Supervised stacking to improve the signal-to-noise ratio of AEM data

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SUMMARY

AEM method has proven to provide useful information on the subsurface for many applications. However, measured decays are affected by many noises, limiting its effectiveness and which may prevent to acquire usable data, especially in resistive environments. Stacking techniques are applied in an attempt to improve the signal-to-noise ratio. However, stacking all decays falling within a stack interval can be ineffective, given the nature of noises that can affect the data from decay to decay. To a lesser extent, arbitrarily increasing the stack size may also be ineffective, especially in an anthropized environment. Stacking is generally done without any real control on the data taken into account.

This paper introduces a supervised stacking method that stacks decays falling within a stack interval considering different combinations and estimates the signal-to-noise ratio of the resulting decays. The estimation of the signal-to-noise ratio is performed using the singular value decomposition filtering which has proven to be effective in identifying and removing noise affecting an AEM dataset.

The supervised stacking method is applied on the raw data. It has been tested on two AEM datasets, acquired in Reunion and Auvergne (France), where EM noise is high and resistivity can easily exceed 1000 ohm.m in some places. The results show that the presented method improves the signal-to-noise ratio and can reduce sferics and certain noises from man-made installations. It provides less noisy decays for post-processing and offers new possibilities for processing AEM data.

Key words: AEM, processing, electromagnetics, time domain, airborne.

INTRODUCTION

Socio-environmental issues are at the origin of more and more projects involving Airborne ElectroMagnetics (AEM). Indeed, the surfaces to be covered and the needed coverage are generally too important for ground investigations. Moreover, AEM method has proven to provide useful information on the subsurface for many applications. Thus, AEM is increasingly used to support water resource management, risk assessments etc… This represents a challenge for the method, for example in terms of imaging, resolution, both lateral and vertical, and depth of investigation, and therefore motivates many developments in modelling and inversion and on AEM systems themselves. However, socio-environmental issues are usually focused in anthropized areas where AEM data can be affected by many noise sources, decreasing ability of AEM to image the subsurface and possibly preventing the acquisition of usable data. Therefore, development of methods to improve the signal-to-noise ratio (SNR), before rejecting the noise, is also crucial.

In order to improve the SNR, the measured decays are stacked during a pre-processing step. It is generally assumed that the larger the stack size, the more the SNR is improved (Spies, 1988). Some work has suggested improvements to stacking. The most common techniques apply thresholds when stacking the data (Macnae *et al.*, 1984 ; McCracken *et al.*, 1984) in order to limit the effect of some important noises, in particular the sferics. Stack size can also be set based on SNR.

However, the stacking is generally done without any real control on the decays taken into account. Indeed, stacking all the decays falling within a stack interval can be ineffective, given the nature of noises that can affect the AEM data from decay to decay. To a lesser extent, arbitrarily increasing the stack size may also be ineffective, especially in an anthropized environment.

This paper introduces a method that shuffles AEM decays into combinations when stacking. This method aims to identify the combinations of decays which seem to lead, after stacking, to the least noisy data and therefore to improve the SNR. The method is first exposed and the approach is then tested on two AEM datasets, acquired in Reunion and north of the Chaîne des Puys (Auvergne, France). The method appears effective in improving the SNR, providing less noisy data for post-processing.

METHOD

During an acquisition, decays are measured by repeating a sequence defined by an emission and the recording of the ground response. In order to improve the SNR, the acquired decays are then usually stacked considering a user-defined stack size.

Instead of stacking all decays falling within a stack interval, the presented methodology proposes to shuffle these decays into combinations of n decays; n ranges from 1 to the defined stack size. Depending on the stack size and the amount of acquired data, it may be too time-consuming to test all possible combinations. Thus, combinations characterised by few or many decays can all be tested. In between, combinations are randomly generated, since the number of possibilities can be very important. The notions of few, many are defined by the user and configured according to the user's computer, the size of the dataset and the desired computation time.

For each combination, the decays are stacked and the SNR of the resulting decay is evaluated to identify the combinations resulting in decays with the highest SNR. These combinations can then be statistically analysed to obtain, for each stack interval, the least noisy decay, which will be post-processed.

It is possible to use different methods to evaluate the SNR associated with the different combinations. For example, machine learning based methods seem well suited to evaluate the SNR. However, the singular value decomposition (SVD) filtering was preferred; filtering based on wavelet decomposition or principal component analysis could also have been used.

The SVD filtering is a statistical procedure that has proven effective in de-noising AEM datasets (Reninger *et al.*, 2011). This filtering has proven its effectiveness in identifying and rejecting different types of noise affecting the data, whether natural (background noise, sferics) or man-made (capacitive couplings). The SVD filtering is statistically adapted to the entire dataset. It was trained on the standard stacked dataset and then the SVD components were used to evaluate the SNR associated with each combination.

RESULTS

The Supervised Stacking Method (SSM) presented above was tested on two surveys carried out by the French geological survey (BRGM). The first was conducted in 2014 in Reunion and the second was conducted in 2020 north of the Chaîne des Puys (Auvergne, France). These two areas are anthropized and many high amplitude noises affect the EM datasets. Moreover, the resistivity can easily exceed 1000 Ω.m in some places resulting in a low SNR. Only the results obtained on the Chaîne des Puys are presented in this extended abstract; similar results were obtained on the data acquired in Reunion.

The SkyTEM 304 system (Sørensen and Auken, 2004) was used during these two surveys. SkyTEM systems have the particularity of emitting two different magnetic moments, a low moment and a high moment, in order to provide near-surface and deep information respectively. Only the results obtained on the high moment are discussed here but the same observations were made on the low moment.

The high moment has a magnetic moment of approximately 145,000 A.m². The on-time has a duration of 2.5 ms and the off-time lasts 4.167 ms; given the very high resistivity expected for the volcanic cover, the duration of the sequence was reduced and the stack size was increased. The decays are defined by 22 time gates, from 70 µs to 3.2 ms, and the defined stack size is 162. The decays falling within each stack interval were stacked 6 by 6, leading to a stack size of 27 for the tests performed.

Figure 1 shows, for a stack size of 27, the number of possible combinations as a function of the number of decays (i.e. the size of the combinations). The number of possible combinations is relatively small for combinations composed of few or most decays. For combinations of intermediate size, the number of possible combinations starts to become important. Given the amount of data acquired during the AEM survey, this can involve significant computation time. Therefore, in this case, only a limited number of combinations was randomly evaluated. Thus, to test the SSM, between a combination size of 7 and 20 (blue lines in Figure 1) only 100,000 random combinations were evaluated for each combination size.

Figure 2 compares, at two different locations, the stacked decays obtained (1) by stacking all the decays falling within the stack interval and (2) by considering the combinations giving the decays with the highest SNR. The decays obtained using the SSM (blue curves) seem to have a better SNR than those obtained in a more standard way (red curves). Figure 2b also gives a glimpse of the ability of the SSM to reduce certain local noises due to the presence of man-made installations in the surveyed area. Indeed, the noise affecting the red curve between gates 5 and 10 has been significantly reduced on the blue curve, thus making it possible to reliably invert the early times.

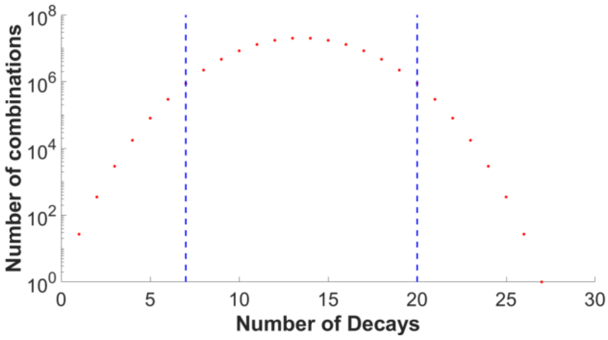

Figure 1. Number of possible combinations as a function of the number of decays, for a total of 27 decays. The blue dashed lines highlight the interval in which the combinations are randomly generated. Outside, all the combinations are evaluated.

Figure 3 compares, on the same portion of flight line, the decays obtained with a standard stacking and with the SSM. The noise on profile b is visibly lower. Decays obtained with the SSM are consistent with each other and up to 7 additional gates can be used at late times (Figures 2 and 3). This shows the ability of the SSM to improve the SNR, without arbitrarily increasing stack size or setting subjective thresholds. Thus, the SSM allows reducing the background noise, which affects the entire dataset. This is imperative in order to improve the depth of investigation of the AEM method. Moreover, certain local noises due to the presence of man-made installations tend to be significantly reduced, for example on decays 4 to 11 and on decays 33 to 57 (Figure 3), thus providing less noisy input data for post-processing to improve imaging of subsurface resistivity contrasts.

These results are promising, in particular for improving the imaging of resistivity contrasts in anthropized areas, where socio-environmental issues are numerous. In some cases, the gain appears to be significant; it should be noted that the decays obtained using the SSM cannot have a lower SNR than those obtained with standard stacking, since this combination is also evaluated.

CONCLUSIONS

It is generally assumed that the larger the stack size, the more the SNR is improved. This study shows that it is possible, as a first step, to noticeably improve the SNR by choosing the right combination of decays before having to arbitrarily increase the stack size. Moreover, the SSM turned out to be effective in reducing certain cultural noises and sferics, which is rarely possible by playing on stack size. Thus, the SSM provides less noisy decays for post-processing.

The SSM tends to improve the depth of investigation and the coverage, while preserving lateral and vertical resolution. These improvements could allow a better characterisation of anthropized areas, where most of the socio-environmental issues are concentrated.

The SSM gave promising results by testing only a limited number of combinations compared to the number of possible combinations. The SSM must still be optimised, especially on the computation time and the number of combinations to be considered. It should be noted that the code is perfectly parallelizable, since each stack interval can be processed independently. However, it may not be possible to consider all combinations without significantly increasing the computation time. The first results would show that the decays with the highest SNR can be obtained from combinations composed of only a few decays. This would then represent an important result for the reduction of the computation time. Tests on the number of combinations to consider are still to be carried out.

The SSM offers new possibilities for improving the SNR, which is essential in the exploitation of AEM data. The SSM is also perfectly complementary to the other existing processing strategies and can be easily implemented in a processing chain.

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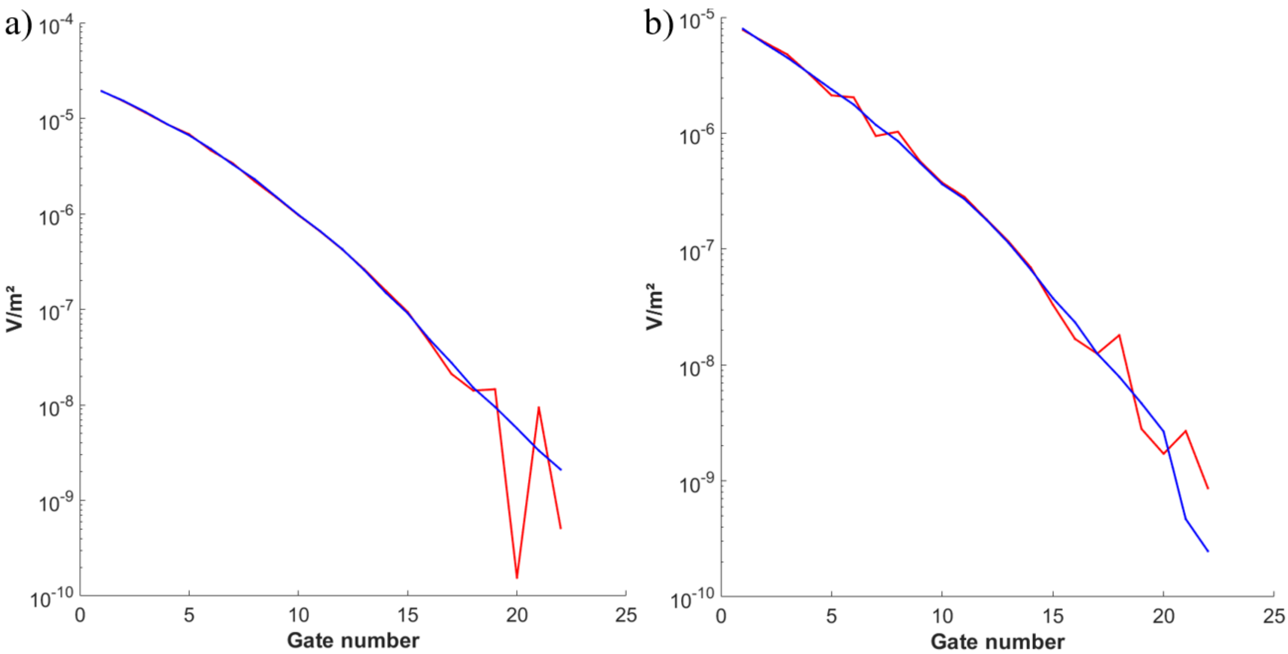

Figure 2. Stacked decays as a function of gate number considering all decays falling within the stack interval (in red) and combinations giving the highest SNR (in blue).

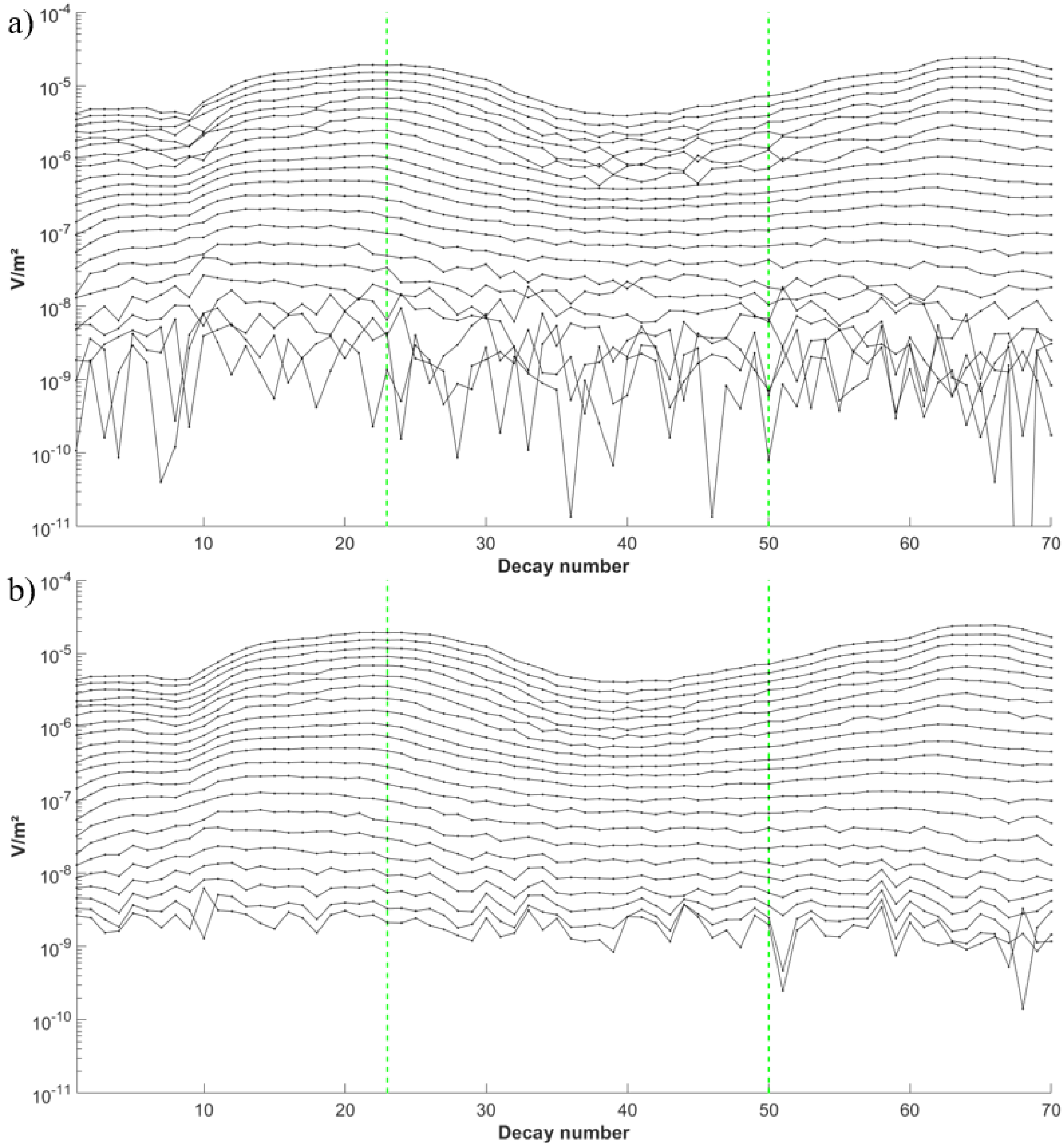

Figure 3. Decays along the same portion of flight line after applying standard stacking (a) and the SSM (b). Green dashed lines highlight the decays shown in Figure 2.