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Application of local optimisation with Steepest Ascent Algorithm for the residual static corrections in a southern Algeria geophysical survey

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ABSTRACT Static corrections in the seismic data processing sequence are one of the most sensitive steps in seismic exploration undertaken in areas with complex topography and geology. Using the stack energy as an objective function for the inversion problem, static corrections can be performed without using the cross-correlation of all traces of a Common Depth Point (CDP) with all other CDP traces. This step is a time-consuming operation and requires huge computer memory capacities. The pre-calculation step of the cross-correlation table can provide greater processing efficiency in practice; by either a local optimisation algorithm such as Steepest Ascent applied to the traces, or a global search method such as genetic algorithms. The sudden change of the topography and the signal/noise (S/N) ratio decrease can cause failure in residual static (RS) corrections operations; consequently, it may lead to poor quality of the seismic section. In this study, we firstly created a synthetic seismic section (synthetic stack), which describes a geological model. Then, the Steepest Ascent Algorithm (SAA) method is used to estimate RS corrections and evaluate its performance, in order that the encountered problems in the field will be overcome. The generated synthetic stack, with a two-layer tabular geological model, has been disturbed by introducing wrong static corrections and random noise. Thus, the model became a noised stack with low S/N ratio and poor synthetic horizons continuity. After 110 iterations, the SAA estimated the appropriate corrections and eliminated disturbances introduced earlier. Moreover, it improves the quality of the stack and the continuity of synthetic horizons. Therefore, we have applied this algorithm using the same methodology for calculating the RS corrections of real data of seismic prospection in southern Algeria; the input data has poor quality caused by near-surface anomalies. We found that our proposed methodology has improved the RS corrections in comparison to currently used conventional methods in the seismic processing in Algerian industry.

Key words: residual static corrections, seismic data processing, stack energy, synthetic stack, southern Algeria.

1. Introduction

There are many techniques to build the Weathered Zone (WZ) model and the primary or residual static (RS) corrections calculation; these techniques include: the coring speed-time method, the static corrections by refraction method, the tomographic inversion method, and integrated modelling methods (Foster and Guinzy, 1967; Feng *et al.*, 2011; Zhang *et al.*, 2014; Zhu *et al.*, 2014).

The approach of RS corrections can be divided into two techniques: cross-correlation picking and the stack maximum power approach (Foster and Guinzy, 1967; Henley, 2012; Sajeva *et al.*, 2017). The cross-correlation approach usually determines the time shift (static shift) with the pointed peaks, which represent the maximum cross-correlations of each trace with the pilot trace of all Common Depth Points [CDPs: Stork and Kusuma (1992)]. The evolution of this approach has been achieved by Foster and Guinzy (1967), Hilterman *et al.* (1968), and Disher and Naquin (1969), Taner *et al.* (1974), Wiggins *et al.* (1976), and Kirchheimer (1983).

The approach of the maximum stack energy (maximum stack power) was proposed by Ronen and Clerbout (1985) and Stork and Kusuma (1992). It iteratively determines each location of the static surface by finding the shift that maximises the energy from the stack. Thus, the use of a stack placed in CDP in the cross-correlation is necessary and very efficient (Askari *et al.*, 2015). Indeed, using the energy of the stack as an objective function of the Steepest Ascent Algorithm (SAA) in the inversion problem of static corrections, can be performed without using the cross-correlation of all traces of a CDP with all others (Foster and Guinzy, 1967; Tarantola, 2015).

2. The Steepest Ascent Algorithm (SAA)

SAA is a non-linear optimisation method that uses the first derivatives of a given function (Fletcher, 1987). Each function has a gradient; the gradient of a function is the vector of partial derivatives. Consider the function given by:

$$f_{CDP}(\Delta t) = f(\Delta t_1, \Delta t_2, \dots, \Delta t_n) \quad (1)$$

where: Δt_1, Δt_2, ..., Δt_n present the static corrections of a given CDP composed of *n* traces, and *f*(.) is a nonlinear function representing the energy of the CDP traces.

Like all vectors, the gradient defines a direction. In fact, the gradient can be used to find the direction of the evolution of the maximum of the function *f*(*x*) (Freund, 2004; Vert, 2006; Do and Reynolds, 2013). The gradient of the energy function can be given by:

$$\nabla f(.) = [\partial f(\Delta t_1)/\partial t_1, \partial f(\Delta t_2)/\partial t_2, \dots, \partial f(\Delta t_n)/\partial t_n]. \quad (2)$$

By defining the normalised vector of the energy function $f(\Delta t)$ as:

$$d = \nabla f(\Delta t_i)/\|\nabla f(\Delta t_i)\| \quad (3)$$

recall from linear algebra that the length of the gradient vector $\nabla f(x)$ is given as:

$$\|\nabla f(\Delta t)\| = (\nabla f(\Delta t_1)^2 + \nabla f(\Delta t_2)^2 + \dots + \nabla f(\Delta t_n)^2)^{1/2}. \quad (4)$$

In addition, $\nabla f(\Delta t_i)/\|\nabla f(\Delta t_i)\|$ is the normalised version (normal component) of $\nabla f(\Delta t)$, the normal vector of the energy function is a vector of unit values directed in the same direction as $\nabla f(\Delta t)$. The gradient of the energy function in points $\Delta t_1, \Delta t_2, \ldots, \Delta t_n$ is also a vector perpendicular to the surface of the function in these points. It is also clear that the increase of the maximum of the stack energy function also occurs in the direction defined by the gradient. Likewise, for a value x moving slightly with a quantity $\delta << d$ in the direction defined by:

$$\nabla f\left(\Delta t^{j}\right) = f\left(\Delta t^{j}\right) - f\left(\Delta t^{j-1}\right) = \delta\left\|\nabla f\left(\Delta t^{j-1}\right)\right\|. \quad (5)$$

The stack power objective function increases by a value of $\delta\|\nabla f(\Delta t^{j-1})\|$ for the iteration. Using this information, we can define the SAA for RS corrections by maximising the stack power objective function $z = f(\Delta t_1, \Delta t_2, \ldots, \Delta t_n)$, where: $(\Delta t_1, \Delta t_2, \ldots, \Delta t_n) \in \mathrm{R}^n$ represent the static corrections of the CDP traces:

- for $j = 1$; $\Delta t = [\Delta t_1, \Delta t_2, \ldots, \Delta t_n]^T = [v_{01}, v_{02}, \ldots v_{0n}]^T$ the vector v_0 is the initial static corrections chosen randomly;
- by moving the CDP energy function $f(\Delta t^{j+1})$ in the direction of $\nabla f(\Delta t^j)$, its value begins to increase correspondingly to the fixed step δ. Let us take the step value equal to unity $\delta = t^*$, and in that direction.

The next value of the energy stack function is then:

$$f\left(\Delta t^{j+1}\right) = f\left(\Delta t^{j}\right) + t^* \cdot \left\|\nabla f\left(\Delta t^{j}\right)\right\|. \quad (6)$$

The obvious question is how to make the best choice of t^*; it can be found by maximising the problem of the next value of the power stack function such that $t^* > 0$ (Gholami, 2013).

Once we found the new power stack value $f(\Delta t^{j+1}) = f(\Delta t^j) + t^* \cdot \|\nabla f(\Delta t^j)\|$, we evaluate $\|\nabla f(\Delta t^{j+1})\|$, if the length of the gradient, which shows the expected increase in function of f, is small, we can conclude that a local maximum of the power stack has been obtained and we can stop. Otherwise, the described steps will be repeated for $j = 2$ and so on.

The main difficulty lies in the fact that there is no deterministic way to judge the small values, it depends on the required precision and is based on trial/error methodology. In this application, a threshold of 0.01 of gradient length has been considered so that better RS corrections can be achieved.

SAA maximises the objective function by walking uphill on the stack power from a starting model, not picking where the peak might be. The purpose of stack power methodology is represented without the need to cross correlate every trace in a CDP with every other CDPs (Foster and Guinzy, 1967; Bergmann *et al.*, 2014).

3. Results and discussion

3.1. Synthetic data

Creating the synthetic data has been realised through the following steps.

3.1.1. Establishment of synthetic stack

It has been ensured by**:**
- creation of synthetic stack shots;
- geometry assignment;
- calculation of static corrections.

The resultant output from this step is a synthetic stack that describes a tabular geological model (Model-I) with two layers. The first layer is at 100 ms and the second layer is at 300 ms as shown in Fig. 1a.

3.1.2. Brute-stack disturbed model

The disturbance of Model-I has been done in two steps; in the first step, inappropriate static corrections have been applied to Model-I; these corrections have been imported randomly.

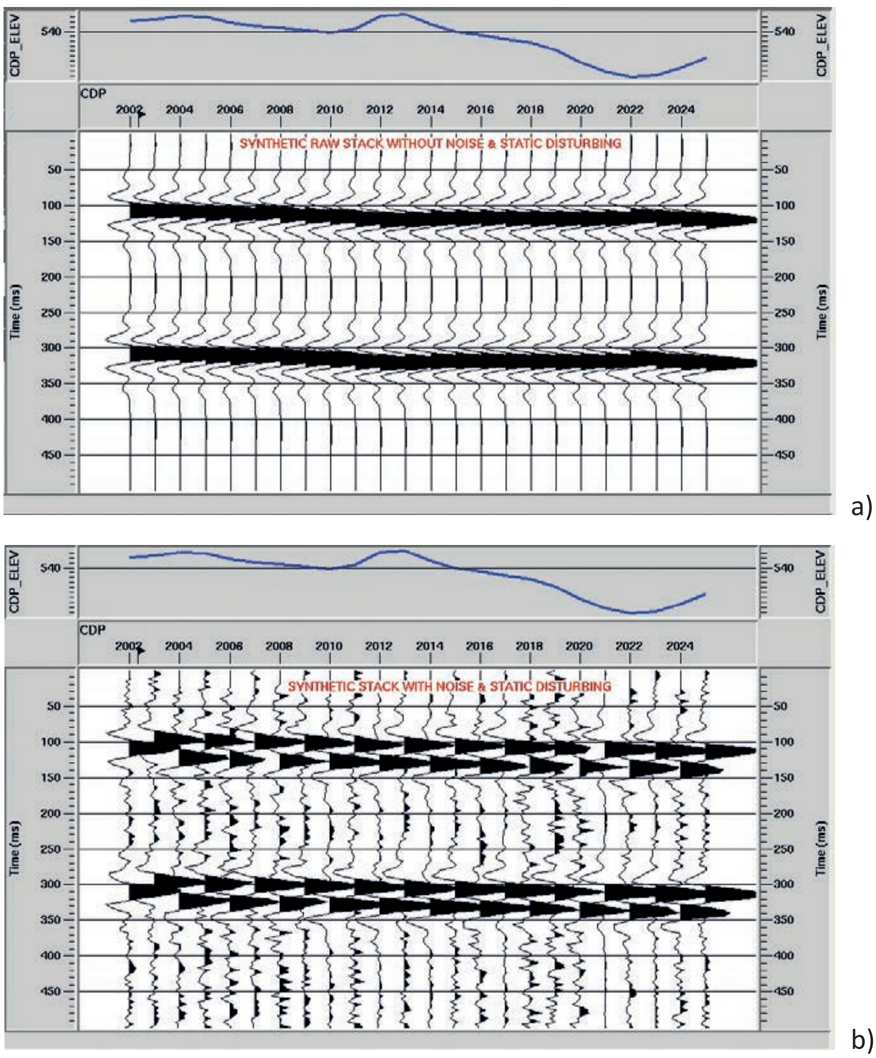


Fig. 1- Synthetic stack (Model-I) (a) and disturbed and noised stack (Model-II) (b).

This step is designed to shift in time the CDP and damage the continuity of the two synthetic horizons. In the second step, Model-I has been affected by random noise added to all the CDP of the synthetic stack. This step causes a decrease in the S/N ratio.

The resultant noised stack with low S/N ratio and inappropriate static amplitude corrections contains a poor continuity of the synthetic horizons. The resulting seismic section with poor quality, named Model-II, is shown in Fig. 1b. Thence, Model-II is the stack on which the proposed approach for RS corrections will be applied.

In each of the following simulation steps, we describe the application of the SAA for calculating the RS corrections. This algorithm can estimate the appropriate corrections and eliminate interference created earlier to improve the quality of the stack and to have acceptable synthetic horizons continuity. Model-II has been generated to test the effectiveness of the SAA. There are several automatic processes for estimating and calculating the RS corrections (Fig. 2), the majority of algorithms use the principle of consistent surface (Landmark Graphic Corporation, 2006).

Diagram in Fig. 2 summarises all steps followed in this study in order to compare the effectiveness of the proposed RS corrections method (SAA optimisation) with the methods used at this time in the Algerian seismic processing industry (static correction by elevation method, and static correction by refraction method). The input of the SAA algorithm is the output of the static correction by refraction because it gave better results than the elevation method, however those results are not satisfactory. Thus, it can be noted that one of the advantages of SAA is that it can be used to improve the static corrections done by the refraction method. Table 1 summarises all the experiments and tests performed on the SAA according to the number of iterations. The reliability of the algorithm has been analysed statistically and visually for different iteration values as detailed in the next sub-sections.

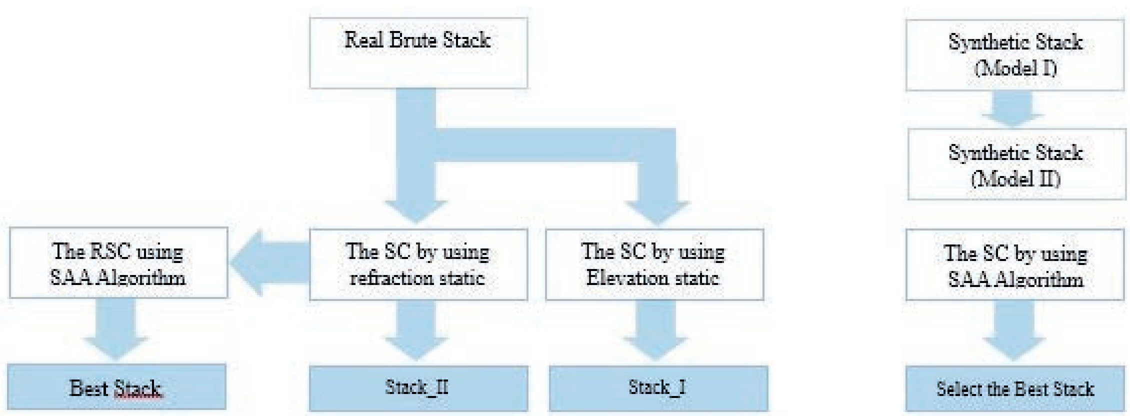


Fig. 2 - Diagram summarizing all realised steps of the study: a) real data application; b) synthetic data application.

Table 1 - Consistency measures with the Residual Static Corrections (RSCs) function of the SAA.

TEST N.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Number of iterations	5	6	7	8	9	10	20	30	40	50	60	70	80	90	100	110	120
Coherence	15	12	17	15	15	20	19	15	15	15	14	14	14	12	20	21	12

In the first test with five iterations, the curve of RS corrections has been calculated for each CDP using the SAA. We notice in Fig. 3b that the continuity is acceptable with acceptable consistency for the CDP interval [2015-2025]. For the rest of the synthetic stack CDP [2002-2014], the quality is bad, the SAA failed and the coherence is almost absent.

We have performed the SAA for 10 iterations wherein the selection of RS corrections is calculated for each CDP by the SAA. These corrections gave us the synthetic stack as shown in Fig. 3c. There is an acceptable continuity with good consistency for the CDP interval [2005-2013] but not so good for the CDP interval [2014-2025]. The quality is bad, the continuity is deteriorated and the coherence is absent for the rest of the synthetic stack (see Fig. 3c). For 10 iterations, it is noted that the quality has been improved because of the acceptable applied RS corrections. In order to improve the estimate of RS corrections and obtain a good synthetic stack, the number of iterations has been increased again by an increment of 10. We continued until 120 iterations. The RS corrections calculated for each CDP by the SAA with 110 iterations gave us the synthetic stack shown in Fig. 3d. We notice an acceptable continuity with acceptable coherence for the majority of the section, the quality is good enough for the rest; however, the problem of cycle skip appeared with two shifts (20 ms) at the level of CDP [2005 and 2006] and (30 ms) at the CDP [2022 and 2023] (Fig. 3d).

This phenomenon has been reduced when compared to the results of 20 to 100 iteration tests, and the quality has been improved in terms of continuity and CDP coherence. As a function of the automatic picking of the synthetic horizon, it is possible to estimate the existing coherence in the stack with RSC-SAA function; the number of coherent CDP has been measured for each

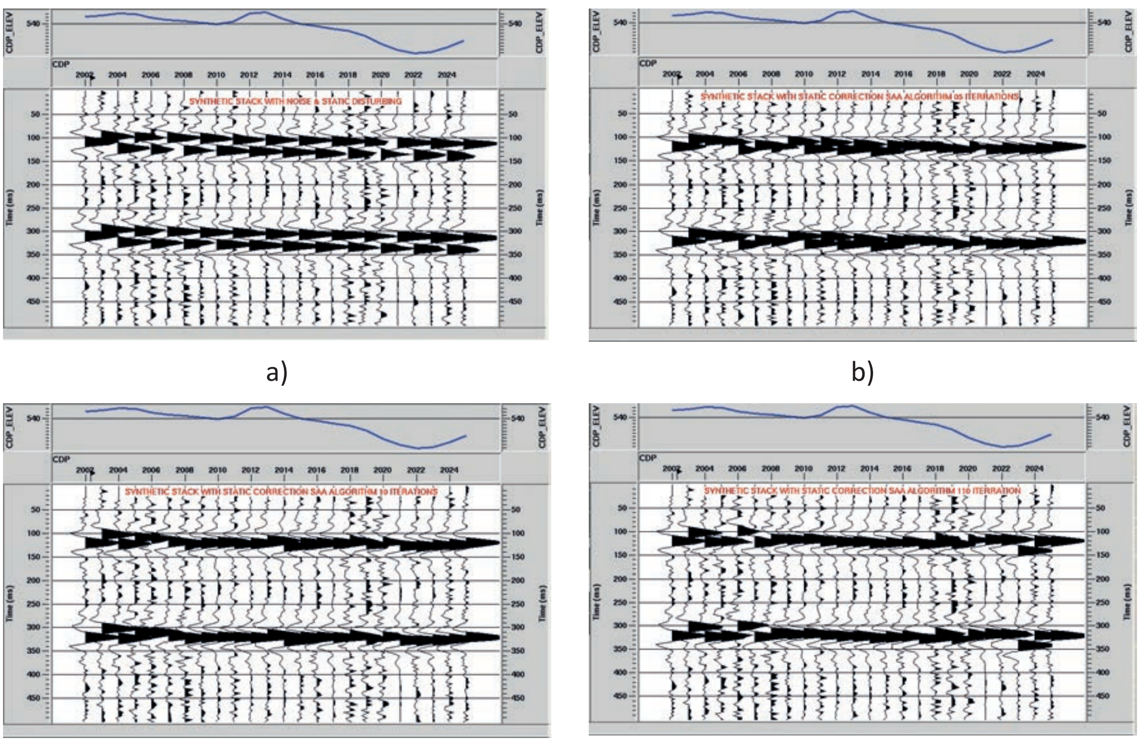


Fig. 3 - Synthetic stack with noise and static disturbing (a), and synthetic stack by using SAA algorithm with 5 iterations (b), 10 iterations (c), and 110 iterations (d).

test result. Table 1 shows the tests performed with the estimated measures of consistency and continuity.

The obtained results are presented in Fig. 4; it illustrates the number of coherent CDP for each synthetic section, where each iteration value gives a synthetic section. The graph in Fig. 4 shows instability in the algorithm, whereas, the values of the coherent CDP increase and decrease from one iteration value to another. The stack with 110 iterations shows a good continuity with a maximum CDP coherence (21), thus we can select these experiment results as the optimum solution for the RS corrections inverse problem.

In this simulation section, the RSC were estimated by the SAA method, which is used as an optimisation algorithm. This method is among the consistent surface techniques (Aleardi *et al.*, 2016); the obtained results led us to conclude that this method may be advantageous and efficient in case of static correction anomalies caused by sudden topographic changes and in mountainous exploration seismic prospection, where the methods of the RS corrections, which use a pilot trace for the cross-correlation step, may fail to give a reliable static correction (Zhang *et al.*, 2014). For these reasons, this algorithm has been applied to real data of seismic prospection with static correction anomalies from the southern Algeria geophysical survey.

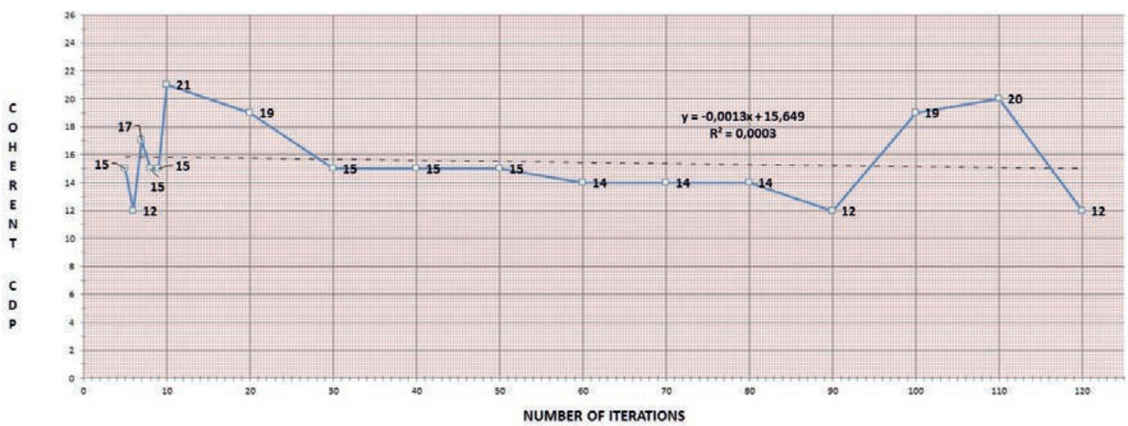


Fig. 4 - Graph of the tests' series and the estimation coherence measurement of the SAA algorithm.

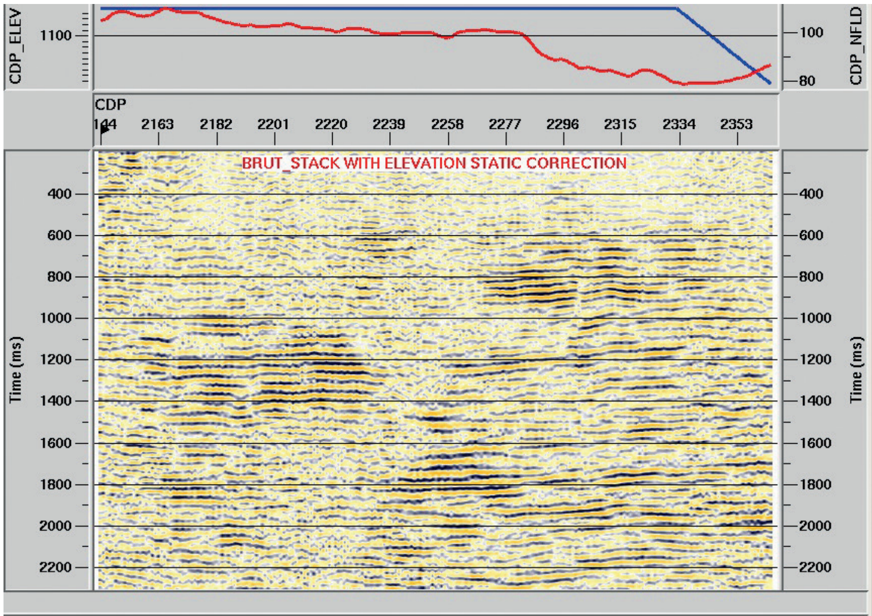
3.2. Results of field data

The application of elevation and refraction methods has given the brute stack shown in Figs. 5a and 5b, respectively.

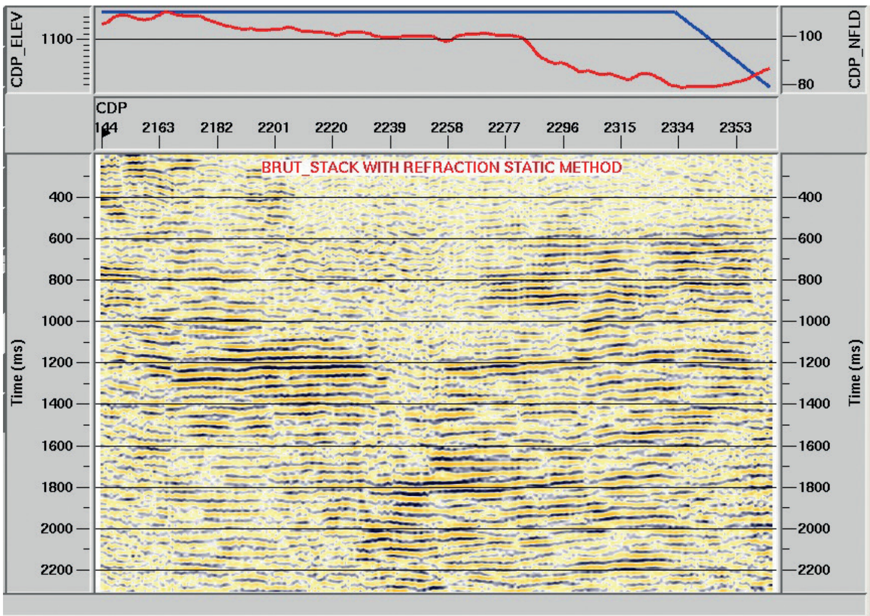
We notice the total absence of the continuity in the three horizon packets for brute stack obtained by using elevation method (Fig. 5a). However, the continuity is acceptable for the following packets:

- first packet in the CDP interval [2144-2267], we notice the appearance of static correction problem of small wave length precisely in the CDP interval [2144-2201];
- the second packet in the CDP interval [2230-2255];
- the third packet is in the CDP interval [2182-2239].

We notice that the quality of brute stack using refraction method (Fig. 5b) is somehow better than the one obtained using elevation method (Fig. 5a). We can also observe that the appearance of new structures and markers did not appear in elevation methods, where:



a)



b)

Fig. 5 - Brute stack obtained by using; a) elevation static corrections; b) refraction static corrections.

- in the first packet; the continuity is acceptable for the CDP interval [2267-2464], an appearance of part of the horizon has been detected with this method unlike the elevation method, precisely in CDP interval [2144-2201];
- in the second packet; we found an acceptable continuity for the whole section except the CDP interval [2230-2255] which does not have continuity;
- in the third packet; we note the presence of continuous horizons.

The obtained seismic section after applying these two primary static corrections demonstrates the existence of short wavelength anomalies for high frequency waves and long wavelength for low frequency waves (Askari, 2013). We applied the SAAs as RS corrections method with the aim of improving the quality of the seismic section and mitigating these anomalies.

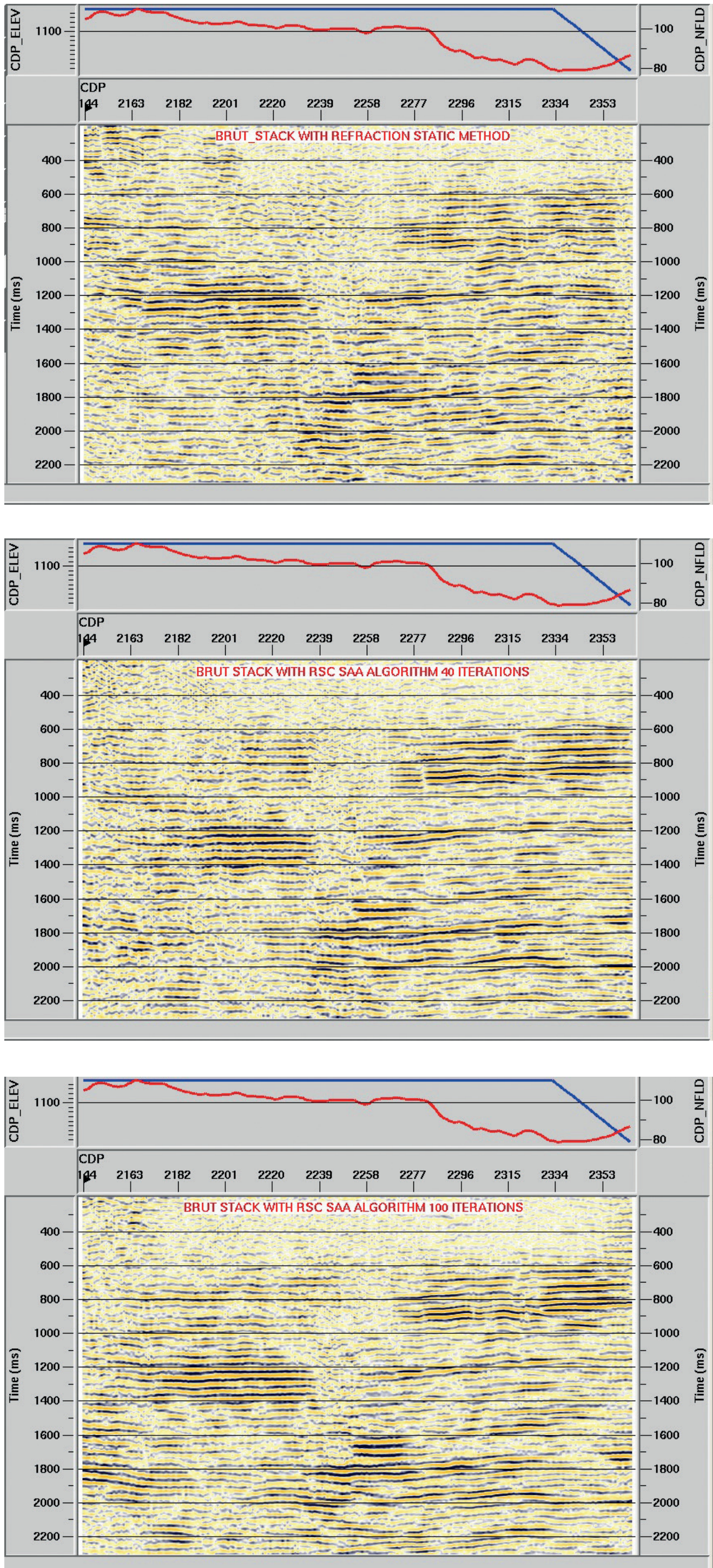
The SAAs as RS corrections do not exclude the conventional methods; however, it is more effective in case of poor quality seismic data and low S/N ratio. These poor-quality data are generally caused by different anomalies where conventional techniques generally fail to give acceptable static corrections. Thus, it is advantageous to test efficiency, reliability, and performance of new algorithms for RS corrections such as SAA.

In this section, we give the results of real data from southern Algeria for RS corrections by using SAA. The obtained best stack sections are shown in Fig. 6. Table 2 shows the different experiments realised for different iteration numbers, varying:

- from 10 to 200, with an increment of 10;
- from 200 to 1000 with an increment of 100;
- from 1000 to 10000 with an increment of 1000.

Table 2 - Consistency measures with the RSC of the SAA.

N°	Wave length	Eigen value	N° of Iterations
1	150	0.8	10
2	150	0.8	20
3	150	0.8	30
4	150	0.8	40
5	150	0.8	50
6	150	0.8	60
7	150	0.8	70
8	150	0.8	80
9	150	0.8	90
10	150	0.8	100
11	150	0.8	110
12	150	0.8	120
13	150	0.8	130
14	150	0.8	140
15	150	0.8	150
16	150	0.8	160
17	150	0.8	170
18	150	0.8	180
19	150	0.8	190
20	150	0.8	200
21	150	0.8	300
22	150	0.8	400
23	150	0.8	500
24	150	0.8	600
25	150	0.8	700
26	150	0.8	800
27	150	0.8	900
28	150	0.8	1000
29	150	0.8	10000

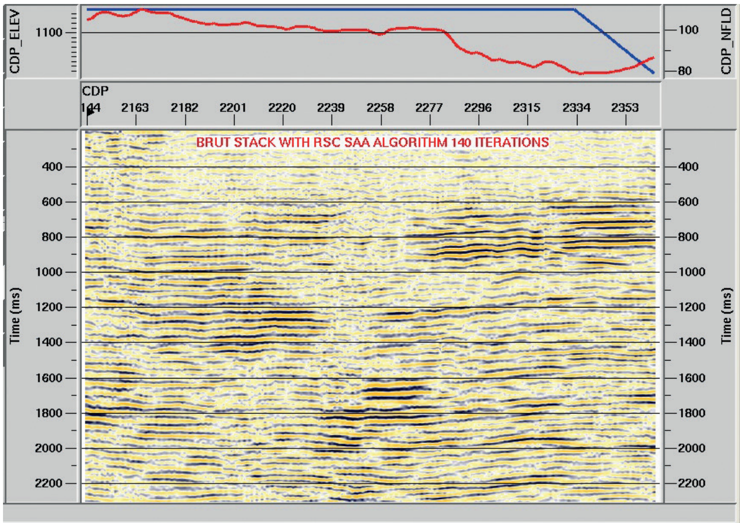


a)

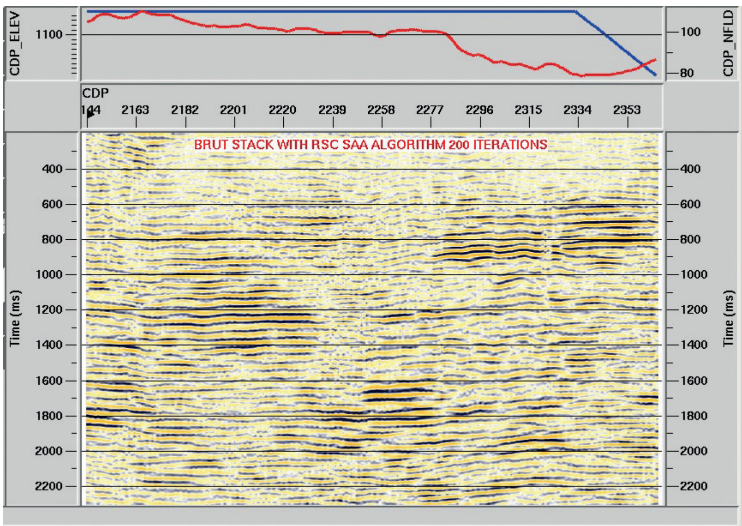
b)

c)

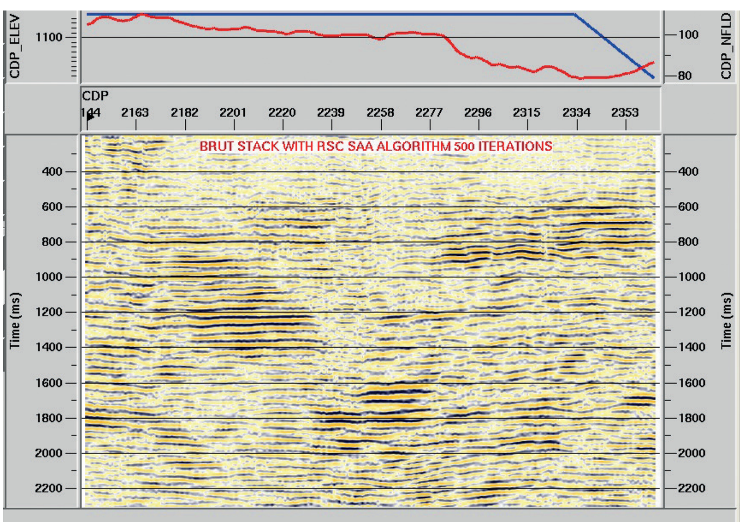
Fig. 6 - Brute stack with refraction (a) and stack of SAA with: 40 iterations (b); 100 iterations (c); 140 iterations (d); 200 iterations (e); 500 iterations (f); 1000 iterations (g); 10000 iterations (h).



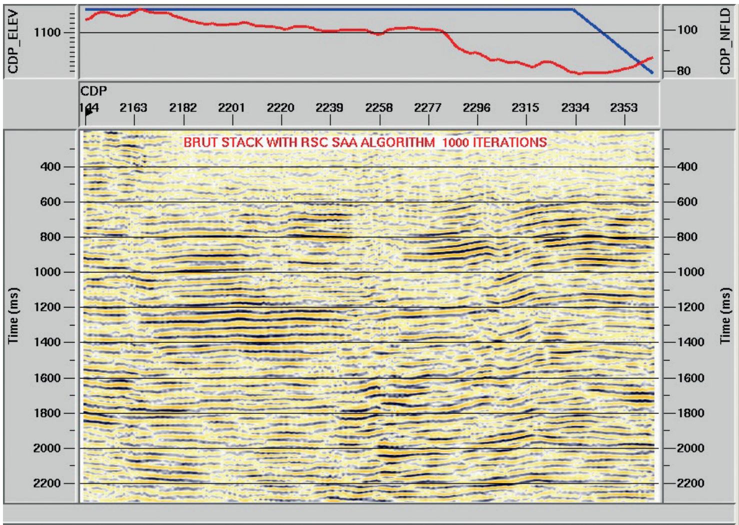
d)



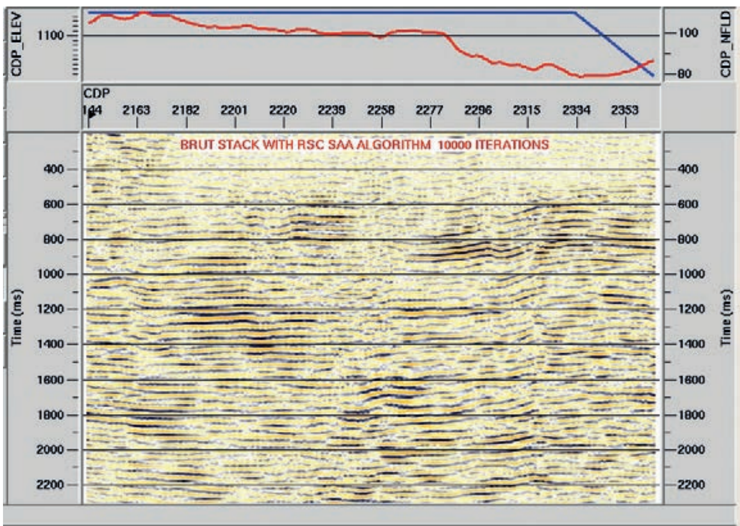
e)



f) Fig. 6 - continued.



g)



h)

Fig. 6 - continued.

Experiments have been realised for RS correction based on SAA; these parametric variation experiments enable evaluating the efficiency of the proposed algorithm, as well as determining the optimal number of iterations for the best solution of RS corrections. It also allows us to determine the optimised number of iterations that gives better RS corrections with an optimised computing time. Fig. 6 shows the selected results that seem interesting and give conclusive remarks for the proposed contribution.

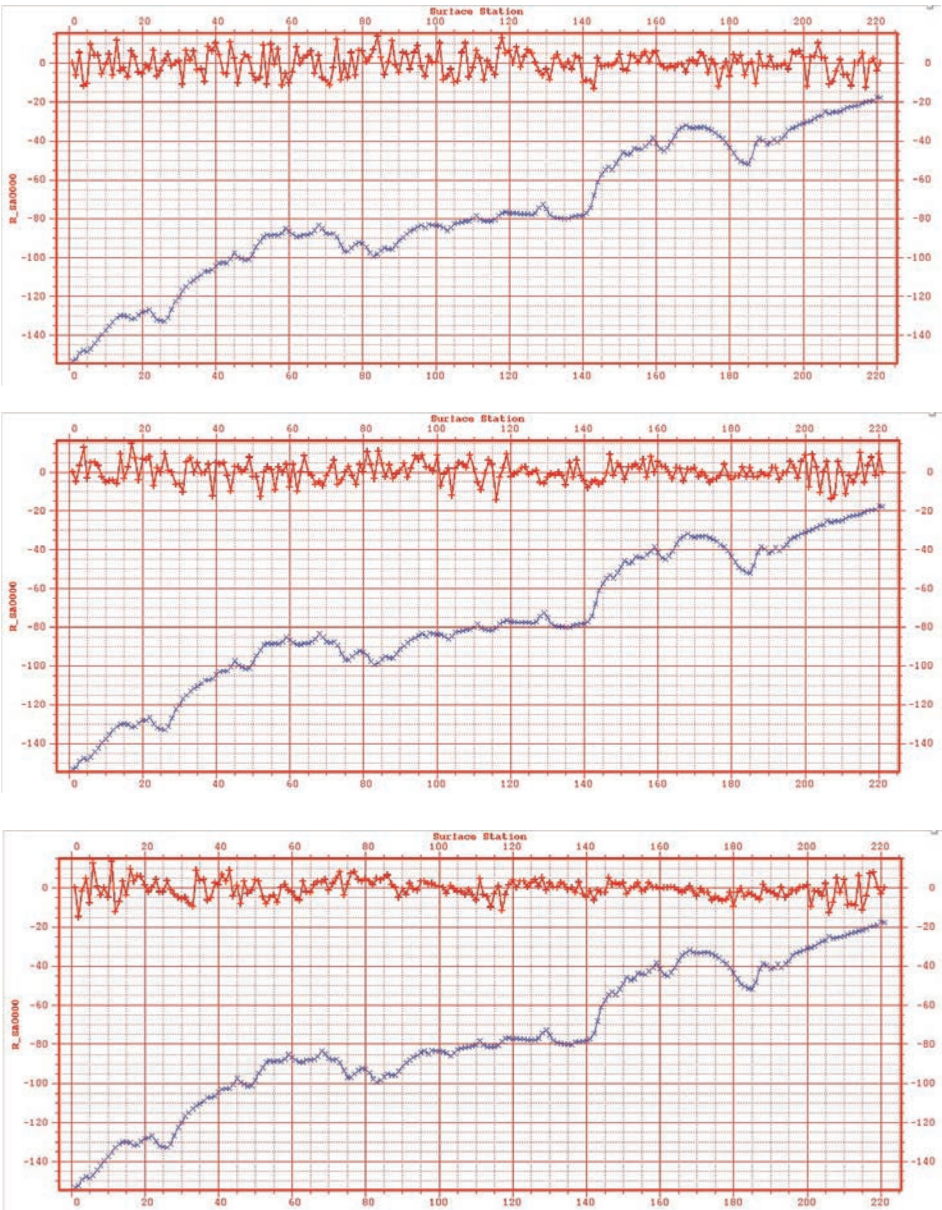
For SAA with 40 iterations (Figs. 6b and 7a), we note that this section contains three horizon packets:

- the first packet is in the time interval [500-900 ms]; it shows an acceptable continuity for CDP interval [2267-2464] and weak continuity in the CDP interval [2201-2238];
- the second packet is in the time interval [1000-1500 ms]; it demonstrates a weak continuity in the CDP interval [2258-2464], a very good continuity in the CDP interval [2163-2229], and acceptable continuity in the CDP interval [2144-2163];
- the third packet is in the time interval [1600-2200 ms]; it has an acceptable continuity in

almost all sections, the part situated in the CDP interval [2182-2215] presents a pseudo absence of the horizons.

The other tests with number of iterations varying from 20 to 200 with 10 iteration steps have been analysed too: the SAA gave acceptable corrections that improved the quality of the sections.

Fig. 7 shows the curves of RS corrections for experiments number 4, 10, and 14 (see Table 2). The quality of the seismic sections has been improved for both horizon continuity and sequence resolution; these improvements were noted for the three CDP packets.

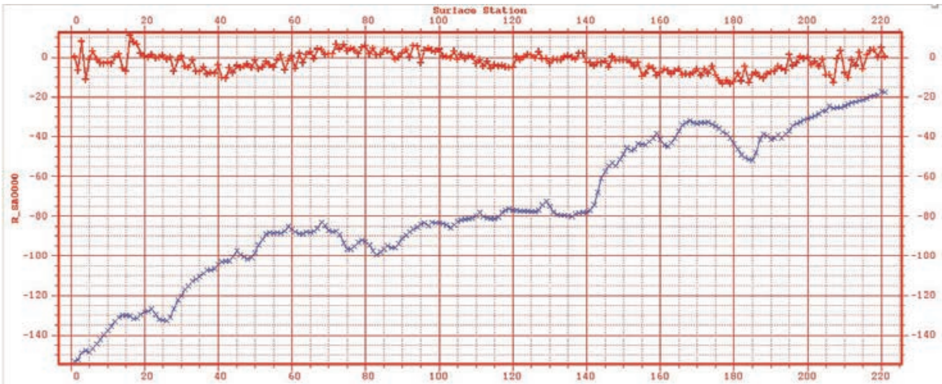


a)

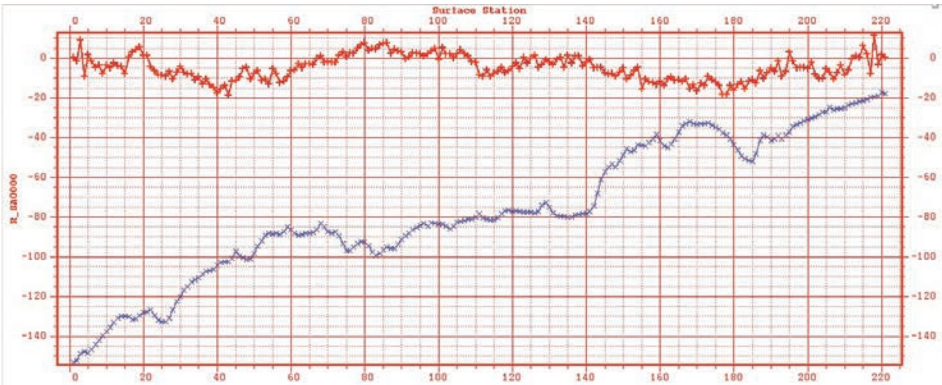
b)

c)

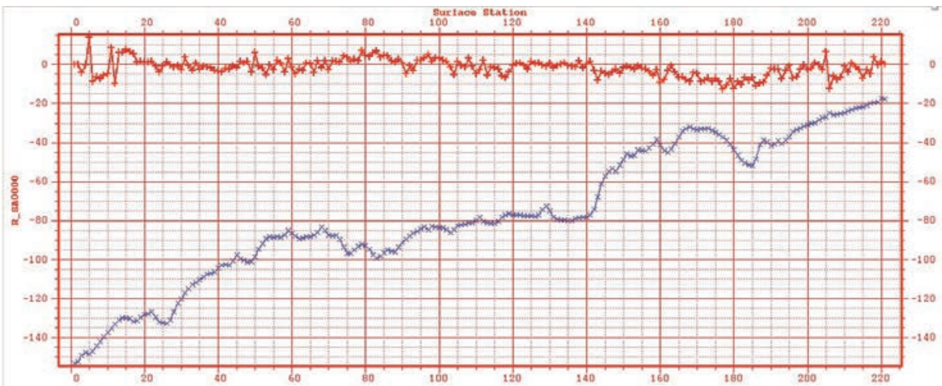
Fig. 7 - Static correction curve using SAA with: a) 40 iterations, b) 100 iterations; c) 140 iterations; d) 200 iterations; e) 500 iterations; f) 1000 iterations; g) 10000 iterations. Blue lines indicate elevation static solutions. Red lines indicate RS solutions.



d)



e)



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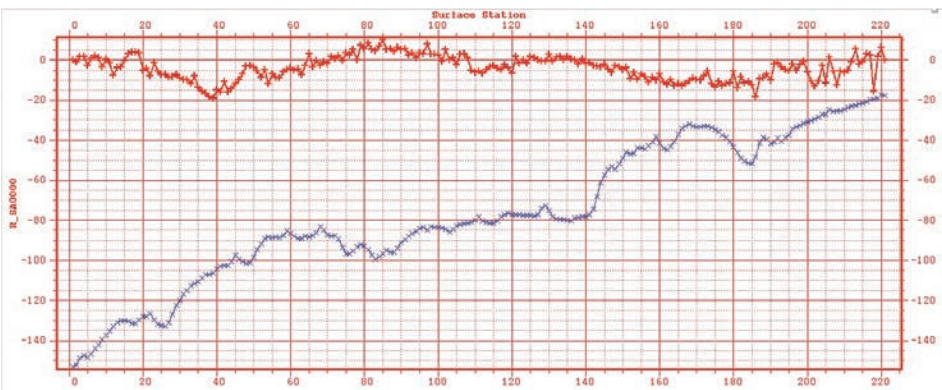

g)

Fig. 7 - continued.

For the objective of trying to improve the quality of the seismic section and suppress the high frequency-low frequency anomalies, we have increased the number of iterations from 200 till 1000 with steps of 100 iterations (Table 2).

We observed that the seismic sections quality is weakened in comparison to results obtained with 140 iterations, which means that the optimum parameters of SAA to give better results is 140 iterations.

Fig. 8 shows the performance of the proposed approach in the CDP domain, the two CDPs

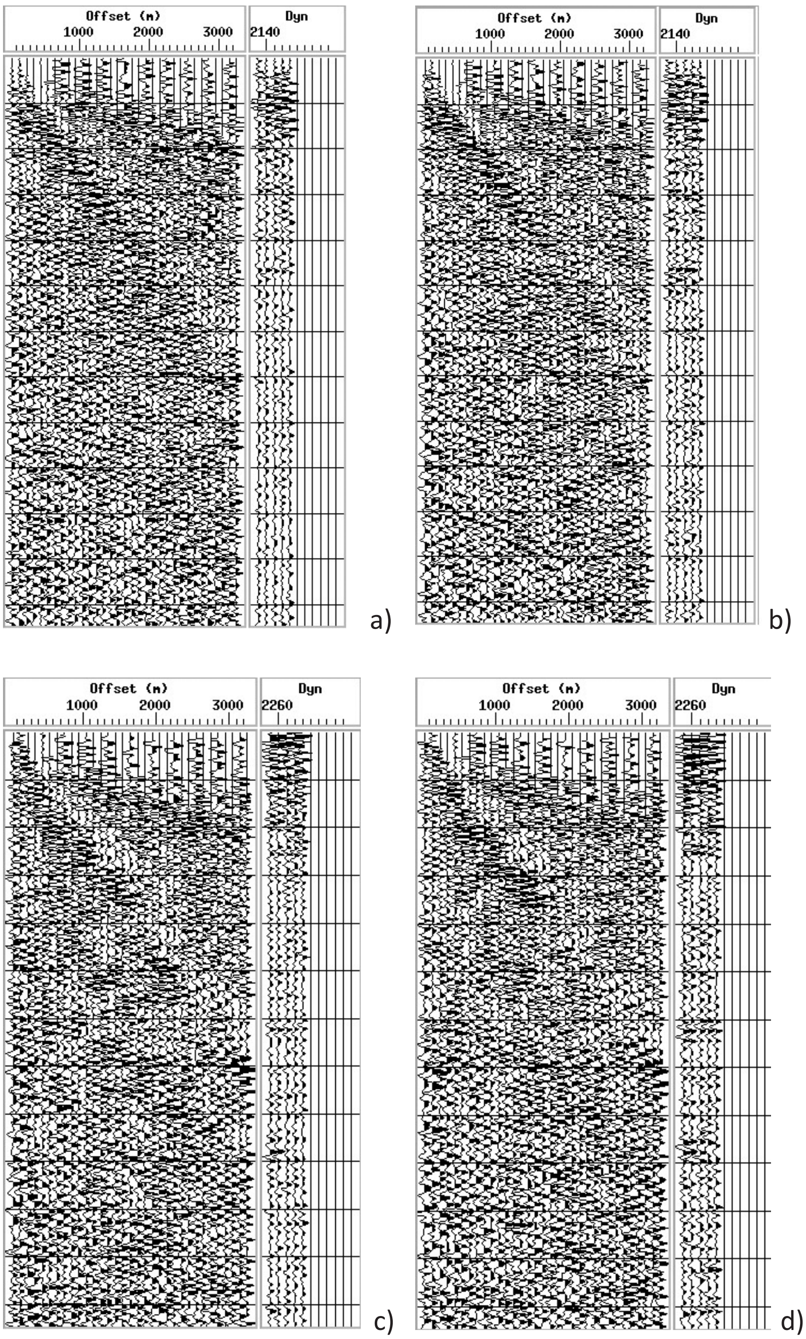

Fig. 8 - CDP gather before and after RS solution with SAA 140 iterations; a) CDP 2144 before RSC; b) CDP 2144 after RSC; c) CDP 2264 before RSC; d) CDP 2264 after RSC.

before (Figs. 8a and 8c) and after (Figs. 8b and 8d) the application of the RS solution with the SAA at 140 iterations. The CDP and the mini stack applied prove that the RS solutions (time-shift) give us a good stack power (Fig. 8).

The maximum stack power for each experiment has been calculated. Fig. 9 shows the variations of the maximum power as a function of SAA iteration number:

- the maximum stack power objective function for the number of iterations varied from 10 to 200, with an increment of 10 (Fig. 9a);
- the maximum stack power objective function for the number of iterations varied from 200 to 1000, with an increment of 100 (Fig. 9b);
- the maximum stack power objective function for the number of iterations varied from 1000 to 10000, with an increment of 10 (Fig. 9c).

We can conclude that the optimal solution, which gives maximum power, is 140 iterations.

a)

b)

c)

Fig. 9 - Real data maximum power stack vs. number of iterations of SAA: a) from 10 to 200, b) from 100 to 1000, c) from 1000 to 10000.

4. Conclusions

The quality of RSC estimation has a threshold; the performance of the algorithm is limited. Following the regression line and the low value of the coefficient (0.0003), we can state that the SAA is unstable. This does not prevent us from observing the stability of our algorithm in a few iteration number intervals; the instability is due to the very poor S/N ratio of real data, since the random noise generates secondary peaks in the cross-correlation function, making identification of the shifts much more difficult.

The coherence variation curve, creating either a large or small shift value calculated based on the number of iterations, is directly related to the cycle skip phenomenon. The local optimisation character of the algorithm, the random noise and the topography variation, are the main causes of occurrence of this phenomenon giving very variant shifts values.

From the results of this study, it is clear that the consistency obtained with the SAA is acceptable. Stack energy is acceptable in parts unaffected by the cycle skip phenomenon. We recommend the combination of SAA with another algorithm that eliminates the cycle skip phenomenon and improves the results estimated by the SAA. To complete this work, we highly recommend the application of the combination Hybrid Genetic Algorithm (HGA/CSAA).

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REFERENCES

Aleardi M., Stucchi E., Sajeva A. and Galuzzi B.; 2016: *Surface-consistent residual statics estimation with genetic algorithms - An application to a near-surface Seismic Survey*, In: Proc. 22nd European Meeting of Environmental and Engineering Geophysics, Near Surface Geoscience 2016, EAGE, Vol. 2016, cp-495-00007, doi: 10.3997/2214-4609.201601908.

Askari R.; 2013: *Surface wave analysis and its application to the calculation of converted wave static corrections.* Doctoral Thesis in Geophysical Sciences, Department of Geosciences, Faculty of Graduate Studies, University of Calgary, Calgary, AB, Canada, 113 pp., doi: 10.11575/PRISM/27941, unpublished.

Askari R., Robert J.F., Helen Isaac J., Hossein Hejazi S.; 2015: *Estimation of S-wave static corrections using CMP cross-correlation of surface waves.* J. Appl. Geophys., 121, 42-53, doi: 10.1016/j.jappgeo.2015.07.004.

Bergmann P., Kashubin A., Ivandic M., Lüth S. and Juhlin C.; 2014: *Time-lapse difference static correction using prestack cross correlations: 4D seismic image enhancement case from Ketzin*. Geophys., 79, B243-B252, doi: 10.1190/geo2013-0422.1.

Disher A.D. and Naquin PJ.; 1969: *Statistical automatic statics analysis.* Geophysics, 35, 574-585.

Do S.T. and Reynolds A.; 2013: *Theoretical connections between optimization algorithms based on an approximate gradient.* Comput. Geosci., 17, 959-973, doi: 10.1007/s10596-013-9368-9.

Feng F., Zhang Y., Deng Z. and Wang H.; 2011: *The multivariate statistic residual static correction method and examples of its application.* In: Expanded Abstracts, SEG Technical Program, pp. 1454-1457, doi: 10.1190/1.3627476.

Fletcher R.; 1987: *Practical methods of optimization, 2nd ed.* A Wiley Interscience Publication, Chichester, NY, USA, 456 pp., doi: 10.1002/9781118723203.

Foster M.R. and Guinzy N.J.; 1967: *The coefficient of coherence: its estimation and use in geophysical data processing.* Geophys., 32, 602-616, doi: 10.1190/1.1439878.

Freund R.M.; 2004: *The steepest descent algorithm for unconstrained optimization and bisection line-search method.* Massachusetts Institute of Technology, Cambridge, MA, USA, 28 pp.

Gholami A.; 2013: *Residual statics estimation by sparsity maximization.* Geophys., 78, V11-V19, doi: 10.1190/geo2012-0035.1.

Henley D.C.; 2012: *Interferometric application of static corrections*. Geophys., 77, Q1-Q13, doi: 10.1190/geo2011-0082.1.

Hilterman J.A., Embree P. and Pflueger J.C.; 1968: *Automated static corrections.* Geophys. Prosp., 16, 326-358.

Kirchheimer F.; 1983: *Long-period static analysis by trigonometric approximation.* In: 53rd Ann. Meeting of SEG, Las Vegas, SEG Technical Program Expanded Abstracts,Paper number SEG 1983-0317, doi: 10.1190/1.1893844.

Landmark Graphics Corporation; 2006: *Landmark Family ProMAX® 5000*. Houston,TX, USA.

Ronen J. and Clerbout J.F.; 1985: *Surface-consistent residual statics correction by stack-power maximization*. Geophysics, 50, 2759-2767.

Sajeva A., Aleardi M., Galuzzi B., Stucchi E., Spadavecchia E. and Mazzotti A.; 2017: *Comparing the performances of four stochastic optimisation methods using analytic objective functions, 1D elastic fullwaveform inversion, and residual static computation.* Geophys. Prospect., 65, 322-346, doi: 10.1111/1365-2478.12532.

Stork C. and Kusuma T.; 1992: *Hybrid genetic autostatics: new approach for large-amplitude statics with noisy data.* In: Expanded Abstracts, SEG Technical Program, pp. 1127-1131, doi: 10.1190/1.1821926.

Taner M.T., Koekler F. and Alhilali A.; 1974: *Estimation and correction of near surface time anomalies.* Geophysics, 39, 441-463.

Tarantola A.; 2005: *Inverse problem, theory and methods for model parameter estimation.* SIAM - Society for Industrial and Applied Mathematics, Philadelphia, PA, USA, 358 pp., ISBN: 0-89871-572-5(pbk).

Vert J.P.; 2006: *Nonlinear optimization: algorithms 1: unconstrained optimization.* INSEAD, Fontainebleau, France, 66 pp.

Wiggins R.A., Lamer L.L. and Wisecup R.D.; 1976: *Residual statics as a general linear inverse problem.* Geophysics, 41, 922-938.

Zhang J., Shi T., Zhao Y. and Zhou H.; 2014: *Static corrections in mountainous areas using Fresnel-wavepath tomography.* J. Appl. Geophys., 111, 242-249, doi: 10.1016/j.jappgeo.2014.10.006.

Zhu X., Gao R., Li Q., Guan Y., Lu Z. and Wang H.; 2014: *Static corrections methods in the processing of deep reflection seismic data.* J. Earth Sci., 25, 299-305, doi: 10.1007/s12583-014-0422-x.

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