Correction of multibeam echosounder data biased by inaccurate water column sound speed

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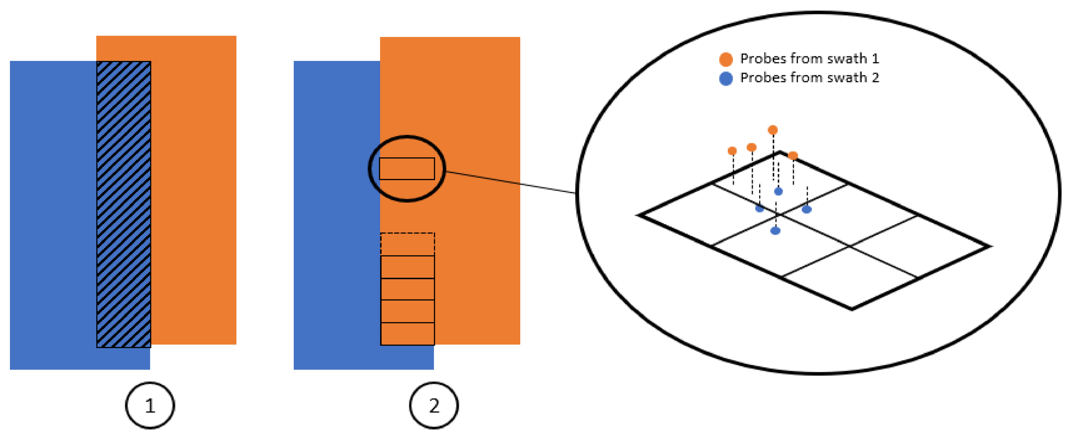
Sound speed correction algorithm principle

The project aims to build an algorithm that corrects systematic errors in multibeam echosounder datasets due to incorrect sound velocity measurement. The sound velocity is a key parameter for deriving the position of soundings.



Steps of the algorithm

The algorithm proposed by Snellen has been implemented [1]. It aims to determine the sound velocity that minimises the standard deviations of the soundings from two adjacent swathes in the overlapping areas (1). The overlap area is divided into segments (2).

The sound velocity that minimises the standard deviations is computed segment by segment. The sound velocity is assumed to be constant for each segment. Soundings are then recomputed using the new sound velocity.

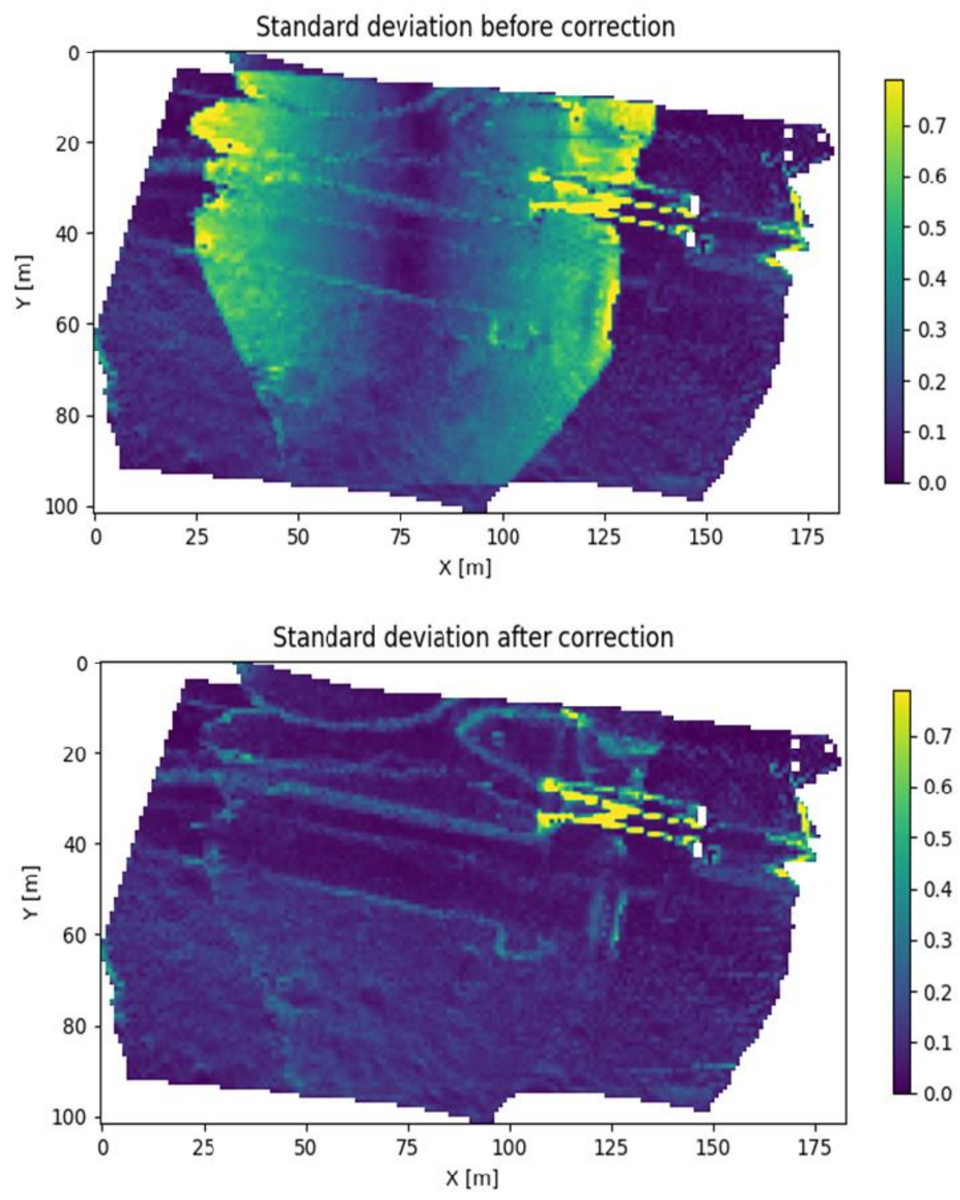
Each segment is composed of C cells (6 here). A constant Sound Speed Profile (SSP) is assigned to each swath. Let us denote $K_{c,n}$ the number of soundings for a given swath in a given cell.

Thus, for each segment, we seek to minimize the sum :

$$E(x)=\sum_{c=1}^{C}\sqrt{\frac{\sum_{n=1}^{N}\sum_{k=1}^{K_{c,n}}(z_{c,n,k}(c_n)-\overline{z}_c(c_n))^2}{\sum_{n=1}^{N}K_{c,n}}}$$

With $x=(c_1,\ldots,c_N)$ and $z_{c,n,k}(c_n)$ the depth of a given sounding, computed with the constant SSP.

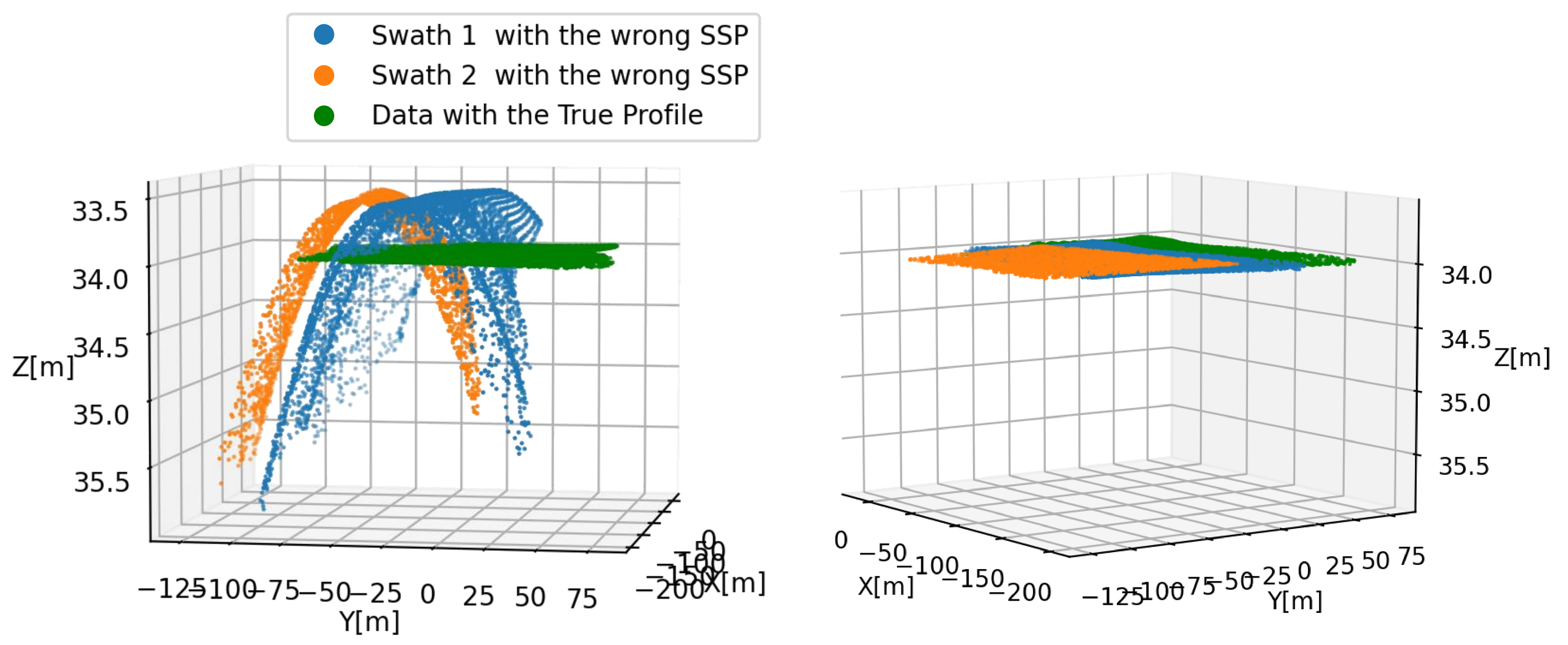
Different methods to minimize *E(x)* exist. Here, we used and compared three methods: a genetic algorithm, the Sequential Least SQuares Programming (SLSQP) function [2] and a blackbox optimization software called NOMAD [3]. When the vector x that minimizes the Energy function is found, the sound velocity is applied to all soundings of the segment.



Standard deviation of a biased survey with two swath. At the top, the survey before correction and down, after correction

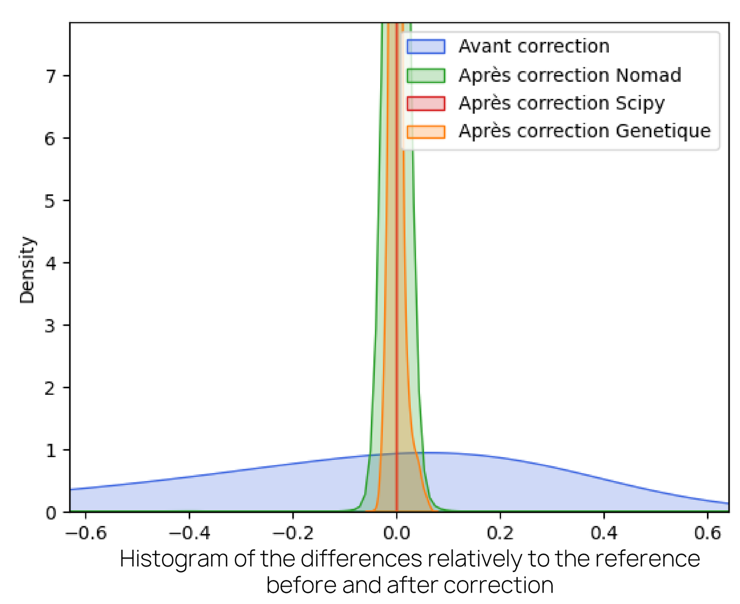
Results: artificial data modelling a flat bottom

A flat seabed with an arbitrary SSP is generated. Data are then recomputed with a biased SSP and the algorithm is then applied. Visually, the biased points cloud appears as "inverted smiles" (left on the figure) which are typical of a wrong SSP correction. Using the SSP computed by the algorithm, the seabed appears flat (right on the figure), which suggests that the resulting SSP is correct.



Correction of artificial data that should become a flat bottom

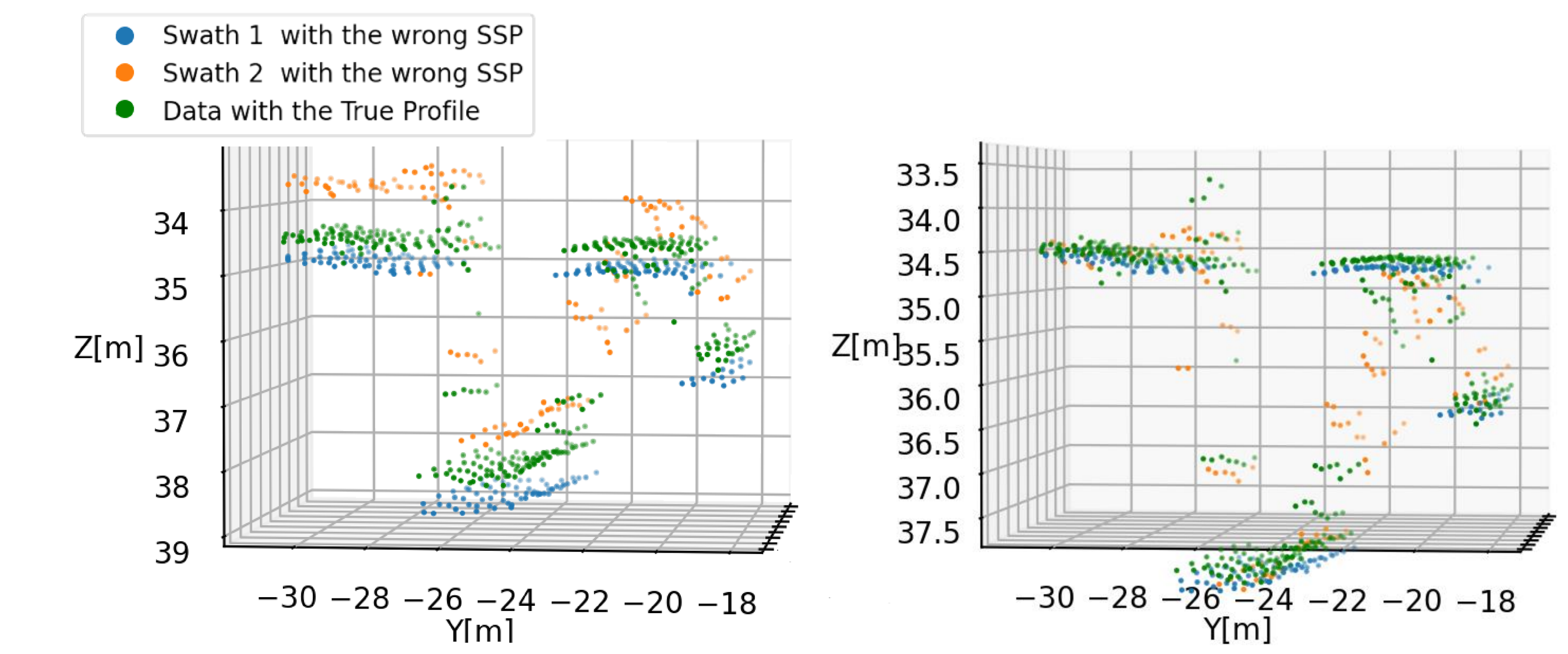
The histogram beside shows the differences between the ideal flat bottom and the data generated with an erroneous and corrected SSP. We notice that the results are very good on this kind of seafloor. All the methods are very efficient with errors smaller than 0.1m. The scipy method is slightly better and faster. The genetic algorithm is slower but gives consistent results.



Histogram of the differences relatively to the reference before and after correction

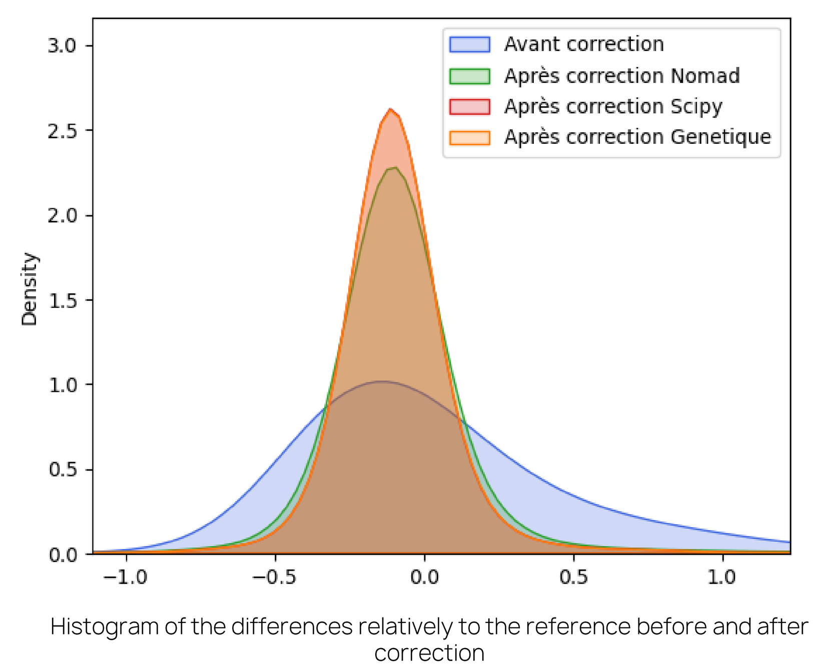
Results : real sea bottom

The algorithm was also tested on in situ data. The study area contains a lock with significant difference in depth (2-3 m). This can be difficult for the algorithm to handle. Nevertheless, we can observe that the algorithm manages to find the SSPs for each segment that minimize well the differences between probes for each swath.



Correction of the probes on a specific relief

The histogram beside shows the differences between the digital terrain generated with the biased data with an erroneous SSP and the correctly acquired data. Of course, the results are not as good as in the case ofthe artificial data. The correction leads to 95% of errors smaller then 0.5m (more than 1m before correction). The SLSQP method performs the best.



Histogram of the differences relatively to the reference before and after correction

This project allowed us to implement and test several aspects of a sound velocity correction algorithm. It would be interesting to extend this study to an entire survey and to determine the best hyperparameters of the optimisation methods. Furthermore, non-negligeable differences have been highlighted between our results and those presented by the original study [1]. The impact of the difference between the true profile and the one used to replay the data would be a key point to investigate.

References :

[1] T. H. Mohammadloo, M. Snellen, W. Renoud, J. Beaudoin and D. G. Simons, "Correcting Multibeam Echosounder Bathymetric Measurements for Errors Induced by Inaccurate Water Column Sound Speeds," in *IEEE Access*, vol. 7, pp. 122052-122068, 2019, doi: 10.1109/ACCESS.2019.2936170.
[2] Kraft, D. A software package for sequential quadratic programming. 1988. Tech. Rep. DFVLR-FB 88-28, DLR German Aerospace Center – Institute for Flight Mechanics, Koln, Germany.
[3] C. Audet, S. Le Digabel, V. Rochon Montplaisir and C. Tribes. NOMAD version 4: Nonlinear optimization with the MADS algorithm. ACM Transactions on Mathematical Software, 48(3), 35:1-35:22, 2022.