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Disturbance detection due to lightning at ionospheric D-region over Malaysia

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ABSTRACT

Previous research on the interference of very low frequency (VLF) signals in the equator region was inadequate and largely concentrated in the middle and high latitude regions. Therefore, this research aims to determine the disruption of VLF waves in the ionospheric D-region above Malaysia, which is in the equator area. This paper presents observations of early/fast, early/slow, and lightning-induced electron precipitation (LEP) events in January 2010. Broadband and narrowband data are monitored and investigated using Japan's JJI Ebino transmitter (32°40' N, 130°81' E) to the receiver at the Universiti Kebangsaan Malaysia (2°55' N, 101°46' E). Broadband and narrowband data are analyzed with theoretical considerations and linked to events from interference in the ionospheric D-region. Many early/fast, early/slow, and LEP events are found to originate from the lightning release activity emitted and may alter the amplitude and VLF signal phase in the lower layer ionosphere over Malaysia.

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1. INTRODUCTION

The very low frequency (VLF) signal or ground wave from 30 Hz to 30 kHz or 50 kHz has been used by researchers for the remote sensing of the lower ionosphere at the altitude of 40-90 km, which is known as the D-layer. Radio, radar, satellite, and optical methods have been used for the remote sensing of the ionospheric D-layer. However, these methods have low effectiveness in sensing the D-region, which is volatile to diurnal solar flare activities and ambient nighttime electron density that is only a few to tens of el/cc high frequency (HF), with frequencies from 3-30 MHz, or very high frequency (VHF), with frequencies in the range of 30-300 MHz; for example, radars require a background electron density of at least 1000 el/cc to detect meaningful echoes [1]–[3]. Suitable techniques for studying the D-region using VLF remote sensing have been reported in several studies [4]–[7]. Previous research on VLF disturbances over the equatorial region, where they are generally concentrated in the middle and high latitude regions, is inadequate. Another research on lightning detection has been conducted by Tenaga Nasional Berhad (TNB) Malaysia using a ground-based approach, known as the lightning detection network (LDN), as reported in [8]. Therefore, this study aims to observe the D-layer VLF wave perturbation over Malaysia, which is in the equatorial region. This study is expected to complement VLF global observation. Figure 1 shows how remote sensing with VLF and VLF receivers is used to study the lower ionosphere altitude of 60-90 km (D-layer). VLF remote sensing can detect disturbances in the D-layer between the transmitter and receiver path, namely, the lightning discharge effects caused by electromagnetic pulse and quasi-electromagnetic fields spreading up and creating a waveguide D-layer conductivity distribution of disturbed and destructive VLF signal field (scattered VLF fields) [9]–[10]. Phenomena that often occur in the ionosphere, such as heating from lightning strikes, cosmic rays, solar flares, gamma rays, natural disturbance, man-made and electron precipitation with magnetospheric electron wave sferics, as disturbance from earthquakes and geomagnetic storms, result in amplitude and phase change or damage the VLF signal [11]–[15].

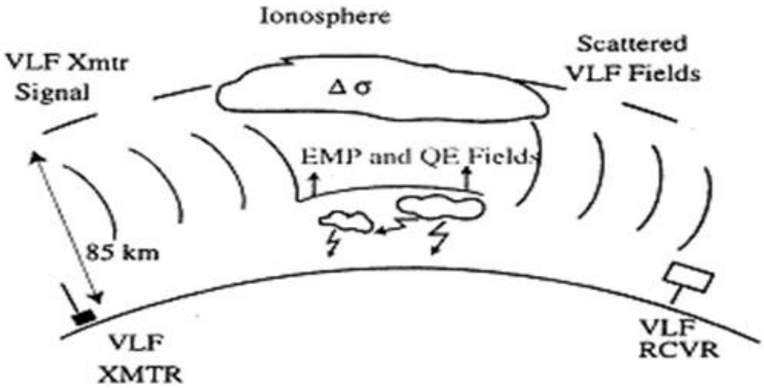


Figure 1. Principle of VLF remote sensing and configuration [16]

This paper reports the detection and observation of the above phenomena, including the disturbances at the D-region, using data from VLF receivers as broadband and narrowband data through the VLF remote sensing technique at Universiti Kebangsaan Malaysia. The Earth's magnetosphere can sustain a wide variety of signal phenomena. These signals are important because they influence the behavior of the magnetosphere and can be used as an experimental tool in investigating the upper atmosphere. One of the studied wave modes is the lightning discharge mode waves [17]–[19]. The VLF remote sensing technique is a good method for studying the D-region. Stanford University has developed an equipment called atmospheric weather educational system for observation and modeling of effects (AWESOME) where a wide range of VLF receivers have been deployed to study solar-related disturbances on VLF waves [20]–[22].

AWESOME is intended for use as a diagnostic tool for studying the disturbance of various D-layers over Malaysia, such as early/fast, early/slow, and lightning-induced electron precipitation (LEP) events. Early/fast and early/slow VLF events are characteristic changes in the amplitude or signal phase of the VLF under the ionosphere produced by lightning-induced conductivity changes in the lower ionosphere. Evidence of an event includes rapid onset (<20 ms, which is "fast"), followed by a relatively slow recovery (usually 10-100 s), and a 20 ms duration of the event causes cloud-to-ground lightning discharge (i.e., "early"). For early/slow events, no delay occurs before the amplitude starts to change (calm down), but full chaos is reached in 1-2 s [23]. Although the previous research investigated the impact of lightning, it did not explicitly discuss its effect on other events resulting from lightning such as detecting other events such as early/fast, early/slow, and LEP.

2. RESEARCH METHOD

The approach employed in this research is as described in the introduction, namely the VLF remote sensing technique. This method, utilizing the AWESOME receiver, has not been previously implemented in Malaysia, i.e. in the equatorial region. Many researchers have extensively used this tool in the past, primarily to observe and study the layers of the D-region. However, this has been done at different latitudes. Continuous data measurement using the equipment consists of two air core wire loop types of antennas with an initial amplifier, assisted by a personal computer with the NI-DAQ7 software, and connected to a VLF receiver and a global positioning system (GPS) with antenna. The signal received from the antenna is passed through a VLF bandpass filter that has a 30 kHz bandwidth in the preamplifier. The signal is then fed to the acquired 24-bit PCI-6034E Dev1 2.66 GHz data.

The AWESOME VLF receivers collect data with 100 kHz sampling and a 300 Hz to 47.5 kHz frequency response at a time resolution of 10 ms. Broadband and narrowband data are recorded as waveforms in the process and can be displayed by the VLF DAQ (data acquisition) viewer using a MATLAB program. In that observation, only one of the data was used and the data obtained by the AWESOME receivers can be easily viewed and analyzed using signal processing and statistics with a MATLAB program designed specifically for VLF data. A team of researchers from Stanford University approved that the methodology set out in the program can run properly to view and analyze the data from AWESOME receivers. Figure 2 shows the AWESOME system block diagram for monitoring, data collection, and storage. This scientific cooperation is especially important given the highly specialized nature of the proposed measurements, which have been pioneered by researchers at Stanford University.

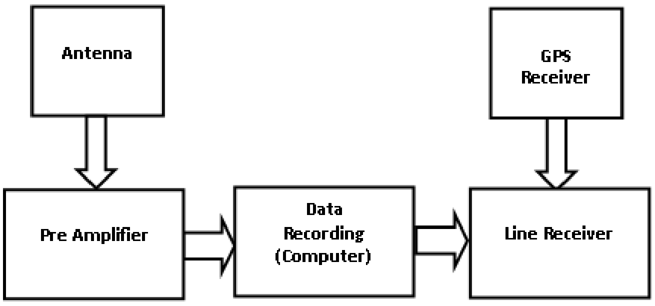


Figure 2. Block diagram of the AWESOME system

The system settings are demonstrated in Figure 3. Figure 3(a) shows the configuration of a set of indoor receivers located within the laboratory. Additionally, Figure 3(b) showcases the VLF antenna installed on the rooftop of the Faculty of Engineering and Built Environment, UKM, serving as the outdoor VLF antenna. Figure 4 shows the signal path map from Japan's JJI Ebino transmitter (32°40' N, 130°81' E) (red circle) to the VLF receiver in UKM, Malaysia (2°55' N, 101°46' E) (blue circle). This study investigated lightning and its derivatives comprehensively. However, additional and in-depth research may be needed to confirm the effect of derivatives, especially regarding early/fast, early/slow, and LEP.

(a) (b)

Figure 3. System setup consists of (a) a receiver (indoor) and (b) a VLF antenna (outdoor)

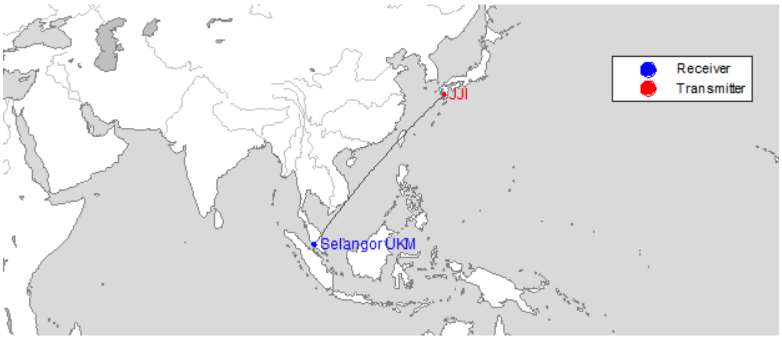


Figure 4. Map of the signal path from the transmitter at Ebino (JJI), Japan to the receiver at UKM, Malaysia

3. RESULTS AND DISCUSSION

The VLF receiver system was set up in July 2009 and has continuously received signal propagation from transmitters located around Malaysia, including that from JJI Ebino, Japan. Data is recorded in universal time (UT) and thus should be converted to local time (LT). Malaysia is 8 hours ahead of UT. Therefore, 0800 must be added to the time; for example, 0000 UT is equivalent to 0800 UT. The amplitude of the data was analyzed to relate phenomena and perturbations with theoretical consideration concerning the occurrence of ionospheric D-region disturbances.

3.1. VLF signal data processing uses DAQ viewer simulation

For data simulation, a MATLAB program was developed by researchers from Stanford University. To use this program, the date and both the receiver and transmitter names are needed in plotting the data, as shown in Figure 5. After the required data are filled, the graphs are formed as shown in Figure 6.

Figure 6 shows the resulting plot sample of the records of data received from JJI Ebino, Japan transmitter for 24 hours (one day), showing the amplitude fluctuations of the narrowband data, with 1 hour (1300 UT until 1400 UT) used for collecting data from the VLF computer and storing at Stanford University. Figure 6(a) displays the VLF signals received from the north-south (NS) direction, while Figure 6(b) depicts the signals received from the east-west (EW) direction.

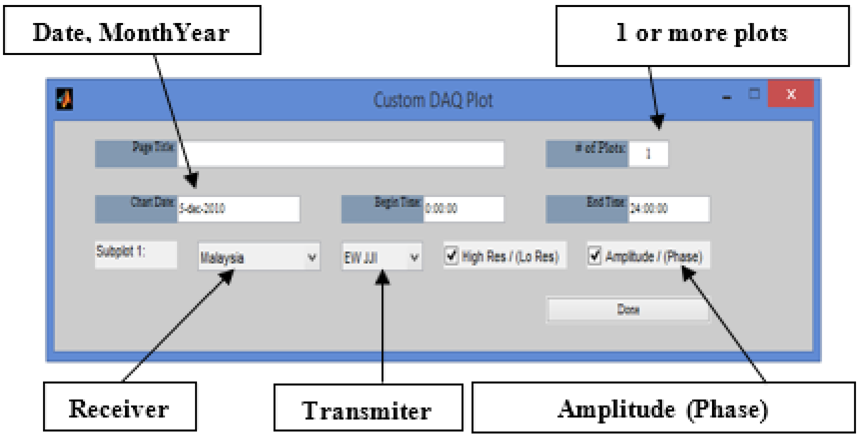
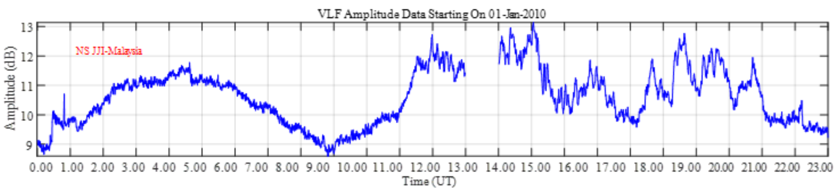
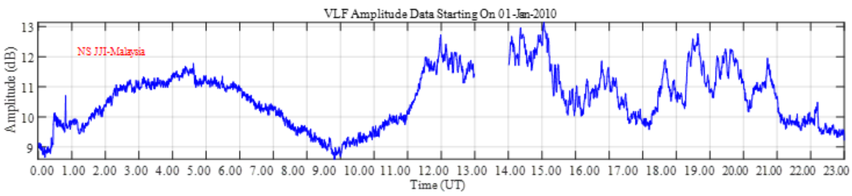


Figure 5. Custom DAQ plot



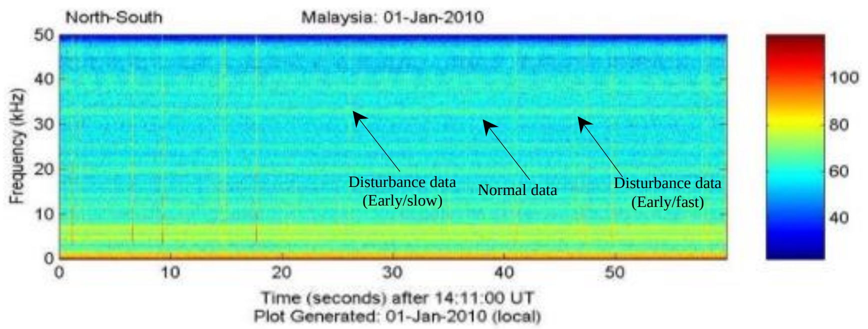
(a)



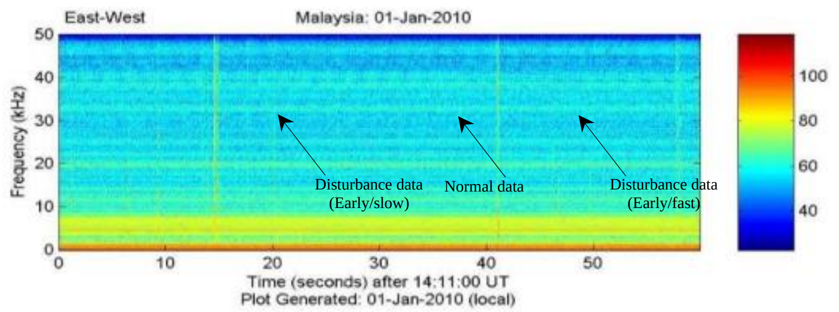
(b)

Figure 6. Plot sample of data received from JJI Ebino Japan transmitter at frequency 22.1 kHz signal at (a) NS and (b) EW

Figure 7 is a spectrogram signal from a VLF JJI transmitter with a frequency of 22.2 kHz, coming from Ebino Japan with 200 kW radio beam power and received by the UKM receiver near the hilly environment of the UKM campus. The spectrogram also shows the broadband data in the form of amplitude, with a frequency range of 0.330 kHz, which can receive signals from NS and EW antennas. Figure 7(a) shows a spectrogram plot of the broadband data received from the NS direction from the antenna. Early/slow and early/fast events can be observed in the broadband data marked with yellow vertical lines. Similar observation can be seen from the EW direction (Figure 7(b)). Figure 8 shows some early/slow events, with early/fast (yellow vertical line) indicating the release of lightning in the area. The early/slow event marked with arrows occurred at 14:11:41 UT, and the early/fast event occurred at 14:11:51 UT on the narrowband data. The chart shows many impulsive signal releases emitted by the release of lightning charges, which are referred to as "atmospheric" or "early/slow, early/fast, LEP events" [24]–[25]. The VLF signal is a variation of amplitude changes fluctuating during the day and at night as a result of the release of the lightning charge emitted [7], [25]–[28].



(a)



(b)

Figure 7. Example of spectrogram broadband data early/fast, early/slow event spectrogram signal at (a) NS and (b) WS

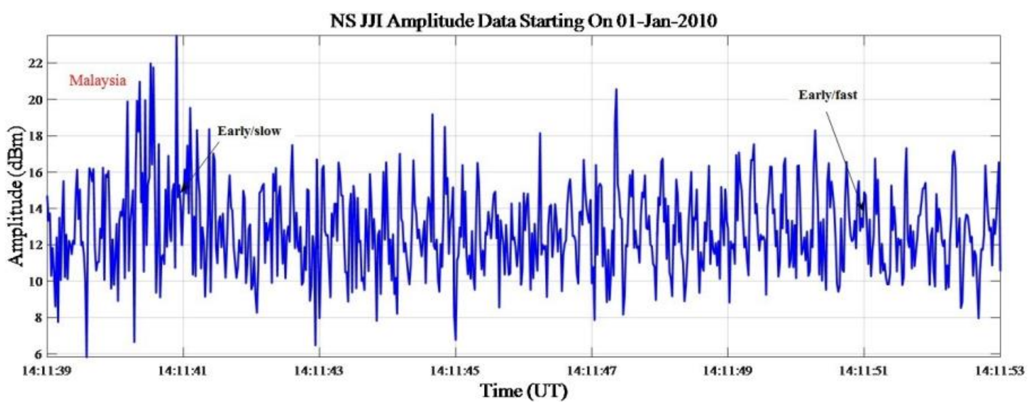
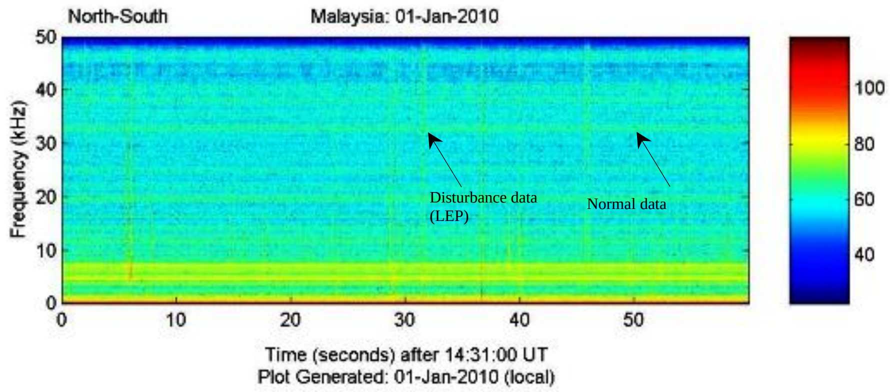
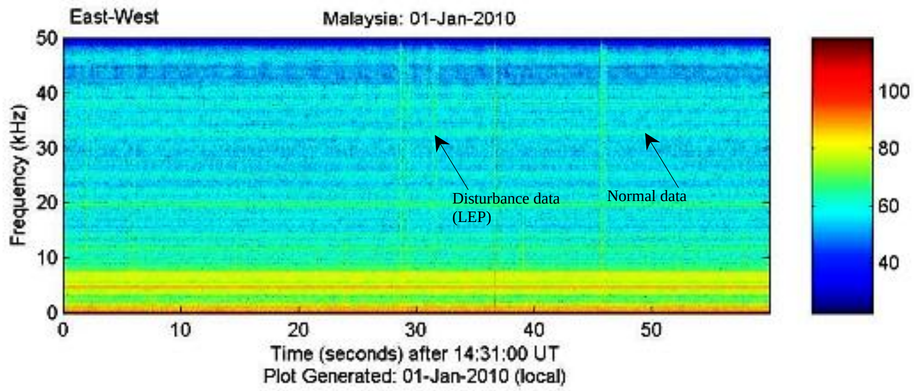


Figure 8. Example of narrowband data early/fast and early/slow event

Figure 9 describes the frequency of the time domain, indicating the frequency of the signal against the time of spectrogram broadband data LEP event. In both Figure 9(a) and Figure 9(b) of the broadband data spectrogram received from the NS direction and EW direction of antennas, respectively, an LEP event can be observed on the spectrogram marked with a yellow vertical line. The VLF signal is also presented as the 60 minutes from 13.00 UT to 14.00 UT for collecting data from VLF computers for storage at Stanford University. The sample data after 14:31:00 to 14:31:60 UT 1 January 2010 is used to identify the incidence of LEP disorder. Figure 10 presents the narrowband data samples from the NS and EW antennas, and LEP events were identified in the period of 14:31:29 to 14:31:31 UT, indicating that an LEP event occurred at 14:31:30 UT.



(a)



(b)

Figure 9. Example of spectrogram broadband data LEP event (a) Spectrogram signal at NS and (b) Spectrogram signal at WS

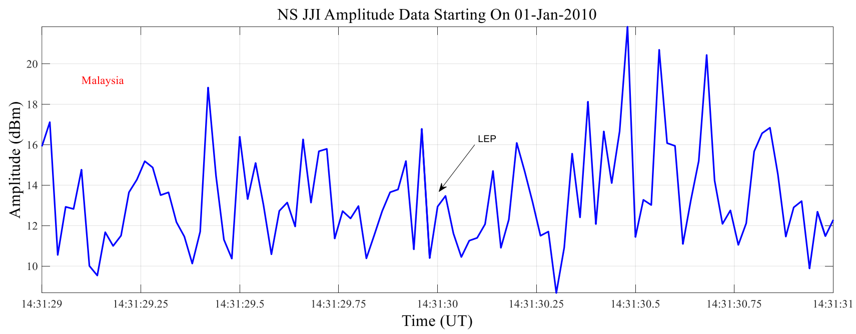


Figure 10. Example of narrowband data LEP event

3.2. Data processing using event detector simulation program

The required data collected must be detected and analyzed using a MATLAB simulation program called event detector. To use this simulation program, the following information is required: time, date, recipient name, and transmitter name. After encoding the details in the events detector, the simulation results are generated as shown in Table 1.

Table 1 shows the sample data obtained from the results of the 1-hour event detector program from 14:09:34 to 14:57:25 UT. Table 1 shows the events and the magnitude of the early/slow, early/fast, and LEP events. Table 2 shows the early/slow, early/fast, and LEP events (lightning properties) for one month from January 1 to 31, 2010, during which 8100 early/slow, 9640 early/fast, and 601 LEP events occurred. All of the above events show that there has been a lightning release event as much as 18341. Early/slow and early/fast events are similar to lightning events directed at VLF signals and alter the amplitudes and phase, whereas LEP events are indirect lightning shooting events (reflections) that point to VLF signals and modify the conductivity of the D-region, resulting in variable changes of the conductivity of the D-region [29]. In comparison to the ground-based method LDN employed by TNB Malaysia, the findings of this research demonstrate a considerable level of effectiveness in lightning detection. This efficacy stems from the identification of various parameters, such as early/fast, early/slow, and LEP, encountered during the research, as opposed to TNB's method, which only yields a single parameter, namely lightning. We found that lightning is correlated with early/fast, early/slow, and LEP. The method proposed in this study tends to have a much higher proportion of accuracy than other methods. Our research shows that the lightning observation method is more robust than previous research. Future research may look at lightning and practical methods for generating usable early/fast, early/slow, and LEPs.

Table 1. Sample simulation results of the early/fast, early/slow, and LEP event detector program from JJI-Malaysia VLF signal from 14:09:34 to 14: 57:25 UT on January 1, 2010

Time	Mag [dB]	Delta time [Dt]	Time delay [td]	Record [s]	Max Rec	Event	Int	Watch
14:09:34	1.094	0	0.14	1800	1800	Early/Fast	Y	N
14:11:41	0.951	-0.06	0.28	1800	1800	Early/Slow	Y	N
14:31:30	-0.796	0.26	0.32	134	248	LEP	Y	Y
14:57:25	0.535	-0.02	0.1	111	111	Early/Fast	N	N

Table 2. Number of early/slow, early/fast, and LEP events in January 2010

Date	Early/Slow	Early/Fast	LEP	Lightning
1	418	447	5	870
2	91	104	0	195
3	96	93	10	199
4	94	105	15	214
5	691	703	15	1409
6	515	621	54	1190
7	243	272	27	542
8	281	343	25	649
9	135	219	9	363
10	242	353	1	596
11	179	313	5	497
12	195	270	14	479
13	235	360	9	604
14	249	390	12	651
15	221	399	6	626
16	192	260	18	470
17	336	382	28	746
18	221	252	28	501
19	216	273	23	512
20	379	361	32	772
21	425	418	45	888
22	296	305	42	643
23	296	305	42	643
24	285	253	29	567
25	425	414	32	871
26	199	264	16	479
27	325	317	22	664
28	243	272	27	542
30	135	219	9	363
31	242	353	1	596
Total	8,100	9,640	601	18,341
Average	522.5806	621.9355	38.77419	1183.2903

4. CONCLUSION

The results of the detection and investigation of interference in the D-region using the broadband and narrowband data from the Universiti Kebangsaan Malaysia receiver of the early/slow, early /fast, and LEP interference events originating from the lightning charge release activity occurred as much as 18,341. As a result of these events, the amplitude and phase of VLF signals can be changed. Amplitude and phase changes, thereby altering the conductivity of the D-region low latitude, mostly occur in the afternoon and evening. Our findings offer definitive evidence that these phenomena (early/fast/, early/slow, LEP) are related to changes in space weather parameters in the D-layer region of the equatorial region, rather than being caused by an increase in the number of acquired data.

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