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by Rahmat Catur Wibowo

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2	Determiner use (a/an/the/this, etc.)	
2	Confused words	
1	Misuse of semicolons, quotation marks, etc.	
1	Conjunction use	
4	Incorrect phrasing	
1	Incorrect punctuation	
1	Incorrect noun number	
2	Faulty subject-verb agreement	
2	Closing punctuation	
3	Wrong or missing prepositions	
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89	**Clarity**	
43	Passive voice misuse	
13	Unclear sentences	
19	Wordy sentences	
5	Paragraph can be perfected	
7	Intricate text	
2	Hard-to-read text	

4	**Delivery**	
1	Inappropriate colloquialisms	
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2	Tone suggestions	
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Measures average sentence length

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1

CONTROLLED-SOURCE ELECTROMAGNETIC (CSEM) DATA PROCESSING WITH HIGH ELECTROMAGNETIC NOISE LEVELS

PENGOLAHAN DATA CONTROLLED-SOURCE ELECTROMAGNETIC (CSEM) DENGAN TINGKAT NOISE ELEKTROMAGNETIK TINGGI

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Abstract. The Controlled-Source Electromagnetic (CSEM) method is one of the electromagnetic methods utilized in geophysical exploration. This method provides a subsurface image through the resistivity anomalies of materials encountered by electromagnetic waves. The research area is located near a major city, resulting in high electromagnetic noise. Electromagnetic noise can be categorized[2] into two types of the noise[3] namely periodic[3,4] noise and sporadic noise. Eliminating noise is a crucial objective to enhance data quality, as it can introduce uncertainty into interpretations. Three noise removal techniques are employed: pre-stack[1] to filter the harmonic noise, stacking to remove the sporadic noise, and post-stack for smoothing. The CSEM data used[5] consists of signals in the time domain with a 10-second period[6] and a 50% duty cycle. The results of[7] applying these noise removal techniques indicate[7] that all three methods are highly effective in noise reduction. The pre-stack[1] technique can remove periodic noise, while sporadic noise is addressed by the stacking technique, and signal smoothing can be achieved[8] using the poststack[9] technique.[10]

Abstrak. Metode Controlled-Source Electromagnetic (CSEM) merupakan salah satu metode elektromagnetik yang digunakan dalam eksplorasi geofisika. Metode ini memberikan gambaran bawah permukaan melalui anomali resistivitas material yang dilewati oleh gelombang elektromagnetik. Daerah penelitian berada dekat kota besar, yang menyebabkan tingginya noise elektromagnetik pada data CSEM. Noise elektromagnetik terbagi menjadi dua jenis, yaitu periodic noise dan sporadic noise. Menghilangkan noise menjadi tujuan penting dalam meningkatkan kualitas data, karena dapat menciptakan ketidakpastian dalam interpretasi. Untuk menghilangkan noise, digunakan tiga teknik noise removal, yaitu pre-stack (filtering), stacking, dan post-stack (smoothing). Data CSEM yang digunakan berupa sinyal dalam domain waktu dengan periode 10 detik dan duty cycle 50%. Hasil penggunaan teknik noise removal menunjukkan bahwa ketiga teknik ini sangat efektif dalam menghilangkan noise. Teknik prestack mampu menghilangkan periodic noise, sedangkan sporadic noise diatasi oleh teknik stacking dan sinyal dapat diperhalus dengan menggunakan teknik poststack.

INTRODUCTION

The Controlled-Source Electromagnetic (CSEM) method is one of the geophysical techniques utilized for exploration activities. The CSEM method[11] provides a subsurface depiction of anomalies in the resistivity values of subsurface materials penetrated by diffusing electromagnetic waves (Ziolkowski & David, 2012). CSEM is highly sensitive to subsurface resistivity, which aids in geological interpretation due to[11] resistivity correlates with rock matrix, porosity, and the[11] pore fluids. Furthermore, source signals can be transmitted in multiple directions and received by several receivers (Ashadi et al., 2022).

In the CSEM method, two signals are recorded by the receivers[12] namely[13,14] the electric field (E-field) and the magnetic field (B-field). CSEM measurements can be conducted in close proximity to[15] inhabited areas, leading to high levels of electromagnetic noise (Paembonan et al., 2017; Henke et al., 2020; Morbe et al., 2020). This[16] significantly impacts the challenging data processing of CSEM due to the high noise in the signals recorded by the receiver (Pankratov & Alexey, 2010). If the data is distorted by the noise[17] or poor quality, the data must be treated[18] using several approached.[17,19] hence[20], a serious[21] consideration must be given to the removal of[23] high electromagnetic noise from the recorded signals.

In the study conducted by Strack et al. (1989), using Long-Offset Electromagnetic data, commonly known as LOTEM, data exhibit high noise levels due to measurements taken near inhabited areas, resulting in cultural noise in raw data. The noise from the industrial area could be handle by using[24] frequency filter. Meanwhile, sporadic noise is best handled[25] using selective stacking with symmetric rejection or area-defined methods, where signal amplitudes are selectively preserved[26] [27], and noise is statistically rejected[28]. The data indicates that for LOTEM sounding points, the symmetric-rejection algorithm significantly enhances the signal-to-noise ratio. After selective stacking, the data is smoothed[29] through recursive averaging. The output from transient signals is then converted into apparent resistivity and inverted into a layered Earth model (Paembonan et al., 2022; Strack et al., 2022).

This[30] is the reason[31] why, in this study, CSEM signals in the time domain with high electromagnetic noise require noise removal and an enhancement of the signal-to-noise ratio. Furthermore, exploring how these techniques can be adapted and applied to different geological settings and conditions where electromagnetic noise is prevalent. The study would contribute to more accurate subsurface imaging and resource exploration, particularly in challenging environments where traditional CSEM data processing methods may struggle with high noise levels.

LITERATURE REVIEW

Electromagnetic Method

The electromagnetic method is a geophysical technique that utilizes electromagnetic waves/signals transmitted through a transmitter below the Earth's surface, with the source of these waves originating from natural or artificial sources (Widarto, 2010). The propagation of electromagnetic waves is based on Maxwell's Law, as illustrated in Figure 1 below. Electromagnetic waves are emitted by a transmitter, and these waves travel or propagate into the Earth, resulting in the generation of a time-varying magnetic field.[32] This electromagnetic field,[33] when passing through or encountering materials with conductive properties, induces the formation of eddy currents or electric currents concentrated within the subsurface conductor. The flow of electric current within a conductor creates a magnetic field around it (secondary magnetic field). The secondary magnetic field produced by these eddy currents is captured or recorded by a sensor or receiver[34] (Widarto, 2010).

Figure 1. Principles of electromagnetic wave propagation (Wilson et al., 2022).

Controlled-Source Electromagnetic

The Controlled-Source Electromagnetic (CSEM) method is an active geophysical technique in which the transmitter, acting as an EM wave source, uses artificial signal sources (Akbar, 2010). When compared [35] to the Magnetotelluric (MT) method, which utilizes natural EM wave sources from within the Earth, the CSEM method exhibits physical properties related to the conductivity and resistivity of rock formations. Furthermore, the CSEM method differs from the geoelectric resistivity method, where the conduction source is derived [36] from an electrical current injected directly into the Earth's subsurface. Acquisition using the land-based CSEM method primarily employs a time-domain system. In Figure 2, the electrode dipole sources are buried just below the surface, while a multi-channel receiver array is positioned at the surface or sometimes placed inside boreholes. The sources utilize high-energy direct current that is suddenly turned [37] on and off. In this manner, the field generated by the source induces currents in the receiver coils and in [38] the Earth. Measurements are typically taken [39] during in– active [40] periods, repeated multiple times, and later processed to enhance the Signal-to-Noise (S/N) ratio.

The depth of penetration [41] achievable and captured by the electromagnetic waves beneath the surface can be referred [42] to as the skin depth. The skin depth is defined [43] as the depth in a homogeneous medium where the amplitude of the induced electromagnetic wave becomes 1/e of its amplitude at the Earth's surface (ln e = 1 or e = 2.718... [44]). In this case, the amplitudes of the E-field and B-field are proportional to the penetration depth δ, such that:

δ=2ωμσ=2ρωμ≈503ρT (1)

where[45] δ represents the skin depth (m), T is the period (s), and ρ is the resistivity of the homogeneous medium. From Equation 1, it can be observed[46] that the skin depth is inversely proportional to frequency and directly proportional to the period, meaning that the longer the measurement time, the deeper the penetration (Lantu, 2014)

Figure 2. Ground CSEM survey setup (Martinez et al., 2022).

Distortions in CSEM Data

Strack (1992) classified types of noise into two categories: periodic noise and sporadic noise[47]. Periodic noise, in general, is generated by PLN voltage, telephone cables, pipes, metal[48] fences in the vicinity of[49] the measurement area. In contrast, sporadic noise is caused[50] by geomagnetic signals, lightning that produces natural transient electromagnetic (TEM) events, AC power lines, the equipment used, and the movement of magnetic devices around the receiver sensors.

METHODS

The research is located[51] in one of the largest states in the United States, which has salt dome structures for oil and natural gas production. The research area map can be seen[52] in Figure 3 below. The data used is secondary data[53] acquired through CSEM method acquisition[53] in area X by KMS Technologies. Three measurement points were used, with signal information in terms of[54] voltage (mV) and time (ms), a measurement period of 10 seconds, and a duty cycle of 50%.

The data processing steps for CSEM in the time domain are shown[55] in Figure 4, where this research will discuss three techniques used for noise removal. In the first stage, a frequency domain filtering technique will be used[56,57], namely a notch filter with a 3dB threshold and a lowpass filter. This[58] means that the CSEM signal, initially in the time domain, will be converted to the frequency domain first[59] using Fast Fourier Transform (FFT), and then FFT will be performed again to transform the signal domain back to the time domain.

The second stage will employ the selective stacking technique, specifically area defined[60] rejection, which will determine the area to be retained[61]. The amplitude frequency[62] distribution will be calculated[63] by shifting an overlapping window over the sorted amplitude for each time sample of all transients. Thus, the percentage of the area beneath each symmetrically positioned distribution curve relative to the maximum will be computed[64], and all data within that area will be preserved[65]. The final stage will utilize the smoothing technique, namely recursive averaging. In this technique, the focus will be on the value of the[66] smoothing coefficient (α) within the range of 0 to 1. The closer the value of α is to 1, the smoother the resulting signal. These three stages, with the specified techniques, will be described in more detail as follows.

Figure 3. Research map showing the area of[67] the survey area.

Figure 4. Tags of CSEM data processing in the time domain.

3.1. Prestack[1] (Filtering)

This process aims to eliminate periodic noise using a notch filter, which automatically removes the 60Hz periodic noise (illustrated in Figure 5) with a 3.00 dB threshold and a lowpass filter that eliminates signals above the specified cut-off frequency. The initial signal [68] processing stage for CSEM signals can be seen [69] in Figure 6.

The amplitude in CSEM signals contains a significant amount of resistivity information. It becomes crucial when the digital filter not only suppresses noise but also preserves amplitudes carrying information (Strack, 1992).

|zn-1|2|zn+1|2=|zp-1|2|zp-1|2 (2)

In other words, the ratio between the pole and zero vectors will remain the same and will result [70] in a recursive formula in the z-domain.

Hz=YzZz=η(z-zn)(z-zn*)(z-zp)(z-zp*)

=ηz2-2αz+1z2-2αηz+1η-1 (3)

with η=zp-1zn-1(normalization gain 1) (5)

defined as x=ηα

we find, [71] y2=2xα-1-x2 (6)

where F(z) is the filter function given by the output function ratio, Y(z), and the input function, X(z); zn and zp are the positions of the zero and pole, respectively; η is the proportionality factor that combines the real part of the pole, x, with the real part of the zero, α; and y is the imaginary part of the pole. To eliminate phase shift, a recursive filter is applied twice to the data: first forward and then backward (Strack et al., 1989).

Figure 5. Frequency spectrum of CSEM data. Periodic noise is identified [72] by spikes at the 60Hz frequency (Original figure from this research).

Figure 6. Signal Ex and Ey filtering process in KMSPro Qc; (a) Raw data, (b) Input parameter for frequency cut-off and order, (c) Raw data before filtering, and (d) Signal result after prestack [1] filtering (Original figure from this research).

In the notch filter, we select a value of 60Hz for rejection at that frequency, and for [73] the lowpass filter, we specify a cut-off frequency of 15Hz and an order of 5, where the mathematical formula for the lowpass filter is expressed [74] as Equation 7 (Shouran & Elmazeg, 2020).

M1p=11+1ffc2n (7)

where [75] fc is the cut -off [76] frequency, and n is the filter order.

Selective Stacking

Sporadic noise can be caused [77] by various sources such [78] as water pumps, electrical fences, trains, factories, and/or [79] passing vehicles near the receiver. This noise is recorded and often goes unnoticed; [80] A safe approach to eliminate this type of noise through data processing is to consider the statistics of all signals and analysis [81] the corresponding amplitude distribution, both of which become increasingly important when there are only a few transients, and sporadic [82] noise is not removed [83] during the stacking process. However, it can significantly distort the stacked results as its amplitude is far above or below the signal level (Strack et al., 1989). When acquiring transients with a short rise time, it is also challenging to integrate spike detector [84] in analog or digital form. Figure 7 shows that selective stacking rejection, based on defined areas, can significantly improve the S/N ratio compared to the regular summation process, which eliminates [85] all data beyond two standard deviations from the mean.

Figure 7. Data stacked[86] using area-defined[86] rejection technique (Strack et al., 1989).

Figure 8. Difference in signals after smoothing. (a) Signal after stacking and (b) Signal[87] after smoothing (Strack, 1992).

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Poststack (Smoothing)

In the[88] final step of transient signal processing, it[88] can be referred to as the smoothing stage. Smoothing using recursive averaging is one of the signal processing techniques[88] to reduce signal fluctuations and produce a smoother signal. In recursive averaging, there is a parameter known as the smoothing coefficient (α), which ranges from 0 to 1. A higher smoothing coefficient range results in a smoother signal (Nugus, 2009).[89] The formula for the recursive averaging technique can be written[90] as Equation 8 below.

$Ft=Xt+(1-\alpha)Ft-1$ (8)

$Ft-1$ represents the previous forecast, Xt represents the current observation, and α is the smoothing coefficient (Nugus, 2009). Figure 8 illustrates the signal results after the smoothing process. This[91] shows that the ringing effect on the signal, which occurred after stacking, has been eliminated, and the signal has been improved[92].

RESULTS AND DISCUSSION

The CSEM signal processing focuses on improving signal quality through pre-stack[1], stacking, and post-stack stages. During acquisition, the signals recorded by the receiver are not entirely the desired signals (illustrated in Figure 9a). Instead, they include other unwanted signals, often referred to as[93] noise, which directly affects[94] the signal-to-noise ratio.

In[95,96] Figure 9,[95] it[95,96] shows how raw data from the CSEM signal is highly noisy and demonstrates the quality improvement achieved through three noise removal techniques. A Notch filter is automatically applied to detect periodic noise at a frequency of[97] 60 Hz (the frequency of the American power line) with a threshold level of 3.00 dB. A Lowpass filter is used[98] to suppress frequencies above the cut-off frequency, which is[99] set[100] at 15 Hz with an order of 5. While periodic noise is effectively removed[101] from the CSEM signal (Figure 9b), sporadic noise is not as easily[102] eliminated.

Figure 9. Processing of CSEM electric field component data. (a) Raw data including[103] noise, (b) Signal[103] after filtering, (c) Signal[103] after stacking, and (d) Signal[1 after smoothing.

Sporadic noise can be compensated for by employing selective stacking with the area-defined rejection technique. The Gibbs phenomenon resulting from selective stacking may cause a ringing effect
(Figure 9c) in the signal, which can be reduced by applying recursive averaging with a smoothing coefficient of 0.9
(Figure 9d). The smoothed CSEM signal is stored for one period. In Figure 10, the CSEM decay illustrates how electromagnetic wave changes over time, influenced by various properties of the materials it passes through. CSEM decay can also indicate the receiver's position based on the amplitude recorded in the CSEM signal.

Figure 10. Comparison between raw data (a-f) and processed data (g-l), showing both raw data of Ey (a, b, c) and Ex (e, f, g), and processed data Ey (g, h, i) and Ex (j, k, l).

The signal quality in the time-domain CSEM data has significant implications for improving the quality of interpretation and accuracy in subsurface structure imaging. This not only facilitates more precise identification of natural resources to be explored but also allows for reduced ambiguity in characterizing lithology and crucial geological formation boundaries in natural resource exploration.
The result show (Figure 10) that most of the noise can be handled with about 70% reduced using frequency-filters approximately 20 % using stacking, and

the rest bout 10% smoothed using average filtering. The data has significantly increased in signal to noise ratio. The data in Figure 11 is ready to be used for the next interpretation steps, inversion.

Regarding this research, despite the applied method successfully reducing a major portion of noise in the time-domain CSEM data, there are still several limitations to be considered. For instance, when dealing with highly complex or variant noise, this method may encounter limitations in its effectiveness. Therefore, further investigation is needed for the development of more adaptive pre-processing techniques and the selection of parameters used in the noise removal stage, especially when variably recorded noise bears a striking resemblance to actual signals. This aims to enhance the quality and reliability of the noise elimination process about 80%. This could describe that the signal processing steps is crucial in time-domain CSEM data leading to the significant contribution for the interpretation

Figure 11. CSEM decay. (a) Point CSEM01, (b) Point CSEM02, (c) Point CSEM03, and

(d) All measurement points.

CONCLUSION

The CSEM signal is disturbed by high electromagnetic noise, leading to uncertainty in the inversion and interpretation process. However, by implementing noise removal techniques, including pre-stack, stacking, and post-stack procedures, the initially noisy signal can be processed into a smoother form[125]. This results in a signal containing subsurface information without noise interference. Therefore, it can be concluded that[126] [130] the application of[127] these noise removal techniques is highly effective[128] in improving the quality of the CSEM signal about[129] 80% and unlocking the potential for a better understanding of subsurface structures.

ACKNOWLEDGMENT

The researcher extends heartfelt gratitude to KMS Technologies for their generous provision of access to and utilization of the CSEM data, which significantly contributed to the success and findings of this study.

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1.	*Prestack; pre-stack; prestack*	Text inconsistencies	Correctness
2.	*be categorized*	Passive voice misuse	Clarity
3.	*Electromagnetic noise can be categorized into two types of the noise namely periodic noise and sporadic noise.*	Ungrammatical sentence	Correctness
4.	*Electromagnetic noise can be categorized into two types of the noise namely periodic noise and sporadic noise.*	Unclear sentences	Clarity
5.	~~used~~	Wordy sentences	Clarity
6.	~~a 10-second period~~ → 10 seconds	Wordy sentences	Clarity
7.	*The results of applying these noise removal techniques indicate that all three methods are highly effective in noise reduction.*	Unclear sentences	Clarity
8.	*be achieved*	Passive voice misuse	Clarity
9.	~~poststack~~ → post-stack, post stack	Misspelled words	Correctness
10.	*The pre-stack technique can remove periodic noise, while sporadic noise is addressed by the stacking technique, and signal smoothing can be achieved using the poststack technique.*	Passive voice misuse	Clarity
11.	*The CSEM method provides a subsurface depiction of anomalies in the resistivity values of subsurface materials penetrated by diffusing electromagnetic waves (Ziolkowski & David, 2012). CSEM is highly sensitive to subsurface resistivity, which aids in geological interpretation due to resistivity cor...*	Paragraph can be perfected	Clarity

12.	*are recorded*	Passive voice misuse	Clarity
13.	, namely	Punctuation in compound/complex sentences	Correctness
14.	*In the CSEM method, two signals are recorded by the receivers namely the electric field (E-field) and the magnetic field (B-field).*	Unclear sentences	Clarity
15.	~~in close proximity to~~ → near, close to	Wordy sentences	Clarity
16.	*This*	Intricate text	Clarity
17.	*If the data is distorted by the noise or poor quality, the data must be treated using several approached.*	Ungrammatical sentence	Correctness
18.	*be treated*	Passive voice misuse	Clarity
19.	*If the data is distorted by the noise or poor quality, the data must be treated using several approached.*	Passive voice misuse	Clarity
20.	~~hence~~ → Hence	Improper formatting	Correctness
21.	~~a~~ serious	Determiner use (a/an/the/this, etc.)	Correctness
22.	*be given*	Passive voice misuse	Clarity
23.	~~the removal of~~ → removing	Wordy sentences	Clarity

24.	*In the study conducted by Strack et al. (1989), using Long-Offset Electromagnetic data, commonly known as LOTEM, data exhibit high noise levels due to measurements taken near inhabited areas, resulting in cultural noise in raw data. The noise from the industrial area could be handle by using freque...*	Paragraph can be perfected	Clarity
25.	*is best handled*	Passive voice misuse	Clarity
26.	*are selectively preserved*	Passive voice misuse	Clarity
27.	preserved**,**	Punctuation in compound/complex sentences	Correctness
28.	*is statistically rejected*	Passive voice misuse	Clarity
29.	*is smoothed*	Passive voice misuse	Clarity
30.	*This*	Intricate text	Clarity
31.	~~the reason~~	Wordy sentences	Clarity
32.	*Electromagnetic waves are emitted by a transmitter, and these waves travel or propagate into the Earth, resulting in the generation of a time-varying magnetic field.*	Passive voice misuse	Clarity
33.	*This electromagnetic field, when passing through or encountering materials with conductive properties, induces the formation of eddy currents or electric currents concentrated within the subsurface conductor.*	Unclear sentences	Clarity
34.	*The secondary magnetic field produced by these eddy currents is captured or recorded by a sensor or receiver (Widarto, 2010).*	Unclear sentences	Clarity

35.	~~When compared~~ → Compared	Wordy sentences	Clarity
36.	*is derived*	Passive voice misuse	Clarity
37.	*is suddenly turned*	Passive voice misuse	Clarity
38.	~~in~~	Wordy sentences	Clarity
39.	*are typically taken*	Passive voice misuse	Clarity
40.	~~in – active~~ → in–active	Confused words	Correctness
41.	penetration depth	Wordy sentences	Clarity
42.	*be referred*	Passive voice misuse	Clarity
43.	*is defined*	Passive voice misuse	Clarity
44.	...	Misuse of semicolons, quotation marks, etc.	Correctness
45.	~~where~~ → Where	Improper formatting	Correctness
46.	*be observed*	Passive voice misuse	Clarity
47.	and sporadic	Wordy sentences	Clarity
48.	and metal	Conjunction use	Correctness
49.	*Periodic noise, in general, is generated by PLN voltage, telephone cables, pipes, metal fences in the vicinity of the measurement area.*	Unclear sentences	Clarity
50.	*is caused*	Passive voice misuse	Clarity
51.	*is located*	Passive voice misuse	Clarity
52.	*be seen*	Passive voice misuse	Clarity

53.	*The data used is secondary data acquired through CSEM method acquisition in area X by KMS Technologies.*	Incorrect phrasing	Correctness
54.	~~in terms of~~ → regarding	Wordy sentences	Clarity
55.	*are shown*	Passive voice misuse	Clarity
56.	*be used*	Passive voice misuse	Clarity
57.	*In the first stage, a frequency domain filtering technique will be used, namely a notch filter with a 3dB threshold and a lowpass filter.*	Unclear sentences	Clarity
58.	*This*	Intricate text	Clarity
59.	~~first~~	Wordy sentences	Clarity
60.	~~area defined~~ → area-defined	Misspelled words	Correctness
61.	*be retained*	Passive voice misuse	Clarity
62.	amplitude-frequency	Misspelled words	Correctness
63.	*be calculated*	Passive voice misuse	Clarity
64.	*be computed*	Passive voice misuse	Clarity
65.	*be preserved*	Passive voice misuse	Clarity
66.	*In this technique, the focus will be on the value of the smoothing coefficient (α) within the range of 0 to 1.*	Unclear sentences	Clarity
67.	~~the area of~~	Incorrect phrasing	Correctness
68.	~~signal~~	Wordy sentences	Clarity
69.	*be seen*	Passive voice misuse	Clarity

70.	*In other words, the ratio between the pole and zero vectors will remain the same and will result in a recursive formula in the z-domain.*	Unclear sentences	Clarity
71.	find,	Punctuation in compound/complex sentences	Correctness
72.	*is identified*	Passive voice misuse	Clarity
73.	~~, and for~~ → . For	Hard-to-read text	Clarity
74.	*is expressed*	Passive voice misuse	Clarity
75.	~~where~~	Wordy sentences	Clarity
76.	~~cut -off~~ → cut-off	Confused words	Correctness
77.	*be caused*	Passive voice misuse	Clarity
78.	, such	Punctuation in compound/complex sentences	Correctness
79.	~~and/or~~ → and, or	Inappropriate colloquialisms	Delivery
80.	~~unnoticed;~~ → unnoticed.	Incorrect punctuation	Correctness
81.	~~analysis~~ → analyze	Incorrect phrasing	Correctness
82.	~~, and sporadic~~ → . Sporadic	Hard-to-read text	Clarity
83.	*is not removed*	Passive voice misuse	Clarity
84.	~~detector~~ → detectors	Incorrect noun number	Correctness
85.	~~which eliminates~~ → eliminating	Wordy sentences	Clarity
86.	*Data stacked using area-defined rejection technique (Strack et al., 1989).*	Ungrammatical sentence	Correctness

87.	~~Signal~~	Wordy sentences	Clarity
88.	*In the final step of transient signal processing, it can be referred to as the smoothing stage. Smoothing using recursive averaging is one of the signal processing techniques to reduce signal fluctuations and produce a smoother signal.*	Paragraph can be perfected	Clarity
89.	*A higher smoothing coefficient range results in a smoother signal (Nugus, 2009).*	Incomplete sentences	Delivery
90.	*be written*	Passive voice misuse	Clarity
91.	*This*	Intricate text	Clarity
92.	*been improved*	Passive voice misuse	Clarity
93.	~~referred to as~~ → called	Wordy sentences	Clarity
94.	~~affects~~ → affect	Faulty subject-verb agreement	Correctness
95.	*In Figure 9, it shows how raw data from the CSEM signal is highly noisy and demonstrates the quality improvement achieved through three noise removal techniques.*	Ungrammatical sentence	Correctness
96.	*In Figure 9, it shows how raw data from the CSEM signal is highly noisy and demonstrates the quality improvement achieved through three noise removal techniques.*	Unclear sentences	Clarity
97.	~~a frequency of~~	Wordy sentences	Clarity
98.	*is used*	Passive voice misuse	Clarity
99.	~~which is~~	Wordy sentences	Clarity

100.	*is set*	Passive voice misuse	Clarity
101.	*is effectively removed*	Passive voice misuse	Clarity
102.	~~easily~~ → quickly	Word choice	Engagement
103.	*Raw data including noise, (b) Signal after filtering, (c) Signal after stacking, and (d) Signal after smoothing.*	Incorrect phrasing	Correctness
104.	*be compensated*	Passive voice misuse	Clarity
105.	effect.	Closing punctuation	Correctness
106.	*be reduced*	Passive voice misuse	Clarity
107.	*is stored*	Passive voice misuse	Clarity
108.	*In Figure 10, the CSEM decay illustrates how electromagnetic wave changes over time, influenced by various properties of the materials it passes through.*	Ungrammatical sentence	Correctness
109.	*This*	Intricate text	Clarity
110.	*be explored*	Passive voice misuse	Clarity
111.	*This not only facilitates more precise identification of natural resources to be explored but also allows for reduced ambiguity in characterizing lithology and crucial geological formation boundaries in natural resource exploration.*	Unclear sentences	Clarity

112.	*The result show (Figure 10) that most of the noise can be handled with about 70% reduced using frequency-filters approximately 20 % using stacking, and the rest bout 10% smoothed using average filtering. The data has significantly increased in signal to noise ratio. The data in Figure 11 is ready t...*	Paragraph can be perfected	Clarity
113.	*Regarding this research, despite the applied method successfully reducing a major portion of noise in the time-domain CSEM data, there are still several limitations to be considered.*	Paragraph can be perfected	Clarity
114.		Tone suggestions	Delivery
115.	*is needed*	Passive voice misuse	Clarity
116.	*Therefore, further investigation is needed for the development of more adaptive pre-processing techniques and the selection of parameters used in the noise removal stage, especially when variably recorded noise bears a striking resemblance to actual signals.*	Unclear sentences	Clarity
117.	*This*	Intricate text	Clarity
118.	by about	Wrong or missing prepositions	Correctness
119.	*This*	Intricate text	Clarity
120.	~~is~~ → are	Faulty subject-verb agreement	Correctness
121.	, leading	Punctuation in compound/complex sentences	Correctness
122.	~~the significant~~ → a significant	Determiner use (a/an/the/this, etc.)	Correctness
123.	~~for~~ → to	Wrong or missing prepositions	Correctness

124.	interpretation.	Closing punctuation	Correctness
125.	*However, by implementing noise removal techniques, including pre-stack, stacking, and post-stack procedures, the initially noisy signal can be processed into a smoother form.*	Unclear sentences	Clarity
126.	*be concluded*	Passive voice misuse	Clarity
127.	~~the application of~~ → applying	Wordy sentences	Clarity
128.	~~effective~~ → practical	Word choice	Engagement
129.	by about	Wrong or missing prepositions	Correctness
130.		Tone suggestions	Delivery
131.		Incorrect citation format	Correctness
132.		Incorrect citation format	Correctness
133.		Incorrect citation format	Correctness
134.		Incorrect citation format	Correctness
135.		Incorrect citation format	Correctness
136.	~~Multuphysics~~ → Multiphysics	Misspelled words	Correctness
137.		Incorrect citation format	Correctness
138.		Incorrect citation format	Correctness
139.		Incorrect citation format	Correctness
140.		Incorrect citation format	Correctness
141.		Incorrect citation format	Correctness

142. Incorrect citation format Correctness