High Resolution 5D Interpolation: Measuring and Compensating for 5D Leakage

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Summary

The noise attenuation that is a familiar observation in the stacks of 5D interpolated data is normally seen as being a beneficial side-effect of the 5D interpolation process. A more cautious view is that the noise attenuation is an indication that not all the information in the prestack data has been preserved, and the fear is that some resolution in the signal has been lost along with the noise. We present a general approach for measuring 5D leakage. 5D leakage is the noise, and possibly the signal, that 5D interpolation (using any technique) fails to interpolate because the data do not completely conform to the simplicity constraints used by the interpolation algorithm. A real data example shows that 5D interpolation fails to interpolate diffraction patterns fully, so resolution in the normal 5D interpolated image is lost. To compensate for the loss of resolution with normal 5D interpolation, we introduce a technique that we call High Resolution 5D Interpolation (Hi5D), which combines the data from the ordinary 5D interpolated traces with an interpolated version of the measured 5D leakage. The Hi5D data tend to retain the full detailed resolution of the original prestack data.

Introduction

The purpose of 5D interpolation is primarily to reduce the generation of migration artifacts during prestack time migration by improving the prestack sampling characteristics of the 3D dataset. There are several algorithms for performing 5D interpolation but we will focus on MWNI here. A large amount of newly interpolated data can be generated by any of these processes. The MWNI method of 5D prestack interpolation (Trad, 2009) generates the new data by using two constraints, a least-squares fitting constraint on the input data and a weighted L2-norm constraint that favours the large “sparse” Fourier coefficients in the construction of traces between existing input traces.

MWNI is able to generate excellent results. However, any interpolation method has limits, and is capable of losing information during the interpolation process. With MWNI and the other interpolation methods there is the possibility that small details in the data can be lost since each method interpolates data by focusing in one way or another on interpolating the major components of the data correctly, with “major components” being defined differently for each method. There are several reports on the value of using 5D interpolation as a means of obtaining improved AVO inversions (e.g. Downton et al, 2008). It is also well known that 5D interpolation can act as an attenuator of both random noise and systematic footprint noise. Since there is nothing inherent in 5D interpolation to distinguish between signal and noise, there is a lingering question of whether each algorithm sets the demarcation line between signal preservation and noise attenuation correctly.

In this paper we tackle the question of whether MWNI is capable of losing resolution during the interpolation process, and we give a concrete answer. The answer, not surprisingly, is yes, resolution can be lost in the 5D interpolation process. We present a general method for measuring the amount of signal that has been lost. We then take the interpolation process one step farther than normal 5D interpolation, and present a method of compensating the original 5D interpolated traces with the measured signal loss in order to obtain a final high-resolution 5D interpolated result.

Method

Figure 1 shows a typical example of stacked 5D interpolated data before and after 5D interpolation with MWNI. We see the normal enhancement of the stack due to noise attenuation. The improvements are most easily seen in the shallow events since the obvious noise in the first few hundred milliseconds has been essentially removed, and the continuity of events has been greatly improved. The impact on the deeper parts of the stack is less obvious, but there is nonetheless a certain amount of noise attenuation that can be observed, although the characteristics of the data appear to be relatively well preserved.

One part of the stack where we might question the integrity of the 5D interpolation is in the middle part of the section, between about 600ms and 1000ms, where a heavily karsted feature has generated a large number of diffractions. The 5D interpolated stack has a smoother appearance than the original trim stack in this area, so although it appears that the major features have been preserved, it appears that the diffractions may have been attenuated. Diffractions are generated by edges, and sharp edge definition is basically what the interpreters need for resolution. So it is very important that diffractions be preserved through the interpolation process. The difference between the two stacks, in Figure 2, shows noise in the shallow section, as expected, and it also shows diffractions and flat events in the middle part of the stack. Unfortunately, the difference stack in Fig.2 cannot be used as an indication of whether or not 5D interpolation has worked well or not. There is a great deal more traces being stacked together in the 5D stack compared to the original trim stack, and the offset and azimuth sampling of the traces is much more uniform in the 5D stack than in the trim stack, so these sampling differences could easily account for some of the differences in the diffractions and flat events that we see in Fig. 2. So we need a better measure of success or failure of the interpolation.

Figure 3 shows an example of a CDP gather from this 3D dataset after 5D interpolation. Notice that the data in the gather appears to show a great deal of integrity in terms of character changes along the flat events, noise and multiples. The parameter choices in the 5D interpolation have been chosen with the utmost care to generate as good an interpolation as possible. However, there is still a character change between the original input traces (Fig. 3b) and the interpolated traces (Fig. 3a) within the gather that is fairly obvious. The original traces appear to be somewhat noisier than the interpolated traces. This is to be expected since MWNI invokes a sparseness (simplicity) criterion on the Fourier coefficients that are used to generate the new traces.

Our simple method for measuring the parts of the input data that 5D interpolation is failing to interpolate (the 5D leakage) is something that we call the flip/flop method. The flip/flop method consists of eliminating the original input traces from the newly 5D interpolated dataset, and then interpolating the data in the original input trace locations using just the 5D interpolated data. i.e. we have flip/flopped the input data and interpolated data around in the interpolation process. The difference between the original input traces and the interpolated data at the input trace locations obtained by the flip/flop method is a measure of the residue, or leakage, from the 5D interpolation process. Notice that the interpolation method that is used to interpolate the original traces from the newly interpolated traces does not have to be the same method that was used in the original interpolation, and there may be good reasons not to use the same method. Normally the first interpolation (MWNI in this case) is interpolating many traces from few traces) and the second interpolation (the flip/flop interpolation) is interpolating a few traces from many traces. So it is not obvious that the same algorithm is best suited to these two different situations.

Figure 4 shows the same CDP gather as in Fig.3 after applying the flip/flop method to the entire 3D dataset. In this case, MWNI was used for both the original interpolation and the flip/flop interpolation. Notice that the traces in the original input locations after the flip/flop interpolation are now more similar to their neighbors than before (Fig. 4a compared to Fig. 3a). Figure 4b shows the difference between the traces in Figure 3a and Figure 4a at the original input locations.

The traces in Figure 4b are a measure of the 5D interpolation leakage. They may look like they consist of nothing but random noise, but stacking up these traces shows the remarkable result in Figure 5. We see the obvious noise at the top of the section, as expected, but we also see a clear image of many diffractions between about 600ms and 1000ms. Just as remarkable is the almost total absence of flat events. Figure 5 is a picture of exactly the aspect of the signal that we would expect MWNI to have difficulty interpolating successfully. Diffractions are subtle features of the signal that take many low-amplitude wavenumbers to describe. Flat events are simple features of the signal that take a smaller number of high-amplitude wavenumbers to describe. Hence, simple flat events are interpolated successfully by MWNI while diffractions leak through. Figure 6a and 6b show a comparison of a time slice at 638ms through the normal 5D stack compared to the corresponding time slice at 638ms for the stack of the 5D leakage traces. The correspondence between the channel-like features in the 5D stack and 5D leakage stack is obvious. It appears that the 5D leakage is greatest at locations in the dataset where edges occur.

The images in Figures 5 and 6 are perhaps a surprising measure of how much information loss can occur during 5D interpolation. However, this measure of the 5D leakage gives us an excellent quantitative estimate of the signal (and noise) that 5D interpolation fails to interpolate, so we are now in a good position to improve the normal 5D interpolation result by using this measure of the information loss to improve the resolution of the final interpolation. Notice that the leakage traces in Figure 4b are calculated at exactly the locations where the 5D interpolation is most accurate: at the input trace locations. To use these measurements of the interpolation error to improve the final interpolation, we make the obvious assumption that, since the interpolation errors are predicted from the traces in the immediate neighborhood of the input traces, then these errors need to be distributed to these neighboring traces. We distribute the leakage in these neighbouring traces, and call the result High Resolution 5D Interpolation (Hi5D) since this interpolation is performed in a way that guarantees the resolution of the stack of the input data.

Figure 6 shows the result of compensating the ordinary 5D interpolated data with the measured leakage, and stacking the result. This Hi5D stack now shows the same strong diffracted energy as the stack of the uninterpolated data in Figure 1.

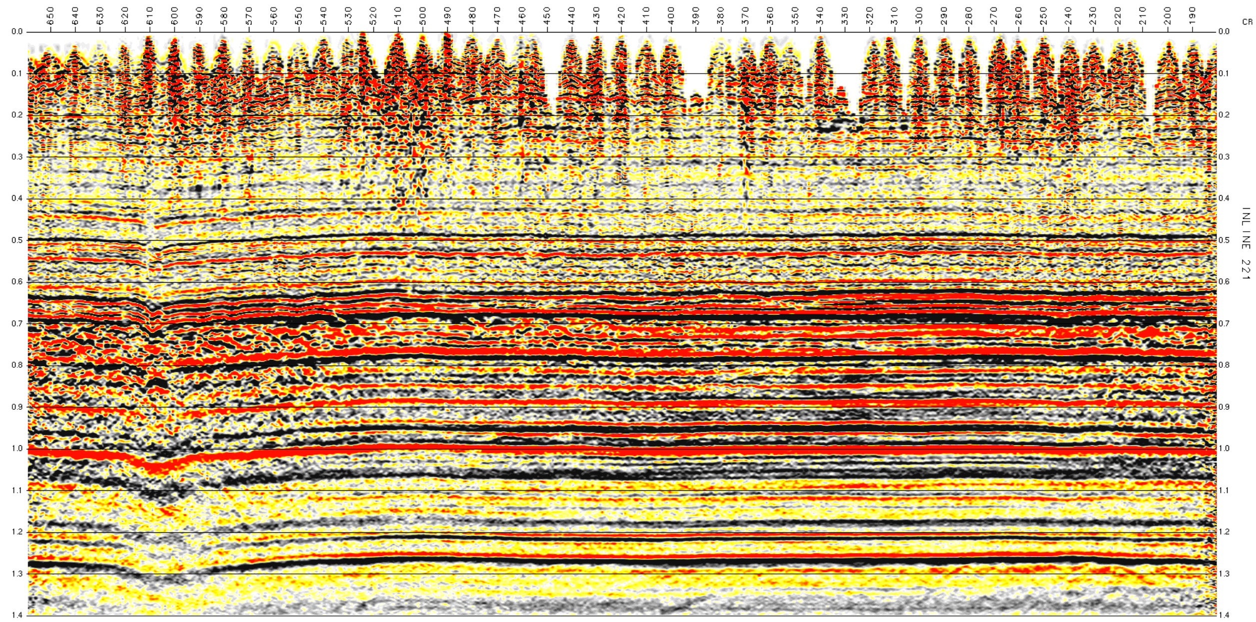

Figure 1a: Inline of 3D stack before 5D interpolation

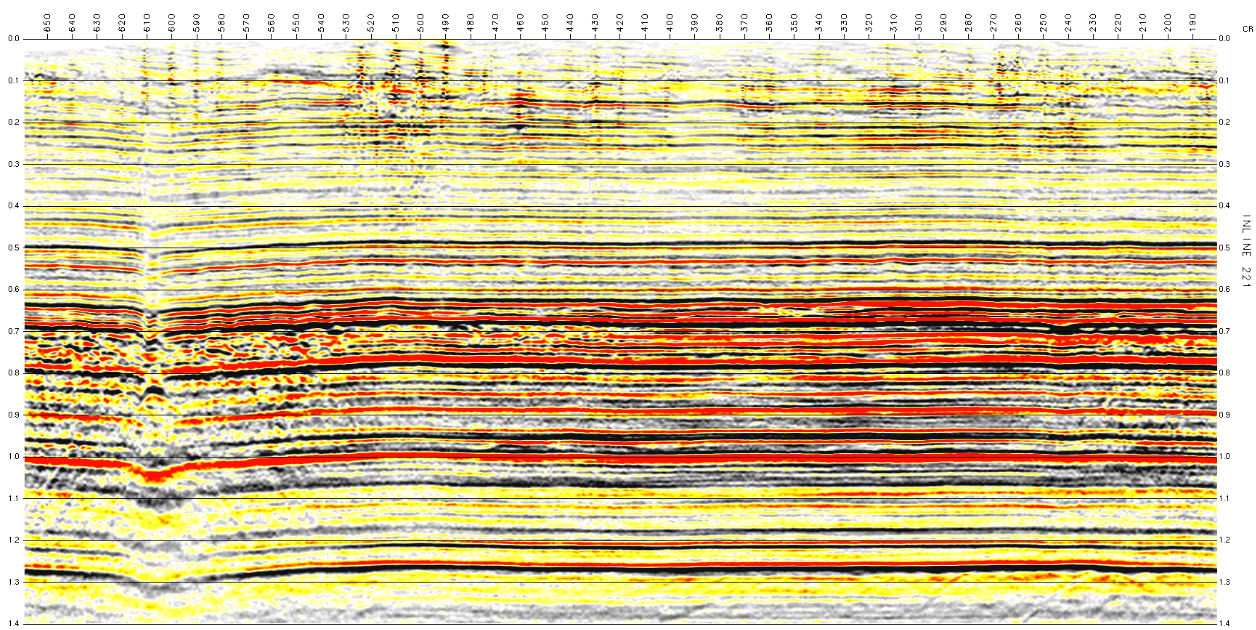

Figure 1b: Inline of 3D stack after 5D interpolation

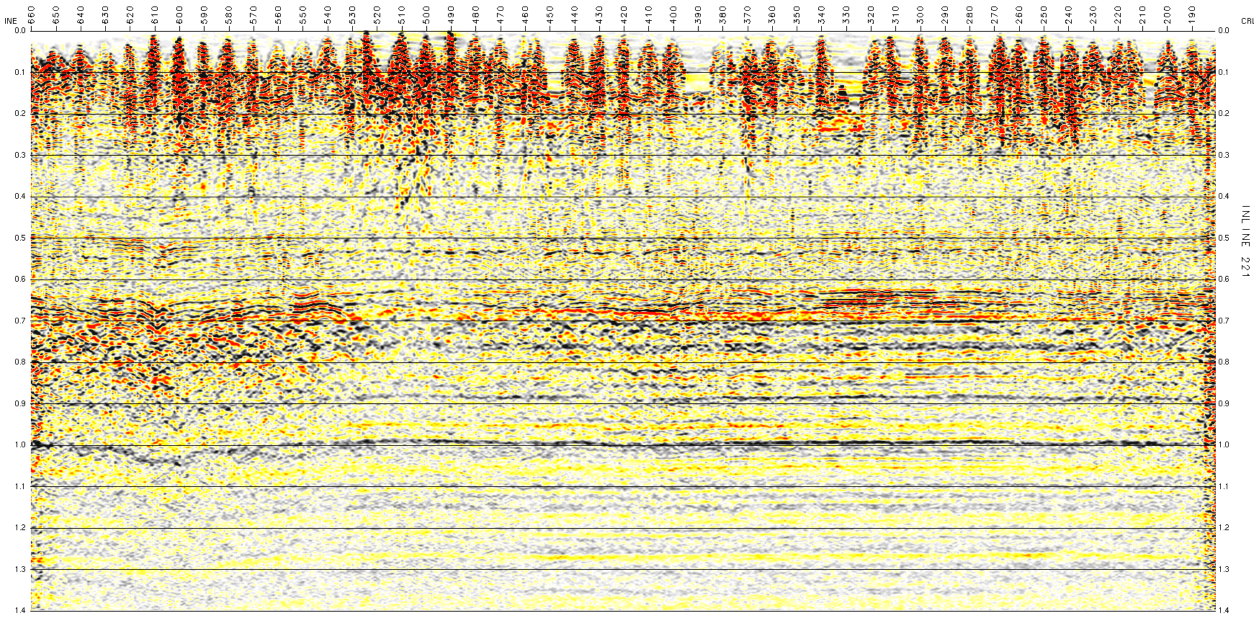

Figure 2: Difference of stacks before and after 5D interpolation

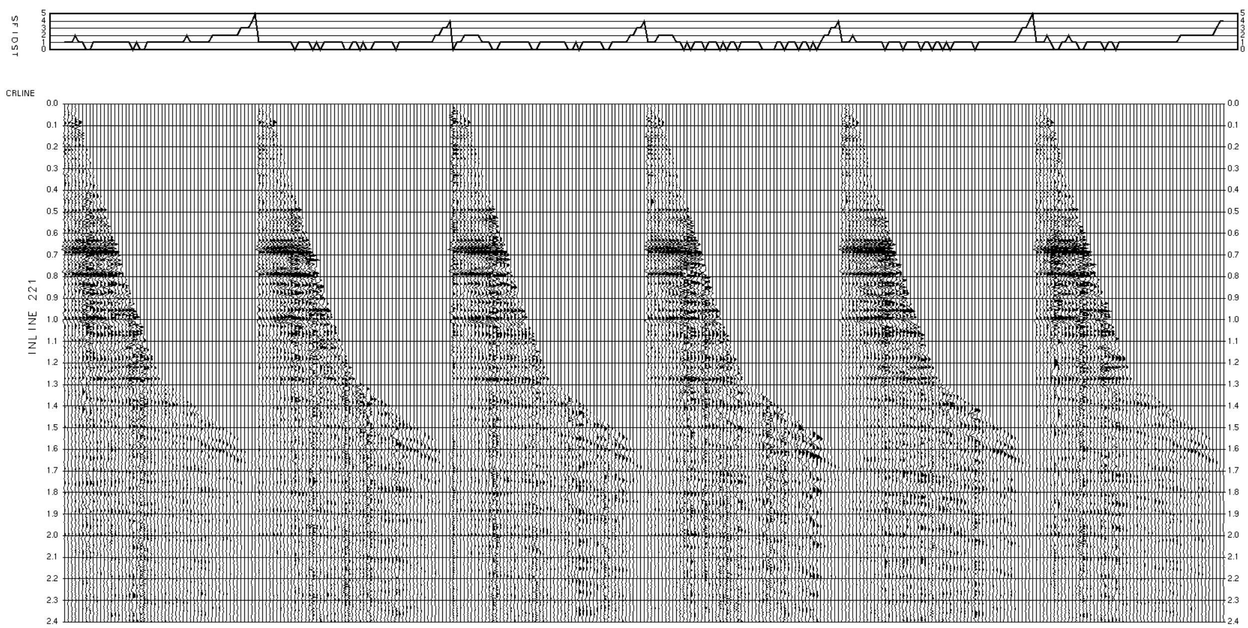

Figure 3a: Typical CDP gather after 5D interpolation sorted by azimuth sectors.

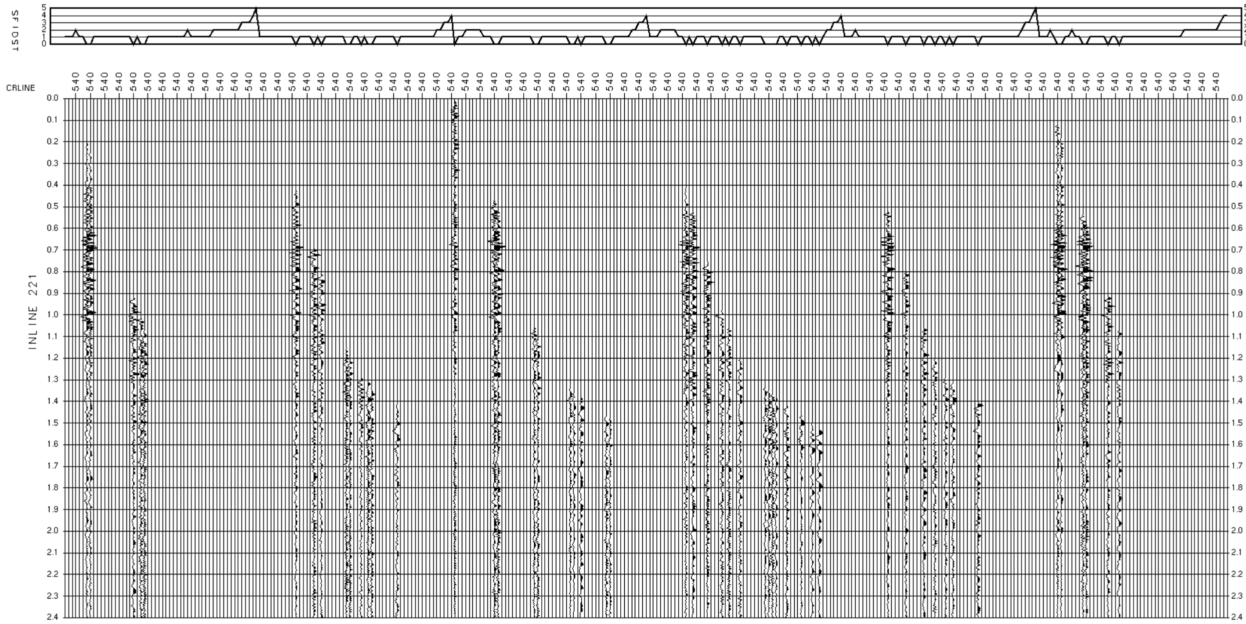

Figure 3b: The original input traces within the CDP gather before 5D interpolation

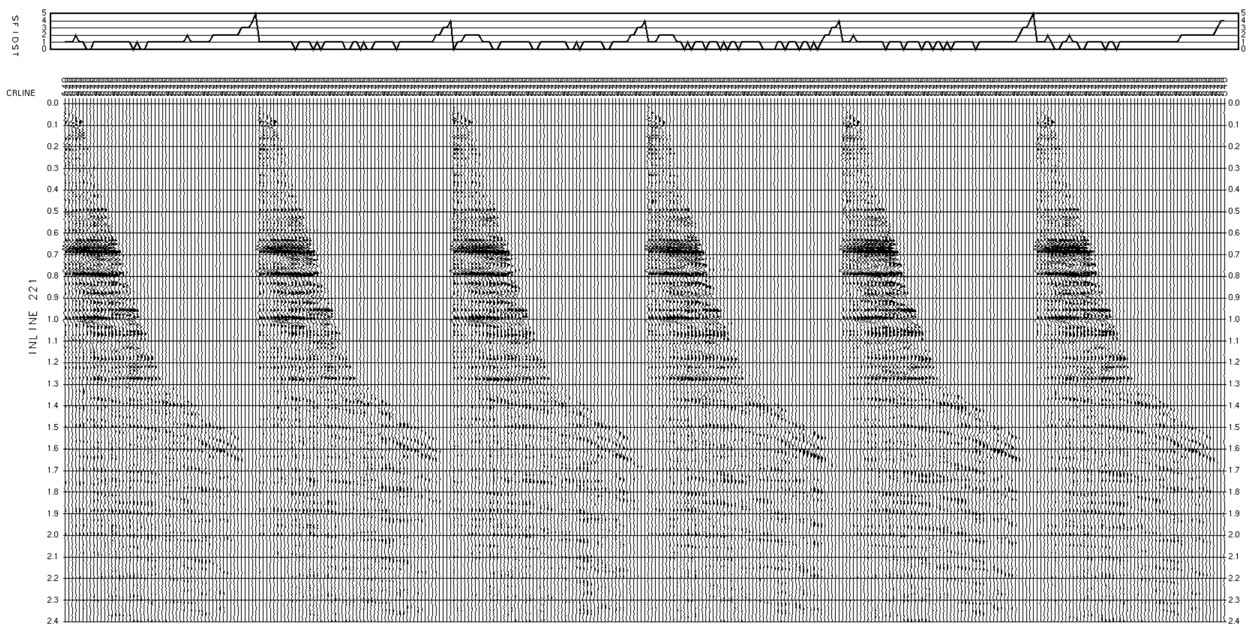

Figure 4a: The same CDP gather as in Fig. 3a but with the original traces interpolated with the flip/flop method described in the text.

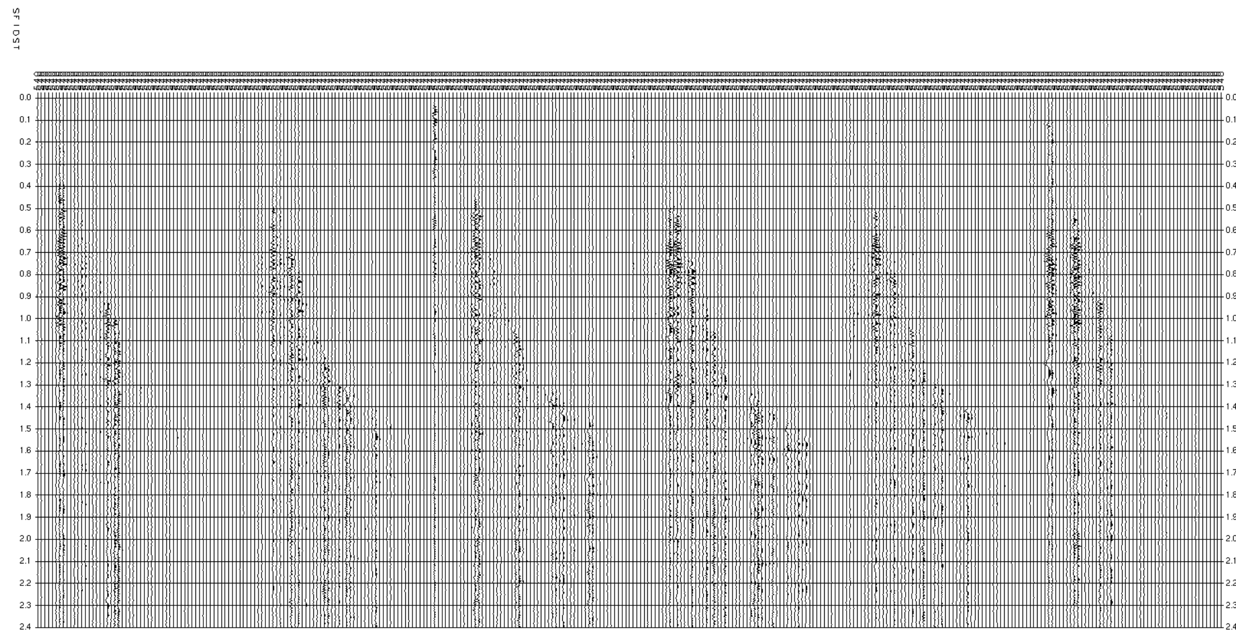

Figure 4b: The difference between the traces in Fig. 3a and Fig. 4a. These traces are a measure of the energy that 5D interpolation has not interpolated: i.e. the 5D leakage.

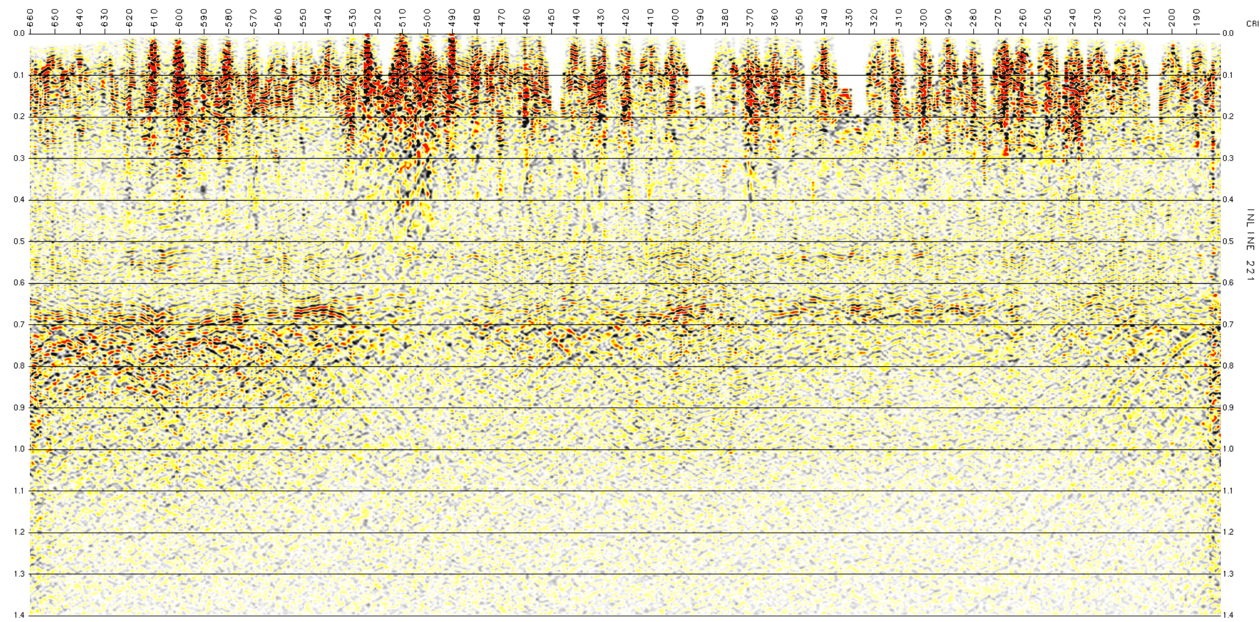

Figure 5: Stack of the 5D leakage. Note the shallow noise, the diffracted energy and the lack of flat events.

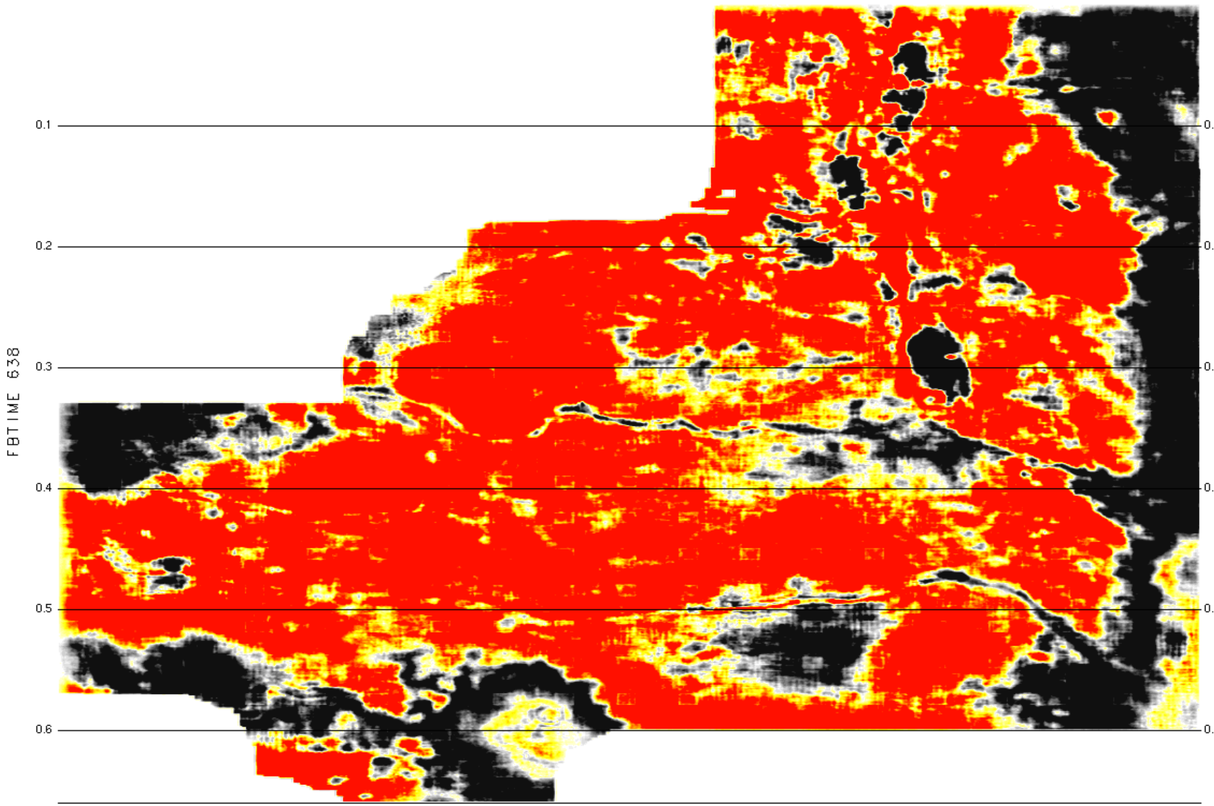

Figure 6a: Time slice of the 5D interpolated stack at 638ms

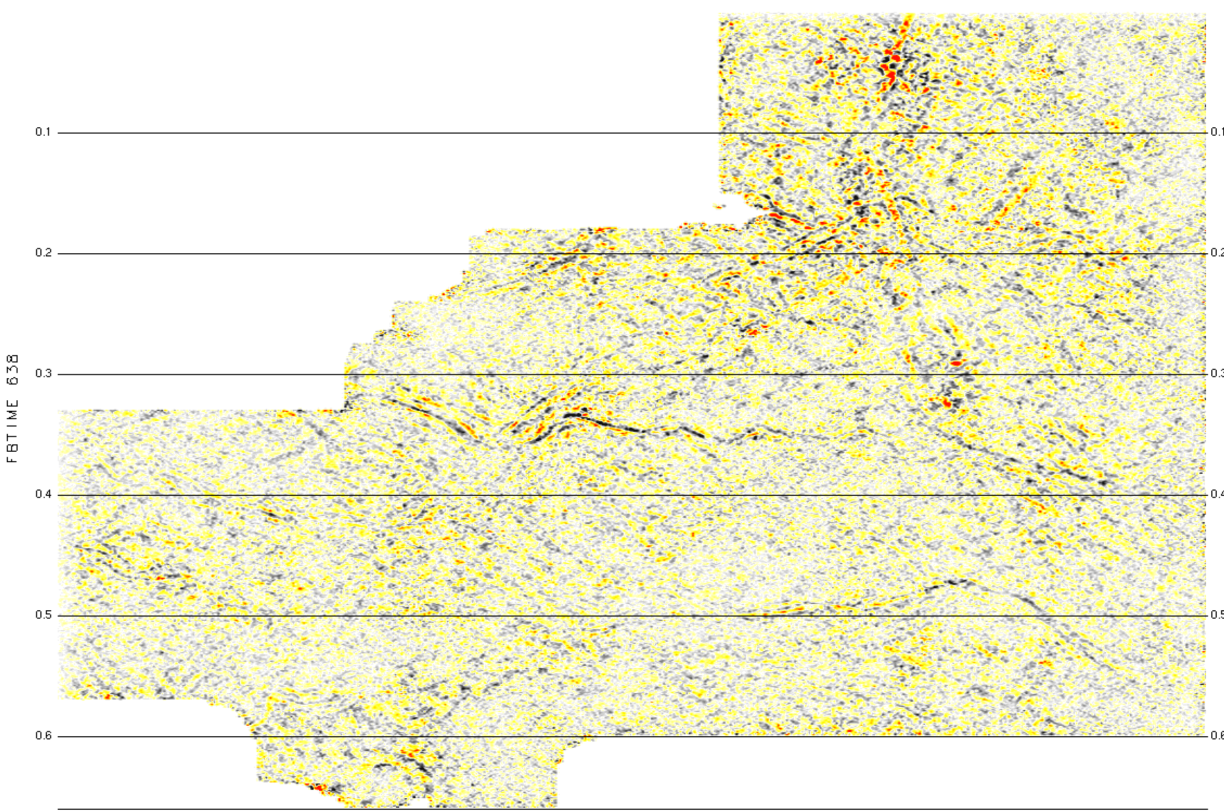

Figure 6b Time slice of the stack of the 5D leakage at 638ms

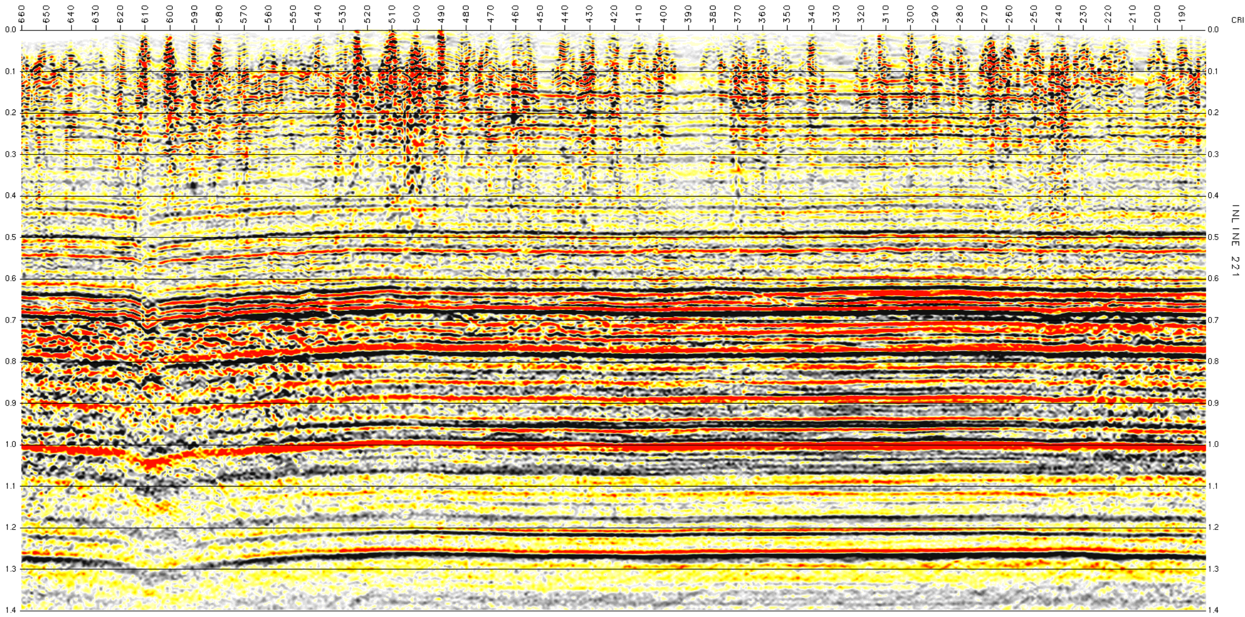

Figure 6a: Hi5D Stack: 5D interpolation with compensation for 5D leakage.

Conclusions

We have presented a method for measuring the amount of energy that is lost during 5D interpolation. This technique involves an additional interpolation step whereby data at the original input data locations are interpolated using just the newly interpolated data from a normal 5D interpolation. It appears to be an accurate measure of the energy leakage in the 5D interpolation process. A data example was used to illustrate how diffracted energy can be lost during normal 5D interpolation. We also showed that the full resolution of the input data can be retained by compensating the original 5D interpolation with the 5D leakage.

Acknowledgements

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References

Downton, J., B. Durrani, L. Hunt, S. Hadley, and M. Hadley, 2008, 5D interpolation , PSTM and AVO inversion for land seismic data: 70th Annual Conference and Technical Exhibition, EAGE, Extended Abstracts, G029.

Trad, D., 2009, Five-dimensional interpolation: recovering from acquisition constraints: Geophysics, **74**, V123-V132.