Combined Attribute Displays

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Summary

Recent advances in computer graphics have made it possible to display seismic data as true three-dimensional surfaces complete with complex lighting effects. A typical 3-D seismic display has three independent components, the 3-D structure, its colouring and a variable density plane (the 'sea level') that cuts through the display. Each component can show a separate attribute and so the display is ideal for showing various combinations of instantaneous seismic attributes. In this paper we use 3-D seismic displays to examine a number of instantaneous attribute combinations.

Of the combinations that are examined, the reflection strength structure overlaid by the seismic amplitude had the most visible benefit. It was very easy to see where the peak energy drifted away from the seismic peaks/troughs. The reverse display of seismic amplitude overlain by the reflection strength display was also informative but in a more general sense.

Colouring the seismic amplitudes with the instantaneous phase was also useful in helping enhance the continuity of weak events. However, the effect was not as pronounced as one might expect because the 3-D display of the seismic data itself is very effective at resolving low amplitude events.

We used the sea level plane to associate high frequency changes in the instantaneous frequency with the seismic data. The sea level plane is an excellent method of visually associating two attributes and in this case it proved better than simply colouring the instantaneous frequency with the seismic amplitudes. The high frequency spikes that protruded through the seismic sea level were visually dramatic and their association with the seismic data was obvious.

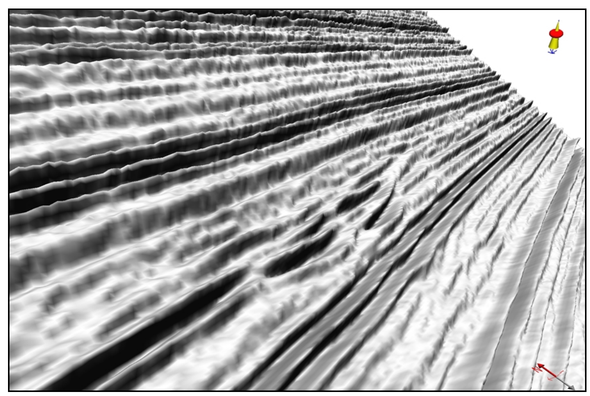

Figure 1: The structural (3-D) component.

Introduction

This paper has two specific objectives. The first is to show the usefulness of displaying instantaneous seismic attributes as three-dimensional surfaces and the second is to examine various combinations of attributes using the three independent components of a 3-D seismic display.

The typical Fourier analysis of a seismic signal decomposes the data with the assumption that the frequency content does not change with time. This assumption is a major drawback for the analysis because seismic data are rarely stationary in time. As any geophysicist knows, the frequency content and phase of a seismic wavelet is continually changing which limits the effectiveness of Fourier analysis.

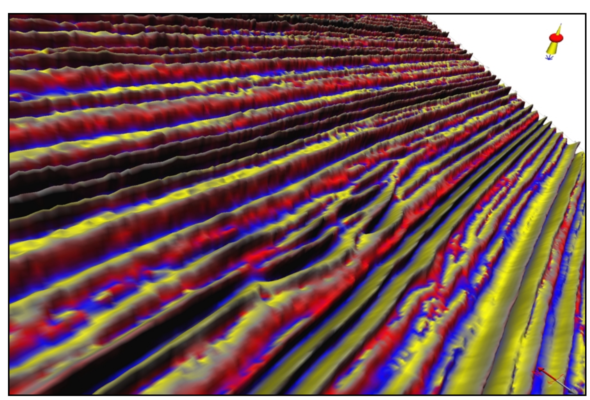

Figure 2: Colouring of the 3-D surface using the instantaneous phase for the colour.

This problem is not restricted to geophysics; in fact, Gabor first developed the concepts of complex trace analysis in the mid-1940's with application to frequency modulated radio signals. The concepts developed by Gabor were extended to the seismic realm in the mid 1970's (Taner, et al 1979).

Unlike the Fourier attributes that show the spectral properties averaged over a window, instantaneous attributes provide a sample-by-sample look at similar properties. The instantaneous frequency, for example, provides a sample-by-sample estimate of a trace's dominant frequency. As a result, instantaneous attributes have become widely used in exploration geophysics. For example, Adriansyah et al 2002, showed how a lowering of the instantaneous frequency when combined with anomalously high reflection strength can be used to indicate the presence of gas. Kim et al, 1994, used instantaneous phase plots to identify major and minor fracturing. Hardage et al, 1998 used 3-D instantaneous frequency as a coherency parameter.

There are, however, several drawbacks when working with instantaneous attributes. The first is that it can often be difficult to relate changes observed in the attribute display back to the original seismic data. Since attribute displays are most often displayed in colour, given our poor sense of colour separation, it can be difficult to discern subtle changes in them. Attributes are also often best used in combination. For example, the combination of high reflection strength and low instantaneous frequency is often indicative of gas but it can be hard to visualize the two together. Finally, since the instantaneous attributes of frequency and phase are amplitude independent, they can be often severely affected by noise, which sometimes renders them uninterpretable.

Combined Attribute Displays

Although instantaneous attributes are used quite often in interpretation, their effectiveness is limited by difficulties in interpreting them. Often, because they are separate from the seismic data, it can be hard to associate changes in attributes with changes in the seismic data itself. This difficulty can be further compounded if we need to compare two attributes directly, such as reflection strength and instantaneous frequency, and then associate the result with the seismic data.

Often, attributes are used as a colour background to a wiggle trace section but this display is limited. If the wiggle trace fill is shown it obscures the attribute we are examining and if it isn't shown then the traces are hard to interpret. Coupled with this is the fact that wiggle trace displays, to be effective, need a large amount of screen real estate. Consequently they are not usually the display of choice.

Three-dimensional seismic displays (also known as SeisScape® displays), however, have three independent elements that can each represent a different attribute. The elements are:

- The three-dimensional structure (Figure 1).
- The colouring of the structure (Figure 2).
- The "Sea Level" plane that cuts through the display (Figure 6).

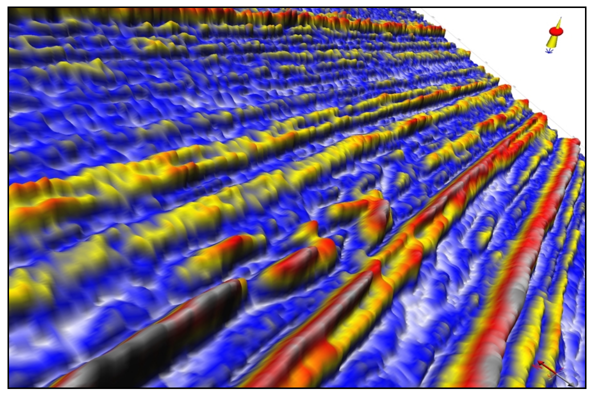

Figure 3: Reflection strength display of the seismic data from Figure 1.

Of the three components, the first two, the 3-D structure and its colouration are easy to understand. The third component, the sea level display (Figure 6), is a variable density display of a particular attribute and it is used to slice through the 3-D structure. It is particularly effective at highlighting amplitude anomalies and it also helps to associate observed anomalies on the structural component with another attribute.

Reflection Strength/Seismic Amplitude

The reflection strength display is a phase independent view of the amplitudes. It is the square root of the trace's energy and thus can show where, in a wavelet, the maximum energy occurs. It can be used for a number of things, including looking for gas related bright spots. However, we will use it here to analyse subtle lithological changes that may not be readily apparent on the seismic data itself.

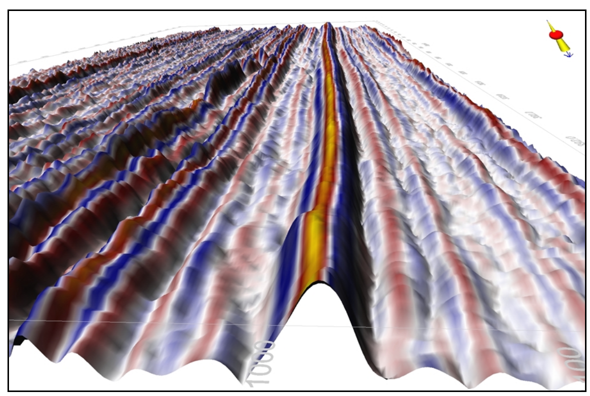

Figure 4: Reflection strength structure coloured by the seismic amplitudes (viewed end on). Notice how the seismic peak amplitude (yellow) twists off the peak of the reflection strength structure.

Realizing that seismic reflections are almost always composite reflections adds an often-unwelcome degree of complexity to an interpretation. Life would be much simpler if each reflection that we observed was a single wavelet. Since they aren't and since closely spaced reflections interfere with each other, the reflection strength display becomes one of the most important instantaneous attributes.

In a consistent lithological environment we would expect that the position of the peak energy with respect to the seismic peaks and troughs would remain the same. Observing how it changes can give us a good idea of how much the lithology is actually changing.

Because of this it is important to be able to closely relate observed changes on the reflection strength display back to the seismic amplitudes. For this reason we have selected the reflection strength/seismic amplitude combination as my first example.

Looking at the prominent peak on Figure 4 we can see that the peak, at the start of the display, closely corresponds to a peak on the seismic data (peaks are yellow, troughs are blue). Following along the event we can see that the yellow peak seismic amplitudes seem to twist off the peak of the reflection strength display. This is what we are looking for in this display combination. It indicates that the peak energy in the wave packet is moving down the trace, away from the peak on the seismic itself.

Instantaneous Freq/Seismic Amplitude

The instantaneous frequency display is the rate of change of the instantaneous phase. As such, it produces a display of the sample-by-sample variation of a trace's dominant frequency. This is one of the more useful attributes and it has been used for such varied tasks as helping identify gas sands, determining edge terminations of stratigraphic plays and for identifying faults in 2-D and 3-D.

As with both the reflection strength and the instantaneous phase displays, this display can also be hard to associate back to the seismic data itself. Being amplitude independent also means that it is prone to high frequency noise spikes, something that is evident on Figure 5.

This combination relates high frequency events on the instantaneous frequency display to the seismic data by extruding the instantaneous frequency structure through the seismic amplitude display. The seismic amplitudes, in this case, are displayed as a variable density plane called a "Sea Level" display (because the plane can be dynamically raised and lowered through the 3-D structure).

Having examined this display in detail we think that is more effective at associating high frequency events to the seismic amplitudes than it would be by simply colouring the structure with the seismic amplitudes. An important task here is to filter out noise spikes that come from very low amplitude areas from high frequency spikes that may be lithologically based. By examining Figure 6 we can see that most of the noise spikes that extrude through the plane come from areas of very low amplitude or from zero crossings. As a result most of them can quickly be discarded. However, in the area of the channel there are a number of high frequency events that clearly are not caused just by low amplitude variations. As such, we can garner a high degree of confidence that what we are seeing around the channel is the result of lithological changes and not just noise.

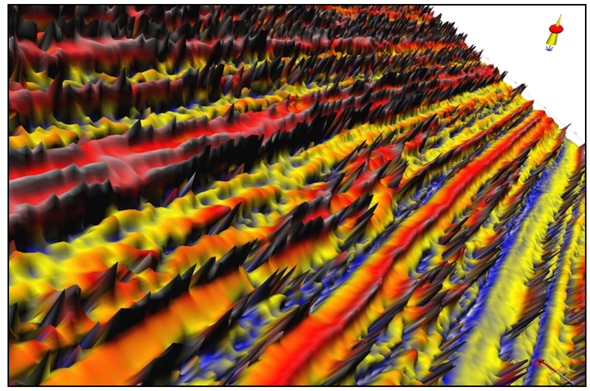

Figure 5: Instantaneous frequency display. Note the prominent noise spikes.

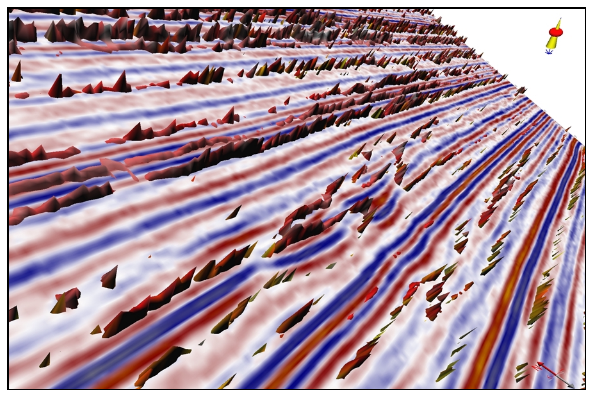

Figure 6: The instantaneous frequency cutting through a seismic amplitude "Sea Level"

We think this is a particularly effective display and whereas it may lack the visual impact of some of the other displays produced here, it communicates a higher degree of information.

Weighted Freq/Seismic Amplitude

The final combination that we will show uses a weighted average frequency coloured by the seismic data itself. Comparing Figures 5 and 7 we can clearly see the effect of the frequency smoothing. Figure 5 shows the local dominant frequency whereas Figure 7 shows the dominant frequency over the smoothing window. We weren't looking for anything dramatic here. What we wanted to see was if colouring by the seismic data made the display more or less useful.

Of the two displays, Figure 7 is more effective at showing where the actual frequency highs and lows are. It is also more visually dramatic. But again, as with all attribute displays, it suffers because we don't know exactly how the highs and lows relate to the seismic data itself. However, looking at the channel on Figure 8, it is easy to see where the high frequencies are in relation to the seismic data peaks and troughs. Also, if you look carefully at the prominent event immediately below the channel you can see that it is also quite easy to follow the changes in the frequency along it.

Conclusions

In this paper we introduced the concept of using three-dimensional seismic displays to show combinations of instantaneous seismic attributes.

Looking at instantaneous seismic attributes in 3-D is far more informative than looking at them as simple variable density images. The 3-D displays have far more visually impact than the corresponding variable density images and they communicate much more information. As such, if for nothing else, they are useful for presentation purposes.

One of the reasons for the visual impact of the displays is that the reflection strength, instantaneous frequency and weighted average frequency are all one sided displays. That is, they do not have peaks and troughs. This makes them even more interpretable in 3-D than is the seismic data itself. The instantaneous frequency is particularly effective in 3-D because it is easier to see which anomalies should be discarded as noise and which ones are lithologically based.

Of the attribute combinations that we experimented with, the reflection strength structure overlaid by the seismic amplitude had the most visible benefit in that it was very easy to see where the peak energy drifted away from the seismic peaks/troughs.

Colouring the seismic amplitudes with the instantaneous phase was also useful in helping enhance the continuity of weak events. However, the effect was not as pronounced as one might expect because the 3-D display of the seismic data itself is very effective at resolving low amplitude events.

We showed one example of using the sea level plane to help associate high frequency changes in the instantaneous frequency back to the seismic data. The sea level plane is another method of associating two attributes and in this case it was better than simply colouring the instantaneous frequency with the seismic data itself. The protruding high frequency spikes were very easy to associate back to the seismic data.

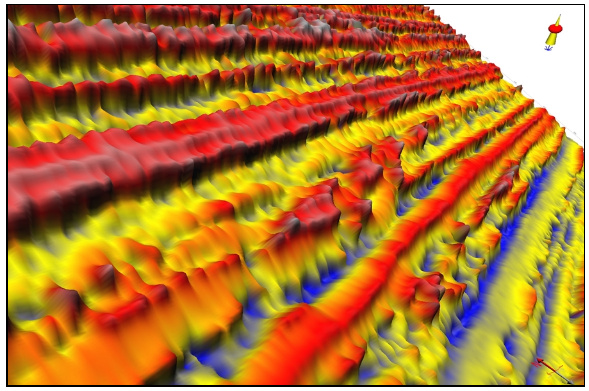

Figure 7: Weighted average frequency. Note the increase in frequency within the channel.

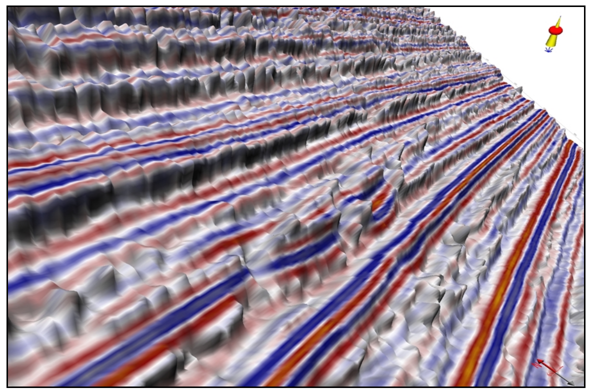

Figure 8:Weighted average frequency coloured by the seismic amplitudes.

References

Adriansyah, A., and McMechan, G.A., 2002, “Analysis and interpretation of seismic data from thin reservoirs: Northwest Java Basin, Indonesia”, Geophysics, Vol. 67, No 1, 14-16.

Barnes, A. E., 1992, “The calculation of instantaneous frequency and instantaneous bandwidth”, Short Note, Geophysics, Vol. 57, No 11, 1520-1524.

Barnes, A. E., 1996, “Theory of 2-D complex seismic trace analysis”, Geophysics Vol. 61, No 1, 264-272.

Barnes, A. E., 2000, “Weighted average seismic attributes”, Geophysics Vol. 65, No 1, 275-285.

Hardage, B. A., Pendleton, V.M., Simmons, J.L.Jr., Stubbs, B.A., Uszynski, B.J., 1998, “3-D instantaneous frequency used as a coherency/continuity parameter to interpret reservoir compartment boundaries across an area of complex turbidite deposition”, Geophysics, Vol. 63, No 5, 1520-1531.

Kim, J.S., Moon, W.M., Lodha, G., Serzu, M., and Soonavvala, N., 1994, “Imaging of reflection seismic energy for mapping shallow fracture zones in crystalline rocks”, Geophysics, Vol. 59, No 5, 753-765.

Lynch, S., 2000, “Ancient Evenings, “Seismic Visualization using very old techniques”, CSEG Recorder, Vol. 25, No 8, 5-6

Taner, M.T., Koehler F., and Sheriff, R.E., 1979, “Complex seismic trace analysis”, Geophysics, Vol. 44, No 6, 1041-1063.