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Article · October 2008

DOI: 10.1109/PASSIVE.2008.4786977

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Mallat's Matching Pursuit of Sperm Whale Clicks in Real-Time using Daubechies 15 wavelets

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Abstract- **This article presents how the wavelet Matching Pursuit (MP) algorithm can perform in real-time, ocean noise elimination and whale clicks detection and segregation. This work is based on two recent advances: the first [Adam 05] proposes to analyze sperm whale signals with Daubechies 15 wavelets. The second is the fast implementation of the MP by INRIA Rennes team [MPTK 06]. We first show that one can interface DB15 with this toolkit. Second, we demonstrate, for the first time, a real use of DB15 on two long whale records reference datasets containing one or several sperm whales to address the click labeling issue. Experiments are conducted on AUTEC Bahamas data, whales are from 5 to 10 km far from the bottom mounted hydrophone. We show that DB15 are efficient for real time click detection, ocean noise and echoes removal. We get 85% of click detection for less than 20% of false alarm. We finally apply our approach to 3 co-clicking whales, and we show promising results of automatic fast segregation and click labeling of simultaneous emitting whales.**

Keywords: **Daubechies Wavelet, Multiple Sperm Whales clicking, ocean noise, real-time, echoes, Matching Pursuit, MPTK IRISA toolkit, acoustic labeling.**

I INTRODUCTION

A sperm whale (*physeter catodon*) click is a transient increase of signal energy lasting about 20 ms (Fig.1,3). The clicks are generally emitted every 1s forming clicks trains (Fig.4). But oceanic noises, multipath effect, and the reflection of the click off the ocean surface, or bottom, or different water layers severely compromise any click detection as detailed in [8,9]. On the other hand, passive Marine Mammal Monitoring (MMM) requires robust and fast click analyses. If Navy MMM system uses an heavy binarised FFT spectrum as click detector for tracking sperm whales [10], the fast Teager-Kaiser (TK) operator has more recently been proposed [11,7]. However, we shown in the case of simultaneous clicking whales that TK is outperformed by the Stochastic Matched Filter combined with a simple echo removal [8], but this yields to a more complex approach. This shows that efficient click detection and separation is still an issue for passive MMM.

It has recently been proposed [1] to use Daubechies 15 (DB15) wavelet for acoustic analysis of sperm whales sounds. It is shown first that DB15 wavelet is suited to the form of clicks (Fig. 1, 3), and second a great strength of the method to noise, third the possibility of recognizing signatures for the distinction of individuals [3].

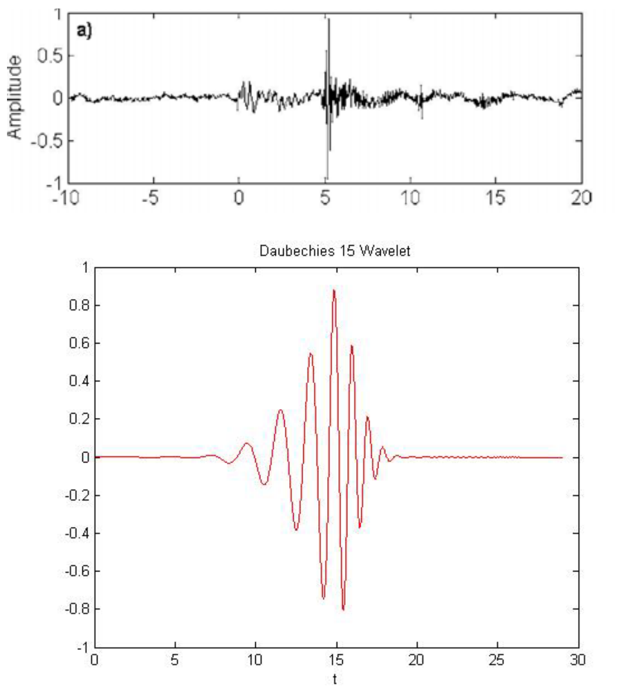

Fig. 1 Top: A real sperm whale click with its multipulsed structure. The click starts at time 0 and finishes near 15 (in millisecond). Bottom: A Daubechies 15 wavelet built by iterations using a cascade algorithm with 15 vanishing moments based on a set of 2 x 30 coefficients (scale + wavelet coefficients).

On the other hand, the MPTK free software from the National Institute of Applied Science Research in Rennes (IRISA-INRIA) offers an implementation of the Mallat's algorithm "Matching Pursuit" [5], with a complexity reduced from $O(N^2)$ to $O(N.logN)$. Thus, despite the constraints on signals to large sampling frequency (likewise the acoustic submarine signals), it allows wavelet decomposition in real time.

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Thus, we propose in this paper to combine DB15 with MPTK for building efficient MMM. We first show how we adapted MPTK to DB15 decomposition. Then we demonstrate the high performance of real-time clicks detection for one whale, and we give preliminary results for multiple whale signature analysis and clicks segregation.

II THE DB15 IN MATCHING PURSUIT TOOLKIT

The DB15 scale function is defined by:

$$\phi(2^{-(p-1)}.k) = \sqrt{2}\sum_{\tau=0}^{\tau=N-1} h(\tau).\phi(2^{-p}.k - \tau)$$

where h(.) represents the scale coefficients. Then wavelet function is :

$$\varphi\,(2^{-(p-1)}.k) = \sqrt{2}\sum_{\tau=0}^{\tau=N-1} g(\tau).\phi(2^{-p}.k - \tau)$$

where g(.) represents the wavelet coefficients. Thus we generate DB15 using a cascade algorithm that we implemented to control scales coefficients

MPTK is a GNU open software, which applies the multi-resolution or signature matching analysis based on mother wavelets called Atoms. We have enriched it with our Daubechies 15 wavelet generator at different scales. Due to MPTK flexibility limit, the most efficient way for this purpose consisted in using the MPTK signature matching mode with different DB scales.

Matching Pursuit algorithm is a simple iterative algorithm depicted in Fig 2. First it updates the inner products, and then finds their maximum and instantiates the corresponding atom, to finally subtract it from the signal. The atoms are stored in a so called "book" and can be summed up to rebuild an approximant of the input signal. This process is iterated until to get a certain SNR between the original signal and its approximant, or during a certain number N of loops (we will use this criterion), or any combination of both. The analyzed signal is then broken down into a certain number of atoms stored in a book, where each atom corresponds to a scale and a specific date in the signal.

III MATERIAL

Experiments are conducted on two real datasets sampled at 48 KHz, from the NUWC and the AUTEC (Naval Undersea Warfare Center of the US Navy - Atlantic Undersea Test & Evaluation Center, Bahamas). The hydrophones are bottom mounted on the ocean floor on the east of the Bahamas at -1500m. The first record (dataset2), corresponds to a single sperm whale as told by different MMM including ours, Navy ones [7,8,10], and also Nosal Bellop MMM (Hawaï univ.). The direct clicks versus echoes in this set have been automatically and manually dated. The second record (dataset1) has been successfully analyzed in [7,8,9] showing that it contains a maximum of four simultaneous clicking sperm whales. All these whales are distant from 5 to 10 km from the hydrophone we consider.

Using our revised version of MPTK, these two datasets were broken down into DB15 wavelets at different scales. These scales are chosen close to the real clicks length or less in order to also match with a click pulse. We present in next section the results for the single whale record, and later for the multiple simultaneous clicking whales.

IV SINGLE WHALE CLICK DECOMPOSITION

We thus decomposed the single whale dataset2 using DB15. In order to minimize the time computation, we tested 8 truncated wavelets of scale 11, 20, 39, 47, 53, 61, 68, 77, 81, 87 bins. We illustrate in Fig. 2 the DB15 matching with a click.

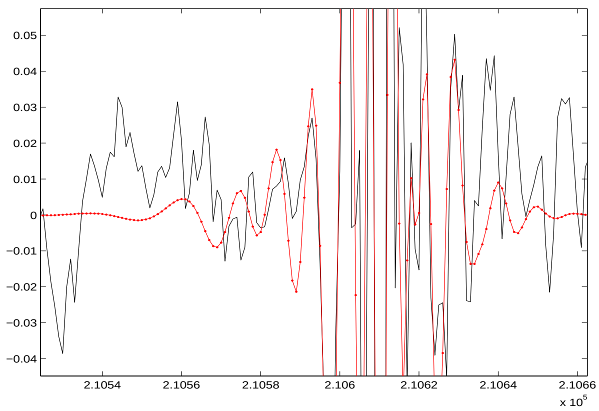

Fig. 3: Zoom on a click (-) and its matching DB15 (.-).

The Fig 4 illustrates the global result on five minute of the dataset, and then we give details on the 10 first second of that signal. We see that half of the echoes have been removed in the rebuilt signal (Fig. 5) using the multiresolution decomposition. But these echoes are removed if we only use the scale 87 (Fig. 6).

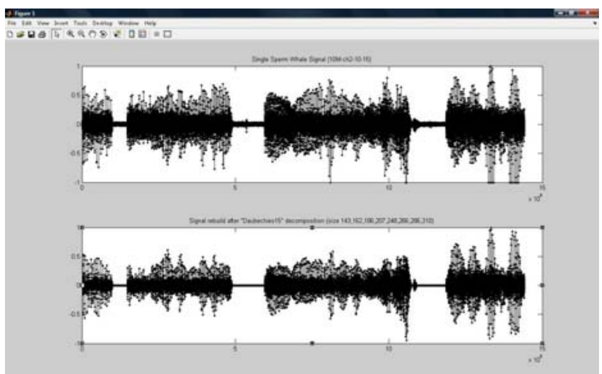

Fig. 4 Top: the signal (5 minutes). Bottom: its rebuilt approximant using 8 different scales, N = 5000 loops.

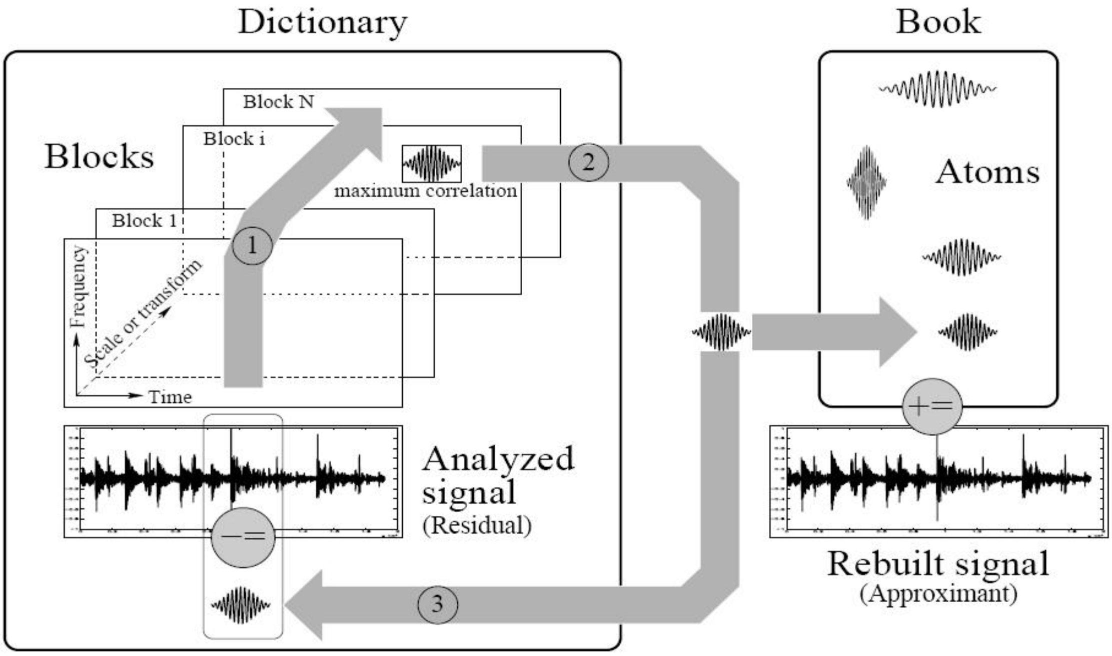

Fig. 2: Matching Pursuit General Algorithm adopted in MPTK [2]. (1): update the inner products and find their maximum; (2): instantiate the corresponding atom; (3): subtract the max atom from the signal ; then re-iterate from the residual. The atoms are stored in a so called "book" and can be summed up to form an approximant.

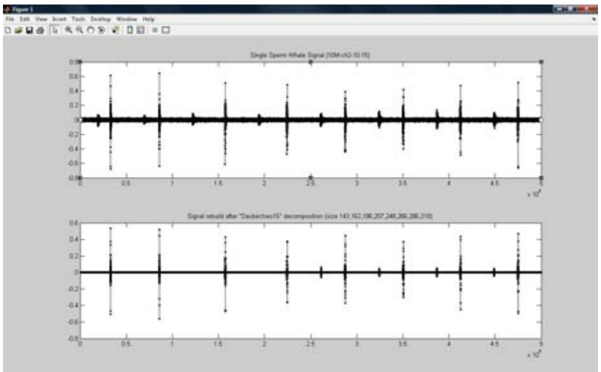

Fig. 5 Top: zoom of signal Fig 4, during 10s. Bottom: its multiresolution decomposition with scales 143, 162, 186, 207, 248, 266, 286, 310 bins (N=5000 for the 5 minutes).

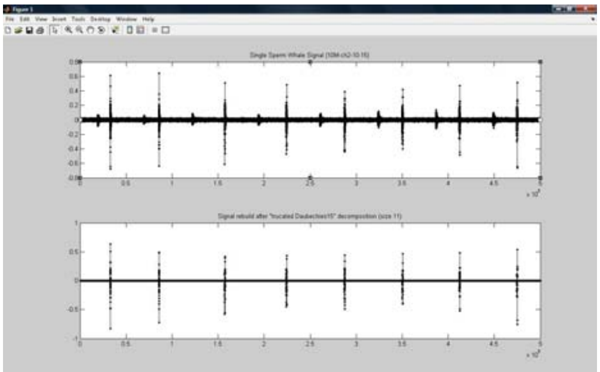

Fig. 6: Idem Fig 5. but with mono-decomposition 87 bins: all echoes of the original signal (top) have been removed (N=5000 for the 5 minutes).

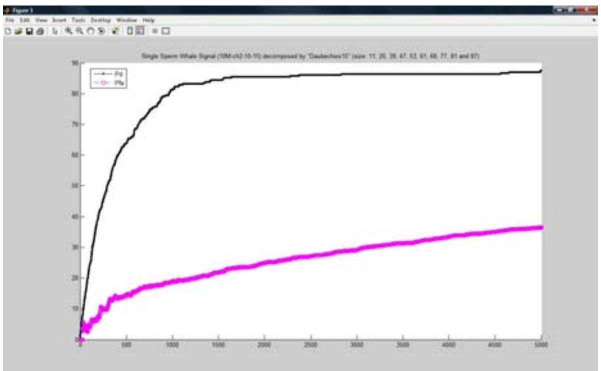

Fig. 7 Left: Probability of click Detection (black) and False Alarm (large pink). Absc.=number N of loops (1 to 5000), ord. = prob. (0 to 100%). Left : multiresolution decomp. with 8 scales.

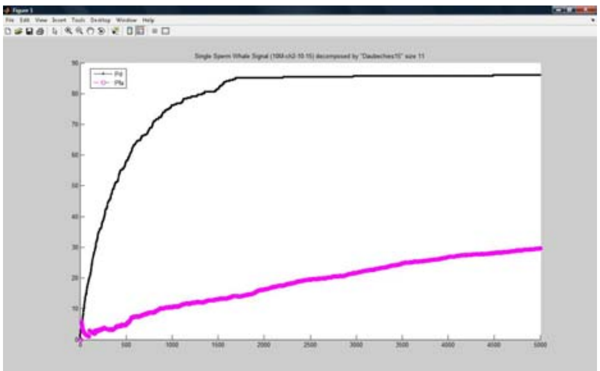

Fig. 7 Right: idem but using only the scale 87, showing similar curves.

In order to compare the multiple wavelet decomposition to the faster decomposition using a single scale, we give their detection statistics in Fig. 7. It demonstrates that a unique scale can perform as well as multiple scales decomposition (85% of Pd and 30% of Pfa). In fact, if a unique scale matches well the click, then it is not necessary to present any other scale which would match echoes or noises (like shown in Fig. 6,7).

V MULTIPLE WHALE CLICKS ANALYSIS

We apply our method on dataset1 that is known to contain at most 4 simultaneous clicking whales [7,8,10]. This first experiment aims to show that a specific scale matches with a specific whale. We run multiple resolution decomposition on a part where only 3 whales are emitting. We then analyze which scale of wavelet labels which click. We present the zoom of the first 10 seconds of this experiment in Fig. 8. It illustrates that we identify 3 different scales that generate a book which rebuilds nearly all the clicks of the original signal, without echoes. Thus one could consider that we have 3 different emitting whales, which is consistent with our knowledge of this set [7,8]. The Inter-Click-Intervals that we measure on each separated click train (one for each scale), are similar to standard values [9].

VI DISCUSSION AND CONCLUSION

This paper shows for the first time a real time Matching Pursuit wavelet decomposition on two sets of real deep ocean high frequency sampled data. First experiments were successfully conducted on a single sperm whale. Second on simultaneous clicking whales, which allow us to demonstrate promising results for automatic click labeling. This paper gives a real application to DB15 for MMM as proposed in [1]. We demonstrate good detection performance and good echo removal. Our system is real time on a standard laptop: 5 min. of signal at 48 kHz are decomposed in 30 sec.

Moreover, wavelet decomposition provides also a compression mechanism that can optimise the storing of data, but also offers a projection for extracting relevant information intrinsic to the sperm whale's signals [1].

In the case of multiple clicking whales, we showed that our dataset decomposition generated a result book of atoms that could be used for counting the emitting whales in a certain area using only one hydrophone. One the other hand, this method could be enhanced using multiple estimations from a hydrophone array, like we are currently testing. Moreover this approach could be also improved using clustering methods [6].

ACKNOWLEDGMENTS

We thank F. Caudal for giving the labels of dataset 2, and for interesting discussions. We thank AUTEC and NUWC for recording the dataset, and O. Adam Univ Paris XII for helping their distribution. We thank R. Gribonval from INRIA Rennes, and Jean-Paul LAURE from Direction Générale de l'Armement (DGA-CELM) for great support during IRISA-MPTK c++ code adaptation. We thank Mr Christophe VIVES, responsible of the submarines activities at CELM-DGA, for having supported the master period of F. Lelandais at LSIS. This research was conducted within the international sea "*pôle de compétitivité"* at Toulon-France, and is a part of the project "Platform for Integration of Multimodal Cetacean data" (PIMC).

REFERENCES

[1] O. Adam, M. Lopatka, C. Laplanche and J-F. Motsch, "Sperm Whale Signal Analysis: Comparison using the AutoRegressive model and the Daubechies 15 Wavelets Transform", Proc. of world academy of science, engineering and technology, vol 4, Feb. 2005 ISSN 1307-6884.

[2] Sacha Krstulovic and Rémi Gribonval, "MPTK: Matching pursuit Made Tractable", ICASSP 2006.

[3] M. Lopatka, "Reconnaissance de signatures acoustiques pour la distinction d'individus dans un groupe de cachalots," iSnS report, University Paris 12, France, 2002.

[4] I. Daubechies, "Ten Lectures on Wavelets", Philadelphia: Ed. Society for Industrial and Applied Mathematics, 1992.

[5] S. Mallat and Z. Zhang, "Matching Pursuits with time-frequence dictionaries", IEEE Transactions on Signal Proc., vol. 41, pp. 3397-3415, 1993.

[6] R.O. Duda, P.E. Hart and D.G. Stork (2000) "Pattern Classification". John Wiley & Sons, New York

[7] H. Glotin, F. Caudal, P. Giraudet, "Whale cocktail party: a real-time tracking of multiple whales", invited paper In int. Journal Canadian Acoustics, sp. ed. on Detection and localisation of MM using Passive Acoustics, March 2008, pages 139-145.

[8] F. Caudal, H. Glotin, ''Stochastic Matched Filter outperforms Teager-Kaiser-Mallat for tracking a plurality of clicking whales'', in IEEE Passive 2008, Hyères.

[9] F. Caudal, H. Glotin ''High level automatic oceanic data structuration: from whale click sequence modulations to behavior analyses'', in IEEE Passive 2008, Hyères.

[10] R. Morrissey, J.Ward, N. DiMarzio, S. Jarvisa, , and D. Moretti, "Passive acoustics detection and localization of sperm whales in the tongue of the ocean," *Applied Acoustics*, vol. 62, pp. 1091–1105, 2006.

[11] V. Kandia and Y. Stylianou, "Detection of sperm whale clicks based on the teager-kaiser energy operator," *Applied Acoustics*, vol. 67, pp.1144–1163, 2006.

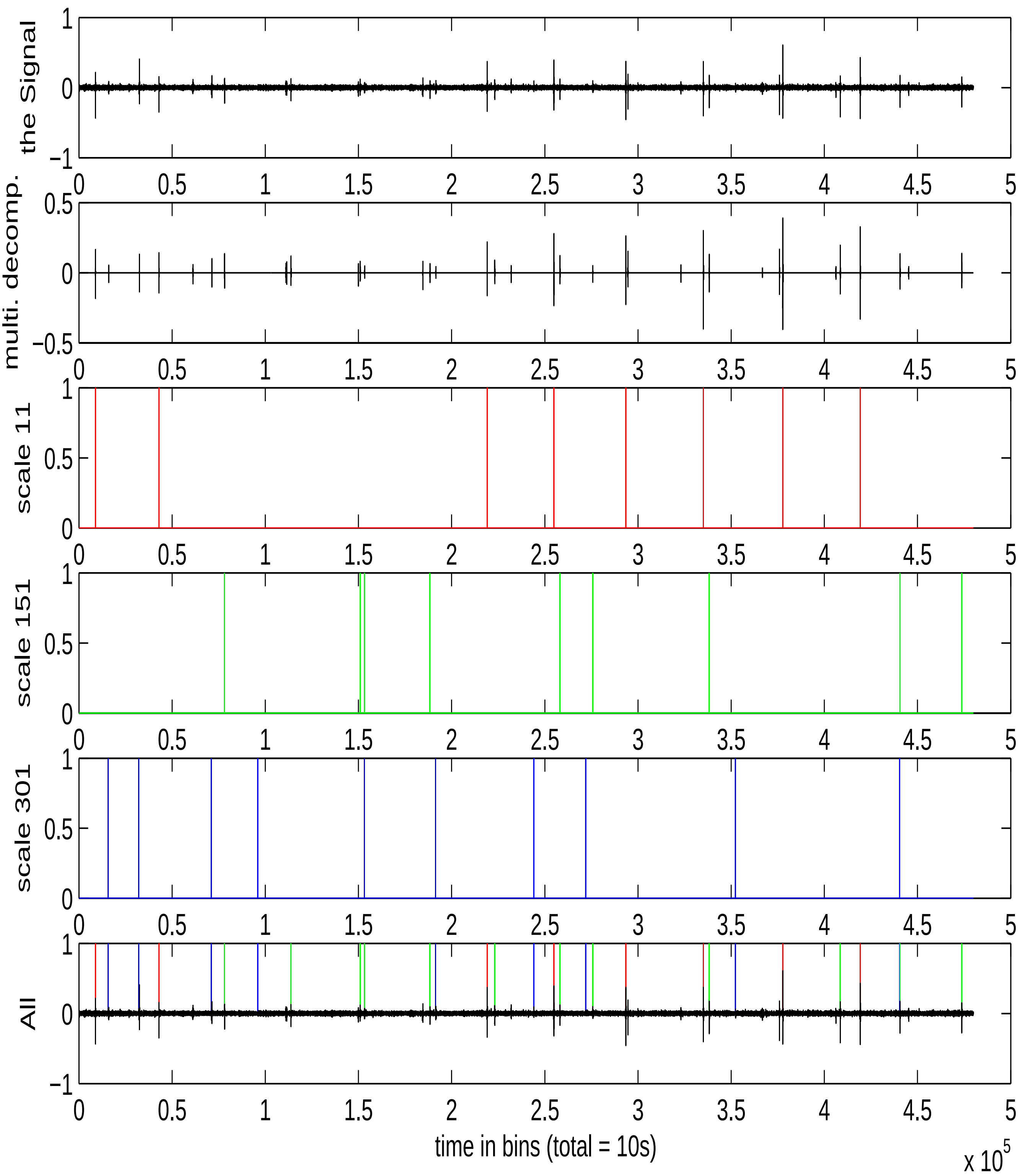

Fig. 8 Top A) the signal (FS=48 kHz) containing 2 or 3 emitting whales. B) the rebuilt signal using 4 scales = 11, 151, 301, 450 bins, N = 5000 for 5 minutes of signal. We see that all non significative signals have been removed. Then we draw as a binary signal the dates where are the first matching wavelet. C) The dates of DB15 scale 11. D) idem of scale 151. E) idem for scale 301. F-Bottom) We illustrate these dates on the original signal to demonstrate the accuracy of the method. Thus one could consider that we have 4 different kind of sources, maybe 3 emitting whales and some echoes, which is consistent with our knowledge of this set [7,8]. Moreover the Inter-Click-Intervals that we measure on each separated click train (one for each scale), are similar to the standard [9].