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1

THE DIRECT-INVERSION DECONVOLUTION AND ITS APPLICATION IN SEISMIC

DATA

Dekonvolusi Direct-Inversion dan Aplikasinya pada Data Seismik

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Abstract. Seismic traces are generated[2] by the convolution of reflectivity and seismic wavelet. Due to limited frequency bandwidth, the reflectivity[3] can not be resolved[4] easily[5]. Deconvolution is a method to increase the frequency bandwidth and gives seismic data higher resolution, which makes it easier to analyze. Deconvolution is a common[6] method in seismic[7] data processing. The mathematical definition of deconvolution is an inverse process of convolution, but the computation of deconvolution uses convolution in its process (Wiener deconvolution).[8] We explained a method that direct[9] from the mathematical definition. We refer to it as direct-inversion deconvolution. The direct-inversion deconvolution process involves the matrix operation between seismic trace and wavelet instead of using the[10] deconvolution-filter[11] [12]. By applying the direct-inversion deconvolution, the produced (or deconvolved) seismic trace shows a better result with higher resolution, regardless of the wavelet's phase.[13] We perform a phase rotation experiment, and the

deconvolution result shows no seismic phase alteration. As[14] comparison[15], we also perform Spiking deconvolution in synthetic[16] data experiment[17]. This method is applied to The North Sea Volve Data Village seismic data, and more thin layers are significantly detected. It turns out that[19] direct-inversion deconvolution gives higher[18] resolution to seismic data.

Abstrak. Trace seismik diperoleh dari konvolusi antara reflektivitas dan wavelet seismik. Karena adanya keterbatasan bandwidth frekuensi, reflektivitas tidak dapat teresolusi dengan baik. Dekonvolusi merupakan suatu metode untuk meningkatkan bandwidth frekuensi dan memberikan data seismik resolusi yang lebih tinggi, sehingga data seismik lebih mudah untuk dianalisis. Dekonvolusi merupakan metode umum dalam pengolahan data seismik.

Definisi matematis dari dekonvolusi adalah proses pembalikan dari konvolusi, tetapi perhitungan proses dekonvolusi menggunakan konvolusi (dekonvolusi Wiener). Kami menjelaskan sebuah metode untuk memberikan makna langsung dari definisi matematisnya, yang kami sebut dengan direct-inversion dekonvolution. Proses direct-inversion dekonvolution melibatkan operasi matriks antara trace seismik dengan wavelet, bukan menggunakan filter dekonvolusi.
Dengan menerapkan dekonvolusi real, trace seismik yang dihasilkan (atau didekonvolusikan) menunjukkan hasil yang lebih baik dengan resolusi yang lebih tinggi, terlepas dari fasa wavelet-nya. Kami melakukan percobaan rotasi fase, dan hasil dekonvolusi tidak menunjukkan perubahan fase seismik. Sebagai perbandingan, kami juga melakukan dekonvolusi Spiking dalam eksperimen data sintetis. Metode ini diterapkan pada data seismik The North Sea Volve Data Village. Hasilnya, terdapat lapisan tipis terdeteks. Jadi,

dekonvolusi inversi langsung memberikan resolusi yang lebih tinggi untuk data seismik.

INTRODUCTION

Deconvolution is a method for the enhancement of [20] seismic's vertical resolution, an essential part of seismic data processing and interpretation. Deconvolution's purpose is to broaden the frequency bandwidth by compressing the seismic wavelet. The seismic frequency is expected [21] to provide broader bandwidth to obtain a higher resolution of seismic data and more thin layers to be resolved [22]. These methods are commonly applied in oil industries to represent subsurface reflectivity better.

There are different types of known deconvolution: spiking deconvolution and predictive deconvolution (Yilmaz, 2001) based on Wiener filtering (Wiener, 1949), assuming the wavelet is stationary or does not change with travel time. However, the seismic wavelet varies in time and depth due to frequency attenuation and wavefront divergence (nonstationary [23]). Therefore, the deconvolution [24] theory proposed some alternatives to solve the nonstationary [23] case.

First, inverse Q-filtering compensates for the frequency attenuation described by quality factor Q (van der Baan, 2012; Y. Wang, 2006). However, this method requires pretty accurate Q-values, which is difficult to obtain in practice. The Q-value affects both seismic frequency and amplitudes. On the other hand, the seismic amplitude is also affected by reflectivity. Then, this may cause uncertainty in Q estimation.

Moreover, the Q-value may be different each time (time-varying). There is research that[25] tried to solve the problems (Merouane & Yilmaz, 2017). However, it has[28] not been tested[26] in real[27] data.

Second, Gabor deconvolution combines the essential ideas of stationary deconvolution and inverse Q filtering (Margrave et al., 2011), or[29] assuming seismic traces are split[30] into segments which are called the molecular-Gabor transform (L. Wang et al., 2013).[31]

Finally, in recent developments, time-varying deconvolution uses the less-assumption technique in its processes, such as using S-transform (Jia et al., 2017; Winardhi & Pranowo, 2019) or other mathematical approaches (Pranowo, 2019; van der Baan, 2008).

A method also uses the modified S-transform (Djeffal et al., 2016),[32] and another[3] method to increase vertical resolution using improved time-frequency spectral modeling, provided by the decomposition of seismic trace using a generalized S-transform (Zhou et al., 2016).

Mathematically, deconvolution is defined[34] as the inverse convolution process by focusing on the basic theory of deconvolution.[35] However, in practice, most deconvolution methods are computed using convolution.

This paper explained the direct-inversion deconvolution, which gives the direct[3] meaning[37] to the mathematical definition. Furthermore, the example[38] of applications in synthetic and real[39] data are also performed[40]. The result of this method is compared[41] to spiking or Wiener deconvolution.

LITERATURE REVIEW

Seismic interpretation and reservoir characterization mostly[42] relies on using[43] relatively narrow bandwidth seismic datasets. To enable the full[44] picture to be seen and characterized, the full[45] frequency spectrum is needed (Reiser et al., 2012).[46] At least, the frequency spectrum is broadened, which can be achieved[47] by using the deconvolution method.

In seismic data analysis theory, the subsurface reflectivity can be derived[48] by deconvolving the wavelet with seismic traces (Goupillaud, 1961; Wuenschel, 1960).[49] The deconvolution defines the deconvolved seismic trace as the reflectivity by inverting the process of convolution[50] instead of using a Wiener filter (Wiener, 1949). The result shows the deconvolved seismic trace as the reflectivity. In this paper, we refer to this deconvolution as direct-inversion deconvolution.

The direct-inversion deconvolution method has a different procedure. The deconvolved seismic trace[52] is not generated[51] by using the Wiener filter. Practically, the procedure only needs the seismic trace and the inverse matrix of the wavelet. In addition, pre-whitening is still needed[53] to handle an ill-conditioned matrix.

Direct-inversion deconvolution is not common[54]. This process rarely[55] uses[56] in deconvolution, even though exist[57,58]. This[59] is because the[60] caustion[61] of matrix's[62] singularity and ill-condition. However, this paper shows that this method can be applied[63] in a synthetic seismogram (which is[64] generated by synthetic reflectivity and certain[65] wavelet) and a real[66] data seismic. It can also increase the data resolution.

Seismic Trace, Convolution, and Deconvolution

Synthetic seismogram or trace is given by convolution model between wavelet and reflectivity series (Goupillaud, 1961; Wuenschel, 1960).[67] This model is expressed by,

st=rt*wt

(1)

where[68] st is synthetic seismogram, rt is reflectivity series, wt is wavelet, and * is a convolution operation.

The process of Eq.1 is illustrated by Fig. 1. Wavelet represents seismic pulse or signal of seismic energy source, while reflectivity series represents the contrast of acoustic impedance between the layer of rocks and signs of layer boundaries.

Deconvolution is the inverse process of the convolution model. Because the convolution gives seismic trace, the deconvolution produces reflectivity series. In both deconvolution and convolution, the wavelet is assumed as a known variable or at least can be estimated.

Fig. 1. Synthetic seismogram modeling based on Eq. 1.

Wiener and Spiking Deconvolution

Wiener deconvolution is intended[69] to modify an input signal to be the desired output using the convolution process (Wiener, 1949; Yilmaz, 2001). Let a seismic trace be input and reflectivity be the desired output, then

Rt=Ft*St

(2)

where[70] St is seismic[71] trace, Ft is Wiener filter, Rt is reflectivity, and * is convolution operation.

Eq.2 can be written in matrix operation as

R=FS

(3)

where S is vector[72] of seismic trace, F is matrix[73] of moving Wiener filter, and R is vector[74] of reflectivity.

The Wiener filter is designed[75] so the input can be the desired output. The relationship between input, desired output, and Wiener filter can be expressed as matrix operation as,

c0c1 ⋮ cnC=a0a-1⋯a-na1a0⋯a-n-1 ⋮ ⋮ ⋱ ⋮ anan-1⋯a0Af0f1 ⋮ fnF

4

where[76] F is Wiener filter, A is Toeplitz matrix of input autocorrelation and[77] C is cross-correlation[78] between input and desired output.[79]
Indeed, the Wiener filter can be obtained by,

F=A+λI-1C

5

where[80] λ is pre-whitening. If our desired output is a spike, C can be replaced[81] with
C=1,0,...,0T

6

Then, the process is known as spiking deconvolution (Yilmaz, 2001).

The filter F is convolved with a seismic trace to get the reflectivity, as shown in Eq.2. In reality, the result of Wiener (or spiking) deconvolution can be reflectivity. It is a broadened frequency (or enhanced) seismic trace. So, Eq.2 can be written[82] as

Sdecon=FS

7

By mathematical definition, deconvolution is the inverse process of convolution. On the other hand, Wiener deconvolution (and its derivatives) uses convolution in its process, which sounds contradictory to its definition. However, because of its result, the Wiener deconvolution is still classified as a seismic deconvolution method.[83] Any method can be considered[84] a seismic deconvolution as long as it can or is intended[85] to produce a reconstructed reflectivity from a seismic trace.[86]

Direct-inversion deconvolution

The convolution process in Eq.1 can be written as matrix operation as,

S=WR

8

where[87] S is seismic[88] trace, R is reflectivity, and W is a matrix of[89] moving or shifting wavelet[90] (Fig. 2).

Fig. 2. Matrix of moving wavelet.

From Eq.7, R is obtained[91] with the objective function by minimizing L2[92] norm of,

minRS-WR2

9

where[93] ·2 is L2[94] norm. The objective function is achieved[95] by using matrix inversion (Meresescu, 2019),

R=W-1S

10

However, W is usually an ill-conditioned matrix. One way to overcome this problem is to add the pre-whitening (or damping) in the inversion process, so

R=W+λI-1S

11

where[96] λ is a pre-whitening.[97]

The pre-whitening handles not only the ill-conditioned matrix but also noise presence. A lower signal-to-noise ratio requires higher[98] λ. However, the Eq.[99]10 sometimes does not handle noise well. Therefore, Eq.8 can be solved using pseudo-inverse,

R=WTW+λI-1WTS

12

Fig. 3. WTW+λI-1WT.

Eq.12 performs the inverse process of deconvolution. So, it can be considered[100] as direct-inversion deconvolution. However, in reality, it is hard to produce reflectivity from a seismic trace.[101] It is because the seismic frequency is band-limited. Instead of producing reflectivity, Eq.12 produces a deconvolved (or enhanced) seismic trace. So, it is wiser to change R in Eq.12 similar to Eq.7 as,

Sdecon=WTW+λI-1WTS

13

where[102] Sdecon is deconvolved[103] seismic trace.[104]

If the wavelet's phase is unknown or uncertain, the wavelet in W is set[105] zero-phase. If we set[106] W is[107] set[108] zero-phase, it does not alter the original seismic phase. However, it is permissible to add wavelet[109] phase in W. There are several methods in phase estimation (Fomel & van der Baan, 2014). If we add phase[110] in W, the direct-inversion deconvolution will de-phasing Sdecon.[111]

In fact,[112] the deconvolution process in Eq. 12 is used implicitly in seismic inversion. For example, model-based inversion uses Eq.12 in its equation (Hampson-Russel Software, 1999; Pranowo, 2019).

DATA AND METHODS

Data

This paper uses three datasets: 2 synthetic and real datasets. The synthetic datasets contain 2 cases. The first one is the synthetic data with very sparse[113] reflectivity (Fig. 4).[114] The other one is synthetic data with denser reflectivity (Fig.5).[115] Each synthetic seismic trace is generated[116] by convolving synthetic reflectivity with Ricker Wavelet 25 Hz. The synthetic data is used[117] to know the behavior of the direct-inversion deconvolution. Meanwhile, the application in real[118] data (Fig.6) is to see[119] whether the direct-inversion deconvolution is applicable in real[120] conditions. The real[121] data is Equinor's Open Data: The North Sea Volve Data Village (Equinor, 2018).

Fig. 4. Sparser Cases Synthetic Data: Reflectivity (a) and Seismic Trace (b).

Fig. 5. Denser Cases Synthetic Data: Reflectivity (a) and Seismic Trace (b).

Fig. 6. The North Sea Volve Village Seismic Data.

Methods

This paper uses direct-inversion deconvolution as the main[122] method. The procedure of direct-inversion deconvolution in a real[123] application:

Extract the wavelet from the seismic data. We suggest using a statistical wavelet (Cui & Margrave, 2014).

Construct moving wavelet matrix (Fig.2)

Determine pre-whitening in Eq. 12. We suggest the pre-whitening between 1% to 10%, depending on S/N.

Apply direct-inversion deconvolution (Eq. 12).

RESULTS AND DISCUSSION

Application to Synthetic Data

Fig.7 shows the result of the direct-inversion deconvolution method to a synthetic seismic trace for the sparser case. The deconvolved seismic trace (Fig.7b) gives a better resolution than the original (Fig.7a). The interfered reflectors more separated after deconvolution. The result is consistent with the denser case (Fig.8). Many reflectors appear, and the wavelet is seen[124] to become narrowed. In the sparser case, there are ringing phenomena from wavelet sidelobes. This[125] is called Gibb's phenomenon, not caused by inversion instability or noise. The direct-inversion deconvolution attempts to broaden bandwidth as much as possible. The consequence of broadening the spectrum to a higher frequency is that the wavelet becomes sharper than the original, but the ringing amplitude appears. Meanwhile, broadening the spectrum to a lower frequency makes wavelet sidelobe amplitude become[126] small.

Increasing the amplitude of the spectrum towards higher frequencies will always result in ringing. This[127] is a trade-off of increasing the frequency. The application of a taper only reduces the effect, but the ringing is still there.

Fig.11 and 12 illustrate how a wider[128] bandwidth can cause ringing. In Fig.11a, there is an amplitude spectrum jump at 125 Hz. This[129] causes a ringing from -[illegible] to [illegible] in the time domain (Fig.12a). In Fig.11b, a taper is applied[130] to the spectrum of Fig.11a. In the time domain, the wavelet of image Fig.12b still shows ringing, although it is less than Fig.12a's. If we widen the taper (Fig.12c), the ringing is much reduced[131]. However, Fig.12c shows a bandwidth that is not as wide as

Fig.12b. Fig.11d is a spectrum belonging to the wavelet ricker wherein the time domain; there is only 1 [132] pair of sidelobes without ringing (Fig.12d). Therefore, ringing presence [133] is unavoidable due to frequency widening, even though a taper is applied.

To test the ability of deconvolution to face nonzero-phase seismic data, we rotate the synthetic data's phase 45° (Fig. 9a and 10a). Then, we perform the same deconvolution parameter like in Fig. 7 and 8. It should be emphasized [134] that, although we shift the seismic data phase to 45°, we do not shift the wavelet in matrix W (Eq. 10). This [135] is performed [136] to simulate the real [137] application, that wavelet seismic phase is difficult to predict.

The results of deconvolution are shown [138] in Fig.9b and 10b. The seismic trace is seen [139] to have a higher resolution. Interestingly, the direct-inversion deconvolution does not alter the seismic phase. After deconvolution, the seismic phases are still 45°. Then, direct-inversion deconvolution is applied [140] for any seismic phase.

Fig. 7. Original (a) and deconvolved seismic trace (b) for the sparser case.

Fig. 8. Original (a) and deconvolved seismic trace (b) for the denser case.

Fig. 9. Original (a) and deconvolved seismic trace (b) with phase rotation 45° for the sparser case.

Fig. 10. Original (a) and deconvolved seismic trace (b) with phase rotation 45° for the denser case.

Fig. 11. Wavelets' amplitude spectrums: (a) boxcar-shaped spectrum, (b) Tukey-shaped (tapered boxcar) spectrum, (c) Hann-shaped spectrum, and (d) Ricker wavelet's spectrum.

Fig. 12. The wavelets (in the time domain) correspond to amplitude spectrums in Fig. 11.

We also compare the direct-inversion deconvolution with Wiener deconvolution to know the difference. Fig.11 shows the comparison between direct-inversion deconvolution (Fig.11b) and spiking deconvolution (Fig.11c). This figure shows that spiking deconvolution produces a trace with a higher resolution. However, as can be seen, the seismic phase changes. This [141] is because [142] Spiking (and Wiener) deconvolution uses the assumption of minimum phase (Cary, 2001;

Yilmaz, 2001). Unlike spiking, direct-inversion deconvolution does not alter the seismic phase while enhancing the resolution.

We add band-limited noise to the sparse case synthetic trace to know how direct-inversion deconvolution behaves in noise presence (Fig. 12a). Fig.12b shows that direct-inversion deconvolution does not boost the noise amplitudes.

Fig. 11. Comparison between original (a), real deconvolved (b), and spiking deconvolved- (c) trace.

Fig. 12. Original (a) and deconvolved seismic trace (b) with band-limited noise.

Application to Real Data

The original seismic data has a limited bandwidth of frequency which does not resolve the thinner layers. Fig.13 illustrates the enhanced resolution after the application of the direct-inversion deconvolution. Fig.13a is the field data, and Fig.7b shows the result after the direct-inversion deconvolution is performed[143]. Thinner layers are detected[144] at shallow depth (2200 – 2600 ms). This[145] concludes that the direct-inversion deconvolution method improves the resolution so that the seismic data can be interpreted[146] and analyzed more easily. In the deconvolution process, we have to estimate the wavelet. This paper uses a statistical wavelet.

We can see the seismic's spectrums to know how broad seismic bandwidth is enhanced (Fig.14). The deconvolved seismic's spectrum (red area) has broader bandwidth than the original data (black area).

The direct-inversion deconvolution, like other methods, cannot enhance bandwidth to broad. It only can broaden the bandwidth to the frequency the original data can retain.

Fig. 13. Real data application. Before (a) and after (b) deconvolution.

Fig. 14. The spectrums of real[147] data before (black) and after (red) deconvolution.

The point of this method is the inverse process of deconvolution as theory defined, without using the Wiener filter which[148] [149] is known as spiking or Wiener deconvolution (Yilmaz, 2001; Wiener, 1949). In Fig.9 and 10, the direct-inversion deconvolution result shows that this method is not dependent on the wavelet phase. It is not necessary[150,152] to assume that the phase is minimum-phase or to rotate the original[151] phase to the minimum phase.

Apart from its advantages, the direct-inversion deconvolution has several cautious. Firstly, we have to predict the wavelet shape, not its phase. The error of wavelet estimation may affect the deconvolution result. The second is Gibb's phenomenon appearance. Actually,[153] this phenomenon is expected[154] since we boost to the higher frequency. The filter-based deconvolution uses the taper function to reduce this phenomenon, not to[155] get rid. However, it cannot be applied to direct-inversion deconvolution unless we apply an additional step. This method can be applied[156] in the stationary case. However, it should[157] be developed or combined with other methods to solve the nonstationary[23] problems.

CONCLUSION

The direct-inversion deconvolution process is performed[158] according to the mathematical definition of deconvolution. The results are shown[159] by deconvolved seismic trace instead of reflectivity and the better version of the seismic image. This method is applied to synthetic data using synthetic reflectivity and Ricker Wavelet 25 Hz, and it gives a higher resolution to the seismic data. A phase rotation does not affect the deconvolution result, which means the result is not influenced by or dependent on the wavelet's phase. The real[160] data also shows a higher resolution after the direct-inversion deconvolution is applied. More thin layers can be seen[161] more clearly, and the frequency bandwidth is broadened[162] to the frequency the original data can retain.

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1.	*The Direct-inversion deconvolution and Its Application in Seismic Data.*	Incomplete sentences	Correctness
2.	*are generated*	Passive voice misuse	Clarity
3.	~~the~~ reflectivity	Determiner use (a/an/the/this, etc.)	Correctness
4.	*be resolved*	Passive voice misuse	Clarity
5.	~~easily~~ → quickly	Word choice	Engagement
6.	~~common~~ → standard	Word choice	Engagement
7.	the seismic	Determiner use (a/an/the/this, etc.)	Correctness
8.	*The mathematical definition of deconvolution is an inverse process of convolution, but the computation of deconvolution uses convolution in its process (Wiener deconvolution).*	Hard-to-read text	Clarity
9.	is direct	Incorrect verb forms	Correctness
10.	~~using the~~	Wordy sentences	Clarity
11.	deconvolution filter	Confused words	Correctness
12.	*We explained a method that direct from the mathematical definition. We refer to it as direct-inversion deconvolution. The direct-inversion deconvolution process involves the matrix operation between seismic trace and wavelet instead of using the deconvolution-filter.*	Monotonous sentences	Engagement
13.	*By applying the direct-inversion deconvolution, the produced (or deconvolved) seismic trace shows a better result with higher resolution, regardless of the wavelet's phase.*	Hard-to-read text	Clarity
14.	~~As~~ → In	Wrong or missing prepositions	Correctness

15.	a comparison	Determiner use (a/an/the/this, etc.)	Correctness
16.	a synthetic	Determiner use (a/an/the/this, etc.)	Correctness
17.	~~experiment~~ → experiments	Incorrect noun number	Correctness
18.	a higher	Determiner use (a/an/the/this, etc.)	Correctness
19.	*This method is applied to The North Sea Volve Data Village seismic data, and more thin layers are significantly detected. It turns out that direct-inversion deconvolution gives higher resolution to seismic data.*	Unclear paragraphs	Clarity
20.	~~the enhancement of~~ → enhancing	Wordy sentences	Clarity
21.	*is expected*	Passive voice misuse	Clarity
22.	*be resolved*	Passive voice misuse	Clarity
23.	*nonstationary; non-stationary*	Text inconsistencies	Correctness
24.	*However, the seismic wavelet varies in time and depth due to frequency attenuation and wavefront divergence (nonstationary). Therefore, the deconvolution theory proposed some alternatives to solve the nonstationary case.*	Unclear paragraphs	Clarity
25.	Research has	Wordy sentences	Clarity
26.	*been tested*	Passive voice misuse	Clarity
27.	~~real~~ → accurate, actual	Word choice	Engagement
28.	*There is research that tried to solve the problems (Merouane & Yilmaz, 2017).*	Unclear paragraphs	Clarity

	However, it has not been tested in real data.		
29.	~~or~~	Conjunction use	Correctness
30.	*are split*	Passive voice misuse	Clarity
31.	*Second, Gabor deconvolution combines the essential ideas of stationary deconvolution and inverse Q filtering (Margrave et al., 2011), or assuming seismic traces are split into segments which are called the molecular-Gabor transform (L. Wang et al., 2013).*	Unclear sentences	Clarity
32.	),	Punctuation in compound/complex sentences	Correctness
33.	~~, and another~~ → . Another	Hard-to-read text	Clarity
34.	*is defined*	Passive voice misuse	Clarity
35.	*Mathematically, deconvolution is defined as the inverse convolution process by focusing on the basic theory of deconvolution.*	Hard-to-read text	Clarity
36.	~~the~~ direct	Determiner use (a/an/the/this, etc.)	Correctness
37.	directly relates	Wordy sentences	Clarity
38.	~~the example~~ → examples	Wordy sentences	Clarity
39.	~~real~~ → natural	Word choice	Engagement
40.	*are also performed*	Passive voice misuse	Clarity
41.	*is compared*	Passive voice misuse	Clarity
42.	~~mostly~~ → mainly, primarily	Word choice	Engagement
43.	rely mostly on	Wordy sentences	Clarity

44.	~~full~~ → whole, complete	Word choice	Engagement
45.	~~full~~ → entire, total	Word choice	Engagement
46.	*To enable the full picture to be seen and characterized, the full frequency spectrum is needed (Reiser et al., 2012).*	Unclear sentences	Clarity
47.	*be achieved*	Passive voice misuse	Clarity
48.	*be derived*	Passive voice misuse	Clarity
49.	*In seismic data analysis theory, the subsurface reflectivity can be derived by deconvolving the wavelet with seismic traces (Goupillaud, 1961; Wuenschel, 1960).*	Hard-to-read text	Clarity
50.	convolution process	Wordy sentences	Clarity
51.	*is not generated*	Passive voice misuse	Clarity
52.	*The direct-inversion deconvolution method has a different procedure. The deconvolved seismic trace is not generated by using the Wiener filter.*	Unclear paragraphs	Clarity
53.	*is still needed*	Passive voice misuse	Clarity
54.	~~common~~ → shared	Word choice	Engagement
55.	is rarely	Incorrect verb forms	Correctness
56.	~~uses~~ → used	Incorrect verb forms	Correctness
57.	it exist	Incomplete sentences	Correctness
58.	~~exist~~ → exists	Faulty subject-verb agreement	Correctness
59.	*This*	Intricate text	Clarity

60.	of the	Wrong or missing prepositions	Correctness
61.	~~caustion~~ → causation	Misspelled words	Correctness
62.	the matrix's	Determiner use (a/an/the/this, etc.)	Correctness
63.	*be applied*	Passive voice misuse	Clarity
64.	~~which is~~	Wordy sentences	Clarity
65.	~~certain~~ → specific, particular	Word choice	Engagement
66.	~~a real~~ → an accurate, an actual	Word choice	Engagement
67.	*Synthetic seismogram or trace is given by convolution model between wavelet and reflectivity series (Goupillaud, 1961; Wuenschel, 1960).*	Passive voice misuse	Clarity
68.	~~where~~ → Where	Improper formatting	Correctness
69.	*is intended*	Passive voice misuse	Clarity
70.	~~where~~ → Where	Improper formatting	Correctness
71.	a seismic, or the seismic	Determiner use (a/an/the/this, etc.)	Correctness
72.	a vector, or the vector	Determiner use (a/an/the/this, etc.)	Correctness
73.	a matrix, or the matrix	Determiner use (a/an/the/this, etc.)	Correctness
74.	a vector, or the vector	Determiner use (a/an/the/this, etc.)	Correctness
75.	*is designed*	Passive voice misuse	Clarity
76.	~~where~~ → Where	Improper formatting	Correctness
77.	, and	Punctuation in	Correctness

		compound/complex sentences	
78.	the cross-correlation	Determiner use (a/an/the/this, etc.)	Correctness
79.	*where F is Wiener filter, A is Toeplitz matrix of input autocorrelation and C is cross-correlation between input and desired output.*	Hard-to-read text	Clarity
80.	~~where~~ → Where	Improper formatting	Correctness
81.	*be replaced*	Passive voice misuse	Clarity
82.	*be written*	Passive voice misuse	Clarity
83.	*However, because of its result, the Wiener deconvolution is still classified as a seismic deconvolution method.*	Hard-to-read text	Clarity
84.	*be considered*	Passive voice misuse	Clarity
85.	*is intended*	Passive voice misuse	Clarity
86.	*Any method can be considered a seismic deconvolution as long as it can or is intended to produce a reconstructed reflectivity from a seismic trace.*	Hard-to-read text	Clarity
87.	~~where~~ → Where	Improper formatting	Correctness
88.	a seismic, or the seismic	Determiner use (a/an/the/this, etc.)	Correctness
89.	~~matrix of~~	Wordy sentences	Clarity
90.	~~wavelet~~ → wavelets	Incorrect noun number	Correctness
91.	*is obtained*	Passive voice misuse	Clarity
92.	the L2	Determiner use (a/an/the/this, etc.)	Correctness

93.	~~where~~ → Where	Improper formatting	Correctness
94.	the L2	Determiner use (a/an/the/this, etc.)	Correctness
95.	*is achieved*	Passive voice misuse	Clarity
96.	~~where~~ → Where	Improper formatting	Correctness
97.	*where λ is a pre-whitening.*	Incomplete sentences	Correctness
98.	*higher*	Incomplete sentences	Correctness
99.	~~the~~ Eq.	Determiner use (a/an/the/this, etc.)	Correctness
100.	*be considered*	Passive voice misuse	Clarity
101.	*However, in reality, it is hard to produce reflectivity from a seismic trace.*	Unclear sentences	Clarity
102.	~~where~~ → Where	Improper formatting	Correctness
103.	a deconvolved	Determiner use (a/an/the/this, etc.)	Correctness
104.	*where Sdecon is deconvolved seismic trace.*	Incomplete sentences	Correctness
105.	*is set*	Passive voice misuse	Clarity
106.	~~we set~~	Wordy sentences	Clarity
107.	~~is~~ → as	Confused words	Correctness
108.	*is set*	Passive voice misuse	Clarity
109.	a wavelet	Determiner use (a/an/the/this, etc.)	Correctness
110.	a phase	Determiner use (a/an/the/this, etc.)	Correctness

111.	~~Sdecon~~ → Second	Misspelled words	Correctness
112.	~~In fact,~~ the	Wordy sentences	Clarity
113.	~~sparse~~ → light	Word choice	Engagement
114.	*The first one is the synthetic data with very sparse reflectivity (Fig. 4).*	Unclear sentences	Clarity
115.	*This paper uses three datasets: 2 synthetic and real datasets. The synthetic datasets contain 2 cases. The first one is the synthetic data with very sparse reflectivity (Fig. 4). The other one is synthetic data with denser reflectivity (Fig.5).*	Monotonous sentences	Engagement
116.	*is generated*	Passive voice misuse	Clarity
117.	*is used*	Passive voice misuse	Clarity
118.	~~real~~ → actual, accurate	Word choice	Engagement
119.	~~is to see~~ → shows	Wordy sentences	Clarity
120.	~~real~~ → natural, actual	Word choice	Engagement
121.	~~real~~ → actual, accurate, fundamental	Word choice	Engagement
122.	~~main~~ → primary	Word choice	Engagement
123.	~~a real~~ → an actual	Word choice	Engagement
124.	*is seen*	Passive voice misuse	Clarity
125.	*This*	Intricate text	Clarity
126.	~~become~~	Wordy sentences	Clarity
127.	*This*	Intricate text	Clarity
128.	~~wider~~ → broader	Word choice	Engagement

129.	*This*	Intricate text	Clarity
130.	*is applied*	Passive voice misuse	Clarity
131.	*is much reduced*	Passive voice misuse	Clarity
132.	~~1~~ → one	Improper formatting	Correctness
133.	~~presence~~	Wordy sentences	Clarity
134.	*be emphasized*	Passive voice misuse	Clarity
135.	*This*	Intricate text	Clarity
136.	*is performed*	Passive voice misuse	Clarity
137.	~~real~~ → actual	Word choice	Engagement
138.	*are shown*	Passive voice misuse	Clarity
139.	*is seen*	Passive voice misuse	Clarity
140.	*is applied*	Passive voice misuse	Clarity
141.	*This*	Intricate text	Clarity
142.	~~This is because~~	Wordy sentences	Clarity
143.	*is performed*	Passive voice misuse	Clarity
144.	*are detected*	Passive voice misuse	Clarity
145.	*This*	Intricate text	Clarity
146.	*be interpreted*	Passive voice misuse	Clarity
147.	~~real~~ → accurate, actual	Word choice	Engagement
148.	, which	Punctuation in compound/complex sentences	Correctness

149.	~~which is~~	Wordy sentences	Clarity
150.	~~not necessary~~ → unnecessary	Wordy sentences	Clarity
151.	~~original~~ → initial	Word choice	Engagement
152.	*In Fig.9 and 10, the direct-inversion deconvolution result shows that this method is not dependent on the wavelet phase. It is not necessary to assume that the phase is minimum-phase or to rotate the original phase to the minimum phase.*	Unclear paragraphs	Clarity
153.	~~Actually,~~ this	Wordy sentences	Clarity
154.	*is expected*	Passive voice misuse	Clarity
155.	~~to~~	Wordy sentences	Clarity
156.	*be applied*	Passive voice misuse	Clarity
157.	*This method can be applied in the stationary case. However, it should be developed or combined with other methods to solve the nonstationary problems.*	Unclear paragraphs	Clarity
158.	*is performed*	Passive voice misuse	Clarity
159.	*are shown*	Passive voice misuse	Clarity
160.	~~real~~ → actual, accurate	Word choice	Engagement
161.	*be seen*	Passive voice misuse	Clarity
162.	*is broadened*	Passive voice misuse	Clarity
163.	, and	Comma misuse within clauses	Correctness
164.	the anonymous	Determiner use (a/an/the/this, etc.)	Correctness
165.	, and	Comma misuse within clauses	Correctness

166.	~~CREWES~~ → CREWS	Misspelled words	Correctness
167.	*Enhancement of Margrave deconvolution of seismic signals in highly attenuating media using the modified S-transform.*	Unclear sentences	Clarity
168.	the variational-mode, or a variational-mode	Determiner use (a/an/the/this, etc.)	Correctness
169.	April,	Punctuation in compound/complex sentences	Correctness
170.	*Meresescu, A.-G. (2019). Inverse Problems of Deconvolution Applied in the Fields of Geoscience and Planetology.*	Unclear paragraphs	Clarity
171.	, and	Comma misuse within clauses	Correctness
172.	the resolution	Determiner use (a/an/the/this, etc.)	Correctness
173.	, and	Comma misuse within clauses	Correctness
174.	~~time–frequency~~ → time-frequency	Misspelled words	Correctness
175.	~~modelling~~ → modeling	Mixed dialects of English	Correctness