Horizon Velocity Analysis Using OCO Rays

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Abstract

In this paper, I present a new method for horizon velocity analysis, which is able to find the RMS velocity that maps an horizon between two different common offset sections. The method introduces the concept of OCO rays and is based on the premise that the media presents a smooth velocity variation. The method was implemented for the 2D case and was applied to determine the velocity field in a synthetic dataset.

Introduction

The main idea of this paper is present a new method of RMS velocity analysis. The method is based on the same premises that a class of a time imaging algorithms, which make use of RMS velocity, are. MZO, time migration and offset continuation are some examples of these kinds of algorithms. For further reading about this subject I suggest the papers of Tygel et al. (1998) and Santos et al. (1997).

In general, time imaging algorithms make use of the RMS velocity field to analytically compute travel times and weight functions. To do it for a particular point in the interior of the earth, these methods assume that the overburden media is smooth enough to be represented by an equivalent homogeneous media, in such a way that there is no big difference in the travel time computed along straight rays traced in the equivalent media from the travel time computed along the effective ray path in the real media. The great advantage of using this assumption is the possibility of generating computationally efficient and robust algorithms. Because of this characteristic, the application of any time imaging algorithms is almost an obligatory step before the use of any depth imaging process.

The method proposed here is an horizon based velocity analysis method, i.e., the RMS velocity is determined along some chosen horizons. The input data required are two sets of pick times for one horizon observed in two different common offset sections. Using the concept of OCO rays, an horizon curve mapping between the two sections is performed with different velocities and for each point the velocity of the best curve fitting is chosen as the representative of the RMS velocity field of that place. OCO rays are the designation that I have given for some trajectories performed by some selected points of the output image when a offset continuation process imaging is performed with different velocities. These rays are related to the velocity rays as defined by Iversen (2001) and to the concept of image waves as presented by Hubral et al. (1996).

OCO Rays

In this section, I present the concept of OCO rays as applied to this work. In order to develop this concept, let's start considering a simple case of a reflector observed in a 2D common offset section whose half-offset is h_1 and where point A with coordinates (ξ_1, t_1) is selected. Then transform the input section, by means of a constant velocity algorithm of offset continuation, into another whose half-offset is h_2, using in this transformation a velocity equals to V_0. After that, select the output point A_0 that corresponds to the image of point A in the new configuration, i.e., in the simulated common offset section. Just to avoid confusion, this point will be referred to as the image point. Repeat this procedure with a set of n different values of velocity $(V_1, V_2, ..., V_n)$ and find the image point for each transformation $(A_1, A_2 ..., A_n)$. For each iteration, collect the coordinates of the image point in a array of coordinates. The OCO ray of point A is the geometric place that contain all the image points collected in the array of coordinates. You can visualize the OCO ray if you trace a line connecting all points of the array coordinates, this line is part of the OCO ray for the selected point A.

Notice that, similar to the traditional velocity rays, the OCO rays are not physical rays, i.e., they don't represent any real trajectory. The OCO ray represents the trajectory of an image point when the velocity field used in the imaging algorithm is changed. Also, notice that, different from traditional velocity rays, the OCO rays are not traced in the domain of the velocity field, but they are traced in the image domain, i.e., the time domain.

Another important aspect to be outlined is that OCO rays are always traced in the time domain, because the output image of any algorithm of offset continuation are always in time, even when the algorithm simulates wave propagation using an interval velocity field in depth.

The Horizon Velocity Analysis Method

The method was designed to find a RMS velocity that maps events from a common offset section to another with a different offset. The method is based on the mapping of reflection curves between these domains, in such a way that no seismic data is used after the horizon curves were picked.

Just to simplify, let's name the curve picked in the section with the smaller offset as the takeoff curve and the other as the target one. The method can be better understood when presented in an algorithm form.

For each point of the takeoff curve:

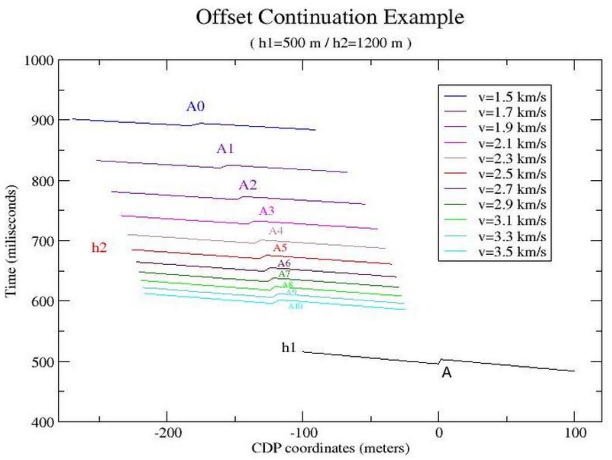

Figure 1: Schematic picture showing the offset continuation with different velocities. On the right-side at the bottom of the picture there is a black line representing a reflector in the input common offset section where point A is selected. On the left-side in the middle and top of the pictures, the colored lines represent the reflector in the simulated common offset sections with the different velocities. Observe the line defined for the set of image points $A_0, A_1, ..., A_n)$ that corresponds to the OCO ray related to point A.

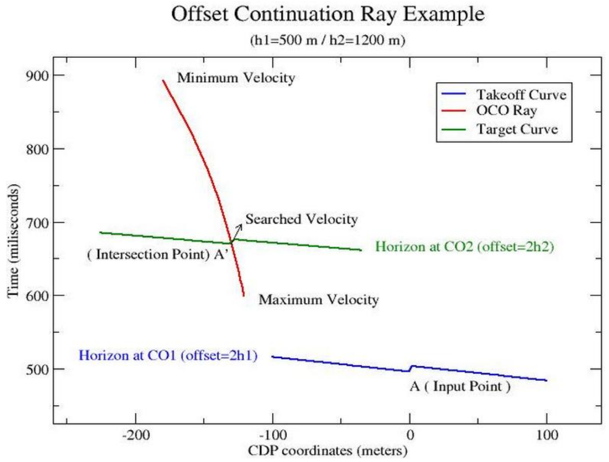

Figure 2: Schematic picture explaining the method of velocity analysis. The blue line represents the reflection curve of a horizon in the input common offset section (takeoff curve). In this curve, a point A was selected for analysis. The green line represents the reflection curve of the same horizon in the output common offset section (target curve). The red line represents the OCO ray traced from the minimum to the maximum expected velocity. Point A' is the intersection between the OCO ray with the target curve and defines the searched RMS velocity.

1. Trace the corresponding OCO ray with a constant step in the velocity.

2. Find the interception of the OCO ray with the target curve.

3. Trace the OCO again with a small step in order to find the interception more accurately.

4. The velocity of the ray at the interception point is the velocity of the equivalent media for the selected point.

5. Submit the triad velocity, ray and target curve to a consistency criteria.

6. Accept or reject the found velocity for the current point.

After performing the above steps for all points, it is possible to apply some filtering in the set of found velocities in order to eliminate any outlier. Finally, an interpolation scheme can be applied to regularize the velocity values along the whole horizon.

In the context of this work, I am not interested in showing how OCO rays are traced, if the reader desires more information about this problem I suggest the reading of the paper of Fomel (2004) where some useful equations are developed and an extensive bibliography is presented.

Application on Synthetic Data

The method was applied to find the velocity field of a 2D synthetic dataset that was generated by ray-tracing. The seismic model consists of seven constant velocity layers separated by six curved interfaces. Figure 3 is the corresponding seismic model converted to time by means of an image ray depth-to-time mapping.

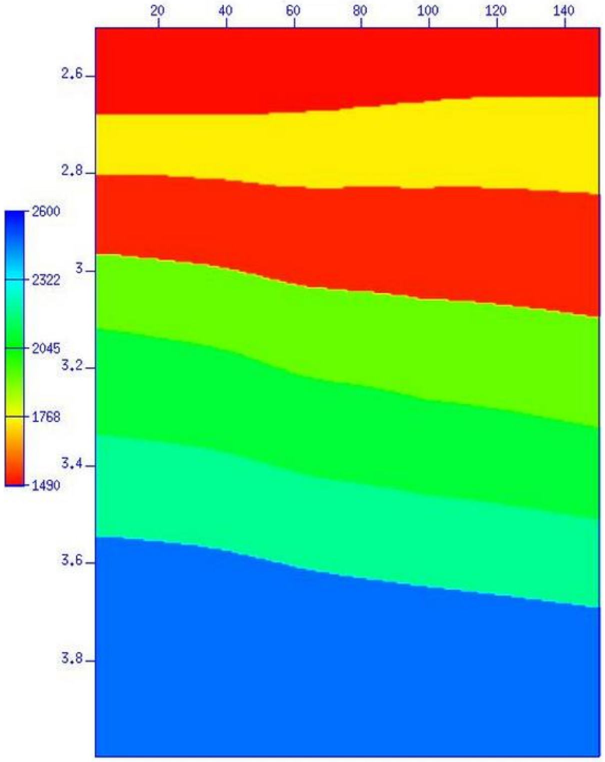

Figure 3: Seismic Model used for generating the synthetic data-set where the method was applied. The legend shows the interval velocities in m/s

The method was applied to each interface individually in such a way that six horizon velocity functions were

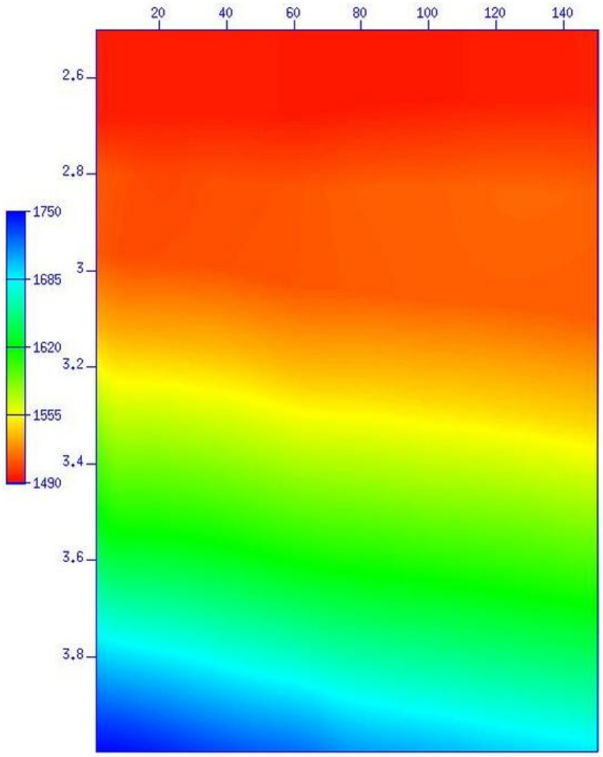

Figure 4: The RMS velocity field. This field was generated by catting the six individual RMS horizon velocity functions that were obtained with the proposed method. For the points located above the first horizon, the value of the RMS of the first velocity was repeated. For the points located bellow the last horizon, the velocities were extrapolated. For points located between two interpreted horizons, a linear interpolation was performed. The legend presents the RMS velocities in m/s.

determined. It is important to notice that these velocity functions are referred to the time of the takeoff section. If we cat these functions to build a velocity field, we would generate a velocity field referred to a particular common offset section, that is not so useful.

As the pre-stack time migration process is the most used time imaging process, it is highly desirable to get a RMS velocity field referred to time scaled to the migrated section. This can be done by carrying out a mapping for the position corresponding to the hyperbolas apex. After mapping the points of all velocity functions, they can be used to build a RMS velocity field which is appropriate to be used in time migration algorithms.

The mapping procedure described above was applied to the six RMS velocity functions determined for the synthetic dataset, generating a RMS velocity field that is presented in figure 4. In order to check the accuracy of the obtained RMS velocity field, it was transformed into a interval velocity field by the application of the Dix formula, see figure 5. This macro-velocity model is very similar to the original seismic model used for modeling. Figure 6 shows the difference between the original converted seismic model and that obtained from the inversion of the RMS velocity field. Observe that the greatest differences appear close to the border of the models. This occurs because the OCO rays can go where the horizons were not picked. Excluding these situations, the maximum observed difference is around $50.0\ m/s$ in the lower layer, that is less than 2% of the expected value.

Summary and Conclusions

I have presented a new method of horizon velocity analysis using the concept of OCO rays introduced in this paper. The method is based on the premise that the media can be locally substituted by an equivalent media of constant velocity, that is the same assumption of the widely applied Kirchhoff time migration procedure. The method was successfully applied in a 2D synthetic model with moderate lateral velocity variation, the estimated model was very close to the one used for modelling. The obtained results in this example indicate that the assumption is apparently more severe than it really is.

The method doesn't make use of any seismic data after the interpretation of target horizons. Because of that, it doesn't demand great computational resources, even when applied in large 3D volumes. Also, there is no need for additional human effort in relation to the traditional methods of velocity analysis.

Another important characteristic of the presented method is that it doesn't requires previous knowledge of the velocity field. If visual quality of the common offset gathers permits, the method can be applied in the initial stage of the seismic processing. Also, the inverted model can be refined by the inclusion of more horizons at any time.

Acknowledgments

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References

Fomel, S., 2004, Velocity continuation and anatomy of residual prestack time migration, Geophysics,**68**, 1650-1661.

Hubral, P., Tygel, M., and Schleicher, J., 1996, Seismic Image Waves: Geophysics, **125**, 431-442.

Iversen E., 2001, Ray systems for propagation of seismic isochrons. Part II: Velocity rays. Expanded Abstracts, 7th International congress of the Brazilian Geophysical Society, 1162-1165.

Santos, L. T.,Schleicher J. and Tygel, M, 1997, 2.5D True-amplitude offset continuation. Journal of Seismic Exploration, **6**, 103-116.

Tygel, M., Schleicher, J., Hubral, P. 1998, 2.5D Kirchhoff MZO in laterally inhomogeneous media. Geophysics, **63**, 557-573.

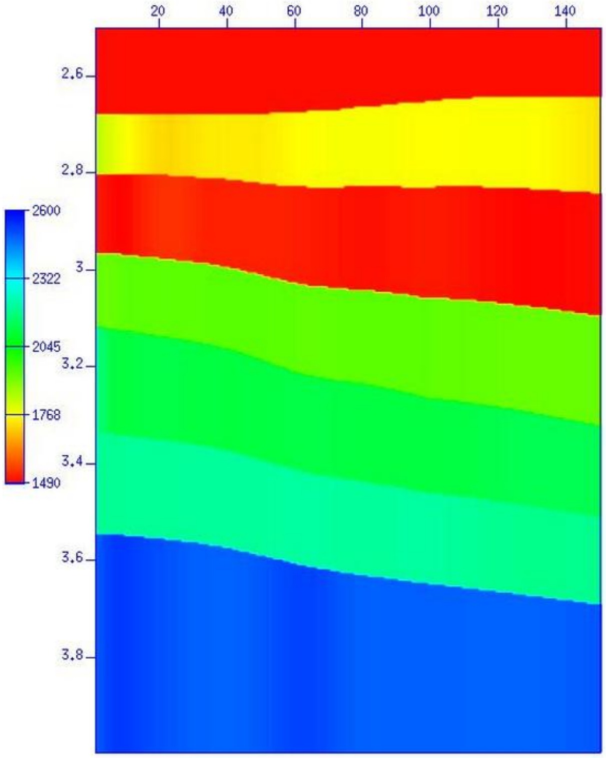

Figure 5: Interval velocity field in time. This field was generated by applying the Dix formula for each cdp of the RMS velocity filed. The legend presents the velocities in m/s.

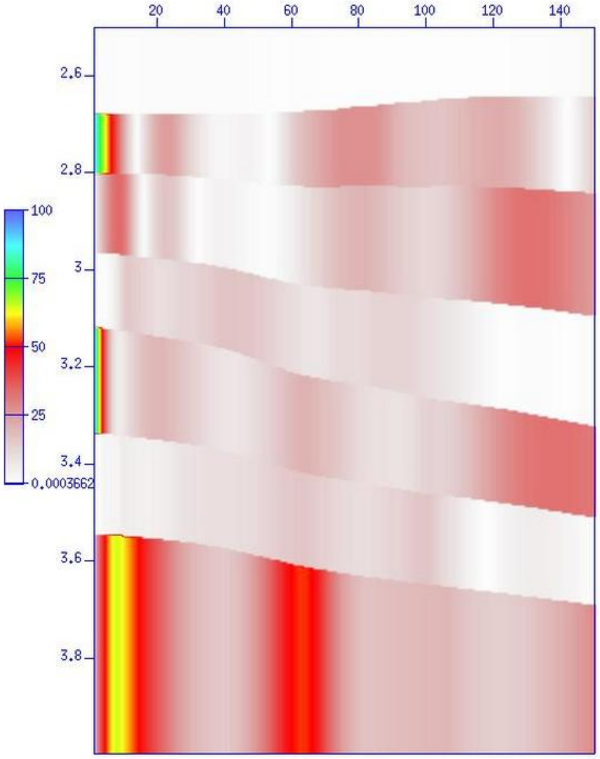

Figure 6: Difference between the original seismic model and obtained interval velocity field. Legends present values in m/s.