A Study of the Difference in Origins of Global Sawtooth Oscillations and Steady Magnetospheric Convection

Gari Banfield, Research Adviser: Dr. DeJong

When the Interplanetary Magnetic Field is driven under steady conditions, two space weather events called Global Sawtooth Oscillations and Steady Magnetospheric Convection can occur. Due to these two events originating from very similar conditions, space physicists do not currently know what makes one type of event happen over the other. During the driving process the geomagnetic storm will go either way with no way for anyone to predict which path it will choose. This research is a small piece in an effort to aid Dr. Anna DeJong in finding any clues as to what conditions have an effect on pushing the storm to go either way. Five algorithms were written from scratch in the Java programming language. These algorithms analyzed, sorted, and plotted over two thousand steady magnetospheric convection events and one hundred thirteen global sawtooth oscillation events over the last eleven years. The axes of these plots were magnetic field of the interplanetary magnetic field in the z-direction and each plot contained one event type versus the other. These algorithms can easily be modified to include other parameters relevant to the two event types. A few of these pairs of plots were found to be similar enough to look further into for future research. This study describes the background information on the subject, the methods for obtaining the results, and a look at some of the more similar pairs of events that were found.

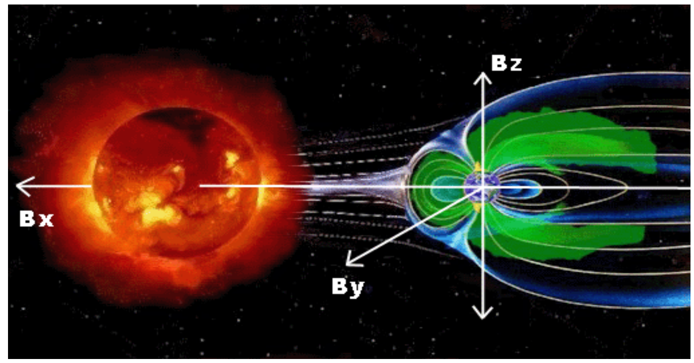
Introduction

Before getting into the details of the two events and what the research entailed, it is necessary to bring to light and describe some of the underlying principles of this study. These include a description of space weather, the solar wind, the interplanetary magnetic field, Earth's magnetosphere, solar flares, coronal mass ejections, and geomagnetic storms.

Space weather is the field of study that this research falls under. It mainly, and for our purposes, refers to the interaction between the Sun and Earth's space environment. However, it can also refer to the Sun's effect on the rest of space, as will be seen in one of the examples of its effects. The consequences of these interactions between the Sun and Earth's space environment can include downed satellites, radiation for astronauts, airline radiation near the poles, blown transformers, corrosion of oil pipes, and the aurorae. All of these effects are from substorms, geomagnetic storms, solar flares, and coronal mass ejections, soon to be described. The electrically charged nature of these interactions can temporarily knock out or permanently damage our satellites, posing risks for global positions systems and military satellites. This electric charge also induces currents in power lines and oil pipes, causing the problems mentioned above. A burst of radiation from the Sun can kill unsuspecting astronauts. This is a major concern if we ever try to send manned missions to Mars. The aurorae are a result of the charged particles moving along Earth's field lines and interaction with particles in the atmosphere. At this time we have poor capabilities in predicting when these events will occur. Most of the time we don't know what has happened until it is nearly upon us. Becoming better at predicting these events is a big concern of this field of study.

The solar wind is an ionized plasma consisting mostly of protons and electrons that is constantly escaping the Sun. Due to the high kinetic energy of these particles and the high temperatures of the corona of the Sun (over one million Kelvin), the solar wind can easily beat out the 618 km/s escape velocity of the Sun. Due to the charge of these particles, the solar wind carries with it the Sun's magnetic field.

The interplanetary magnetic field is the Sun's magnetic field that is moved by the solar wind and is carried out in all directions. It is measured in geocentric coordinates using the Geocentric Magnetospheric System (GSM). As seen in the figure, this system has the x direction pointing toward the Sun, the z direction along Earth's magnetic field, and the y direction perpendicular to Earth's magnetic dipole to complete the right-handed system. As the interplanetary magnetic field moves out it travels in a spiral due to the rotation of the Sun. This effect is similar to water leaving a rotating sprinkler.

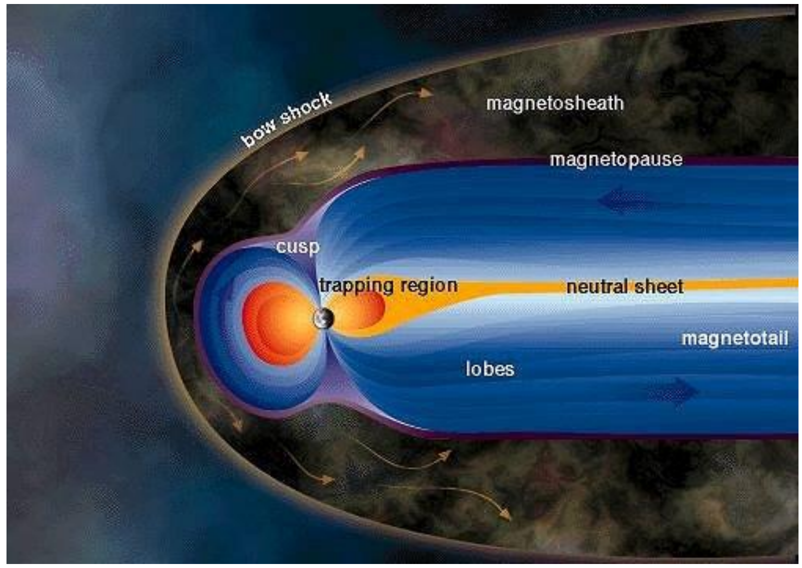


Earth is surrounded by a magnetic field formed from the motion of its molten iron core which makes our planet geologically active. When the solar wind bombards the Earth's magnetic field, it forms a cavity called the magnetosphere. This magnetosphere protects us from most of the solar wind by deflecting it around the Earth.

Solar flares are a quick burst of energy of the Sun that can be up to 6.25 X 10^{25} Joules. This amount of energy is the same as 160,000,000,000 megatons of TNT being set off (Wikipedia: Solar flare). The particles from a solar flare take about one or two days to reach the Earth, moving at a pretty fast pace. During solar maximum there can be several per day, while during solar minimum there can be less than one a week.

Coronal Mass Ejections are much larger than solar flares but shoot off less energy and move considerably slower. They often follow a solar flare. The particles from a coronal mass ejection take about one to five days to reach Earth. During solar maximum there can be about three per day, while during solar minimum there is about one every five days.

Geomagnetic storms are the main concern of this study. When the interplanetary magnetic field is oriented anti-parallel to Earth's magnetic field, that is to say southward driven (-Bz), the south ends of the field touch with the Earth's magnetic field and cause a complex process known as magnetic reconnection in the magnetosphere. The nightside of the magnetosphere is stretched out into a magnetotail as the dayside compresses, as seen in the figure on the right. Eventually the magnetotail can stretch no farther, and like a rubber band it snaps back and releases all of the plasma into the nightside of Earth's space environment. These particles can become trapped in the radiation belts (such as the Van Allen radiation belt) and cause damage to satellites. The particles can also travel along Earth's magnetic field lines and form the aurorae at the poles. Geomagnetic storms, especially the strong ones, are often caused by coronal mass ejections.



The Two Events

The first event is referred to as Global Sawtooth Oscillations. If the interplanetary magnetic field Bz is negative, steady, and *strong*, the magnetosphere will continuously load and unload, meaning the rubber band will stretch and snap back repeatedly. This type of event happens periodically. A common way of looking at it is a bucket filling up, spilling over and releasing all of its contents, and repeating this process over and over.

The other event is called Steady Magnetospheric Convection. If the interplanetary magnetic field Bz is negative, steady, and *moderate*, then the magnetosphere will reach a steady state where there is no large unloading. The dayside reconnection rates eventually equal the nightside reconnection rates, and the plasma and energy instead of unloading is diverted back to Earth in little bursts rather than one big burst like in the case of the sawtooth event. Steady Magnetospheric Convection is analogous to a leaky bucket with holes in the bottom. The bucket fills up and releases its contents, but eventually the water is entering the bucket at the same rate that the water is leaving the bucket.

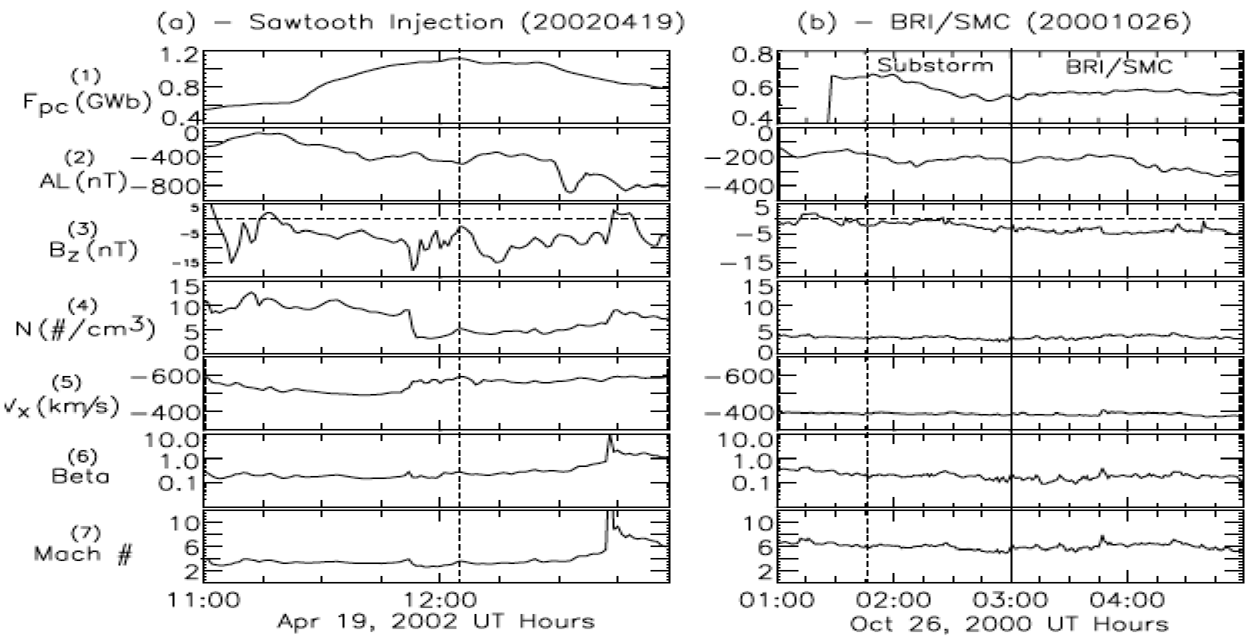


Figure by Dr. Anna DeJong

The above figure shows some parameters of the two events, with global sawtooth oscillations on the left and steady magnetospheric convection on the right. The main concern of this study are the Bz plots on the third row from the top. The periodic nature and higher magnitude of the sawtooth events can be seen, while the steady magnetospheric convection event has a smaller magnitude and even Bz values.

Methods

Two lists were compiled by others from eleven years of storm data. One list contained over two thousand steady magnetospheric convection events and their onset times. The other list contained one hundred thirteen global sawtooth oscillation events and their onset times. I was also given eleven year's worth of one-minute omni data from a collection of satellites around Earth. Each minute of this data contained a year, month, hour, day, minute, and over forty data measurements taken for that minute. Five algorithms were written in the Java programming language to handle this large number of data.

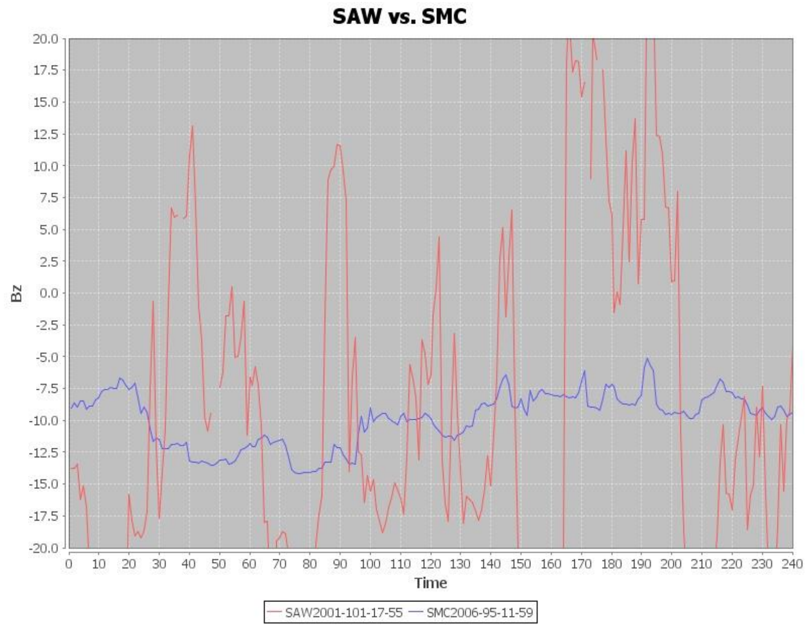
The first two algorithms, SawMeanValues and SMCMeanValues, took two hundred forty minutes worth of data, from two hours before the onset time and two hours after the onset time, and took the average of a list of parameters, including the Bz values used in this study. The mechanics of this program were to read through an ascii file containing the onset time of all the events, find the necessary omni data file/files to read in, store the two hundred forty values for each parameter in arraylists (making sure to skip over NaN values from when the satellites were not collecting data), and taking the average of these parameters over the two hundred forty minutes. Problems ran into with this program were leap years, converting month and day readings into the number of the day out of the total year (ex: February 1st would be Day 32 out of the year), the switching of omni data files from one month to a previous or following month, handling the NaN values correctly so as not to corrupt the averages, and handling huge amounts of data without running into an out of memory error. The leap year and converting month and day readings to just days problems were fixed simply by adding in an if statement to add an extra day to each day value after February. If the two hours before or after an event changed months, reading in just the ascii file for the onset month threw an out of bounds error. In order to fix this problem, the program was altered so that it ran a specific method that opened multiple month data files if the day of the year happened to be the last of first of the month and if the time happened to be less than 2 hours into the day or greater than 22 hours into the day. The NaN values were easily handled by Java. If the data read in as “99” or any number of 9’s in a row, the value was taken to be a NaN value and the total number to divide the average by was reduced by one. Handling the large amount of data was fixed by only having one ascii file of one-minute data open at a time. The original program attempted to add each month’s worth of omni data to an arraylist, but the program quickly threw an out of memory error. Once these averages were all taken they were printed out into an ascii file containing the average values for important parameters, as well as the date and onset time for each event.

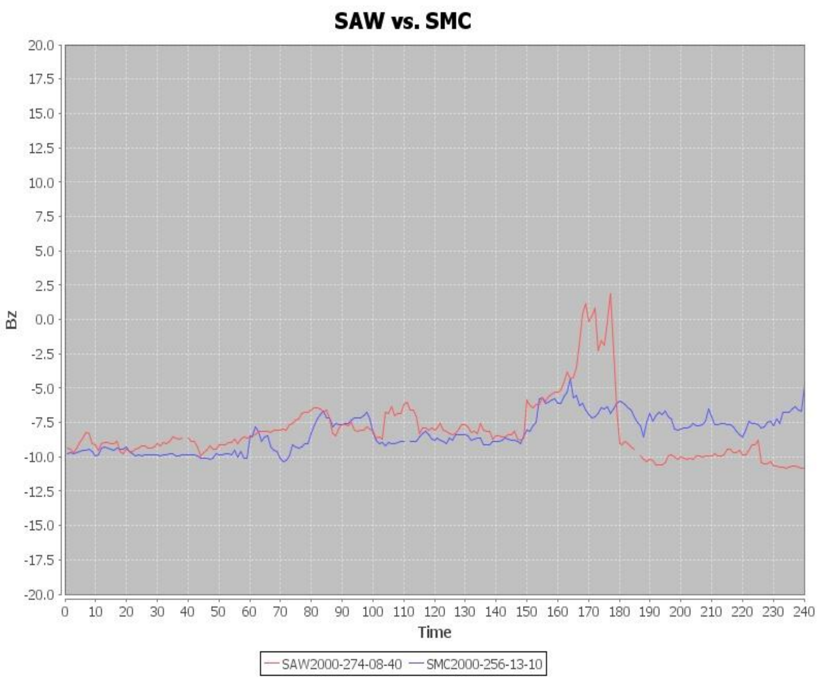
The next two algorithms were written in an effort to save a lot of time and effort in the final comparisons of plots for the project. These two algorithms, SawBins and SMCBins, read through the files containing the average Bz values for both events and binned them in bins of 0.5 nanoTesla. These bins ranged from about -15 nT to 15 nT. The only problem encountered with this program was the bin files overwriting each other each time an event was added. This was fixed after much tinkering by switching around some of the for loops.

The final and most important program was the plotting program. This program used the JFreeChart Java package to print out plots of sawtooth events versus SMC events that were contained in the same bins. With one sawtooth event versus one SMC event on each plot, the program printed out 10038 plots to sift through. The main issue with this code was the length of time it took to finish running, which was sixteen hours.

With the plots printed, the next and final state of the study was carried out. Each of the 10038 plots was scrolled through in an effort to find a pair of a sawtooth and SMC event that had similar Bz values for the two hundred forty minute time frame observed. The plots were split into categories of bad, maybe, and good. Those in the maybe and good categories will be looked into further in future research.

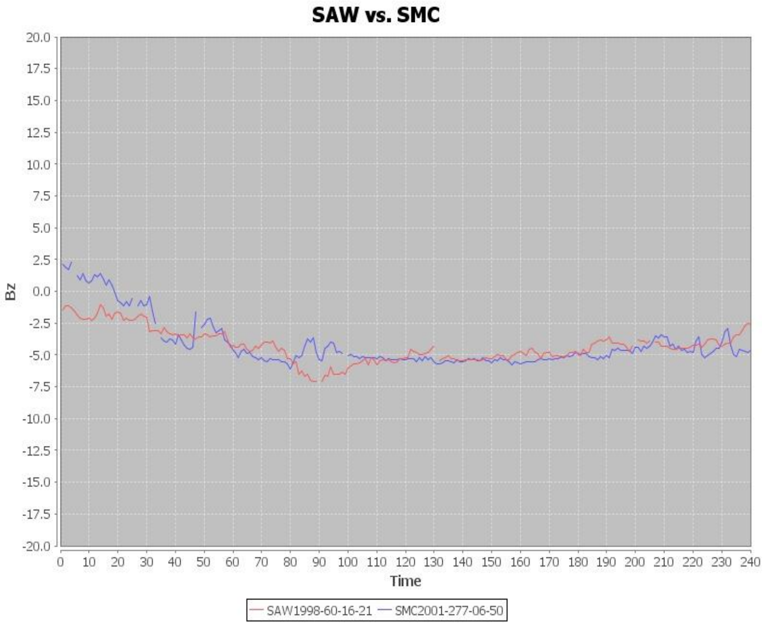
To the right is a plot with a bad similarity in Bz values. The sawtooth event is in red and the SMC event is in blue. The one hundred two minute mark along the x-axis is the onset time. Notice how the two events have barely any overlap.

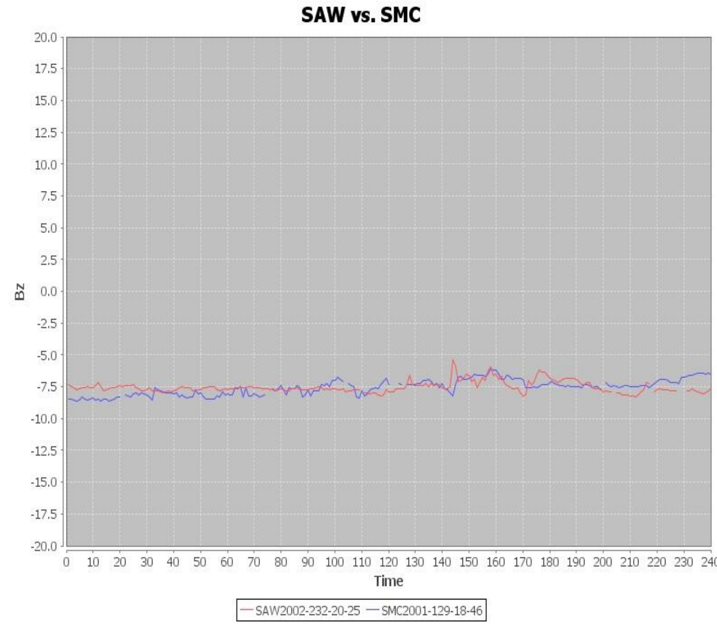




This next figure shows two events much closer in Bz values over the two hundred forty minute time frame. This event was sorted into the maybe category due to it being relatively close but trailing apart after about the one hundred eighty minute mark.

The next two plots below show two of the closest pairs of events found. Notice how over the whole time frame their barely differ in Bz values and overlap often. These two events were sorted into the good category.





Overall, fifty-five pairs of events made it into the maybe category and three pairs of events made it into the good category.

Improvements/Given More Time

Any improvements made to the project would focus on making the code run faster and making it more time efficient to sort through the results. The plotting program took sixteen hours to run and the SMCMeans program took three hours to run, proving to be quite troublesome if an error occurred halfway through running. One method suggested was to find a way to not open up the ascii file each time in the for loop, as this took up to ten seconds for each event.

Another useful improvement would be to write a correlation coefficient program. This program would compare the two events plotted and throw away any events below a certain acceptable threshold. This would save many hours of sorting through the plots and categorizing them, knocking the number to look through down by thousands.

Given more time more parameters would be compared, including plasma beta, proton density, electric field, Alfven mach number, and the x velocity of the solar wind. The averages for these values were already printed out in the mean-value algorithms; it would just be a simple matter of binning and plotting them in the same manner as the Bz values.

Bibliography

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