# SIMPLE METHOD FOR MULTIPLE SOUNDINGS EXTRACTION FOR WIDE BEAMWIDTH ECHOSOUNDERS

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***Abstract:*** *Bathymetric multibeam echosounders (MBES) classically improve their bottom detection resolution by increasing the number of beams with narrower beamwidths. Many independent detections are thus obtained when extracting one sounding in each beam. However when the pulse footprint on the bottom gets narrower than the beamwidth, which often happens at high incidence angles, it is possible to extract several independent bottom detections within the same beam.*

*These high-density soundings extraction methods present a still higher interest for MBES designed with rather "wide" beams (say 3° or more), so as to offer other benefits, such as compacity, low-cost, or low sidelobe levels as for fishery applications.*

*This paper presents a simple way to derive multiple detections from wide beamwidth systems, which does not involve direct phase-ramp processing such as truncating, cleaning, smoothing and angle-crossing determination. Upon amplitude criteria all samples from a phase ramp are selected, and geographically positioned through their slant range and antenna relative angle, deduced from the raw phase values. Detections corresponding to seabed echoes are then selected through geometrical contiguity criteria and allocated to geographical grid nodes. Depth of each grid node is then taken as median depth of related detections.*

*Results of such processing are presented upon characteristic seabeds, and compared to MBES-embedded high-density extraction. Resolution and accuracy issues of different strategies are discussed.*

***Keywords:*** *multibeam, bathymetry, interferometry, beamwidth*

## 1. INTRODUCTION

Bathymetric multibeam echosounders (MBES) classically improve their bottom detection resolution by increasing the number of beams with narrower beamwidths. Many independent detections are thus obtained when extracting one sounding in each beam. However when the pulse footprint on the bottom gets narrower than the beamwidth, which often happens at high incidence angles, it is possible to extract several independent bottom detections within the same beam [1].

These high-density soundings extraction methods present a still higher interest for MBES designed with rather "wide" beams (say 3° or more), so as to offer other benefits, such as compacity, low-cost, or low sidelobe levels as for fishery applications [2].

This paper presents a simple way to derive multiple detections from wide beamwidth systems, which does not involve direct phase-ramp processing such as truncating, cleaning, smoothing and angle-crossing determination. Upon amplitude criteria all samples from a phase ramp are selected, and geographically positioned through their slant range and antenna relative angle, deduced from the raw phase values. Detections corresponding to seabed echoes are then selected through geometrical contiguity criteria and allocated to geographical grid nodes. Depth of each grid node is then taken as median depth of related detections.

Results of such processing are presented upon characteristic seabeds, and compared to MBES-embedded high-density extraction. Resolution and accuracy issues of different strategies are discussed.

## 2. MATERIAL : SIMRAD ME70 FISHERY MULTIBEAM ECHOSOUNDER

The proposed soundings extraction method is applied to ME70 MBES data. This MBES is designed to cope with water column data quantitative analysis requirements, in relation with fishery studies, such as biomass estimation [3]. Each beam transmits a specific frequency and presents a wide beamwidth compared to usual MBES, so as to achieve sufficient sidelobe reduction. Fig. 1a presents ME70 fishery mode configuration used by Ifremer.

ME70 offers also a more classical bathymetric option, with single swath and single frequency transmission, whose caracteristics are also presented in Fig. 1b.

Fig. 2 presents examples of water column swath views obtained in fishery and bathymetry configurations. Water column data remains very clean near the seabed in the fishery configuration thanks to the low sidelobe levels, but few and wide beams provide reduced bottom description.

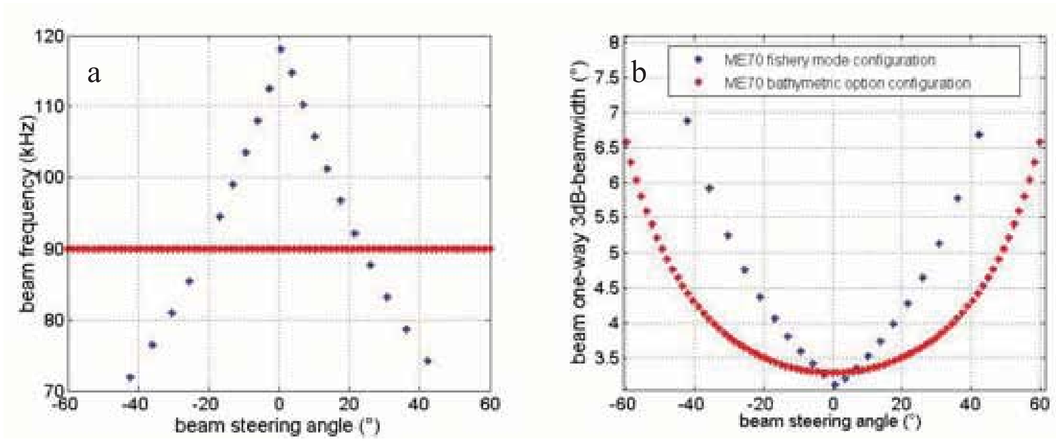


*Fig.1: Beams across-track steering angles, frequencies, and across-track beamwidths for the fishery configuration (21 beams, blue) and bathymetric option (81 beams, red)*

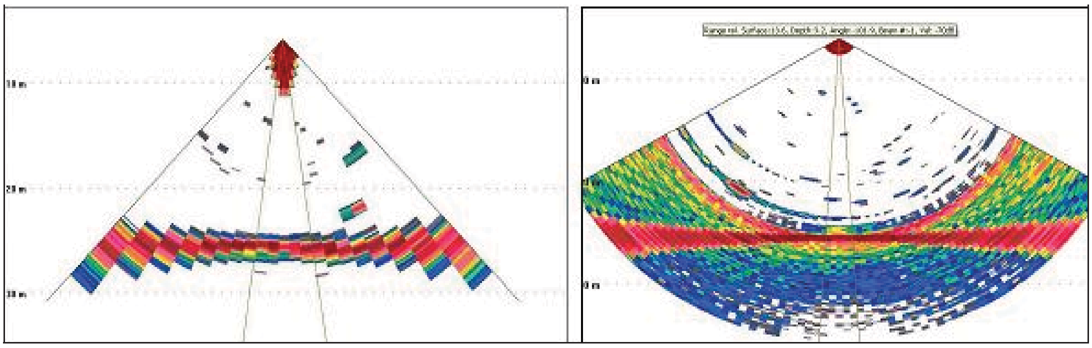

*Fig.2: Swath view in fishery configuration (left) and bathymetric option (right)*

## 3. METHOD FOR BUILDING DIGITAL TERRAIN MODEL

### 3.1. Data

For each ping transmission and each beam of ME70, backscattered signal amplitude along time is available, as well across-track interferometric phase data within the beam, related to the echo mechanical angle of arrival. Along-track interferometric phase is also available along time for this sounder, enabled by square antenna design. This is an interesting feature profitable to interferometric localisation [4], whose impact is not detailed in this paper.

Example of data is given in Fig. 3. The left part shows amplitude and angle behaviour along time for a beam whose steering angle is close to bottom normal incidence. Bottom echo is brief and exhibits a strong amplitude. The right part of Fig. 3 relates to a beam whose steering angle is away from bottom normal incidence. Seabed echo is composed of numerous samples, corresponding to pulse successive footprints sliding on the bottom along the beam, resulting in phase ramp observation.

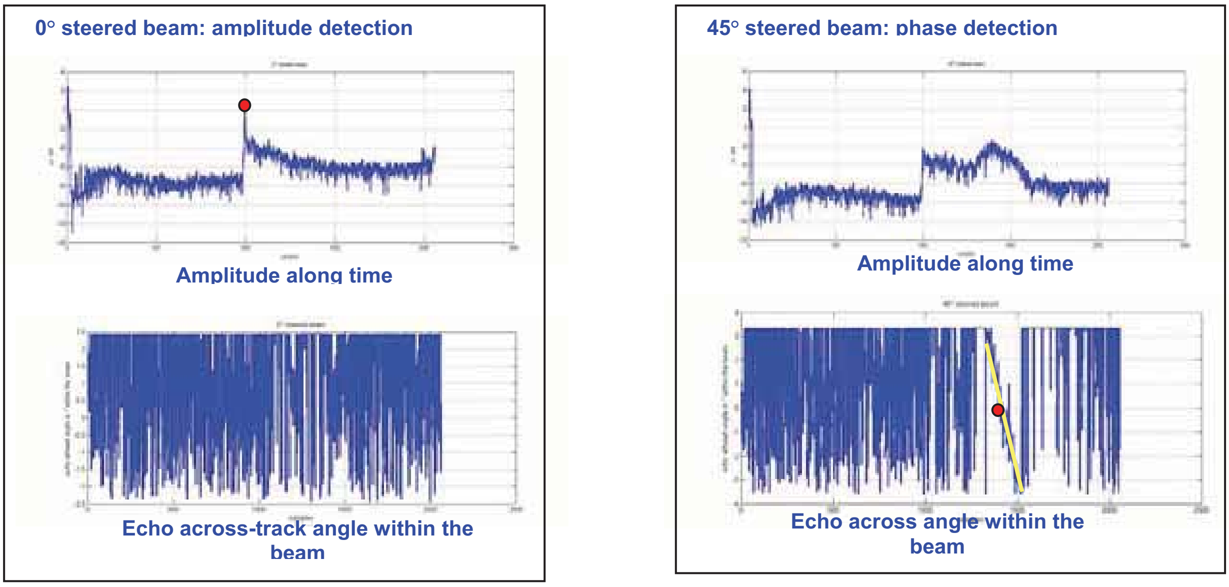


*Fig.3: Amplitude and across-track angle data along time, for one ping transmission, for two different steered beams*

### 3.2. Principle

A straightforward way to extract soundings of one ping of MBES data is to estimate for each beam the time of arrival of the echo originated by the portion of bottom located on the beam axis, through amplitude or zero-crossing phase detection (red dots Fig. 3) [1]. This provides one sounding per beam. However in the case of wide and sparse beams systems, this results in too rough bottom description.

In the case of beams whose axis is not too close to bottom normal incidence, more than one sounding per beam can be extracted. Instead of estimating just the range of the echo whose angle of arrival corresponds to beam axis, several ranges corresponding to successive angles of arrival can be determined, providing several soundings [1]. This generally implies to locate the phase ramp, to clean and smooth it, and to truncate it into several parts to perform the angle-crossing determination.

A different approach is proposed here. No direct processing is performed over the phase ramp. Beam samples corresponding to potential bottom echoes are selected, and geographically positioned through their slant range and mechanical angle given by their phase value. The bottom echoes selection is then refined through geographical contiguity criteria, and digital terrain model is deduced from the remaining cloud of soundings.

### 3.3. Samples selection

ME70 presents the particularity to provide amplitude calibrated data. Calibration procedures are performed through sphere calibration protocols [5] [6], where sounder target strength (TS) measurements over a reference metallic sphere are compared to reference TS value. Samples amplitude can be also compensated for 2D beam pattern as along and across-track angles are measured. This enables to select samples corresponding to significant echoes just by comparing their amplitude transposed into calibrated TS or bottom backscattering coefficient to a given absolute threshold.

Water column echoes differing from bottom ones can be retained with this threshold, as this is the case for fish schools for example. They are kept at this stage and differentiation will occur later.

This first selection is convenient for ME70 fishery mode, with its very low sidelobe levels, both in across and along-track direction.

However with a more conventional bathymetric design, as ME70 bathymetric option, numerous water column samples corresponding to bottom echo perceived through beam sidelobes will be selected. Their density and proximity to the seabed will make them difficult to separate from bottom soundings through geographical coherence criteria.

To cope with this, for a given ping and a given time sample, maximum amplitude over all beams is considered, and only samples from beams whose amplitude exceeds this amplitude minus 15dB are selected. This is repeated for each successive time sample and allows to exclude sidelobe echoes, as illustrated in Fig. 4.

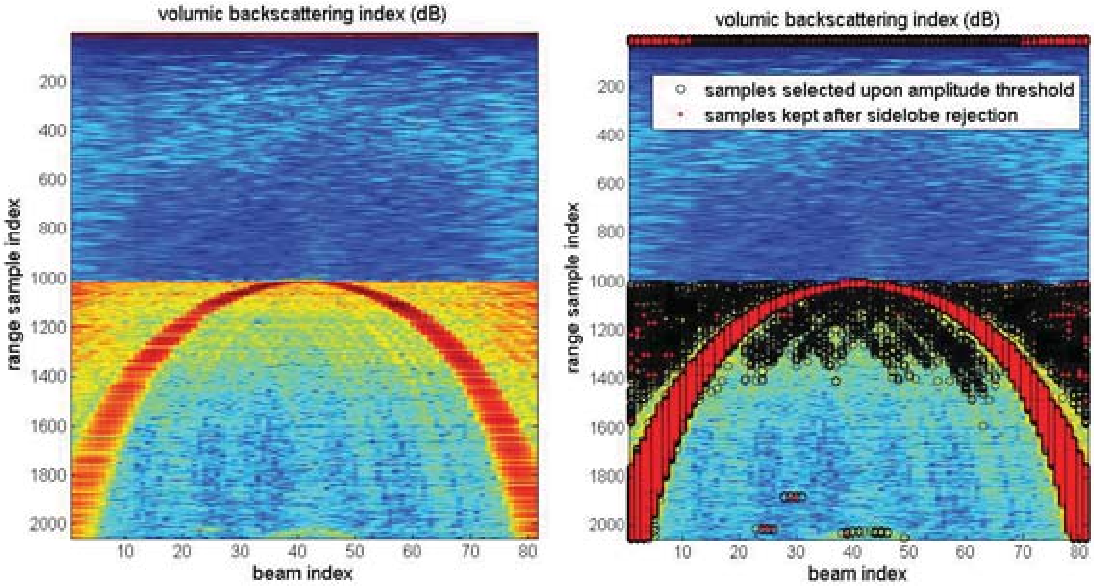


*Fig.4: Left: bathymetric option water column data for one ping. Right: amplitude thresholding selects bottom sidelobe samples(black), variable threshold per range enables to reject them (red)*

### 3.4. Geographical positioning and bottom echoes selection

Each previous selected echo can be positioned towards antenna through its slant range and accurate angle of arrival provided by beam steering and interferometric split-beam angle. If along-track angle is not available, 0° is considered in along-track direction. Geographical positioning is achieved by integrating vessel attitude, position, and antenna installation parameters, as detailed in [7].

Bottom echoes differ from others in that they form an extended contiguous layer. This can be used to discriminate them.

Detections can be labelled into groups: two detections that are closer than a given distance share the same label. The label group with the most numerous detections is considered as bottom detections one.

This kind of algorithm is however very computationally demanding. A simpler method consists in considering a geographical grid. Each detection is related to the closest grid node. Then for each grid node, only the group of the deepest associated detections is considered as bottom detections. That is: all the detections allocated to the grid node are depth ordered, and the first detection whose depth difference with the previous deeper one exceeds a given gap is considered as water column echo, as all the shallower ones.

The bottom depth finally allocated to the geographical grid node is taken as the median depth of the related bottom detections, as illustrated in Fig. 5.

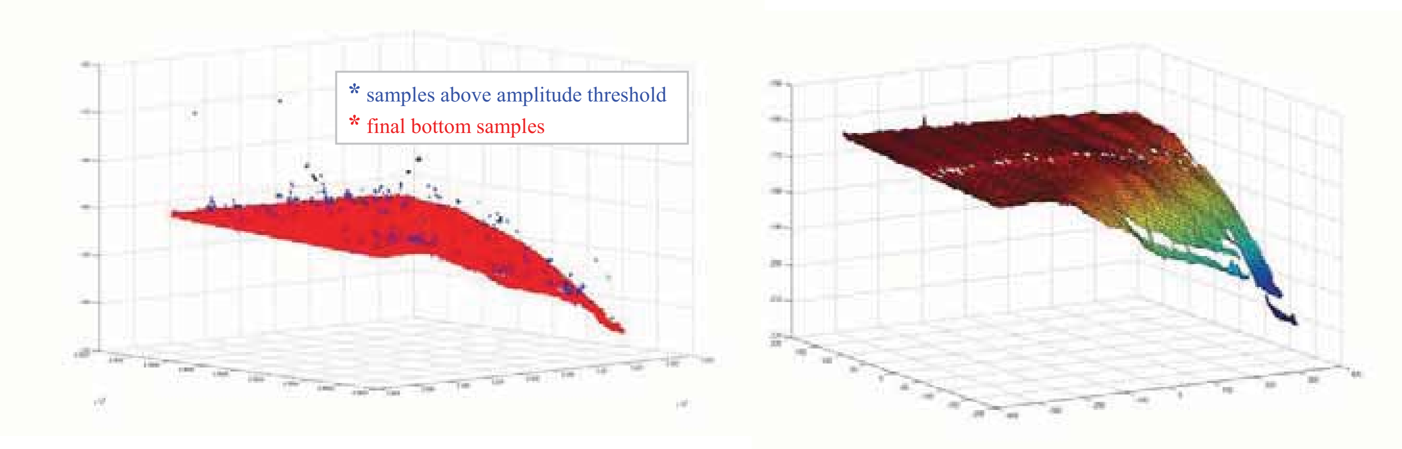


*Fig.5: Soundings positioning, bottom echoes selection, and DTM result for ME70 fishery mode. Left: In red, bottom detection finally selected. In blue, water column echoes discarded. Right: DTM obtained through bottom detection median filtering*

## 4. RESULTS : ME70 FISHERY MODE COMPARED TO EM710

DTM obtained with ME70 fishery configuration is compared in Fig. 6 to result given by a Kongsberg EM710 MBES, on a single line acquisition over Armen area, off Brest. Water depth goes from 45m to 90m. EM710 frequency is 90kHz, vertical beamwidths are 0.5°x1° in along and across-track directions, 256 beams are built giving 400 soundings per swath with High Density extraction. Pulse length is 0.2ms for EM710 and 1ms for ME70.

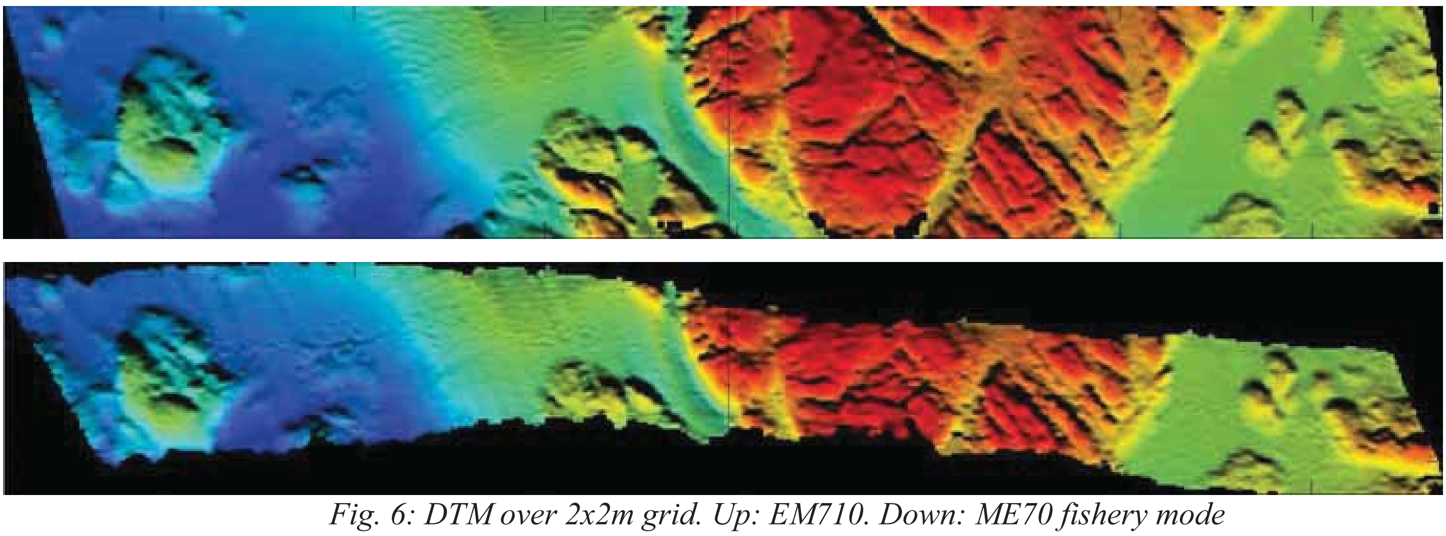

*Fig. 6: DTM over 2x2m grid. Up: EM710. Down: ME70 fishery mode*

ME70 DTM is limited by its swath width, and artefacts are observed at nadir since proposed method is not meant to apply well near normal incidence. But for this grid resolution, result looks quite similar to EM710 bathymetric MBES one, which is a good result considering differences in sounders caracteristics.

However, a 2x2m grid is not the resolution that suits the best EM710 data in this case. Grid resolution that gives the most detailed features before producing data gaps and noise is 1x1m, for which results are shown in Fig. 7. This reaches ME70 configuration limits, as data exhibit more noise.

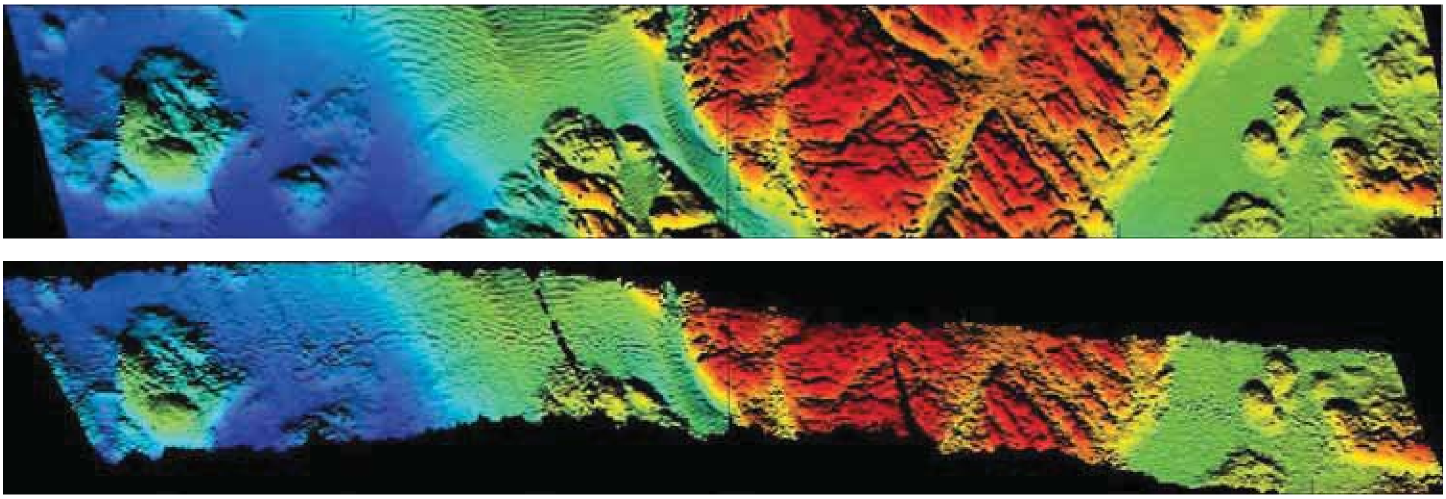

*Fig.7: DTM over 1x1m grid. Up: EM710. Down: ME70 fishery mode*

Proposed method provides very decent bathymetric results compared to performant bathymetric MBES, considering sounder caracteritics and settings optimised for water column data quality, and far from bathymetric sounder canonical features .

## 5. DISCUSSION

### 5.1. Precision and resolution: ME70 bathymetric option compared to embedded extraction

To go further in the extraction method assessment, achieved precision and resolution performances have to be investigated.

A first step is to compare soundings dispersion and bottom relief description obtained with the proposed algorithm applied to ME70 bathymetric option to the ones with the MBES embedded high density extraction.

To compute soundings dispersion relative to across-track steering angle, algorithm is adapted to provide ping-beam data format: for each ping, a series of depths is associated to a fix set of steering angles, corresponding to the sounder high density angles (200 soundings for 81 beams). The depth associated to a given angle and a given ping is simply the median depth of the selected bottom soundings for this ping, whose mechanical angle lies within a given interval around the targeted angle.

A first survey line is used, over a flat bottom with a 100m water depth. For each HD beam steering value, soundings depth standard deviation over all pings is computed. Fig. 8 shows comparative results.

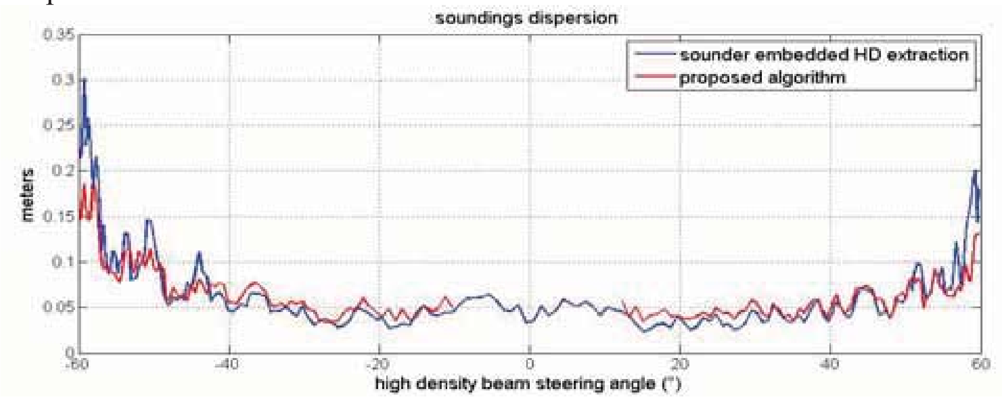


*Fig.8: Soundings depth standard deviations vs steering angle for sounder embedded HD extraction and proposed algorithm*

The proposed extraction method exhibits soundings standard deviation mainly similar to sounder output for angles away from normal incidence, maybe lower at high steering angles. However, this could be because extraction method smoothes more the data than embedded one, resulting in lower soundings dispersion over flat bottom, but reducing resolution performance.

Profiles over a single swath are compared over a seafloor presenting relief features in Fig. 9. Loss of resolution is not apparent, but it does not allow to conclude without better idea of what order of resolution performance is expected.

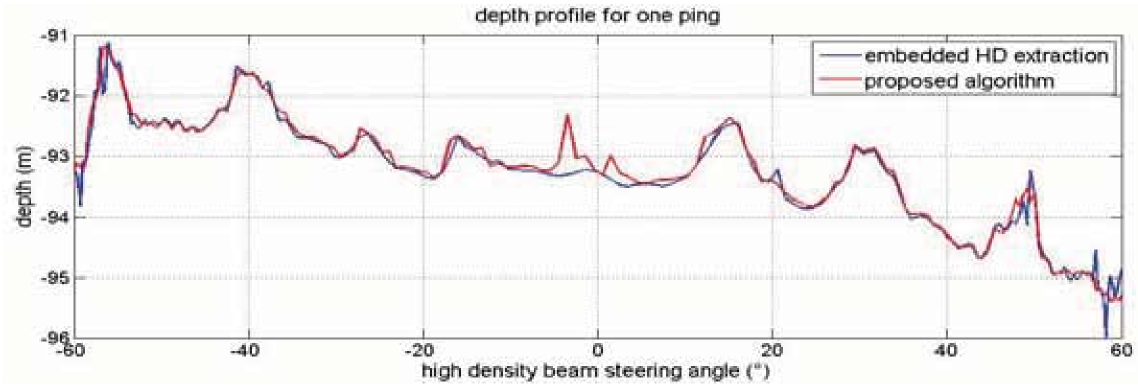


*Fig.9: Depth profile for a single ping provided by sounder (blue) and obtained with proposed algorithm (red)*

### 5.2. Considerations on precision/resolution trade-off

All mentioned approaches require to define a given range of data that will be used to extract one sounding: extent of the phase ramp to perform a regression estimate, size of the grid cell used to average single soundings. This impacts the precision and resolution of resulting bathymetry [8] [9]. Mixing N independent samples will degrade the raw resolution in the same proportion, and will improve measurements standard deviation by a $\sqrt{N}$ factor.

The following simplified model can help to set a criteria to define which extent of data should be used to extract individual soundings, that is, which resolution is relevant to expect, with regard to the achieved precision.

Considering at first a 2D situation (across-track distance x, and depth z), and assuming that phase noise and then angle noise $d\theta$ is known, raw uncertainty in x and z positioning can be expressed as:

- $dx = H.\tan^2\theta.d\theta \qquad dz = H.\tan\theta.d\theta \qquad (1)$

for a MBES strategy where the range for a given angle is estimated, H being the water depth.

- $dx = H.d\theta \qquad dz = H.\tan\theta.d\theta \qquad (2)$

for an interferometer strategy where the angle for a given range is estimated.

Resolution is usually expressed as dependant on sea floor configuration, determining whether pulse footprint or beamwidth is the limiting parameter. However, if resolution is expressed as the distance between the two closest points (or surface acoustic centers) that sounder will give independent measures of, expressing thus the sounder capacity in the most favourable bottom configuration,  it reduces to pulse length projection:

- $res\_x = \dfrac{cT\sin\theta}{2} \qquad res\_z = \dfrac{cT\cos\theta}{2} \qquad (3)$

A number of averaging points N enabling to reach a 1/10$^{th}$ ratio of uncertainty to resolution appears as a reasonable trade-off order, 1/100$^{th}$ appearing as excessive, and 1/1 not sufficient.

- $N \geq 10^{2/3} \max\left(\dfrac{dx}{res\_x}, \dfrac{dz}{res\_z}\right)^{2/3} \qquad (4)$

## 6. CONCLUSION

A simple method using raw interferometric soundings localisation has been proposed and tested to extract high density bathymetric data from large beamwidth MBES. Working on the data directly positioned in the geographical domain is a translation of phase ramp processing, but enables to have a more direct and intuitive apprehension of underlying trends and implications, as geographical contiguity, outliers rejection, bottom soundings density coverage, raw soundings dispersion. It also provides a natural way to combine information from different pings when geographically overlapping at grid scale.

First guidelines to determine which accuracy/resolution trade-off is to be considered is proposed and should be confronted to in-situ data, and related to MBES design considerations, through their impact on phase ramp noise.

## REFERENCES


[1] **Lurton, X.,** An Introduction to Underwater Acoustics: Principles and Applications, *2nd ed. Springer*, 2010.

[2] **Weber, T. C., Demer, D. A., Cutter, G. R., Wilson, C.** , Working from Top to Bottom with the ME70 Multibeam Echosounder, *ICES Working Group on Fisheries Acoustics Science and Technologies*, 2010.

[3] **Trenkel, V. M., Mazauric, V., Berger, L**., The new fisheries multibeam echosounder ME70: description and expected contribution to fisheries research*, ICES Journal of Marine Science*, volume 65, pp. 645-655, 2008

[4] **Cutter, G. R., Demer, D. A.**, Multifrequency Biplanar Interferometric Imaging, *IEEE Geoscience and Remote Sensing Letters*, volume 7, pp. 171–175, 2010.

[5] **Foote, K. G., Knudsen, H. P., Vestnes, G., MacLennan, D. N., and Simmonds, E. J.**, Calibration of acoustic instruments for fish density estimation: a practical guide, *ICES Coop. Res. Rep.,* volume 144, 1987.

[6] **Ona, E., Mazauric, V., and Andersen, L. N.**, Calibration methods for two scientific multibeam systems, *ICES Journal of Marine Science*, volume 66, pp. 1326–1334, 2009.

[7] **Berger, L., Poncelet, C., Trenkel, V. M.**, A method for reducing uncertainty in estimates of fish-school frequency response using data from multifrequency and multibeam echosounders, *ICES Journal of Marine Science*, volume 65, pp. 1155–1161, 2008.

[8] **Lurton, X., Augustin, J.**, A measurement Quality Factor for Swath Bathymetry Sounders, *IEEE Journal of Oceanic Engineering*, volume 35, pp. 852-862, 2010.

[9] **Schmidt, V. E., Weber, T. C., Trembanis, A. C.** , Automated Optimal Processing of Phase Differencing Side-scan Sonar Data Using the Most-Probable Angle Algorithm, *IEEE OCEANS*, 2012.