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D-Region VLF Monitoring System

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Abstract

The use of VLF signals to monitor the changes that occur in the ionosphere resulting from solar variability, has helped to understand how different ionospheric layers depend upon the Sun. These different ionospheric layer responses play a significant role in determining space weather impacts. Our system was created to be a permanent monitor to study the effects on the D-region of the ionosphere and explore any major impacts due to sun radiation exposure. The use of inexpensive equipment proved to be effective and the key point in the creation of this system

Introduction

The ionosphere is the part of the earth's upper atmosphere in which ionization occurs. This is due to the atoms reacting to solar ultraviolet and x-ray radiation exposure. It extends from 60 km to 1,000 km of altitude, and it is subdivided into regions which change with variation of sun radiation exposure. These regions are different from the neutral layers of the atmosphere. Each ionospheric region reflects different radio wave frequencies. The D-region serves as a waveguide for Very Low Frequencies (VLF, < 30 kHz) allowing the radio wave to travel to distant places [1].

The creation of a VLF monitoring system gives us an insight on the effects of solar radiation in ionospheric activity by collecting signal strength data from remote radio transmitters. As the sun rises or sets, there is a change in ionospheric activity due to a change in solar radiation exposure. These changes impact the different regions in the Ionosphere as shown in Figure 1. Our system is set to study the changes in the D-region of the ionosphere.

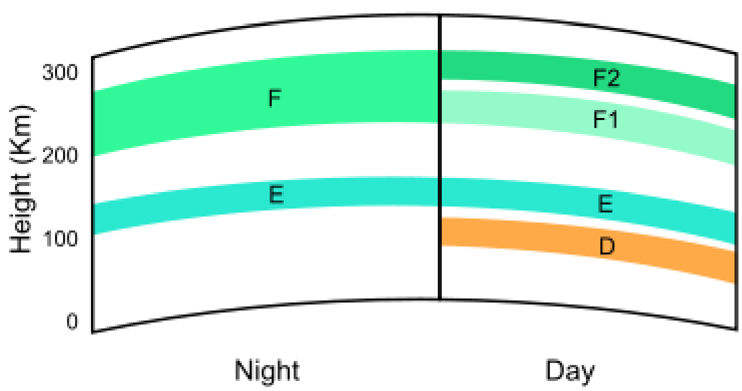

Figure 1. Comparison of the Ionospheric regions during day and night time [2].

Theory

Our system receives the VLF signal from two US Navy radio stations; one is NLK 24.8 KHz in Jim Creek, Washington, and the other is NML 25.2 KHz in La Moure, North Dakota [3]. A Raspberry Pi 3 serves as the computer interface and storage unit. Two loop antennas connected to two SID monitors custom-made from Stanford University work as the receivers producing a voltage (-5V to +5V) related to the received signal strength at its fixed frequency [3]. The voltage is digitized by a DataQ analog-to-digital converter, producing serial data. The serial data is read into the Raspberry Pi via the USB port. The software records data with the Universal Time stamp in a file covering one UT day, At the end of the day the data file is plotted with gnuplot [4].

The SID monitor works by detecting/filtering, amplifying, rectifying, and integrating to measure signal strength. The signal strength averages out the peaks from the AM-detection stage. The sky wave components of the RF signal are the result of one or more bounces off the ionosphere. Sky waves are detected using a wire-loop antenna. The magnetic component from the RF signal is converted via induction into a small electrical signal that is then amplified. This relates to how much ionization has occurred and at what level of the ionosphere the VLF wave "bounces" from which can be then interpreted as the cause of the changes in signal strength [5].

Experiment

For the creation of the monitoring system we required:

- Two loop antennas
- Two SID monitor custom-made from Stanford University
- Raspberry Pi 3
- DataQ analog-to-digital converter
- Cooler
- Cooling fan

The Raspberry Pi is an inexpensive and tiny computer, about the size of a credit-card. Using Raspbian (the version of Linux for Raspberry Pi) it possesses enough power to do everything that any desktop computer can, and because of its small size it can fit anywhere [6]. Our Raspberry Pi and SID monitor were placed inside of a modified cooler to protect them from weather phenomena (such as rain, snow or hot days) with a cooling fan to keep the temperature stable. The antennas were located at an angle that maximize the capture of the signal strength from both stations. Our equipment was placed on the rooftop of the Science and Engineering Research building at the Logan campus of Utah State University (Figure 2). Due to the capabilities of the Raspberry Pi 3 and its connection to Wi-Fi, we connected the Raspberry Pi to the university network, and monitor remotely its data and status.

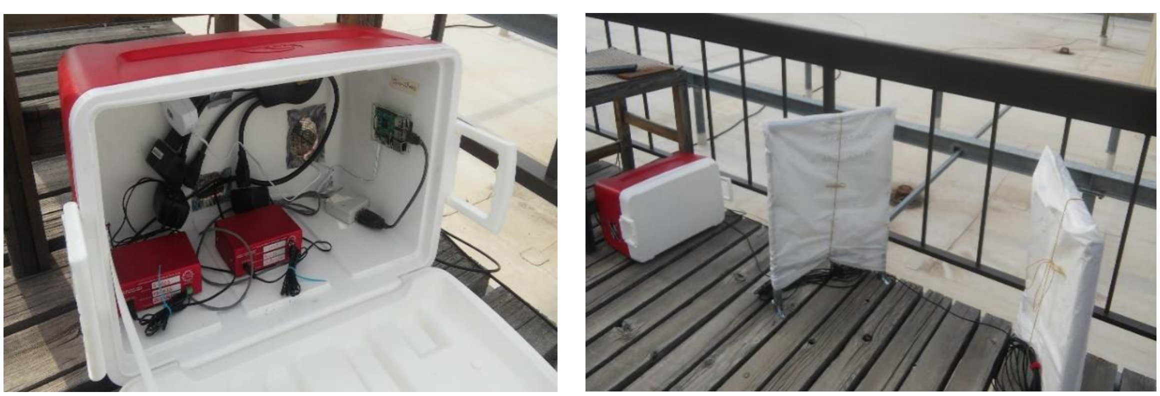

Figure 2. Experimental equipment placed inside the cooler for weather protection (left). Set up of the equipment at the rooftop of the Science and Engineering Research Building (right)

Results

The system collects data from the receivers every five seconds and puts it in a text file. After a period of 24 hours it uses the data to create a graph using gnuplot. Figure 3 presents a graph of the plot data for our VLF monitoring system during what we call a “quiet day” with no major solar event.

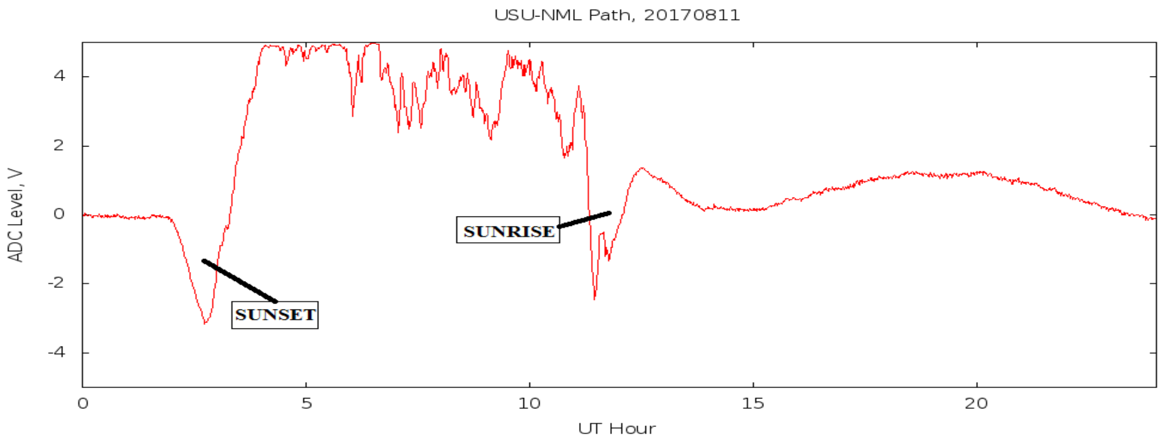

Figure 3. Graph of the NML signal during August 11, 2017.

The fall and rise indicated in the picture are related to the transition of night and day time. The signal level we see is the sum of two or three rays coming from the transmitter: a surface wave that follows the ground, a one-hop (transmitter-ionosphere-receiver) path, and probably a two-hop (transmitter-ionosphere-ground-ionosphere-receiver) path. As the sun angle changes, the one-hop and two-hop phases change, and we see constructive and destructive interference. This is an indication of a change in ionospheric activity, which has direct effect on the signal strength. Solar activities such as solar flares also have an impact on the signal strength. The effect depends on the transmitter-receiver paths. At our location we generally see enhancements, but at other locations (Colorado for example [9]) they may see drops in signal during flares due to destructive rather than constructive interference for the path on the graphs as shown in Figure 4. It can be seen the little spike corresponding to the flare it matches with our data collection at 20 UT.

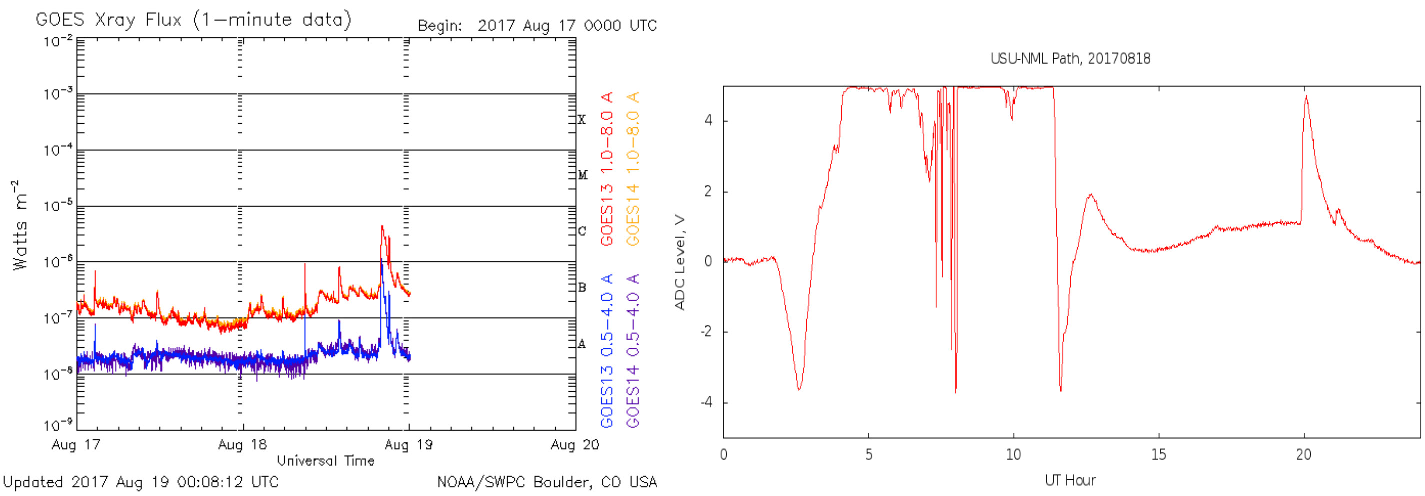

Figure 4. Solar flare activity provided by space weather website for 18 August 2017 (left). Graph of the NML signal during the same day (right).

We used the space weather website to monitor any incoming flares [7][8], or major solar events and compare their strength with our detected signal. Our system was used to follow the path of totality during the events of the solar eclipse of 21 August 2017 and verify the effects of the eclipse on the ionosphere (Figure 5) [9]. Our results presented a decrease in signal strength at the moment of totality that is consistent with that of the sunset. A small x-ray flare can be seen during the moment of totality, and it was confirmed by the space weather website.

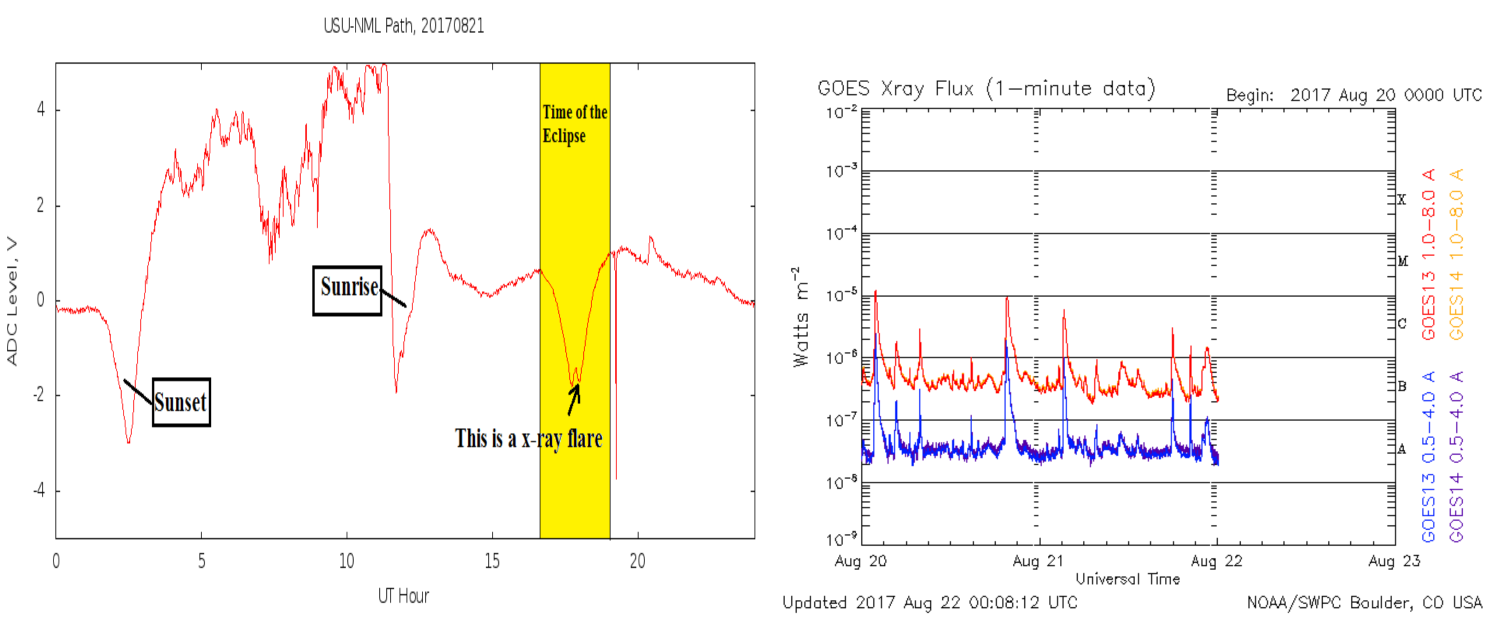

Figure 4. Graph of the NML signal during the day of the eclipse

Conclusion

VLF signal was used to monitor the D-region because of it ties into USU modeling work of the upper atmosphere, and our data has proven to be consistent with it. The D-region of the ionosphere is dependent on solar radiation exposure that creates the ions that forms it. A change in the amount of ionization is reflected by a change in the waveguide of the VLF signals, and the inexpensive equipment set up has proven to be a perfect fit for the creation of the monitoring system.

References

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