

SAUCE: A new technique to remove cultural noise from HRAM data

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There is little doubt that manual editing to remove cultural noise from high-resolution aeromagnetic (HRAM) data yields cleaner data than automated techniques. However, because the manual technique is very slow, relatively expensive, and tedious, it is not preferred by many HRAM processors. For this reason, we have developed a semi-automated cultural editing (SAUCE) technique to remove cultural noise from HRAM data. SAUCE is a modified version of the manual technique, but it is much faster (at least five-fold), more cost-effective, and less tedious.

As in the manual technique, SAUCE differentially picks and removes noise related to culture while preserving magnetic signals related to subtle geologic features. Furthermore, it can be easily extended to other geophysical methods susceptible to cultural noise such as airborne electromagnetic data.

This paper describes SAUCE and compares it to other existing automated techniques.

Background. A main objective of HRAM surveys is to locate subtle anomalies that are important in mineral and oil exploration and development. However, such anomalies, especially in highly populated areas such as the Western Canada Sedimentary Basin (WCSB), are often masked by undesirable magnetic responses from manmade objects which we call cultural noise. The main sources of cultural noise are oil wells, pipelines, high-voltage power lines, railroads, buildings, and other large metal objects such as bridges. Cultural noise is more evident in HRAM data than data from conventional aeromagnetic surveys because the former are flown at low altitude (<150 m above the ground). This, of course, is what makes HRAM data well suited to map shallow and subtle geologic features in intrasedimentary rocks, and deep and regional geologic structure in crystalline basement rocks.

Cultural noise is characterized by high frequency (short wavelength) and high amplitude. Its bandwidth frequently overlaps signals attributed to subtle and shallow geologic features (for example, kimberlitic plugs, buried channels, drainage systems, dipping layers which outcrop and hydrothermal alteration halos).

In addition, cultural noise can mislead inexperienced interpreters into treating noise as real geologic signal, has the potential to degrade the signal (thus reducing the ability of using some important analytical techniques in image enhancements, e.g., second vertical derivative and the analytic signal), and severely affects depth solutions to magnetic sources using inversion techniques such as Euler and Werner deconvolution. Therefore, it is very important to remove cultural noise from HRAM data prior to processing and interpretation, especially when the objective is to map shallow geologic targets. However, if the objective of an HRAM survey is to map only deep geologic targets, then the removal of cultural noise may not be essential. However, even long wavelengths are contaminated because the sharp spikes in cultural noise have broad bandwidth.

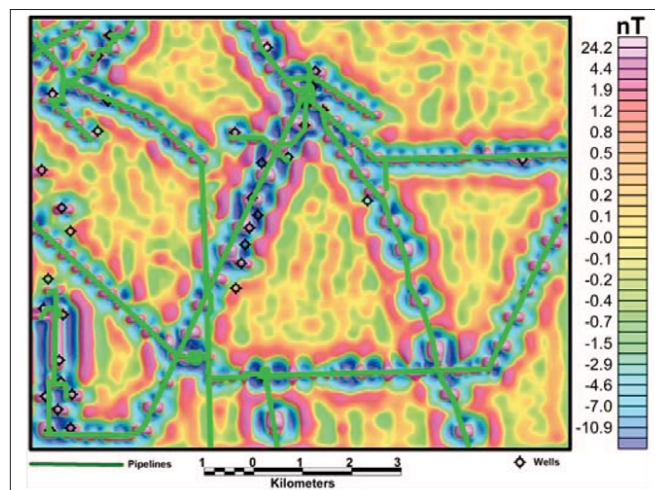


Figure 1. A map of the arbitrary HRAM data selected to demonstrate the technique. This map also shows the location of wells and pipelines that produced the cultural noise on the 600 m high-pass filter plotted in the background.

Review of existing techniques. HRAM data mainly contain two types of undesirable noise components—white noise (Gaussian noise) and cultural noise (random or Poisson noise). Both the white noise (mostly related to instrumentation) and cultural noise are in the high-frequency end of the spectrum of the signal. However, the white noise can be easily removed by a suitable digital filter because it is predictable and we have a good statistical understanding of how its sources behave. Unfortunately, this is not the case with cultural noise which is unpredictable and randomly distributed within the HRAM data and has the same characteristics as signals generated from subtle geologic features. Therefore, it is difficult to separate cultural noise from the HRAM data using digital filters.

Upward continuation or flying surveys at higher elevations suppress cultural noise amplitudes without eliminating the noise. Therefore we feel these approaches are ineffective.

Several years ago we compared a fully manual approach to a semi-automated neural net approach and a fully automated filtering approach. These methods had both strengths and weaknesses with the “best method” being decided by personal preference. Fully manual methods produced the most completely edited result, but at significant cost in terms of effort and expense. Some automated techniques try to model cultural noise. The corrected total magnetic field is calculated by subtracting the magnetic effect of a magnetic source (e.g., a power line). This technique depends on knowing both the location and the nature of the magnetic noise, and this may not always be possible. Recent attempts to use very fast simulated annealing inversion schemes for modeling noise get around the unknown nature of the noise, but fail to be completely successful because of the huge variety of waveforms in cultural noise.

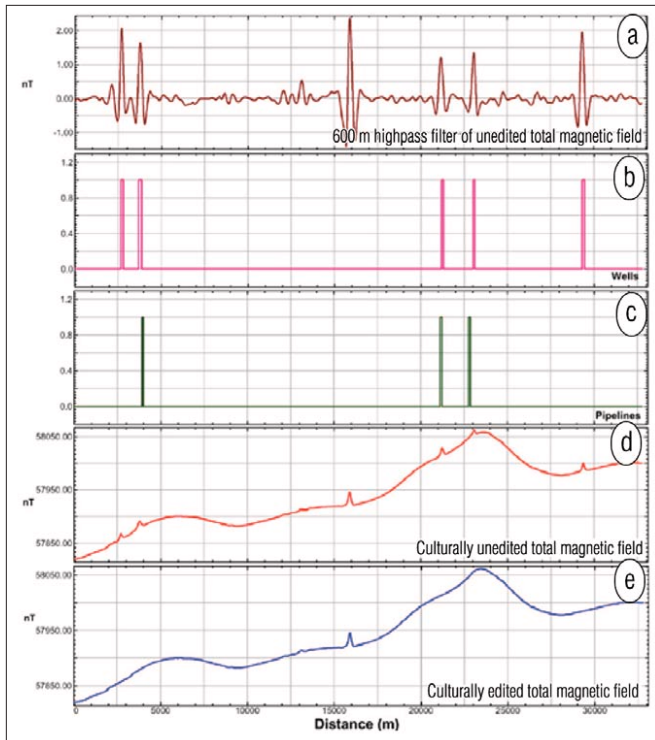


Figure 2. An example of an HRAM line that was culturally edited by SAUCE: (a) a 600 m high-pass filter that serves as a guide to detect the extent and magnitude of the noise signal in the data, (b) a binary channel showing locations of pipelines across the line, (c) a binary channel showing locations of wells, (d) the original aeromagnetic channel prior to cultural editing, and (e) the culturally edited aeromagnetic channel using SAUCE.

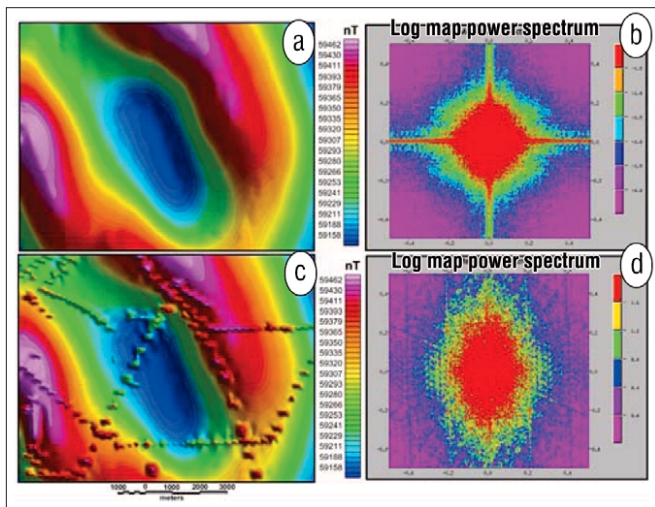


Figure 3. A map showing the results of using SAUCE to remove cultural noise from the arbitrary HRAM data: (a) the total aeromagnetic intensity map after cultural editing, (b) the power spectrum map of the culturally edited grid shown in (a), (c) the total aeromagnetic intensity map prior to cultural editing, and (d) the power spectrum map of the unedited grid shown in (c).

Comparison of manual and SAUCE techniques. SAUCE was designed to remove only noise associated with man-made culture from aeromagnetic data. In order to understand why it is faster and more cost effective than the manual technique, we will summarize and compare the main steps used in these approaches. The classic manual approach to removing cultural noise involves:

- 1) The fourth difference is calculated for the unedited total magnetic field channel in the line database. This generates a channel containing spikes which might be attributed to cultural noise and/or subtle geologic signals.
- 2) The spike channel in the database is plotted at a suitable scale.
- 3) The locations of these spikes are picked manually and marked on the profiles.
- 4) The spikes are checked against ground-track videotapes of the survey to determine if the source of each spike is related to cultural noise.
- 5) Spikes identified, during video checking, as resulting from culture are plotted on a map along with the flight lines and known culture (e.g., wells and pipelines).
- 6) The interpreter inspects the profiles on a workstation, checks each line against the map prepared in step 5, and interactively edits the data by replacing the noisy data with a best-fitting polynomial curve that uses the original sampled data points on either side of the edited spike. This maintains data continuity and retains as much geologic signal as possible in the area affected by the cultural noise.

The new technique, SAUCE, involves:

- 1) Culture files (pipelines, oil wells, railways, and others) are compiled for the survey area, preferably in vector format such as DXF or SHAPE files. In a culturally complex area it is more convenient to make a separate file for each type of culture.
- 2) The culture files are converted into a binary raster file using any image processing software. Binarization of an image consists of assigning to each pixel a value only equal to zero or one. The pixels with values equal to one show cultural locations; pixels with values equal to zero show areas of no culture.
- 3) The binary files are sampled along flight lines and imported into the HRAM database lines as separate channels. It is also useful to sample a high-pass filter of the total magnetic field for reference during interactive cultural editing. The high-pass filter will enhance the noise in the data and helps separate magnetic from non-magnetic culture.
- 4) The HRAM survey is scanned line-by-line and interactively edited at locations where known culture occurs, just as in the manual technique.
- 5) The culturally edited channel is gridded, put in the database, and visually inspected for any suspected noise that is not related to known culture.
- 6) The videotape is examined at locations suspected of generating cultural noise which is removed from the data if confirmed.

This scenario eliminates the need to inspect the complete set of the videotapes as is done in the manual procedure. Furthermore, there is no need for constant reference to paper maps. In the manual procedure, the operator frequently goes back and forth between a paper map showing the culture and a workstation showing the flight lines to find the exact location of the culture on the screen relative to the map. This is very tedious and time consuming. It may also lead to serious errors because the operator can easily pick a wrong profile for editing.

Testing on a representative example. Figure 1 is a high-pass filter of the total magnetic intensity grid of an HRAM data set. The noise in the data is very evident. The overlay of

pipelines and wells shows that most noise in the area is caused by cultural sources related to oilfield development. To remove this cultural noise, we followed the steps outlined above. Figure 2 is an example of an HRAM line so edited. The unedited magnetic channel is also shown for comparison. In this example almost all high-frequency signals associated with pipelines and wells were removed from the data. However, a subtle magnetic anomaly at the center of the profile was not removed. This anomaly is not associated with any known culture and could be related to a shallow geologic feature, for example a kimberlitic intrusion. An automated cultural editing technique would have removed this anomaly along with the cultural noise.

Figure 3 shows the final result of the cultural editing by our method. The spectral effect of cultural editing is illustrated in the 2D power spectra of the culturally edited and the unedited maps (Figures 3b and 3d). It is evident from Figure 3 that noise dominates the high-frequency and (to a lesser degree) the middle-frequency components of the spectrum. If such spikes are not culturally edited, the low-frequency component of each spike will appear as a subtle low-frequency feature in filtered versions of the data which are designed to image deep targets.

Comparison to existing automated techniques. An arbitrary 1D HRAM line was selected and culturally edited using SAUCE, spatial filtering, Fast Fourier transform (FFT), and wavelet analysis techniques.

Spatial filter example: Many digital filters are available to remove noise from a signal in the spatial domain. The moving average and the median filters are very commonly used as low-pass filters to attenuate noise inherent in many types of data. For this reason we selected these two filters for our comparison. Figure 4 shows the result of running a 51-point (~500 m) moving average and a 51-point median filter on the test line. The noise was removed effectively without altering the shape of the anomaly of interest. However, both filters removed a subtle anomaly (near 16 000 m) that was not attributed to culture.

FFT example: Some filters remove noise from HRAM data by assuming all spectral information beyond a certain frequency threshold is noise. In other words, if the cultural noise is confined to a defined area of the spectrum, it is possible to design a filter to remove it from the data. Unfortunately, cultural noise is distributed all over the spectrum because of the broad-band nature of spikes, and it is impossible to filter it out without taking out geologic signals as well.

Figure 5 shows the result of applying two FFT filters on our test line—a 1 km low-pass filter and a 0.2 km upward-continuation filter. As expected, the two filters removed geologic signal along with cultural noise. However, it appears that the upward-continuation filter has performed relatively better than the low-pass filter in removing high-frequency low-amplitude anomalies from the data while preserving some character of the subtle geologic anomaly at 16 000 m.

Wavelet transform example: The FFT method is well suited to analyze stationary signals (signals that do not change significantly over time). However, for nonstationary signals, the FFT method loses spatial information when we transform the signal to the frequency domain. When we look at the FFT of a signal, it is impossible to tell where a particular event took place. HRAM data contain nonstationary components, such as noise, that have a very short duration, and in which frequency and amplitude change over the spectrum.

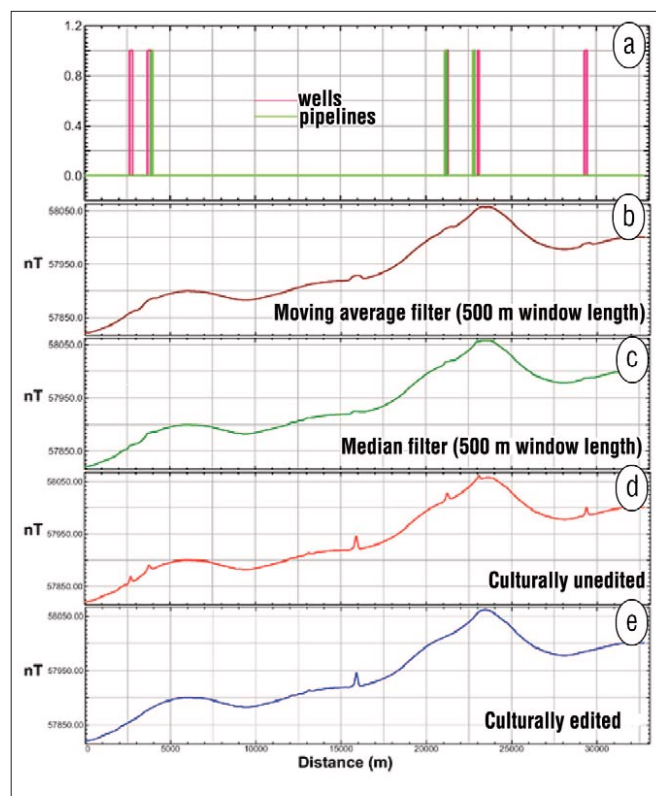


Figure 4. The results of comparing SAUCE to spatial moving average and median filtering techniques for removing cultural noise from HRAM data. The top plot shows the locations of pipelines and wells along the line.

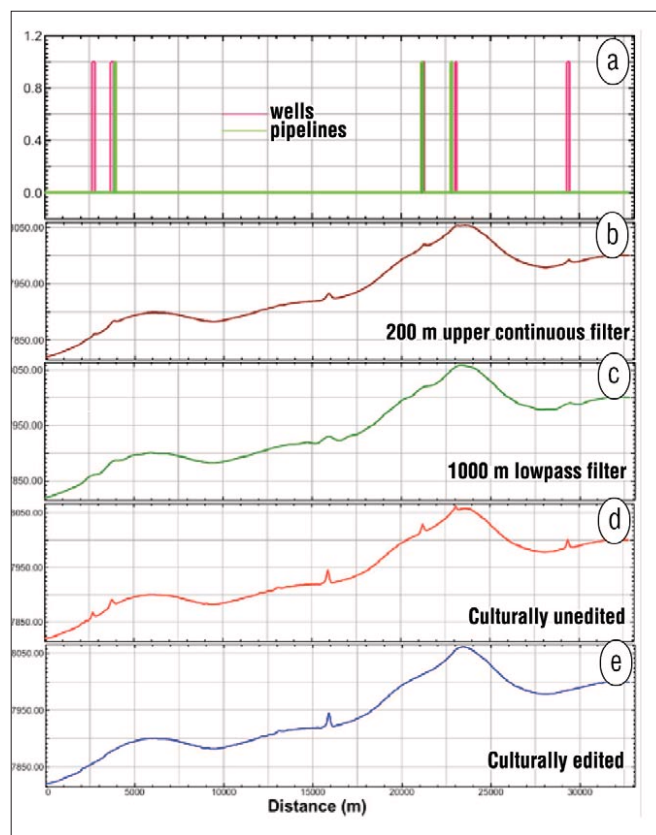


Figure 5. The results of comparing SAUCE to FFT-based, low-pass and upward continuation filtering techniques for removing cultural noise from HRAM data. The top plot shows the locations of pipelines and wells along the line.

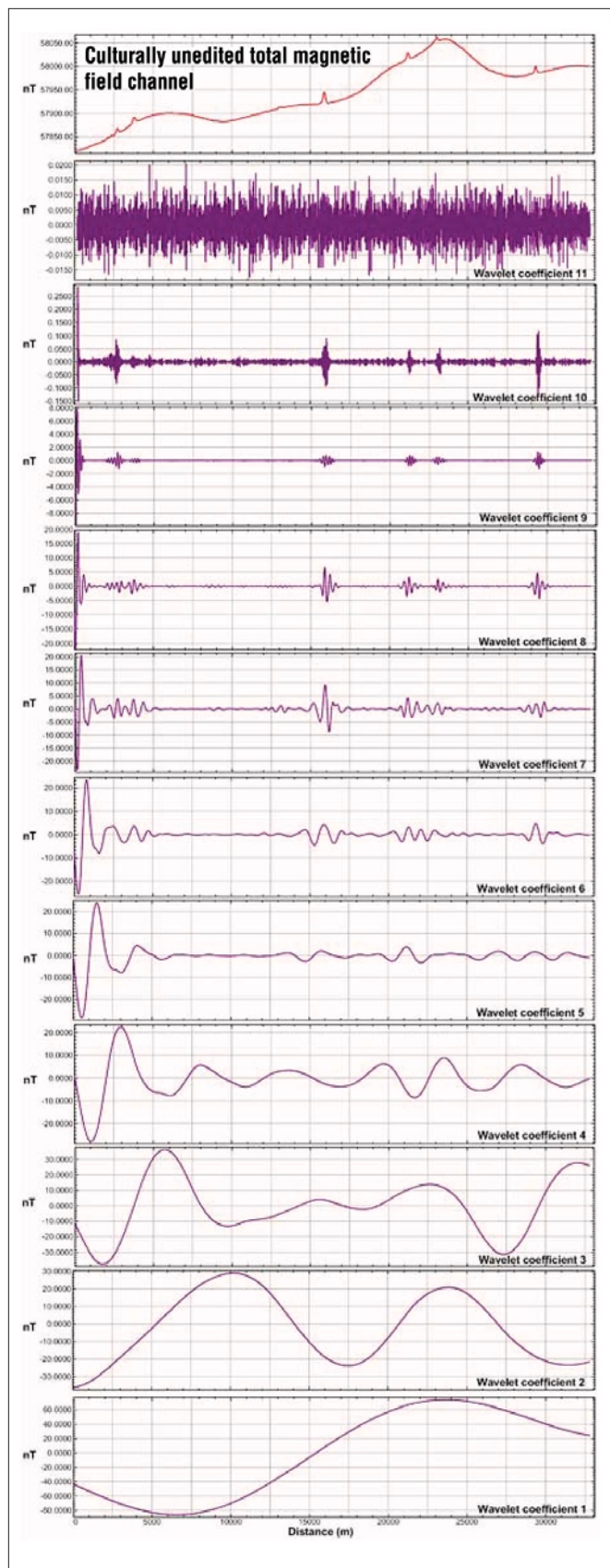


Figure 6. Coefficients of the wavelet transform decomposition of the selected line using Daubechies 20th order base. The larger coefficients are attributed to the signal whereas the smaller coefficients are attributed to the noise. Denoising using wavelet transform is based on thresholding of the wavelet coefficients. This can be accomplished by setting the high frequency coefficients, for example wavelet coefficients 11 to zero.

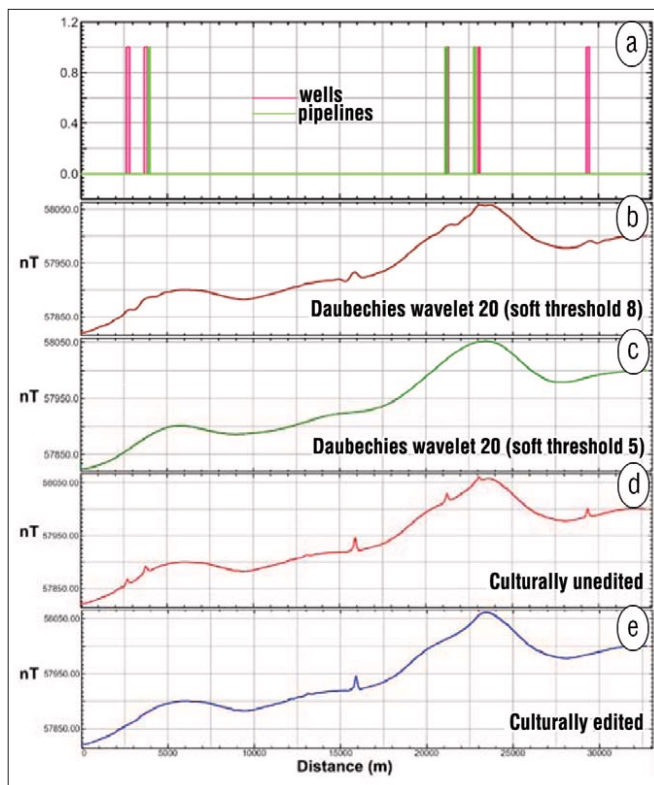


Figure 7. The results of comparing SAUCE to wavelet transform technique for removing cultural noise from HRAM data. The top plot shows the locations of pipelines and wells along the line.

Removing noise from HRAM data using a wavelet transform method is based on using different thresholds for different wavelet coefficients. The idea is to transform the data into different wavelets (e.g., Figure 6), in which large coefficients are attributed to the signal and the smaller coefficients to the noise. Noise can be separated from the signal by manipulating these coefficients. The wavelet transform allows some components of the spectrum to be removed by setting their coefficients to zero. The signal can then be reconstructed via the inverse wavelet transform.

Wavelets essentially break up HRAM data into multiple frequency components, each with different details. The wavelet analysis is similar to the Gabor transform (windowed, short-time Fourier transform), in the sense that the signal is multiplied with a function, and the transform is computed separately for different segments of the signal. However, in wavelet analysis, the width of window also changes as the transform is computed for every spectral component. This is probably the most significant characteristic of a wavelet transform. The wavelet is not a constant window function like the Gabor transform. It can be expanded or contracted by changing the wavelet scale value (S) each time the wavelet is moved through the data series. The various window scales of the wavelet function lead to different frequency values. If we look at a signal with a large window, we would notice large or regional features. Similarly, if we look at a signal with a small window, we would notice small or local features. This makes wavelets interesting and useful.

Many wavelet functions (e.g., Daubechies, Haar, Coiflet) are available. We chose a Daubechies' 20th order wavelet because Daubechies wavelets generally have good resolution in both space and frequency. Our test used an eleven level decomposition. The result (Figure 6) shows 11 sets of wavelet coefficients. Coefficients 11, 10, 9, 8, 7, 6, and prob-

ably 5 give the details corresponding to the high-frequency components (including the white noise and the cultural noise). Wavelet coefficients 1, 2, 3, 4, and probably 5 correspond to the low frequencies. The sum of the 11 sets of wavelet coefficients comprise the original signal (plotted in red on the top of Figure 6).

The high-frequency component of the signal (white noise in the data) appears confined to coefficient 11. To remove the white noise, the high-frequency wavelet coefficients in 11 should be replaced with zero or removed before inverting the data.

Cultural noise appears mostly dispersed in coefficients 5-10. Therefore, to remove cultural noise from the data, coefficients 5-10 must be replaced with zero. However, zeroing these coefficients will obviously remove subtle geologic signals along with cultural noise. This is evident in Figure 7 where we have plotted results of wavelet noise removal calculated at two different threshold levels. This demonstrates that attempting to remove cultural noise from the data using wavelet transform could remove useful geologic information.

Conclusions. The SAUCE technique described in this article is much faster and cost-effective than strictly manual techniques at removing cultural noise from HRAM data. Furthermore, as with manual techniques, it can be used efficiently in removing cultural noise from HRAM data without altering the shape of the geologic signal.

This method appears more effective than automated techniques in removing cultural noise because the latter often fail to distinguish between cultural noise and subtle geologic signals in the HRAM data. However, some of these techniques,

especially the wavelet analysis, can augment our method in removing white noise from the data. Finally, this method can be easily automated and implemented on geophysical data processing software. The technique can also be extended to remove cultural noise from electromagnetic data.

Suggested reading. "Robust modeling with erratic data" by Claerbout and Muir (*GEOPHYSICS*, 1973). "Manual approaches to the removal of cultural noise from high-resolution aeromagnetic data acquires over highly developed areas" by Cuss (*First Break*, 2003). "Wavelets and other phase space localization methods" by Daubechies (Proceedings of the International Congress of Mathematicians, 1995). "Analysis and interpretation of aeromagnetic data affected by intense cultural noise" by Fedi et al. (EAEG 2003 *Extended Abstracts*). "Removal of dc power line magnetic field effects from airborne total magnetic field measurements" by Gharibi et al. (*Geophysical Prospecting*, 2000). "Cultural editing of HRAM data: comparison of techniques" by Hassan et al. (*Canadian Journal of Exploration Geophysics*, 1998). "Denoising of aeromagnetic data via the wavelet transform" by Leblanc and Morris (*GEOPHYSICS*, 2001). "An application for removing cultural noise from aeromagnetic data" by Muszala et al. (*GEOPHYSICS*, 2001). "Removing culture from southern Texas—a magnetic cleanup and image revolution" by Pearson (SEG 1996 *Expanded Abstracts*). **TJE**

Acknowledgments: The authors thank their colleagues at GEDCO for constructive criticism.

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