C-Wave Imaging: Kirchhoff PSTM versus DMO

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Introduction

Recently pre-stack depth migration has been extended to handle converted wave data and new methodologies for performing C-wave focusing analysis have been proposed and successfully tested (Audebert et al, 2001). Unfortunately, the layer-by-layer model building inherent to the PSDM sequence is still a delicate and time consuming task. That is why the PSTM route, with its more robust approach to velocity picking, remains very appealing, despite its simpler assumptions. Kirchhoff PSTM is routinely applied on huge 3D data sets for compressional waves. Such an algorithm has also been developed to handle converted waves. This requires dealing with, either both $V_p$ and $V_s$ velocity fields or with the $V_c = \sqrt{V_p V_s}$ and $\gamma = V_p/V_s$ fields. We show how double scans and bi-spectral analysis derived from the C-wave PSDM methodology can be adapted to the PSTM technique. We illustrate this approach both on the 2D Oseberg synthetic data set and on 2D and 3D real data and show the imaging improvement as compared to a more standard DMO route.

Method

**DMO route:** For asymmetric C-wave mode the transformation to zero-offset is broken down into two steps: a zero-dip correction (NMO + conversion point lateral shift), followed by the dip-dependent move-out correction (DMO), (Herrmann, 1998). To deal with the fact that the DMO route is model-oriented and not data-adaptive, iterative velocity analysis associated with focusing analysis have to be performed first on a priori Common Conversion Point (CCP) gathers and then adjusted on DMO-corrected traces.

**PSTM:** Our migration algorithm, based on the diffraction principle in a 1D medium, handles travel times that are uniquely defined by the time-variant hybrid velocity located above the diffracting point. In a first-order approximation (short spread) the travel times are described by a double square hyperbolic move-out controlled by two effective parameters, $V_c$ and $\gamma$, according to equation (1):

$$t_{m}(\tau_m, V_c, \gamma, x_m) = \frac{\tau_m^2}{(1 + \gamma)^2} + \frac{(x_m - h)^2}{\gamma V_c^2} + \sqrt{\frac{\tau_m^2}{(1 + \gamma)^2} + \frac{(x_m + h)^2}{\gamma V_c^2}}$$

(1)

where $\tau_m$ is the migrated two-way vertical time recorded at position 0 and $t_c$ is the diffracted time recorded at distance $x_m$ from the migrated position 0.

Note that shot-receiver depth differences (OBC) and topography variations (land) are taken into account. The ($V_c$, $\gamma$) couple will be optimized in order to focus the energy at each migrated location in time and space and the optimal couple ($V_c$, $\gamma$)$_{opt}$ will represent the best compromise between the lateral positioning and the NMO correction. These lateral and time-variant quantities should be considered as effective parameters. We are assuming here that an equivalent homogeneous RMS medium can adequately describe the kinematic properties of the actual subsurface, although a slightly modified version of equation (1), based on shifted hyperbola (Suaudeau and Siliqi, 2001) can be used to account for higher-order terms and VTI effects.

2-D Synthetics and Methodology:

A 2D elastic linearized modeling was performed by the IFP on their synthetic Oseberg model, which shows a clear dipping structure (Bourgeois et al, 1994). The acquisition geometry consists of 69 shot records (30m apart) of 41 channels (60m apart). A bin size of 15m gives 84 CDP gathers of 48 traces, one half with positive offsets, the other half with negative offsets, ranging in absolute value from 60m to 1200m, by a 60m increment.

We ran our PSTM on this regular data set to output either migrated stack sections or migrated pre-stack Common Imaging Points (CIP) gathers with signed offsets. On such migrated gathers, sampled every 20 CIP positions, we devised and validated a focusing analysis methodology.

The CIP gather patch table (Figure 1a) with $V_c$ increasing from left to right and $\gamma_{eff}$ from top to bottom shows clearly that $V_c$ controls the flatness of events (C-wave move-out) and that $\gamma_{eff}$ drives the apparent dipping or gather asymmetry. Symmetry attribute maps (Figure 1c), based on the computation of cross-correlation of opposite offset traces (Figure 1b), show that the optimal $\gamma_{eff}$ value is 1.8, regardless of the $V_c$ value. Attribute maps computed from stacked gathers corrected from their asymmetry offer a clear estimate of the optimal $V_c$ velocity (2100m/s for CDP 240). From these observations a methodology can be proposed. Generate first a signed offset gather series corresponding to a $\gamma_{eff}$ scan, using the initial velocity field. The most
symmetrical gather gives the optimal $\gamma_{\text{eff}}^{(\text{opt})}$. Then, keeping this $\gamma_{\text{eff}}^{(\text{opt})}$ fixed, compute a gather series corresponding to a $V_c$ scan. Regardless of the values chosen for the initial model ($\gamma_{\text{eff}}, V_c$), the two-step mono parameter scan ($\gamma_{\text{eff}}$ then $V_c$) is able to converge towards the optimum solution. The full scan of the two dimensional $V_c, \gamma_{\text{eff}}$ domain can be avoided. This methodology, described for 2D data, can be extended to 3D data if the traces are sorted by azimuth. To check the quality of the CIP lateral shift a focusing analysis is used based on the lateral cross-correlation of the positive and negative offset PSTM stacks. Such a time-variant cross correlation provides a relevant QC of the results when the geology itself presents some lateral variations.

Figures 1: Oseberg: a) CIP gather patch table scanning the $(V_c, \gamma_{\text{eff}})$ domain; b) Cross corr of both half gather pairs.

Figure 1c: Oseberg: Left: Cross Correlation In Tau P domain for same scanning of $(V_c, \gamma_{\text{eff}})$. For each patch vertical axis correspond to $\tau$ and horizontal axis to $p$. For symmetrical gather maximum is located in center of each patch. Right: energy map for $P=0$ and $\tau=60\text{ms}$ on each patch.
2-D Real Data Example.

A 2D 4C OBC data set was processed using both routes: NMO+CCP+DMO+Post Stack migration and PSTM. The conventional processing of the converted-wave data provided initial stacking velocity fields for positive and negative offsets and an initial time-variant gamma function. Assuming these two initial \( V_c \) fields to be adequate, we first scanned the \( \gamma_{\text{eff}} \) field (70%, 100%, 130%). After updating the time variant \( \gamma_{\text{eff}} \) function by the cross correlation focusing technique, a velocity scan (95%-110%, 2% increment) was performed to provide PSTM bilateral CIP gathers (positive and negative offsets). The velocity field was picked on these CIP gathers, and new PSTM stacks were computed (for positive, negative and full offset range). Cross correlation focusing QC shows that the gamma function ruling the lateral shift has been improved. In comparison with the C-wave migrated DMO image, the PSTM section offers better event continuity and improved fault definition (Figures 2a, 2b).

To validate the CIP gather analysis technique we also computed, as we did for the synthetic Oseberg model, positive and negative offset CIP gathers, sampling the bispectral domain \( (V_c, \gamma) \), at several CCP positions. On tables of CIP gather patches the event flattening criteria allowed easy discrimination of \( V_c \) but with differences observed in each column (with respect to \( \gamma \)) being so tiny, confidence in the optimal \( \gamma \) based on symmetry measurements is low. As events are rather flat and horizontal in each geological compartment such low sensitivity is to be expected. Hence, CC focusing analysis taking into account a larger section portion is in such a case more appropriate to determine the gamma function.

3-D Real Data Example: Teal South (Gulf of Mexico)

To evaluate the impact of multi-component methodology on reservoir monitoring the ERCH Consortium launched the Teal South 4D experiment (Entralgo, 2001). Two 3D OBC 4C data sets were acquired at less than two years interval in Eugene Block 354 in the Gulf of Mexico. Both data sets were fully processed and the last acquisition results, corresponding to the better quality data, are presented here. The target area consists of 10752 bins of 12.5mx12.5m in size (112 CDPs x 96 lines). The vertical component (hydrophone calibrated) and two horizontal components, projected in both directions C1 and C2 (104° and 14° clockwise from North) were migrated. Concerning the horizontal components, the velocity and gamma fields of conventional processing (DMO route) were used as the initial function for the scanning. The time-variant gamma field was picked on PSTM migrated stack sections computed for a perturbation series of the central gamma function. The \( V_c \) fields were picked on a dense grid of CIP gathers (every 8 CIPs and every 16 lines, corresponding to a total of 105 analysis positions) retaining the previous final gamma function. Several gather patch tables corresponding to different time windows were also produced as QC for line 1104. It confirmed the mono parameter scan analysis.

The PSTM section of component C1 shows for deep events at 3700 ms a continuous dome shape, which is also present on the vertical component sections. Such a feature is not visible on the C-wave migrated DMO stacks (Figure 3).

Conclusion

Compared with conventional migrated DMO stacks, PSTM allows better imaging of the abrupt lateral variations, such as faults and structured events. As with compressional waves, the main advantage of the PSTM lies in the fact that the estimation of the velocity and gamma parameters is done directly in the final migrated position and with less iterations than with the C-wave DMO route.

References


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Figures 2a (top): 2D real data: Migrated PS DMO stack (left) versus PS PSTM (right); 2b (bottom): Close-up of Figure 2a.

Figure 3: Teal South: Migrated C-wave DMO stack (left) versus C1 PSTM section (right).