starting from the S5 norm² as a basis, we provide to students an educational program that enables them to define robust methodologies to face complex hydrographic surveying problems.

It is now widely known that only 60 to 70% of the industry demand for hydrographers is satisfied, which means that institutes could increase their capacity without having any student³ placement problem. In quantitative terms, in the European Union, the training capacity is about 75 Cat A students per year (the ENSTA-Bretagne course representing 40% of this capacity). The industry (mainly survey companies, dredging companies and offshore companies), the hydrographic offices and governmental institutes would need between 110 and 125 trained hydrographers.

A direct consequence of this fact is that the industry has to recruit as hydrographers, students that have limited background in hydrography; namely land surveyors, engineers, etc. Therefore, due to a mechanical effect between the lack of well trained personnel and the growing demand, the level of practice will certainly decrease in the near future, if not already done. But what do we mean by a decrease of the level of practice? We believe (or observe) that surveyors that did not undertake any training course in hydrography will be more and more dependent on the technology, sometimes without mastering the basics of this technology, so being unable to identify the source of errors that are always present during a survey. This fact, combined with a more complex

and integrated technology (multibeam systems, inertial sensors, for instance) may create an increasing dependency on the technology (which includes equipments and software).

From the training institutes' point of view, this situation may seem to be comfortable, the demand for students being much more than the training capacity. But in a long term view, we believe that the lack of well trained hydrographers may lead to some kind of "blind" or "automated" practice of hydrography, which might affect the future need for well trained Cat A level hydrographers. This means that increasing the training courses capacity is one of the key responses, but this aim seems difficult to achieve in the global context of reduction of public sector expenses. Indeed, hydrography training courses requires important infrastructures and investment (survey vessels, costly equipments, and staff).

Another key point, which is the major focus of this paper, is to promote high standards of education for hydrography; namely training the student to a detailed knowledge of equipments, to provide proper education for identifying the sources of errors with an adequate level of scientific education in physical and mathematical modelling. We shall focus on three main topics that greatly impact the quality of a course:

The scientific methodology:

Rather than using built-in tools or software to solve complex problems, we first provide students with a knowledge of the mathematical and physical background of the method that will be used by making them implement basic algorithms. They are then invited to use their detailed knowledge of these tools to solve hydrography related complex problems. As an outcome, students are not reliant on black-box solutions. This approach of hydrography education seems very important to us, since hydrographers have permanently to assess the quality of survey data and to identify sources of errors.

Putting practicals and theoretical course modules alternately:

Every essential subject includes practicals (either by simulation or by dealing with real data) that progressively drive the students towards at sea training. The first practical training sessions at sea are organized quite early in the course, and aim at putting students in situations which are sometimes not manageable with their actual knowledge. Other practical sessions are organized through the course, the final one being a survey project where students are fully autonomous. During all the phases of survey projects, students are naturally driven to mobilize their scientific knowledge in order to process, analyze and interpret data.

² Which is now referenced as the FIG/IHO/ICA/S5 norm

³ In these figures, the educational capacity includes students that we train for non-EU hydrographic offices.



Figure 1 A view of Brest, the city is located on the right side (south side, which is the area used for ENSIETA hydrographer practices at sea. On the right, a view of the ENSTA-Bretagne campus.

The paper is organized as follows: first we describe the outline of the ENSTA-Bretagne course content. Then we describe the several practical situations that face students during their education and how a continuous closed-loop between training and data analysis helps to develop highly skilled hydrographers.

2 ENSTA-Bretagne Course Outline

2.1 Context

The hydrography course has existed at the ENSTA-Bretagne since 1971, and is now the reference French IHO Cat A course. Being a French "Grande Ecole" under the authority of the French Ministry of Defence, the ENSTA-Bretagne trains 2 military engineers per year who join the SHOM after graduation, and 28 civilian students who will work with the industry. The "Grandes Ecoles" ensure the quality of their education by their recruitment through a national competitive examination, common to a large set of institutes. The scientific level at the entrance of the ENSTA-Bretagne is adequate for dealing with topics ranging from sensor physics understanding to abstract mathematical modelling. The main goal is to give students the ability to measure the physical properties of the environment, thanks to their physics background, to process large data sets and finally, to provide abstract representations of those data, thanks to mathematical and computational methods.

Located in Brest, the ENSTA-Bretagne course benefits from the presence of most of the French marine science institutes: SHOM, IFREMER, and Brest University. Moreover, the ENSTA-Bretagne as a "Grande Ecole" has the possibility of recruiting external lecturers from other universities or from the industry. The lecturing team of the course is therefore a mix of professionals and university professors.

The number of graduated hydrographers from the ENSTA-Bretagne increased around 2008-2009, due to a complete course redesign in 2006 which aimed at better fitting with the maritime industry needs. From an average of 5 students around 2000, last year's graduation class

comprised 30 students, which makes the ENSTA-Bretagne the largest Cat A course in the European Union.

2.2 Course short description

The ENSTA-Bretagne course duration is two years, and leads to a Master level degree (diplôme d'ingénieur). As the French educational system is quite specific, *Figure 2* shows a synoptic view of the programme structure, including relations with the classical university programmes. *Table 1* shows the list of the course modules and the evaluation type: E means exam, and P means project. One can see that most of the evaluation is based on projects. We will describe projects in more detail in the next section.

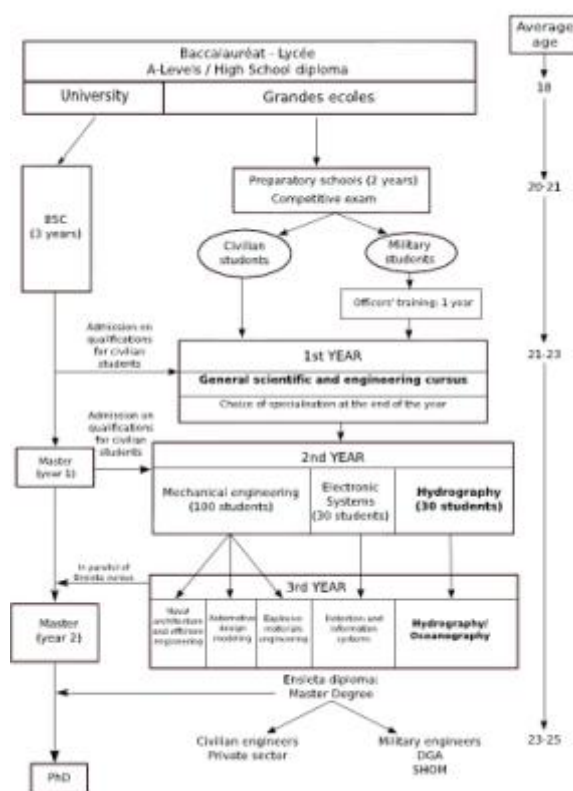


Figure 2. Overview of Programme structure

YEAR 2					
Semester 1			Semester 2		
Module name	Hours	Evaluation	Module name	Hours	Evaluation
Geodesy	25	E	Maritime Training	25	
Bathymetry	60	EP	Hydrography	40	EP
Oceanography	30	E	Remote sensing, GIS	50	P
Positioning	60	EP	Bathy data proc.	45	EP
Geo. databases	20	P	Water levels	35	E
Digital signal proc.	35	P	Geophysics	35	EP
Meteorology	15	E	Image processing	25	P
Numerical methods	25	P	Inertial Navigation	25	P
Acoustics	25	P	Survey Project	100	P
SUMMER TRAINING: 2 months in industry					
YEAR 3					
Semester 1					
Module name	Hours	Evaluation	Module name	Hours	Evaluation
Pre-dredging survey project	80	P	Sediment dynamics	30	E
Hydrography for off-shore construction	20	P	Inertial navigation and optimal filtering	30	EP
Hydrography for coastal engineering	20	P	Coastal modeling	40	P
Cartography	35	E	Data assimilation	20	P
Law of the sea	15	EP			
OPTION Advanced bathymetry (120h)			OPTION Oceanography (120h)		
Semester 2					
MASTER THESIS, 5 months					

Table 1. Outline of the course modules, teaching hours, and evaluation type for the second and third school year.

As shown in Table 1, the ENSTA-Bretagne course includes a set of oceanographic course modules that are largely beyond the scope of the S5 norm. ENSTA-Bretagne students are capable, due to their good mathematical and information technologies background of performing studies in the field of oceanographic modelling.

One can observe from this Table that the course incorporates a detailed module on inertial navigation, which may seem strange. Having observed the lack of knowledge of students in this field, and taking into account the fact that INS system may be a serious source of hydrographic uncertainty (maybe much more than MBES systems in some cases), we decided to setup this new course, focusing on the understanding of navigation equations, ground alignment methods (static or in motion), and optimal estimation of position with navigation aids (GPS in air, and Doppler or LBL under-water).

2.3 Practicals

Practicals are organized in such a way that students can work more independently. We describe only the hydrographic surveying part, but keep in mind that oceanographic practicals are also organized with the aim of gathering, analyzing and modelling CTD data coupled to tide and ADCP data.

From the hydrographic survey point of view, practicals consist of:

The Hydrographic Survey project: In this project, teams of three students are tasked to survey some small areas of the Brest commercial harbour. The project is graded with respect to quality and confidence of results, methodology, project management, and communication. One of the aims of the project is to survey the area specified by the client, by using at least three different systems: a SBES (or mechanical profiler), a MBES, and a Side-scan sonar. The data returned by these three different sensors have to be correlated, in terms of hydrographic accuracy and ability to detect obstructions. Both data sets have to be reduced from water level by at least two methods: a classical tide reduction, using tide gauge data and heave data, and a RTK levelling method, using the ellipsoidal height of the chart datum.

The summer internship: Students have to perform survey work in a foreign organization (dredging company, survey company, hydrographic office). This period must include at least 3 weeks of at sea work and 5 weeks of office work. The minimum internship duration is two months, and students must deliver a written report and perform a project presentation.

For the 2008/2009 series, the distribution of students was the following:

Dredging companies: 9 students,
Survey companies: 10 students,
Hydrographic offices (Brazil, NL, FIN, CAN, UKHO, SHOM): 6 students,
University of Oceanographic Labs : 5 students.

The pre-dredging survey project: This project is the last survey project. Students have to work without any supervision in real conditions. Instructors play the roles of clients giving assignments and requiring quality control procedures. Students have to make a tender, as they would have to rent the survey equipment from the ENSTA-Bretagne. They have to perform a survey, a volume computation and to prove the quality of results. Each student can practice with the ENSTA-Bretagne survey equipment, namely:

The survey vessel "Panopée": A 7.6 catamaran, with 100 HP engines, speed range 2-17 knots, draught: 40cm. This survey vessel allows working sessions including three students, and two members of the teaching staff (technician/pilot, professor).

A RTK GPS system: Reference station and mobile station from Magellan, used at sea. The reference station is installed on the roof of the Brest Pilots Station, the mobile station is onboard the Panopée Vessel.

A 2D/3D laser scanner: Leica HDS6200.

A land based RTK system: Aquarius 5002 from Thalès Navigation, which is used for land survey purposes and topometric works.

Two SBES: Simrad-Mesotech 210Khz, 120kHz.

A sub-bottom profiler: Tritech 210kHz-20Khz.

A side-scan sonar: Tritech.

A single beam mechanical profiler: Tritech.

Two MBES sensors: A R2SONIC with Quinsy acquisition system, a Tritech Horizon, with PDS2000 acquisition system.

Sound velocities probes: Valeport (surface and profiling VOS probes)

Two tide gauges: Aanderaa.

A MRU6: Seatex.

An OCTANS 4: Ixsea.

A 3D motion simulator platform: TRI30 from IXmotion.

A GPS compass: Hemisphere.

A CTD gauge: SBE37 from Seabird.



Figure 3. The Panopée survey craft

3 Hydrographic survey training analysis

In this section, we focus on the new training system that the ENSTA-Bretagne recently implemented. Survey industry feedback has provided some interesting results. This new training course is based on several facts:

1. Hydrographic data gathering, processing, and analysis require a wide variety of skills, ranging from physics (sensor technology) to information technologies, applied mathematics (data processing). Assessment of data quality can only be done by people with a detailed knowledge of all processes involved in a hydrographic data production scheme.
2. Surveys are now performed with survey systems which include many different technologies (acoustics, positioning, inertial measurements, mechanical integration, acquisition devices and software, data processing tools, visualization tools). In order to be able to plan a survey with minimum quality requirement and to assess data quality, the total propagated error assessment requires a deep understanding of each sensor, and not only to consider them as black boxes whose accuracy is given by the manufacturer.
3. Hydrographic surveyors at Cat A level have the role of chief surveyors, and therefore will have (after some years spent gaining experience in industry) the responsibility of a complete survey work, which mobilizes significant financial resources. Therefore, they have to be extremely reactive when the survey system behaviour is not satisfactory. This requires a deep understanding of all the components of a survey system.
4. An interaction between institutes, hydrographic tool developers, and the industry is necessary to deliver a complete education in a complex field such as hydrography.

4 Panopée is the name of a Nereide from the Greek mythology. She had prediction skills and the ability to see everything

5 Thanks to a sponsoring of R2SONIC that provides a 2024 unit twice a year for a one month period.

The progressive practical training that we implemented is based on three principles: first to alternate practical exercises with theoretical course modules, in order to develop their ability to think independently. Secondly, to alternate training periods within the industry with academic education, in order to give them the opportunity to discover other point of views or methodologies than the one we deliver at the ENSTA-Bretagne. Finally, to perform their master thesis in focusing on a scientific subject related to hydrography, in order to initiate them to applied research which can be very helpful for their future adaptation to new technologies.

In order to achieve these goals, we scheduled our course in the following way:

Academic scheduling				
Semester 1	Semester 2	Semester break	Semester 3	Semester 4
Main topics				
Hydrography			Oceanography	Both
Practicals				
P1	P2		P3	
Internships				
		Summer training		Master thesis

Table 2: Scheduling of practicals at ENSTA-Bretagne. "P" letters means practicals which includes at sea works and data processing

From Table 2, practicals alternate with theoretical course modules, and that internships alternate with practicals.

As a result, we give students assignments including at sea work before a complete education about the tools they manipulate. The effect is to force them to accept the idea that a theoretical background is absolutely necessary in order to perform proper work in hydrography. For example, the first practical P₁ is a patch test that they carry out for a multibeam system. The data selection is done by using dedicated software (CARIS HIPS), but the data processing is done by students themselves, by using a free scientific computation environment (Scilab), therefore without dedicated patch test software. They have to manipulate the data, and to choose a statistical method in order to estimate latency, pitch, roll and yaw misalignment angles from several profiles.

Students face quite a difficult situation as data may be affected by ray-bending, the time resolution for latency estimation over a footstep is affected by the footprint of the sounder and therefore the operating frequency of the sounder. Their knowledge of acoustics does not enable them to solve this kind of problem. The bathymetry course module, which comes just after, details the answers to all these questions. In this way, the bathymetry course module is motivated by a first at sea practice experience, and gives answers to problems that the students faced in reality.

At the end of their hydrography education in Semester 1 and 2 of the course, students perform a survey project P₂. At this stage other problems are to be solved including vertical references determination methods, data cleaning, choice of a sounding reduction method, motion sensor misalignment, etc. After the first survey, they have to perform both a sounding reduction by using tide and heave information. The students were at this stage not aware that heave compensators may be unreliable in some situations. Therefore, tide reduction might be affected by bad heave compensation. They discover this fact through practice, and we intentionally do not make any prior induction of inertial navigation before the third survey project. Having identified some errors from a comparison with LRK reduction which does not involve heave measurement, they can take benefits and be very motivated by the inertial navigation course module that explains sources of errors in heave compensators. Moreover, in comparing the two sounding reduction techniques they quite often realize that none of them is the best, but that in some situations, LRK is better, and in some other tide information coupled to heave is better: this is the first contact with hydrographic surveying complexity in terms on data quality assessment.

In facing such difficult situations without a deep knowledge of the tools they use, and when everything ' goes wrong ' students quickly understand that without detailed knowledge of each part of a survey system, they cannot detect errors, make a diagnostic and correct them properly.

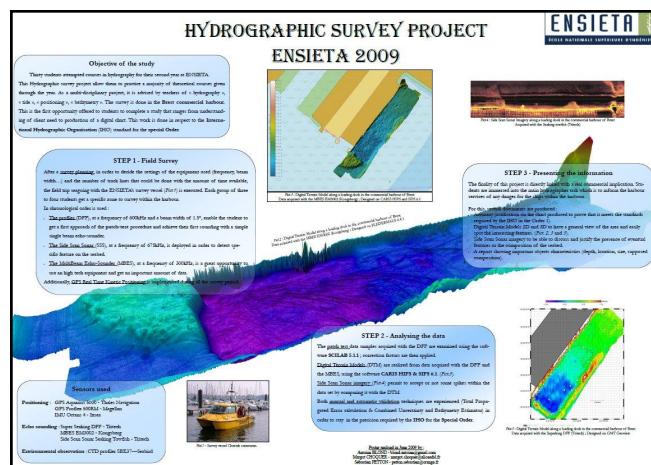


Figure 4. See details on next page

Figure 4. An example of student work for the 2009 survey project session. They surveyed an area with a side-scan sonar, a multibeam sonar, a single beam mechanical profiling sonar, and made comparisons results in terms of DTM, target detection and height estimation.

The last stage of the hydrographic survey practical education is a pre-dredging survey which is carried out by one team (the whole group of student). The student group receives several assignments from a (virtual) client, in terms of products, confidence indexes, volumes computation, etc. Then, the group is divided in subgroups of 3 students. A project manager is elected, and he (or she) organizes the project work, assigning the tasks (determination of vertical references, tide gauge installation and check, calibration of equipment, survey of the different areas). The survey area is generally chosen in a difficult estuary which produces VOS variations, levelling problems due to bad tide modelling, and the chart datum is not available. The project has to report to the client specification, with an indication of the survey quality. This last survey project is the opportunity for student to face a real complex survey situation and to try to get the best quality of data. This project enables us to check the ability of each subgroup to address difficult surveying problems, and to quantify properly hydrographic errors. This concludes the hydrographic survey education of our student. They are evaluated by an expert from industry, in order to guarantee the independence of the grading.

It is also worth mentioning the problem of survey software training. It is right that the practice of complex softwares, for data acquisition, for data processing and visualization is a key point, as students will have to use some of those tools in the industry. But, we insist on the fact that a hydrographer's education only based on the *utilization* of software tools is *not sufficient* for at least two reasons:

- * Hydrographers need to know the basic principles of the numerical algorithms they use. To do so, it is highly desirable that students program basic prototype algorithms of these methods by themselves. For instance, sounding data cleaning, detection algorithms in acoustics or spherical positioning for LBL. It is essential for getting a detailed knowledge.
- * When they have to focus on a specific problem (for instance heave estimation from inertial sensors and LRK by using a Kalman estimator) they will have no other solution than to program the computer code by themselves. Dedicated software will not be sufficient.

We believe that hydrographers have to receive a proper education in information technologies, and that more and more, data processing will be a central activity in hydrography. Indeed, the use of multibeam echosounders, the future use of laser scanners coupled to multibeam will create massive datasets, which require advanced data processing tools to make full usage for charting. Without this education, hydrographers would be limited to the surveying activity, which is not sufficient for Cat A level hydrographic surveyors.

We also believe that the black-box "culture", when applied to hydrographic surveying may lead to unexpected errors. For instance, using modern softwares which offer functionalities in automatic data processing, data cleaning, digital terrain model production, without detailed knowledge of their basis prevent any objective accuracy assessment. For instance, producing a DTM with a variable sounding density by using an averaging method may lead to unexpected errors. Specific methods must be applied, which are sometimes not available in classical software suites.

3.1 Internships

In Table 2 we have shown that two internships are mandatory in the ENSTA-Bretagne course. The first one is a summer training period, which must be performed abroad, and must include at sea survey and data processing for a minimum period of 6 weeks. Thanks to a close cooperation with the survey industry, all of our 30 students perform this internship in very good conditions, and they have the opportunity of experiencing their knowledge in real-world situations. This fact should not be neglected, as we observed that after this summer training period, *all students* return to the ENSTA-Bretagne with a very high degree of motivation and a new vision of their education (they seem to be more mature as they have seen that theoretical background is useful for fieldworks). We thank all our industrial partners for this essential contribution to our course. Allowing students to discover hydrographic surveying in industry at some point of the two years of the syllabus provides real added value to our academic education.

3.2 Focusing on a master thesis subject

The hydrographer education is completed after a master thesis. ENSTA-Bretagne students have to perform their internship outside of the institute: private companies or university labs. But the master thesis is realized under our advice, and for some students, this includes periods at the ENSTA-Bretagne in the framework of a cooperation with industrial partners.

The main aim of the master thesis is to focus student work on a research subject related to hydrography or to oceanography. In the field of hydrography, we investigate with industrial partners new subjects (like laser scanning, sonar data fusion, characterization of multibeam errors on specific bottom types, data cleaning algorithms), or subjects related to hydrographic error characterization (multibeam errors on specific bottom types, inertial sensors error understanding, underwater positioning aids). This last stage of ENSTA-Bretagne education is essential as the student will learn how to face a difficult generic problem, to mobilize parts of their hydrographic education to analyze situations, to offer new solutions, to implement and to test them and finally to analyze the results they obtained.

We list here some examples of master thesis topics which have been performed in cooperation with survey companies or survey departments of dredging companies: The use of range-aided navigation systems for spoolpiece metrology; vertical reduction for a seamless digital database; silt layer variability in the port of Rotterdam; motion sensor error characterization; hybridization of motion sensors and RTK signals for heave estimation; analysis of multibeam behaviour on dumped rocks on the seabed; testbed comparison of multibeam systems; structure positioning with laser scanner data; and tests and improvement of data cleaning algorithms.

4 **Conclusion**

The experience of the mixing of practical and theoretical course modules throughout the ENSTA-Bretagne course have been positive. Thanks to a close cooperation with the industry, training periods efficiently complement our academic courses, and they represent real added value: for companies who can select experienced and motivated people, after final graduation, and for the hydrography course which efficiently increases with the induced student motivation. We have also seen that basic science background is absolutely necessary to hydrographers to enable them to have a detailed knowledge of every part of a complex survey system, and to assess the hydrographic data quality. Developing the educational capacity and the level of education seems necessary, since hydrography at Cat A level requires a high level of expertise and the capacity to define a survey plan, to make diagnostics on erroneous or incoherent data, and to assess data quality.

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Biographies of the Authors

Nicolas SEUBE obtained a PhD in applied mathematics from Paris Dauphine University in 1992. He was awarded the winner of the SIAM prize for the best student paper competition at ICIAM'91. Then, during ten years, his research interests were in dynamic systems theory, and he authored more than 20 papers on viability analysis of non linear systems, observers design, and applications to underwater system design (Autonomous Underwater Vehicles, Gliders, Floats). In 2002, he obtained an HDR and became a full Professor. Since then, his research interests are motivated by underwater technologies and hydrographic surveying. In 2005, he became coordinator of the hydrographic course of the ENSTA Bretagne, and developed a research group in bathymetry, hydrographic instrumentation and cartography. His present research interest includes cartography-aware ship dynamics, inertial sensors errors identification and modeling, bathymetric data processing and uncertainty management in hydrographic surveying.

Nathalie Debese received an engineering degree in Computer Science from The University of Technology of Compiègne (UTC) in 1989, and a MSc degree in Statistics. She obtained a PhD in System Control Theory in December 1992 for her research works at IFREMER - the French research institute for exploration of the sea - on the *Learning registration of the navigation through bathymetric data*. She worked from 1995 to 2009 in the SHOM - the French hydrographic and Oceanographic service - as the MBES co-project manager. As an expert in bathymetry, she contributed to the definition of the MBES data quality workflow. She was also involved in several research projects focusing on bathymetric data processing. Since 2009, she works with the ENSTA Bretagne as an Associate Professor in the "Ocean Sensing and Mapping" group. Her research interests include automatic cleaning of bathymetric data, surface's modeling, geometrical and morphological properties of digital terrain, features extraction and representation, data compression and registration algorithms.

Rodéric Moitié received his Msc degree in Computer Science from ENSIMAG (Ecole Nationale Supérieure d'Informatique et de Mathématiques Appliquées de Grenoble) in 1996. For five years, his research interests were in dynamic systems and underwater robotics. Since 2002, his research interests are related to underwater technologies and hydrographic surveying. In 2004 he became involved in the training of students undertaking the hydrographic course of the ENSTA Bretagne, and joined a research group in bathymetry, hydrographic instrumentation and cartography. His present research interest includes cartography-aware ship dynamics and bathymetric data processing.

A COHERENT TIDAL DATUM FOR THE TORRES STRAIT

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Abstract

The Torres Strait is a complex waterway to the north of Australia linking the Arafura and Coral Seas. Sea level data from 13 islands were provided with the intention of validating the GPS extension of AUSGeoid98 to the Torres Strait. A comparison between the Australian Height Datum (AHD) determined from the AUSGeoid98 model and Mean Sea Level (MSL) identified differences of up to 1.57m. A coherent tidal datum was established with a seasonal adjustment to the long-term level from Thursday Island. The seasonally adjusted MSL from this study should be considered as an approximation of AHD in the Torres Strait.



Résumé

Le détroit de Torres est une voie navigable complexe au nord de l'Australie, qui relie les mers d'Arafura et de Coral. Les données sur le niveau de la mer de 13 îles ont été fournies dans l'intention de valider l'extension du GPS d'AUSGeoid98 au détroit de Torres. Une comparaison entre le système de référence australien (AHD) déterminé à partir du modèle de AUSGeoid98 et le niveau moyen de la mer (MSL) a mis en évidence des différences allant jusqu'à 1,57m. Un zéro des marées cohérent a été établi avec une correction saisonnière du niveau à long terme, à partir de Thursday Island. Le MSL corrigé des variations saisonnières de cette étude doit être considéré comme une approximation du AHD dans le détroit de Torres.



Resumen

El Estrecho de Torres es un canal complejo al norte de Australia, que conecta los Mares de Arafura y Coral. Se proporcionaron datos del nivel del mar de 13 islas, con la intención de validar la extensión GPS de AUSGeoid98 al Estrecho de Torres. Una comparación entre el Plano de Referencia Australiano (AHD) determinado a partir del modelo AUSGeoid98 y el Nivel Medio del Mar (MSL) identificó diferencias de hasta 1,57m. Se creó un Datum de Mareas coherente con un reajuste de nivel estacional a largo plazo a partir de la Isla Thursday. El MSL reajustado estacionalmente a partir de este estudio debería ser considerado como una aproximación del AHD en el Estrecho de Torres.

Introduction

The Torres Strait is unique in the way that tides and weather driven forces interact across and along the Strait. The Strait is a topographically very complex, shallow, body of water that links the Coral Sea to the east with the Arafura Sea to the west (Wolanski, 1994). The amplitude and phase of the tide changes rapidly through the strait, mostly along the shallow and constricted centreline (Saint-Cast, 2008). The strait enables movement of water between the two seas while the tidal phase of the two water bodies is incoherent within the strait (Wolanski et al, 1988). To the east the tide is chiefly semi diurnal and to the west it is predominantly diurnal (Easton, 1970). This creates a region of interaction in the Strait between diurnal and semi-diurnal tides that is very complex (Saint-Cast, 2008). This tidal incoherency can result in large differences in level of up to 6m (Wolanski et al, 1988). There is very little long term sea level information from the region in general. Historically the focus has been on the shipping lanes in the southern regions of the strait for maritime safety purposes. Over time, datum information was adopted independently for each island without links between the islands or between the islands and mainland Australia. Island connections to the Australian Height Datum (AHD) would allow for the integration of existing tide gauge data, elevation models, topographic mapping imagery and simplify island management activities such as coastal development. Connection to AHD will also allow a coherent datum for storm surge modelling, sea level rise studies and Hydrographic surveys.

This paper presents the results of harmonic analysis of sea level data collected through a field study undertaken with the initial aim of establishing GPS connections to the AHD across islands in the Torres Strait and to further the knowledge of tidal dynamics within the Torres Strait region. Connecting to AHD proved problematic, hence connection to a coherent tidal datum, and to a seasonally adjusted mean sea level as an approximation of AHD is investigated here.

Methods

Sea level data recorded at thirteen island sites across the Torres Strait between the period of 27 May to 30 June 2008 were provided by Griffith University. The methods used to collect and transform this data from raw pressure to sea level referenced to a levelled tide staff datum are given in the Griffith University report "Torres Strait Tidal Survey" (Zier et al, 2009).

To classify the tidal characteristics of the project sites, they were divided into three groups based on their collective location (*see Figure 1*). The sites in the Coral Sea form the eastern group; those close to PNG form the central northern group and the sites north of Cape York, the central southern group.

The form factor was calculated for each site as the ratio of the major diurnal constituents to the major semi-diurnal constituents as: $K1+O1/M2+S2$. The form factor is defined in the Australian National Tide Tables (ANTT) as; a site is considered to be semi-diurnal if the ratio is less than 0.5 and diurnal if the ratio is greater than 0.5 (Australian Hydrographic Service RAN, 2009).

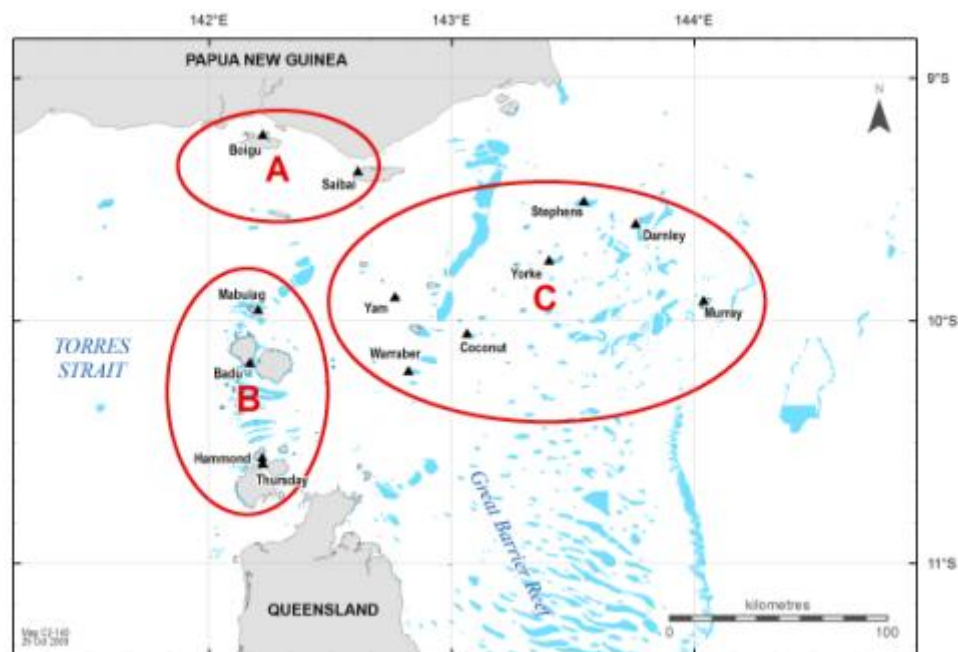


Fig . 1 / Project site grouping (A) Northern central sites (B) Southern central sites and (C) Eastern sites.

The sea level data consisted of two and five minute averaged levels (for three sites) referenced to the zero of each tide gauge. Hourly levels were then extracted from this sea level data. This data was initially transformed via a regression from the tide gauge (zero) datum to the datum (zero) of a tide staff. The tide staffs were installed close to the tide gauges and connected to local benchmarks via levelling surveys. The times and heights of high and low water were extracted from the hourly levels with the intention of doing datum transfers between the Thursday Island data and the Hammond Island, Badu Island, Mabuiag Island and Yam Island data. The transfer consisted of regression analysis between the reference site and the secondary site.

The hourly sea level readings referenced to tide staff zero were then analysed using the “Foreman Tidal Package” (Foreman M., 1977). As part of the harmonic analysis procedure, the tidal constituents from a nearby site with a long data set was used to infer the shallow water effects as the data-sets here were only 35 days in length. Analysis of such a short data-set will not identify some tidal constituents hence these must be inferred from a nearby site with a long data-set (Pugh, 1996). There were two sites used as base inference sites.

becomes the tidal datum for each site and is referred to as “LAT 2008”. The Highest Astronomical Tide calculated in this paper is also referred to as HAT2008. The methods used to calculate the diurnal and semi-diurnal tidal planes were based on the simplified formulae (see Table 1) used in the ANTT ([Australian Hydrographic Service RAN, 2009](#)).

The Australian Height Datum (AHD) is defined as MSL at 32 tide gauges around Australia over the period 1966 to 1968 (Brown, 2010). So in the absence of a levelled AHD value and in this case where the AUSGeoid98 model introduces large errors, AHD can be represented by long term MSL at a particular site. A suitable MSL value was calculated by applying an offset to the MWL of the sea level data. The offset used was essentially the difference between MWL at Thursday Island (this project) and the published Thursday Island long term MSL. The Thursday Island tide gauge was set to the well established (LAT) datum at that site. Hence the shift from the short term MWL to the long term MSL was observed directly there.

Semi-diurnal Planes	Simplified Formulae
MHWS	$Z0+(M2+S2)$
MHWN	$Z0+abs(M2-S2)$
MLWN	$Z0-abs(M2-S2)$
MLWS	$Z0-(M2+S2)$
Diurnal Planes	
MHHW	$Z0+(M2+K1+O1)$
MLWH	$Z0+abs(M2-(K1+O1))$
MHLW	$Z0-abs(M2-(K1+O1))$
MLLW	$Z0-(M2+K1+O1)$

Table 1. Simplified formulae used to calculate tidal planes from the Australian National Tide Tables, 2009 (Australian Hydrographic Service RAN, 2009).

Thursday Island tidal constituents were used for the Central Southern sites while Twin Island Constituents were used as the inference constituent set for the Eastern and Central Northern sites. These inference tidal constituents were supplied by the National Tidal Centre (National Tidal Centre, 2009).

The constituent set from the analysis formed the basis for calculating Lowest Astronomical Tide (LAT) and tidal planes including Highest Astronomical Tide (HAT). Tidal predictions were generated for the Tidal Datum Epoch (TDE) 1992 to 2011 and LAT and HAT levels were determined from these tide predictions. The difference between LAT and the zero of the data was used to adjust HAT and the Mean Water Level (MWL) of the raw data to a LAT datum. This new datum then

Included in the offset was the difference between the calculated LAT and the current LAT provided by the National Tidal Centre for Thursday Island (0.23m). The seasonal correction at Thursday Island was assumed to be the same across the study region and applied accordingly.

The methods used to calculate HAT carry an unknown level of uncertainty because of the shortness of the data sets that the calculations are based upon. The definition of HAT (PCTMSL, 2009) assumes an observed data-set of sufficient length. In this context “sufficient length” should be long enough to include the nodal factors, that is, greater than 18.6 years. In our case, the observed data was only 35 days in length.

However at Thursday Island there is an observable indication of this difference and the data from all sites were recorded over the same sampling period. This has allowed an offset to be applied to all sites.

Connections from the tide staffs to local, island based, primary survey and recovery marks were established by Griffith University (Zeir et al, 2009). With LAT datum now established for each site relative to tide staff zero's, it is possible to extend the LAT2008 datum to the local bench marks. The Department of Natural Resources and Water (DNRW) followed up the benchmark levelling work of Griffith University with GPS determinations of primary and recovery benchmark Ellipsoidal heights. The benchmarks were then connected to the AHD via the Ausgeoid98 model. For further details on the AUS-Geoid98 model see Featherstone et al, 2006.

Results

The observed sea levels for the first seven days of the 35 day sampling period are presented for the three groups in *Figure 2*. The tidal dynamics are generally coherent within each group with some notable exceptions. Within the eastern group, tidal dynamics are similar during the spring tide but some small differences are apparent during the neap period. Of the central southern sites, one site shows a different dynamic with respect to the other sites in the group.

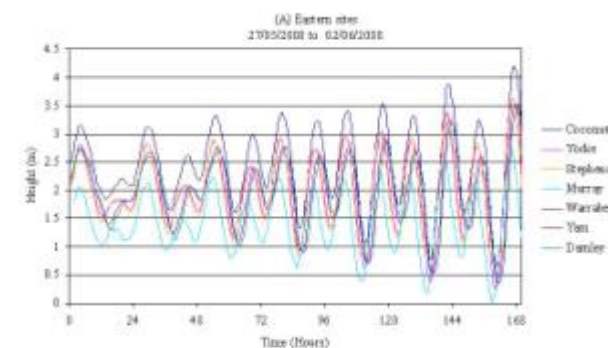
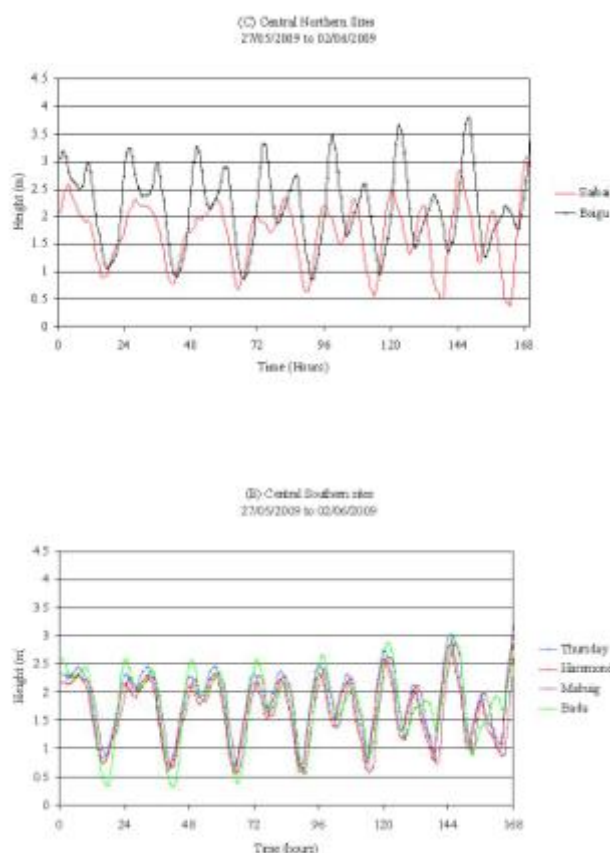


Figure 2 The first seven days of sea level data set to an arbitrary datum and divided into three groups, (A) Eastern sites; Coconut, Yorke, Stephens, Murray, Warraber, Yam and Darnley Islands (B) Central Southern sites; Thursday, Hammond, Mabuiag and Badu Islands and (C) Central Northern sites; Saibai and Boigu Islands.

From *Figure 2*, the level at Badu Island converges on day 6 and 7 away from the levels of the other sites in the Central Southern group. This happens at the time of the inequality and it appears that another high tide peak converges with the following high tide at Badu before this happens at the other sites. The tidal dynamics of the two central northern sites differ considerably and reflect the change from being semi-diurnal in the east (in the Coral Sea) to being dominantly diurnal in the west of the Torres Strait in the Gulf of Carpentaria (Saint-Cast, 2008).

The regression (tidal transfer) between the reference site of Thursday Island and the other central (north and south) islands was significant to Hammond Island as evidenced by an R^2 value greater than 0.99, see *Table 2*. This was not the case however with regressions to other sites in these two groups. The regressions from the eastern reference site of Yam Island to the other five sites has revealed that Warraber Island has similar tidal dynamics to Yam Island with an R^2 value of greater than 0.99 see *Table (3)*. This close relationship was not evident with regressions to the other eastern group islands.

Site	Ratio	R^2
Thursday Island (reference site)	1.0	1.0
Hammond Island	0.997	0.995
Badu Island	1.148	0.946
Mabuiag Island	0.999	0.973
Boigu Island	1.160	0.9247
Saibai Island	0.923	0.890

Table 2. Tidal transfer between Thursday Island and Hammond Island, Mabuiag Island and Badu Island.

Site	Ratio	R ²
Yam Island (reference site)	1.0	1.0
Coconut Island	1.093	0.985
Darnley Island	1.012	0.965
Murray Island	0.828	0.966
Stephens Island	1.075	0.944
Warraber Island	1.000	0.997
Yorke Island	1.059	0.974

Table 3. Tidal transfer between Yam Island and Yorke Island, Warraber Island, Stephens Islands, Murray Island, Darnley Island and Coconut Island.

MSL from the analysis is presented in *Table 4* and *Figure 4*; there were five sites where the published (Australian Hydrographic Service RAN, 2009) MSL varied considerably from these. A range of between 1.78m at Murray Island to 2.28m at Coconut Island is evident in the project MSL.

For each site the adjusted MSL, along with seasonal constituents Sa (annual) and Ssa (semi annual) from the closest site where published values (Australian Hydrographic Service RAN, 2009) are available were included in the constituent list. Some sites have published seasonal constituents and were used accordingly (see *Table 4*). As justification for the choice of the seasonal constituents used in this analysis, modelled seasonal annual constituent “Sa” were supplied by the Australian Maritime College (Mason, 2009) (not presented here).

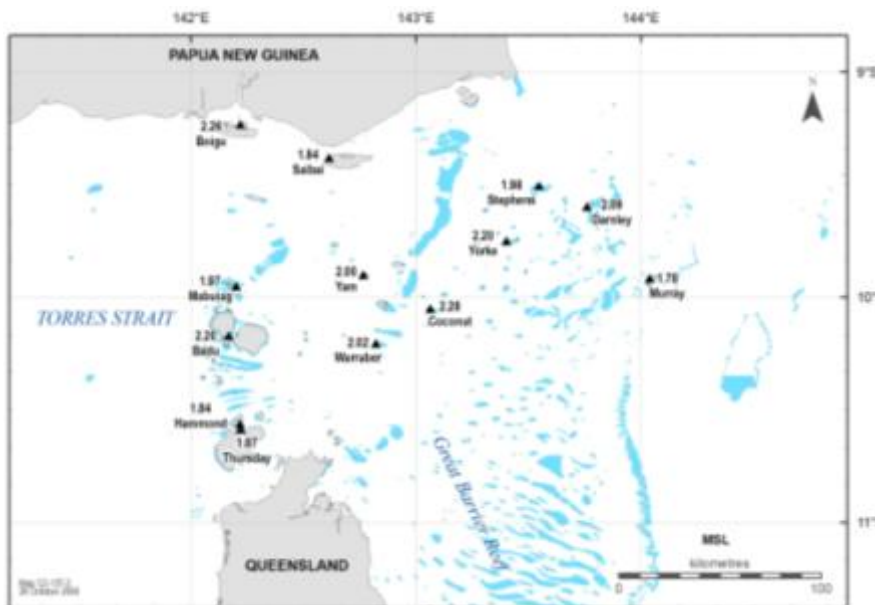


Figure 3 MSL based on the project data. In metres above LAT2008.

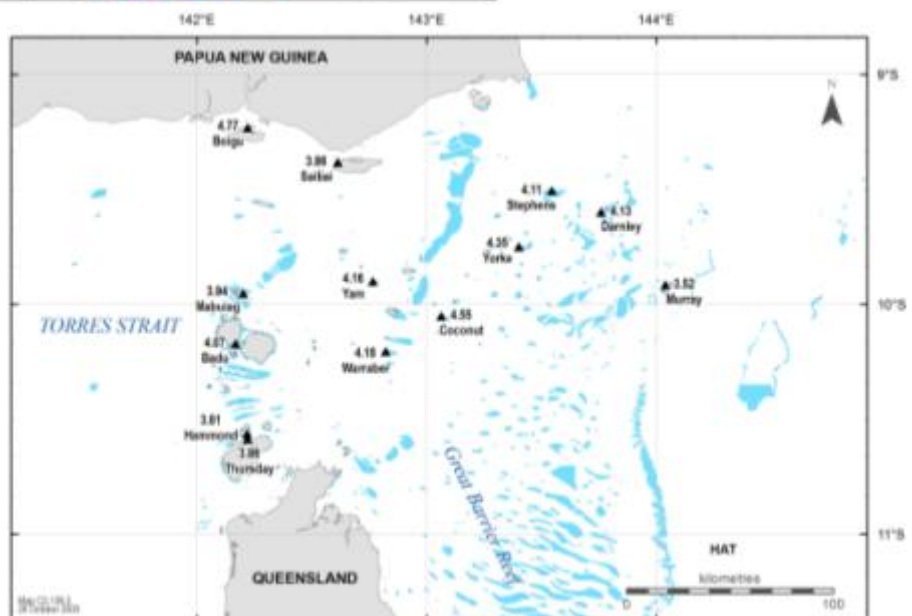


Figure 4 HAT2008 calculated from tide predictions for the period 1992 to 2011 derived from the project data. In metres above LAT2008.

Some notable differences are evident between the two sources of Sa. Boigu Island has a published magnitude of Sa that is around 10 cm higher than the modelled Sa and a phase difference of over 10 degrees. A recalculated HAT was 0.09m (not listed here) lower using the modelled Sa. There are no published seasonal constituents for Saibai Island, those from Yam Island were used for Saibai Island and the same effect of reducing HAT was noted when the modelled Sa (magnitude and phase) was used.

The phase of the modelled Sa was considerably different for the Eastern sites of Yam Island and Stephens Island. A re-analysis of HAT with the modelled phase revealed a small drop of 0.02m-0.04m (not shown here) so the published Sa phase was used here. The Seasonal constituents for Yam Island were used for the remaining Eastern sites as the Yam constituents fall within the modelled amplitude of Sa.

Site	M2 Amp. Phase	S2 Amp. Phase	O1 Amp. Phase	K1 Amp. Phase	Sa Amp. Phase	Ssa Amp. Phase
Badu Is	0.453 124.9	0.269 340.6	0.369 140.6	0.633 202.7	0.113 322.8	0.011 4.7
Boigu Is	0.452 156.5	0.447 51.5	0.271 161.0	0.591 225.8	0.261 308.7	0.049 293.1
Coconut Is	0.715 333.9	0.442 323.3	0.172 163.2	0.408 206.6	0.077 339.9	0.028 42.6
Darnley Is	0.720 309.9	0.368 291.6	0.161 160.5	0.353 199.8	0.077 339.9	0.028 42.6
Hammond Is	0.342 57.5	0.343 342.6	0.248 146.8	0.509 205.0	0.113 322.8	0.011 4.7
Mabuiag Is	0.375 59.5	0.424 7.5	0.210 153.0	0.500 213.1	0.113 322.8	0.011 4.7
Murray Is	0.571 291.9	0.303 267.6	0.141 155.5	0.300 194.0	0.077 339.9	0.028 42.6
Saibai Is	0.386 29.4	0.537 24.0	0.197 171.41	0.514 225.3	0.077 339.9	0.028 42.6
Stephens Is	0.748 314.2	0.371 297.9	0.164 154.5	0.349 200.3	0.093 330.4	0.017 47.3
Thursday Is	0.359 62.3	0.337 343.2	0.252 144.8	0.532 204.4	0.113 322.8	0.011 4.7
Warraber Is	0.614 349.7	0.444 338.8	0.174 163.7	0.432 211.8	0.077 339.9	0.028 42.6
Yam Is	0.577 1.2	0.475 354.6	0.177 168.1	0.455 216.8	0.077 339.9	0.028 42.6
York Is	0.728 320.0	0.404 308.4	0.165 163.0	0.374 204.1	0.077 339.9	0.028 42.6

Table 4. Tidal Constituents as Amplitude (m) and Phase (degrees). Sa and Ssa taken from ANTT (Australian Hydrographic Service RAN, 2009) for Boigu Island, Stephens Isles, Thursday Island and Yam Island. Badu Island, Hammond Island and Mabuiag Island Sa and Ssa from Thursday Island. Coconut Island, Darnley

The calculated project HAT2008 levels were generally close to the ANTT published levels with four sites being lower by between 4 cm and 13cm and four sites being higher by between 23 cm and 41 cm. The remaining five sites have no published HAT levels. It should be noted that the ANTT HAT levels are rounded to one decimal place whereas the project HAT2008 levels are to two decimal places.

Figure 4 presents HAT2008 levels relative to LAT2008 based on the project data, the highest HAT2008 values are at Boigu Island and Coconut Island. The project HAT2008 of 3.86m for Thursday Island is the same as the HAT given in the ANTT for Thursday Island. HAT2008 and MSL at Stephens Island were very close to the published levels verifying the removal of erroneous data that resulted from the tide gauge bottoming out on a low tide (not presented here - see Metters, 2009).

Central Southern Group					Central Northern Group	
Datum Level	Thursday Island	Hammond Island	Badu Island	Mabuiag Island	Boigu Island	Saibai Island
TGBM	PM 10078 6.375	PM 145548 4.459	PM 164065 4.959	PM 89051 8.312	PM 140483 4.136	PM 173502 4.598
Top of Ramp	na	4.05	5.046	4.891	4.560	4.349
HAT2008	3.86 (3.86)	3.81 (3.75)	4.07	3.85 (Talab 3.9)	4.77 (4.9)	3.86
MSL	1.87 (1.87)	1.84	2.20	1.93	2.26 (2.45)	1.84 (1.71)
Island Datum	0.00	0.04	0.536 (ISLW)	0.294	0.074	-0.248
LAT2008	0.00	0.00	0.00	0.00	0.00	0.00
Eastern Group						
Datum Level	Yam Island (Iama)	Sue Island Warraber)	Coconut Island (Poruma)			
TGBM	PM 146546 4.666	PM 146550 4.752	PM 156559 5.008			
Top of Ramp	4.358	4.559	4.335			
HAT2008	4.16 (4.2)	4.18 (4.16)	4.55 (4.2)			
MSL	2.00 (1.96)	2.02	2.28 (1.99)			
Island Datum	-0.124	0.009	-0.163			
LAT2008	0.00	0.00	0.00			
Eastern Group						
Datum Level	York Island (Masig)	Stephens Island (Ugar)	Darnley Island (Erub)	Murray Island (Mer)		
TGBM	PM 146543 4.364	PM 164053 4.615	PM 146551 5.009	PM 164054 5.499		
Top of ramp	4.615	4.632	4.556	not levelled		
HAT2008	4.35	4.11 (4.1)	4.13 (3.9)	3.52 (3.1)		
MSL	2.20	1.98 (2.00)	2.09 (1.82)	1.78 (1.44)		
Island datum	0.115	0.122	0.17 (ISLW)	0.034		
LAT2008	0.00	0.00	0.00	0.00		

Table 5. Connections from LAT2008 to Island datum, MSL, HAT2008, bench mark at the top of each boat ramp and TGBM. HAT value in brackets from the Queensland Tide Tables 2010 (QTT, 2010) for Thursday Island only. Hammond Island transferred from Thursday Island. Warraber transferred from Yam Island and the remainder from the Australian National Tide Tables (ANTT, 2009). MSL in brackets from the ANTT (ANTT, 2009). All values are in metres.

The vertical distance between LAT2008 and HAT2008 to primary bench marks are given in Table (5). A complete list of the Griffith University connections, other historic surveys, connections to the ellipsoid, tidal constituents and tidal planes are given in Metters, 2009. The vertical separation between local benchmarks is consistent using both GU levelling surveys and the DNRW ellipsoidal determinations (Metters 2009). This verifies the levelling survey work. However the connections from the tide gauges to the benchmarks cannot be verified directly.

Site	Height above MSL	Height above AHD	Difference MSL-AHD
Thursday Island	3.518	3.613	-0.095
Hammond Island	2.094	2.122	-0.028
Badu Island	2.759	3.258	-0.497
Mabuiag Island	6.382	7.656	-1.274
Boigu Island	1.876	2.706	-0.83
Saibai Island	2.071	2.793	-0.722
Yam Island	2.666	4.232	-1.566
Sue Island	2.732	3.204	-0.472
Coconut island	2.158	2.524	-0.366
York Isles	2.515	2.895	-0.38
Stephens Island	2.635	2.89	-0.255
Darnley Island	3.09	3.953	-0.863
Murray Island	3.719	4.681	-0.961

Table 6. Difference between the Project MSL and Australian Height Datum for one benchmark at each site.

A comparison of the AHD determinations with project MSL reveals large differences (see Table 6). Of the thirteen sites only two give a close relationship with less than 0.1m difference and nine sites were different by up to 1.0m. The difference between MSL and AHD were considerable at Yam Island by -1.57m and Mabuiag Island by -1.27m difference.

The change in tidal dynamics from east to west in the strait is seen in the form factor for each site. The Eastern sites have a form factor generally less than 0.5 with the exception of Warraber Island and Yam Island, both of which are close to 0.5. Hence the Eastern sites are generally semi-diurnal (refer Figure 5). The form factor of the central sites ranges from 0.89 at Mabuiag Island to 1.39 at Badu Island and these can be considered to be more diurnal in nature.

Discussion

The sea level data of this project, although short in length enabled a sound basis for establishing a coherent tidal datum across thirteen islands in Torres Strait.

The datum transfer from Thursday Island to Hammond Island and from Yam Island to Warraber Island is useful in verifying the results of the tidal analysis. The tidal regime is similar at Hammond and Thursday Islands and this is clarified with a high R^2 of greater than 0.99 from the regression between the two sites. The tidal regime is also very similar at Yam Island and Warraber Island with a high R^2 also greater than 0.99. HAT2008 levels of 3.81m and 4.18m derived from project tidal constituents were very close to the transferred HAT levels of 3.75m and 4.16m at Hammond Island and Warraber Islands respectively. For the islands north of Hammond Island, the tidal regime differed by more than 5 % of Thursday Island. Islands to the east of Warraber Island expressed a tidal regime that differed by 1.5% to 5.4% that of Yam Island.

The similarity in tidal dynamics at Hammond Island and Yam Island is also confirmed with similar form factors at each site. This is also the case between Yam Island and Warraber Island (see Figure 5). The large variance in form factors within the south central and eastern groups confirms that tidal transfers could not be used. The form factor of the two northern central sites are the same, however the tidal dynamics are clearly different as seen in Figure 2(c).



Figure 5. Tidal form factor (as $K1+O1/M2+S2$) for the project sites

The tidal planes and particularly MSL have been derived from short data-sets of 35 days. This data length is sufficient to incorporate most tidal cycles but does not account for longer tidal cycles such as the 18.6 year nodal cycle. An offset was applied in view of accounting for this unknown difference between the MSL derived from these short data-sets and MSL derived from a long dataset. The levels of MSL and HAT2008 derived from the project data after adjustment for seasonal and long-term factors varied by more than 10 cm from published values for five out of the eight published sites. This difference reflects the difference between the LAT2008 datum and the datum of the published sites.

The seasonal constituents S_a and S_{sa} cannot be verified directly for most of the project sites as there just isn't enough sea level information available from the region. In order to determine the seasonal or annual component of sea level from observed data there must be one year or more of sea level readings. There is more than one year of readings available for Thursday Island. For the other islands in this project where there are published seasonal constituents, the data that formed the basis of these constituents was less than one year in length and in some cases snippets of data from different years were joined to make up one year (personal communication with the National Tidal Centre). The modelled seasonal constituents reduced the level of HAT. If you consider that one of the main uses of HAT is as a reference point for development work including floor levels, it would be better to use a higher estimate of HAT rather than a lower estimate. A higher HAT will give some tolerance to allow for potential increases in sea level and HAT (through sea level rise etc). A lower HAT will increase the risk of inundation and flooding through building floor levels being too low.

Considerable difference was seen between the project MSL and AHD determined via AUSGeoid98 at many of the island sites. The MSL-AHD difference also varied between sites within the strait. Also notable is a general gradient in the difference increasing from South to North and to the Northeast. At Thursday and Hammond Islands, MSL was within 0.1m of AHD. There were six sites with a MSL-AHD difference of greater than 0.5m which exceeds the accuracy of AUSGeoid98 of ± 0.5 m (Featherstone et al., 2001). There are two possible causes of these anomalies; firstly the inability of the AUSGeoid98 to represent AHD (MSL) in the north of Australia where there is a known gradient in the AUSGeoid98 towards the North of Australia of 0.5m (Brown, 2010). The other possible cause of these anomalies lies in the adjustment to a long term MSL. MSL was derived from short term data-sets and the offset applied to adjust it to an approximation of a long term MSL may not be appropriate for application to all of the islands.

MSL has a range of between 1.78m at Murray Island to 2.28m at Coconut Island. The actual (but unknown) difference between this short term mean level and the long term MSL will very likely differ from this difference at Thursday Island. These two factors suggest that connecting to the AHD with GPS from the Torres Strait islands warrants further investigation. The overall objective of this project is to establish a datum that is coherent within the strait. With the difference between AHD and MSL in mind and the coherent nature of the project data, it is recommended that MSL derived here be used as an alternative to AHD in Torres Strait.

This study verifies the dynamic nature of the tide in the Torres Strait. The form of the tide can change over short distances in the Strait as evidenced by the difference in the tidal dynamics between Boigu Island and Saibai Island which are only 45 kilometres apart. Of particular interest is the change from a semi-diurnal tide in the Coral Sea to dominantly diurnal in the southern central section. The observation of Easton (Easton, 1970) of a change from semi diurnal in the East of the strait to being predominantly diurnal to the West of the strait is verified here. The form factor of sites to the east in the Gulf of Carpentaria, and to the south east on the north east coast of Queensland extends this change in dynamics. Just to the west of the strait the form is 1.47 at Goods Island and 1.54 just south at Weipa. In the south east of the Gulf of Carpentaria, the form factor is a much larger 6.48 at Karumba. The form factor at ports on the north east coast of Queensland is around 0.5.

There is a considerable difference in height along the strait where the maximum difference in sea level height at any one time for the project period was 3.3m (not presented here) between Darnley Island and Badu Island. Although not as large as the 6m difference claimed previously (Wolanski et al, 1988), it demonstrates the difference in phase of the two water bodies that the strait connects (Wolanski, et al, 1988 and Saint-Cast, 2008). This difference has implications for safe shipping transit through the strait.

Tidal planes including HAT2008 were calculated and referenced to LAT2008 and to the local benchmarks. This will enable local authorities to revise the local knowledge of tidal planes (particularly HAT) for use in coastal development and inundation mitigation. If HAT and the tidal planes presented in this report are to be used for purposes such as storm surge and sea level rise mitigation, coastal development and maritime safety, then it is recommended that an arbitrary level of error be applied. Where the accuracy of HAT is important for these purposes, it is recommended that these data-sets be extended to a more suitable length through long term installations of tide gauges. Long term installations will also be needed to verify the LAT2008 datum and MSL from this project.

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Ray Peddersen is the Senior Tides Officer in the Spatial Information section of Maritime Safety Queensland. He holds an Associate Diploma Surveying (1974) and Graduate Diploma Commercial Computing (1985). He commenced work with the Queensland Department of Harbours and Marine in 1974 as a Survey Assistant and worked extensively along the Queensland coast from the Gold Coast to Port Douglas. Since 1982 he has been working in the tidal unit of the then Harbours and Marine now part of Maritime Safety Queensland. He has helped develop tidal processing software and the TIDES database. He is currently responsible for providing tidal services including; quality assurance, analysis, predictions and advice from a network of over 30 operating tide gauges around coastal Queensland.

THE TRANSFORMATION OF SHOM

By G. BESSERO (France)
Ministry of Defence - France¹



Abstract

Heir to the first national hydrographic office in the world created in 1720 as a support service within the French Navy, the French Naval Hydrographic and Oceanographic Service (SHOM) was turned in 2007 into an autonomous public establishment under the custodianship of the Defence Minister. This article reviews the preparation and the implementation of the transformation and evaluates the results at the completion of the three year mandate of the first Director General of the new SHOM. Although the regulatory framework may vary from country to country, the governance model seems well tuned to the stakes that national hydrographic offices must face.



Résumé

Héritier du premier service hydrographique national du monde, créé en 1720 en tant que service de soutien de la marine française, le Service hydrographique et océanographique de la marine (SHOM) est devenu en 2007 un établissement public autonome sous la tutelle du ministre de la défense. Cet article présente la préparation et la mise en œuvre de la transformation et évalue son bilan au terme du mandat de trois ans du premier directeur général du nouveau SHOM. Bien que le cadre réglementaire varie d'un pays à l'autre, le modèle de gouvernance retenu paraît bien adapté aux enjeux auxquels les services hydrographiques nationaux sont confrontés.



Resumen

Herederio del primer servicio hidrográfico nacional del mundo, creado en 1720 como servicio de apoyo de la Marina Francesa, el Servicio Hidrográfico y Oceanográfico de la Marina Francesa (SHOM) se convirtió en el 2007 en un establecimiento público autónomo bajo la tutela del Ministerio de Defensa. Este artículo presenta la preparación y la implementación de la transformación y evalúa los resultados al término del mandato de tres años del primer director general del nuevo SHOM. Aunque la nueva estructura regulatoria puede variar de un país al otro, el modelo de gestión parece bien adaptado a los intereses a los que deben enfrentarse los servicios hidrográficos nacionales.

¹ This paper represents the views of the author and not the official view of the French Ministry of Defence

1. Background

Officially established in 1720 as “Dépôt des cartes et plans, journaux et mémoires concernant la navigation”, the French Hydrographic Office (SHF) was the first national HO in the world. As long as the merchant and military navies were intertwined and controlled by the State with a specific ministerial department in charge of all naval and maritime issues, there was no discussion that the most appropriate location of the SHF was within the French Navy. The situation evolved with the growth of commercial and leisure maritime activities. After World War II, the development of marine research, offshore exploration and exploitation activities together with the emergence of environmental issues contributed to an even broader spectrum of stakeholders interested in HOs’ outputs. These changes led to raising periodically the question of the most appropriate governance and funding models for the SHF. However considering that the Defence requirements associated with a world-class Navy and its deterrent component were still the major drivers of the SHF activities, no major change of its position was seriously considered until the late 1980s. The “Service hydrographique de la marine” became the “Service hydrographique et océanographique de la marine (SHOM)” in 1971. The name change reflected the wider perimeter of its activities; the new decree defining SHOM duties confirmed its status as a naval service under the sole authority of the Chief of the Naval Staff. Although a number of inspection reports between 1971 and 2003 underlined the increasing inadequacy between the restrictive status of SHOM and its broad national responsibilities, the status quo prevailed. Only a small step was taken in 1983 with the establishment² of an advisory committee bringing together the representatives of the various categories of users concerned by SHOM activities to discuss survey programmes and the adequacy of SHOM products. A new impetus was given in 2003 with the decision of the Interministerial Committee of the Sea, (CIMER) chaired by the Prime Minister, to review the missions and the funding of SHOM in order to meet civil requirements for marine geographic information, especially in the coastal zone, which are not intended to be funded systematically through the Defence budget.

2. Preliminary Studies and the Decision to Transform SHOM

Following the CIMER decision, the Director of SHOM proposed the Defence Minister through the Chief of the Naval Staff to invite a prominent personality to implement the review.

The mandate was notified on the 14 January 2005 by the Defence Minister to Mr André Lebeau, a geophysicist by training, former Director of the French Meteorological Agency (1986-1995), former President of the French Space Agency (1995-1996) and member of the French Maritime Academy. Based on his own considerable experience in managing and transforming public services, the analysis of the relevant documentation and interviews with representatives of the major stakeholders, in April 2005 Mr Lebeau produced a guidance report which recommended to transform SHOM into a national public administrative establishment. This new organisation would have an inter-ministerial governance to consolidate its position within the national environmental framework in order to account in the most efficient manner for the diversity of requirements related with the description of the marine physical environment from the coastal zone to the deep ocean. After considering the guidance report, in June 2005 the Defence Minister requested some additional investigations related with the implementation of the proposed transformation and the comparison with the situation in other countries. The additional elements were presented to the Minister at the end of September 2005. SHOM’s new Director was nominated on the 1st October 2005 and in November was tasked with evaluating the feasibility and conditions of the implementation of the recommendations of Mr Lebeau. This evaluation was conducted by a small project team chaired by the Director and composed of its closest collaborators and addressed three main issues. The first one encompassed the internal impact on the staff, the organization and the functioning procedures and involved a thorough consultation with union representatives. The second, covered the impact on the relations with the other components of the Ministry of Defence (MoD) and was handled through a team composed of SHOM Deputy Director and a Naval Staff representative. The third issue dealt with the relations with SHOM partners outside Defence. As Mr Lebeau’s recommendations meant that SHOM remained a public organ, the transformation would not have any significant impact on international relations and thus the evaluation did not require any specific consideration about this aspect.

² In France, there are basically three types of organizations in charge of national public services:

- the State administration which is under the direct authority of the government,
- the independent administrative authorities which regulate specific activities independently from the government,
- the autonomous public establishments which have a legal personality independent from the State.

Various types of public establishments have been defined over time at the national and local levels. Nowadays there are four main categories at the national level:

- the administrative public establishments which are mainly funded by public funds ,
- the industrial and commercial public establishments which can operate in both public and competitive sectors,
- the scientific and technical public establishments which operate in research and education sectors,
- the cultural public establishments which operate in the cultural sector.

The evaluation report was submitted to the Defence Minister in January 2006 together with a set of six proposals summarized as follows:

(i) The purpose of SHOM is to guarantee on behalf of the State the quality and availability of the information which describes the marine physical environment, both coastal and oceanic, through coordinating its collection, storage and dissemination, in order to meet public requirements, both civilian and military, in a European perspective, as cost effectively as possible. This activity of national public hydrographic and oceanographic service requires inter-ministerial governance under the custodianship of the Defence Minister.

(ii) The activity of national public hydrographic and oceanographic service is funded essentially by public funds, allocated by the State or obtained from the European Union or from local authorities. The organ in charge of this activity is not meant to intervene in the competitive sector.

(iii) The organ in charge of the national public hydrographic and oceanographic service is set up as a national public administrative establishment under the custodianship of the Defence Minister.

(iv) The regulatory framework of the new establishment and the terms governing its relations with the other components of the MoD will secure the advantages and efficiency factors of the existing organization, including the dual use of the national hydrographic and oceanographic infrastructure.

(v) The adequacy between the resources and the objectives will be ensured by a pluriannual contract taking into account the general directives for the public sector, the need to consolidate the contribution to the safety of navigation and to Defence support and the need to develop the support of public maritime and coastal policies in line with the associated specific funding.

(vi) The transformation of SHOM will be handled in order to become effective on 1st January 2007.

After some fine tuning of the impact on the provision of Defence support, the transformation principles were approved and the transformation process was officially initiated by a ministerial decision dated 4 April 2006.

3. Implementation of the Transformation

3.1. Overview

The transformation was run as a project called “SHOM 2007” with the structure put in place for the preliminary studies, including an internal project team chaired by SHOM Director and a MoD working group co-chaired by SHOM Deputy Director and a Naval Staff representative.

The progress was monitored by the Cabinet of the Defence Minister through monthly reports and ad hoc meetings. Four main tasks were run in parallel:

- regulatory framework and organization,
- funding model,
- human resources,
- public relations.

From the outset, the Director made the commitment to minimize the impact on both staff and hydrographic production.

3.2. Regulatory Framework and Organization

The transformation of SHOM required a decree from the Prime Minister which had to be approved by the ministers concerned and reviewed by the State Council. The process proved more arduous than expected although the Defence Cabinet limited the inter-ministerial consultation strictly to the five civilian ministers represented in the Board of Directors: Budget, Industry, Transport, Environment and Overseas Territories. The draft decree was submitted to the State Council in December 2006, together with three other draft decrees adjusting the MoD organization accordingly. The review was finalized in February 2007. It took another two months to get the decree signed and finally it was published in the Official Journal in May 2007³.

The text is arranged in five chapters dealing respectively with missions, organization and functioning, administrative and funding regime, human resources and transitory and miscellaneous provisions.

The chapter on the missions states that SHOM is responsible for the knowledge and description of the marine physical environment in its relations with the atmosphere, sea bottom and coastal zones and for predicting its change overtime. It spells out three main missions:

- SHOM is the French national hydrographic service appointed to collect and check all the information necessary or merely useful to ensure the safety of maritime navigation;
- SHOM supports Defence authorities and units for the preparation and conduct of military operations as well as for the development and use of weapon systems;
- SHOM supports national and local authorities for the implementation of public maritime and coastal policies in its domain of competencies.

SHOM duties include managing the relevant national databases and making its products available to the general public. SHOM is designated as the French representative in the International Hydrographic Organization (IHO).

³ Decree n° 2007-800 of 11 May 2007 published in the Official Journal of 12 May 2007. A copy is inserted in IHO publication M-16 (Ref. 1). In 2008, the decree was incorporated in the regulatory section of the Defence Code (articles R3416-1 to 30).

The most contentious issue in the inter-ministerial consultation proved to be the provision dealing with the obligation made to all public services and establishments to communicate to SHOM all the bathymetric and geophysical data collected under their authority in French maritime areas. It was finally upheld, with the stipulation that the conditions of use be formalized in a formal agreement between the data providers and SHOM. An additional clause specifies that the authorization to conduct marine research activities in maritime areas under French jurisdiction may be subject to the obligation to communicate the collected data to SHOM.

The chapter on the organization and functioning specifies that SHOM is administered by a Board of Directors and led by a Director General. It describes their responsibilities and specifies which duties the Board may delegate to the Director General. In summary, the Board sets out strategic orientations and approves the annual budget and accounts while the Director General is responsible for day-to-day management and is the legal representative of the institution. The term of office of the Board Members as well as of the Director General is three years. Early on, the Defence Cabinet had decided to limit the number of Board Members to a maximum of twenty in order to keep it manageable. That led to the following composition:

- the Chairman and five members representing the Defence Minister,
- five members representing a selection of civilian ministers (Budget, Transport, Environment, Industry and Overseas Territories),
- the Secretary General of the Sea⁴,
- four qualified personalities,
- four representatives of the staff (one representing the military staff and three representing the civilian staff).

Two innovative provisions are included in this chapter. The first one deals with the designation of the Chairman of the Board. Instead of the standard provision which lets the Government select the Chair among the members of the Board on a case by case basis, the Chief of the Naval Staff is designated as Chair in his official capacity, in recognition of the importance of maintaining a close relationship between SHOM and the Navy. The second provision requires the Director General to be a qualified hydrographer according to the competency standards of the IHO. The existence of such standards (Ref. 2) was sufficient to convince the State Council of the legitimacy of this provision linked with SHOM responsibility in providing adequate hydrographic services for the safety of navigation.

This chapter also identifies two specific components within SHOM: the survey units and the training school. It specifies that their organization is defined by a ministerial order.

The three other chapters are based on standard regulations applicable to public establishments. They include the possibility for SHOM to arrange capital loans and to create subsidiaries or acquire shares in private companies for instance to value research outputs or to participate in cooperative endeavours.

Most of the application orders required by the decree had been prepared in parallel and were published in the French Official Journal before the end of July 2007. They covered organizational aspects, such as the organization and functioning of the survey units and the training school, nominations (Board Members, Director General, Deputy Director, Accounting Officer), as well as SHOM human resources and infrastructure. In line with a previous decision of the Defence Minister which had moved SHOM head office from Paris to Brest in December 2005, the location of SHOM registered office was set in Brest (*Fig. 1*). The first meeting of the Board of Directors took place on 23 July 2007, formally establishing the new governance of the institution.



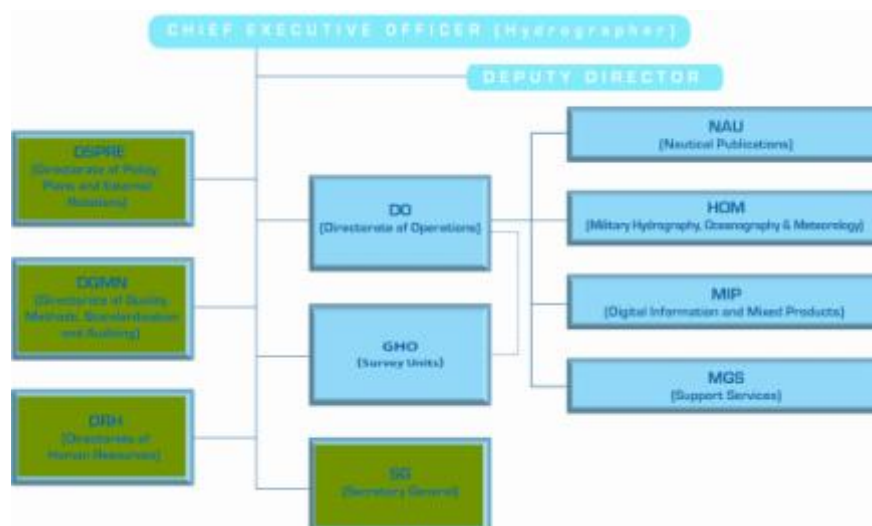
Fig. 1. SHOM facilities in Brest

⁴ The Secretary General of the Sea assists the Prime Minister with coordinating the activities of all the administrations involved in maritime issues. In that function, it was considered that he could represent the ministries which do not have their own representative in SHOM Board of Directors, such as, for example, the Ministry of Foreign Affairs, the Research Ministry and the Ministry of Agriculture and Fisheries.

The new organization of SHOM which had been prepared in 2006 was formally established in June 2007 and was confirmed by the Board of Directors at its first meeting. It distinguishes functional and production organs (*Fig. 2*).

administration for surveys in New Caledonia (85 days in 2006) while the overall ratio of public support versus Defence support in SHOM activities was of the order of 35/65.

Fig. 2. SHOM organizational chart



The functional organs are:

- the strategy, planning and external relations directorate,
- the quality, methods, standardization and management control directorate,
- the human resources directorate,
- the general secretariat, responsible for administrative, financial and legal matters.

The production organs include the operations directorate and three hydrographic and oceanographic groups in charge of conducting surveys. The operations directorate is organized in three product divisions aligned with the three missions (nautical products, military products, data management and mixed products). A fourth division is in charge of logistic support, including the procurement and maintenance of survey equipment. The survey units are meant to operate from ships belonging to the Navy or to civilian institutions under bilateral conventions with the ship owners.

3.3. Funding Model

When SHOM was a service of the Navy, its resources had to come from or through the Defence budget. It means that non-budgetary resources would transit through the Treasury, including the income from the sales of charts and nautical publications, and in practice it was very difficult to access financing from non-Defence partners. The overall cost of SHOM in 2006 was evaluated at 68 M€ covered by 45 M€ of aggregated resources from the Defence budget, 3 M€ of sales of products and services and 20 M€ of in-kind support (including ship time for surveys, 90% of which funded by the Navy).

The contribution from the civilian sectors was basically limited to the provision of ship time through the maritime

Although the objective of the transformation was to adapt both the governance and the funding model of SHOM to its wide-ranging responsibilities, it was acknowledged that securing access to new sources of funds would take time and efforts, the more so in the general context of reducing public expenditures. The transition budget for the remaining part of the year 2007 and the first full-year budget of 2008 were established in continuity with the previous situation in which the main part of the resources came from the Defence budget. In parallel the establishment of a pluriannual contract setting the goals and the associated means which had been started in 2006 was continued under the supervision of the Board of Directors and became a standing item on its agenda. It was relatively easy to agree on ambitious high level goals assigned to SHOM which were consolidated with the adoption by the Board of SHOM strategic vision at the end of 2008 (Ref. 3) but it proved much more difficult to obtain appropriate funding commitments from the relevant customers. The associated funding model identified four main sources of funding:

- the public service subsidy to be supported by the Ministry of Defence as custodian of SHOM,
- the revenue from the sales of products and services,
- the contractual financing of specific Defence activities,
- the contractual financing of non-Defence activities.

The study of non-Defence financing was centred on two main projects: the Litto3D project related to the provision in partnership with the French National Geographic Institute of a high resolution land-sea digital terrain elevation model to support integrated coastal management (Ref. 4) and the national application of the European marine strategy framework directive (Ref. 5) dealing in a first stage with the assessment of French marine waters and the determination of “good environmental status”.

Reaching a consensus on the contribution of the various partners was a lengthy process and both the 2009 and 2010 budgets were elaborated and approved on a case by case basis. Finally the Board agreed in May 2010 on SHOM first contract of objectives and performance covering the period 2010-2012, which was then signed by the Defence Minister on 21 July 2010. *Table 1* summarizes the provisional results for this period. They are based on a constant annual subsidy, a reasonable growth of sales taking into account the increasing demand for digital products and a significant increase of non-Defence contractual financing which had already reached 2 M€ in 2009. These figures do not include in-kind support related to the provision of ship time which is to remain at an average level of 920 days/year with 830 days provided by the Navy and 90 days provided by the Government of New Caledonia. Additionally the contract calls for SHOM to investigate new sources of revenues through the provision of expertise and services to the private sector, as long as they are in compliance with European and national regulations on competition and the use of public data. The objective was that sales and contractual financing amount to 20-30% in 2015.

3.4. Human Resources

The transformation of SHOM did not have any significant impact on staff regulations. The new public establishment continues to employ a large majority of military personnel and civil servants and is submitted to the same limitations than the former Navy service as far as contracting its own staff from the open job market is concerned.

This is allowed only for non-permanent posts or for posts requiring specific qualifications which are not available in the military or civil services. However, the establishment can now recruit directly within the employment cap approved by the Board and does not have to process all recruitment through the MoD.

It was noted early in the procedure that the transformation would require internalizing a number of functions which previously were mutualised across the MoD. They include human resource management, accounting functions and legal advice. Also taking into account the reinforcement of the marketing function, the Navy agreed to endow SHOM with seven additional posts. Altogether the employment cap was set at 525 staff for 2008. As a token contribution to the general downsizing of public employers, it was reduced to 523 in 2009 and to 521 in 2010. In principle this number should remain stable until 2012 with the possibility to recruit up to 30 additional staff on non-permanent posts covered by contractual financing. It is worth noting that salaries and related expenditures represent about 60% of SHOM annual budget.

3.5. Public Relations

A communication plan was initiated in May 2006 and revised regularly. It was coordinated with the MoD information and communication directorate, and the Navy information and public relation service.

(M€)	2010	2011	2012
Income			
<i>Public service subsidy</i>	42,2	42,2	42,2
<i>Sales of products and services</i>	4,0	4,1	4,3
<i>Contractual Defence financing</i>	5,5	4,9	4,3
<i>Non-Defence contractual financing</i>	3,9	11,7	9,7
<i>Interest and financial products</i>	0,2	0,2	0,3
Total income	55,8	63,1	60,8
Expenses			
<i>National hydrography</i>	6,9	6,9	6,9
<i>Defence support</i>	11,2	10,7	10,1
<i>Public policy support</i>	5,4	11,9	10,6
<i>Common activities and logistics</i>	33,5	33,5	33,0
Total expenses	57,0	63,0	60,6
Profit (Loss)	(1,2)	0,1	0,2

Table 1. SHOM provisional consolidated balance sheet 2010-2012

The priority was to keep the staff fully informed on the rationale of the transformation process, its consequences and its progress. The relevant documentation was posted on SHOM intranet and an information booklet was distributed to each staff in June 2006. Formal and informal internal meetings were held regularly at various hierarchical levels. An interactive forum was set up on SHOM intranet to handle questions and comments from the staff on a continuous basis.

The main MoD authorities were kept informed personally by the Director and an information flyer was distributed to all Defence partners. Three conferences were given to the Naval Staff in December 2006, to a training session for commanding officers in January 2007 and to the 2007 edition of the “Defence Hydro-Metoc Days” in June 2007. An inset on SHOM transformation was inserted in the MoD brochure on the 2007 budget.

On the occasion of the first World Hydrography Day on 21 June 2006, two press conferences were organized simultaneously in Brest and Paris to present the objectives of the transformation of SHOM in the context of the role of hydrography and the contribution of France to the objectives of the IHO. This was followed by sending an information flyer to more than 350 French stakeholders. Also in February 2007, a conference was given by SHOM Director at the French Maritime Academy (Ref. 6).

The information of international partners was addressed through the national reports presented at the meetings of Regional Hydrographic Commissions and through SHOM annual reports. A number of National Hydrographers were also present at the celebration of the second World Hydrography Day on 21 June 2007 in Paris where the new statute of SHOM was presented.

The transformation of SHOM was also an item in the 2006 and 2007 editions of the annual letter of information distributed to the general public and accessible on SHOM website (Ref. 7 & 8). A new information package including a video and a flyer in both French and English was made available in June 2007.

The final event of the plan was a communication on SHOM transformation at the weekly MoD press conference on 27 September 2007 on the occasion of the World Maritime Day dedicated to “current environmental challenges”.

In order to develop and consolidate long term support from SHOM’s many stakeholders, it was recognized that a substantive effort was required to strengthen lobbying and public relation capabilities in line with the development of new services and products along five main axes:

- the provision of an extended range of digital products and services,

- SHOM’s involvement in the integrated management of coastal areas,
- the applications of numerical modelling of the ocean,
- the role of in situ observation network of the marine environment,
- SHOM’s contribution to early warning networks.

4. Assessment

At the end of the first three years’ cycle of SHOM in its new statute which coincides with the adoption of SHOM first contract of objectives and performance and the handover to its second Director General, it is a good time to assess the benefits and drawbacks, if any, of the transformation. So far, only benefits have been identified.

The new organization and the new human resource management and accounting procedures associated with the new statute were implemented without any significant discontinuity in SHOM functioning. In order to take further advantage of the momentum of change, the overall process-based management system was streamlined in-depth. The ISO9001:2000 certification which had been finalized in 2006 was confirmed with the new system in March 2008. Some of the gains in efficiency could have been obtained in the former statute. However the obvious progress in the control of and visibility on human resources and financing is a direct consequence of the new statute.

Thanks to the constant dedication of SHOM staff, the transformation was completed without any disruption of the services provided by SHOM to its traditional customers: the production of chart and nautical publications as well as the provision of Defence support were maintained at a high level in both quality and quantity, in the demanding context of the transition to digital products.

In the meantime, the results obtained so far indicate that the progress in developing and promoting new services in support of marine and coastal public policies is in line with the ambition of the transformation. This is illustrated by the following examples.

After the experimentations conducted from 2005 to 2007, the new statute allowed SHOM to launch, in partnership with IGN, the production phase of the Litto3D® project already mentioned. The first two major contracts were signed in 2009, one to survey French territories in the Indian Ocean (Reunion, Mayotte and Eparses islands), with financing from the Ministry of Environment, the French marine protected areas Agency and the local authorities, and the other to survey the littoral area of Languedoc-Roussillon along the Mediterranean coast, with financing from the local authorities.

Additionally, an agreement was signed with IGN in 2008 to release the first edition of the SCANLittoral® cells for metropolitan France and overseas. SCANLittoral® is the digital seamless raster series of charts depicting seamless nautical and terrestrial information for the entire coasts (Fig. 3). This product is not only expected by national security services but is also awaited by many GIS operators, as confirmed by the increasing number of digital cartography requests for non-navigational purposes.



Fig. 3. Visualisation of SCANLittoral® on the national Geoportail GIS portal

At European level, SHOM was able, as public establishment, to take part in two projects. The Geo-Seas project that was launched in 2009 aims at building and deploying a unified marine geoscientific data infrastructure for the federation and sharing of marine geological and geophysical data from national organizations across Europe (Ref. 9). The second project, also launched in 2009, deals with the development of a pilot hydrography portal as one of the preparatory actions of the future European marine observation and data network (EMODNET); it aims at facilitating access to bathymetric data through the production and dissemination of digital terrain models (Ref. 10).

On the international scene, the real-time SHOM tide gauge network (RONIM) was recognised as a key component for the French contribution to regional tsunami warning systems developed around the world under the aegis of the Intergovernmental Oceanographic Commission (IOC) (Ref. 11). This role was materialised in 2009 with the launch of the CRATANEM project, which aims at setting up the French contribution to the IOC tsunami early warning and mitigation system in the North-eastern Atlantic, the Mediterranean and connected seas (NEAMTWS). As a public establishment, SHOM is a full-fledged partner of the project under a contract co-sponsored by the Ministry of Environment and the Ministry of Interior.

A different area where the change of statute was a key factor is the implementation of the hydrographic survey component of the Western Indian Ocean Marine Highway Development and Coastal and Marine Contamination Prevention Project sponsored by the Global Environment Facility (GEF) in partnership with the International Maritime Organization, the World Bank and the European Union (Ref. 12). As public establishment SHOM was able to reach an agreement with the World Bank on optimum conditions for the completion of the survey. The survey was carried out in the first semester of 2010 (Fig. 4).

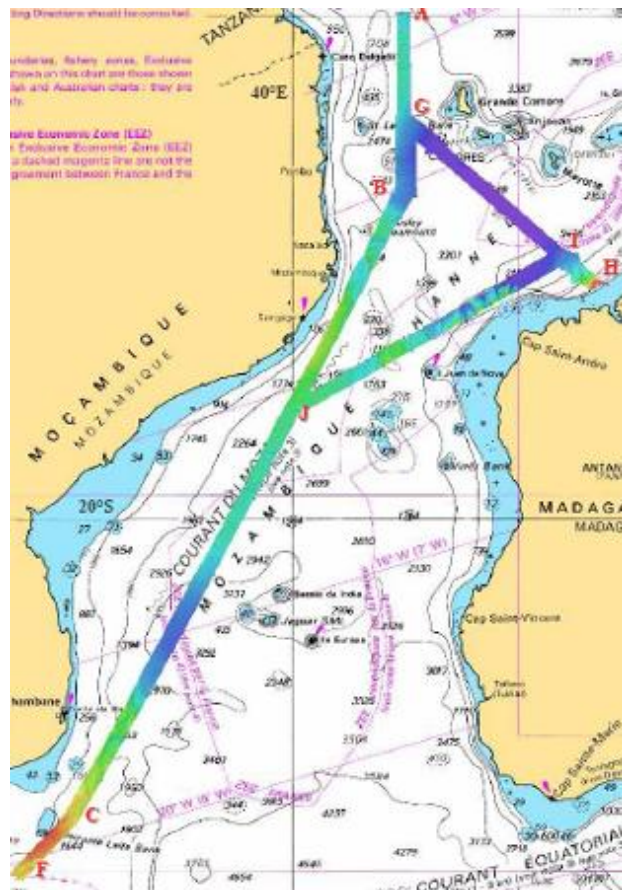


Fig. 4. SHOM Survey of the Western Indian Ocean Marine Highway

The development of operational coastal oceanography is another important element of the environmental support package to the decision aids on maritime and coastal policies where the new statute was instrumental in consolidating SHOM contribution. As a public establishment SHOM did consolidate its role of active promoter and partner of initiatives such as the real time demonstrator Previmer co-sponsored by the State and the Brittany Region (Ref. 13) and the on-going national Mercator programme embedded in the maritime component of the European GMES⁷ initiative through the MyOcean project (Ref. 14).

⁷ GMES : global monitoring for environment and security.

5. Conclusion

The transformation of SHOM into a public establishment after more than ten years of efforts is clearly a success. In line with SHOM's wide-ranging role, the new statute is characterized by inter-ministerial governance and the capabilities to access to non-Defence financing sources and to partner with all stakeholders. The dual character of many activities conducted by SHOM makes its involvement necessary, and often essential, in numerous sectors which are not limited to safety of navigation and Defence support. For security, sustainable development, integrated coastal zone management, protection of the environment, decisions that are critical for the future and the protection of our maritime heritage must be supported by a recognised, qualified, reliable, cartographic foundation and by high-performance coastal oceanographic models. It was clearly a necessity to significantly improve both the support and the efficient use of SHOM's capacities and services. It ensures that SHOM continues to respond to new challenges and meets the needs of an evolving context in which knowledge-management and the efficient distribution of geospatial and environmental information are becoming the most important outcomes for the development of integrated maritime and coastal policies.

The Transformation of SHOM is a significant step, and surely not the last one, in a long and worthy history of more than 290 years of service to mariners. It is also a significant step in ensuring that SHOM continues to be a major contributor to the International Hydrographic Organization (IHO). The transformation also requires that SHOM develop its "faire savoir" in line with its uncontested "savoir-faire". SHOM's active contribution to the "Grenelle de la mer" forum and to the National Strategy for the Sea and Oceans approved by the French Government in December 2009 (Fig. 5) is a good omen.

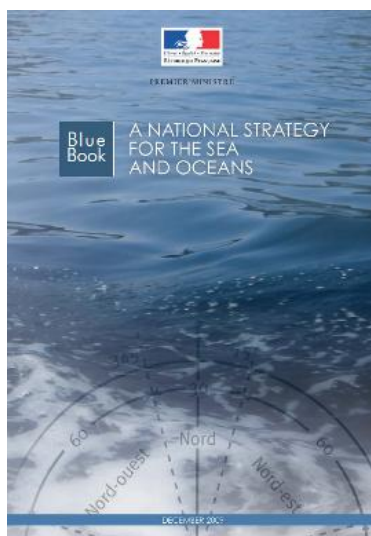


Fig. 5. French Blue Book on the national strategy for the seas and ocean

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Biography of the Author

Gilles Bessero served in SHOM as military hydrographic officer from 1976 to 1999. After a stint with the French Defence Procurement Directorate (DGA) from 1999 to 2005, he returned to SHOM as director on 1st October 2005 and implemented the transformation process through which SHOM became a public establishment. He served as the first Director General of the new establishment from June 2007 to June 2010. At the end of his mandate, he was appointed to the inspectorate of DGA as inspector in charge of the naval sector. Member of the French Maritime Academy, he is also chair of the Inter-Regional Coordination Committee of the IHO.

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MULTIBEAM SONAR PERFORMANCE ANALYSIS VALUE AND USE OF STATISTICAL TECHNIQUES

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Abstract

The Naval Oceanographic Office uses quantitative methods employing statistical measurements to analyze and evaluate the performance and behavior of multibeam sonar bathymetry systems. Datasets are made that determine the residual differences between a reference surface and multibeam sounding files as a function of beam angle. The resultant beam-wise analysis facilitates artifact detection, trends, overall uncertainty, dataset limitations, and system performance compliance against specifications or other special requirements. The technique used is presented with examples of its application in analyzing system performance, data processing, and survey planning in two actual case studies.



Résumé

Le Service océanographique naval utilise des méthodes quantitatives employant des mesures statistiques pour analyser et évaluer le fonctionnement et le comportement de systèmes bathymétriques sonar multifaisceaux. Des ensembles de données sont constitués et déterminent les différences résiduelles entre une surface de référence et des fichiers de sondage multifaisceaux en tant que fonction d'angle de faisceau. L'analyse dans le sens du faisceau qui en résulte facilite la détection d'objets, les tendances, l'incertitude globale, les limitations des ensembles de données et la conformité du fonctionnement du système avec les spécifications ou d'autres exigences spécifiques. La technique utilisée est présentée avec des exemples de son application dans l'analyse du fonctionnement du système, le traitement des données et la planification des levés dans deux études de cas réelles.



Resumen

El Servicio Oceanográfico de la Marina utiliza métodos cuantitativos que emplean medidas estadísticas para analizar y evaluar el rendimiento y el comportamiento de los sistemas de batimetría que utilizan el sonar multihaz. Se crean colecciones de datos que determinan las diferencias residuales entre una superficie de referencia y los archivos de sondeos multihaz como función del ángulo del haz. El análisis del haz resultante facilita la detección del artefacto, las tendencias, la incertidumbre general, las limitaciones de las colecciones de datos, y la conformidad del rendimiento del sistema frente a las especificaciones o a otros requerimientos especiales. Se presenta la técnica utilizada con ejemplos de su aplicación al analizar el rendimiento del sistema, el procesado de datos, y la planificación de los levantamientos en dos estudios de casos reales.

Overview

Prior to fielding an operational multibeam echosounder aboard Naval Oceanographic Office (NAVOCEANO) ships, rigorous testing is conducted to assess the system performance and limitations associated with its use on the intended vessel. These tests include baselining system noise levels, determining the system capabilities (e.g., swath width, depth range, and target detection ability), and evaluating system performance to meet uncertainty specifications.

The NAVOCEANO multibeam sonar system (MBSS) comprises the new sonar suite life-cycle overhaul for the T-AGS 60 class ships. It includes replacing the hull-mounted Simrad EM121A deep water sonar and EM1002 shallow water sonar with the Kongsberg EM122 and EM710 sonar systems, respectively. The T-AGS 60 ships are being cycled through an overhaul rotation of one ship per year for the six ships. Currently, five ships have completed their overhaul while one more is still scheduled.

Previous sea acceptance testing had limited the test sites to hard bottom areas. After the third MBSS installation (USNS Pathfinder) was placed in operational service in August 2009, a severe degradation problem was observed in the EM122 data over an area having an acoustically “soft” bottom characterized by high absorption and low reflectivity. The characterization of the artifacts created by the degradation and efficacy of methods to resolve the problem using statistical techniques form the first case study of this paper. In the second case study, USNS Mary Sears operated the Simrad EM1002 on an operational survey with the starboard beams exhibiting inordinate system noise levels due to hardware malfunction that significantly degraded the system performance. That case study demonstrates using the beam statistics analysis to aid decision-making for data validity during post-processing and as a tool for survey planning to optimize survey execution while meeting survey uncertainty requirements.

The use of statistical techniques for examining multibeam sonar performance has been employed for over two decades at NAVOCEANO. The techniques have also been used by academia as well (for example, de Moustier 2001). The use of the techniques here emphasizes their application to the sonar baseline evaluation and capability, monitoring changes in capability and performance, and use as a tool for operational survey optimization.

Reference Surface Construction

Essential to the performance evaluation of a multibeam echosounder is the availability of a reference surface that can be used as ground truth for the test data. While independent information from sources other than the system under test is desired for establishing the reference

surface, often there is no other source available. In those cases, the system is tested against itself, and only the more certain inner-beam data from the system that is being tested is used to build a reference surface. The application of certain procedures as discussed below to create the reference surface makes a valid and consistent evaluation possible. For the T-AGS 60 class ships having multiple multibeam echosounders that cover shallow and deep regimes, the overlap zones of operation are suitable for gauging one system against the other. The use of multiple ships facilitates the development and use of a calibration test area for analyzing repeatability of results between survey ships.

In preparation for collecting the sonar data used in creating the reference surface, the multibeam sonar system is configured with all necessary parameters to ensure a valid dataset is acquired. Great care is taken in ascertaining all installation locations and angles associated with the determined master reference plane. Follow-on patch tests are then conducted for obtaining any residual timing, roll, pitch, and heading corrections associated with the navigation, timing, and motion systems used.

Before collecting the reference surface line data, accurate sound velocity measurement is established with a conductivity, temperature, depth (CTD) sensor or expendable bathythermograph (XBT) for real-time application. Sound velocity is acquired at periodic intervals, depending on the environment and needs of the system under test. After the data collection, all other known reducers are applied (e.g. tides) to achieve as accurate a dataset as possible.

The tedious attention to detail involving the system configuration setup, execution of patch tests, and collection and application of environmental factors is intended to minimize systematic errors that otherwise bias the resultant data in some way and introduce unwanted error into the bathymetric measurement. The complexity of multibeam sonars along with the highly dynamic operational environment can result in very challenging efforts to control the systematic error sources, both static and dynamic (Hughes Clarke 2003).

Reference surface survey lines are spaced at much closer line spacing than routine survey lines. Reference survey line spacing is typically less than the water depth with a high percentage of overlap (45 degree outboard angle). This arrangement ensures that a very high sounding density is used in the gridded dataset and that only the most accurate and least noisy data are included in the reference surface construction. Typically, as the beam angle within the swath increases outboard, sound velocity errors and signal-to-noise degradation increase data uncertainty, only the inner 90 degrees or less of the swath is used in the reference surface.

Note: The inclusion of names of any specific commercial product, commodity, or service in this paper does not imply endorsement by the U.S. Navy or NAVOCEANO.

A flat, featureless seafloor is desired for the reference surface. Flat bottoms facilitate uncovering system artifacts that are often masked with sloping or featured bottoms and minimize errors associated with positioning. As a minimum, the dimensions of the reference surface should ensure that the swath width coverage of the system under test is completely contained within the reference surface for both inline and orthogonal line azimuths.

Following the collection of the reference lines, the data are carefully reviewed to ensure removal of blunders, outliers, and otherwise bad data. These cleaned lines are then input into a gridding program to generate the reference surface. Bin size for the grid is nominally set between one to two times the footprint size of the sonar in the nadir region.

Beam-Wise Statistics Generation

NAVOCEANO typically collects a full set of reference data in orthogonal directions and uses all data from both directions in the reference surface as seen in Figure 1. The test data being evaluated are minimally edited (or not at all). Outliers that are not caused by the system itself under normal operation but are caused as a result of extreme environmental factors such as transducer aeration from rough seas or acoustic interference from other sources are removed from the test data.

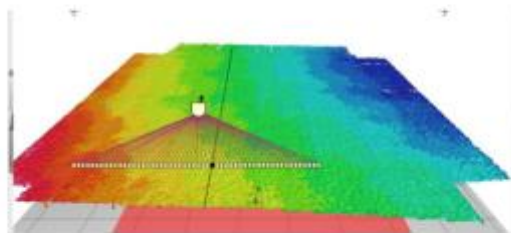


Fig. 1. Reference surface created from a full set of reference data collected orthogonal directions. The tracking of one beam of the swath across the reference surface is diagramed.

The previous T-AGS 60 sonar system (EM121A) provided 121 non-overlapping equi-angular distributed beams, having $1^\circ \times 1^\circ$ nominal footprint size. This distribution allowed for referencing beam angle synonymously with beam number. The current generation of sonars can produce over 400 overlapping beams per swath in selectable distribution patterns. For each beam in the test data file, the residual depth is calculated by subtracting the beam depth from the reference surface, and these residuals

are then binned to the nearest 1° interval. The mean and standard deviation for each angle bin are then calculated and displayed. In this way, the beam statistics can still be plotted against “beam angle,” forming the basis of the beam-wise evaluation technique described in this paper.

Plotting the Statistical Data

The beam statistics tabular output is plotted in profile for system performance analysis. The graphs generally depict the mean depth residual of each beam (in 1-degree bins) and associated standard deviation (dispersion) as a relative percentage of depth or absolute depth. Beam angles are plotted with the outboard port side (left) to the outboard starboard side (right).

An example beam statistics plot is shown in Figure 2, which is derived from an entire set of EM122 test lines over an EM710 reference surface in a hard bottom area approximately 800 m deep. The following is an explanation of the key elements of the plot:

(1) The plot header provides basic information about the plot. In this case, the *%depth residual* term indicates the vertical scaling is referenced as a percentage of depth residual rather than depth residual.

(2) The *(1.96 sigma)* term indicates that the plotted dispersion values for each beam angle are based on the 95% two-tailed normal probability distribution computed for that beam angle for the test dataset.

(3) The *<Order1>* term indicates the IHO Order level of uncertainty applicable for the test data depth that will be plotted as horizontal red bars above and below the abscissa axis of the plot. These bars are provided for comparative convenience to observe whether the system under test is compliant with any desired IHO level requirement for total vertical uncertainty (TVU) of the system-determined beam depths. The TVU computed is based on the average depth of the reference surface (as a single point) and formulae published in IHO S-44, 5th edition standards (2008) for hydrographic surveys. The IHO standards assume a 95% confidence level of the data, which is a 1.96 sigma (1.96σ) dispersion based on a normal distribution.

(4) The last parameter on the top header line between the arrow brackets, in this case *<NWGem122-b.bmsts>*, is the filename source containing the data used to construct the beam statistics plot.

(5) The term *avg(z, num pts, bias)* is annotated on the second header line. The *avg(z)* corresponds to the overall average (mean) depth of the dataset (839.8 m in this case). The *avg(z)* value here is the depth value used for the IHO uncertainty calculation discussed in (3) above.

(6) The *avg (num pts)* term corresponds to the average (mean) number of points used in the sample set per beam angle (36,087 in this case). The *num pts* parameter is indicative of the reasonableness of the sample size for computation of the descriptive statistics. Multibeam sonar ping rates rise significantly as the water shallows resulting in tens or even hundreds of thousands of soundings averaged per beam angle, depending largely on whether one or more test lines are included in the test dataset. Correspondingly, water depths on the order of 4,000 m often result in *avg (num pts)* values that are tens-of-times less than shallow water testing. The distribution of *num pts* as a function of beam angle is not uniform but is U-shaped by the nature of the geometry and the sampling involved as well as system parameter settings. The extreme outboard beam angles may have from 2 to 5x the *num pts* value as at nadir, so if *avg (num pts)* is 2,000, the nadir beam angles may have 1,000 samples each, whereas the outboard angles may have 4,000 each. The more samples that are available for each beam angle presumably results in more accurate statistics for evaluating the system performance and behavior. However, the duration time of collection must ensure proper sounding controls are maintained, e.g., tides and sound speed profiles.

(7) The *avg (bias)* term corresponds to the overall average (mean) value of all beam-angle depth residuals in meters of the test dataset over the reference surface. In this example, the bias is computed as +0.377 m, meaning that, on average, the depth for any beam angle is 0.377 m above the reference surface. A negative value infers the test data having an average depth below the reference surface.

(8) Three curve-sets are graphed on the plot: (a) The mean depth residual value as a function of beam angle is graphed as the red-green curve. (b) The associated scaled standard deviation values for a particular beam angle are colored blue and graphed in error-bar style about the mean value. (c) The pronounced red horizontal lines provide an IHO metric for system performance. The metric may be a strict compliance requirement dictated by the operational water depth (e.g., water depths 40 m or less) or may indicate an extrapolated uncertainty requirement provided for comparative purposes. Figure 2 shows the IHO Order 1a confidence level specification as projected to a depth of 840 m. Technically, IHO Order 2 would be the proper compliance order to use if a survey was to be conducted to meet IHO requirements at this depth. However, most multibeam sonars easily meet Order 2 specifications, and it is of more interest to gauge the system by more stringent requirements, particularly if the system may be used in a wide range of depths.

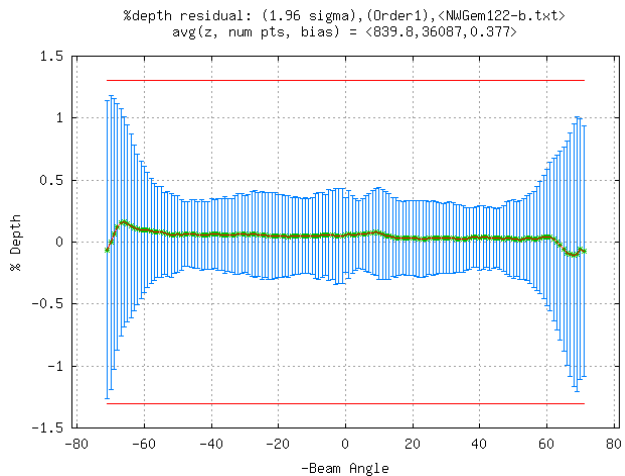


Fig. 2. Beam statistics plot of the EM122 against an EM710 reference surface over a hard bottom in 800-m water depth. This graph shows the expected U-shaped pattern of uncertainty revealed by the profile of the blue standard deviation error bars, where the uncertainty increases with beam angle. All data fall within the IHO Order 1a specification indicated by the horizontal red lines.

In the case of Figure 2, all of the error bars across the swath are between the red horizontal bars indicating the system is compliant with extrapolated IHO Order 1a requirements.

The wide, flat U-like shape of the blue error-bars profile in Figure 2 is also consistent with the modeled performance of multibeam sonars where the uncertainty increases in outer beams (Hare et al. 2004).

Analysis of Plots

As discussed previously, the beam statistics plots display the mean depth residual values as a function of angle with associated scaled standard deviation and IHO uncertainty bounds. The mean depth residual values are considered to best represent systematic errors or biases. The standard deviation values for each beam angle are created from both random error sources and dynamic systematic error sources. Hughes Clarke (2003) discusses dynamic systematic error sources in multibeam sonar systems at length. For the beam statistics analysis presented here, the standard deviation values are considered just random errors that follow a normal distribution. The empirical rule of statistics for a normal distribution is applied (Ott and Longnecker 2001), and the confidence interval for any beam can be computed as the sum of the mean and a scaled value of the standard deviation (Coleman and Steele 1999). Using typical 95% confidence level guidance utilized in hydrographic applications, these plots graph both the mean value of each beam angle and the maximum magnitude of the mean value of each beam ± 1.96 standard deviations for that beam angle.

Analysis of the beam statistics plots can facilitate:

- Detecting artifacts
- Identifying across track trends
- Assessing overall uncertainty performance
- Evaluating system performance compliance against the manufacturer's specifications, IHO specifications, or other special requirements

Figure 3 contains a sample beam statistics plot (top) and bathymetric view of depth (bottom) for an EM122 test line across an EM710 reference surface in a shallow water area (150 m). Normally, only the EM710 would be operated in this water depth, as the EM122 is intended for deeper water operation. However, Figure 3 provides an excellent example to correlate features between the two graphics and highlight the beam statistics benefits mentioned above.

(1) The EM122 sonar system supports yaw stabilization by breaking the transmit swath into multiple sectors. The angular coverage of each of the four transmit sectors composing the swath is annotated in the beam statistics plot along with each sector's respective seafloor coverage extent in the bathymetry view. Notice that at each sector boundary, 1-2, 2-3, and 3-4 are observed standard deviation peaks (blue error-bars), which indicate artifacts present at the sector boundaries at this unusually shallow operating depth. Although the standard deviations peak at the 1-2 and 3-4 sector boundaries, the mean difference plot (green trace) dips rapidly to zero at the corresponding boundaries (A and B marks). This statistical combination means that although the mean depth residual values at these sector boundaries are zero (i.e., agree with the reference surface), there is actually considerable variance in the residual depth difference values at these beam locations when compared to the reference surface. The higher variance indicates the sector boundaries tend to be a "noisier" location in the swath even though the overall average of the noise is zero.

(2) The beam angles associated about the A and B locations in the beam statistics plots are associated with the elongated ovals marked in the bathy view. Here, the A and B points become lines representing the beam angle tracking along the surface. Short dotted guidance lines are drawn within the orange ovals to represent the A and B tracks. The starboard (B) side has a particularly noticeable blue-green-yellow color delineation all the way along the survey line, correlating with the notable dip observed at A and B.

(3) For the beams between the A and B locations, it can be observed that the mean difference plot (green trace) shows all beams having positive depth residuals, indicating the EM122 beams are all reading values shallower than the EM710 surface. The curve slopes up from A to the left side of zone C. In the C area, the mean difference curve decreases somewhat, indicating a slight

channeling or trenching effect could be anticipated in the data. A peak in the mean difference occurs at D, about +18 degrees beam angle, and decreases down to point B. These observations show the use of beam statistics to capture across track trends.

(4) The C area is annotated on the lower bathy image, and a particularly distinct trenching area is seen in the dark blue stretch of pixels. The area is associated with a sector boundary area. White pixels are entire beam dropouts. High variations in the nadir area along track are represented by the yellow, green, and blue soundings. Even the red IHO Order 1 maximum allowable uncertainty is exceeded, demonstrating beam statistics use at assessing artifact impact on meeting survey specifications.

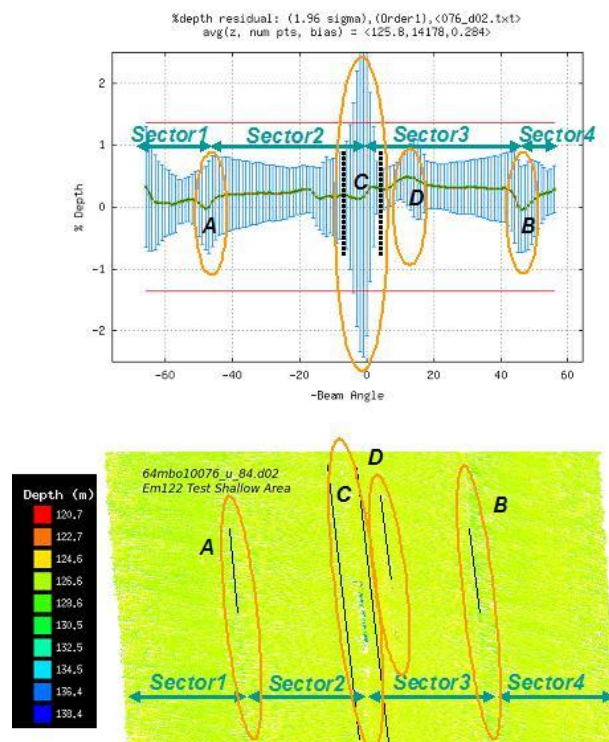


Fig. 3: A sample beam statistics plot (top) and bathymetric view of residual depths (bottom) for the EM122 across the EM710 reference surface as an example to correlate features between the two graphics.

EM122 Case Study in an Acoustically Soft Bottom

The EM122 data degradation problem reported for an acoustically soft bottom detection aboard USNS Pathfinder was manifested in the sonar waterfall display during acquisition. Figure 4 shows the symptom over a flat bottom at 800-m depth. Here, the upper image (waterfall view from the sonar display) is severely corrupted in the nadir region. The black areas at nadir are beam dropouts. The lower section shows an across track profile of a survey line that clearly demonstrates the center area suffers a trenching artifact that renders the beams overall deeper (basic shape outlined by orange curve).

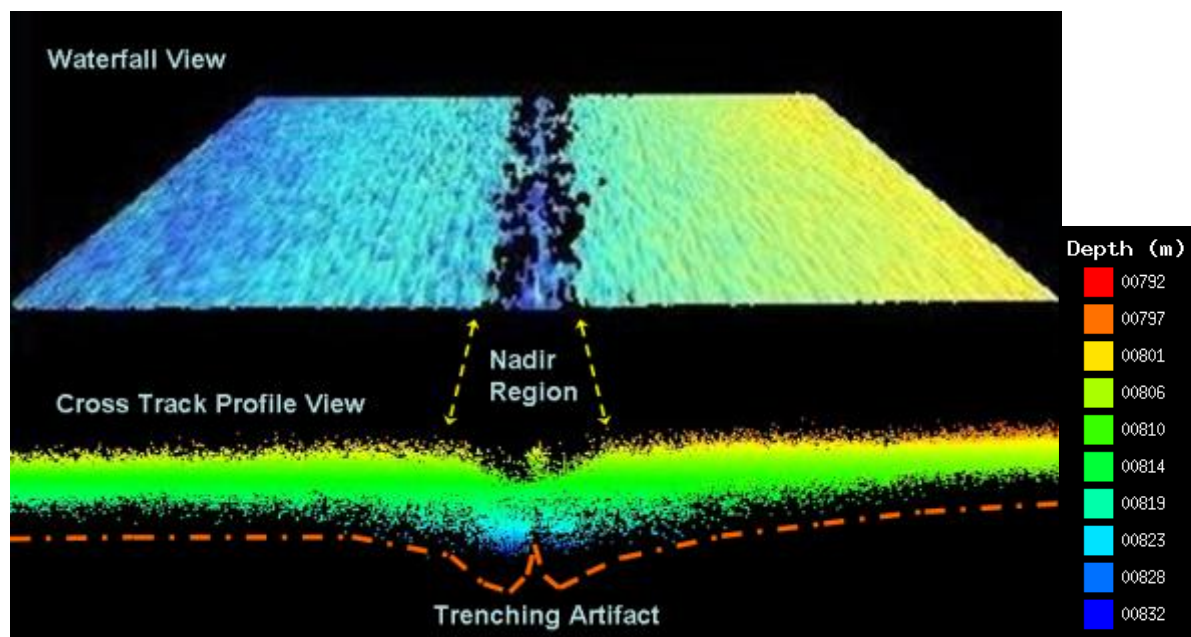


Fig. 4: Penetration problem on USNS Pathfinder, 600409.

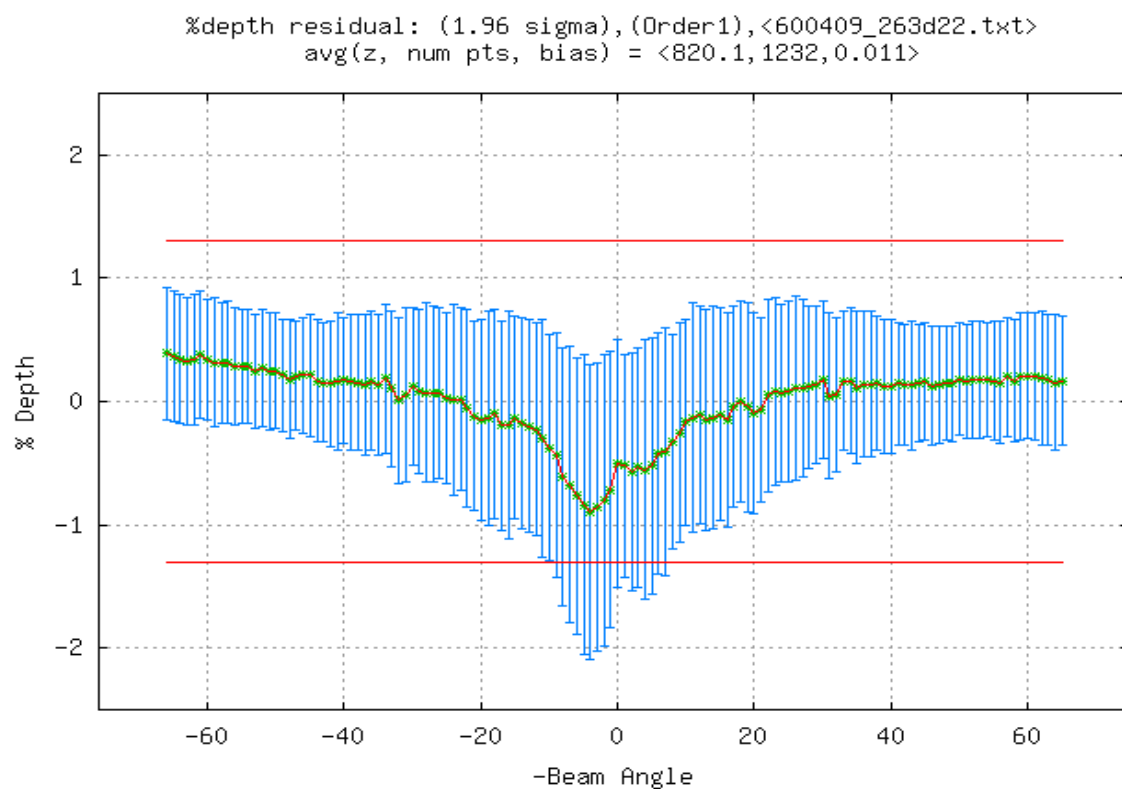


Fig. 5: Statistics plot of EM122 test line over EM122 reference surface from Pathfinder 600409 data. The excessive uncertainty in the nadir region is uncharacteristic of the typical uncertainty footprint for multibeam systems demonstrated in Figure 2.

An EM122 reference surface was constructed with the EM122 data to calculate the beam statistics shown in *Figure 5*. Ironically, in this case, the inner beams had to be excluded, and only the outer beams were used to construct the reference surface because of the data degradation and dropouts in the nadir area. Beam statistics determined that the depth errors were in the range of 2% of water depth at a depth of 800 m.

A system failure was initially suspected of causing the degraded performance. That explanation was dismissed once a second EM122-equipped ship and another ship with the legacy EM121A sonar surveyed the same area and replicated the degraded performance. (No other deep water non-Kongsberg sonar systems were available for comparison testing to determine if the phenomenon is the result of a system artifact associated with bottom detection algorithms or if the basic physical acoustics would likewise degrade the performance of similar systems.)

After consultation with the manufacturer, it was assumed that these 12-kHz deep water sonars were suffering a bottom penetration problem caused by the acoustically “soft” seafloor. Three 10-foot cores were obtained in the area to start facilitating a better understanding of the sediment acoustical properties that may be causing the penetration problem.

All the cores demonstrated a greenish-brown sticky clay-mud throughout. The bottom was so soft that the entire core barrel penetrated the bottom, as evidenced by mud remaining on the top of the coring barrel after recovery. As a result of those findings, the manufacturer worked on resolving the problem, and during the follow-on testing aboard USNS Heezen, these solutions were tested and evaluated.

The EM710 sonar operates in a much higher frequency band (70-100 kHz) than the EM122, providing much better spatial resolution, but at significantly less range capability. Normal operations would switch from EM710 use to EM122 use at about 500-m depth since the EM122 swath coverage has well surpassed the EM710 swath coverage at this depth. As a contrasting system, the EM710 was used on Heezen sea trials to construct a reference surface for evaluating EM122 performance. The EM710 did not experience any performance degradation in the same area. This resultant EM710 reference surface is shown in *Figure 6*. The reference surface constructed employed a 20-m cell size using the standard inner 90 degrees of swath from overlapping data files collected in both north-south and east-west directions

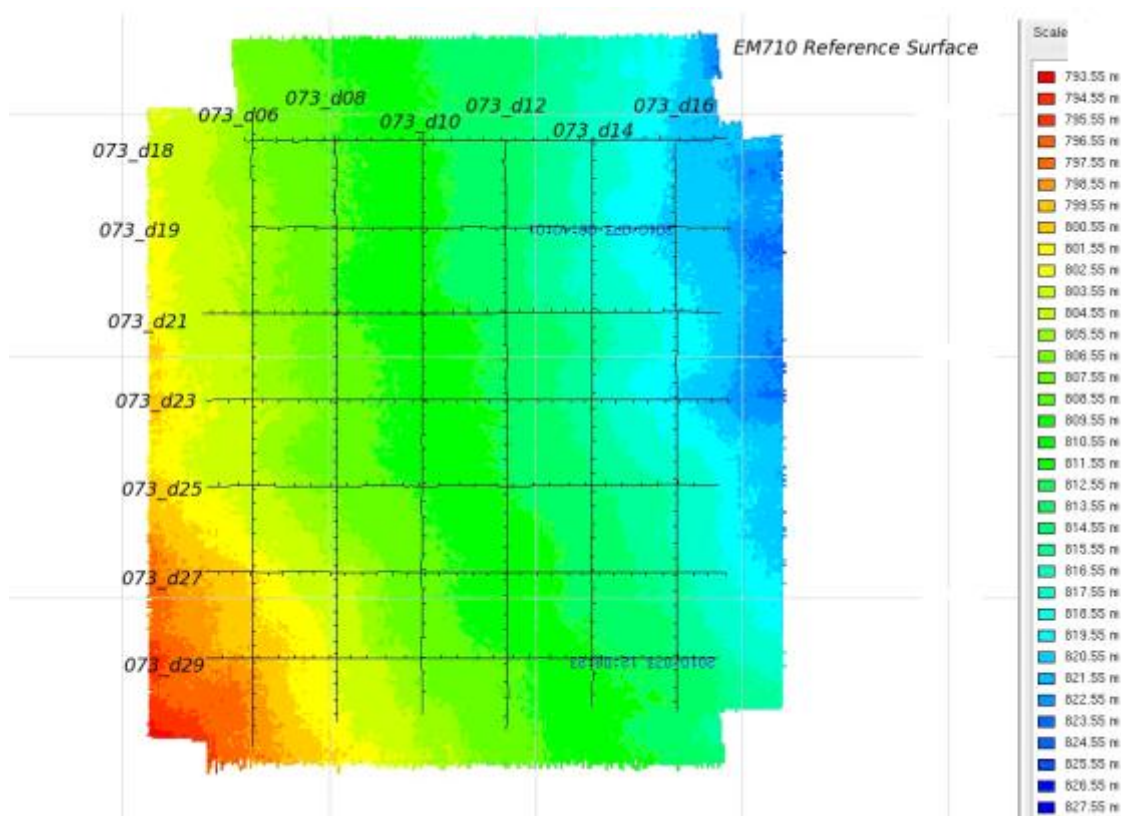


Fig. 6: EM710 reference surface in 800-m test area.

The first beam statistics plot of the EM122 line run against the EM710 reference surface before any system and processing unit (PU) upgrades is provided in *Figure 7* with the corresponding color-coded 3D perspective bathymetric view in *Figure 8*. By comparing *Figures 5* and *7*, it can now be seen that using the EM710 as the reference surface source provides a more accurate representation of the severity of the penetration effect on the EM122 system. *Figure 5* has a mean difference curve with beams outboard of 20 degrees being above the reference surface and the inner ± 20 degrees below the reference surface. The average mean difference for all beams, *avg (bias)*, is 0.01 m. *Figures 5* and *7* are scaled identically, and a quick observation shows the entire swath having a negative mean difference curve, indicating the whole swath is deeper than the EM710 reference surface. Thus, the penetration problem is affecting the entire swath. The very large -5.5-m *avg (bias)* value computed using the EM710 reference dataset in *Figure 7* is a simple descriptive statistic that helps illustrate the penetration problem severity, as typical *avg (bias)* values with other datasets comparing the two sonars are generally 0.3 m or less. A pronounced region of trenching occurs around ± 15 degrees about nadir, with the 95% confidence level of the data in this region well outside the 1.3% IHO Order 1 requirement and even exceeding 2.5% of depth near nadir.

The white and dark blue patches on the bathymetric survey line view in *Figure 8* show the dropouts and trenching at nadir.

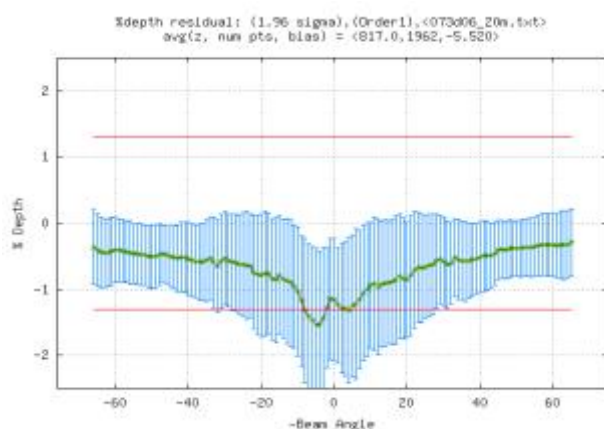


Fig. 7: Beam statistics plot of the EM122 against the EM710 reference surface before implementing the upgrade. A substantial central area between beams ± 15 degrees well exceeds Order 1a specification (red lines). The -5.52 bias value, *avg (bias)*, with all beam angles having a negative residual mean value indicates penetration over the entire EM122 swath when compared to the EM710 reference surface.

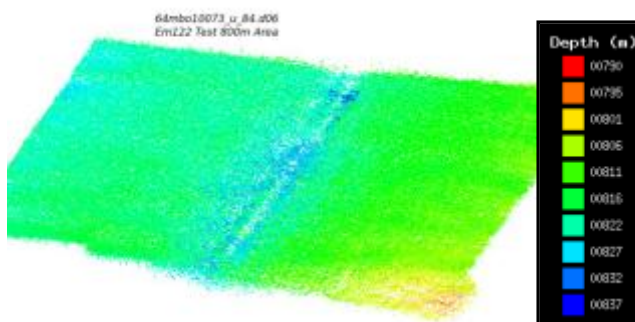


Figure 8: Single line data file, corresponding to *Figure 7*, before the PU upgrade. Note the dark blue areas in the swath center area that show the trenching problem caused by bottom penetration.

Sonar System Changes

Once the initial baseline dataset was acquired, the EM122 system was upgraded from version 3.6.5 to 3.7, which included sonar transceiver upgrades. This upgrade added two new features intended to mitigate the EM122 penetration problem. The first feature is an operator-selectable penetration filter with settings of Off, Weak, Medium, and Strong.

Whereas the penetration filter works on the received echograms, the second new feature attacks the problem by adjusting the transmit beam pattern and provides an automated selection for along track directional steering or tilting of the transmit beam. Normally, the along track steering direction parameter is set to zero, and the system dynamically beam steers the transmit beam directly vertical (nadir) to the ship for all pings as the ship pitches. The EM122 can also be forced to manually steer the transmit beam to both nadir and non-nadir angles ranging from -10 degrees (aft) to +10 degrees (fore).

The automated steering capability self-examines signal returns and decides on an optimal selection for the along track steering. In Heezen sonar tests, the steering chosen was varied, ranging from -8, -9, and -10, which is code for automated selection of the along track steering within fore and aft nadir angles of ± 2 , ± 3 , and ± 4 degrees, respectively.

Datasets were collected at the various penetration filter and along track steering selections.

Sonar Parameter Setting Test Results

Figures 9 and 10 show the first data file acquired after the EM122 Seafloor Information System and PU upgrades on Heezen. Significant differences between the plot and image sets of *Figures 7 and 8* (before the upgrade) can be observed compared to *Figures 9 and 10* (after the upgrade). Most notably, the peak excursion around ± 8 degree beam angle of the error-bars has dropped by some 25% from *Figure 7*.

The width of the error bar region that exceeds the Order 1a specification is now a much narrower region about the nadir area, indicating a marked uncertainty improvement in the overall swath also reflected by the overall bias value, *avg (bias)*, dropping from 5.3 m down to 4.1 m.

These data show some initial success in mitigating the penetration problem even without invoking the new penetration filter or along track steering feature settings. Because of the significant improved performance from the upgrade, the along track steering and penetration filter features are now standard features with the EM122 sonar and constitute a permanent firmware change that establishes a new performance baseline.

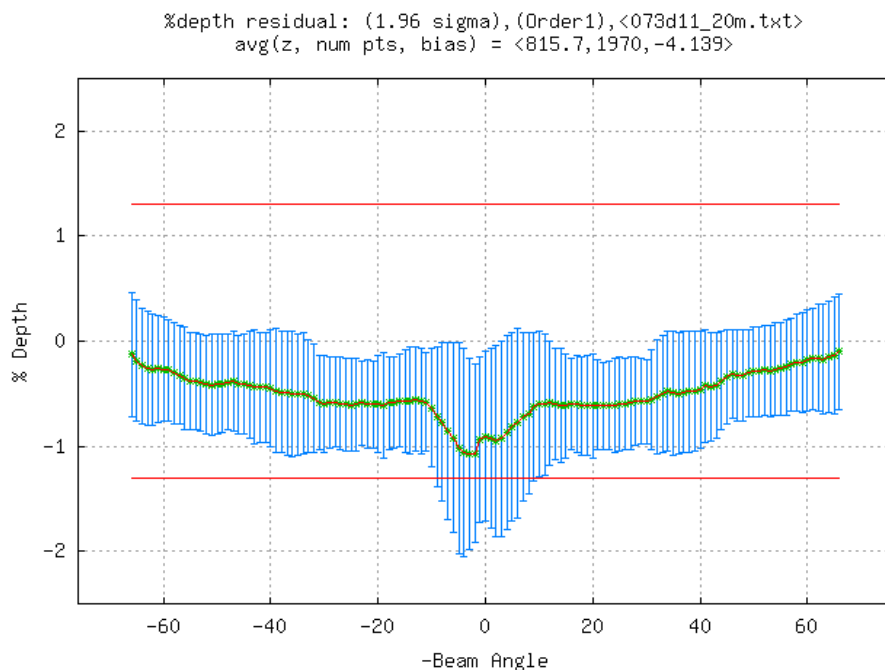


Fig. 9. Beam statistics plot of the EM122 against the EM710 reference surface before implementing the upgrade. A substantial central area between beams ± 15 degrees well exceeds Order 1a specification (red lines). The -5.52 bias value, *avg (bias)*, with all beam angles having a negative residual mean value indicates penetration over the entire EM122 swath when compared to the EM710 reference surface.

Fig. 10. : First data file, corresponding to Figure 9, after the upgrade with filters turned off. Note the lessening of the dark blue nadir area compared to Figure 8.

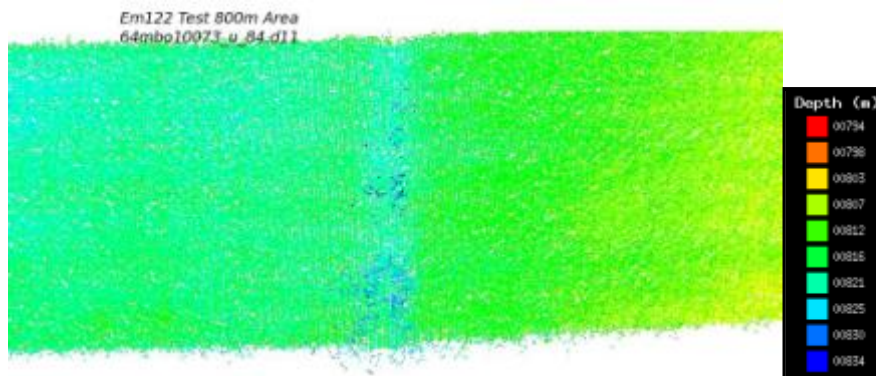


Figure 11 shows the effect of the penetration filter alone at its various settings and leaving the along track steering in the default nadir steering mode. Starting in the upper left and going clockwise, the penetration filter was set to Off, Weak, Medium, and Strong, respectively. Again, note the improvement in overall penetration alleviation as indicated by the lower overall mean difference value, *avg* (*bias*), and successive reduction in peak uncertainty. It was concluded from these plots that the Off and Weak settings did not make any major impact on the beam statistics results. However, a considerable change is made between the Weak and Medium selections, and little change occurs between the Medium and Strong modes.

The mean curve plots in the four graphs of Figure 11 all trend in a bowl-like shape from port to starboard, and all mean values for each beam angle are negative, indicating that the entire swath is still affected by the penetration problem. The situation is improved, but not resolved. While in this specific test area, a Medium or Strong setting is best; in other areas, when transitioning from a soft to harder bottom, these settings may be too aggressive, and a Weak setting may be needed. Beam statistics processing in a different area could help determine the optimum filter setting there.

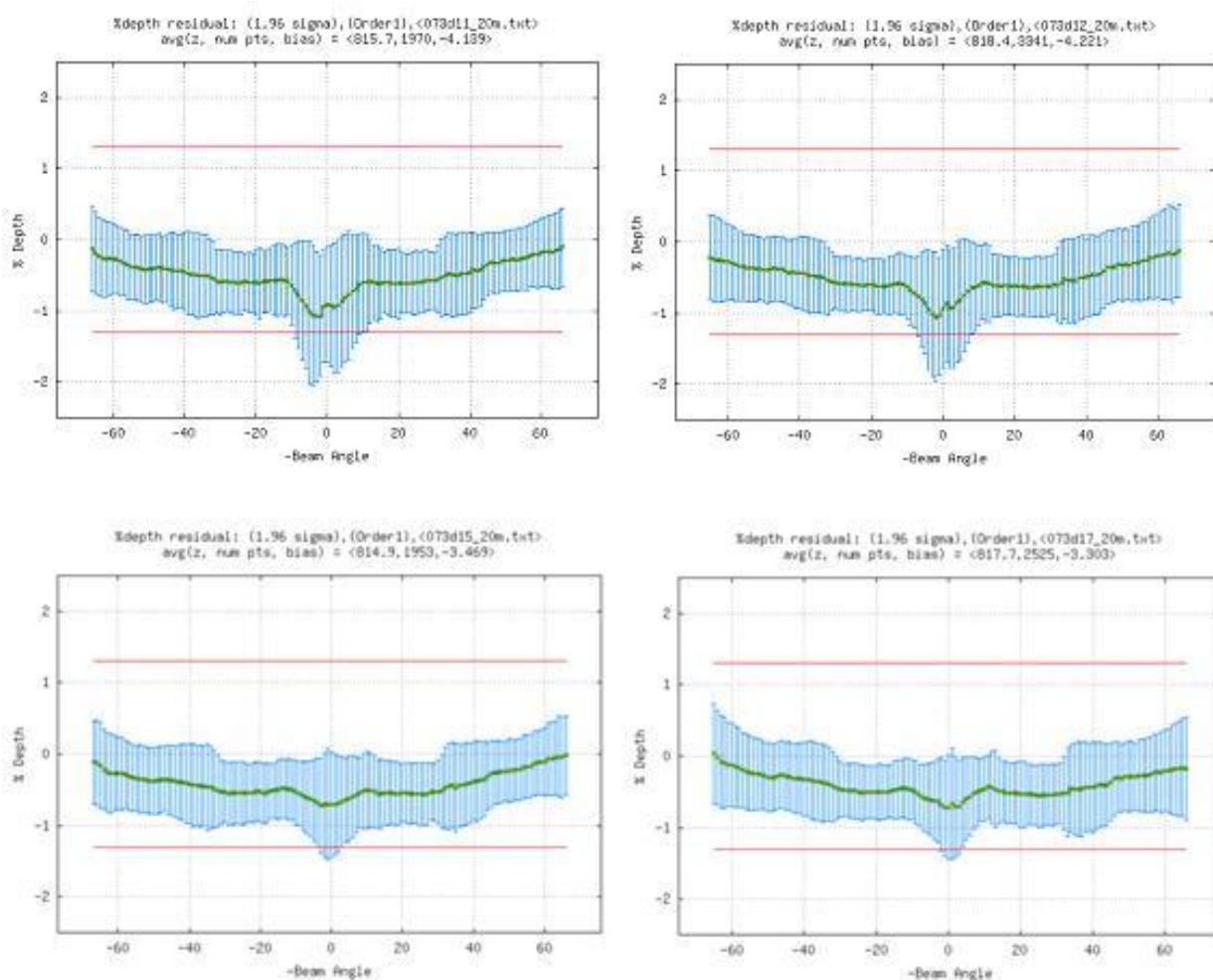


Fig. 11. : Effects of the penetration filter alone. Starting in the upper left and going clockwise, the penetration filter was set to Off, Weak, Medium, and Strong, respectively.

Figure 12 shows the effects of changing the along track steering direction from static nadir to automated non-nadir. Starting in the upper left and going clockwise, the along track beam settings were set to Off, ± 2 , ± 3 , and ± 4 degrees, respectively, with the system determining the optimum steering angle to skew the 1° transmit beam fore or aft and to avoid a direct specular hit on the sea-floor and instead slightly graze it.

Figure 12 seems to indicate that the best along track steering selections are settings of -9 and -10 (± 3 degrees and ± 4 degrees, respectively) based on peak mean difference curves. The OFF and $\pm 2^\circ$ plots look very similar to each other, but a noticeable improvement in lowering the overall bias, *avg (bias)*, value is obtained with a steering of $\pm 3^\circ$ or $\pm 4^\circ$.

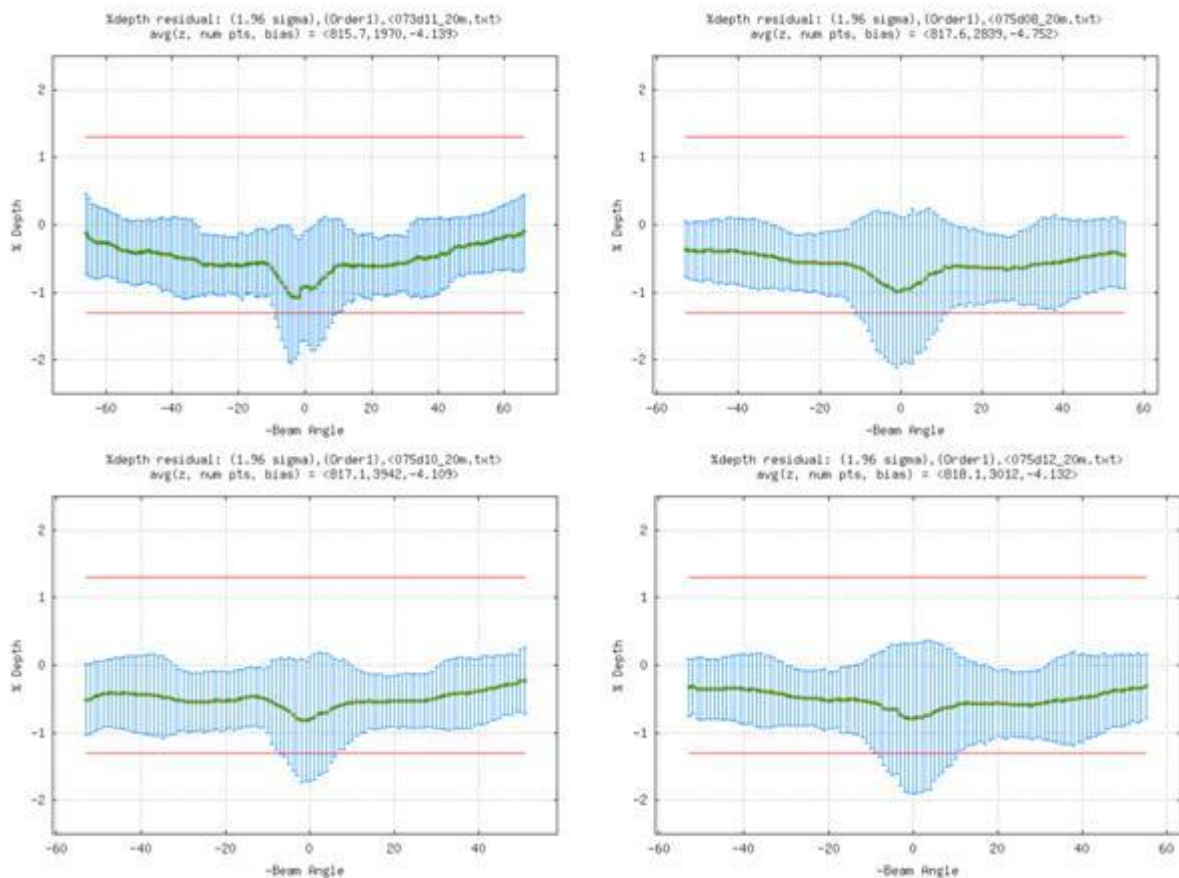


Fig. 12. : Effects of changing the along track steering direction from static nadir to automated non-nadir. Starting in the upper left and going clockwise, the along track beam settings were set to Off, ± 2 , ± 3 , and ± 4 degrees, respectively.

Figure 13 shows the best beam statistics results achieved with a combination use of both penetration filter setting at Medium and along track steering set at ± 2 degrees. A definite improvement can be seen in comparing these plots from those of Figures 7 and 8. Note in Figure 13 the nadir area error-bar peak zone is greatly suppressed, and a much more level spread of uncertainty is present across the swath with all standard deviation bars below the IHO Order 1 threshold. (Still, an overall average difference, *avg (bias)*, of about -3 m exists between the data file and the reference surface.)

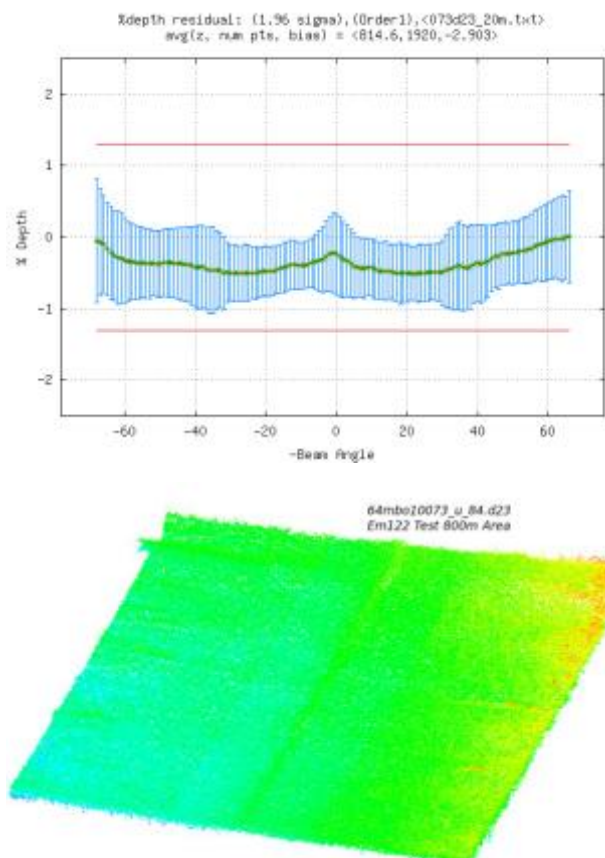


Fig. 13. : Best results using a combination of parameter settings; penetration filter was set to Medium, and the along track beam steering was ± 2 degrees.

Case Study of Beam Statistics Use for Survey Planning and Post-Processing

The beam statistics technique may also be used to evaluate data collected during an operational survey and provide key guidance for survey planning to optimize survey execution and subsequent post-processing. On a recent bathymetry survey aboard USNS Mary Sears, the 95-kHz Simrad EM1002 multibeam sonar was employed in shallow water depths, averaging 53 m deep. For the first four survey days, the starboard beams exhibited excessive noise until hardware troubleshooting relieved the problem. Figure 14 shows raw data from a swath

profile view of an EM1002 line, demonstrating the degree of noise on the starboard side. The beam statistics technique was used to determine what portions of the swath were acceptable to use in later post-processing stages. From the results, survey planning was adjusted to ensure 100% coverage was achieved from adjacent swaths with acceptable quality data.

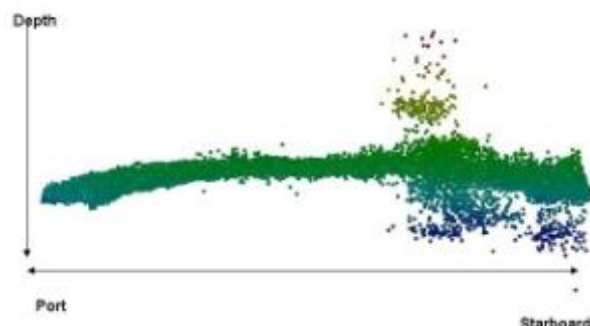


Fig. 14. : Swath editor north-looking display of raw EM1002 errant starboard beams.

The nearshore location of this survey area resulted in a highly dynamic and unstable sound speed profile structure both spatially and temporally with heavy influence from fresh water inflow altering temperature and salinity profiles. The ship did not possess either an underway CTD or sound velocimeter profiler sensor, and on-station CTDs were collected but were too time-consuming and spatially limiting to employ as often as needed. XBTs were dropped frequently, but they provided no salinity data and thus produced an inherently less accurate sound speed profile than CTDs. Even latencies from XBT processing times degraded the sound speed profile data temporally. Spatial under-sampling of sound speed profiles typically results in sound refraction errors causing “frowns” or “smiles” on a swath profile view for an otherwise flat bottom. The refraction effect can add significant error to the estimated depths across the swath, most notably affecting the outer beams.

The EM1002 transducer array has a draft of about 5.5 m. On some lines within the survey area, variations of the sea surface sound velocity at the transducer array would drop by 6 m/s for a few minutes at a time. At 9-m depth, sound speed profiles were observed to vary by as much as 40 m/s throughout a 2-day period. Figure 15 depicts swath profile views of several adjacent survey lines to illustrate the severe outer beam curvature. The initial explanation for the frown-shaped profiles assumed under-sampled sound speed profiles throughout the water mass and limited accuracies with XBTs as the sensor probe rather than CTDs. However, a later examination appears to indicate that an erroneous outer beam calibration value also contributed to the curvature problem, and may in fact be the predominating factor. The substantiating reason for con-

outer beam angle calibration value as the predominating influence on the outer beam profile curvature is because *Figure 16* clearly demonstrates a fairly flat mean curve (green/red trace) from -15 degrees inboard to -50 degrees outboard. The EM1002 begins beam steering its beams out past 50 degrees, which matches where the beam statistics plot begins the downward curvature. The outer beam calibration value was also re-inspected and found to be at an unusually large value than what had been typically used on that vessel.

The difference between the nadir depths (generally considered to be the best estimate of the actual bottom depth because they are minimally affected by refraction) and the deepest outer beam depths for the several swaths in *Figure 15* is about 1.3 m. The IHO Order 1a 95% confidence level specification for 53-m water depth is ± 0.85 m, indicating an initial visual failure to comply with IHO requirements at these beam angles. Beam statistics analysis determined the available swath width able to meet the Order 1a requirement.

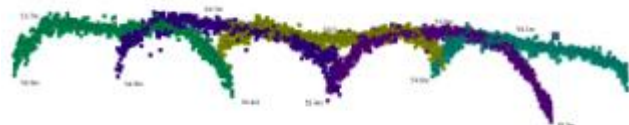


Fig. 15. : Example of pervasive outer beam error exceeding IHO Order 1a requirement.

Beam Statistics Results

The selection of data that was even suitable to build a reference surface was assessed by inspection of the tabular values by a file viewer program. Visual examination of the beam number with corresponding depth and beam angle provided a rough, qualitative determination for avoiding data that were clearly noisy (by virtue of significant depth change in adjacent beams) or affected by outer beam curvature. Beam angles between -55 and +40 degrees were selected for constructing a reference surface. The beam statistics plots of raw (unedited) sample data over the reference surface are shown in *Figure 16*, which largely confirms the visual inspection of the tabular data. The red lines bound the Order 1a specification. The red/green mean trace in the plot bends down on both port and starboard sides, indicating both sides suffer the apparent erroneous outer beam calibration value while the starboard side is also subject to excessive noise caused by the malfunctioning hardware.

Now having the plotted results of *Figure 16* rather than merely eye-balling suspect data to be rejected in the first stages of post-processing while visually scanning the data,

the processor can collectively remove those beams within the offending beam angles exhibiting degraded data noted by having error bars extending beyond the Order 1a bounds or that are part of the outerbeam calibration problem.

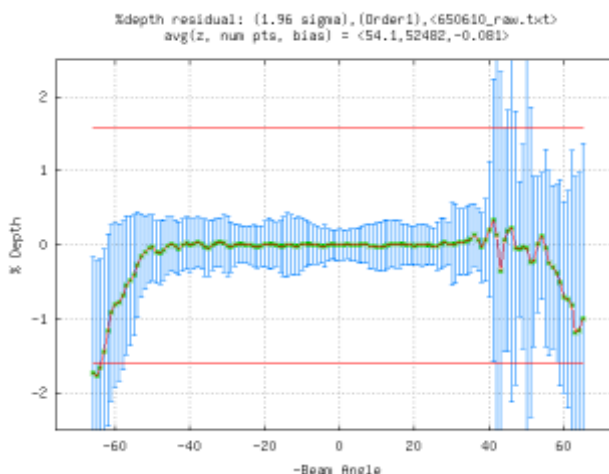


Fig. 16. : Beam statistics results of unprocessed EM1002 test data over a reference surface. Beams outboard of -50 degrees depict a quickly increasing uncertainty in depth determination for the port side, while beams outboard of +40 degrees depict an escalating uncertainty for the starboard side.

Using these results, the data collection strategy was adjusted so that the survey line spacing was decreased to facilitate covering the starboard side noise with adjacent beams until the damaged EM1002 hardware was replaced.

To mitigate the excessive error in the outermost beams, the swath width was decreased to ± 55 degrees for the remainder of the survey operation. *Figure 17* shows the final processed data after beams were removed and swath editing of the remaining portion of the data was completed. All remaining data then fell within an acceptable uncertainty tolerance.

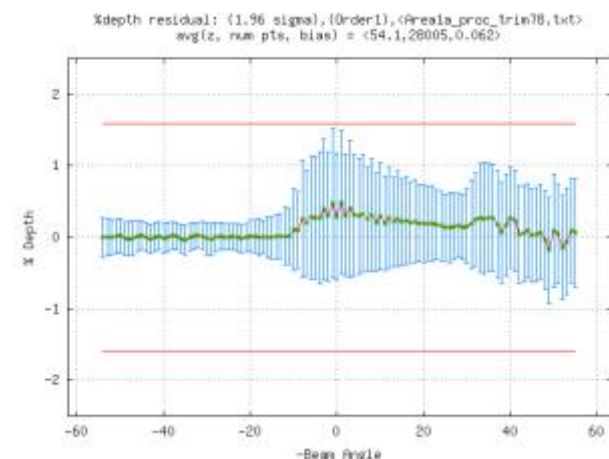


Fig. 16.: Example of pervasive outer beam error exceeding IHO Order 1a requirement.

Conclusions

The use of beam statistical application and analysis for multibeam sonar systems can help evaluate sonar performance. Specific benefits include characterizing sonar system artifacts and trends, assessing the operational performance capability and limitations of systems and/or datasets against requirements, and evaluating the effectiveness of sonar features and parameters. The particular lessons from the first case study involving USNS Pathfinder EM122 sonar began with the major advance that was made by the manufacturer in mitigating the soft bottom penetration problem associated with this $1^\circ \times 1^\circ$ deep water sonar. Implementation of two new features in the sonar collection software was successfully and quantitatively analyzed by using the beam-wise statistics technique, with the conclusion that in an acoustically soft bottom test area, a medium or strong penetration filter worked well to address the penetration problem. Beam steering using the automated along track beam steering setting also helped mitigate the penetration problem. However, the combinational use of penetration filter and beam steering was the most effective and best means of mitigating the penetration problem.

The second case study showed that the beam statistics analysis can provide valuable input to post-processing the multibeam data to help determine data degradation trends, flag beams within angles that should be systematically rejected, and diagnose problem sources. This knowledge can then be used as feedback for survey planning to prevent degraded data at the collection stage.

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Biographies of the Authors

Clay Whittaker is an electronics engineer in the Systems Engineering Division of the Naval Oceanographic Office. He has 24 years of experience in the procurement, integration, testing, and fielding of hydrographic and oceanographic equipment. He holds a BS degree in Electrical Engineering from San Diego State University.

Susan Sebastian is a technical lead for Bathymetry Validation Division of the Naval Oceanographic Office (NAVOCEANO) after graduating from the University of Southern Mississippi Category A Hydrography Program in 2001. She fortunately has the opportunity for worldwide travel yearly, performing survey field work and collecting and processing many datasets in both deep and shallow water environments. She has participated in many sea trials for new sonar systems and has written much of the at-sea operational process documentation. She sails as the Senior NAVOCEANO Representative or Lead Hydrographer while at sea and leads process improvement efforts and data analysis projects in the Navigation Department while at the home office at Stennis Space Center. She co-facilitated the Multibeam Uncertainty Management Workshop held in conjunction with the Canadian and U.S. Hydrographic conferences over the past nine years.

David H. Fabre is technical lead of the Bathymetry Databases Division of the Naval Oceanographic Office. He received BS and MS degrees in Applied Mathematics from Nicholls State University, in Thibodaux, Louisiana, in 1987 and 1989. Since 1990, he has been working indirectly and directly to support the U.S. Navy. His past efforts include software implementation for multibeam patch testing, total propagated error modeling, and multibeam sonar acceptance testing. Recently, he has been working toward providing uncertainty attribution for archive bathymetry. He strives to enhance bathymetric and hydrographic processing capabilities.

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***KINGDOM OF SAUDI ARABIA
NEW HYDROGRAPHIC VESSEL FOR THE FACULTY
OF MARITIME STUDIES OF THE KING ABDULAZIZ UNIVERSITY***



***THE INTERNATIONAL HYDROGRAPHIC CONFERENCE
- HYDRO2011-
HOSTED BY THE AUSTRALASIAN SOCIETY***



***ADDRESS BY THE CHIEF OF THE NAVAL STAFF,
ADM. NIRMAL VERMA, AT THE INTERNATIONAL
HYDROGRAPHIC SEMINAR - HYDROIND 2011
IN NEW DELHI - 03 MAR 11***

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KINGDOM OF SAUDI ARABIA
NEW HYDROGRAPHIC VESSEL FOR THE FACULTY OF MARITIME STUDIES
OF THE KING ABDULAZIZ UNIVERSITY



The King Abdulaziz University was founded in 1967 in Jeddah, Kingdom of Saudi Arabia. It was initially established as a private university by a group of businessmen and converted to a State University in 1971.

One of the faculties of the University is the Faculty of maritime studies, which has four departments: Marine Engineering, navigation hydrography, port and maritime transportation. The faculty objectives are:

- Quality education in science and marine studies to support the needs of the community in various bodies of marine
- Follow-up of various marine phenomena and their regional and local
- Community awareness in the areas of maritime studies and environmental requirements through the establishment of seminars and campaigns to preserve the environment.

One of the latest development of the King Abdulaziz University, particularly its Faculty of maritime studies has been the launch of its **“first hydrographic surveying vessel”** named < **KAU-Hydrography-1** > capable of conducting hydrographic surveys in the open sea with the most modern equipment. She carries multi-beam, single-beam, side scan, ROV, sub-bottom profiler, GPS RTK, DGPS Seatex Seapath 200RTK and more.

This new capability offers a substantial support to the Hydrographic Survey Training Course conducted at the Faculty; contributes to scientific research projects of National and International interest as well as provides service to the national maritime community in general. To be particularly noted are the capabilities of this hydrographic vessel that allows the Faculty of maritime studies to study the sea floor bathymetry following the standards set up by the International Hydrographic Organization. Data collected can contribute to the production of reliable new nautical charts or to improve the quality of the existing charts. This is a concrete contribution to accomplish SOLAS regulations under IMO monitoring.

The characteristics of the < **KAU-Hydrography-1** > are:

Length	15.5m	Breath	5m	Max Draft	1,46m
Max Speed	6 Knots	Cruising speed	10 Knots	Gas oil	4 tons
Fresh water	2 tons	Range	1200 NM - 5days	Surveying range	6 at 20 days
Hull :	catamaran	Gross tonnage GRT	36 T	Engines	02 volvo 420hp



Hydro 2011:

down under

The Australasian Hydrographic Society [AHS] will be hosting the **2011 annual International Hydrographic Conference Hydro 2011** on behalf of the International Federation of Hydrographic Societies [IFHS]

This signature event will consist of the following:

- A three day conference with both Keynote Speakers and Concurrent Sessions presented by experts in the hydrographic field from around the world.
- Proposed off site tours.
- Pre conference workshops and application/ product training.
- An extensive exhibition during the Conference for delegates to interact with manufacturers and service providers.
- Conference Social and Partners Program.
- Pre and Post Touring Opportunities.



Register your interest online in sponsoring, exhibiting, presenting or just attending at our conference website:

www.hydro2011.com

All online expressions of interest received before 21 December 2010 will be entered into a draw for a complimentary room night at the Conference Venue during the Conference dates.

Join us in Western Australia, the former home of the America's Cup, at the Esplanade Hotel, Fremantle on 7-10 November 2011.

**ADDRESS BY THE CHIEF OF THE NAVAL STAFF, ADM. NIRMAL VERMA,
AT THE INTERNATIONAL HYDROGRAPHIC SEMINAR (*HYDROIND 2011*)
IN NEW DELHI - 03 MAR 2011**

Honourable Raksha Mantriji, Shri AK Anthony, Honourable Minister of Shipping, Shri GK Vasan, Vice Admiral Alexandros Maratos, President International Hydrographic Bureau, Vice Admiral BR Rao, Chief Hydrographer to the Government of India, industry partners, distinguished members of the hydrographic community from participating nations, ladies and gentlemen :



1. It gives me immense pleasure to be in the midst of eminent hydrographers from across world at this international seminar, which I think has a theme that is both apt and appropriate. In my view, hydrography is indeed an important instrument for regional cooperation and maritime safety and I compliment the Indian Naval Hydrographic Department for conceiving and conducting this important event. The seminar clearly reflects the Department's efforts to bring together hydrographers from across the world to support a significant common purpose.
2. To my mind, the ever-increasing attention paid by most states to the maritime dimensions of national security and well-being is a defining feature of the 21st century international environment. The seas today provide nations the means to not only enhance their economic prosperity and physical security, but to also combine efforts to counter common challenges and exploit opportunities to enhance the common good. Being a relatively non-intrusive, but extremely useful and necessary discipline, hydrography has extremely high potential as an element of international collaboration.
3. You would be aware that exchange of nautical information as a phenomenon is probably as old as man's association with the sea itself. Well before the advent of governmental hydrographic services, sailors in the Indian Ocean acquired and passed on to each other nautical information of interest through word of mouth and charts of varying accuracy and complexity. In the modern era, hydrographic activity and international hydrographic cooperation achieved a more organised character with the establishment of national hydrographic services.
4. Why is hydrographic cooperation a genuine necessity in today's world?
5. In my view, it is because a collaborative and integrated national and regional approach to hydrographic services has an inherent economic, humanitarian and scientific logic that cannot be ignored.
6. First, the economic dimensions. The wave of globalisation from the late 19th to the early 20th century established global maritime trade as the harbinger of prosperity. Navigational safety, a pre-requisite for maritime trade, was, therefore, a stimulus for cooperation. The collective international concern for maritime safety brought nations together to codify this cooperation and form the International Hydrographic Organisation in 1921 - in many ways, an endeavour that emulated what was an ancient mariner's natural instinct.

7. Today, the importance of maritime trade in sustaining the global economic system cannot be overstated. 90% of world trade by volume and 70% by value continue to ply over the surface of the seas. The enduring attributes of maritime transportation, namely low cost, high access and large carrying capacities, will continue to drive growth in this sector. By providing a rapid and commercially profitable means of transportation, ships have not only enhanced trade, but also intensified the processes of economic interdependence and globalization.

8. Infact, the very nature of today's mercantile marine symbolises globalisation and interconnectedness. A modern merchant ship is a global enterprise - built in one country; registered in another; owned by a company in a third; manned by a crew of probably different nationalities; and carrying cargo to and from many other nations spread across the world. A navigational accident would, therefore, impact stakeholders of varying nationalities simultaneously. This makes hydrographic services an element of common purpose.

9. Merchant fleets need updated hydrographic and marine safety information for the areas they are likely to visit or transit through. The sheer volume and complexity of efforts involved in compiling and disseminating this implies that no single agency or nation has the resources to ensure this on its own. Even if resource constraints were overcome, the issue of standardizing data-representation by transcending linguistic and cultural barriers would remain. Nations, therefore, have to pool resources and share nautical information and, in the interest of global trade and commerce, view enhancing safety and preventing accidents at sea as a collective maritime responsibility.

10. Second, the humanitarian dimensions. Cooperation in hydrography is particularly relevant to regions that are vulnerable to natural disasters and have large populations living on the coastline. Parts of South and South East Asia clearly fall into this category, going by recent experience. While hydrographic services play an important role in coastal zone management and enable the planning of coastal infrastructure in a way that reduces the likely humanitarian and economic consequences of a natural disaster, their role in restoring port and harbour services after such a disaster strikes cannot be undermined. This is particularly important since large volumes of aid and relief can only come by the sea. In this regard, I would like to cite the stellar role played by hydrographic services in the aftermath of the 2004 Tsunami in the Indian Ocean.

11. Cooperation is also driven by a third aspect - technology. Today's technology impacts how the hydrographer collects, processes and collates data and pieces them together into products for use by mariners. Emerging technology provides the means and tools that enhance the efficiency of hydrographic survey and allow regular and frequent updating of nautical information. It also requires hydrographers to interact frequently with all users and stakeholders to be able to do so.

12. Global positioning and satellite surveillance systems used extensively in hydrography today, and digital navigational products such as Electronic Chart Display and Information Systems and Electronic Navigation Charts, are too expensive to be owned, operated or manufactured by all users individually. Besides, hydrography itself has grown beyond making charts and facilitating navigational safety, into a wide range of critical maritime services such as port and harbour maintenance, coastal engineering, coastal zone management, offshore resource development, marine habitat management and pollution control. By themselves specialist fields, these call for a larger level of cooperation and interaction among all users, stakeholders and practionners that are spread beyond national or regional boundaries.

13. I have highlighted what I thought was a strong economic, humanitarian and technological rationale for hydrographic cooperation. There is, however, another factor that cannot be lost sight of — that of capacity building. Not all regions and nations have the ability today to provide the required hydrographic services within their jurisdictions. There still remains much to be done in building and sustaining the capacities of all states to do so. This is particularly true for the Indian Ocean littoral.

14. You are all aware that surveys and resurveys are ongoing processes that enable us to understand shifts in marine geography and cater to the ever-changing requirements of maritime safety. The continuous exploitation of the seabed, coupled with the compulsions of oil and gas economics, has created new cruising patterns in the approaches to many ports and harbours. Simultaneously, under keel clearances have also continued to reduce. These have made new demands on our hydrographic agencies and defined new hydrographic requirements. It is in common interest to enable coastal states to provide credible hydrographic services in the areas under their control. I hope this forum will focus its efforts in identifying new ways to do so.

15. In this connection, I take the opportunity to highlight here the commitment of the Indian Naval Hydrographic Department to national and regional capacity building. The Department has, over the years, contributed significantly to international maritime requirements by furnishing accurate and reliable hydrographic services that have enhanced offshore development and safety at sea. It undertakes extensive surveys in coastal and inland waters and the deep seas, to ensure navigational safety, and facilitate oceanographic and environmental observation; pipeline and cable routing; and EEZ, continental shelf and maritime boundary delineation. Its many products are used not just by mariners, but increasingly by research organisations and other marine corporations. We are proud of its effort to promote hydrography in the region - perhaps even beyond it - and of its endeavour to increase the ability and capacity of maritime neighbours to provide necessary hydrographic support in the region. We look at the Department continuing to be an important element of the Indian Navy's regional engagement initiatives in the decades to come.

16. I conclude my remarks by making two broad points: first, cooperation in the hydrographic domain can no longer be seen as a matter of choice: it is an endeavour for common good and ought to be seen as such; and second, hydrographic cooperation has broader geopolitical benefits: while primarily promoting maritime safety, it serves as an instrument of international confidence building and friendship.

17. That is why a seminar of this nature is relevant to all of us. It permits meaningful interactions that enable all stakeholders to meet and exchange views that improve and enhance our hydrographic capabilities and performance. It also brings together practitioners and stakeholders to debate the role of hydrography in furthering maritime safety and regional cooperation. Importantly, it gives the surveyor, the modern maritime explorer of sorts, an opportunity to meet his compatriots from other nations and brainstorm on how his trade could be further expanded and enriched.

18. It has been a pleasure to be with all of you this morning. I hope you would find the proceedings of this seminar interesting and engaging. I take this opportunity to wish you the very best in your endeavours. And particularly for our friends from foreign navies - I sincerely hope you have an enjoyable and professionally fulfilling experience during your stay in India.

Thank you

Note : See over Admiral Nirmal Verma , Chief of the Naval Staff biography.

Admiral Nirmal Verma assumed command of the Indian Navy on 31 Aug 09, as the 20th CNS and the 18th Indian to take over this office.

Admiral Nirmal Verma is a specialist in Communication and Electronic Warfare. His nearly four decades of experience spans across various afloat and ashore appointments. His sea tenures include Commands of INS Udaygiri, a Leander Class Frigate; INS Ranvir, a Kashin Class Destroyer; and the Aircraft Carrier, INS Viraat. In assignments that shape future leadership of the Indian Navy, he has commanded the Indian Naval Academy at Goa, been Head of Naval Training Team at the Defence Services Staff College, Wellington, India, and Senior Directing Staff (Navy) at the National Defence College, New Delhi.

Admiral Verma's career is an amalgamation of Indian and global experience. As part of crew for the first Kashin Class Destroyer inducted into the Indian Navy in 1980, he trained in the former Soviet Union. He has attended professional mid and senior level courses at the Royal Naval Staff College, Greenwich, UK and the Naval Command Course at the US Naval War College, Rhode Island respectively.

Upon elevation to Flag Rank, as a Rear Admiral he has contributed to consolidation of growth and development of the Naval Commands first as the Chief of Staff of Eastern Naval Command and thereafter as Flag Officer Commanding Maharashtra Naval Area.

Evolution of the maritime capabilities and policies for future induction were steered by Admiral Verma in his capacity as the Assistant Chief of Naval Staff (Policy & Plans). On promotion to Vice Admiral in Nov 2005, he guided the Human Resource Development programmes of the Navy, formulating personnel and service policies as the Chief of Personnel.

In his capacity as the Vice Chief of Naval Staff, Admiral Verma, structured the framework for the transformation of the navies combat capabilities and infrastructure development. Prior to taking over as the Chief of Naval Staff, Admiral Nirmal Verma, as the Flag Officer Commanding-in-Chief, Eastern Naval Command, he provided impetus to synergise the Coastal Security infrastructure.

The Admiral is a recipient of Param Vishisht Seva Medal and Ati Vishisht Seva Medal for meritorious service, and is also the Honorary Aide-de-Camp to the President of India.

Admiral Nirmal Verma is married to Madhulika and they have two sons Hemant and Anant, who are in the creative and business fields respectively.

Note: The above information is from the IN website.

The link is as given below:

<http://indiannavy.nic.in/cns.htm>



General Information

BOOK REVIEW

Integrated Bridge Systems Vol 2 ECDIS and POSITIONING

Dr Andy Norris

Published by The Nautical Institute, London, 2010.

ISBN 978-1-90915-11-7

215 p.

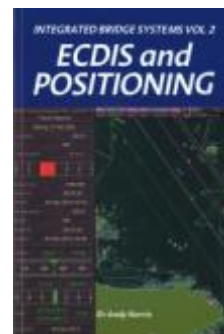
One of the challenges of the ECDIS technology is to understand how all the components fit together from a practical mariner's perspective. To operate this technology, the mariner needs to have a good appreciation of the positioning technology and its characteristics regarding accuracy and integrity; the underlying Electronic Navigation Chart (ENC) data presented to the mariner (in comparison to a traditional paper chart product); and how to operate and interpret the software (ECDIS) to ensure the data is optimally displayed and understood.

This book has been especially written for the mariner and not for hydrographers or engineers. Like any software application, the benefit of its use depends upon how the user interacts with it and how much they understand its operations. Whilst the first 6 chapters of this book describe the technology, the key chapters follow in that they describe how to use ECDIS for various navigation practices such as route planning (Chapter 7), route monitoring (Chapter 8) and how to use ECDIS when an Electronic Navigation Chart (ENC) is not available (Chapter 9). The reader should pay particular attention to Chapter 10 regarding training and the Familiarisation Checklist which provides an important resource for users to develop and test their skills.

The book is well written in English, is well designed and has numerous clear illustrations to expand on the text.

The book is divided into three sections. Chapter 1 provides an overview of positioning and geodetic fundamentals. Chapter 2 describes the modern electronic positioning technologies including GPS, GLONASS, Galileo, eLORAN, differential systems, inertial systems and the use of radar and other visual information. Chapter's 3 to 10 provide a comprehensive treatise on the use of electronic charts for navigation and provide a satisfactory level of information for a practical course based on the IMO Model Course 1.27 for ECDIS.

Ian Halls/Bill Daniel (Australian Hydrographic Service)



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