Studying and Analysis a VLF Radio Waves Reflection from The Ionosphere Layer in Thi-Qar Site

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Abstract

Very Low Frequency (VLF) transmitter signals propagate in guided modes through the earth-ionosphere waveguide (EIWG) with very little attenuation and can be received literally around the globe. The measurements of the amplitudes of VLF signals is the most cost effective method for studying the propagational features of VLF waves in the EIWG and probe the transient ionospheric disturbances in the D-region. Our space weather monitors measure the effects on Earth which produce by solar flares by tracking the changes in VLF radio transmissions as itreflected by ionosphere. Solar Center at Stanford University's has developed an inexpensive space weather monitors that students can install and use . The instruments detect changes to the earth's ionosphere caused by solar flares and other disturbances. A Super SIDs receiver was installed in the location of the Faculty of Science - University of Thi-Qar , to start the project through the design of our antenna. Data collection and analysis is handled by a local PC . VLF signals from the five navigational transmitters; 1) TBB , Turkey (26.7 KHZ), 2) DHO38 , Germany (23.4 KHZ) , 3) HWU , France (21.75 KHZ), 4) GQD , UK (22.1 KHZ) , 5) NON , Occupied Palestine (29.9 KHZ) continuously from May 2017 to 15 September 2017 and analyzed to accomplish the scientific objectives of this work.

The signal strengths vary over the 24-hour period due to varying illumination of the transmitter receiver great circle paths (TRGCPs) by the sun. The night and day time signal strengths are different from each other due to the change in the reflection conditions at the lower ionosphere. Besides this, the signal strengths are largely affected by the discontinuity over the day and night propagation paths at the terminator which results in signal fading (minima) during sunrise and sunset transition of the terminator. Effects of solar flares that occurred during the monitoring period on the amplitudes of five VLF transmitter signals as mentioned earlier have also been studied. The amplitude enhancements of 1.3-15 dB for the solar flares of classes B9.2 - X9.3 respectively have been observed.

Keywords: solar flare , ionosphere , VLF signals , sudden ionospheric disturbance .

1- Introduction

Space weather has its origins in the Sun.Space weather technology is interested in the space environment around earth all the way to the sun.The sun continually produces two main types of energy into space – electromagnetic (EM) radiation and corpuscular rays.The particles in the upper part of the atmosphere ionized by the incident solar radiationas well as cosmic rays from outer space and the ionosphere is created which is a conducting layer that surrounds the Earth.The ionosphere is located at an altitude ranging from 80 km - 400km. It is divided into three main regions: D, E and F. F region can be divided into F1 and F2 ,since the main reason for ionizing these layers is solar radiation, which exists only during the day,therefore the density of the electron changes during the day and night.The ionosphere is the part of the Earth's atmosphere that reflects radio waves , this is Because it is a layer ionized by the influence of solar radiation and contains negative electrons and positive ions and this property causes the reflection of radio waves,L. Liuet al. (2011).The emission of x-rays from the sun is irregular and increases strongly during solar flares and ionizes gases in the earth's atmosphere in layer D and below layer E at height of 70-90 km , the ionization becomes large during the peak of the solar cycle ,A. Kumar and S. Kumar (2014). The most influential radiation on the ionized layer is the extreme ultra violet (EUV) because it is fixed but varies from month to month depending on the number of sunspots. This radiation absorbs at altitudes between 100-400 km by oxygen and nitrogen molecules (O, O_2, N +, N_2).It is responsible for ionization in regions (F2, F1, E). UV radiation is absorbed by ozone layer and does not cause ionization , it has a longer wavelength than EUV , J. Laštovička et al. (2008).In addition, cosmic rays contribute to the ionization of ionosphere particles and are largely responsible for ionization.

Some frequencies used in atmospheric and naval navigation systems , they are also disturbed by the impact of solar activity.Energy from solar flares or other disturbances (such as gamma-ray bursts) when they reach the Earth's upper atmosphere, we observed that ionization in the ionosphere increases suddenly.Thus, the density of the electron-ion and the location of the layers has been changed.The term sudden ionospheric disturbances (SID) is usually applied to these disturbances affecting the ionosphere in an easy manner and the ionosphere takes time (a few seconds to several minutes) after the disorder to restore itself to the normal state , K. Davies (1990) ,Liu J. Y. et al. (1996).These devices detect changes in the ionosphere caused by solar flares and other disturbances.Most space weather sensors measure the effects on the earth from solar flares by tracking the changes in the transmission of very low-frequency radio waves (VLF), reflecting the earth's ionosphere. VLF radio waves come from transmitters established by different countries to connect with submarines.The signal strength of these waves changes when the sun affects the earth's ionosphere, causing ionization, and thus changes where the waves bounce back.Most devices monitor these changes in signal strength. The space weather monitoring device monitors only the form of energy that comes from the solar activity of the X-ray and the maximum ultraviolet energy.We will rely on this program to monitor ionospheric disturbances. VLF refers to a class of radio waves ranging from 3 kHz to 30 kHz in frequency with wavelengths ranging from 10 to 100 km. VLF applications include communications under sea and ocean waters, radio navigation services, and secure military communications.In these frequency ranges, radio waves can bounce off the ionosphere and propagate within the so-called earth-ionosphere waveguide(EIWG), which is defined as an area extending from the surface of the earth and the ocean to the top of the D and E layers in the ionosphere and penetrate of 40 meters within the salt water.The significance of the large wavelength extends over large distances. VLF radio waves can be used as a mechanism for sensing disturbances in the lower ionosphere that is region D.At about 60 km in altitude, the VLF radio waves are reflected by Earth and the ionosphere allowing it to travel around the world similar to waves in the waveguide of a parallel plate. Due to the unstable propagation of VLF waves on the lower ionosphere, it is very useful for sensing the disturbance occurring in this layer.

The propagation of the radio waves in the ionosphere varies with the time of day and the season of the year, and the solar cycle. The propagation of VLF waves during the day is quite stable while at night the reflection area of the ionosphere is more volatile.The change in amplitude occurs because of daytime variation so that the changes are more pronounced during sunrise and sunset where the amplitude received are more sensitive to changes in the ionosphere compared with daytime propagation.Solar flares is classified into: B, C, M and X according to peak flux (watt per square meter, W / m^2). Table (1) shows the intensity of the flux corresponding to different categories of flares.

Table 1. Classification of solar flares based on its intensity.

Solar flare class	**Intensity $\langle W/m^2 \rangle$**
B	$I \leq 10^{-6}$
C	$10^{-6} \leq I < 10^{-5}$
M	$10^{-5} \leq I < 10^{-4}$
X	$I \geq 10^{-4}$

2- Measurements and instruments

VLF remote sensing is based on high-resolution measurements of the amplitude of propagation signals from transmitters , J.M. Paul (2000). Solar radiation at UV and shorter wavelengths is considered "ionizing", so the energy of photons at these frequencies can remove the electron from an atom or a neutral gas molecule during the collision. In this process, part of this radiation is absorbed by the atom ,which leads to produce a free electron and a positive ion.

At higher levels of the earth's outer atmosphere, solar radiation is very strong, but there are only a few atoms to interact with, so ionization will be low here. It is believed that ions are produced in the earth's atmosphere partly by cosmic rays, but mostly by solar radiation. The latter could include particle radiation (during periods of storms), ultraviolet radiation, and x-rays. To a large extent, the dominant factor appears to be solar ultraviolet and light X-rays.Sydney chapman assumed the presence of an ideal layer in the ionosphere called the chapman layer where this theory was developed by him, It is assumed that the ionizing solar radiation entering the atmosphere decreases as it goes down the atmosphere where it is balanced with concentrations of gases forming the atmosphere at a certain height, where less These concentrations as we go to the top of the atmosphere when the generation of electrons at high rates. The production of ions for the chapman layer increases according to the angle of the zenith angle (X), which is the angle made by the sun with the column, when the sunrise is the highest value for this angle and the back is reduced until it reaches its lowest value and then begins to increase again at some time in the afternoon,and at the sunset reaches its highest value. The amount of this angle depends on the location of the measurement and on the time of the year , K. Davies (1966) ,T. Beer (1976). The rate of the production of ions is given by relation (1):

$$q_m = q_0 cosx \qquad (1)$$

Where: q_m represents the maximum rate of ions production, at noon with the angle (x) is equal to zero,therefore$q_m = q_0$, either at sunrise and sunset angle is x = 90 so $q_m = 0$.

The VLF typical receiver,composed from : antenna, coaxial cable, linear receiver with amplifier, digital converter, computer and storage , as shown in Figure (1).

Each antenna is connected to a three-step amplifier: a low-noise special amplifier using identical PNP transistors, the frequency offset step, and the signal output step.The aim of any receiving antenna is to convert an electromagnetic wave into a voltage. A magnetic loop antenna is a winding of copper wire around a frame (for air-core loops).A loop antenna is actually sensitive to the magnetic field and not the electric field (it is also called a *magnetic* loop). The Faraday's law of induction (or the law of electromagnetic induction) states that the induced electromotive force

(ε_{ind}) in a loop is directly proportional to the time rate of change of magnetic flux *Φ(t)* through the loop according to the relation:

$$\varepsilon_{ind}(t) = -\frac{d\Phi(t)}{dt} \qquad (2)$$

Where:(ε_{ind}) is the induced electromotive force, in Volt , and *Φ* is the magnetic flux across the circuit, in webers (Wb ≡ V·s).

The type of antenna that can capture VLF radio signals is called a loop antenna. Basically, a loop antenna is an inductor capacitor that fluctuates in some frequencies. Since the electromagnetic field emitted by VLF transmitters passes through the loop, it will produce a very small electric current (~ 0.1 mV) in the wire. We can improve the chance of capturing this very small signal by increasing the number of turns or enlarging the antenna size. As the number of turns increases, the amplitude will also increase, reducing the resonance frequency. Also, as the number of turns increases, the wire resistance also increases, causing low signal amplitude. The antenna was designed from a wooden frame in the form of octagonal along each side of 85 cm, and a wire was drawn double diameter of single wire 0.9 mm and a length of about 200 meters around this frame, and the number of turns 30 turn . Figure (2) shows the antenna used in our current study.

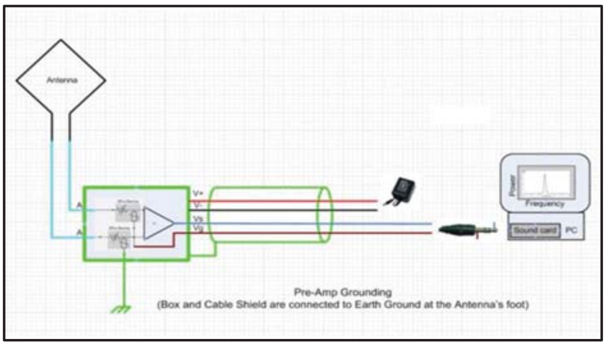

Figure 1. Simplified layout of the VLF signal receiver.

Figure 2. Octagonal antenna of wood at the monitoring station of the Faculty of Science, Thi-Qar University.

The RG-58 cable is the standard cable with 50 ohm resistors. The radio signals captured by the antenna was very small, approximately 0.1 mV, so we need an amplifier to amplify the signal about a thousand times to a level that can be sensed by the sound card of the computer.The amplifier we used was obtained from Stanford University, California, USA. The digital converter is the sound card in the computer that converts the signal from analogue to digital.The digital converter must support high definition (HD), which can record up to 96 kHz sample rate. Finally, we used a program to track the intensity of the transmitted VLF signals, processes the data and displays the graphs (recording the amplitude of signals over time). This program with the device imported from Stanford University, which was designed to detect sudden ionospheric disturbances caused by intense x-ray flare when there are solar flares on the sun. The spectrum lab was also used to determine the names of received VLF transmitters , the above procedure is shown in figure (3).

In this paper we test the sudden ionospheric disturbances caused by solar flare events from different signals of the VLF transmitters received at the University of Thi-Qar, Faculty of Science. The signals received from VLF transmitters are as shown in Figure (4), where the vertical protrusions standing at the normal interference level represent the signal received from the transmitters, the level of interference may increase or decrease from time to time. In Figure (5), the typical change in signal amplitude when the sun is quiet (a quiet day), which mean there are no solar events.

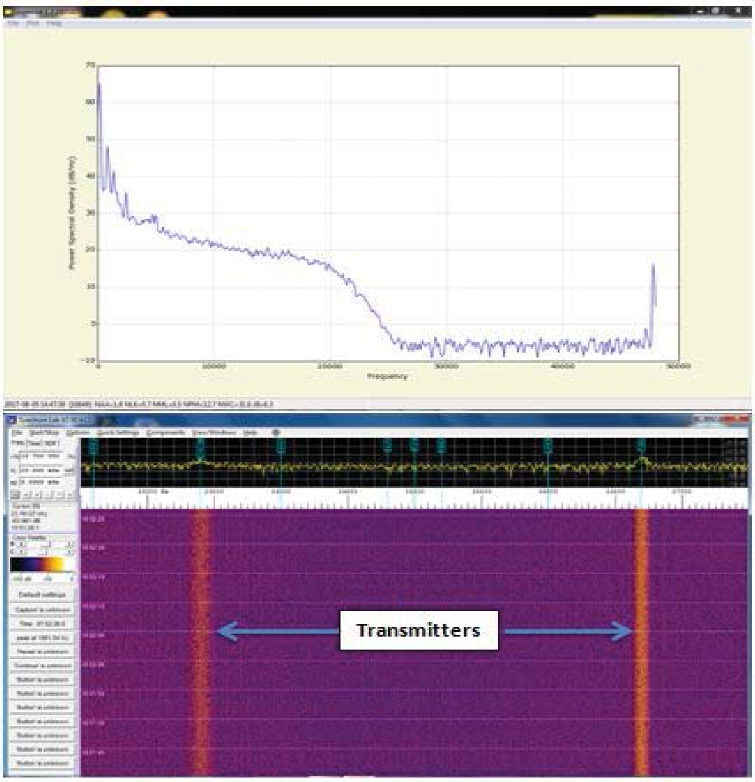

Figure 3. Illustration of the ionosphere detection program and spectrum lab.

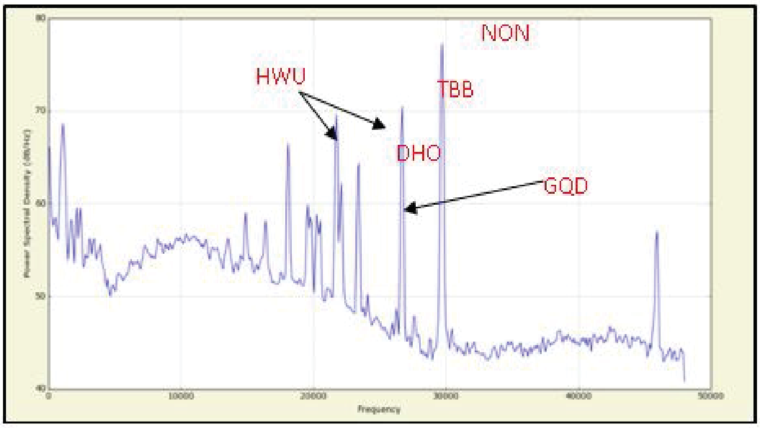

Figure 4. VLF transmitter signals received at the monitoring station of the Faculty of Science - ThiQar University.

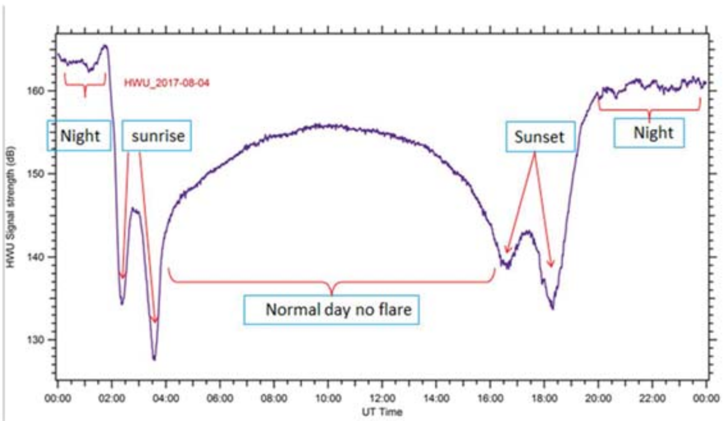

Figure 5. Daily change of the HWU signal when the sun is not active.

Data from the geostationary operational environment satellite (GOES) were used to detect solar flare through solar geophysical data, include the start time of the soft x-ray emissions, x-ray class, Hα and active regions location , R. D. Straw (2007). GOES is a joint work of NASA and the National Oceanic and Atmospheric Administration (NOAA). The quiet X-ray imager (SXI) is the main instrument on GOES board, which provides regular monitoring of active solar regions, coronary holes, and solar flares. The resulting graphs give information about the sun and how it affects the Earth. We then confirm our data with satellite data (GOES) on the SEC website. Look at the charts to see if there are any significant spikes in the data. The spikes will rise very steeply; reach the highest point, and then return to the same level, as in figure (6) below.

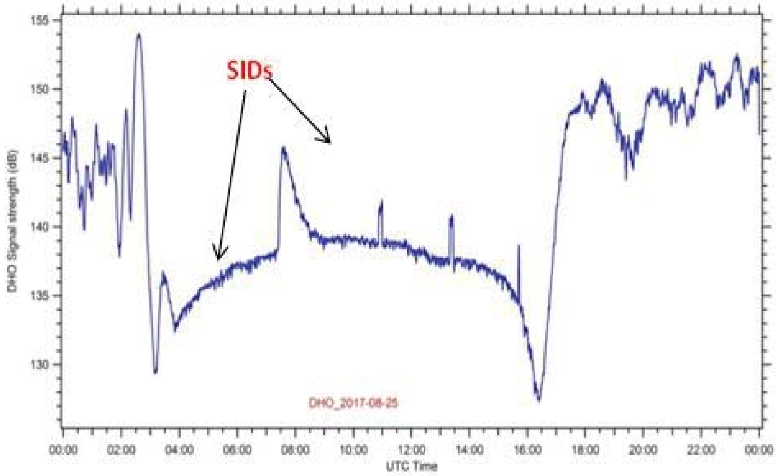

Figure 6. Ionospheric disturbances that represent the amplitude increase in fin form.

These spikes represent the possible solar events. We can compare our SID data with data from GOES satellite. GOES Sample Chart As in Figure(7), the different colored lines represent data from several channels and other satellites. The X axis is the time; the Y axis indicates the intensity of the flare. If the timing of the spikes on our chart has good agreement with the spikes on the GOES data charts, this indicates that which means we have detect flare events.

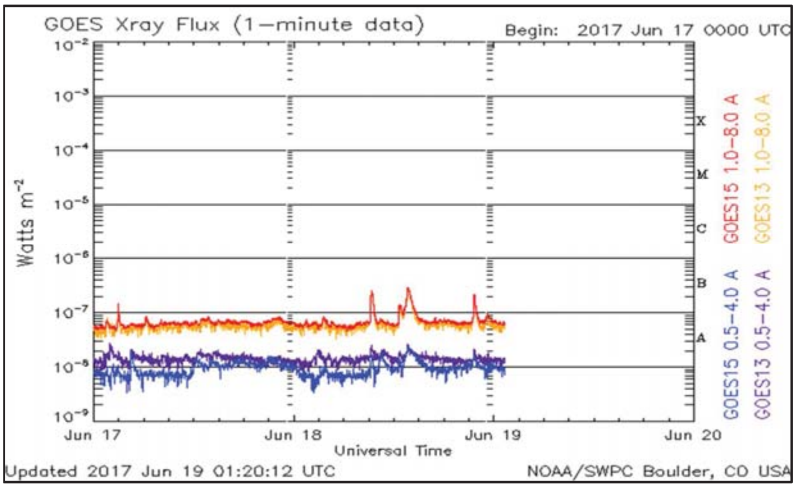

Fig. 7. GOES X-ray flux , http://www.swpc.noaa.gov/products/goes-x-ray-flux

3- Results

VLF signals from different transmitters (previously mentioned) were received at ISIO Station which located atThiQar University, Faculty of Science, as shown in Figure (4). Solar events that give a C-type solar radiation can be seen clearly and occur most often. Class M events occur less, and Class X occurs much less than the previous ones. In this study, the amplitude disturbances (ΔA) resulting from solar flares from VLF emissions are determined by $\Delta A= A_{peak} - A_{background}$, where A_{peak} is the peak amplitude value during the solar flare and $A_{background}$ is the average monthly power value at Peak amplitudetime. This method is similar to that used by Todoruki and others , Y. Todoroki et al. (2007).

The sudden ionospheric disturbances caused by the incidence of soft solar X-rays generated by solar flares were studied due to a strong solar event. The effect of the fall of this X-ray will change the ionization state, which will be reflected in the VLF signal. , And we can see this by sudden change in the amplitude of signals received.

Case 1:Two of the X2.2 and X9.3 solar flares were observed on September 6, 2017 and are clearly very strong and the effect of this flares was observed on the VLF NON signal amplitude (this is named because it is not listed Within the list of VLF transmitters). flare X2.2 started at 8:57 UT and ended at 09:17 UT while X9.3 started at 11:53 UT and ended at 12:10 UT. The signal of the other transmitters was confused during that day. The change in signal amplitude with the change of flux during this flare is shown in Figure (8). ΔAwas calculated with 15 dB for X9.3 and 10 dB for X2.2. This flare also dates back to the active region of 2673 on the sun.

The second case: A C5.5-type solar flare was detected on 25 August 2017 and increased VLF signal amplitudes received from HWU, DHO and TBB transmitters. Where it started at 07:15 UT and ended at 07:46 UT. The variation in HWU, TBB, and DHO signal amplitudes is shown in Fig. (9). during this flare, ΔA was calculated with 7.5 dB for the DHO signal and 3.2 dB for the HWU signal and 2 dB for the TBB signal. The three signal amplitudes increase after 7:15 UT and return to the normal daily level at about 08:10 UT, indicating that the ionization lasted 20 min after the end of the solar flare.

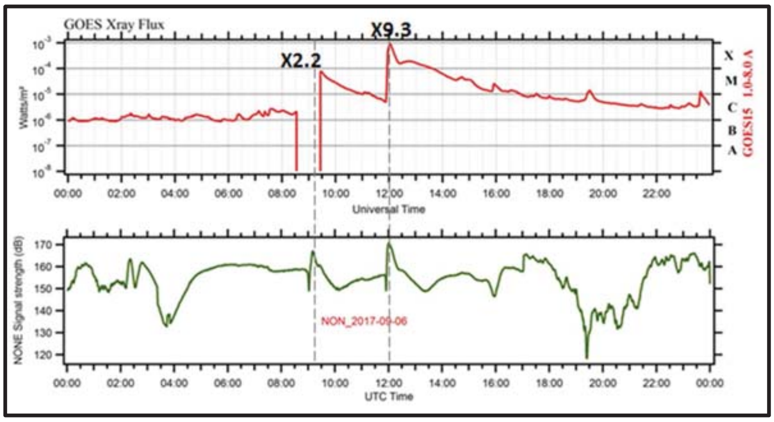

Figure 8. Solar events on 6 \ 9 \ 2017, where the top (red line) represents the X-ray fluxfrom GOES satellite and the diagram below represents the change in the amplitude of the signal received in our station from NONE.

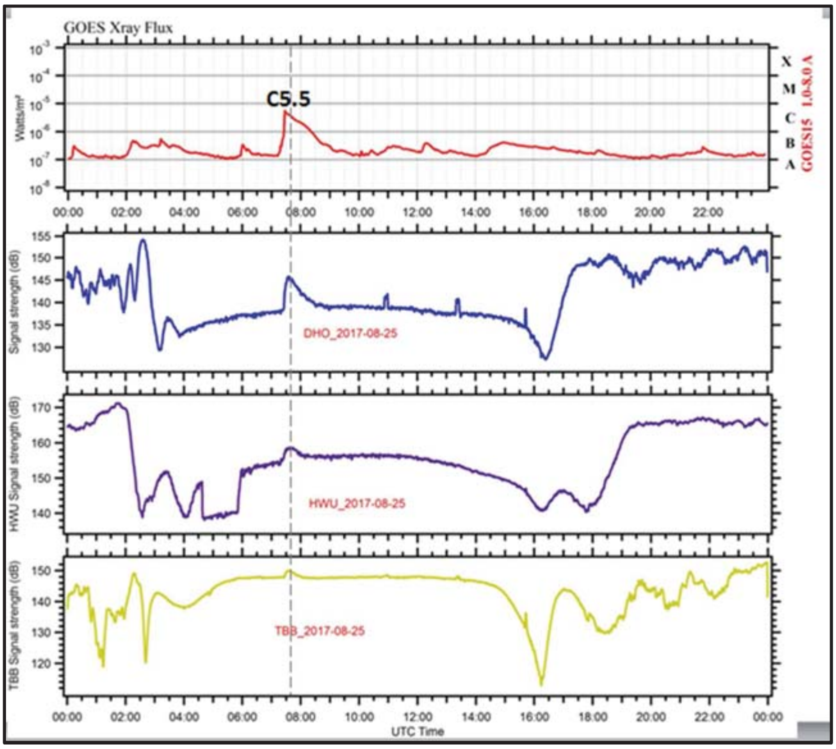

Figure 9. Solar events on 25/8/2017, where the upper part (the red line) represents the X-ray flux of the satellite GOES and the diagram below represents the change in the amplitude of the signal received at our station of DHO, HWU, TBB transmitters.

4- Discussion

In our current study, for the first time in Iraq and in the city of Nasiriya, the VLF signal reception station, in cooperation with Stanford University, was designed and constructed, in which data received as a result of reflection of the waves from The ionosphere layer and then we were able to quantify this disturbance by knowing the change in VLF amplitude. Soft solar x-rays that occur on the same day and time are also monitored and compared with these changes in signal amplitude.

We have observed in this study by presenting and analyzing the results obtained as a result of the work and monitoring of our station (ISIO) and for a period of five months from the month of May to the end of mid-September 2017 and approved in the last years of the solar cycle (24), Here the sun in the ineffective where the sun is called by this name always end of its solar cycle, which is usually 11 years for each full cycle. This period of inactivity, which has low solar flares, was very typical of our work. Our timing of choosing the study was very correct because we expected that a few isolated events would be observed. This is what has already happened, which also reflected the accuracy of our readings and the absence of any interference or effects between them and Consecutive events and short time.

Our selection of the summer season for the monitoring process also gave us a positive boost to the length of the daytime monitoring period, as is known in Iraq. In this ideal environment of monitoring, we found from our previously presented and analyzed results that we can say that the amplitude is relatively variable with the incident x-ray flux logarithm. The amplitude can be useful and convenient for extrapolating X-ray flux when the GOES detectors saturate during a very powerful solar flare to determine the actual flux strength associated with strong solar flares. All the flares studied here occurred when the signal was received in daylight. The best curve for amplitude disturbance is fully compatible with the flare strength similar to the shape previously obtained by Macri and Thompson , W. M. McRae, and N. R. Thomson(2004) and Thomson et al.(2005). However, data points are lower than those reported by these researchers.The increase in the amplitude of the VLF signals with increased solar flare intensity can be qualitatively explained as follows: With the increase of the flare flux, two phenomena may occur. The first is the increase in the electron density of layer D and the other is the electron density distribution with height, The EIWG limit becomes more severe and low. As a result, VLF signals are reflected at sharp limits with relatively lower penetration in layer D and therefore less attenuated / under-absorbed than under normal propagation conditions.

The lower ionosphere has a different sensitivity to solar flares depending on solar activity, where it is more sensitive when the sun is less active (low solar activity). During the minimum solar activity, the small flares may show detectable disturbances over VLF emission amplitude where X-ray flux is low during the minimum solar activity. Our results indicate that the solar flares rated B9.2 and above can show detectable changes in amplitude along the propagation path of VLF during the low solar activity period. It is also observed that the signal strength points change during 24 hours and have different values At night and day, but produce the same shape. It was also found that disturbances in amplitudes during flares were slightly different in comparison with the X-ray flux data from GOES.

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