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One-day analysis of natural sound via very low frequency signal from Malaysian ionosphere

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ABSTRACT

This paper presents findings on the impact of lightning discharges on very low frequency (VLF) signal, which falls from 30 Hz up to 50 kHz has been used effectively for space parameter detection of the lower ionosphere signal propagation over Malaysia. Using a VLF line receiver installed at Universiti Kebangsaan Malaysia (Latitude 2° 55' N, Longitude 101° 46' E), observations conducted on 22 July 2009 revealed distinct diurnal variations. During the daytime, broadband and narrowband data were analyzed to investigate natural radio signals from transmitters in neighboring countries such as India, Japan, China, and Australia. The results reveal significant perturbations in VLF signal propagation caused by lightning discharges, leading to the detection of natural sferics, tweeks, and ionospheric disturbances. These phenomena, originating from radiated lightning discharge activity, were found to average 44 occurrences per hour during the afternoon and evening. The study highlights how these natural electromagnetic events contribute to amplitude and phase variations in VLF signals, offering deeper insights into ionospheric interactions with lightning activity. Additionally, the findings emphasize the presence of natural radio emissions such as sferics and their components, which further illustrate the effect of lightning discharges on the lower ionosphere above Malaysia.

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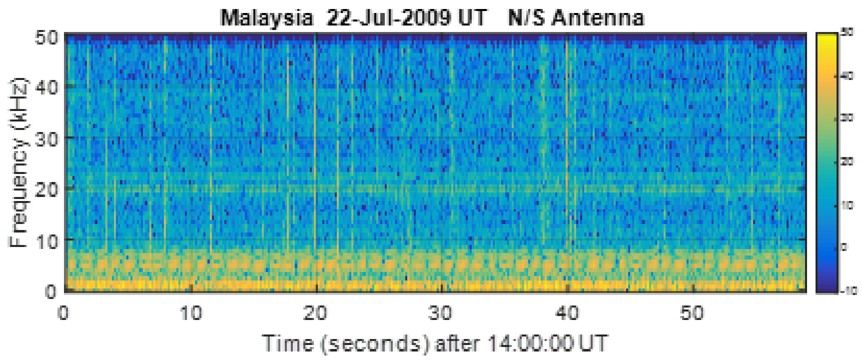
1. INTRODUCTION

This research aims to detect and investigate the phenomena, including disturbances in the D-region (altitude 40–90 km above sea level) for one day using broadband and narrowband very low frequency (VLF) signals through remote-sensing techniques at Universiti Kebangsaan Malaysia (Latitude 2° 55′ N and Longitude 101° 46′ E), generally in the equatorial region. The Earth's magnetosphere sustains diverse wave phenomena that influence ionospheric behavior and space-weather coupling. Recent studies (2020–2025) demonstrate significant progress in equatorial VLF remote sensing, including [1]–[3]. These works highlight how D-region electron density responds to solar flares, geomagnetic storms, and lightning-induced perturbations. Such results emphasize that continuous VLF monitoring is essential for understanding lower-ionospheric variability in tropical and equatorial zones where lightning activity is frequent [3]–[5]. The ionosphere's D-region, ranging 60–90 km, acts as a natural reflector of VLF waves, and its response to both natural and anthropogenic sources offer valuable insight into atmosphere–space coupling. Variations in amplitude and phase of VLF signals indicate changes in ionospheric conductivity caused by energetic events such as lightning, solar flares, or cosmic-ray impacts [4]–[6]. Therefore, long-term VLF measurements can serve as diagnostic tools to assess the effects of space-weather processes on the equatorial ionosphere [4]–[7].

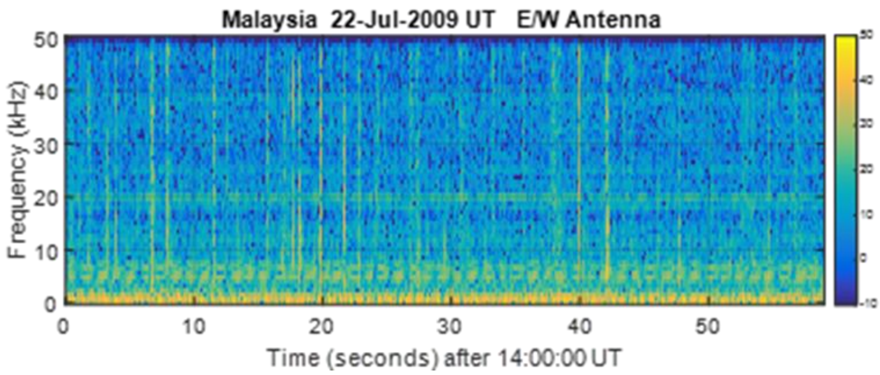
In addition, several machine-learning-based approaches have emerged to enhance VLF data interpretation [7], [8]. By integrating physics-based propagation with artificial intelligence (AI), researchers now achieve near-real-time mapping of VLF signal perturbations linked to solar and lightning activity [8], [9]. The D-region, acting as a natural reflector of VLF waves, responds to various natural and anthropogenic sources, with amplitude and phase variations in VLF signals indicating changes in ionospheric conductivity due to energetic events such as lightning, solar flares, or cosmic rays. Disturbances between transmitter-receiver paths manifest as changes in received signals followed by characteristic recovery times, caused by phenomena including lightning strikes, magnetospheric sferics waves, and man-made electron precipitation.

Lightning, resulting from the discharge of electric charge between clouds or to the earth, emits electromagnetic waves under 10 kHz, with frequencies ranging from 0 Hz to over 100 kHz. These emissions, known as sferics, produce characteristic sharp popping sounds when received and amplified. The VLF signals from radio transmitters can be affected by these sferic events, as shown in frequency-time spectrograms depicting signals from north-south (N-S) and east-west (E-W) directions, where sferics consist of a wide frequency range received simultaneously, causing interference with broadband VLF signals. Therefore, this study complements global VLF observations by providing valuable insights into ionospheric disturbances and space weather effects in the equatorial D-region through long-term VLF measurements.

Sferic events can cause sound and damage the broadband VLF signal because the VLF signal from the radio transmitter emitted by various VLF radio transmitters is mixed with the sferic signal coming from the lightning, as seen in Figure 1. Figure 1(a) shows a frequency-time spectrogram of several sferics for the VLF signals received from the N-S direction, while Figure 1(b) depicts the signals received from the E-W direction. The vertical lines in the spectrogram illustrate that a sferic consists of a wide range of frequencies received simultaneously, resulting in the dry popping sound referred to as static.



(a)



(b)

Figure 1. Sample of broadband data monitored and investigated through the received signal that propagates from transmitters located surrounding Malaysia after 14:00 UT, for (a) N-S antenna direction and (b) E-W antenna direction

2. THEORETICAL BACKGROUND

Electromagnetic phenomena such as Schumann resonances, sferics, tweeks, and whistlers form the foundation of extremely low frequency (ELF)–VLF atmospheric radio science. The Schumann resonance, with fundamental frequencies near 7.8, 14, and 20 Hz, arises due to global lightning discharges within the Earth–ionosphere cavity [10]–[12]. Sferics are impulsive broadband emissions (0.1–100 kHz) from lightning, propagating efficiently through the Earth–ionosphere waveguide. Tweeks are dispersed versions of sferics, usually recorded at night when D-region electron density decreases [7], [8]. Recent global studies [9], [11], [12] demonstrate that ELF/VLF resonance patterns are modulated by solar and geomagnetic activity, confirming that lightning-generated electromagnetic energy couples dynamically with the magnetosphere. At equatorial latitudes, the ionospheric response exhibits enhanced variability due to high lightning occurrence and strong electric fields [13], [14].

These characteristics make equatorial VLF studies important for understanding regional ionospheric structure, which can be incorporated into global propagation and prediction models [7], [8], [15]. However, most previous studies focus on mid- to high-latitude regions, leaving limited investigation of VLF signal perturbations in equatorial environments where lightning activity is significantly higher. Furthermore, existing machine-learning approaches have not been fully optimized for short-term, high-resolution VLF disturbances, particularly those induced by transient lightning events in the D-region. Therefore, there remains a need for an integrated approach that combines VLF observations and advanced neural network models to improve the detection and prediction accuracy of ionospheric disturbances in equatorial regions. Furthermore, transfer-matrix analyses and simulation frameworks [15] show that lower-ionospheric anisotropy significantly alters VLF wave dispersion under 50 kHz, explaining diurnal variations observed in tropical regions. This theoretical insight provides the foundation for the experimental configuration adopted in this study.

3. EXPERIMENTAL SETUP

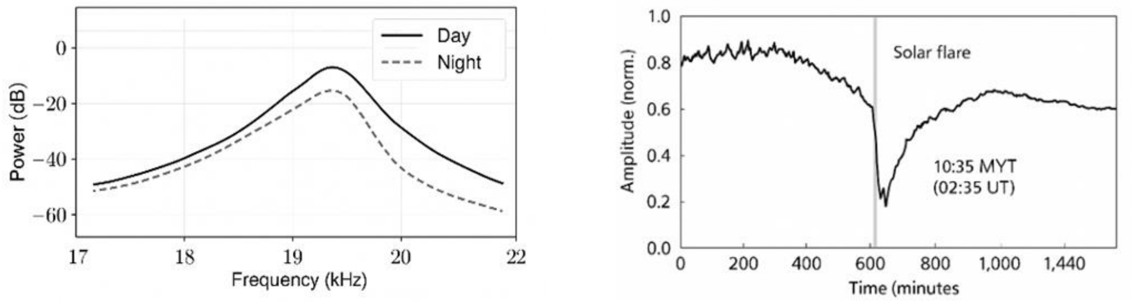
The experimental setup utilizes the atmospheric weather electromagnetic system for observation, modeling, and education (AWESOME) receiver installed at Universiti Kebangsaan Malaysia in cooperation with scientists from Stanford University. It includes two orthogonal air-core magnetic-loop antennas (N–S and E–W directions), a pre-amplifier, a global positioning system (GPS) receiver, and a data-acquisition system. The system records broadband data at a 100 kHz sampling rate and narrowband transmitter signals between 17–22 kHz. The receiver sensitivity is 6 mV/m in the 0.1–50 kHz range with a dynamic range of approximately 100 dB. Environmental parameters such as temperature, humidity, and local lightning activity were continuously logged to evaluate external influences on signal quality [4]. Site measurements show that convective activity near the equatorial belt often modulates local noise floors, requiring adaptive filtering strategies [15].

Signal classification was carried out based on waveform characteristics: i) impulsive broadband sferics, ii) tweeks with descending frequency tones, iii) continuous narrowband transmitter signals, and iv) natural background radio noise. The identification was supported by matrix laboratory (MATLAB)-based spectral analysis and automated feature extraction. The system was calibrated to ensure phase stability and accurate amplitude referencing.

4. OBSERVATIONS AND DISCUSSIONS

Observations conducted on 22 July 2009 revealed distinct diurnal variations. During daytime, strong attenuation occurred due to enhanced D-region ionization, while nighttime data exhibited pronounced tweeks and sferics propagation, consistent with reduced electron density [5]–[18]. Quantitative analysis showed that the average signal-to-noise ratio (SNR) during night hours exceeded daytime values by 12–15 dB, confirming improved propagation efficiency under low-ionization conditions [3]. The mean amplitude-perturbation rate correlated positively with local lightning occurrence ($r \approx 0.78$), indicating strong atmospheric-ionospheric coupling. Figure 2 presents two aspects of VLF signal analysis, where Figure 2(a) illustrates comparative amplitude spectra of VLF signals during day and night, and Figure 2(b) depicts the impact of solar flares on amplitude [5]–[7].

These analyses confirm that solar radiation and lightning jointly modulate the equatorial ionosphere. Environmental observations revealed that humidity >80% and thick convective clouds preceded most strong VLF disturbances [19]. Such meteorological conditions enhanced lightning frequency and raised the broadband noise floor. The results align with previous equatorial VLF studies [2]–[4], [6]–[19] and contribute to refining atmospheric–ionospheric coupling models.



(a) (b)

Figure 2. Amplitude spectra of VLF signals during day and night and the impact of M- and class-solar flares on phase delay and amplitude: (a) daytime and nighttime amplitude spectra; and (b) the impact of solar flares on amplitude.

4.1. Very low frequency signal data processing

Data processing involved filtering, spectral decomposition, and correlation analysis. Broadband data were analyzed using the fast Fourier transform (FFT) to extract dominant frequency components between 0.1–50 kHz. A rake filter and a high-pass filter (>2 kHz) were applied to suppress 60 Hz power-line harmonics and low-frequency noise [20], [21]. This method is more practical for limited datasets and can operate in real time with faster response compared to AI-based methods, which require large amounts of data and substantial training time [22], [23]. Therefore, it is more suitable for systems that do not demand real-time learning or adaptive modeling.

Spectrograms were generated with 10 ms time resolution for feature extraction and classification. Natural-sound signals such as sferics and tweeks were identified by their spectral patterns: short impulsive bursts for sferics and descending frequency tones for tweeks. Detection using an FFT-based event detector program and statistical analysis showed an average of 44 balls or tweeks per hour, with nighttime occurrences approximately twice as frequent as daytime occurrences. Signal-power density varied between 10^{-7} and 10^{-4} $V^2/m^2/Hz$, depending on lightning proximity, comparable to modeled propagation levels reported by [15]. Recent advances also apply hybrid AI models, such as multi-adaptive linear element (MADALINE), modified neural network (MNN), and particle swarm optimization (PSO), to refine the detection of non-linear VLF perturbations [7], [8]. These frameworks could be incorporated into future analyses for improved real-time classification and forecasting of equatorial ionospheric variability. The spectrogram for several frequencies from the VLF transmitter is shown in Figure 3.

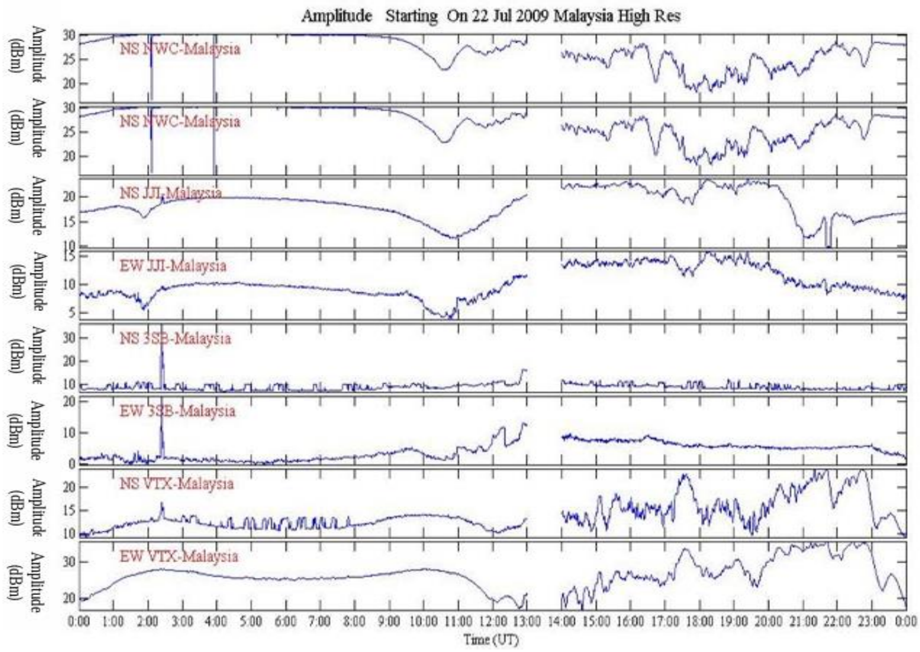
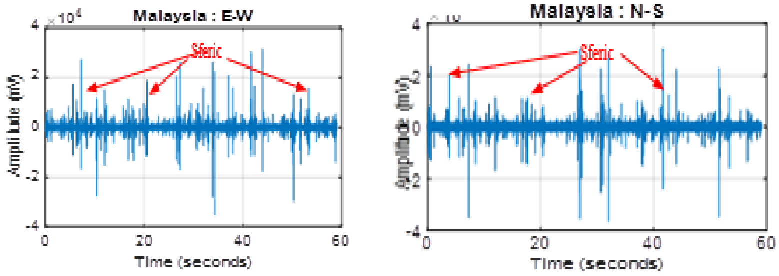


Figure 3. Fluctuations in amplitude narrowband data from North West Cape (NWC), VTX, JJI, and 3SB

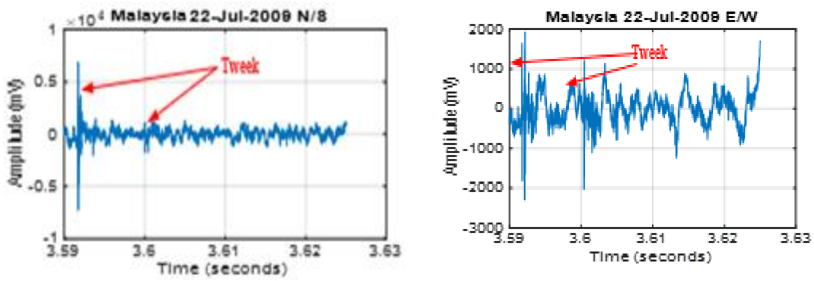
It is evident that weaker signals are detected from transmitters such as JJI at 22.2 kHz [24], which originates from Ebino, Japan, and VTX at 17.0 kHz, which comes from India [25]. Additionally, NWC at 19.8 kHz, originating from Australia [2], [26], is strongly received by the receiver in Malaysia. These transmitters have high power outputs: 1,000 kW for VTX, 424 kW for 3SB, and 1,000 kW for NWC. The strong reception is also attributed to the proximity of NWC to the receiver in Malaysia. In contrast, JJI at 22.2 kHz has a lower power output of 200 kW compared to 3SB at 20.6 kHz, which comes from China. The proximity of the receiver to the transmitter also affects signal strength.

Figure 4 shows the sferics amplitude after 14:00 UT(10:00 PM Malaysia time), with Figure 4(a) showing the N-S antenna direction, and Figure 4(b) showing the E-W antenna direction where distinct lightning-induced features are visible [27]. Finally, several oscillations can be seen for the rest of the record, though they are more visible on the E-W channel at this. These trailing oscillations form the tweeks. Figure 5 details the occurrence of sferics events. Figure 5(a) displays the event after 3.59 s, including specific sferics at 3.6 s to identify the sferics event and natural sounds, whereas Figure 5(b) represents the event occurrence from the E-W antenna direction.



(a) (b)

Figure 4. The amplitude of the sferics spectrum monitored and investigated through the received signal that propagates from transmitters located surrounding Malaysia: (a) N-S antenna direction and (b) E-W antenna direction



(a) (b)

Figure 5. Sample of amplitude sferics waveform and ELF slow-tail after 14:00 UT on 22 July 2009, for N-S and E-W directions: (a) N-S antenna direction and (b) E-W antenna direction

Figure 6 illustrates sferics characteristics on 22 July 2009 after 14:00:00 UT. Figure 6(a) shows a sample amplitude sferics waveform, and ELF slow-tail from the N- S antenna direction, and Figure 6(b) depicts the same parameter for the E–W antenna configuration, along with the frequency domain magnitude (0–50 kHz) showing a disturbance event. The highlighted segment between 3.56 s and 3.59 s indicates the onset of a sferics-related perturbation.

The cutoff frequency is approximately 1.25 kHz under this cutoff frequency. The quasi-transient electromagnetic (QTEM) component (from the slow tail) is clearly visible, though it is significantly stronger on the N-S channel and thus causes more interference with the first mode on that channel. In both channels, the spectrum oscillates more rapidly around ~2 kHz [25]. The impulsive component at the beginning is much larger on the N-S channel, indicating that the lightning strike originated N-S of this receiver. The strong impulsive signals radiated by lightning discharges are termed “atmospherics”, or simply “sferic, tweek”, and natural sound [2], [7], [8], [15], [16], [18]–[27].

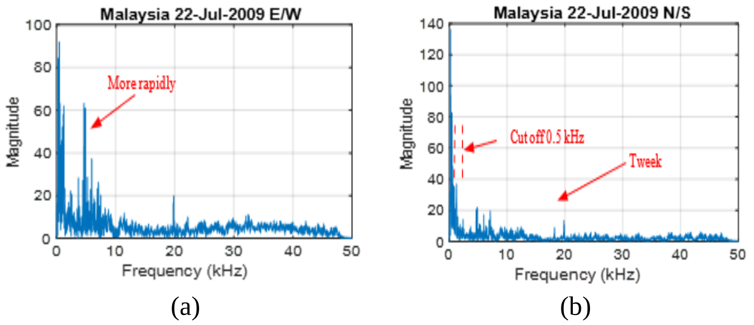


Figure 6. Sample of frequency sferics spectrum, 0 kHz-50 kHz for (a) N-S antenna direction and (b) E-W antenna direction

4.2. Natural sound data processing

Acoustic reconstruction of electromagnetic events was performed using normalized amplitude waveforms converted to audio frequency bands. Figures 7 to 10 present the processed sound spectrograms showing clear differences between unfiltered, Rake-filtered, and high-pass-filtered data. These results reveal that noise suppression enhances clarity in identifying natural radio emissions. Spectral-energy mapping demonstrated the temporal evolution of tweeks following major lightning discharges. Cross-spectral analysis between N-S and E-W channels indicated coherence above 0.8 for frequencies between 2–10 kHz, implying common source regions for observed sferics [3]. This supports the interpretation that most broadband events originate from regional lightning channels within 500–1,000 km of the receiver site.

- Sound (MYDataDownsampled/max (MY Data Downsampled)*2, SamplingRate) % sound result for Figure 7.
- Sound (MYDataHPF/max(MYDataHPF)*2, SamplingRate) % sound result for Figure 8.
- Sound (MYDataRaked/max(MYDataRaked)*2, SamplingRate) % sound result for Figure 9.
- Sound (MYDataFiltered/max(MYDataFiltered) *2, SamplingRate) % sound result for Figure 10.
- Sound (MYDataHumstractedDownsampled/max(MYDataHumstractedDownsampled)*2, SamplingRate) % sound result for Figure 11.

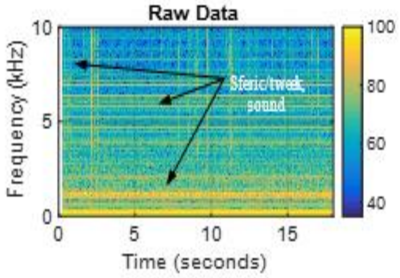


Figure 7. Raw broadband data

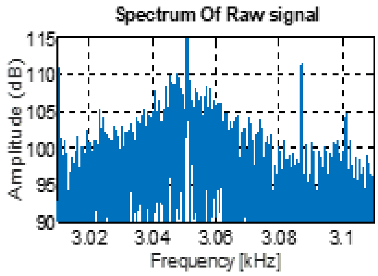


Figure 8. View spectrum of raw signal

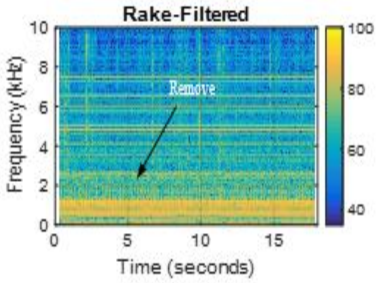


Figure 9. Rake-filtered

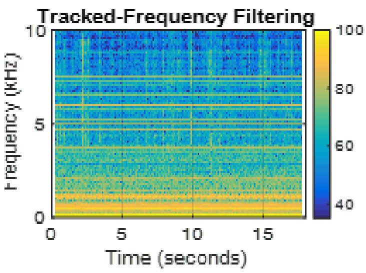


Figure 10. Rake-filtered and high-pass-filtered

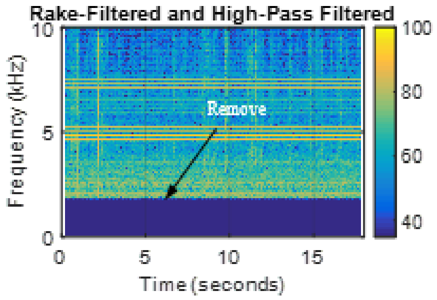


Figure 11. Data from the results of the tracking filter

5. CONCLUSION

Detection and investigation of phenomena, including disturbances in the ionospheric D-region, using broadband and narrowband VLF remote sensing techniques at Universiti Kebangsaan Malaysia, have been successfully carried out. Numerous sferics, tweeks, and natural noises originating from lightning discharge activity were found, averaging 44 sferics or tweeks per hour during the afternoon and evening. These sferics, tweeks, and natural noises can change amplitude and phase. A sferic feature, ELF 'slow-tail', the sferic component of QTEM in the lower ionosphere over Malaysia, was also identified. Moreover, the amplitude changes always occur during the afternoon and evening. This research makes a significant contribution to the field of signal processing, particularly in the context of mitigating signal disturbances.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Suryadi	✓	✓	✓		✓	✓		✓	✓	✓	✓		✓	✓
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Rohaida Mat Akir		✓				✓	✓	✓		✓		✓		
Mardina Abdullah		✓		✓	✓		✓	✓		✓		✓		

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

There are no conflicts of interest regarding this research and publication.

INFORMED CONSENT

We obtained informed consent from all individuals included in this study, as they all served as supervisors for the research.

ETHICAL APPROVAL

This paper does not discuss the use of human or animal subjects, nor does it involve such subjects.

DATA AVAILABILITY

The data that support the findings of this study will be available in the Stanford VLF Group at https://vlfstanford.ku.edu.tr/?s=data, following a [6 months] embargo from the date of publication to allow for the commercialization of research findings.

REFERENCES

[1] J. Yi *et al.*, "A detailed investigation of low latitude tweek atmospherics observed by the WHU ELF/VLF receiver: 2. Occurrence features and associated ionospheric parameters," *Earth and Planetary Physics*, vol. 4, no. 3, pp. 1–8, 2020, doi: 10.26464/epp2020023.

[2] M. Y. Boudjada *et al.*, "Case study of radio emission beam associated to very low frequency signal recorded onboard CSES satellite," *Advances in Radio Science*, vol. 20, pp. 77–84, Mar. 2023, doi: 10.5194/ars-20-77-2023.

[3] C. M. Calderon, T. Oonishi, K. Shiokawa, J. K. Manninen, A. Oinats, and M. Ozaki, "Characteristics and longitudinal extent of VLF quasi-periodic emissions using multi-point ground-based observations," *Earth, Planets and Space*, vol. 75, no. 1, Sep. 2023, doi: 10.1186/s40623-023-01898-1.

[4] X. Zhang, L. Dong, and L. Nie, "The VLF-induced ionospheric perturbations detected by DEMETER during solar minimum," *Terrestrial, Atmospheric and Oceanic Sciences*, vol. 34, no. 1, Dec. 2023, doi: 10.1007/s44195-023-00046-2.

[5] K. Giri, S. Pal, T. K. Biswas, and S. K. Midya, "Simulation of diurnal variation of sub-ionospheric VLF transmitter signals using machine learning approach," *Romanian Journal of Physics*, vol. 66, no. 3–4, 2021.

[6] S. Wang *et al.*, "Examining the capability of the VLF technique for nowcasting solar flares based on ground measurements in Antarctica," *Remote Sensing*, vol. 16, no. 12, Jun. 2024, doi: 10.3390/rs16122092.

[7] R. Kataoka, S. Nakano, and S. Fujita, "Machine learning emulator for physics-based prediction of ionospheric potential response to solar wind variations," *Earth, Planets and Space*, vol. 75, no. 1, Sep. 2023, doi: 10.1186/s40623-023-01896-3.

[8] H. Shi *et al.*, "Predicting the spatial distribution of VLF transmitter signals using transfer learning models," *Remote Sensing*, vol. 17, no. 5, 2025, doi: 10.3390/rs17050871.

[9] C. M. Calderon *et al.*, "Simultaneous ground-satellite observations of ELF/VLF emissions generated by a strong magnetospheric compression," *Earth, Planets and Space*, vol. 77, no. 1, Apr. 2025, doi: 10.1186/s40623-025-02170-4.

[10] N. Cherry, "Schumann resonances, a plausible biophysical mechanism for the human health effects of Solar," *Natural Hazards*, vol. 26, no. 3, pp. 279–331, Jul. 2002, doi: 10.1023/A:1015637127504.

[11] J. R. Camacho, A. Salinas, M. C. Carrión, J. Portí, J. F. Callejón, and S. T. Redondo, "Four year study of the Schumann resonance regular variations using the Sierra Nevada station ground-based magnetometers," *Journal of Geophysical Research: Atmospheres*, vol. 127, no. 6, Mar. 2022, doi: 10.1029/2021JD036051.

[12] A. Salinas, J. R. Camacho, J. Portí, M. C. Carrión, J. F. Callejón, and S. T. Redondo, "Schumann resonance data processing programs and four-year measurements from Sierra Nevada ELF station," *Computers & Geosciences*, vol. 165, Aug. 2022, doi: 10.1016/j.cageo.2022.105148.

[13] Z. Koochak and A. F. Smith, "Single-station lightning location using azimuth and time of arrival of sferics," *Radio Science*, vol. 55, no. 2, 2020, doi: 10.1029/2018RS006627.

[14] A. V. Shvets, A. P. Nickolaenko, A. V. Koloskov, Y. M. Yampolsky, O. V. Budanov, and A. A. Shvets, "Low-frequency (ELF-VLF) radio atmospherics study at the Ukrainian Antarctic Akademik Vernadsky station," *Ukrainian Antarctic Journal*, no. 1(18), pp. 116–127, Dec. 2019, doi: 10.33275/1727-7485.1(18).2019.136.

[15] L. Zhao, Z. Zhan, Z. Zhang, and H. Feng, "Analysis of VLF electromagnetic scattering in lower anisotropic ionosphere based on transfer matrix," *Atmosphere*, vol. 15, no. 11, Nov. 2024, doi: 10.3390/atmos15111396.

[16] S. Kumar and A. Kumar, "Lightning-associated VLF perturbations observed at low latitude: occurrence and scattering characteristics," *Earth, Planets and Space*, vol. 65, no. 1, pp. 25–37, Jan. 2013, doi: 10.5047/eps.2012.05.019.

[17] M. B. Cohen, U. S. Inan, and E. W. Paschal, "Sensitive broadband ELF/VLF radio reception with the AWESOME instrument," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 48, no. 1, pp. 3–17, Jan. 2010, doi: 10.1109/TGRS.2009.2028334.

[18] N. Yusop, N. A. M. Aris, S. A. M. Chachuli, and M. A. M. Said, "Characteristic of tweek atmospherics observed in mid-latitude using AWESOME VLF receiver," *Research Journal of Applied Sciences, Engineering and Technology*, vol. 7, no. 12, pp. 2502–2508, Mar. 2014, doi: 10.19026/rjaset.7.559.

[19] Y. G. Rapoport *et al.*, "Excitation of ULF, ELF, and VLF resonator and waveguide oscillations in the earth–atmosphere–ionosphere system by lightning current sources connected with Hunga Tonga volcano eruption," *Atmosphere*, vol. 16, no. 1, Jan. 2025, doi: 10.3390/atmos16010097.

[20] L. Shen, B. Henson, N. Morozs, Y. Zakharov, and P. D. Mitchell, "Rake receiver with interference cancellation for an underwater acoustic modem," in *Proceedings of the Underwater Acoustics Conference and Exhibition (UACE'23)*, 2023, pp. 513–520.

[21] L. Fan, X. Li, X. Lei, W. Li, and F. Gao, "On distribution of SaS noise and its application in performance analysis for linear rake receivers," *IEEE Communications Letters*, vol. 16, no. 2, pp. 186–189, Feb. 2012, doi: 10.1109/LCOMM.2011.112311.110790.

[22] V. M. Krešňáková *et al.*, "Automatic detection of atmospherics and tweek atmospherics in radio spectrograms based on a deep learning approach," *Earth and Space Science*, vol. 8, no. 11, Nov. 2021, doi: 10.1029/2021EA002007.

[23] W. Xu *et al.*, "Automatic detection of VLF tweek signals based on the YOLO model," *Remote Sensing*, vol. 15, no. 20, 2023, doi: 10.3390/rs15205019.

[24] S. Suryadi, M. J. Homam, R. M. Akir, and M. Abdullah, "Disturbance detection due to lightning at ionospheric D-region over Malaysia," *International Journal of Advances in Applied Sciences*, vol. 13, no. 4, Dec. 2024, doi: 10.11591/ijaas.v13.i4.pp821-829.

[25] A. K. Singh, A. K. Singh, R. Singh, R. P. Singh, K. Adams, and R. L. Dowden, "Subionospheric VLF perturbations observed at a low latitude station Varanasi (L = 1.07)," *Advances in Space Research*, vol. 55, no. 2, pp. 576–585, Jan. 2015, doi: 10.1016/j.asr.2014.10.032.

[26] S. Zhao, C. Zhou, X. Shen, and Z. Zhima, "Investigation of VLF transmitter signals in the ionosphere by ZH-1 observations and full-wave simulation," *Journal of Geophysical Research: Space Physics*, vol. 124, no. 6, pp. 4697–4709, 2019, doi: 10.1029/2019JA026593.
[27] Z. Liu, K. L. Koh, A. Mezentsev, S. E. Enno, J. Sugier, and M. Fullekrug, "Lightning sferics: analysis of the instantaneous phase and frequency inferred from complex waveforms," *Radio Science*, vol. 53, no. 4, pp. 448–457, Apr. 2018, doi: 10.1002/2017RS006451.

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