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Noise removal in MRS applications: field cases and filtering strategies

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SUMMARY

The usefulness and reliability of magnetic resonance information to characterize water bearing geological structures has been widely demonstrated these last two decades all over the world and many future applications just begin. The main limitation of MRS applicability is its sensitivity to the electromagnetic noise which results in a long and site dependent measuring duration, and generally prove to be impossible in urban conditions. Many improvements have been performed all along the development of MRS technology. Nowadays, numerous mono and multi-channel processing schemes have been published, but efficiency remains site and time dependent. We have reviewed data from various contexts and compared the noise removal efficiency and impact of the filtering on synthetic signal added to real noise data. We also used methods derived from magneto-telluric to study the structure of the noise and present a continuous EM field monitoring during a storm event in mountain where we performed a MRS survey. We observed that the reconstruction of natural noise is a percentage of the ambient noise, the ratio is almost stable. Despite this observation of stable removal performance, it means that when the level of noise is multiplied by 10 to 100 and more… it is better to stop measuring MRS and wait for a quiet period of time.

Key words: MRS, multi-channel, filtering, noise.

INTRODUCTION

MRS community has grown since the last 2 decades and many applications among the geosciences field have been demonstrated or just considered yet. Theoretically, information carried by the MRS signal is very rich and measuring sequences from NMR (Nuclear Magnetic Resonance) spectroscopy let expect a wider range of application. The contribution of MRS to complete the geophysical toolbox of non-invasive methods for water resources exploration, management or protection, is great and should greater. But the electromagnetic noise remains a key factor because the SNR (signal to Noise Ratio) vary drastically from a site to site, and with time especially in link with industrial activity (late in the night is generally better), weather (storms and magnetic activity at sunset in low latitudes). After more than 15 years of technical development and MRS application in many countries, we routinely faced this issue.

As a non-exhaustive review of innovation in MRS filtering protocol, one could first refer to J. Bernard (2007) on the typical field work lay-out and Legchenko (2013) for a full review of the state of the art. Early in the MRS application, the figure of eight loop (Trushkin et al. 1994) and narrow rejecting filter (commonly called notch) of the local industrial power frequency harmonics (Legchenko and Valla, 2003) are routinely used and almost necessary in many cases. Both have their drawbacks, the longer the cable, the higher the resistance and for a given cable length, the investigation depth if lower with the figure of eight loop. Notch filter, if very efficient generally reach its limits when the industrial frequency is not stable and if the Larmor frequency is close to one of these harmonics. I was recently addressed by Jiang et al. (2011) and Penz and Girard (2014).
Multichannel or reference based filtering, common practice in geophysics and other domain, is nowadays routinely practiced and its efficiency is reported for a while (Walsh, 2008, Girard et al., 2011). Nevertheless, the ways to apply reference filtering are plenty. A good thing is that the same multi-channel dataset could be reprocessed and the result enhanced by changing the processing algorithm. Among the difficulties, one could note that it is generally needed to remove spikes in the time domain before reference filtering could be applied. One could refer to the recent work of Costabel and Muller-Petke (2014) on the despiking strategies and Muller-Petke and Costabel (2014) on a comparison between time-domain and frequency domain reference filtering.
Another major point is that the noise structure is generally evolving fast in the 1kHz to 3 kHz frequency range of interest for MRS. Adaptive algorithms are almost necessary to remove both the industrial frequencies (Dalgaard et al. 2012). Last, statistical optimization could be used (Ghanati et al. 2014) with various efficiency depending on the SNR.

METHOD

We present a selection of field cases applications where reference filtering proved to be very efficient, decreasing the noise level drastically and others where the gain is very limited.
But the filtering efficiency should not be evaluated on the basis of noise removal, but also on the availability of keeping

the MRS signal untouched. The final goal is to enhance the SNR to get a more reliable signal for imagery and material characterization.

Increasing the number of stacks is always recommended is a safe manner to decrease uncorrelated noise. But, MRS signal is dependent on the geomagnetic field and the well-known relationship in-between (Girard et al. 2005). The MRS signal natural variation will make the averaging decreasing the quality of the MRS signal. It would be especially the case under latitudes where diurnal geomagnetic variations are strong and if stack duration if long such as when data acquisition is made mixing intensity of pulses (Q values) during the sounding.

We have used linear theory such as used in magneto-telluric method (Chave and Jones 2012 for a complete review of MT method). One can define a record of an EM field component as the sum of a “coherent signal” and “noise”. The “signal” part is the part of the record that can be reconstructed as a linear combination of other EM field components and other reference sites. In MT, the coherent part at regional scale is link to the MT response, and the residual is assumed to be noise. With controlled sources, such as in MRS, the “coherent part” is the one that can be reconstructed from the remote receivers and the residual is the MRS signal + remaining noise. The multi-channel filtering efficiency will be limited by this remaining part. The complexity of the transfer function, its stability with time and the residue amplitude are indicators of the noise structure.

MONITORING OF EM FIELD VARIATIONS

Over the various conditions encountered, a particularly difficult case is the situation in mountains. Even in remote location (with logistical issues), mountains appear to not be the best location for MRS nor TEM (time domain EM) measurement. Nevertheless, it is a place where geophysical imagery could be of great help for natural hazard mitigation for instance. In parallel to a MRS survey performed on the Tete Rousse glacier – St Gervais in French Alps, we brought a MT station, with 4 channels, and recorded the EM field before, during the beginning and after a typical daily storm encountered in this location during summer.
We computed the power spectrum density for the two horizontal electric field components (Ex, Ey) and the vertical magnetic component (Hz) and one horizontal component (Hy). We calculated the reconstruction of each component from the others for each frequency bin and obtained a residue that is the part which could not be reconstructed from the 3 other component, despite they were all very close (tens of meters away).
As depicted in Fig. 1, the vertical magnetic field (the one dominant in MRS recording) varies of 2 orders of magnitude during averaged day and the beginning of the storm (we had to stop measurement before lightening destroys our equipment). The horizontal magnetic field variation is less. One should recall that these amplitude evaluation are averaged on a 5 min recording and on the frequency range 400 to 1600 Hz. The peak values are several orders higher. One should not be surprized by the fact that the residue (Hz noise) is lower on the vertical component Hz than on the horizontal Hy. It is linked with the availability of the 2 electric field components which help Hz reconstruction.

A similar observation has been performed on the two horizontal electric field components (Fig. 2). To illustrate the spectrum content of the 400 to 1600 Hz frequency range, one can see on Fig. 3 (magnetic field) and Fig. 4 (electric field) that no coherent peak dominates the spectrum, which is supposed to be mainly due to natural signals.

A first interesting observation is that the ratio H / H_noise is almost constant all over the day. Whatever the amplitude of H, a constant ratio can be filtered. It is interesting to notice that it is not the case on the electric field components where an almost constant level of noise remains even when higher amplitudes occur.

CONCLUSIONS

Coherent industrial noise is well filtered by multi-channel filtering. A factor of 5 to 50 is generally obtained. This ratio is in agreement with the ratio observed applying MT like methods to estimate the possible reconstructed signal on electric and magnetic field components.
Nevertheless, in the case of a weather event such as a storm, unlike the electric field, the reconstructed magnetic field (filtered part) is proportional to the amplitude of H and hence, when the noise magnetic amplitude increases of 1 or 2 magnitude orders, the residual part also, and the SNR decreases in proportion. Such data revealed to be not useful, even with a high number of stacks. It is then better to wait for a quiet period to perform the MRS measurement.

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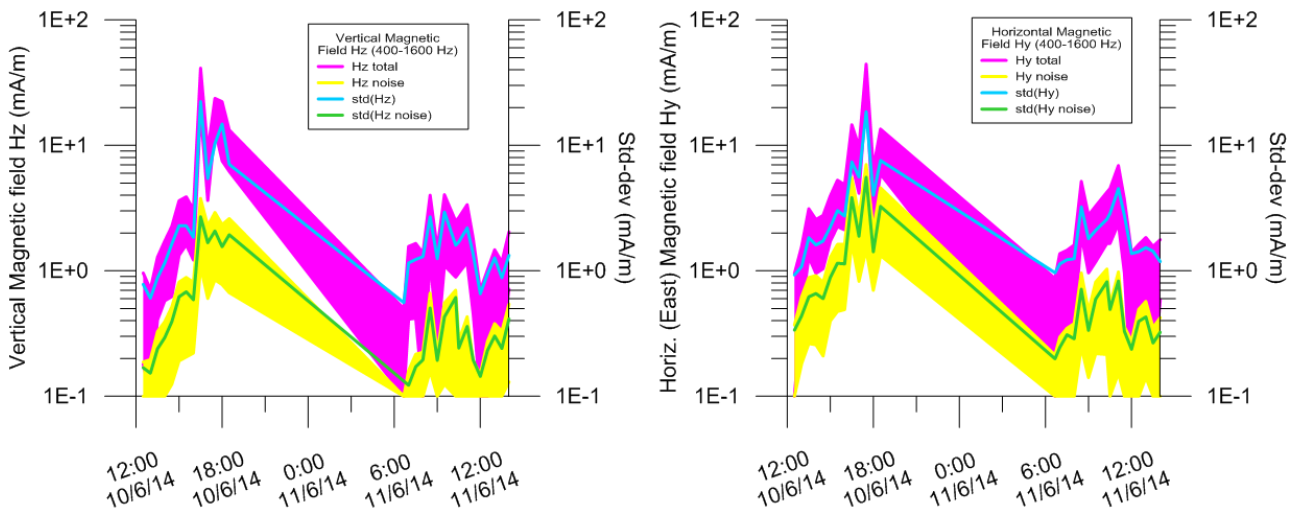

Figure 1. Magnetic field (vertical component left and horizontal right) measured every 30 min with a MT station (4kHz sampling frequency). Amplitude is averaged between 400 to 1600 Hz. Total field is the recorded data, noise part is the residual with the best linearly reconstructed signal from the 3 other components of E & H measured synchronously.

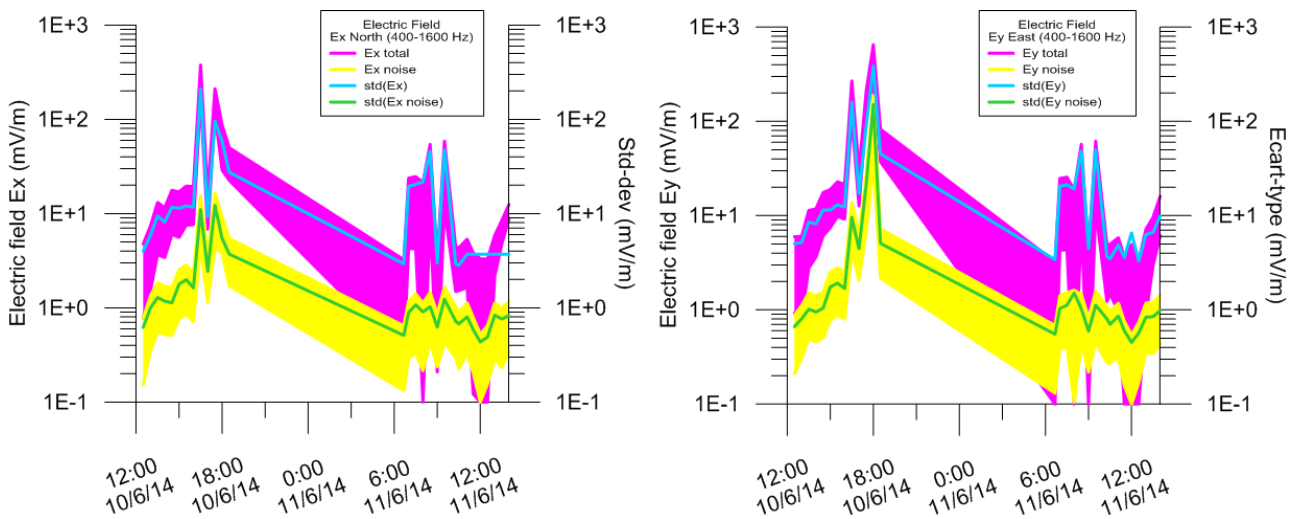

Figure 2. Electric field (north component left and east right) measured every 30 min with a MT station (4kHz sampling frequency). Amplitude is averaged between 400 to 1600 Hz. Total field is the recorded data, noise part is the residual with the best linearly reconstructed signal from the 3 other components of E & H measured synchronously.

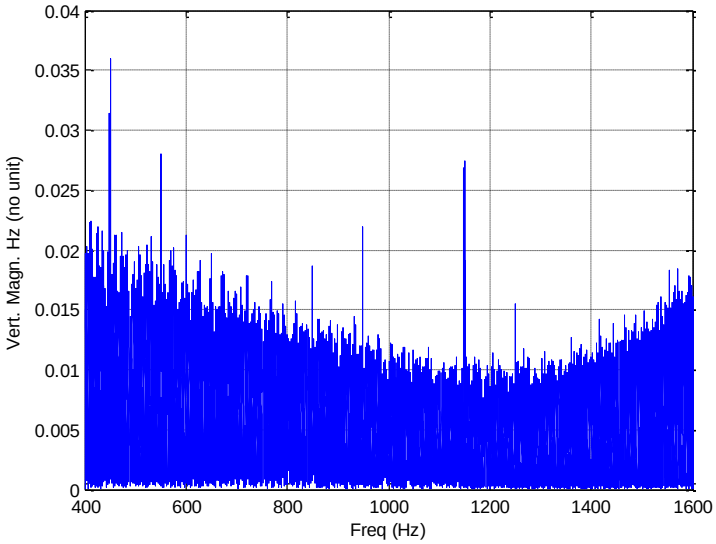

Figure 3. Sample of Vertical Magnetic field frequency spectrum: in this remote mountainous site, harmonics of the industrial noise (fundamental 50 Hz and 16.67 Hz) are below the natural noise level (amplitude is not calibrated here).

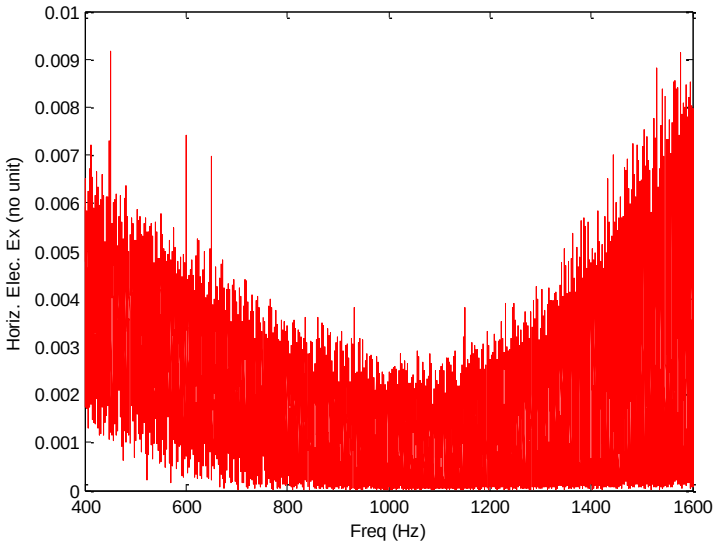

Figure 4. Sample of a Horizontal Electric field frequency spectrum: in this remote mountainous site, harmonics of the industrial noise (fundamental 50 Hz and 16.67 Hz) are below the natural noise level (amplitude is not calibrated here)..