Stretch-Free Stacking

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ABSTRACT

I present a novel method of computing a CMP stack directly from an NMO-uncorrected gather in a way that avoids NMO stretch. The method replaces NMO correction and stacking with a single-step inversion to zero offset. The results are generally higher frequency than a normal stack, and may contain less noise and multiple if a much more open mute than usual is used.

One drawback to the method is that an NMO-corrected CMP gather is never formed, although it can be mimicked with a series of offset-limited stacks. The inability to produce a proper stretch-free NMO-corrected gather limits the method's applicability. One successful use, however, is described in this year's convention paper "The Paradigm or the Process: An Ongoing Case Study Using Stretch Free Stacking" (Hunt, et al, 2003).

Canadian and U.S. patents are pending on this method.

Introduction

Normal moveout (NMO) stretch is a fundamental and long-standing problem in seismic processing. *Fig. 1* shows an artificial uncorrected gather. After normal moveout correction the early events are stretched at the far offsets. If we stack this unmuted gather, the early events suffer a severe loss of high-frequency energy, and thus resolution. This can appreciably reduce the interpretability of the section.

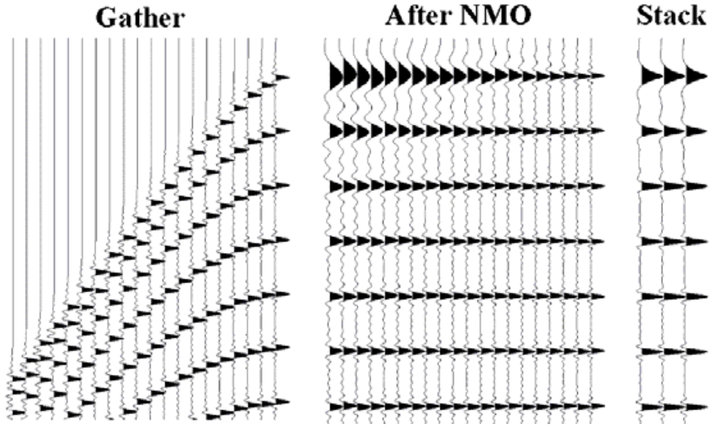


Fig. 1: The effects of NMO stretch on an unmuted gather.

There have been many attempts to solve the NMO stretch problem. The most universal is front-end, or stretch, muting, where samples at the beginning of a trace that have suffered severe NMO stretch are zeroed out. This presents some problems: first, muting may leave very little fold at early times, reducing the noise suppression provided by stacking. Indeed, for 3-D volumes particularly, muting may leave no fold at all for many CMP's at early times, creating gaps in the stack. Second, muting to remove NMO stretch is most severe at far offsets, reducing the multiple suppression provided by CMP stacking. Third, we may wish to preserve far-offset information for AVO analysis. Fourth, picking the correct mute can be difficult and time-consuming.

Rupert and Chun (1975) introduced perhaps the first non-muting solution for NMO stretch, which they called Block Move Sum NMO. Traces are first subdivided into overlapping blocks of samples. Each block then has constant-shift NMO applied, and the blocks are summed with weights to form the NMO-corrected gather. The improvements, judging from their examples, were quite mild. A related approach was described by Shatilo and Aminzadeh (2000), where the NMO function is kept constant in the vicinity of discrete events. Their method demands that the processor picks which events are to be stacked without stretch, and it is not clear how to deal with overlapping events with different velocities. Byun and Nelan (1997) patented the application of time-varying filters to NMO-corrected traces to reverse the loss of high frequencies. Lichman (1999) introduced Phase Moveout, an intriguing approach that redefines NMO as a phase-only process. Since the amplitude spectrum of each unstacked trace is preserved, no loss of high frequencies is possible.

Hicks (2001) describes a method for removing NMO stretch during stacking based on a Parabolic Radon Transforms (PRT), as well as a method which removes stretch from an NMO-corrected CMP gather based on a hybrid Fourier-Radon transform. There are a few drawbacks to these method: first, the processor must pick an appropriate path through the Radon transforms, or rely on an automatic picker whose robustness in the face of noise is questionable; second, they give poor results for overlapping events with different velocities; third, the methods may give poor results for subtle events which are not picked, and whose presence the processor may not even be aware of.

Claerbout (1992) describes the Inverse NMO Stack, which recasts NMO correction and stacking as an inversion. This resolves the problem of crossing events but not that of stretch. Nevertheless, it's an enlightening perspective on these processes. Here I present a novel method to avoid NMO stretch which combines the ideas of Claerbout's Inverse NMO Stack with Rupert and Chun's Block Move Sum. The method is simple, robust, and easy to use.

Method

Consider the NMO correction of a single trace. It doesn't matter how sophisticated the NMO equation is – whether it compensates for surface effects or nonhyperbolic effects such as anisotropy and vertical velocity gradient – the correction comes down to calculating moveout time as a function of zero-offset time (*Fig. 2*, left side). The problem with this is that it assumes events occur instantaneously, and of course they don't. The seismic wavelet is at least 20 ms long, and often much more. The result is that a different moveout is applied to the beginning of the wavelet than to the end, creating NMO stretch. What we want is to have the moveout held constant for a duration at least as long as the seismic wavelet (*Fig. 2*, right side), so that constant moveout is applied to an entire event. NMO becomes, however, a multi-valued function. With this as impetus, the method is as follows:

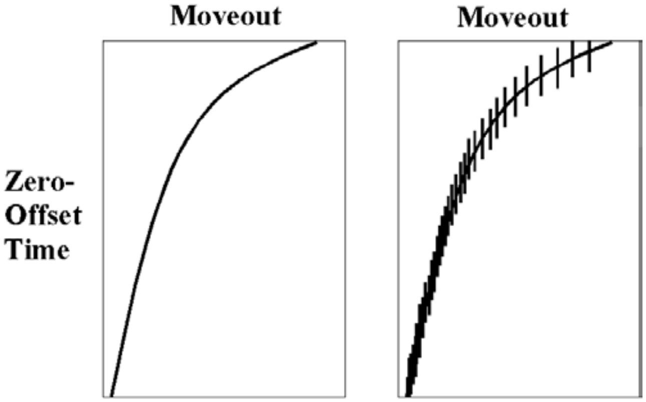


Fig. 2: A standard moveout function for a given trace (left), and the moveout function held constant for the length of the seismic wavelet at all time points (right). NMO is now a multiple-valued function.

Begin with an uncorrected CMP gather with a mild front-end mute applied, perhaps one designed only to remove strong refracting energy. Assume also that accurate stacking velocities have been picked in the usual manner. Now define *constant-moveout intervals,* or *CMI's,* which are sampled intervals of a prescribed length typically between 16 and 32 ms. At a zero-offset trace, the first interval begins at the top of the trace, the next interval begins some fixed increment below that, the third begins the same increment below that, and so forth until the end of the final interval is at the bottom of the trace (*Fig. 4*). The increment is a fraction of the interval length, typically only one or two samples long, so that the CMI's are strongly overlapping.

For non-zero-offset traces we don't define new CMI's, but instead shift the time position of each CMI so that its centre follows the NMO curve across the gather (*Fig. 4*).

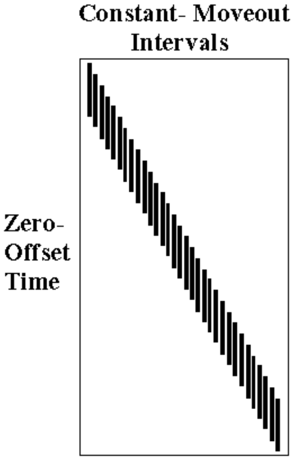


Fig. 3: At zero offset, the CMI's are defined at regular intervals down the entire trace, so that they are strongly overlapping.

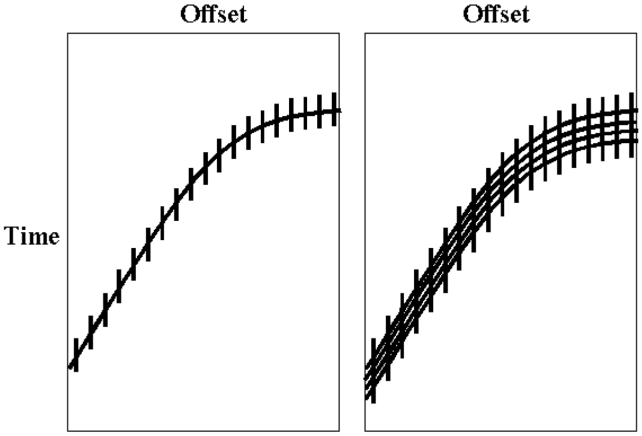


Fig. 4: At left is a single CMI as it follows the normal moveout curve through a gather. At right are four overlapping CMI's as they move through the gather.

Now think of the gather sample values as being the sum of the CMI values when placed at their proper time positions for each trace. Based on this model, solve for the CMI values by performing a statistical fit to the gather values. This might be done, for example, through a simultaneous least-squares fit using conjugate-gradient iteration (Claerbout, 1992). Form the stacked trace by summing (not averaging!) the CMI values together when positioned for zero offset.

The method can be considered a type of highly specialized Radon transform. I will call the result a *Stretch-Free Stack*, or *SFS*.

Performance Of The SFS

Fig. 5 compares the SFS with our normal unmuted stack from *Fig. 1*. Although the SFS shows some deterioration in frequency at early times, it is far superior to a normal stack. *Fig. 6* compares a muted normal stack to an unmuted SFS on noise-contaminated data. Thanks to the mute, most of the stretch problems are gone. The unmuted SFS, however, is now cleaner than the normal stack at early times due to its higher fold. *Fig. 7* compares a muted normal stack to an unmuted SFS on multiple-contaminated data. The SFS has less multiple than the normal stack at early times due to the greater range of offsets.

Does this mean that the SFS is better at suppressing noise and multiples than a normal stack? No, in general it's worse, *unless* the SFS allows a much more open mute to be used than the normal stack. The SFS is usually higher frequency under any circumstance.

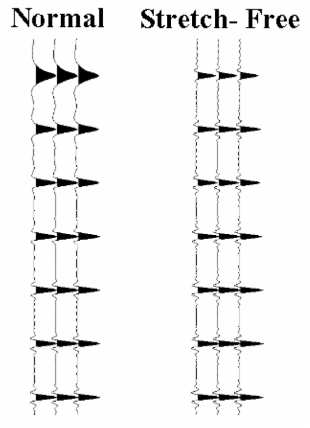


Fig. 5: Unmuted normal stack versus SFS.

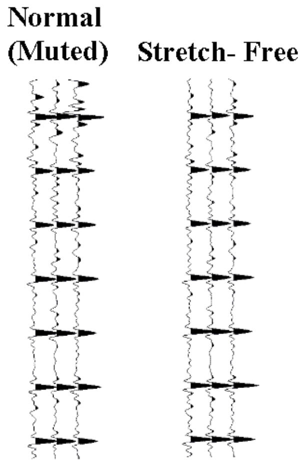


Fig. 6: Muted normal stack versus unmuted SFS for noisy data

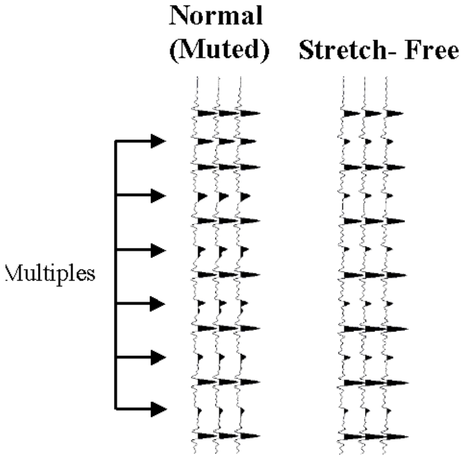


Fig. 7: Muted normal stack versus unmuted SFS for multiple-contaminated data

Fig. 8 shows an artificial gather having a sudden increase in stacking velocity, resulting in crossing events. Standard NMO correction and stacking results in highly distorted events. Of course, a stretch mute would solve this, but would produce a severe loss in fold. The SFS, on the other hand, has no problem with crossing events since it is an inversion rather than a simple remapping of sample values, allowing it to separate out energy from different events.

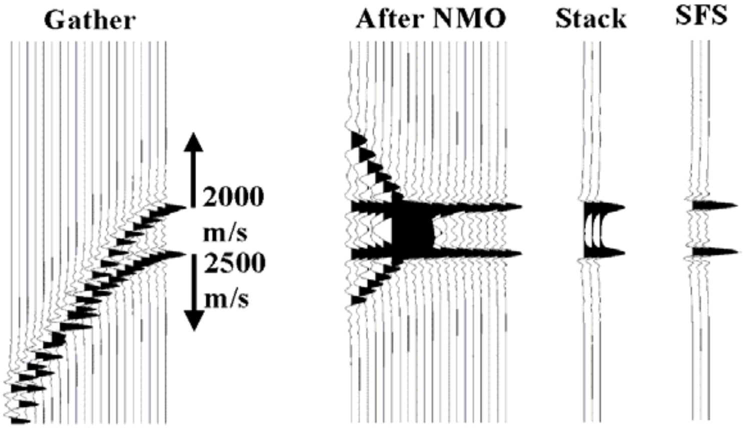


Fig. 8: A gather with crossing events does not respond well to NMO correction and stacking unless it's severely muted. An SFS handles crossing events better since it's an inversion.

Real Data Examples:

One obvious application is AVO analysis. Unfortunately, the SFS goes directly to stack without generating NMO-corrected gathers. We can mimic an NMO-corrected gather, however, by taking a series of limited-offset SFS's (*Fig. 9*).

Although the result shows less stretch than an NMO-corrected gather, a loss of amplitude can occur at far offsets – that is, when the input gather for any one offset-limited stack does not contain any near offset traces. Much of the true amplitude of the events can be recovered, however, by a time-variant scaling of the SFS derived from the minimum amount of NMO stretch at each time point.

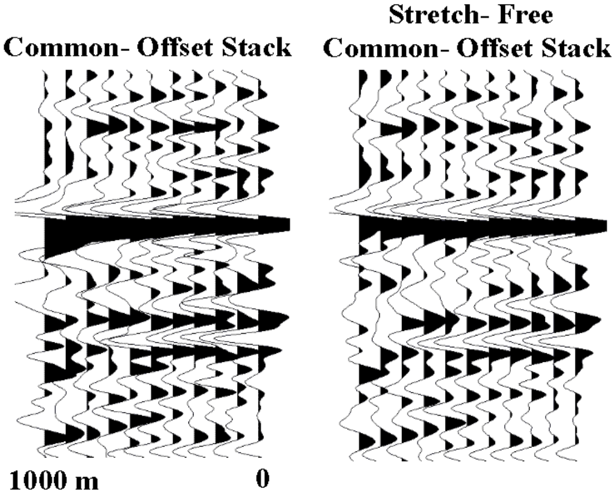
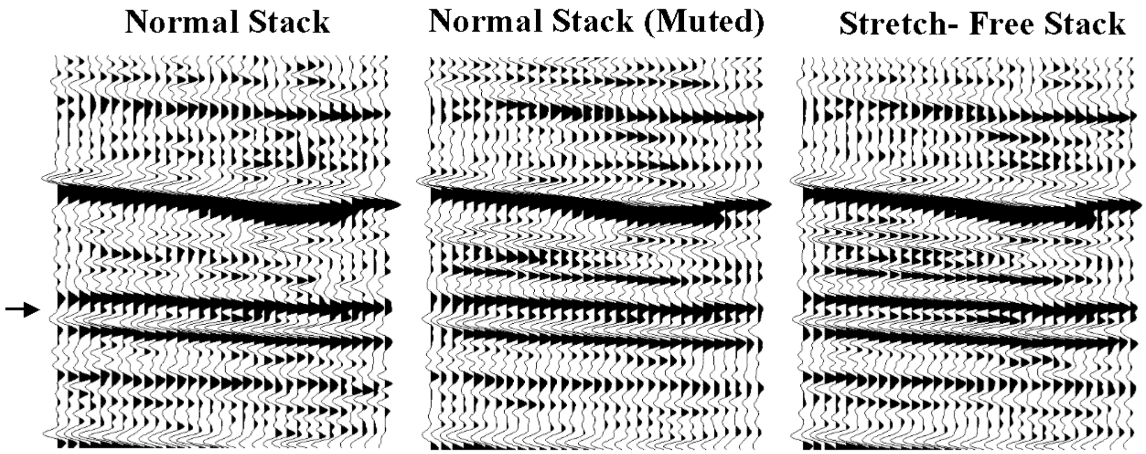


Fig. 9: Standard common-offset stacks (left) and "stretch-free" common-offset stacks which are actually offset-limited SFS's (right).

A case study featuring stretch-free AVO is given by Hunt, et al (2003), at this convention. A more sophisticated (and difficult) method of stretch-free AVO analysis is described by Downton and Lines (2002).

Fig. 10 shows a line which has a sudden vertical jump in stacking velocity, creating considerable NMO stretch. Typical NMO and stack without a stretch mute creates a poor result (left). Applying a rather severe stretch mute (middle) sharpens up the image considerably, and uncovers reflectors not evident in the unmuted stack. The unmuted stretch-free stack (right) is sharper still. Note especially the event pointed to by the arrow. This line has no particular noise or multiple problems – if it did, the severe stretch mute applied in the middle stack would be undesireable.



Normal Stack

Normal Stack (Muted)

Stretch- Free Stack

Fig. 10: Typical unmuted stack, typical muted stack, and unmuted stretch-free stack.

Conclusions:

The method presented here (Canadian and U.S. patents pending) is not the first algorithm to avoid NMO stretch, but it is one of the most robust and easiest to use. Although an NMO-corrected gather is a useful processing artifice, it's difficult to give it a physically meaningful interpretation. This might be seen as the source of our problems with stretch. The SFS avoids this by the going directly from uncorrected gather.

We do not propose that stretch-free stacking should replace standard NMO and stacking under all circumstances; rather we see it as a tool to be used only in very specific situations. Current research is focusing on determining what those situations are, and the legitimacy of the result (Hunt, et al, 2003). Possible applications are wherever NMO stretch significantly interferes with processing and interpretation, including shallow coal and shale methane plays, AVO analysis, long offset data, and zones with severe vertical jumps in velocity.

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