STABILITY OF MRS MEASUREMENTS AND ESTIMATING DATA QUALITY

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INTRODUCTION

The objective of this study was to estimate the accuracy of the equipment currently used for magnetic resonance sounding (MRS) measurement, namely Numis$^+$, developed by IRIS instruments and BRGM. It is vital to evaluate data quality in order to constrain the inversion results. Improvements in data quality over the years have enabled the use of increasingly complex algorithms, including the effect of the electric conductivity model and a frequency offset lying between the Larmor frequency and the pulse frequency. The sensitivity of the MRS measurements renders this technique applicable to water-level monitoring.

FIELD MEASUREMENTS

For this study, we carried out MRS measurements four times a day at four different dates (May 5th, 15th, 23rd and 27th of 2003) at a test site at St-Cyr-en-Val, near Orléans, France. We used two types of Numis$^+$ equipment, a renewed prototype and a standard Numis$^+$, each twice a day. The same acquisition parameters were maintained for all the measurements, namely a figure-of-eight antenna with sides of 37.5 m (one turn of wire) to reduce industrial noise (Trushkin, et al., 1994). With this loop the ambient electromagnetic noise was varying between 300 and 500 nV in the bandwidth of +/-100 Hz around the Larmor frequency. The length of the exciting pulses was τ=40 ms. We used 16 values for the pulse (q=I. τ) and 36 signals were stacked for each pulse. The same transmitting frequency near the mean Larmor frequency for this site was adopted for all soundings: 2014 Hz. This frequency allowed us to use a narrow notch filter to remove the 50 Hz harmonics (Legchenko and Valla, 2003). These parameters are a compromise between the best possible data quality and the time needed to undertake a maximum number of soundings under the same conditions.

The values of the 16 pulses q cannot be exactly the same for every sounding with the Numis$^+$ equipment, which is why for the comparison of different soundings we first fitted a smooth curve on each sounding (in the least square sense), excluding at the same time a few anomalous points. This interpolation allows us to compare the different curves. Figure 1 shows the amplitudes of the entire smoothed MRS data set measured with two different instruments. It can be seen that, the soundings are in good agreement up to q<2000 A.ms. The instability of the last part of the signal can be explained by the variation in the geomagnetic field during the day whereas the frequency of the exciting field is maintained constant (Legchenko, 2003). The relative standard deviation calculated through all soundings ($\sigma_{rel} = \sigma$ / mean value) allows us to identify three signal parts (see Figures 1 and 2):

1: the signal is very low and the signal-to-noise ratio is low

2: the signal-to-noise ratio is high

3: the signal-to-noise ratio is lower and the signal varies after the geomagnetic field.

ESTIMATING DATA QUALITY

The RMS for each signal is estimated using the mean signal of that day as the 'true signal':

$$RMS_{k,j} = \sqrt{\frac{\sum_{i=1}^{N}\left[\left(s_{true,j,i} - s_{k,j,i}\right)^2\right]}{N}}$$, for the kth sounding of the jth day (N=number of pulses q).

The same mean RMS value of 5.8 nV is obtained whether calculated on the full length of the signal or without part 3 (Table 1).

	RMS for the full signal					RMS for q < 1600 A.ms				
Date	Numis$^+$1	Numis$^+$1	Numis$^+$2	Numis$^+$2	Total	Numis$^+$1	Numis$^+$1	Numis$^+$2	Numis$^+$2	Total
May-05	1.8		5.9	5.5	4.8	1.9		4.1	3.5	3.3
May-15	4.6	4.5	6.0	3.8	4.8	3.1	4.9	6.7	4.2	4.9
May-23	6.6	7.7	6.7	8.2	7.3	7.5	8.3	7.6	8.0	7.9
May-27	7.9	2.9	6.1	7.0	6.3	9.0	2.4	7.0	7.9	7.1
Mean (nV)	5.2		6.1		5.8	5.3		6.1		5.8
Mean w.o.5-may	5.7		6.3		6.1	5.9		6.9		6.6

Tab. 1. RMS on the raw data

If the results of May 5th are removed because only three measurements were made that day, we obtain a mean RMS of 6.1 nV for the complete signal, and 6.6 nV for pulses q < 1600 A.ms. This latter higher RMS value is not surprising, because amplitude is higher in the first part of the signal than at the end of the curve.

As we suspected one Numis$^+$ machine was overestimating the signal relative to the other, we calculated the difference with the 'true signal' for each day:

$$\varepsilon_{k,j} = \frac{1}{N}\sum_{i=1}^{N}\left(s_{true,j,i} - s_{k,j,i}\right)$$, for the kth sounding of the jth day (N=number of pulses q).

	Difference to the 'true signal'			
Date	Numis$^+$1		Numis$^+$2	
May-05	-0.3		4.9	-4.7
May-15	3.3	1.5	-2.0	-2.8
May-23	4.9	6.2	-3.7	-7.4
May-27	6.2	1.4	-2.9	-4.8
Mean (nV)	+3.9		-3.9	

Tab. 2. A systematic error: MRS values with Numis$^+$1 > Numis$^+$2.

We observe a systematic error >0 for Numis$^+$1 compared to Numis$^+$2. A correction of -3.9 nV was thus applied to the data measured with Numis$^+$1, and +3.9 nV to that measured with Numis$^+$2, which results in an RMS gain of about 1 nV compared to the raw data values (Table 3).

	RMS for the full signal					RMS for q < 1600 A.ms				
Date*	Numis^{+}1	Numis^{+}1	Numis^{+}2	Numis^{+}2	Total	Numis^{+}1	Numis^{+}1	Numis^{+}2	Numis^{+}2	Total
May-15	3.3	4.8	6.0	2.8	4.4	3.1	4.1	6.8	3.1	4.5
May-23	5.3	6.2	5.8	6.4	6.0	6.0	6.9	6.3	6.3	6.4
May-27	6.5	2.6	5.5	5.8	5.3	7.3	2.2	6.2	6.6	5.9
Mean (nV)	4.8		5.4		5.2	4.9		5.9		5.6
Bef. corr.	5.7		6.3		6.1	5.9		6.9		6.6

*The data of May 5th are removed because only three measurements are available.

Tab. 3. RMS estimation after correction of the systematic error

After correction, the RMS demonstrates more clearly the stability of the measurements, which can be estimated at less than 6 nV.

MRS MEASUREMENTS AND THE GEOMAGNETIC FIELD

During our experiments it was observed that the geomagnetic field varies throughout the day of measurement, which means that the Larmor frequency also varies. These observations were compared with the geomagnetic record at the magnetic observatory of the 'Chambon la forêt' part of the INTERMAGNET network (see for example Figure 3). It is known after modelling results that the phase shift of the MRS signal is more sensitive to the frequency offset between the oscillating source field and the Larmor frequency (of the oscillating response field) than the amplitude. The consequence of variations in the geomagnetic field on the phase values thus makes estimation of the accuracy of the phase measurement more complicated. This subject is thus currently out of scope of this paper.

CONCLUSIONS

Under experimental conditions in St-Cyr-en-Val area it was found that the instability of the measurement of MRS amplitude with Numis^{+} system is less than +/- 6%, even though the frequency shift with the Larmor frequency is a few Hz.

It should be understood that the accuracy of measurements depends on the signal to noise ratio which in turn depends on the amount of subsurface water and stacking number. Consequently, results can be always improved by increasing the stacking number. From the other hand, time variations of the ambient electromagnetic noise and the geomagnetic field may change conditions of measurement and thus make a correct interpretation of MRS data difficult or, under some conditions, even impossible for very long soundings.

In order to use correctly advantages of the complex nature of the MRS signals, it is necessary to consider time drift of the geomagnetic field all along the measurements in the inversion scheme of the MRS signal.

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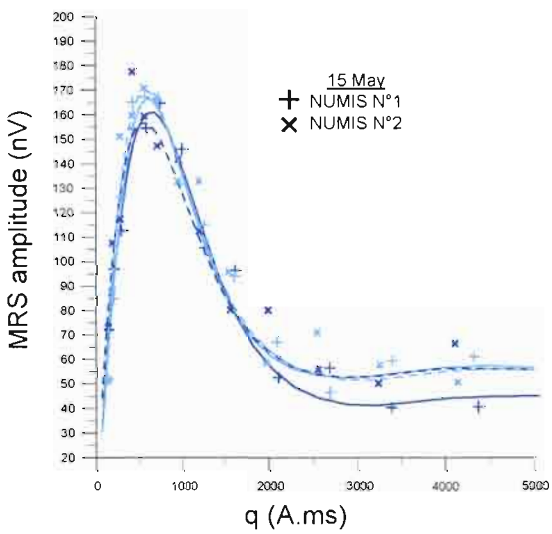

Fig. 1. Example of the MRS soundings.

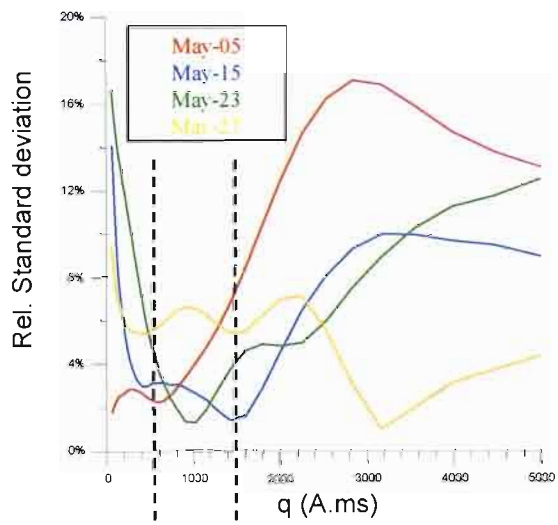

Fig. 2. Relative standard deviation.

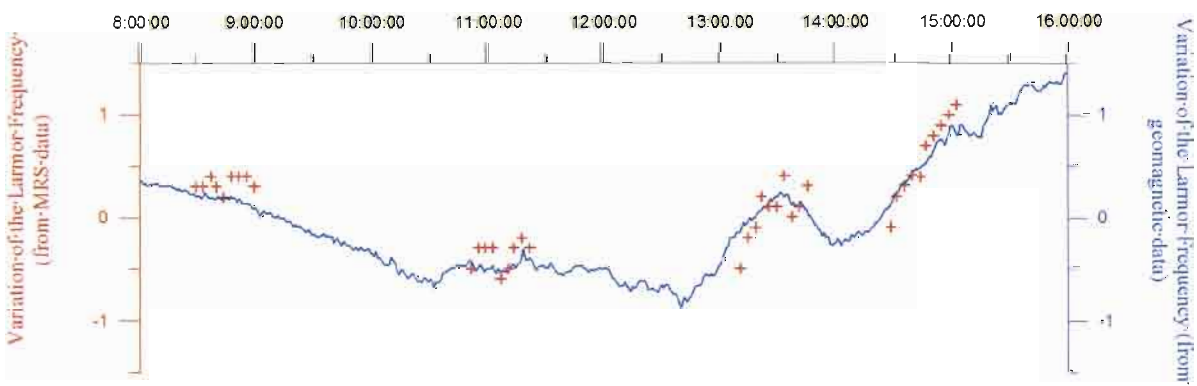

Fig. 3. Drift of the Larmor frequency calculated every minute from the geomagnetic record at the magnetic observatory of the 'Chambon la forêt' part of the INTERMAGNET network (data of May 15th), and MRS measurements of the Larmor frequency (crosses) during St-Cyr-en-Val experiments.

MRS

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