# Minimum depth, mean depth or something in between?

Haji Mohammadloo, Tannaz; Snellen, Mirjam; Simons, Dick; Dierikx, Ben; Bicknese, Simon

**Publication date**
2017

**Document Version**
Final published version

**Published in**
Proceedings of the 25th Hydrographic Conference

**Citation (APA)**
Haji Mohammadloo, T., Snellen, M., Simons, D., Dierikx, B., & Bicknese, S. (2017). Minimum depth, mean depth or something in between? In *Proceedings of the 25th Hydrographic Conference: Rotterdam, The Netherlands, 14-16 November 2017*

Presented in Hydro1,Rotterdam, The Netherlands, 14-16 November 2017

# Minimum depth, mean depth or something in between?

Tannaz H. Mohammadloo[a], Mirjam Snellen[a], Dick G. Simons[a], Ben Dierikx[b], Simon Bicknese[b]

[a]Acoustics Group, Department of Control & Operations, Faculty of Aerospace Engineering, Delft University of Technology, Kluyverweg 1, 2629 HS, Delft, The Netherlands

[b] Rijkswaterstaat Centrale Informatievoorziening, Derde Werelddreef 1, 2622 HA, Delft, The Netherlands

## Abstract

Reliable information about the sea- and river-bed bathymetry is of high interest for a large number of applications. The Multi-Beam Echo-Sounder (MBES) system is able to produce high-resolution bathymetry data at relatively limited costs. In general, these measurements, providing a depth for each beam and every ping, are processed to obtain a more ordered structure, such as a grid. Approaches for assigning a depth to the centre of a cell (in a grid) often use the shallowest or the mean depth in each cell. However, while the grid derived from the latter might be too deep compared to the shallowest depth, using the former 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, i.e. both the uncorrected and corrected standard deviation. While the standard deviation reflects the variations of the raw depth measurements in each cell, the corrected standard deviation accounts for the effect of slopes in easting and northing directions and hence, in general, provides a more realistic description of the depth uncertainty in a cell. 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.

## 1. Introduction

An accurate representation of sea-floor 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 into a more ordered structure such as a grid. Approaches for assigning a depth to the cell center often employ the shallowest or mean depth in a cell. Here, 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. Its advantage is preserving the shallowest depth which is of importance for the safe navigation. The disadvantage, however, is that the resulting grid might be unrealistically shallow due to the presence of erroneous measurements, remaining after validation. To overcome this drawback, one can use the mean depth. However, problems might occur as the hazardous object might be left undetected.

## 3. Mapping depth based on regression coefficients

Considering all soundings that are located within a cell (assuming a large enough cell and/or hit counts), a linear plane can be fitted through the depth measurements in the cell, where its regression coefficients account for the potential presence of slopes. The depth at an arbitrary location in the cell is thus 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. It should be noted that considering

## 4. Mapping depth based on (corrected) standard-deviation

To mitigate the drawbacks of the mean and shallowest depth, one has to ensure that the effect of outliers, remaining after validation, is accounted for, while avoiding to obtain an artificially deep grid. One approach is thus to use the combination of the mean depth and standard deviation of the depth measurements. The disadvantage of the standard deviation is that it can be contaminated by the presence of slopes and hence the standard deviation is not solely a representative of the depth variations. Another alternative is to use a combination of the mean depth and the standard deviation corrected for the presence of slopes. This value accounts in a more realistic way for potential actual deviation of the depths within the cell from the mean value.

# 5. Result

## 5.1. Data Description

The introduced alternatives are applied to data derived from two surveys in the vicinity of the Eemshaven seaport (*A*) and in the Westerschelde estuary (*B*), see Figure 1 and Figure 2 respectively. The MBES used for the data acquisition was an EM3002D and around 85 million soundings were obtained in each survey. Depth variations occurring over a relatively small distance in the southern part of area *A* (see Figure 1) and the existence of a manmade trench in area *B* (see Figure 2) has 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 by the developed module 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 this cell. 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 neighbouring cells.

## 5.2. Shallowest depth using regression coefficients

Using the mathematical shallowest depth based on the regression coefficients results in unreasonable 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 unreasonable bearing in mind the cell size. The point cloud of the data is processed to investigate the cause. Shown in Figure 3 is the distribution of the soundings within this cell. As can be seen, the points are not well-distributed. This results in obtaining coefficients which actually should only be used to determine the depth in close vicinity of the points and not the cell corners.

## 5.3. Shallowest depth using (corrected) standard-deviation

Shown in Figure 4 and Figure 5 are the differences between the mathematical shallowest depth derived from the mean depth and standard deviation (1-$\sigma$ confidence level) and the shallowest depth measured for 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 which is not observed in the bathymetry map of either areas and is possibly due to the imperfect knowledge of the sound speed profile. For the flat areas, these features can prohibit the realistic assessment of the effect of using mean depth or its derivatives. However, for the non-flat areas the largest differences seem to be due to real bathymetric features. Figure 6 and Figure 7 represent the differences between the mathematical shallowest depth derived from the mean depth and the corrected standard deviation (1-$\sigma$ confidence level) and the shallowest depth measured for the areas *A* and *B* respectively. As expected, the percentages of cells in which the former is shallower than the latter are decreased to around 1%. The largest differences are again associated with real morphological features.

### 5.4. Seafloor profile based on introduced alternatives

Shown in Figure 8 and Figure 9 are the profiles of the seafloor along the black line (shallowest part in area *A*) in Figure 1 and green line (relatively flat area in area *B*) in Figure 2 using the minimum, mean, corrected and uncorrected shallowest depths. As the corrected standard deviation is always smaller than the uncorrected one, the mathematical minimum derived using the former is closer to the mean depth compared to one obtained from the latter. Consequently, the 1-$\sigma$ uncorrected mathematical minimum would be closer to the mean depth.

## 6. Conclusions

There is a need for alternatives to the mean and shallowest depth in a cell as the hazardous objects might be left undetected and the final grid might be too shallow using the former and latter respectively. Combination of the mean depth and the corrected and uncorrected standard deviation of the cell proved to be successful candidates. While the former only accounts for the variations of the raw depth measurements, the latter takes the effect of the possible slopes in a cell into account and hence gives a more realistic description of the depth variation in a cell. Neither of these representations prohibit the identification of the real bathymetric features.

## Biography

Tannaz Haji Mohammadloo is a Ph.D candidate at the Acoustic Group at the Faculty of Aerospace Engineering, Delft University of Technology (TU Delft), The Netherlands. She received her Bachelor and Master degree in Survey Engineering and Geodesy from the University of Esfahan, Iran, in 2011 and 2013, respectively.

Mirjam Snellen received her Master degree in Aerospace Engineering from TU Delft, in 1995 and her Ph.D degree in geoacoustic inversion from the University of Amsterdam, The Netherlands, in 2002. Currently, she is an Associate Professor at the Acoustic Group at the Faculty of Aerospace Engineering, TU Delft.

Dick G. Simons received his Master degree in physics and his Ph.D degree from the University of Leiden, The Netherlands in 1983 and 1988, respectively. In 2006, he became Full Professor at the Faculty of Aerospace Engineering at TU Delft. He is Associate Editor of the IEEE Journal of Oceanic Engineering and a member of the scientific committee of European Conferences on Underwater Acoustics.

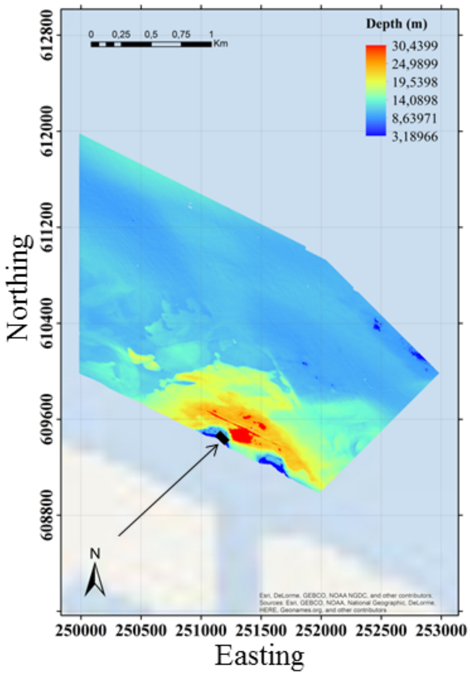


Figure 1. Bathymetry map of the area *A* in the vicinity of the Eemshaven seaport. The black thick line indicate the location where the seafloor profile is obtained for (see Figure 8)

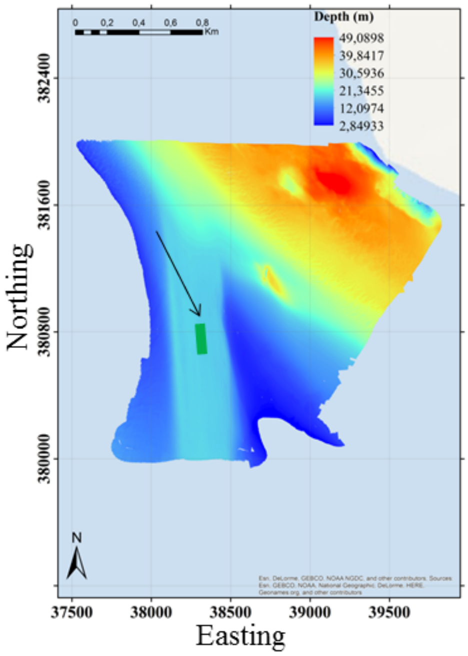


Figure 2. Bathymetry map of the area *B* in Westerschelde estuary. The green thick line indicate the location where the seafloor profile is obtained for (see Figure 9)

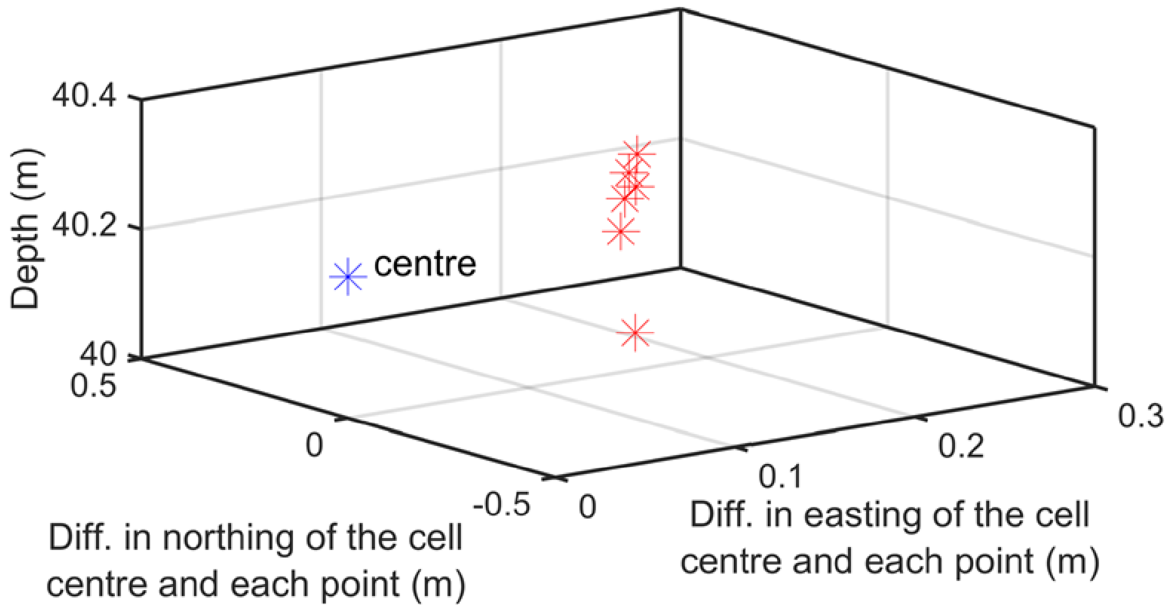


Figure 3. Distribution of the points in the cell with unreasonable depth values at the corners. The mean depth in the cell is 40.218

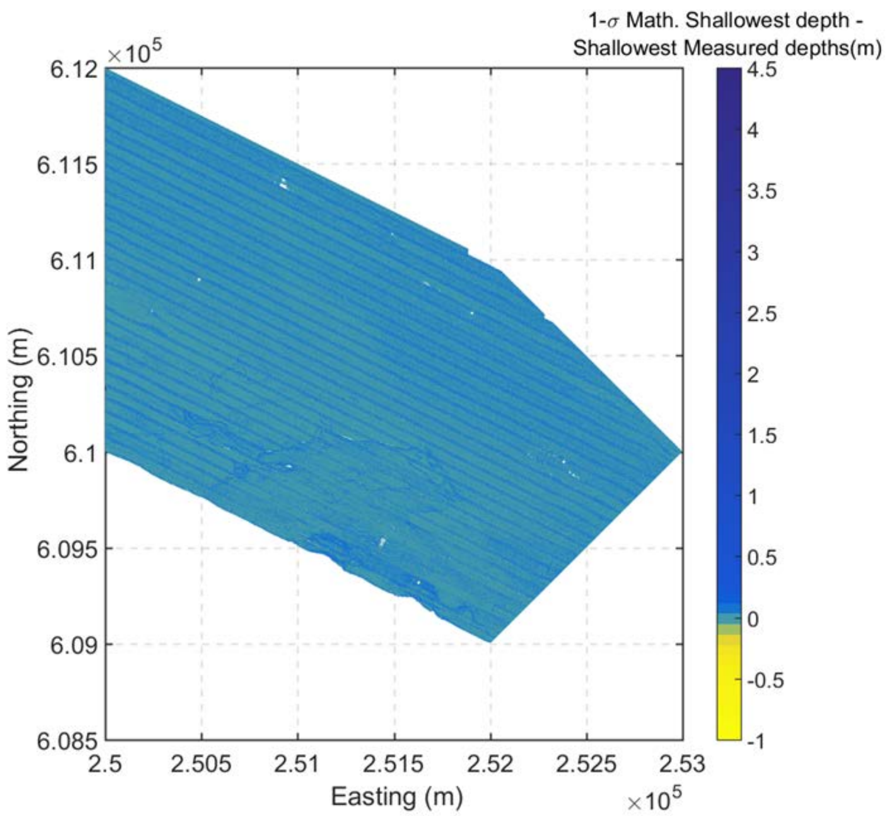


Figure 4. Map of the difference between the 1-$\sigma$ mathematical shallowest and the shallowest depth measured in the area *A*.

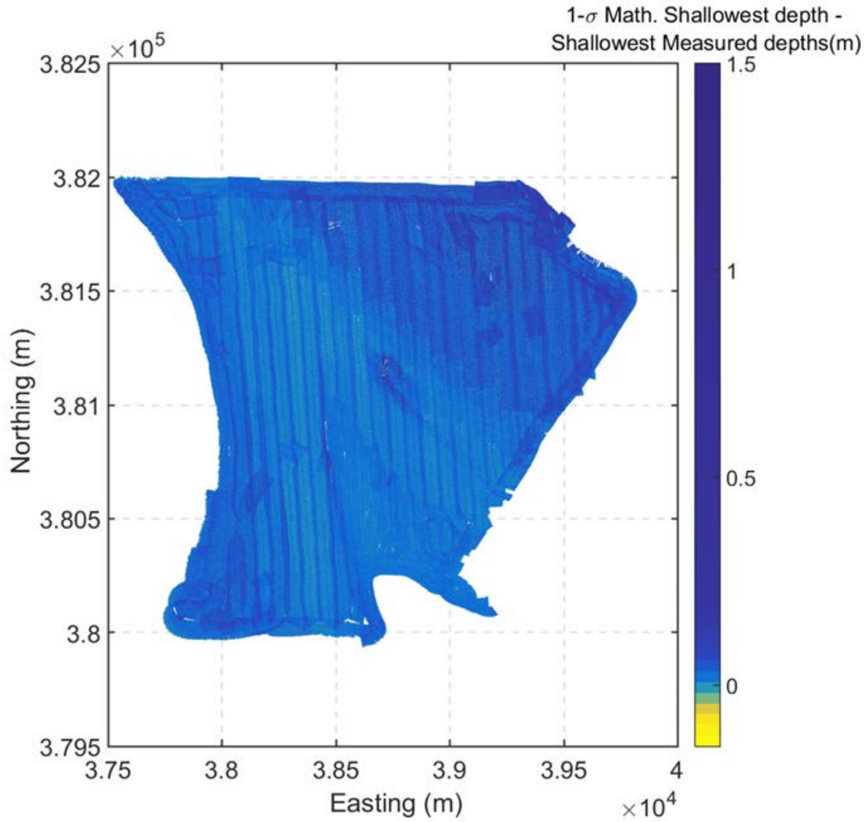


Figure 5. Map of the difference between the 1-$\sigma$ mathematical shallowest and the shallowest depth measured in the area *B*.

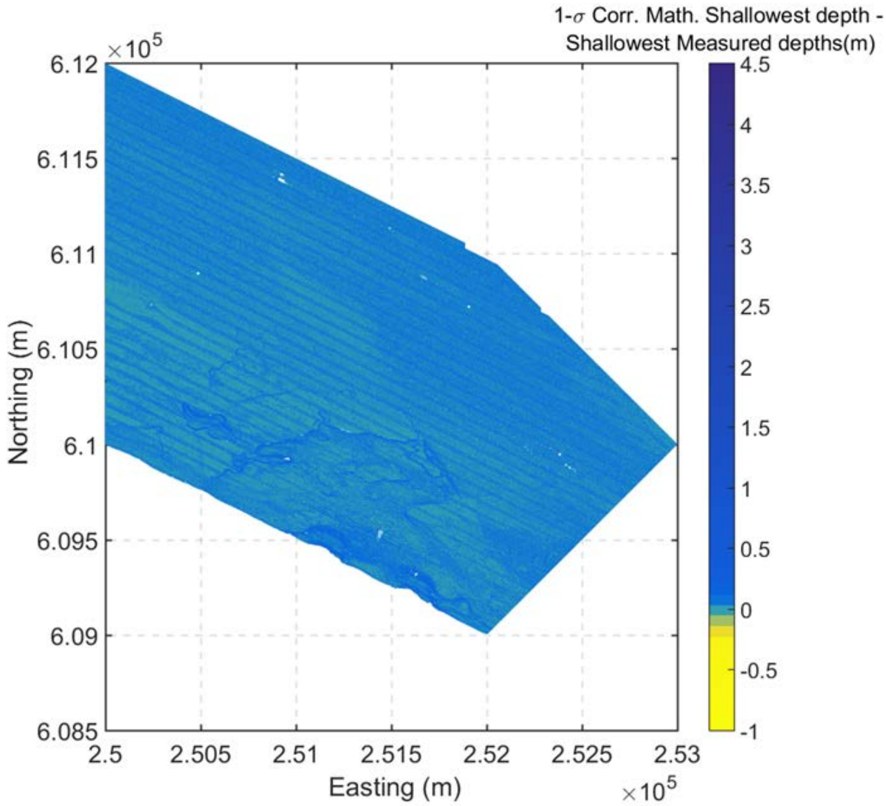


Figure 6. Map of the difference between the 1-$\sigma$ corrected mathematical shallowest and the shallowest depth measured in the area *A*.

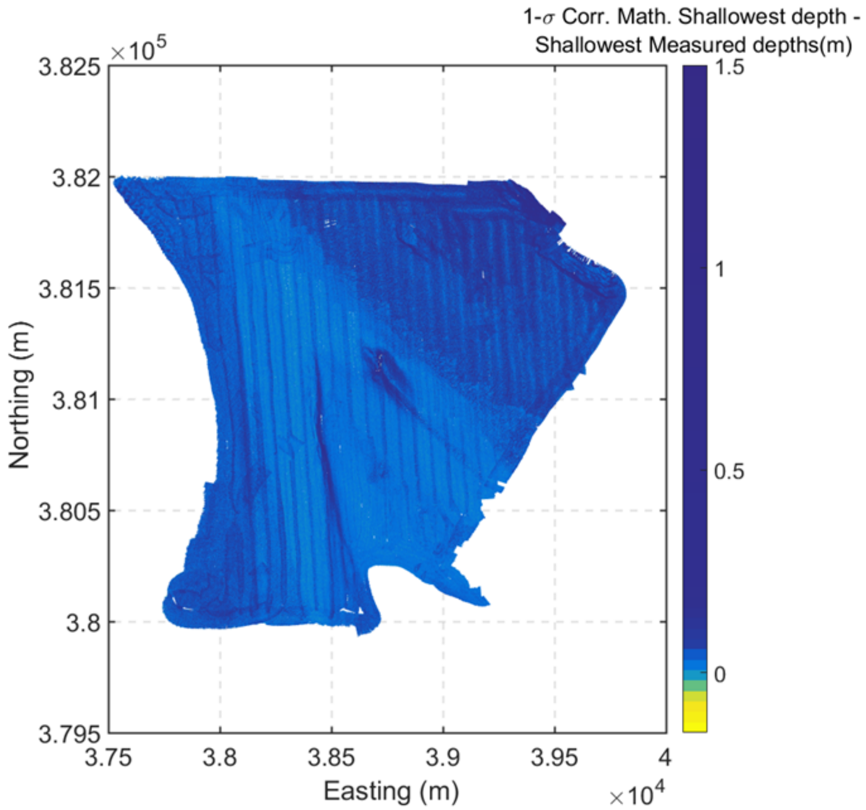


Figure 7. Map of the difference between the 1-$\sigma$ corrected mathematical shallowest and the shallowest depth measured in the area *B*.

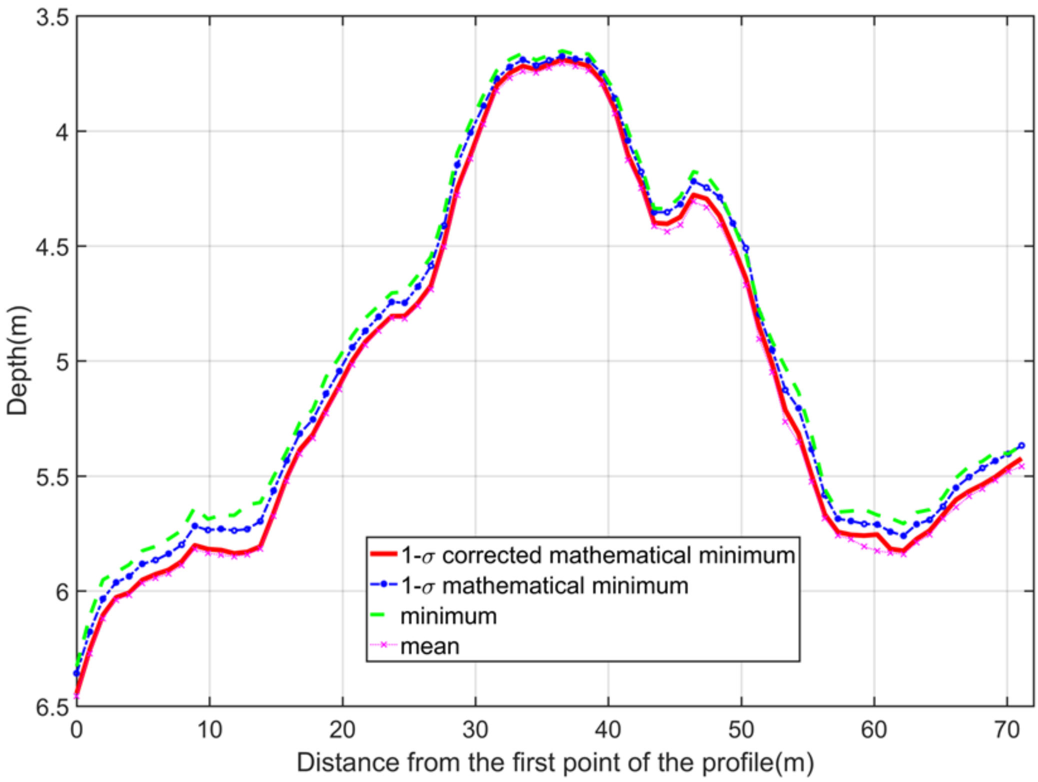


Figure 8. Profile of the black line shown in the bathymetry map of the area *A* (Figure 1) using four different depths.

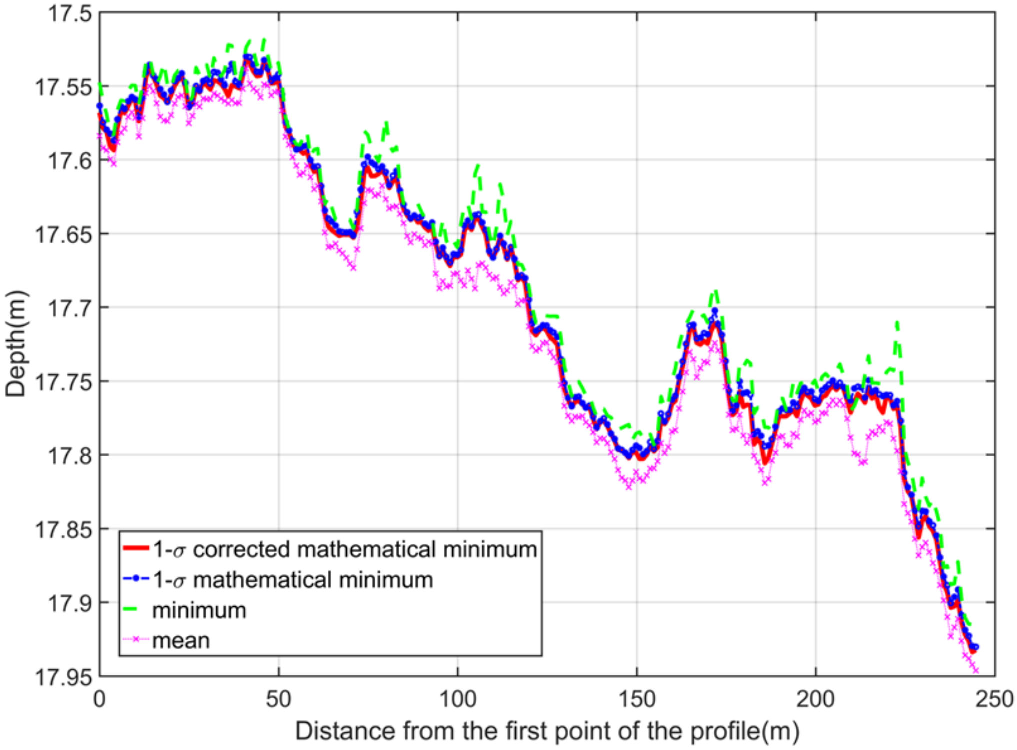


Figure 9. Profile of the green line shown in the bathymetry map of the area *B* (Figure 2) using four different depths.