RMS velocity and average velocity ratio for P-S data processing

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ABSTRACT

Prestack migration by equivalent offset and common scatter point is an alternative method to conventional prestack migration. This method may be applied to converted wave data and extends the concept of equivalent offset to include the appropriate P- and S- wave velocities. In the estimation of the total traveltime in the DSR equation, RMS velocities are required for both the P and S velocities. The P velocity is available from standard P-P processing, and the S velocity is obtained from initial estimates of a converted wave velocity that is a combination of P and S velocities. An assumption of this process is the ratio of the RMS and average velocities are similar for both the P-wave and S-wave velocities. This assumption is evaluated.

INTRODUCTION

Average velocity V_{ave} is defined at a specific time or depth as the depth divided by the traveltime to that depth. The average velocity is commonly calculated by assuming a vertical path, parallel layers and straight raypaths, or the total distance divided by the sum of the transit times in each layer.

RMS velocity V_{rms} is defined as the square-root of the sum of the square of the interval velocity multiplied by the transit time, divided by the sum of the transit times, and is used to simplify the traveltime computations in a layered medium. The RMS velocity is typically slightly larger than the average velocity for a given time.

When the two values are similar, the RMS velocity can be used to provide a rough estimate of the depth. The ratio of these to velocities is assumed as constant value and they are used to estimate the travel time in the DSR equation for converted wave velocities for the estimation of equivalent offset. These ratios are demonstrated with data from Northeastern British Columbia (NEBC).

Converted wave migration using the EO concept

The prestack migration by equivalent offset and common scatter point is an alternative method to conventional prestack migration. This method is also ideally suited for converted wave processing.

Converted wave processing assumes that the downward propagating energy is a P-wave and the reflected energy is a shear wave. This S-wave is recorded with 3-component receivers (Bancroft and Wang., 1994, Wang, 1997). The processing methods start with the DSR equation (14) or (17) from Guirigay and Bancroft, 2010, with the appropriate P and S velocities for each leg of the ray path, as illustrated in Figure 2. From equation (14) and using the concepts of prestack time migration and RMS velocities for both, the P-wave and S-wave energy, the traveltime is defined by:

$$t = \left[\left(\frac{t_{0p}}{2}\right)^2 + \frac{{h_s}^2}{V_{p-rms}^2}\right]^{1/2} + \left[\left(\frac{t_{0s}}{2}\right)^2 + \frac{{h_r}^2}{V_{s-rms}^2}\right]^{1/2}, \tag{1}$$

where $V_{p\text{-}rms}$ and $V_{s\text{-}rms}$ are the respective RMS velocities for P and S waves. The vertical zero- offset traveltime of the source raypath is t_{0p}, and the vertical zero-offset traveltime of the receiver raypath is t_{0s}. The distances h_s and h_r are shown in Figure 1. The depth of the conversion point is z_0 and corresponds to t_{0p} and t_{0s}, i. e.,

$$z_0 = \frac{t_{0p}\ \ V_{p-ave}}{2} = \frac{t_{0s}\ \ V_{s-ave}}{2}. \tag{2}$$

Replacing t_0 by z_0, yields:

$$t = \left[\left(\frac{z_0}{V_{p-ave}}\right)^2 + \frac{{h_s}^2}{V_{p-rms}^2}\right]^{1/2} + \left[\left(\frac{z_0}{V_{s-ave}}\right)^2 + \frac{{h_r}^2}{V_{s-rms}^2}\right]^{1/2}, \tag{3}$$

or

$$t = \frac{1}{V_{p-rms}}\left[\left(\frac{z_0\, V_{p-rms}}{V_{p-ave}}\right)^2 + {h_s}^2\right]^{1/2} + \frac{1}{V_{s-rms}}\left[\left(\frac{z_0\ \ V_{s-rms}}{V_{s-ave}}\right)^2 + {h_r}^2\right]^{1/2}. \tag{4}$$

The same traveltime t for the equivalent offset h_e is given by:

$$t = \frac{1}{V_{p-rms}}\left[\left(\frac{z_0\, V_{p-rms}}{V_{p-ave}}\right)^2 + {h_e}^2\right]^{1/2} + \frac{1}{V_{s-rms}}\left[\left(\frac{z_0\ \ V_{s-rms}}{V_{s-ave}}\right)^2 + {h_e}^2\right]^{1/2}. \tag{5}$$

If we assume the ratio of the RMS and average velocities, V_{rms} and V_{ave} for the P and S wave velocities to be constant, the constant k may be defined as

$$k \approx \frac{V_{rms}}{V_{ave}} \approx \frac{V_{p-rms}}{V_{p-ave}} \approx \frac{V_{s-rms}}{V_{s-ave}}, \tag{6}$$

This allows for the definition of a pseudo depth

$$\hat{z}_0 = z_0 \frac{V_{rms}}{V_{ave}}, \tag{7}$$

for each square root equation (7) can be written as

$$t = \frac{1}{V_{p-rms}}\sqrt{\hat{z}_0^2 + h_e^2} + \frac{1}{V_{s-rms}}\sqrt{\hat{z}_0^2 + h_e^2}. \tag{8}$$

The square-root portions are equal, giving the hyperbolic traveltime equation

$$t = \left(\frac{1}{V_{p-rms}} + \frac{1}{V_{s-rms}}\right)\sqrt{\hat{z}_0^2 + h_e^2}. \tag{9}$$

This equation can also be written as

$$t = \frac{2}{V_c}\left(\hat{z}_0^2 + h_e^2\right)^{1/2}, \tag{10}$$

where V_c is defined as

$$V_c = \frac{2V_{p-rms}V_{s-rms}}{V_{p-rms}+V_{s-rms}} = \frac{2V_{p-rms}}{(1+\gamma)} = \frac{2\,\gamma V_{s-rms}}{(1+\gamma)}\ . \tag{11}$$

The equivalent offset h_e for converted waves can be written as:

$$h_e^2 = \frac{t^2V_c^2}{4} - \hat{z}_0^2. \tag{12}$$

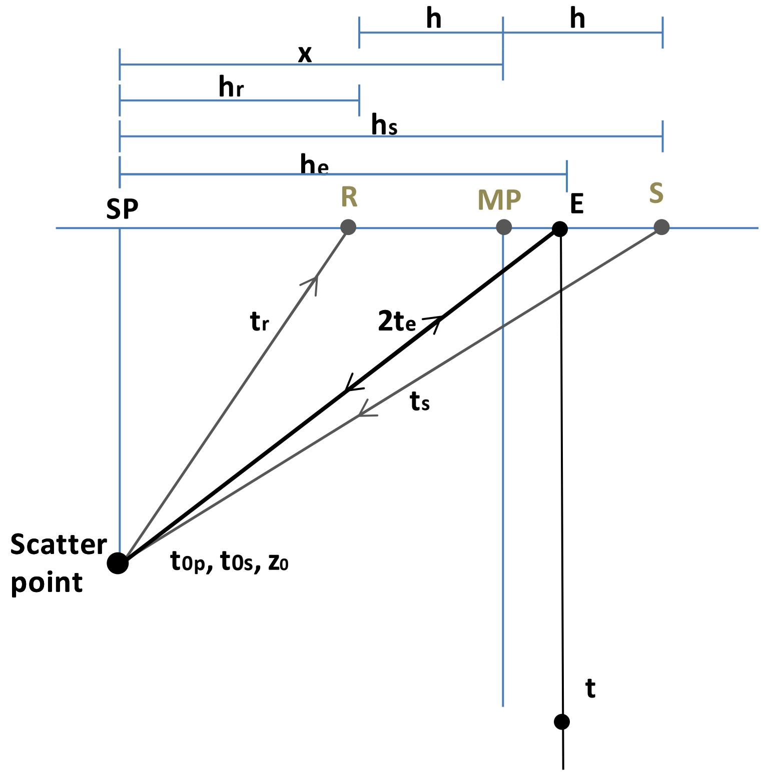

FIG 1: The raypaths and traveltime for a scatter or conversion point.

Common conversion scatterpoint (CCSP) gathers can be formed by binning the input traces at the equivalent offset. The time t is computed using equation (5) from initial estimates of V_p and V_s. The reflection energy in the gathers is hyperbolic and simple moveout correction, with a newly estimated V_c, completes the prestack migration of the converted wave data.

Critical to the process of obtaining accurate initial estimates of Vc is the assumption stated in equation (6). These relationships will be evaluated with real data.

Ratio of the RMS and average velocities

The assumption made in equation (6) is demonstrated using real data from Northeastern British Columbia (NEBC). The S velocities were converted to equivalent depths of the P velocities and then scale to P times for comparison.

Figure (2) and Figure (3) show the RMS and average velocity ratio for P and S velocity respectively. Both images justify the assumption that both ratios are relatively similar and are equal to one at zero time and increases slightly with time.

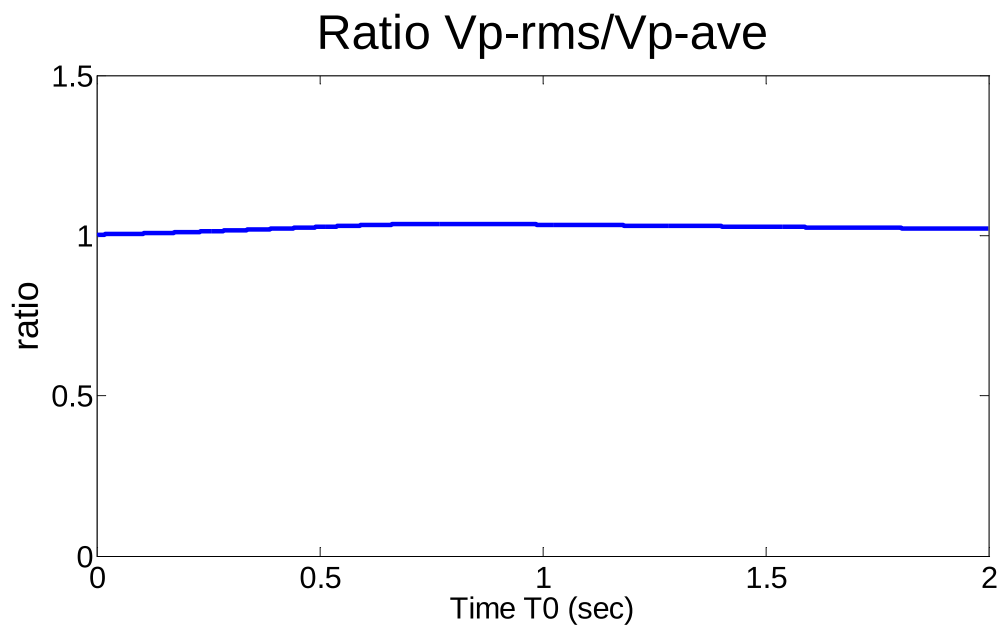

FIG 2: Ratio RMS and average velocity for P-wave velocities.

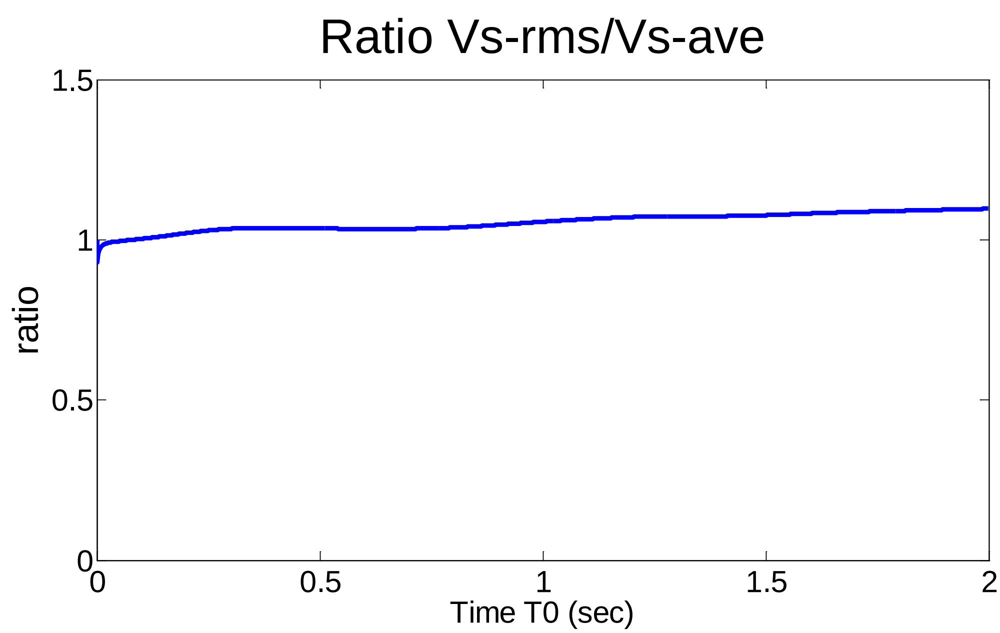

FIG 3: Ratio RMS and average velocity for S-wave velocities.

Ratio of the ratios

A more important relationship R that justifies equation (6) and the use of pseudo depth $\hat{z}$ is the ratio of the P and S velocities, i.e. the ratio of the P RMS and average velocities divided by the ratio of S RMS and average velocities or

$$R = \left(\frac{V_{P-rms}}{V_{P-ave}}\right) / \left(\frac{V_{S-rms}}{V_{S-ave}}\right). \quad (13)$$

We wish to evaluate the similarity of the P and S pseudo depths. Equation (6) is now written as

$$\hat{z}_P = z\frac{V_{P-rms}}{V_{P-ave}} \text{ and } \hat{z}_S = z\frac{V_{S-rms}}{V_{S-ave}}. \quad (13)$$

or

$$\frac{\hat{z}_P}{\hat{z}_S} = \left(\frac{V_{P-rms}}{V_{P-ave}}\right) / \left(\frac{V_{S-rms}}{V_{S-ave}}\right) = R. \quad (13)$$

The value of R for the previous data is displayed in Figure 4. A red line at 1.0 has been superimpose to illustrate the accuracy of the fit, especially less than one seconds. This area is important in estimating the initial velocities for converted wave data as the Vp and Vs velocity ratio deviates more in this area.

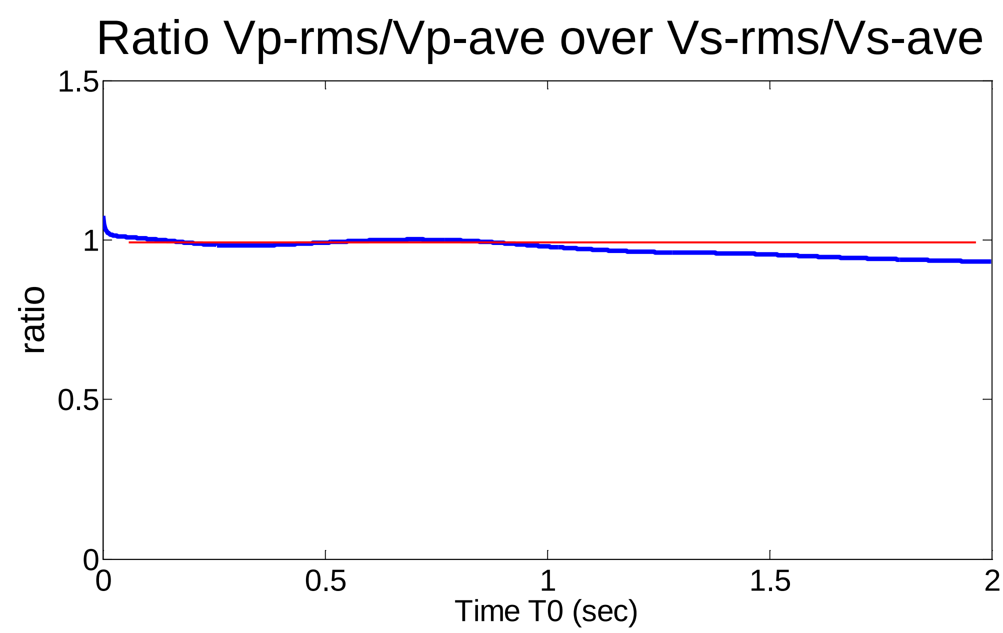

FIG 4: Ratio RMS and average velocity for P-wave velocities over Ratio RMS and average velocity for S-wave velocities.

COMMENTS AND CONCLUSIONS

The DSR equation for prestack migration of converted wave data can defined with appropriate P and S velocities for each leg of the ray paths. Using the RMS and average velocity relationship between these two modes of propagation, a converted wave velocity V_c can be derived. This velocity is used to form initial estimates of the S velocity before forming the CCSP gathers, and after the CCSP have been formed, a newly picked V_c is used to apply hyperbolic moveout correction on the CCSP gathers.

An initial estimate of the S velocities is base on the assumption that the pseudo depths of the P and S wavefields are similar. An example of real data shows the ratio of these depths to be very close to unity, justifying the assumption.

ACKNOWLEDGMENTS

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APPENDIX A

Figure containing the V_p, V_s and V_c velocities.

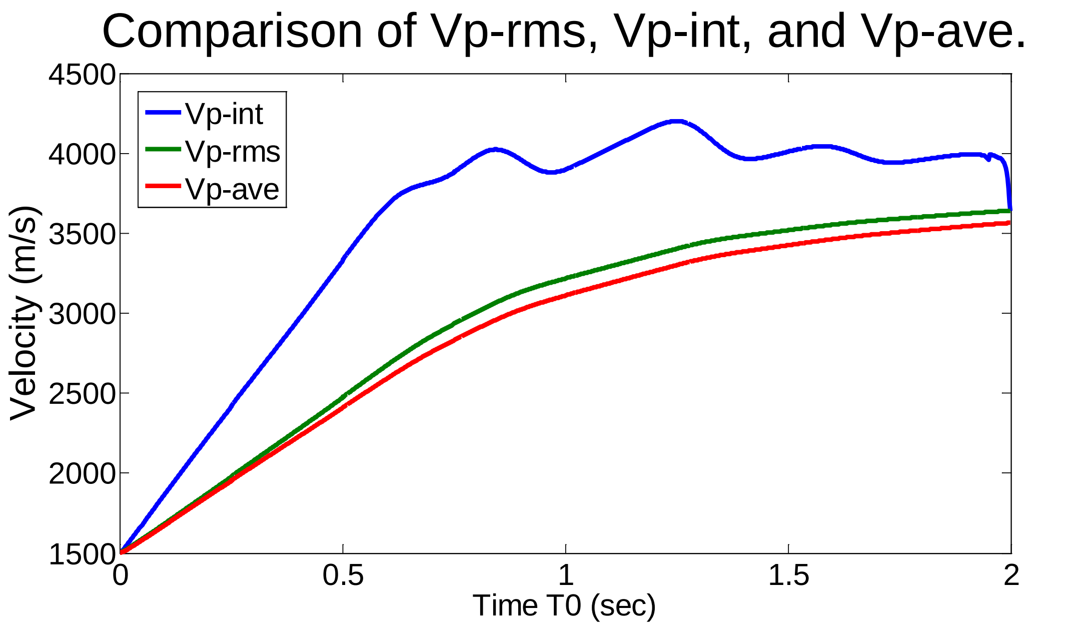

FIG A1: Interval, RMS and average velocities for the P data in T0p time.

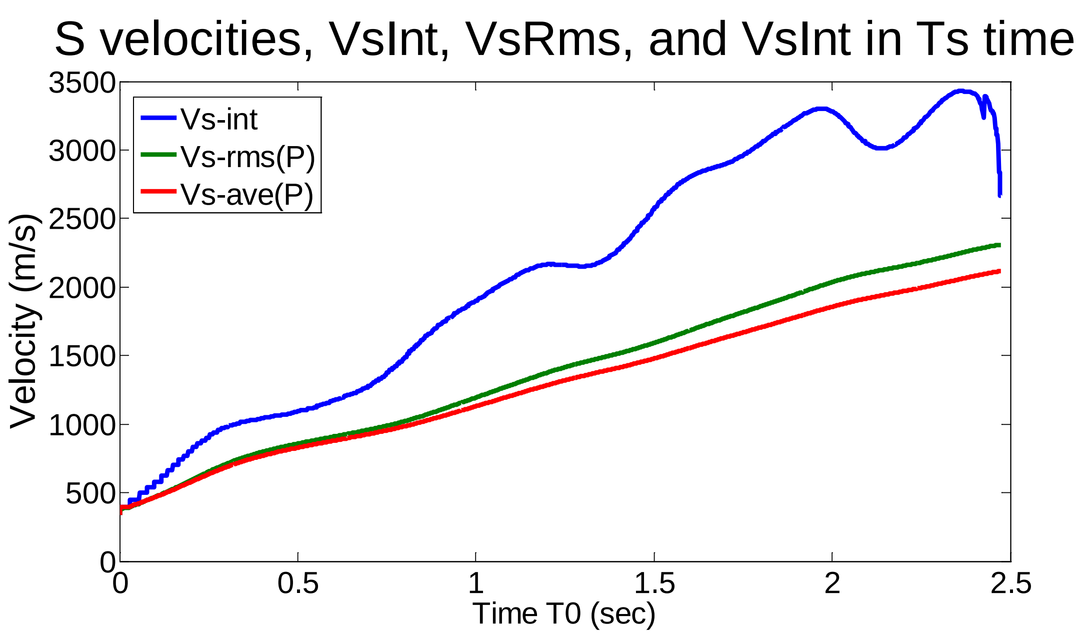

FIG A2:Interval, RMS and average velocities for the S data in T0s time.

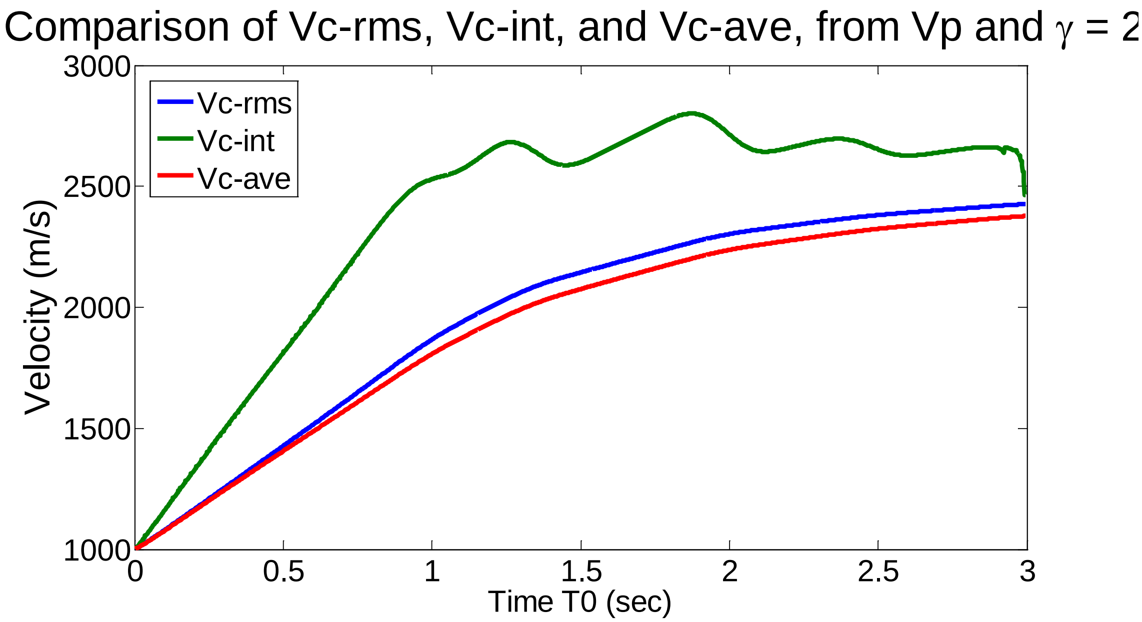

FIG A3: Interval, RMS and average velocities for the C data in T0c time when assuming a constant γ of 2.0.