# Reverse time migration velocity analysis: A real field data example

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**Abstract**

Depth migration by reverse time migration requires the knowledge of a smooth approximation to the seismic velocity field. This background velocity model can be estimated by wave equation migration velocity analysis (WEMVA), an automatic process based on minimizing the errors in the kinematics of the depth migrated image. In this paper we present a WEMVA method where we use a combination of semblance and differential semblance to measure the errors in the positioning of reverse time migrated images. The errors are then turned into velocity updates by a gradient based optimization scheme. We apply the method to a 2D line extracted from a 3D marine survey acquired over the Snorre field in the North Sea. The resulting WEMVA velocities obtained from the field data are compared to the background velocities obtained by first arrival traveltime tomography (FATT), and also to well logs.

## Introduction

Wave equation migration velocity analysis (WEMVA) is based on focusing of migrated data and uses an automatic optimization procedure to estimate the background velocity field. The approach is based on formulating an objective function that measures to what extent offset- or angle-gathers are focused or flattened respectively, and then minimizing the objective function with respect to the velocity field.

WEMVA methods can vary widely as to what measure of misfit is used and as to which migration algorithm is employed to create the image. Chavent and Jacewitz (1995) implemented WEMVA by using a similarity-index and reverse-time migration (RTM) to compute the velocity field. Biondi and Sava (1999) used one-way migration operators and image perturbations for computing corrections to the initial wavefield, and Sava and Biondi (2004) extended this approach to a fully non-linear iterative scheme. Shen et al. (2003) used the Double Square Root approach to depth migration and an objective function based on Differential Semblance (Symes and Carazzone, 1991) to estimate the velocity field. The approach was also extended to shot-profile migration based on one-way migration operators (Shen and Symes, 2008). Mulder (2008) used depth migration based on the two-way wave equation in the frequency-domain and an objective function related to the differential-semblance approach to implement a non-linear scheme for computing the velocity field. Gao and Symes (2009) proposed to use a differential semblance misfit function and RTM to solve the velocity estimation problem, and also gave an initial theoretical framework. Weibull and Arntsen (2011) implemented a RTM based velocity analysis with a modified differential semblance measure, which helps to prevent instabilities related to the amplitude sensitivity of the two-way wave equation.

In this paper we present a WEMVA method based on a combination of the similarity-index, Differential Semblance and RTM. We apply the method to a 2D line extracted from a 3D marine survey acquired over the Snorre field in the North Sea. The resulting WEMVA velocities obtained from the field data are compared to the background velocities obtained by first arrival traveltime tomography (FATT), and also to well logs.

## Method and Theory

The velocity analysis is based on non-linear optimization of the following objective function:

$$J = DS - SI + J_{reg}. \tag{1}$$

The objective function is composed of three parts, the differential semblance misfit ($DS$), the similarity-index ($SI$) and a regularization factor ($J_{reg}$).

The differential semblance misfit measures the error of the velocity model, and is given by (Weibull and Arntsen, 2011):

$$DS = \frac{1}{2}\left\| h\frac{\partial R}{\partial z}(x,z,h)\right\|^2 = \frac{1}{2}\int dx \int dz \int dh\, h^2 \left[\frac{\partial R}{\partial z}(x,z,h)\right]^2, \tag{2}$$

where $R$ is the RTM image volume parametrized by subsurface horizontal half-offsets (Rickett and Sava, 2002):

$$R(x,z,h) = \sum_s \int_0^T dt\, U(x+h,z,t,s)D(x-h,z,t,s), \tag{3}$$

and $U$ and $D$, are, respectively, the reconstructed receiver and source wavefields over all times ($t$) and for all sources ($s$).

The main assumption behind differential semblance is that, at the correct velocity, the migrated image ($R$) is optimally focused at zero half-offset. The objective of differential semblance optimization is to take an initial image and through an iterative procedure output a focused image, at which point the velocities are optimal. The difficulty in this procedure is that the differential semblance misfit is very sensitive to the amplitudes of the image, and amplitude-related artifacts are generally present in the solution of the optimization. These artifacts are not related to improved focusing, but only cause damping of the amplitudes of the migrated image.

The key to successfull velocity analysis is thus to understand how the image amplitudes are affected by the velocities, and then to apply measures to minimize the sensitivy of the image amplitudes to the velocities. One very effective measure is to apply a spatial derivative filter to the image, since this will reduce the amplitude sensitivity related to the backscattering of the two-way wave equation (Weibull and Arntsen, 2011). Other effective measure is to combine the Differential Sembalnce misfit function with the similarity-index (Chavent and Jacewitz, 1995; Zhou et al., 2009). The similarity-index measures the stack quality of the image. It is very nonlinear, but has a strong peak at the correct background velocities and helps to prevent the amplitude dimming related to artifacts in the solution of the differential semblance optimization (Shen and Symes, 2008):

$$SI = \frac{\gamma}{2}\left\|\frac{\partial R}{\partial z}(x,z,h=0)\right\|^2 = \frac{\gamma}{2}\int dx \int dz \left[\frac{\partial R}{\partial z}(x,z,h=0)\right]^2, \tag{4}$$

where $\gamma$ is a predefined constant.

Finally, bounding the shallow parts of the model and adding a derivative regularization further prevents the excessive roughening of the velocity model:

$$J_{reg} = \frac{\alpha(x,z)}{2}\left\|\frac{\partial v(x,z)}{\partial x} + \frac{\partial v(x,z)}{\partial z}\right\|^2 + \frac{\beta(x,z)}{2}\left\|v(x,z) - v_{prior}(x,z)\right\|^2, \tag{5}$$

where $\alpha$ and $\beta$ are weight vectors, and $v_{prior}$ is the vector containing a priori known values of velocity.

**Examples**

The method is tested on a field dataset taken over the Snorre field offshore Norway. The data is originally a 3D dataset, from which we extract a 2D line. The geometry of the data consists of a line with minimum offset of 150 meters and maximum offset of 5 kilometers. The original receiver interval is 25 meters and the original shot interval is 18.75 meters. The data processing included multiple removal, and muting of direct wave, wide-angle reflections and refractions. The maximum frequency of the data was filtered down to 30 Hz, so that a coarse grid of 20 by 20 meters could be used for modeling and migration.

The starting point for the velocity analysis is a 1D velocity model shown in figure 1A. The model is constructed from a smoothed well log. The result of optimization on the velocities after 49 iterations is shown in figure 1C. Due to the limited aperture of the data, WEMVA is only able to update the upper 2-3 kilometers of the model. The shallow part of the model contains also large oscillations, which is possibly an artifact related to the amplitude sensitivity, but could also be due to the lack of offset information. These oscillations can in principle be removed by adding a stronger regularization, however this would potentially oversmooth the result, and that is not what we want. For comparison, the velocities computed with FATT are shown in figure 1E.

Figures 1B, 1D and 1F, show a comparison of the RTM images produced with the initial 1D, WEMVA, and FATT velocities respectively. The image produced by the velocities obtained by WEMVA is significantly different from the other two images. In some areas, the differences in positioning amount to more than 50 meters in vertical misfit between the WEMVA and the other velocity models. Figure 2A shows a comparison of optimized angle gathers extracted from the RTM images produced with the 1D inital model (left), WEMVA model (centre), and FATT (right). The angle gathers are computed from the respective RTM image volumes using a subsurface offset to angle mapping (Biondi and Symes, 2004). The gathers show that, at least in the upper 2 km, the events are more flat in the model obatined by WEMVA than they are in the other models. Figure 2B shows the results of the optimization compared to well logs. The well logs are not lying directly on the line, but are offset from the line by distances ranging from 300 to 650 meters. Nevertheless, we can see that the optimization method is unable to explain the fine scale details of the velocity logs, but is mainly estimating the smooth background features, which are necessary for obtaining more optimal traveltimes.

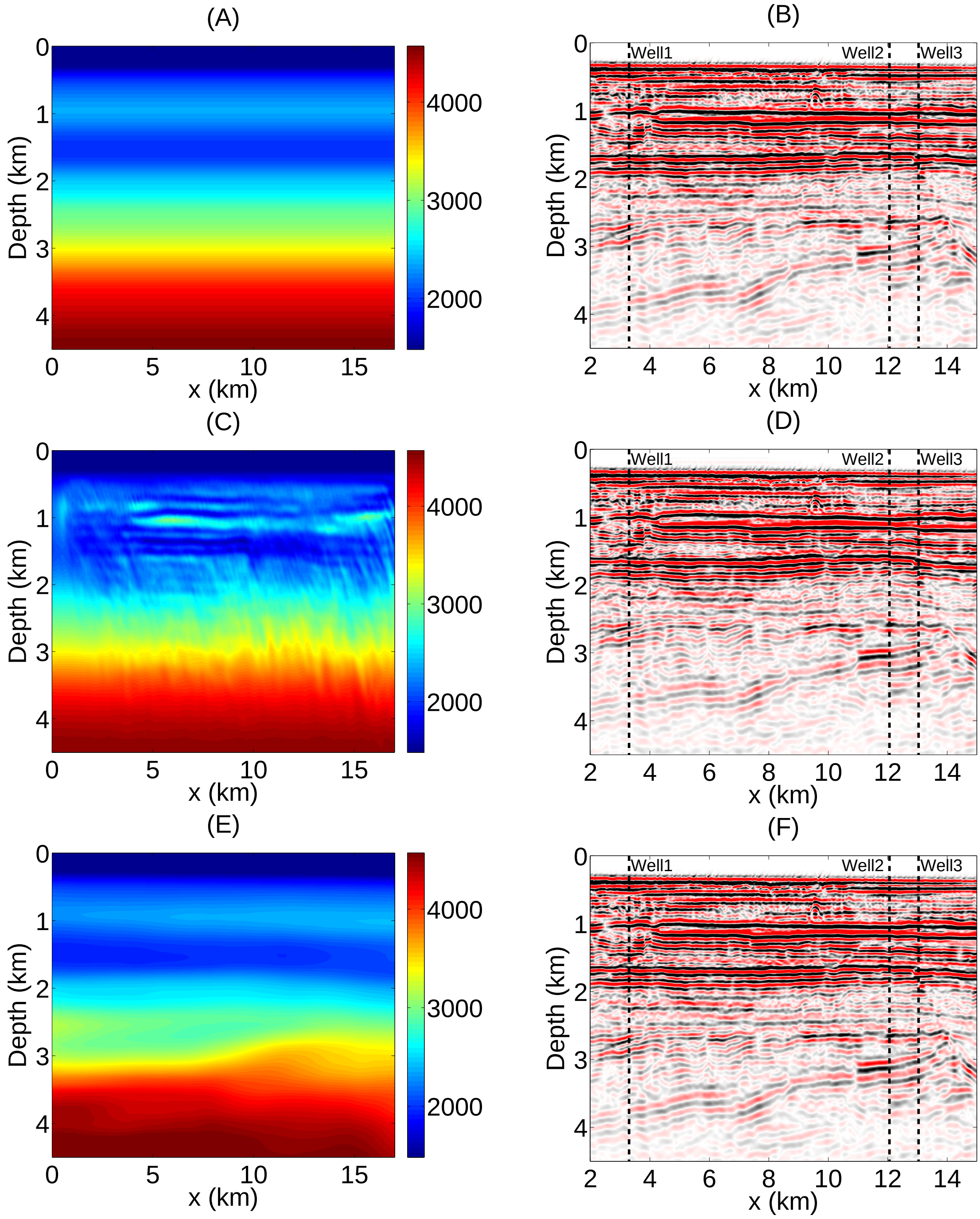


***Figure 1*** *Left: Velocity models (m/s); Initial (A); After WEMVA (C); After FATT (E). Right: RTM images; Initial (B); After WEMVA (D); After FATT (F).*

## Conclusions

Overall, the results show that the method is capable of improving the quality of the depth migrated image. The results also show that the reverse time migrated image produced after WEMVA is better focused than that obtained by FATT for the considered frequencies.

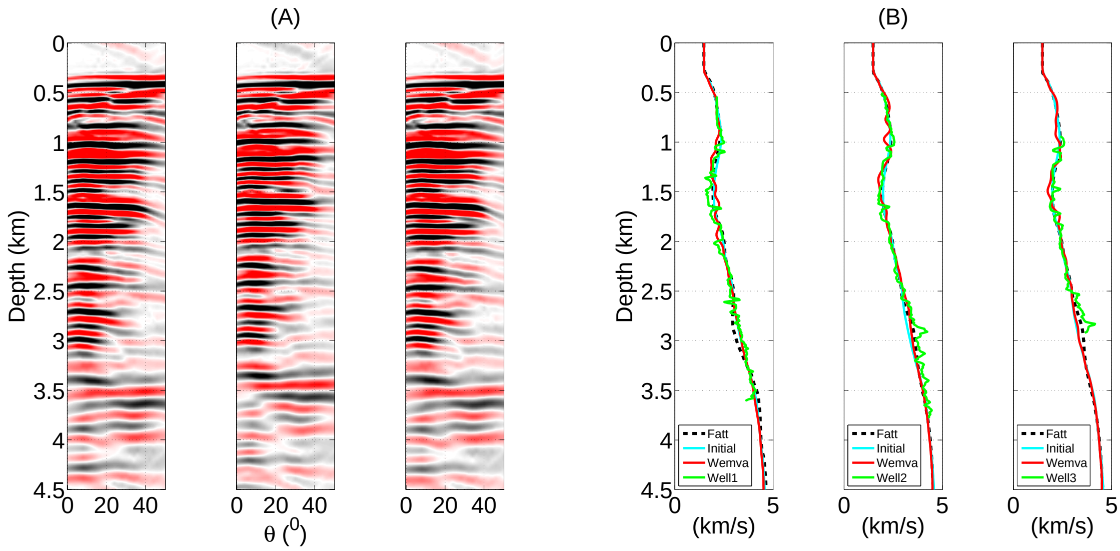


***Figure 2** (A) - Angle gathers obtained from RTM: Initial (left); After WEMVA (centre); After FATT (right). (B) - Comparison of the velocity models to well logs. Well positions are shown in figure 1.*

The main difficulty of the method is to avoid the amplitude-related artifacts in the solution, which requires strong smoothing regularization to be applied. This prevents the method from obtaining finer details of the velocity model which could be important for the traveltimes. Another limitation of the method is the high computational cost, which currently is limiting its use to 2D and low frequency datasets. Results could be further improved by adding more frequencies and the whole 3D dataset.

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