Article

MINIMUM DEPTH, MEAN DEPTH OR SOMETHING IN BETWEEN?

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Abstract

Reliable information about the seafloor and river-bed bathymetry is of high interest for a large number of applications. A Multi-Beam echo sounder (MBES) system is able to produce high-resolution bathymetry data at relatively small cost. These measurements, providing a depth for each beam and every ping, are processed to obtain a more ordered structure, such as a grid. Most approaches for assigning a depth to the centre of a cell (in a grid) use the shallowest or the mean depth in each cell. However, while the grid derived from the mean depth might be too deep compared to the shallowest depth, using the shallowest depth approach can result in an artificially shallow grid, affected by outliers. This paper introduces a number of alternatives to the current methods by combining the mean depth with statistical properties derived from the point cloud of the MBES data. In addition, the possibility of assigning a depth based on the regression coefficients of each cell is considered. The methods introduced have been tested on data acquired in different survey areas. The resulting grids have been compared to their shallowest and mean counterparts to obtain a better understanding of their advantages and limitations.

Résumé

Des informations fiables sur la bathymétrie des fonds marins et des lits fluviaux présentent un grand intérêt pour de nombreuses applications. Les systèmes de sondeurs acoustiques multifaisceaux (SMF) sont à même de produire des données bathymétriques à haute résolution à un coût relativement faible. Ces mesurages, qui fournissent une profondeur pour chaque faisceau et pour chaque ping, sont traités afin d'obtenir une structure plus ordonnée, une grille par exemple. La plupart des approches permettant d'attribuer une profondeur au centre d'une cellule (dans une grille) utilisent la profondeur la plus petite ou la profondeur moyenne au sein de chaque cellule. Néanmoins, si la grille dérivée de la profondeur moyenne peut être trop profonde par comparaison à la profondeur minimale, l'utilisation de l'approche de la profondeur la plus petite peut aboutir à une grille artificielle-ment peu profonde, affectée par des valeurs anormales. Cet article présente plusieurs alternatives aux méthodes actuelles en combinant la profondeur moyenne avec des propriétés statistiques dérivées du nuage de points des données issues de SMF. En outre, la possibilité d'attribuer une profondeur basée sur les coefficients de régression de chaque cellule est envisagée. Les méthodes présentées ont été testées sur des données acquises dans différentes zones hydrographiées. Les grilles qui en ont résulté ont été comparées à leurs équivalents en eaux peu profondes et de profondeur moyenne afin de parvenir à une meilleure compréhension de leurs avantages et de leurs limites.

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Article

Resumen

La información fidedigna sobre la batimetría del fondo marino y del fondo fluvial es de gran interés para un gran número de aplicaciones. Un sistema de ecosonda multihaz (MBES) puede producir datos de batimetría de alta resolución a un coste relativamente pequeño. Estas mediciones, que proporcionan una profundidad para cada haz y cada pulso, son procesadas para obtener una estructura más ordenada, como una retícula. La mayoría de los enfoques para atribuir una profundidad al centro de una celda (en una retícula) utilizan la profundidad menos profunda o la profundidad media en cada celda. Sin embargo, mientras que la retícula derivada de la profundidad media podría ser demasiado profunda comparada con la profundidad menor, el uso del enfoque de la profundidad menor puede resultar en una retícula artificialmente poco profunda, afectada por valores anómalos. Este artículo introduce un número de alternativas a los métodos actuales mediante la combinación de la profundidad media con propiedades estadísticas derivadas del punto de la nube de los datos MBES. Además, se considera la posibilidad de atribuir una profundidad basada en los coeficientes de regresión de cada celda. Los métodos introducidos han sido probados en datos adquiridos en diferentes áreas de levantamientos. Las retículas resultantes han sido comparadas a sus contrapartidas menos profundas y medias para lograr una mayor comprensión de sus ventajas y limitaciones.

1. Introduction

An accurate representation of the seafloor or river-bed bathymetry is of high importance for purposes such as safe navigation and nautical chart production. Currently, MBES systems are used for the collection of high-resolution bathymetry data by performing a large number of measurements which are processed to obtain a more ordered structure such as a grid. Approaches for assigning a depth to the grid cell's center often employ the shallowest or mean depth in a cell. In this paper, we introduce a number of alternatives to the two current approaches based on a combination of the mean depth and statistical properties of the depth measurements.

2. Mean and Shallowest Depths

The most straightforward candidate for the depth at the cell center is the shallowest depth which is of primary importance for safe navigation. The disadvantage of using this depth value, is that the resulting grid might be unrealistically shallow due to the presence of erroneous (shallow) measurements. To overcome this drawback, one can use the mean depth. However, problems might occur as hazardous objects might be left undetected.

3. Mapping depths based on regression coefficients

Considering all soundings that are located within a cell (assuming a large enough cell and/or hit count), a linear plane can be fitted through these depth measurements, where its regression coefficients account for the potential presence of slopes. The depth at an arbitrary location in the cell can be derived by using the intercept of the plane and the regression coefficients. As the slopes are assumed constant over the cell, the mathematical shallowest depth is derived by identifying the shallowest depth amongst the depths at the four corners.

4. Mapping depths based on (corrected) standard deviation

To mitigate the drawbacks of the mean and shallowest depth, one has to ensure that the effect of outliers is accounted for, while avoiding an artificially deep grid. One approach is to use the combination of the mean depth and standard deviation of the depth measurements. The standard deviation can be seen as a measure that also accounts for the presence of slopes. Hence, the standard deviation is not solely a representative of the measurement uncertainties.

Another alternative is to use a combination of the mean depth and the standard deviation corrected for the slopes present in the cell. This measure should represent the mean depth in a cell, while being corrected for the uncertainties in the measurements. However, for regions with slopes this might overestimate the depths.

5. Results

5.1 Data Description

The introduced alternatives are applied to data derived from two surveys, one in the vicinity of the Eemshaven seaport (*A*) and one in the Westerschelde estuary (*B*) (**Figures 1 and 2** *respectively*). The MBES used for the data acquisition was an EM3002D and around 85 million soundings were obtained in each survey.
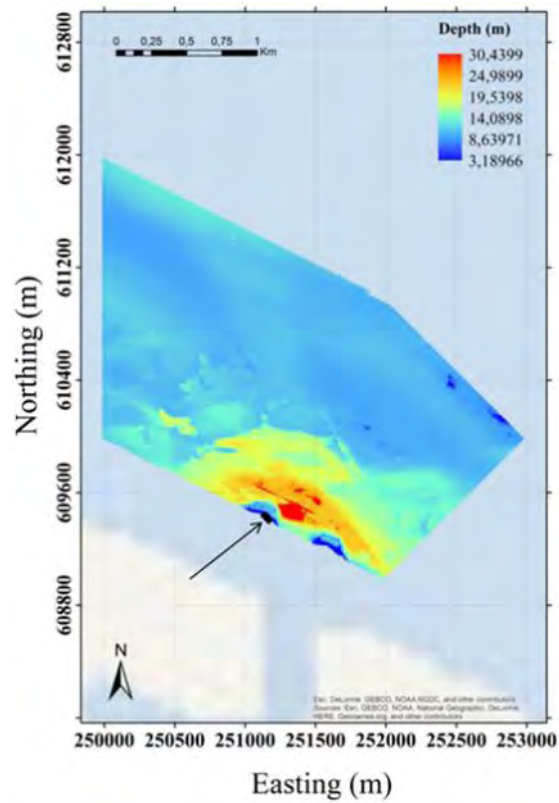
Figure 1. *Bathymetry map of the area A in the vicinity of the Eemshaven seaport.*
The black thick line indicates the location where the seafloor profile is obtained (see Figure 8).
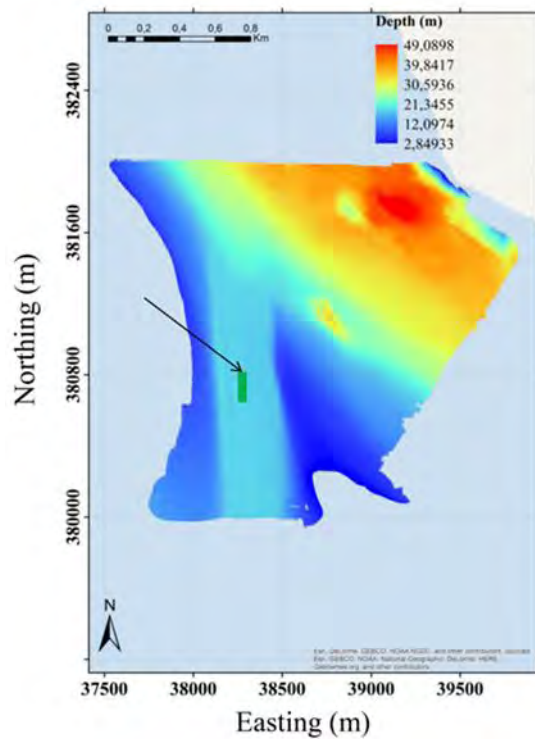

Figure 2*. Bathymetry map of the area B in the Westerschelde estuary.*
The green thick line indicates the location where the seafloor profile is obtained (see Figure 9).

Depth variations occurring over a relatively small distance in the southern part of area *A* (***Figure 1***) and the existence of a man-made trench in area *B* (***Figure 2***), have motivated us to assess the performance of the different alternatives in these regions.

It should be noted that the statistical features (regression coefficient, corrected and uncorrected standard deviation) are calculated using a dedicated software module. The module enables statistical features to be calculated only if the number of soundings in a cell exceeds five (at least 3 are required to determine the parameters of the linear plane and the additional soundings are for increasing the degrees-of-freedom). Otherwise, Not-A-Number (NAN) values are returned for the cell. In order to assign a realistic value to the statistical features for the cell with less than 6 soundings, use is made of the average values of eight neighboring cells.

5.2. Shallowest depth using regression coefficients

Using the mathematical shallowest depth based on the regression coefficients, results in unrealistic depth values for some cells. As an example, for a cell in the area with a mean depth of 40.2 m, the mathematical shallowest depth returned by the method is 14.9 m which is unrealistic given the cell size. The point cloud of the data is processed to investigate the cause. ***Figure 3*** shows the distribution of the soundings within this cell. As can be seen, the points are spatially not well distributed.
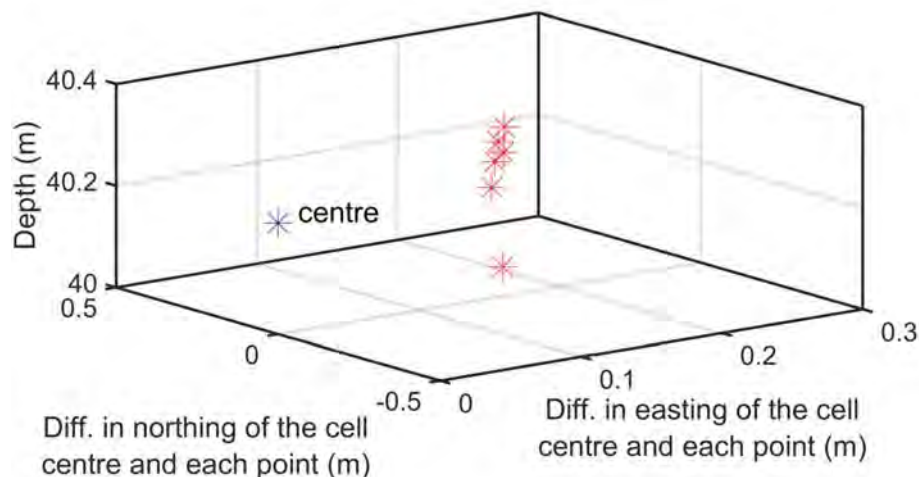

Figure 3. *Distribution of the points in the cell with unrealistic depth values at the corners. The mean depth in the cell is 40.22.*

This results in coefficients which actually should only be used to determine the depth in close vicinity of the points and not the cell corners. A possible solution is to consider a threshold and discard the regression coefficients of the cells where the coefficients exceed the threshold. The feasibility of adopting this solution is currently being assessed.

5.3. Shallowest depth using (corrected) standard deviation

Figures 4 and 5 show the differences between the mathematical shallowest depth derived from the mean depth and <u>uncorrected</u> standard deviation (1-σ confidence level) and the actual shallowest depth measured for the cells in the areas *A* and *B* respectively. For nearly 6% of the cells, the former is shallower than the latter. The results also show a dependency along the sailing direction at the outer parts of the swaths which is not observed in the bathymetry map of either areas and is due to the larger depth uncertainties for the outer parts of the swaths. This results in a larger difference between the mean and shallowest depths.
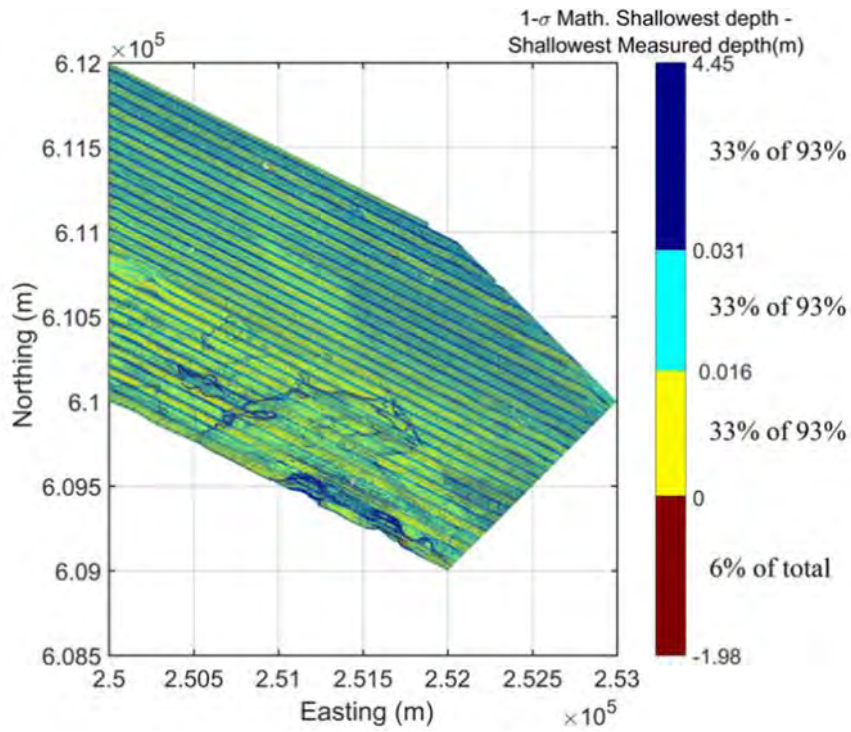
Figure 4. Map of the difference between the 1-σ mathematical shallowest and the actually measured shallowest depth in area A.
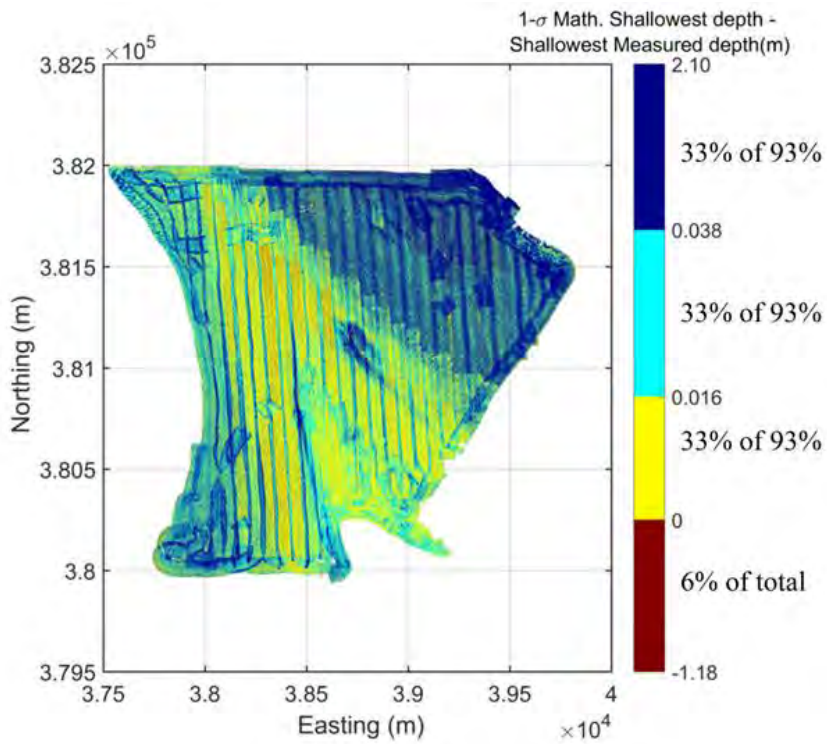

Figure 5. Map of the difference between the 1-σ mathematical shallowest and the actually measured shallowest depth in area *B*.

Note: For **Figures 4, 5, 6 and 7**, the positive range of values represented by each colour is selected such that each range represent equal percentages of data points for which the derived depths are deeper than the shallowest measured depths. The red colour presents those data points where the derived depths are shallower than the shallowest measured depths.

These depth uncertainties are caused by a variety of contributions, such as uncertainties in the MBES range measurements, uncertainties in the beam angle, the water column sound speed and position of the MBES and the attitude sensors on the ship. For illustration purposes, **Figures 6 and 7** represent the differences between the mathematical shallowest depth derived from the mean depth and the <u>corrected</u> standard deviation (1-σ confidence level) and the actual shallowest depth measured for the cells in the areas *A* and *B* respectively.
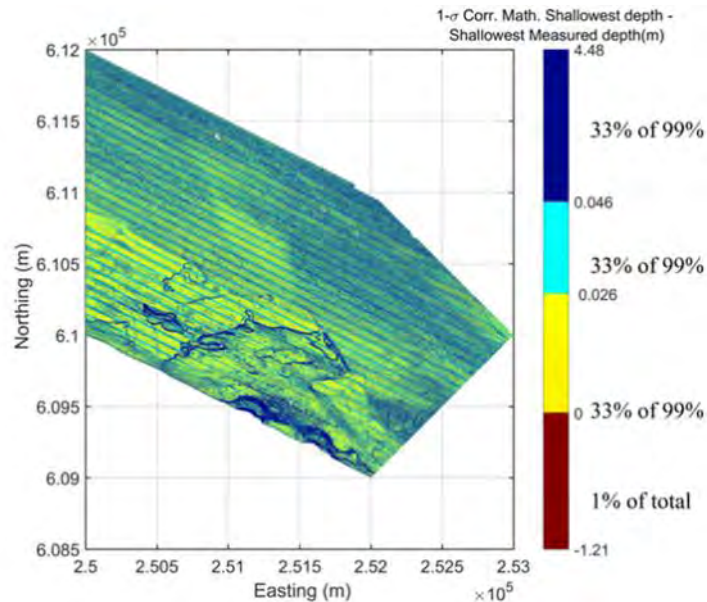

Figure 6. *Map of the difference between the 1-σ corrected mathematical shallowest and the actually measured shallowest depth in area A.*
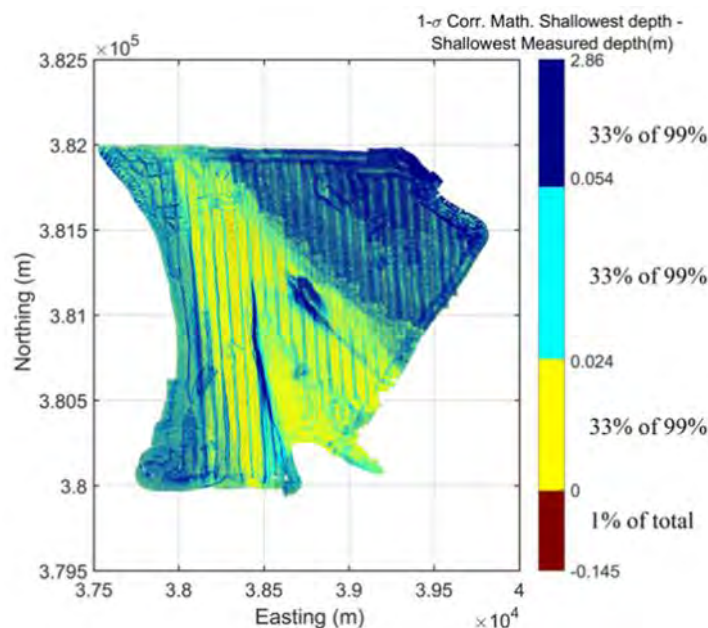

Figure 7. *Map of the difference between the 1-σ corrected mathematical shallowest and the shallowest depth measured in the area B.*

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As expected, the percentage of cells in which the obtained depth is shallower than the actual shallowest measured depths is decreased to around 1%. This measure can be considered to capture both the mean and the uncertainties in the MBES measurements, but neglects any effect of the slopes. In this respect, it has a large risk in not capturing the actual shallowest depths. Still, the maximum increase in depth differs only slightly from that obtained by using the uncorrected standard deviation (**Figures 4 and 5).** A more mathematically sound approach is to use the shallowest depth at the corners, derived from the linear fit to the depth measurements within a cell, which is a topic for further investigation.

5.4. Seafloor profile based on introduced alternatives

Figures 8 and 9 depict the profiles of the seafloor along the black line (shallowest part in area A in **Figure 1**) and the green line (relatively flat area in area B in **Figure 2**) for the shallowest, mean, and the two depths based on the mean and (corrected and uncorrected) standard deviation. As the corrected standard deviation is always smaller than the uncorrected value, the mathematical shallowest depth derived using the former is closer to the mean depth compared to one obtained from the latter.
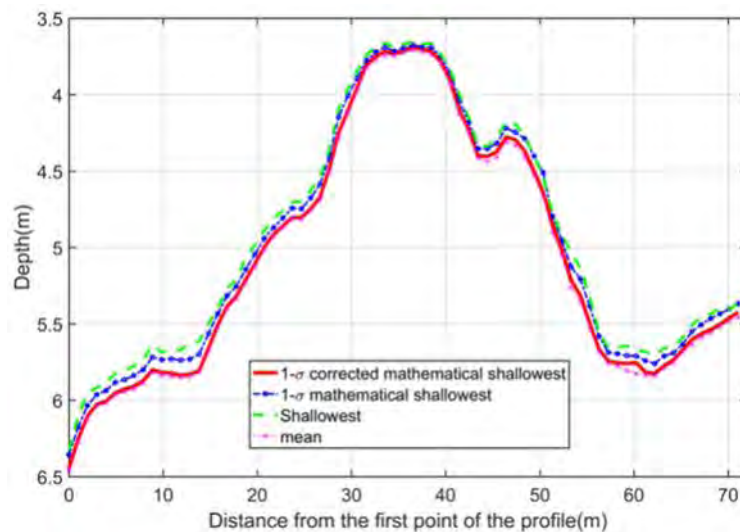

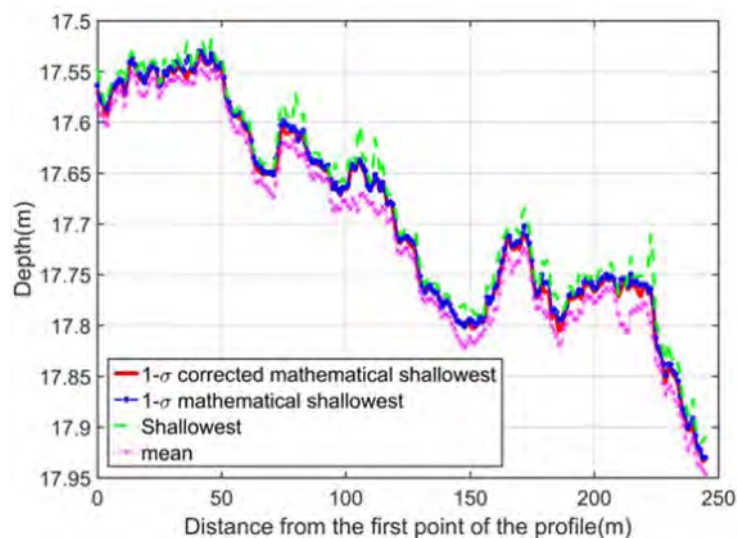*Figure 8. Profile of the black line shown in the bathymetry map of area A (Figure 1) using four different depths.*

Figure 9. Profile of the green line shown in the bathymetry map of area B (Figure 2) using four different depths.

6. Conclusions

There is a need for alternatives to determine the mean and shallowest depths in a grid cell as hazardous objects might be left undetected and the final grid depth value might be too shallow. Combination of the mean depth and standard deviation of the cell is considered a successful candidate. However from tests conducted, this method resulted in depths that are often (6%) shallower than the shallowest measured depth.

A further alternative solution could consider the combination of the mean and corrected standard deviation, which takes the effect of the possible slopes in a cell into account for the calculation of the standard deviation and does not require the calculation of regression coefficients. This results in less cells with depths that are shallower than the shallowest measured depths.

However, this combination is not recommended at this time and research on more realistic measures to account for the depth variation in a cell is still needed. Considering the features, it was found that neither of these representations prohibits the identification of the real bathymetric features.

7. Author Biographies

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Simon Bicknese studied at the Nautical College Noorder Haaks in Den Helder. He sailed for several years as a deck officer with the merchant navy. He joined the survey department from Rijkswaterstaat in 1984. He is now technical advisor for hydrographic issues.
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