

Assessing the Relationship between Solar Weather and (SID) through VLF Signal Analysis

Very Low-Frequency Signal Data Collection and Analysis

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Introduction

Space Weather, defined by NOAA, encompasses the Sun's and Earth's interactions. These interactions include Solar Flares, Coronal Mass Ejections (CME), auroras, and geomagnetic storms. Solar flares are intense flashes of light from the Sun's surface caused by explosive events that release large amounts of energy and charged particles into space (Alves et al., 2017; Kumar et al., 2015). CMEs are violent expulsions of plasma from the Sun into space.

These phenomena can significantly impact Earth's ionosphere, particularly in the D-region. These are also known as Sudden Ionospheric Disturbances (SID), and they affect the behavior of Very Low Frequency (VLF) radio signals used for various communication and navigation systems (Kumar et al., 2015). The D-Layer is the lowest ionospheric region, usually between 50 to 90km (Gomonov et al., 2020).

Solar storms' effects on Earth can be studied to understand better how the universe behaves and the Sun's and Earth's interactions. Also, it is essential to consider how much damage past solar storms caused and what they can cause. The British astronomer Richard Carrington's observations in 1859 were the first scientifically documented solar flares events (Bell & Phillips, 2006). Those observations identified solar flares and solar eruptions as the cause of geomagnetic storms. Later known as the Carrington Event, the storm ionized the atmosphere to such an extent that it overcharged the telegraph lines in America and Europe—burning some transformers and power stations (Riley et al., 2018).

Two major solar flare events happened in 1972, interrupting phone communications for long distances across states. In 1989, another solar flare caused a geomagnetic storm that damaged the Quebec Hydro station, leaving six million people without electricity. There are

other examples of devastating solar effects on Earth (Bell & Phillips, 2006; Magnuson, 2012; Magnuson & Parsons, 2011).

Considering these past events, it is inevitable that other extreme events will hit Earth's atmosphere. Extrapolating from the intensity of these events, one can predict the effects of such a storm on Earth's technological infrastructure. The National Research Council (NRC) report in 2008 details the damages an extreme geomagnetic storm could cause our society. The estimates range from 1-2 trillion dollars for the first year and keep 130 million in the USA without power for years, with the recovery taking 4 to 10 years (Cappucci & Kunches, 2023; Magnuson, 2012; Magnuson & Parsons, 2011).

Even though science is a long way from being capable of forecasting solar storms, there can be studies of the phenomena and their impact on the world. In current society, a crucial matter is if science can predict the degree of damage that energetic solar phenomena, such as solar flares, may cause to nature, living organisms, technology, and the surroundings (Srećković et al., 2021). Recently, three X-class solar flares, considered the most powerful category on the scale, have burst forth from the Sun's surface. Following an extended dormancy phase, the Sun is becoming increasingly active and exhibiting signs of turbulence. Specialists suggest that the beginning of the new solar cycle might have a dramatic onset, potentially affecting Earth (Cappucci & Kunches, 2023).

Research Objectives

To measure VLF signal propagation changes during enhanced solar activity periods and demonstrate the relationship between solar emissions and SIDs.

Research Problem and Questions

Research Problem

Space Weather influences the Earth's Ionosphere and causes SIDs. However, this precise relationship and its impact on VLF signal propagation remain unclear (Gu et al., 2023; Srećković et al., 2021).

Research Question

To what extent do Solar Flares and CMEs of varying intensities affect the characteristics of SID events regarding VLF signal propagation? What is the relationship between these events, and what is the effect on VLF signal propagation?

Assumptions of the Research Question

- Solar flares have a measurable effect on the ionosphere.
- Solar flares cause ionospheric disturbances, affecting VLF signal propagation (Srećković et al., 2021; Sulic & Sreckovic, 2014).
- Solar flare intensity and the solar activity level have a quantifiable impact on SID characteristics.
- The ionospheric D-region is the primary area of interest for investigating the effects of solar flares on VLF signals.

Related Questions Addressing Assumptions

- Can VLF signal data reliably detect and analyze SID events?
- Can selected Space Weather effects be observed and analyzed using simple radio equipment?
- How do changes in the ionospheric D-region parameters relate to solar flare intensity and activity levels?

Hypothesis

Solar events are associated with SIDs; analyzing the VLF signal propagation during periods of solar activity will reveal a pattern of signal fluctuation. As detected by VLF radio noise, sudden ionospheric disturbances can be used to monitor solar events.

Experimental variables in this project include

- The independent variable is the Solar events.
- Dependent variables: Changes in the VLF signal characteristics, such as amplitude, onset duration, and cessation.
- Controlled variable: The experiment can control for the receiver's geographical location, time of day, and local atmospheric conditions.

Methodology

Overview: The amplitude of VLF radio signals and noise filtered to range between 3 and 15KHz will be sampled every 10 seconds. The locally collected value will be logged using computer software and correlated with relevant solar event information obtained from the NOAA Space weather prediction center.

Hardware and Antenna for signal reception and recording

This study will use a microcontroller such as a Raspberry Pi 4, an Arduino, or a similar device as the hardware platform based on VLF monitoring setups (VLF, 2020). For the Antenna, there are two options: building a simple loop antenna made of copper wire is easy to assemble and affordable for VLF signal reception; alternatively, purchasing a commercially available VLF loop antenna would be convenient (VLF, 2020).

VLF Signal Amplification and Filtration

The radio frequency where SIDs are observable shares the frequency range with many artificial and naturally-generated radio signals; therefore, the signals of interest must be filtered and amplified to reduce the effects of local interference before recording (VLF, 2020). Examples are power lines, electronic devices, and lightning storms, among many others.

Hardware Assembly

Putting together the hardware components is a simple process that follows the step-by-step instructions outlined by (VLF, 2020). The loop antenna receives the signal and sends it to the preamplifier's input, and the preamplifier's output links to the bandpass filter's input. Then, the bandpass filter's output connects to the input of the ADC. Finally, data will be logged from the microcontroller to local or remote disk files.

Software Implementation and Technical Requirements

Logged data will be retrieved and analyzed by correlating the local VLF noise data observations with the NOAA's Space Weather Prediction Center data.

Solar Flare Monitoring and Analysis

Thus the effects of solar flares on the Ionosphere D-Region can be studied by timestamping the collected data and correlating it with solar flares occurrences (Kumar & Kumar, 2018). Integrating the data with the VLF sensor data will make it possible to study the correlations and analyze the effects of solar flares on VLF signals (Gu et al., 2023; Sulic & Sreckovic, 2014).

Data Documentation Recording and Storing

A fundamental part of the project is appropriately documenting the experiment. That includes the hardware design, software implementation, and analysis of the results, which will be valuable for the research paper and future reference. This documentation will also facilitate the

replication of the study by other researchers interested in examining the impact of solar flares on VLF signals (Kumar & Kumar, 2018).

Project Timeline

The estimated duration for this project is 120 days. The initial 30 days will include procuring and setting up the required hardware and installing the software. Subsequently, 30 days will be allocated exclusively for capturing the signals. After that, 30 days to analyze the data and draft a preliminary report. The final 30 days for making revisions and refining the document.

References

- Alves, L. R., Souza, V. M., Jauer, P. R., da Silva, L. A., Medeiros, C., Braga, C. R., Alves, M. V., Koga, D., Marchezi, J. P., de Mendonça, R. R. S., Dallaqua, R. S., Barbosa, M. V. G., Rockenbach, M., Dal Lago, A., Mendes, O., Vieira, L. E. A., Banik, M., Sibeck, D. G., Kanekal, S. G., & Baker, D. N. (2017). The Role of Solar Wind Structures in the Generation of ULF Waves in the Inner Magnetosphere. *Solar Physics*, 292(7), 1–15. <https://doi.org/10.1007/s11207-017-1113-4>
- Bell, T. E., & Phillips, D. T. (2006, May 6). A super solar flare. *NASA*. https://science.nasa.gov/science-news/science-at-nasa/2008/06may_carringtonflare
- Cappucci, Matthew, & Kunches, Joe. (1 C.E., Winter 2023). Sun is waking up, and it looks stormy. *Washington Post, The*.
- Gomonov, A., Yurik, R., & Zolotov, O. (2020). Earth's ionosphere D-region vertical electron density profile data during March 1-31, 2017, according to high-latitude Tumany observatory partial reflection radar measurements and Polar Geophysical Institute's model. *Data in brief*, 31, 105848. <https://doi.org/10.1016/j.dib.2020.105848>
- Gu, X., Yi, J., Wang, S., Hu, Z., Xu, W., Ni, B., Li, B., He, F., Chen, X., & Hu, H. (2023). Comparison of VLF Signal Responses to Solar Flares along Daytime and Nighttime Propagation Paths. *Remote Sensing*, 15(4), 1018. <https://doi.org/10.3390/rs15041018>
- Kumar, A., & Kumar, S. (2018). Solar flare effects on D-region Ionosphere using VLF measurements during low- and high-solar activity phases of solar cycle 24. *Earth, Planets, and Space*, 70(1), 29. <https://doi.org/10.1186/s40623-018-0794-8>

- Magnuson, S., & Parsons, D. (2011, November). Solar Storms Could Plunge Nation into Darkness. *National Defense*, 96(696), 14+.
https://link.gale.com/apps/doc/A272894325/AONE?u=linclin_vcc&sid=bookmark-AONE&xid=be6b707a
- Magnuson Stew, P. D. (2012, February). Catastrophic Solar Flare Scenario Touches Off Stormy Debate. *National Defense*, 96(699), 13+.
https://link.gale.com/apps/doc/A280102038/AONE?u=linclin_vcc&sid=bookmark-AONE&xid=d6be0268
- National Oceanic and Atmospheric Administration (NOAA). *Data Access NWS Space Weather Prediction Center*. <https://www.swpc.noaa.gov/content/data-access>
- National Research Council (NRC). Division, O. E. A. P. S., Space, S. B., & Committee, O. T. S. A. E. (2009). Severe space weather events: Understanding Societal and Economic Impacts: A workshop report: extended summary. *Washington, DC: The National Academies Press*. <https://doi.org/10.17226/12643>
- VLF receiver for Sid Monitoring. (2020, May 7). *PhysicsOpenLab*.
<https://physicsopenlab.org/2020/05/07/vlf-receiver-for-sid-monitoring/>
- Riley, P., Baker, D., Liu, Y. D., Verronen, P., Singer, H. & Gudel, M. (2018). Extreme Space Weather Events: From Cradle to Grave. *Space Sci Rev* **214**, 21.
<https://doi.org/10.1007/s11214-017-0456-3>
- Srećković, V. A., Šulić, D. M., Ignjatović, L. & Vujčić, V. (2021). Low Ionosphere Under Influence of Strong Solar Radiation: Diagnostics and Modeling. *Applied Sciences* (2076-3417), vol. 11, no. 16, Aug. 2021, p. 7194. <https://doi.org/10.3390/app11167194>.

Sulic, D. M., & Sreckovic, V. A. (2014). A comparative study of measured amplitude and phase perturbations of VLF and LF radio signals induced by solar flares. *Serbian Astronomical Journal*, (188), 45+.

https://link.gale.com/apps/doc/A417738180/AONE?u=linclin_vcc&sid=bookmark-AONE&xid=6300d9f9