Square-wave processing of MEGATEM data

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SUMMARY

The recording of raw or streamed EM survey data, as done by CGG during MEGATEM surveys, allows for the reprocessing of the acquired EM data, including square-wave processing. During the latter, the recorded EM response to the actual half-sine waveform is replaced by the EM response to a square-wave, derived via deconvolution/convolution in the frequency domain. This makes the on- and early-time information more accessible for data modelling, including 1D inversions and conductivity-depth transformations. Square-wave EM data can also be corrected for survey height, transmitter-receiver offset and transmitter attitude. That correction allows for the interpretation of early-time EM response grids, which generally offer better spatial resolution than derived conductivity-depth slices.

The advantages of square-wave processing are demonstrated on a MEGATEM data set acquired in 2013 in South America. With survey terrain clearance ranging from 100 – 1600 m, due to the rugged topography, early-time grids of elevation-corrected square-wave data outlined the shallow conductivity structure, whereas early-time grids of the original half-sine data mostly reflected the variable system elevation. Further, derived conductivity-depth sections of the square-wave data show more lateral continuity than the sections derived from the original half-sine data. These results show that the early-time information of square-wave is more accessible than in the original data, facilitating interpretation of shallow conductivity structures.

Key words: 1D inversion, airborne electromagnetics, data processing, Fourier deconvolution.

INTRODUCTION

The recording of streamed EM data, as done by CGG during MEGATEM and HELITEM surveys allows for the thorough spectral analysis (Lane et al., 1998) and reprocessing of these data sets, including Fourier deconvolution. The benefits of the latter include the correction for instrument drift and the replacement of the variable system response with a constant ‘ideal’ response (Annan, 1986; Macnae and Baron-Hay, 2010; Prikhodko et al., 2013; Rasmussen et al., 2017b). Square-wave processing is a Fourier deconvolution method that replaces the actual waveform with a perfect square wave (100% duty-cycle). The latter is the standard processing method applied to TEMPEST and SPECTREM data (Lane et al., 2000; Leggatt et al., 2000). The analysis and square-wave processing of MEGATEM data acquired in 2013 in South America is discussed in the following.

RAW DATA ANALYSIS

The power spectrum of raw streamed AEM data, recorded in South America at high terrain clearance, is shown in Figure 1. It shows coil-motion or earth-field (EF) noise at frequencies below 25 Hz, the active-source signal at the base-frequency of 25 Hz (BF) and corresponding odd harmonics, the powerline noise at 50 Hz (PL) and odd harmonics (lower in amplitude than the active-source signal). VLF responses are indicated in the frequency range from 16-25 kHz. The coil-motion response is the main reason why AEM systems generally don’t use base-frequencies below 25 Hz.

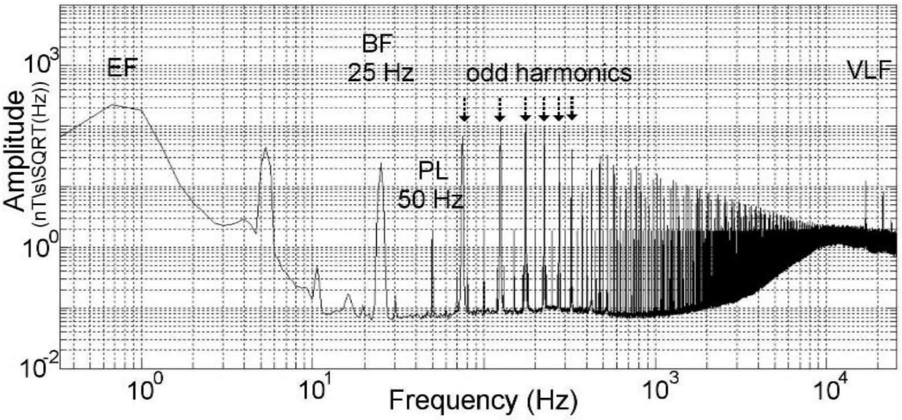

Figure 1: Spectral density of y-component MEGATEM high-elevation data (no ground response) acquired at a sampling rate of 51,200 Hz.

A time series of voltages recorded by the y-component receiver is shown in Figure 2. The left panel shows how the EM response is dominated by the primary field. The right panel of Figure 2 shows 1) a spherics event, 2) how the primary-field amplitude can change strongly over fairly short distances, as the coupling between the transmitter loop and receiver coil changes, and 3) coil-motion noise, induced in the sensors mainly by the rotation of the receiver coils in the static earth's magnetic field.

The VLF signal recorded during active-source EM surveys is considered as noise, and attempts are made to reduce the impact on the EM signal, which can be significant at the earliest time channels (Macnae, 2015; Rasmussen et al., 2017a). A close-up of Figure 1 in the VLF frequency range is shown in Figure 3. It demonstrates that these data are affected by the signal from six VLF transmitters. A comparison of the predicted and observed VLF response is shown in Figure 4. Rather than treating VLF responses as noise, the VLF signal can also be extracted from the streamed data and inverted for the near-surface conductivity structure (Sattel and Battig, 2016).

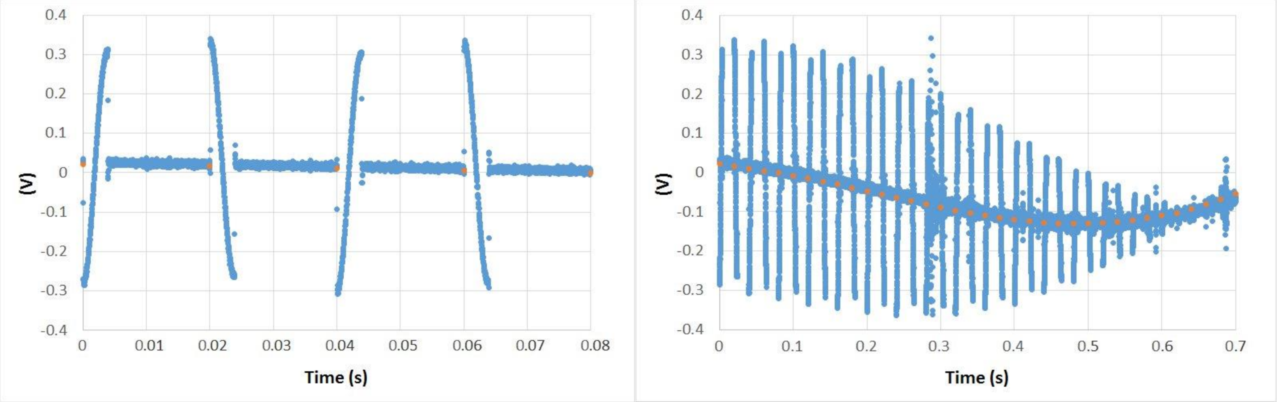

Figure 2: Time series of raw y-component data of 4 (left) and 35 half-cycles (right). The data are strongly affected by coil motion noise (marked with orange dots) and a spherics event (right panel at profile centre).

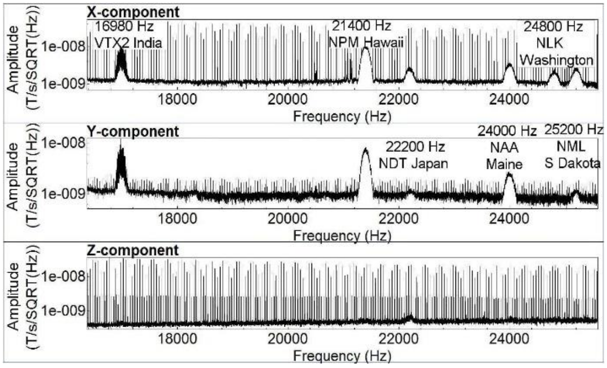

Figure 3: Spectral density in the VLF range. Signals from VLF transmitters are recorded from the continental U.S., Hawaii, India and Japan.

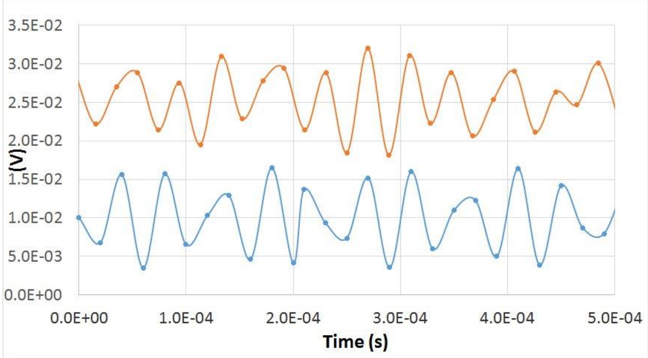

Figure 4: Close-up of the raw data (horizontal range = 0.5 ms) reveals the VLF response (orange) in the time domain. The predicted VLF response at 21.4 kHz is shown in blue.

The MEGATEM system records the EM response of a transmitted half-sine pulse, and the data are processed in the time-domain. The first part of the data processing takes place in real-time during the survey and includes noise removal (coil-motion and powerline), primary-field removal and stacking. The stacking of EM responses of consecutive half-cycles is generally very effective in reducing powerline noise, unless the powerline response saturates the receiver electronics or currents are induced in the grounded powerline poles. Traditional post-survey processing includes drift correction, spherics removal, filtering and binning. The data recorded during the transmitter on-time are generally not used during the modelling and interpretation stage, even though they might contain valuable information (Sattel, 1998).

SQUARE-WAVE PROCESSING

Square-wave processing is an alternative method to the standard processing of MEGATEM data in order to make the on- and early-time information more accessible and to facilitate the EM data interpretation. During square-wave processing, the data are deconvolved of the actual system response or half-sine waveform and convolved with a perfect square wave (100% duty-cycle). These waveforms are shown in Figure 5. The input parameters for the deconvolution include the Fourier-transformed observed voltages V and transmitter current I and the reference voltages V_a and transmitter current I_a recorded at high terrain clearance, where the ground EM response is negligible:

$$\Psi(\omega) = \frac{V(\omega)/I(\omega)}{V_a(\omega)/I_a(\omega)} \quad (1)$$

The ground EM square-wave response is derived from Ψ after convolution of Ψ with a square-wave and the removal of the primary-field response.

A comparison of the original and square-wave processed MEGATEM data from South America, with corresponding conductivity-depth sections (CDS) is shown in Figure 6. Overall, the reprocessed profiles have a less noisy appearance, and the derived CDS shows more lateral continuity than the original data and CDS.

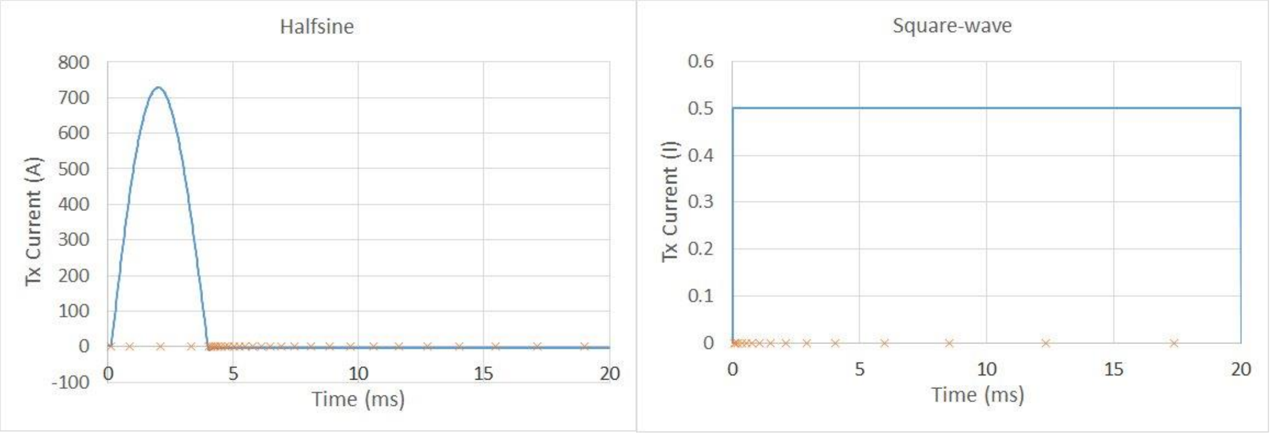

Figure 5: Original half-sine current waveform and square wave. The centre window times are indicated by crosses.

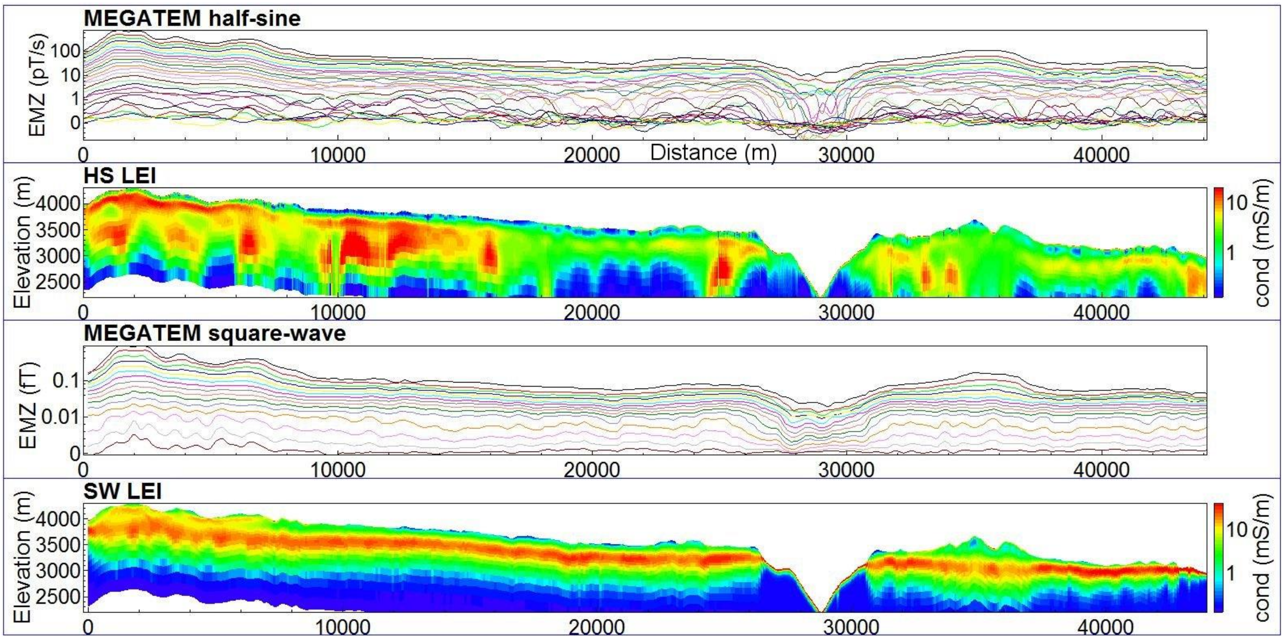

Figure 6: Comparison of original MEGATEM half-sine data (top) and reprocessed square-wave profile (bottom) with corresponding conductivity-depth sections, derived by layered-earth inversions.

Another advantage of square-wave B-field data is that they can be corrected for survey height (along with changes in the transmitter-receiver offset and transmitter pitch and roll) as discussed by Green (1998). His apparent dipole depth (ADD) method is routinely applied to TEMPEST data in order to improve the spatial resolution of early-time grids.

The effect of the ADD correction is demonstrated in Figures 7 and 8. Figure 7 shows square-wave *Bz* responses before and after ADD correction along with the system geometry parameters that are corrected for. Among these parameters, the variable terrain clearance has the strongest effect on the *Bz* response. Along the shown profile, the early-time channels of the ADD-corrected EM data show much less variation in amplitude than the uncorrected data, indicating the subsurface conductivities to be fairly uniform and the uncorrected data responses to be affected strongly by the AEM system's terrain clearance. However, when the latter exceeds 1200 m (see Figure 7, distance range -8000 m to -4000 m) the ADD correction fails, because the EM responses are close to the data noise level.

Figure 8 shows grids of early-time channel amplitudes, including the square-wave response before and after ADD-correction and the original half-sine data. The disappearance of the along-line striping, apparent on the uncorrected grid, after ADD correction, indicates that the striping originates in the continually changing coupling between the transmitter, ground and the receiver. Further, the ADD-corrected grid displays conductivity patterns not recognizable on the other early-time grids. A comparison with the DTM indicates that the strongest responses occur in topographic lows. Despite the severe vertical relief across the survey area, the ADD-correction worked very well. Only in places, where the terrain clearance exceeded 1200 m, the recorded signal amplitudes were too low to be properly ADD-corrected.

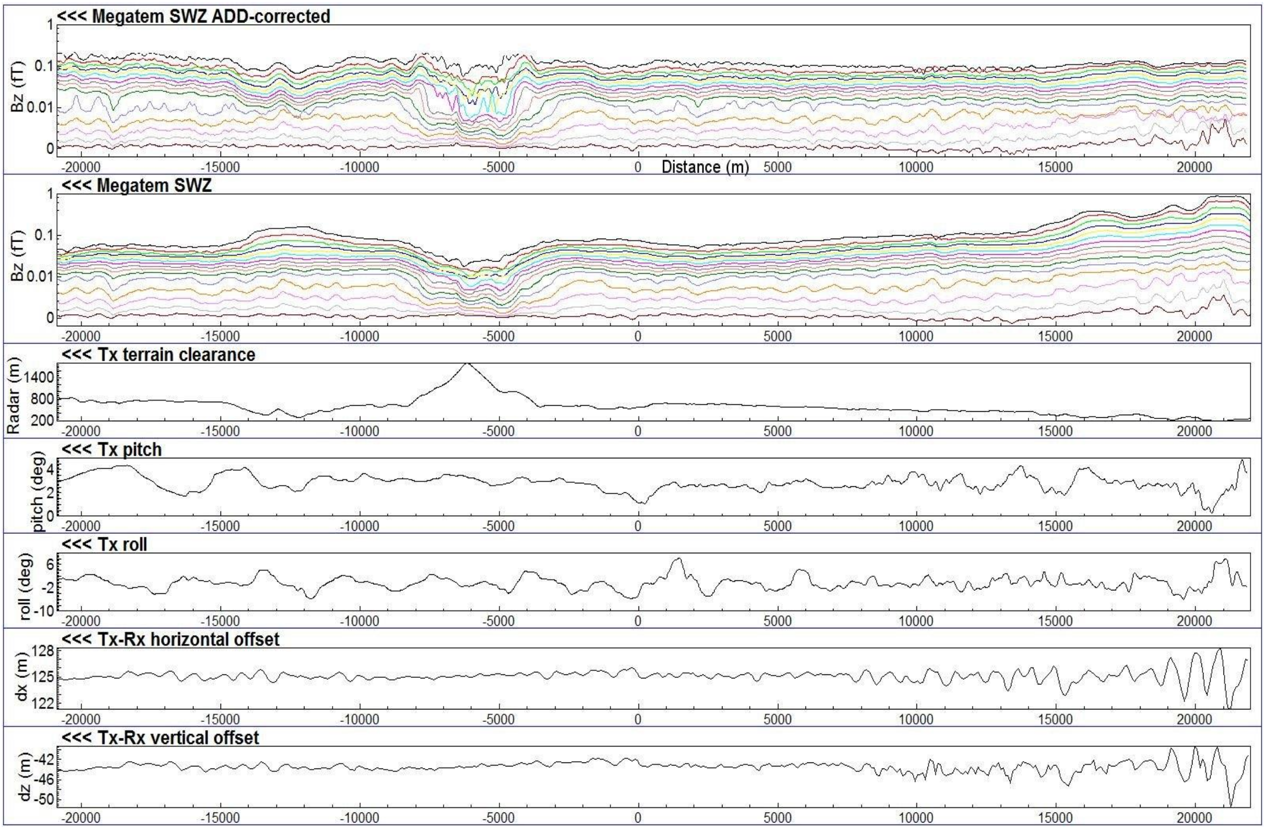

Figure 7: Comparison of square-wave *Bz* data, before and after ADD-correction with system geometry parameters. The corrected data were computed for a Tx terrain clearance of 500 m, Tx pitch and rolls of zero degrees and Tx-Rx offsets of 125 m (horizontal) and 45 m (vertical).

CONCLUSIONS

The analysis of raw AEM data indicates how various kinds of noise are affecting the data. As an alternative to traditional data processing performed in the time domain, Fourier deconvolution processing can result in improved EM data. The discussed field data results show that additional information can be gained from square-wave processing streamed MEGATEM data. Square-wave processing made the early-time information more accessible, which resulted in improved conductivity models at shallow depths as indicated by conductivity-depth sections and early-time amplitude grids.

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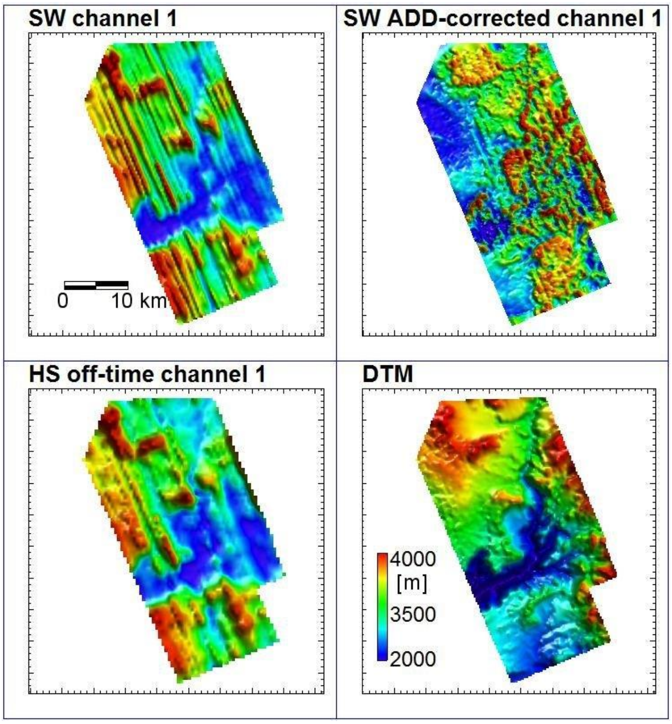

Figure 8: Comparison of early-time amplitudes of square-wave *Bz* data, before and after ADD-correction (top), the original half-sine responses and the DTM (bottom).

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