Wavelet Stability: Raising The Bar

Brian Link, Stewart Trickett, Florian Romanescu, and Constantine Tsingas*
Kelman Technologies Inc

2005 CSEG National Convention

GEOPHYSICAL INNOVATIONS Made in Canada 2005 CSEG National Convention

Summary

Link and Trickett (1997) argued that wavelet instability is a serious problem that is often ignored because it is difficult to identify and prevent. They suggested we use processing flows and quality controls that are specifically designed to prevent lateral phase instability in the stacked section. Today, however, we also require wavelet stability in the offset domain. This is needed for accurate pre-stack inversion of seismic data to obtain lithologic and fluid content information. An integrated series of tools have been developed in recent years that enable inversion to be more successful on land data, addressing such problems as noise, far-offset NMO, NMO stretch, and multiples.

Introduction

Link and Trickett (1997) presented an SEG paper entitled "Wavelet Instability: Issues and Risk Management Strategies." The paper addressed the processing requirements for ensuring lateral wavelet stability dictated by an increasing need to identify increasingly subtle stratigraphic plays. It stressed the need to consistently use an integrated series of processing procedures and quality controls that were capable of the following: a) prevent lateral phase errors in the majority of cases, b) recognize them if they did occur and, c) correct them after they have been recognized

It is now 2005 and the bar has been raised. The 1997 paper concentrated primarily on producing a migrated stacked section that was free of lateral wavelet instability. The goal was to give the interpreter the assurance that any observed subtle lateral phase changes could be interpreted as a response to an actual change in the geology at the horizon of interest. This was particularly important if post-stack inversion was used to highlight the slightest changes in the seismic response. Now, we not only do post-stack inversion, but we often attempt full pre-stack elastic inversion on land data to acquire information about lithology, reservoir fluids, rock properties, and so on. This means that we now require the pre-stack data to have sufficient and stable S/N and resolution from the near to the far traces. The goal of this paper is to update our understanding of the requirements for wavelet stability to include the pre-stack domain and to illustrate how seismic processing technology has responded to the challenge.

Let's review the basic processing requirements for lateral wavelet stability as we understood them in 1997. The following three paragraphs and Figure 1 are taken from the above mentioned paper:

> The prevention, recognition, and correction of lateral wavelet instability are critical to exploration success in stratigraphic plays. A comprehensive series of processing procedures and quality control displays can provide improved risk management of this problem. We design our processing flow such that, on a routine, consistent basis, procedures for the prevention of lateral wavelet instability are incorporated. First, we recognize that the effects of noise leaking onto the deconvolution operators cause most wavelet instability problems so we use various amplitude spectral preconditioning processes that attempt to eliminate the noise. Second, we quality control the computed deconvolution operators using an interactive tool which allows us to investigate the amplitude and phase spectra of each source and receiver. If we find evidence that noise effects have leaked through onto the operators we can then either edit the noise directly on the operators or redesign our amplitude spectral preconditioning strategies and repeat the operator computation.
>
> Even with the best quality control procedures before the application of deconvolution, it can sometimes happen that wavelet instability is found to exist on the reflection data after deconvolution. We use various displays such as shot and receiver stacks to check for, and define the problem and then correct it with an interactive program which does pre-stack shot by shot and receiver by receiver phase matching. At the post deconvolution, pre-stack stage, we simply measure the magnitude of the problem and correct it with surface consistent all-pass phase-only operators. Ideally, where possible, we would go back to the prevention mode and compute minimum phase operators that correct the problem up front. It is also important to use a post stack analysis tool that will routinely produce a simple display that will act as a red flag for wavelet instability. At minimum, the interpreter should have this lateral phase diagnostic available before making the decision to drill a subtle stratigraphic play so that the risk factor attributed to the possibility of wavelet instability can be included in the decision making process.
>
> Our phase correction needs are shown in Figure 1. As an industry we tend to settle for a gross correction to zero phase post stack by applying a constant-phase correction to well data. Relatively little attention is paid to removing the non-linear phase errors and to

checking for lateral phase consistency. We believe that if we can first improve the lateral phase consistency we will be in a better position to estimate a complete frequency-dependent correction to zero phase. As an industry, we also tend to put a great deal of effort into broadening the data bandwidth, which is indeed a noble and useful goal. However, in so doing, if we have not properly addressed our phase correction needs, we may actually be harming our ability to correctly interpret the lithologic significance of lateral character changes.

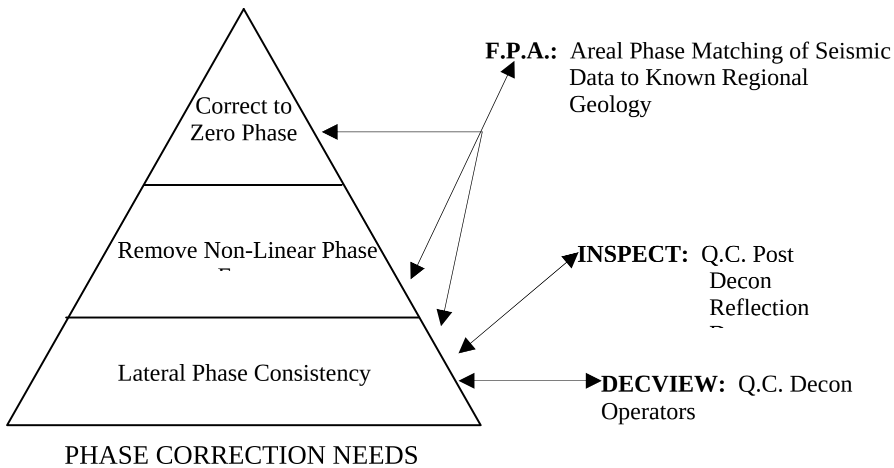

Figure 1: The hierarchy of needs for phase correction. The interactive tools on the right allow us to control statistical instabilities in batch type processes. The final constant-phase correction to zero phase will only is successful if we first address the need for lateral phase consistency and removal of non-linear phase errors.

Developments that allow the possibility of pre-stack inversion on land data

In the Western Canadian Basin, and in many parts of the world, the acceptance of pre-stack inversion on land data as a reliable tool is still evolving. In many marine environments the seismic data has sufficient quality such that inversion has been broadly accepted in the interpretive process. Also, in areas such as the Gulf of Mexico, lithology and fluid changes due to the presence of hydrocarbons in relatively young, unconsolidated sediments are much more readily recognized than in other parts of the world where harder, more consolidated rocks prevail.

In land data, very real difficulties for pre-stack inversion exist. The following list identifies the problems and suggests proposed solutions:

Noise: Koza and Castagna (2003) and Downton and Lines (2001) examined the effects of noise on various types of AVO plays, and found that moderate to severe noise can cause certain classes of anomalies to become unreliable or undetectable. Renard and Lailly (2001) propose the use of robust statistics during seismic inversion to avoid distortion due to coherent noise. They demonstrate that traditional seismic inversion, combined with poor noise removal, can lead to disastrous results.

Noise can be categorized as powerline, random, or coherent. Most processing centres have algorithms for removing powerline noise, often along the lines of the "model and subtraction" method of Butler and Russell (1993). These have been so successful that the powerline noise problem can now be considered mostly solved.

Most methods for removing random noise are designed for stacked data. Adapting these methods for prestack land data, with theirs irregular geometries and low CMP fold, is a problem. Traditional methods based on Fourier or Radon transforms are often harsh and artifact prone, and so now are rarely used. Recently methods have been proposed by Trickett, et al (2003) and Aiyuan and Xinyuan (2003) involving "locally surface-consistent" algorithms. Trickett's algorithm allows us to escape the "chicken and egg" problem of trying to estimate statics on noisy data.

Coherent noise is generally the most troublesome It was often not necessary, however, for the processor to remove all of it. When estimating surface-consistent deconvolution or statics, for example, the processor could often choose to exclude contaminated parts of the data during the design phase. With prestack inversion, however, this is not an option. The effective removal of coherent noise, without damage to the underlying signal, becomes critical. Chiu and Butler (1997), for example, describe a method that allows accurate modeling and subtraction of linear noise, with amplitude fitting to limit the impact on reflection data.

Far-Offset NMO: Very far offsets are required to help identify the various types of AVO/AVA classes. Travel time estimates are greatly affected by both anisotropy and vertical velocity heterogeneity at these far offsets. Higher-order NMO (or η-term NMO) velocity picking and application techniques have been developed that allow the removal of the hockey stick effect on our seismic data. This enables the use of even further offsets (and even noisier data) in the interpretation process.

NMO Stretch: Use of the further offsets for inversion purposes is sometimes limited by NMO stretch, which distorts the seismic wavelet at these offsets (Swan, 1997). Even the most robust inversion techniques often require that we extract offset-varying wavelets from near, middle, and far stacks before the inversion process can go forward. The wavelets extracted are only valid for a small time interval since the effects of NMO stretch are dynamic. A number of "stretch-free" methods of normal moveout have been proposed in recent years (Trickett, 2003), such that we can use near, middle and far offset stacks without having to worry so much about these effects. Hunt, et al (2003), gave one such case study. Downton and Lines (2002) suggest AVO analysis before NMO.

Multiples: Multiples that have little or no velocity differentiation from the primaries are a serious problem. The degree of contamination is highly variable with offset, and directly limits the accuracy of any AVO/AVA inversion process. Traditional techniques such as hyperbolic Radon multiple suppression are not useful in these cases. Surface-Related Multiple Elimination (SRME) has been well established as a successful approach for marine data. Borselen, et al (2004) have now shown how SRME can be applied to land data. The most exciting characteristic of this approach is that it is totally data driven.- it does not require knowledge of primary or multiple velocities. It does, however, require good signal-to-noise, which is often not found in land data. With improved pre-stack noise-removal tools such as those described above, however, SRME for land data may be within reach.

Conclusions

Since 1997, we have made tremendous progress in using far offsets in the interpretive process. New noise suppression routines have been developed that are capable of removing the noise with minimal damage to the underlying primaries. Higher order (or anisotropic) NMO has allowed us to accurately predict the travel time behavior to much higher angles of incidence. Stretch-free stacking (SFS) has been developed so that we can now look at near, middle and far stacks without worrying about major errors due to NMO stretch. Revolutionary multiple modeling routines that are data driven, and do not require a knowledge of velocity or the ability to discriminate between primary and multiple velocities, have been proven for marine applications and are now being tested on land data.

Our goal is to make pre-stack inversion viable for land data by stabilizing the wavelet in the offset domain. As a bonus, however, post-stack analysis will also improve. For example, well-log tying, horizon attribute extraction, and post-stack inversion should all benefit from better pre-stack processing.

References

Aiyuan, H. and Xinyuan, Z., 2003, Random noise attenuation under surface-consistent consideration, 73rd Ann. Internat. Mtg.: Soc. of Expl. Geophys., 2036-2039.

Angus, K., Link, B., and Kieruff, F., 1990, "How pre-stack noise can cause post stack polarity identification problems: a case study from Northern Alberta", SEG abstracts, 285.

Borselen, Fookes, Schonewille, Tsingas, West, Al Jeelani, and Nahhas (2004), Pre-stack land surface and interbed demuliple methodology: An example from the Arabian Pensinsula, CSEG Recorder 29, # 5. 36-42

Butler, K. E. and Russell, R. D., 1993, Subtraction of powerline harmonics from geophysical records (short note): Geophysics, Soc. of Expl. Geophys., **58,** 898-903

Cambois, G., and Hargreaves, N., 1996 "Zero-phase conversion of marine data using one-parameter phase filters and kurtosis maximization", SEG Abstracts, 1591-1594.

Chiu, S. K. and Butler, P., 1997, 2-D/3-D coherent noise attenuation by locally adaptive modeling and removal on prestack data, 67th Ann. Internat. Mtg: Soc. of Expl. Geophys., 1309-1311.

Downton, J. and Lines, L., 2001, AVO feasibility and reliability analysis in the presence of random noise: Recorder, **26,** no. 6, 66-73.

Hunt, L., Trickett, S., Levesque, D., McKenny, P., Link, B. and Jamieson, S., 2003, The effect of stretch-free stacking on a clastic exploration play in Alberta, Canada, 73rd Ann. Internat. Mtg.: Soc. of Expl. Geophys., 321-324.

Hutchinson, D., 1987, "Surface consistent effects: A unified approach to deconvolution and statics", presented at the 49th meeting of the EAEG.

Hutchinson, D. and Link, B., 1984, "A solution to the problem of deconvolving noisy seismic data", SEG abstracts, 515.

Hutchinson, D. and Link, B., 1994, "Phase balancing using interactive workstations", CSEG abstracts, 116.

Link, B. and Hutchinson, D. , 1994, "The correction of lateral phase variations", CSEG abstracts, 118.

Koza, S. and Castagna, J., 2003, The effects of noise on AVO crossplots, 73rd Ann. Internat. Mtg.: Soc. of Expl. Geophys., 274-276.

Downton, J. and Lines, L., 2002, AVO before NMO, 72nd Ann. Internat. Mtg: Soc. of Expl. Geophys., 233-236.

Link, B., Trickett, S., 1997 "Wavelet Instability: Issues and Risk Management Strategies", SEG abstracts, 1039-1042.

Renard, F. and Lailly, P., 2001, How to handle correlated noise in seismic inversion, 71st Ann. Internat. Mtg: Soc. of Expl. Geophys., 690-693.

Swan, H. W., 1997, Removal of offset-dependent tuning in AVO analysis, 67th Ann. Internat. Mtg: Soc. of Expl. Geophys., 175-178.

Trickett, S., Link, B. and Goodway, B., 1996, Improving wavelet stability by turning the deconvolution black box into a glass box, 66th Ann. Internat. Mtg: Soc. of Expl. Geophys., 1599-1602.

Trickett, S., Grimm, J., Aleksic, V. and McVee, D., 2003, Prestack f-xy eigenimage noise suppression, 73rd Ann. Internat. Mtg.: Soc. of Expl. Geophys., 1901-1904.

Trickett, S., 2003, Stretch-free stacking, 73rd Ann. Internat. Mtg.: Soc. of Expl. Geophys., 2008-2011.

Ulrych, T., Velis, D., and Sacci, M., 1996 "Wavelet estimation revisited", Seismic Source Signature Estimation and Measurment, SEG, 664-667.