Wave-field downward continuation for seismic migration velocity analysis.

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Summary

We present an alternative approach for seismic migration velocity analysis based in depth downward continuation, as a way to perform layer-stripping velocity analysis. For the development of this technique we used a prestack downward extrapolation by using F-X explicit finite-difference operator. This method allows us to estimate accurately velocity distribution by using conventional residual curvature analysis (RCA) on resynthesized data to a lower datum. Results on synthetic data clearly showed that our velocity analysis method tends to be effective for complex media.

Introduction

Prestack depth migration is a very attractive tool for doing velocity estimation in geologically complex regions because of its high sensitivity to the velocity model. Many approaches to pre-stack migration velocity analysis have been developed such as depth-focusing analysis (DFA)(Yilmaz and Chambers, 1984; MacKay and Abma, 1992) and RCA (Al-Yahya,1989; Deregowski, 1990). All these techniques update velocities under the assumptions of small offsets, lateral velocity homegeneity, small dips and hiperbolic residual moveout. It is well known that these limitations lead to inaccurate velocity estimations in geologically complex areas.

Layer-stripping method has been extensively used for overcoming all those limitations. However, accumulated errors in the estimation of velocity migration for shallower layers can adversely affect the accuracy of the estimation for underlying layers. Bevc (1995) suggested that it can be advantageous to perform velocity estimation from a datum that it is closer to the target of interest. In this paper we combine the wave-field downward continuation (WFDC) and the RCA methodology for migration velocity estimation which produces an enhanced layer-stripping approach.

We perform a qualitative study with synthetic data to show the benefits of downward continuation as a tool for migration velocity estimation. First of all, we use a stratified velocity model to analyze how the proposed methodology compares with the conventional layer-stripping approach, in terms of velocity estimation for deeper layers. Our results show that the hyperbolic event increases on common imaged gathers (CIG) after downward continuation. Meanwhile, the effective offset for RCA analysis decreases with downward continuation. So, WFDC allows to recompute CIG gathers in regions where the RCA approach achieves better results.

Wave-field downward continuation (WFDC)

The concept of wave equation datuming has been applied to pre-stack depth migration of data coming from areas with irregular topographies (Berryhill, 1979; Reshef,1991; Becv, 1995). Basically, this is the process of upward or downward continuing a wave-field between two shaped surfaces.

For our purpose, we have chosen a WFDC operator based on finite-diference solution of the Soubaras' F-X explicit operator (Soubaras, 1992). Since any error in the datuming process could strongly deteriorate the subsequent velocity migration analysis of datumed gathers, it is important to show the robustness of the WFDC operator. Figure 1 shows a particular earth model with a rugged topography and its associated shotgather that illuminates the interface. In Figure 2, we can appreciate the shotgather after downward continuing several meters below the lowest level of the topography. Note how the effect of the topography has been removed after WFDC.

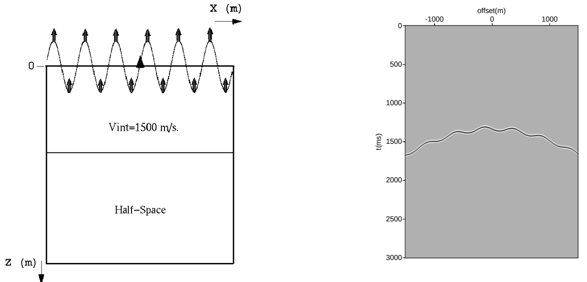

Fig. 1: Earth model with a rugged topography (right) and its corresponding shot gather (left).

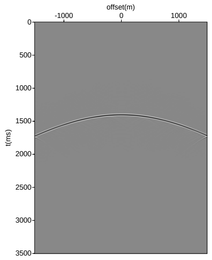

Fig. 2: Shot gather from Figure 1 after downward continuation.

Methodology

Figure 3 and 4 summarize the conventional layer-stripping procedure and the proposed method with WFDC, respectively. The migrated data is sorted into CIG traces. Here, we use pre-stack Kirchhoff depth migration of common offset profiles. Then, we measure the imaged depth, $z(h)$, and the true velocity, v, by using the relation,

$$z^2(h) = z_0^2 + rh^2 \tag{1}$$

where z_0 is the actual depth of the target defined by the migration velocity and by the normal incidence traveltime; h is half offset and, r, is a relation that involves the migration velocity, c, and the true velocity as follows,

$$r = \frac{c^2}{v^2} - 1 \tag{2}$$

The analysis is performed layer by layer. We start with an initial model of velocity for each block. Then, the amount of residual curvature, derived from the semblance profiles for the parameter r, indicates how the migration velocity should be updated. All these steps are repeated for the next block. It is important to note, that depth migration is performed on data recorded at the surface (see Figure 3). In contrast, for the case in Figure 4, all the data is datumed through the previous corrected velocity layer. So, the next prestack depth migration runs into the resynthesized common offset data.

Application on synthetic data

Flat Layer Model

Figure 5 shows a very simple earth model which consists of two flat layersFirst, we performed a traditional velocity analysis (see Figure 3) for the second homogeneous layer. After two iterations, the interval velocity converged to 2346 m/s, which represents a minimal error of 2% in the estimation. Figure 6 shows a final CIG and its corresponding semblance display for the parameter r. It is noticeable, the presence of two horizontal events at 1000 m and 2500 m in the CIG profile, and their associated r values around zero, as it is expected from this analysis.

Then, we repeated the analysis, but now the data were datumed to a depth of 1000 m. With WFDC, we got a better interval velocity equal to 2340 m/s, in the first iteration. Figure 7 shows the imaged flat event at $z = 1500$ m in the corresponding final CIG profile. It is important to note that a curvature starts to develop for far offsets at $z = 1500$ in the CIG data. To find out the meaning of this observation, we perfomed again the same velocity analysis, where the far offset data were left out. After the analysis, the final velocity was 2301 m/s. This results strongly suggests, that the effective offset for the RCA method decreases after WFDC.

This model was also used to study the effect of accumulative velocity errors on deeper layers. To do this, we assumed 5%, 10% and 15% of deviation from the true velocity in the first layer. For each case, we estimated the interval velocity for layer two by datuming the data at

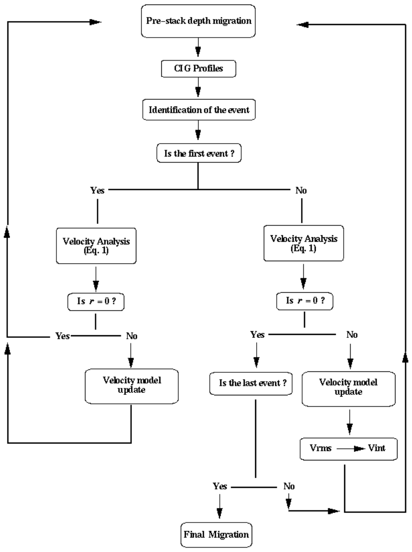

Fig. 3: Conventional stripping-layer velocity analysis.

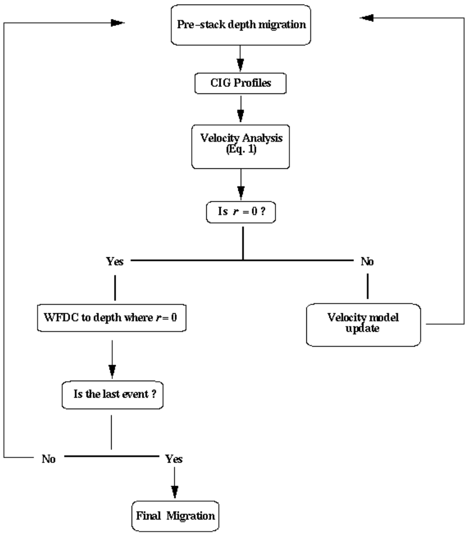

Fig. 4: Enhaced stripping-layer velocity analysis by using downward continuation.

$z = 1000m$. Then, for the cases of 10% and 15% we maked the same analysis but redatuming the data at $z = 1100m$ and $z = 1150m$, respectively. The graphic in Figure 8 displayed all the obtained results. In this example, it is remarkable how the WFDC velocity analysis improves the estimation of the interval velocities when the data is downward continued to levels of depth closer to the target of interest. Also notes, that this methodology drastically reduced the errors on velocity estimation in comparison with those ones obtained by the conventional procedure (compare results for $z = 0m$ and $z = 1000m$ in Figure 8).

Dipping Layer Model

Figure 9 shows a dipping layer model with steep dips varying from 30 to 60 degrees. Each block represents a homogeneous velocity medium. Figure 10 contains the resulting imaged sections (each one resythesized to a datum of $z = 0m$, $z = 400m$ and $z = 800m$, respectively) by using the overlying interval velocity estimaded with our method. As we can see in Figure 10, we recovered a good image for each dipping event which indicates a succesfully estimation of the velocity distribution above the corresponding steep event. Therefore, it seems that this methodology allows us to estimate interval velocities in complex media.

Finally, we want to present a comparison between the hyperbolic appearance of a particular event in a CIG profile and the hyperbole derived by using the true velocity and the migration velocity in equation (1)(called the analytical curve); for a particular situation related to the depth location B in the model (see Figure 9). The top graphic in Figure 11 shows the response of point B in a CIG gather (solid line) and the respective analytical curve (dotted line), both ones before WFDC. Similarly, The bottom graphic displays the same curves after WFDC. In the first case, it is evident the lack of hiperbolic moveout in the solid curve, because of the presence of strong lateral velocity variation in the model at the location B. However, the hiperbolic apparence in the CIG gather obviously increased after WFDC. Futhermore, this event in the CIG gather approximates better the analytical curves in the second case. This result clearly explains why the RCA method works properly in CIG data after downward continuation.

Conclusions

Errors in velocity estimation on shallower layers can affect the velocity analysis on deeper ones. These effects could be attenuated in an effective way if a WFDC is performed on the prestack data. However, care should be maked in the WFDC procedure and also in the estimation of the velocity for the overlying layers. The hyperbolic moveout in CIG gathers increases after downward continuation. In contrast, the effective offset for RCA decreases with WFDC. Both results, based on the synthetic data shown in this paper, suggest that layer-stripping approach combined with WFDC is a very promising methodology for making velocity analysis in complex areas.

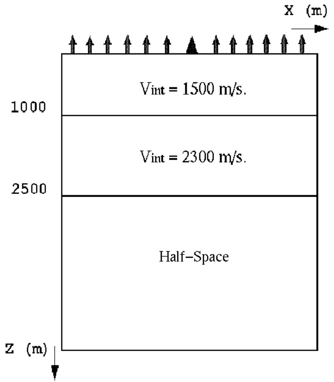

Fig. 5: Flat layer velocity model

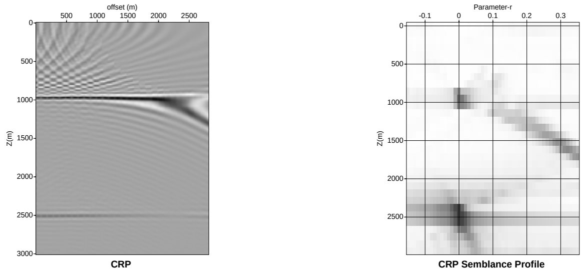

Fig. 6: Velocity analysis results for the second layer using the traditional methodology.

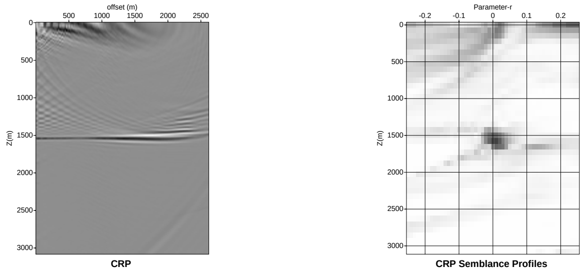

Fig. 7: Velocity analysis results using WFDC.

Acknowledgements

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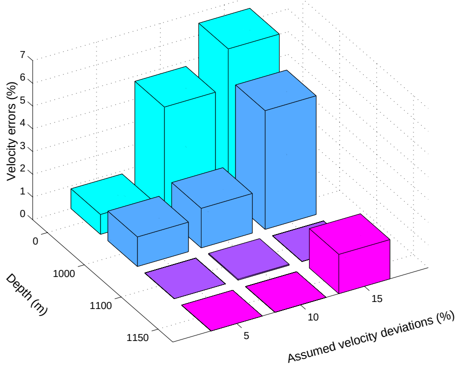

Fig. 8: Error comparation

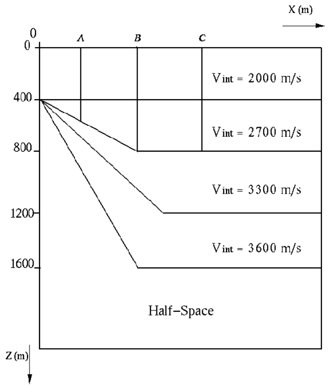

Fig. 9: Dipping-Layer velocity model

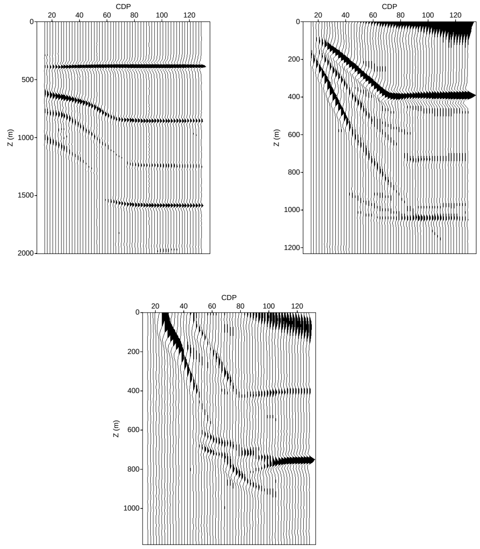

Fig. 10: Results of the velocity anlysis using WFDC methodology.

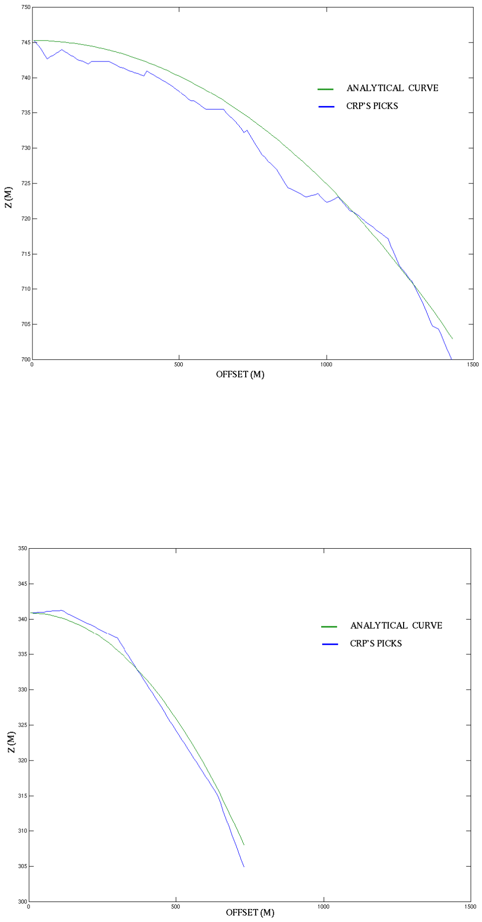

Fig. 11: Comparation between theoretical curve and crp's pick, after (top) and before (botton) downward continuation

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