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Abstract

Solar flares are energy bursts that affect the Earth’s ionospheric density. Coronal mass ejections (CMEs) are plasma clouds that come off the Sun. It is unknown if or how these CMEs affect the ionosphere. This study is two-fold: to construct an antenna that attaches to a SID (Sudden Ionospheric Disturbance) monitor to begin data collection for future research and to compare past CME events with corresponding SID graphs. The SID monitor measures ionospheric changes by tracking changes in very low frequency radio waves. Using previous research studies, it is hypothesized that CMEs will have a distinguishable impact within SID data.
Solar activity can cause extreme turmoil in our high tech society. The radiation and plasma from solar activity can destroy million dollar satellites, explode gas and oil pipelines, and disrupt the Earth’s magnetic fields. Solar activity can also cause large scale blackouts, leaving major areas without power for days. Disrupted bird migration, GPS malfunction, electrified telephone wires, and auroras are all effects of magnetic storms, which are caused by solar activity (10).

Solar flares are the most violent form of solar activity. They are the sudden release of magnetic energy, causing an increase in radiation given off across the spectrum, including extreme ultraviolet waves. Flares occur most often during the solar maximum phase of the 11 year solar cycle. The solar cycle starts at solar minimum, a phase where there is little if any activity on the surface or photosphere of the Sun. As the cycle progresses, the number of sunspots, active regions on the photosphere, increase and move closer to the solar equator. The cycle peaks at solar maximum, where solar activity occurs daily. A complete solar cycle lasts approximately eleven years. We are currently in the beginning solar minimum phase of Cycle 24 and predicted solar maximum for cycle 24 is 2011 or 2012 (10).

Solar flare radiation travels at the speed of light, and reaches the Earth in approximately 8.3 minutes. The main effect of this radiation is evident in ionospheric changes. The ionosphere is the layer of Earth’s atmosphere approximately 60 km above the surface of the Earth that is ionized by the Sun. The ionosphere is also responsible for the propagation of radio waves. The ionization change caused by an unusual increase in radiation from the Sun is called a sudden ionospheric disturbance (SID). SID’s can affect the way radio waves travel through the atmosphere (13).
A SID monitor is a device created to study the ionospheric responses to the Sun. It does this by tracking very low frequency waves. Very low frequency waves are appropriate for this use because they are constantly being transmitted and can be received nearly anywhere on Earth. SID monitors are tracking VLF signals from 23 stations in 10 countries. The SID network works on a series of receivers and transmitters. Each transmitter has its own frequency, and each receiver is tuned to pick up one of these frequencies. This way, the data is collected globally, the sunset/sunrise effects on the transmitter and receiver are equal, and there is a constant collecting of data, even when one transmitter is under maintenance. Currently, SID data is being analyzed for its information on ionospheric response to sunrise and sunset effects. Lightning also produces an ionospheric response detectable within SID data (13). The only type of solar storm shown to have any impact on the ionosphere is solar flares (13).

Coronal mass ejections, or CMEs, are another type of solar storm. They occur when there is a sudden increase in the radiation given off by the Sun, such as the increase given off by a flare. The radiation causes plasma from the corona, or outer atmosphere of the Sun, to be forced out in the direction of the energy. These plasma masses carry their own magnetic field and are defined as CMEs. They move at speeds ranging from 900 to 1400 kilometers per second, reaching the Earth anywhere from 12 hours to 6 days after their eruption. CMEs are manually detected within coronagraph images. A coronagraph is a telescope that places a blocking disk in front of the solar disk in order to see and study the corona. A common source for coronagraphic images is the Large Angle and Spectrometric Coronagraph (LASCO) instrument onboard the Solar and Heliospheric
Observatory (SOHO) spacecraft. To date, SID monitors have never been used for detecting CMEs (13).

The purpose of this study was to determine if earthbound CMEs have a significant impact on the lower ionosphere that is detectable within SID data. Earthbound CMEs were identified by the appearance of a width of 360° in the coronagraph images provided by the LASCO instrument on the SOHO spacecraft (14). The SID data from 2-3 days after the appearance of the halo CME, the approximate arrival time for a CME, was compared to data where there was no solar activity to identify a change caused by a CME. Additionally, this study included the construction of an antenna to attach to a SID monitor to start collecting data for future research.

**Procedures**

**Antenna Construction**

The Stanford Solar Center is sponsoring the Space Weather Monitor program, which distributes VLF monitors used for solar study purposes to students around the world. Seneca was chosen as a site to receive and operate a SID monitor.

1. The antenna, a wire-loop antenna, was constructed to be attached to a SID monitor to begin the collection of data for use in future research.

2. The antenna design required approximately 3 meters of PVC pipe, which was cut into 4 pieces, various PVC connector pieces, and 120 meters of 18 gauge insulated wire.

3. The frame of the antenna was built from the PVC pipe and is 1.8 meters in height and width.
4. Once the frame was built, a length of wire was kept in the center of the antenna for later use, and the wrapping of the wire began.

5. The wire was wrapped around the frame 22 times to form one large wire loop, which picks up the VLF signal.

6. A length of wire was taken back to the middle after the wrapping was completed.

7. Both lengths of wire in the middle, the beginning and ending of the wire loop, were attached to one side of a terminal block.

8. Zip ties were placed around the group of wires to insure they stayed in place and did not separate from one another or come unwound.

9. A coax cable was used to connect the antenna to the SID monitor. The outer sheathing of the cable was removed, exposing the center conductor and the ground wire. The ground wire was twisted together and attached to the opposite side of the terminal block. The center conductor was also attached to the terminal block on the same side as the ground wire.

10. The other side of the coax cable was connected to the monitor using a Bayonet Neill-Concelman connector.

11. The antenna was placed outside with the loop pointing towards our transmitter, which is located in LaMoure, ND. A compass was used to find the correct bearing of 341°.

12. Data collection at site SENMO (Seneca, Missouri) began on January 12, 2009.
Analysis of Historic Data

As data has been collected at our site for only 3 months, the second part of this study involved the use of historic data. Data from sites WSO in California, PEAB in Boston, and Germany-DLR in Germany were used in this study.

1. This study focused on earthbound halo coronal mass ejections. Starting at October 8, 2005 through June 30, 2008, a list of every halo CME was compiled searching the SOHO LASCO CME catalog found at http://cdaw.gsfc.nasa.gov/CME_list/. Halo CMEs appear to have a width of 360°, meaning they are visible around the entire circumference of the Sun (see figure 1 below).

2. Using this list, the EIT 195 images for the corresponding dates and times were viewed to look for any extreme ultraviolet signature change on the visible side of the Sun. This would indicate that the halo was earthbound and likely to have a significant impact on the Earth.

3. SID data files from 2 and 3 days after the appearance of a previously identified earthbound halo CME were downloaded for later use in graphing. The difference
of 2-3 days after the LASCO sighting was chosen because that is the approximate arrival time of a CME at the Earth.

4. Each monitoring site had a constant, a graph of a “normal” day, in which there was no solar activity or other interference and followed the typical daily pattern for that particular site. This data file was also downloaded for later use in graphing. See Figure 2.

5. Using Excel, both data files, the constant and the day in question, were graphed on the same line graph in order to compare them to see if there were any changes that were possibly caused by CMEs.

6. To narrow down a more precise arrival time of the CME, contact with Dr. Richard Mewaldt, a solar scientist from California Institute of Technology, led to the access of a list of near earth interplanetary coronal mass ejections from 2005 through 2007.

7. The shock arrival times were changed from Universal time to local time for each of the three SID monitoring sites to determine if the shock arrived during the day.

8. The new dates were downloaded and graphed in order to determine if the lower ionosphere is affected by CMEs in a way detectable within SID data.
Results

<table>
<thead>
<tr>
<th>UTC Date and Time</th>
<th>Monitor Site</th>
<th>Local Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>12/31/05 00:00</td>
<td>PEAB (Boston)</td>
<td>1:00 PM</td>
</tr>
<tr>
<td></td>
<td>WSO (California)</td>
<td>4:00 PM</td>
</tr>
<tr>
<td>04/14/06 13:00</td>
<td>PEAB</td>
<td>8:00 AM</td>
</tr>
<tr>
<td>07/09/06 21:36</td>
<td>PEAB</td>
<td>4:36 PM</td>
</tr>
<tr>
<td></td>
<td>WSO</td>
<td>1:36 PM</td>
</tr>
<tr>
<td>11/01/06 17:00</td>
<td>PEAB</td>
<td>12:00 PM</td>
</tr>
<tr>
<td></td>
<td>WSO</td>
<td>9:00 AM</td>
</tr>
<tr>
<td>11/28/06 13:00</td>
<td>Germany</td>
<td>2:00 PM</td>
</tr>
<tr>
<td>12/14/06 14:14</td>
<td>WSO</td>
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</tr>
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<td>12/15/06 20:00</td>
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<td>3:00 PM</td>
</tr>
<tr>
<td></td>
<td>WSO</td>
<td>12:00 PM</td>
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<tr>
<td>12/16/06 17:55</td>
<td>PEAB</td>
<td>12:55 PM</td>
</tr>
<tr>
<td>01/14/07 12:00</td>
<td>PEAB</td>
<td>7:00 AM</td>
</tr>
<tr>
<td>11/19/07 17:00</td>
<td>WSO</td>
<td>9:00 AM</td>
</tr>
</tbody>
</table>

This is a chart showing the CMEs used in correspondence with SID data to determine if the CME caused any noticeable changes within SID data. The first column is the shock arrival date and time in Universal time. The middle column shows the SID monitoring site used, meaning these were the sites that had the shock arrive during daylight hours. The last column shows at exactly what time during the day the shock arrived.
This graph is the Boston site for the January 14, 2007 event. The arrow indicates the time of CME shock arrival. There is no real difference between the two dates. The other graphs produced similar results in all but one graph. See Appendix A.
This is the one graph that showed a notable difference between the normal and CME days at the time of CME shock arrival, again indicated by the arrow. It isn’t known if the change is caused by a CME but the trend in the other graphs do not indicate it to be. Additional research would be needed to determine if different CME attributes, such as speed and mass, affect the lower ionosphere.

Conclusions

The antenna is built and data collection is taking place. The analysis of historical data revealed that the shock from a CME does not have a noticeable impact that is detectable within SID data. They are either not sensitive enough to detect the disturbance or CMEs do not affect the lower ionosphere at the time of shock arrival.
**Future Research**

In this study, the graphs were analyzed for an effect near shock arrival time. I am currently looking at other times, like after the main phase of the CME, to look for effects.

A possible direction for next year concerns the use of data from our site. Since the angle of the sun varies with the seasons, will the intensity of the flare change at a given latitude? This would be determined by analyzing data from site SENMO for one year.

**Acknowledgements**

I would like to thank Shannon Sample, our science research instructor, Dr. Nicholas Gross of Boston University, and Dr. Richard Mewaldt from California Institute of Technology for their guidance in this project. I would also like to thank Stanford University for the use of the SID monitor.

**Bibliography**


5. Gross, Nicholas (2008, November 22). Email correspondence.


Appendix A