Weighted AB semblance using very fast simulated annealing

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Abstract

We present a modification applied to a work presentend by Ebrahimi et. al, 2017, that shows the weighted AB semblance method which deals with the AVO phenomenon in velocity spectra. This method is based on the use of two weighting functions applied to the AB semblance coherence measure. The first weighting function, uses the ratio between the first and the second singular value of the time window. The second weighting function is based on the position of the seismic wavelet in the time window. Each weighting function depends on two empirical coefficients, determined by the analysis of a matrix which contains the measure called ECM (Energy Concentration af Matrix). In this work, we made a modification in the calculus of these coefficients values. We use the method Very Fast Simulated Annealing to get the best coefficient values that generates a spectrum with the best resolution. We applied the method in both synthetic and real CMP gathers. Results show that the VFSA made easier to obtain the coefficient values. These values allow to generate velocity spectra with excelent resolution.

Introduction

Velocity analysis is one of the most important steps in CMP seismic processing. This is because, a good accuracy in the obtaining of these velocities, generating a good velocity field, will provide a seismic image that allows a good interpretation of the data.

The velocity spectrum is a very useful tool for velocity analysis. In it, we can associate seismic event with their respective velocities, using a coherence measure. Therefore, it's necessary that the coherence measure has a good resolution to determine the velocities.

Currently, the conventional coherence measure is the semblance (Taner and Koehler, 1969) and, in spite of being effective in most practical situations, it presents a poor resolution in cases of interfering events and AVO anomaly. To improve the resolution of conventional semblance, researchers developed some methods of high resolution velocity spectra to solve specific cases that harm the quality of the spectrum.

Sarkar et al., 2001 and Fomel, 2009 developed a coherence measure called AB semblance which is not affected much by amplitude variations, but it presents a resolution that is twice lower than conventional semblance Biond and kostov, 1989, Barros et. al., 2012 and Ursin et. al, 2014 used eigen-structure properties applied to the time window and new coherence measures to develop velocity spectra with better resolution than conventional semblance.

Other category of methods to improve the resolution of velocity spectra is adding weighting terms to convencional semblance as in Luo and Hale, 2012 and Chen at al., 2015. Recently Ebrahimi et. al. 2016 used a new method of weighted semblance that are based on singular values of the data matrix and the position of the wavelet in time window to discards coherence values that lest contribute to velocity resolution, obtaining velocity spectra with excelent resolution. Ebrahimi et. al. 2017 extended their applying the method in the AB semblance, obtaining a good compromise between the resolution and ability of coping with AVO anomaly.

The methods presented by Ebrahimi et. al 2016 and Ebrahimi et. al 2017 are dependent of two pairs of empirical coefficients. This work aims to improve the obtaining of this coefficient values, using the algorithm of inversion Very Fast Simulated Annealing.

Results show that Very Fast Simulated Annealing is a useful tool to get this coefficient values, generating velocity spectra with excelent resolution.

AB Semblance

The most utilized coherence measure is the semblance, given by

$$S = \frac{1}{N} \frac{\sum_{i=1}^{M} (\sum_{j=1}^{N} a_{ij})^2}{\sum_{i=1}^{M} (\sum_{j=1}^{N} a_{ij}^2)} \tag{1}$$

where a_{ij} are the amplitude values of the time window, N is the number of traces and M is the number of time samples. It is defined as the ratio between the energy of the estimated signal and the energy of the data in the analysis window, and it is normalized to be between zero and one (Taner and Koehler, 1969). Conventional semblance can be viewed as the squared correlation of a matrix with a constant (Fomel, 2009).

Fomel, 2009, defined AB semblance as the squared correlation with a trend $b_{ij} = A + Bx_j$, where x_j is the offset. So we have

$$S_{AB} = \frac{1}{N} \frac{\sum_{i=1}^{M} (\sum_{j=1}^{N} a_{ij} b_{ij})^2}{\sum_{i=1}^{M} (\sum_{j=1}^{N} a_{ij} \sum_{j=1}^{N} b_{ij}^2)} \tag{2}$$

The values of A and B can be found from the least-squares fitting of the trend amount to the minimization of

$$Q(A,B) = \sum_{i=1}^{N} (a_{ij} - A - Bx_j)^2 \tag{3}$$

Substituting the trend b_{ij} in equation 2, using A and B calculated from the least-squares fitting of the equation 3 we have the AB semblance coherence measure.

Fomel, 2009, using analytical derivations and numerical experiments, showed that AB semblance is not affected much by the amplitude variations, on the other hand, its resolution is twice lower than conventional semblance.

Weighted AB semblance

The method presented by Ebrahimi et. al., 2017 is based on the application of two weighting functions to the AB semblance values aiming to improve the resolution of the velocity spectra. These functions are more sensitive to velocity and time changes. We can define the weighted AB semblance as

$$S_{wAB} = W_{svd} \times W_{pow} \times S_{AB} \tag{4}$$

W_{svd} is based on the ratio between the first and the second singular values, after applying SVD filtering to the time window (Freire, 1986; Barros, et al., 2012, Ursin et al., 2014). In this work, we used the Power Method (Barros et. al., 2012 ; Ursin et al., 2014) to obtain the singular values. W_{pow} is based on the position of the seismic wavelet in the time window. Both weighting functions are sigmoid functions and emphasize the AB semblance values when correct velocities and times are used, and deemphasize the AB semblance values when used wrong velocities and wrong times. (Ebrahimi et al., 2017)

W_{svd} is defined as

$$W_{svd} = \frac{10}{1+e^{-a(\frac{\sigma 1}{\sigma 2}-b)}} \tag{5}$$

where a and b are empirical coefficients. This function is based on the property that, if a seismic event in the time window has high spacial correlation, the first singular value $\sigma 1$ has a much larger value than the second singular value $\sigma 2$. Thus, W_{svd} is very sensitive to changes in velocity, improving the resolution of the spectra in this direction.

W_{pow} is defined as

$$W_{pow} = \frac{100}{1+e^{-c(POW-d)}} \tag{6}$$

where c and d are empirical coefficients. POW is given by

$$POW = \frac{1}{|t_{cm} - t_{center}| + \varepsilon} \tag{7}$$

and t_{center} is the center of the time window, ε is a small positive constant to prevent the division by zero, and t_{cm} is the center of mass of the time window given by

$$t_{cm} = \frac{\sum_{i=1}^{M}\left(i \times \sum_{j=1}^{N}|a_{ij}|\right)}{\sum_{i=1}^{M}\sum_{j=1}^{N}|a_{ij}|} \tag{8}$$

For a zero-phase wavelet, POW reaches the maximum value when the time window is extracted by true values of velocity and two-way zero-offset time, in this case, the event will be positioned at the center of the time window, the value of the denominator in equation 7 is close to zero and the maximum weight is assigned to this time gate. For a time window extracted by incorrect velocity and two-way zero-offset time, the denominator is increased, and thus, less weigth to be awarded. Therefore, W_{pow} is highly sensitive to the arrival time of the events in the time analysis window (Ebrahimi et. al., 2016, Ebrahimi et. al., 2017).

Obtaining the coefficients

Both pairs of coefficients in the two weighting functions control the slope and turning point of the sigmoid functions. According to Ebrahimi et. al., 2017, they are related to the sparsity of the velocity spectrum, that is, increasing the value of two coefficients in both weighting functions, the velocity spectrum becomes sparser. These coefficient values are determined by analysis of a matrix that contains the measure called ECM (Energy Concentration of Matrix) given by

$$ECM = \frac{1}{\sum_i \sum_j |x_{ij}|^{0,01}} \tag{9}$$

where x_{ij}, in this case, are the amplitudes of the velocity spectra. The ECM matrix is generated as follows:

- Fixes the coefficient values of one of the weighting functions, for example, to analyse W_{svd} we make c = 1 and d=1;
- Generates velocity spectra using various values of the two others parameters;
- Calculates the ECM of the velocity spectra for each pair of coefficient values.

In Figure 1 we see the matrix containing ECM values for a synthetic CMP for each pair of coefficients for W_{svd} and W_{pow}. The coefficient values are determined by analysis of this matrix using trial values.

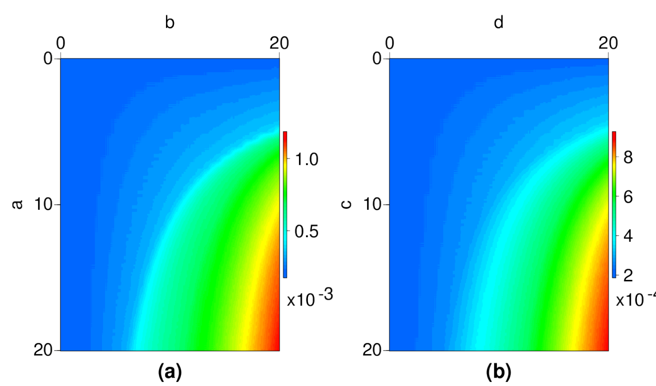

Figure 1: ECM matrix for analysis of the pair of coefficient values a and b in (a), and for analysis of the pair coefficient values c and d in (b).

Very fast simulated annealing

This method simulates a cooling of a solid, its algorithm is described as follow (Sen and Stoffa, 1995; Soares 2009): Assume that the model's parameter m^i at iteration (annealing step or time is represented by m_k^i as

$$m_{min}^i \leq m_k^i \leq m_{max}^i \tag{10}$$

where m_{min}^i and m_{max}^i are the minimum and maximum values of the model parameter m_k^i. The value of this parameter is pertubated in the iteration $k+1$ by using the following relation

$$m^i_{k+1} = m^i_k + y^i \left(m^i_{max} - m^i_{min} \right) \quad (11)$$

being that $y^i \in [-1, 1]$, generated from the following distribution

$$g_T(y) = \prod_{i=1}^{NM} \frac{1}{2\left(|y_i| + T_i\right) ln\left(1 + \frac{1}{t_i}\right)} = \prod_{i=1}^{NM} g_{Ti}(y_i) \quad (12)$$

Thus a random number u^i drawn from a uniform distribution U[0,1] can be mapped into the above distribution with the following formula

$$y_i = sgn\left(u_i - \frac{1}{2}\right) T_i \left[\left(1 + \frac{1}{T_i}\right)^{|2u_i - 1|} - 1 \right] \quad (13)$$

For this distribution, we can obtain the global minimum statistically by using the following cooling schedule

$$T^i(k) = T^{0i} exp\left(-c^i k^{1/NM}\right) \quad (14)$$

where NM is the number of models, T^{0i} is the value of the initial temperature for the i parameter, c^i is an attribute used for the control of the temperature schedule. The criterion of acceptance of the models is given by Metropolis algorithm (Metropolis et al., 1953) as follows:

- Starts with an initial model m_0 with energy $E(m_0)$;
- Makes a small pertubation to the model $m^j = m^i + \Delta m^i$;
- Calculates $\Delta E^{ij} = E(m^j) - E(m^i)$;
- If $\Delta E^{ij} \leq 0$, the new model is always accepted;
- If $\Delta E^{ij} > 0$, the new model is accepted with the probability $P = exp\left(\frac{\Delta E^{ij}}{T}\right)$.

Method

For making easier the obtaining of the best pair of coefficients for each weighting function, we applied the method of inversion Very Fast Simulated Annealing to determine directly the correct coefficient values that will give a velocity spectra with the best resolution. The measure equivalent to the objective function in this method is the value of the ECM. As the ECM is a measure of sparsity of a matrix, that is, the higher the ECM value the higher is the value of sparsity, the resolution of the velocity spectra is proportional to the value of the ECM. Thus, we used the VFSA to converge for the maximum, giving a set of coefficients that provides a maximum value, or close to the maximum value of ECM. After to define the correct values of coefficients, we utilize them to generate the velocity spectrum with the weighted AB semblance as a coherence measure.

Numerical results

We applied the method in a synthetic CMP gather with 50 traces, 1000 time samples, sampling interval of 4 milisseconds, containing one event with two-way zero-offset time equals to 2.0 s and $v_{rms} = 1500 m/s$. This event has a reverse polarity. Ebrahimi et al., 2017 used a similar CMP gather using the coefficient values a = 5.0 , b=10.0 c = 5.0 and d=5.0. After applying the method, we obtained the coefficients a = 7.2, b = 10.1, c = 4.4 and d = 5.0. Figure 2 shows the synthetic CMP gather in (a) and its velocity spectra, normalized to be between zero and one (Figs. 2b - 2e). Comparing the results, we can see that conventional semblance suffered with the effect of reverse polarity, on the other hand, AB semblance could deal with this effect, but its resolution is poorer than conventional semblance. Weighted AB semblance deals with the AVO phenomenon and solves the problem of low resolution of AB semblance. Figures 2d and 2e show similar results, validating the effectiveness on the use of the VFSA in obtaining the coefficients values.

We also tested the method in a real CMP gather from Gulf of Mexico. The parameters of acquisition are 24 traces, 1000 time samples, sampling interval of 4 milisseconds. In this CMP gather, we can see an AVO anomaly from t=0.7 to 1.1s. Ebrahimi et al., 2017 used the same CMP gather using the coefficient values a = 10.0 , b=1.3 c = 10.0 and d=1.1. After using the VFSA method, we obtained the coefficients values a = 11.4, b = 2.0, c = 17.0 and d = 3.5. Figure 3 shows the CMP gather in (Fig. 3a), and its respective velocity spectra, normalized to be between zero and one (Figs. 3b - 3e). Comparing the results, we can see that conventional semblance does not detect the presence of events in the area of AVO anomaly, on the other hand, AB semblance detect these events, but its resolution is poorer than conventional semblance. Weighted AB semblance for the real data, deals with the AVO phenomenon and improves the problem of low resolution of AB semblance. Figure 3e shows that the coefficient values, obtained by the use of VFSA, provided a velocity spectrum with better resolution than the others coefficient values obtained through ECM matrix analysis used in Ebrahimi et al., 2017, (Fig. 3d), but it was not too effective to detect events in the area of AVO anomaly.

Conclusions

The weighted AB semblance coherence measure considerably improved the resolution of the velocity spectra. Compared with the conventional semblance, this measure allowed to better recognize interfering events, and that which present amplitude variation along offset.

The application of the Very Fast Simualated Annealing improved the obtaining of the coefficient values, since we determine its values directly, so that this procedure became less empirical.

Results show that the obtaining of the coefficients by the analysis of ECM matrix and using Very Fast Simulated Annealing provided similar results for the synthetic CMP, though, the second one is less laborious in the obtaining of the coefficient values. For the real CMP gather, coefficient values obtained using VFSA provided a velocity spectrum with better resolution, but it didn't overcome the first one in the detection of events in the region of AVO anomaly.

It's important to emphasize that, the method presented in this work, needs additional studies, as in the improvement of convergence of method.

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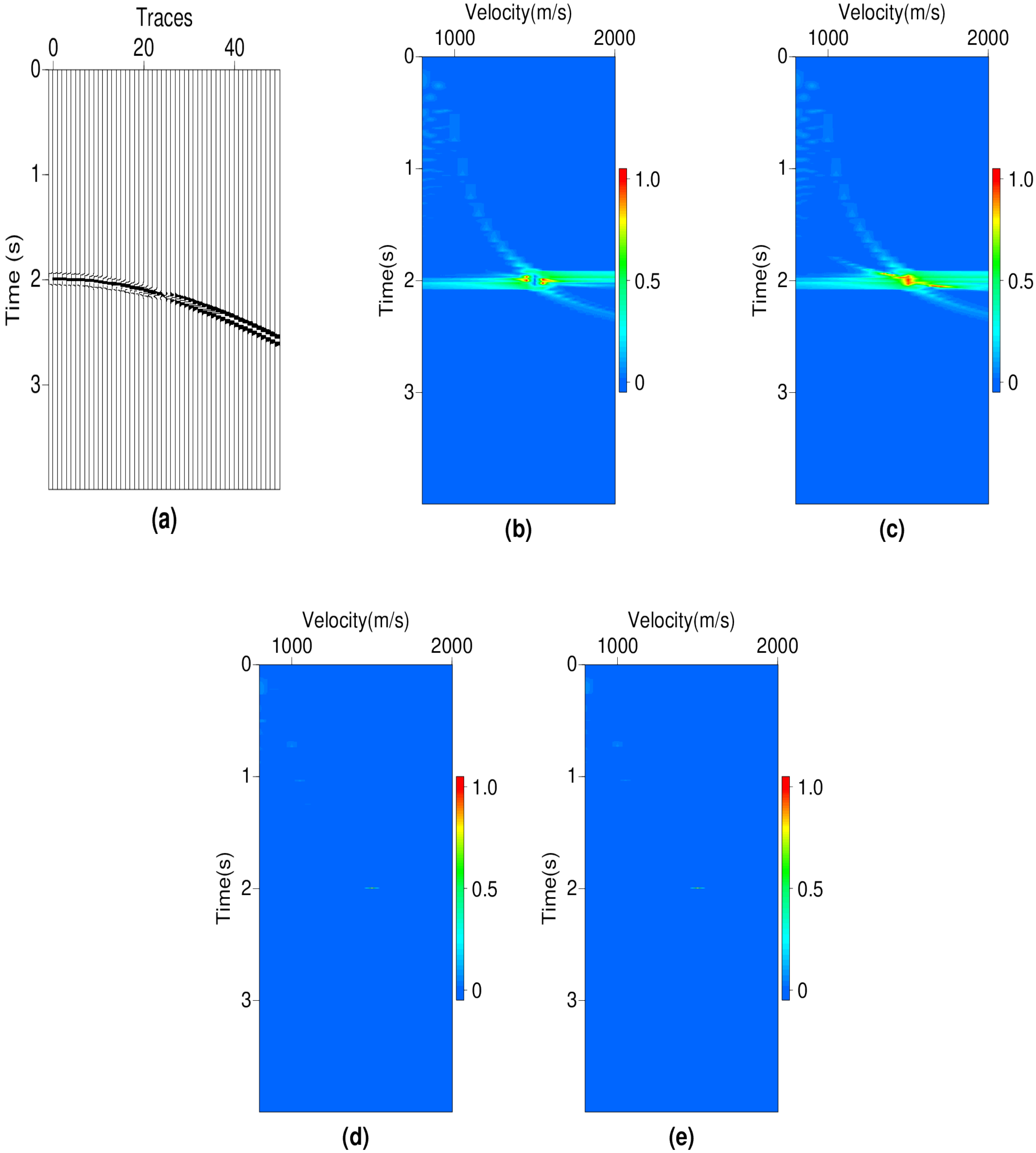

Figure 2: Synthetic CMP gather in (a) and its velocity spectra using conventional semblance in (b), AB semblance in (c), weighted AB semblance in (d) and weighted AB semblance using VFSA in (e).

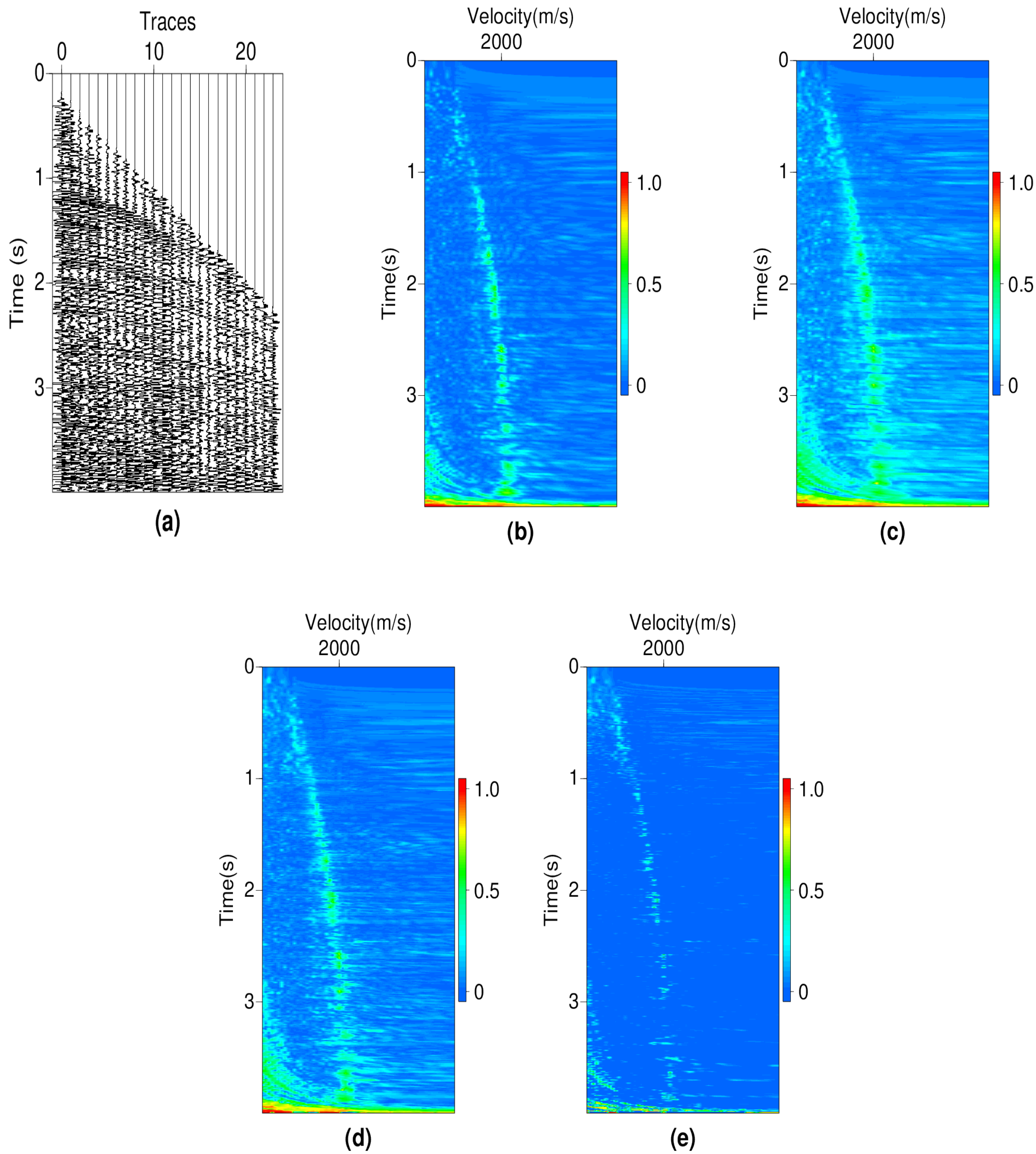

Figure 3: Real CMP gather from the Gulf of Mexico in (a) and its velocity spectra using conventional semblance in (b), AB semblance in (c), weighted AB semblance in (d) and weighted AB semblance using VFSA in (e).