A Correlation Study of Steady Magnetospheric Convection in the Northern and Southern Hemispheres

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Abstract:

The purpose of this study is to compare magnetometer data from the northern and southern hemispheres to find if there is a correlation in the specific space weather event steady magnetospheric convection. Using data from OMNIWeb by NASA as well as data taken recently in the southern hemisphere, a comparative algorithm will be used to find overlap in specific SMC events, as well as plot the onset and duration of each event. Statistics will then be done to see if this correlation is significant and if the theory of SMC correlation and magnetospheric interaction has to be updated to fit our findings.

Introduction:

Recently, space weather research has become an important asset to protecting technology, including satellites and GPS communication. Space weather is the study of dynamic events caused by the sun that effect the Earth's upper atmosphere and magnetosphere. Events include substorms, geomagnetic storms, coronal mass ejections, and many more. This study will be concerned with the definition of steady magnetospheric convection (SMC), a magnetospheric event. SMCs are defined as the steady state of magnetospheric and ionospheric currents connected to the Earth's magnetic poles. This type of phenomenon can cause geomagnetic activity without the typical substorm signature of a sudden burst of current, or charged particle flux, to the Earth. [*DeJong at el*., 2008]. Instead, SMCs can be described as a "leaky bucket effect" in which the current going from the magnetosphere to the Earth is constant, bringing with it a constant flow of charged particles. SMC events are found by calculating indices relating to the currents passing through the magnetic north pole of the Earth. These indices, AL, AU, and AE, are obtained from ground magnetometers near the magnetic poles of the Earth. From the magnetic north pole magnetometers, the overall status of the magnetosphere was inferred through these indices. Little information was known about the magnetic south pole until recently in a study by Weygand, J. M., E. Zesta, and O. Troshichev [*Weygand at el.,* 2014]. Previously the state of the magnetosphere and SMCs were only indicated by the northern hemisphere, but with the addition of new southern magnetometer data, we can study whether those two currents systems are the same.

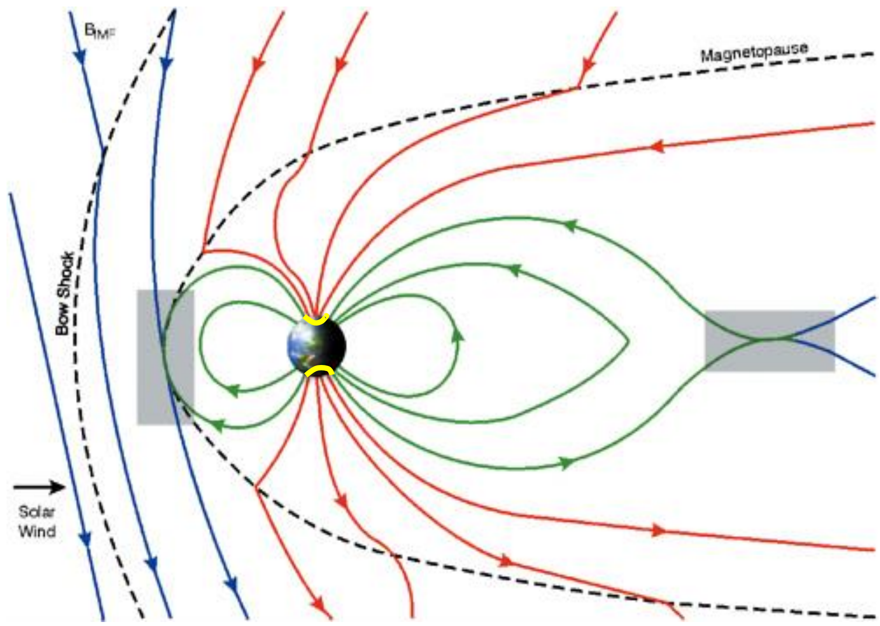


Figure 1: The Earth's magnetosphere and the interactions with the interplanetary magnetic field coming from the plasma expelled by the Sun. The blue lines represent the IMF, while the green and red lines represent currents, closed and open field aligned currents respectively. The dark boxes indicate where magnetic reconnection occurs.

In this study, we will aim to show whether the currents connecting the northern and southern hemisphere during an SMC event are equal. We will use an algorithm to find SMC events from years 2005 to 2011 in two separate data sets corresponding to the northern and southern hemispheres. From there, we will construct a list of correlating events in each hemisphere, as well as document the dates of all SMCs for statistical analysis. In the end, we hope to find distinct differences between the data sets, showing that the currents are unequal and thus changing the way we view north/south pole interactions with the magnetosphere.

Theory:

Steady magnetospheric convection is defined as a steady current stream going from the Earth's magnetosphere to the ionosphere through multiple current systems. This current is made up of energized protons and electrons that act both as individual particles and as a fluid, a plasma. Plasma motion can be described by the set of equations called magnetohydrodynamics or MHD. MHD is the current model we use to describe the Earth's magnetosphere and space weather events. It blends electromagnetic theory with fluid mechanics to describe the motion and interactions between the electric and magnetic fields that the plasma of the magnetosphere is housed in. The list of single fluid MHD equations is as follows:

$$\rho \, \partial v/\partial t = j \times B - \nabla p + \rho g$$

$$E + v \times B = n\, j$$

$$\partial \rho/\partial t + \nabla \cdot (\rho v) = 0$$

$$\partial \sigma/\partial t + \nabla \cdot j = 0$$

Although the plasma of the Earth's magnetosphere is not a single fluid, it is made up from electron, proton, and neutral fluids, we can use approximations to get an idea of how the plasma will react to electric and magnetic fields.

Along with the MHD equations, plasma is much like a current. As plasma moves around the magnetosphere, it causes a net flow of charged particles, or the definition of current. The current is designated as the direction of flow of the protons in the plasma. The electron flow, due to the properties of electromagnetism, will move in the opposite direction. **Figure 2** shows how the magnetosphere looks in two dimensions (it is actually more complicated and in three dimensions in reality) when there is a steady current, or there is steady magnetospheric convection.

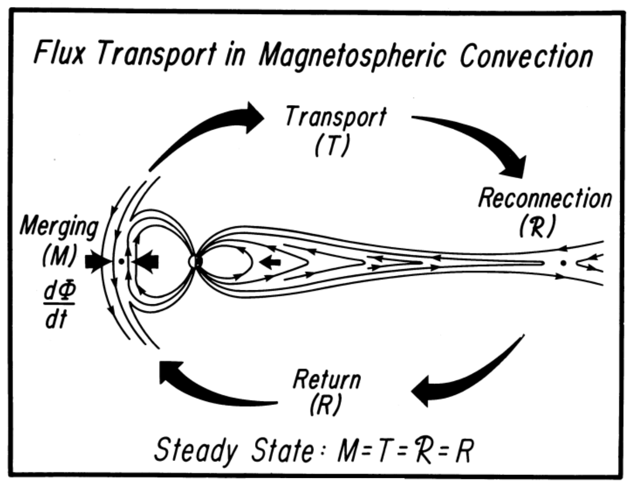


Figure 2

When the current systems of each section are equal, we designate this as an SMC event. This figure can also be examined as a circuit with a load and split currents. If the resistance, or conductance, is equal in both the northern and southern hemisphere, then equal amounts of current will flow through each. If they are not equal, then more current will flow through one than the other, depending on which has a higher resistance. In the past, space scientists have assumed that during a steady state current cycle in the magnetosphere, the currents going to the north and south are equal due to equal conductance. In this study however, we hypothesize that the current system going from region R to the Earth's magnetic north pole is not the same as the one going to the south pole.

Methods:

Historically our understanding of SMCs has been limited to data from the northern hemisphere, which we then used to describe phenomena in the southern hemisphere. Recently, southern magnetometer data has been taken, thus enabling the ability to cross reference the northern data to find whether it is an accurate way to describe southern events.

Using the programming language IDL, we will construct an algorithm which scans over a year's worth of auroral electrojet low (AL) data to find indicators of SMCs. This code will be run at separate times for both the northern and southern AL data sets. Events will be gathered from both sets of data and will be examined to find any overlap in events. The events must overlap by 15 minutes ideally, but the time-gap may change due to other possible problems with finding correlation. If the events overlap by 15 minutes or less, they will be considered the same event, and therefore the currents in both hemispheres will be considered the same.

Three different codes were used to cipher through the data. The first code found the SMC events by looking for times in the magnetometer data where the AL value was below -75 for at least three hours. These events were found for both the north and the south sets of data. Because the southern set of data had less events found for the -75 cut off, lower cut offs (-65, -55, -45) were used to see if it made a difference in the number and duration of events. It also found areas of the data where no data was present and set those areas as NAN's to only look at the times where both sets of data were present.

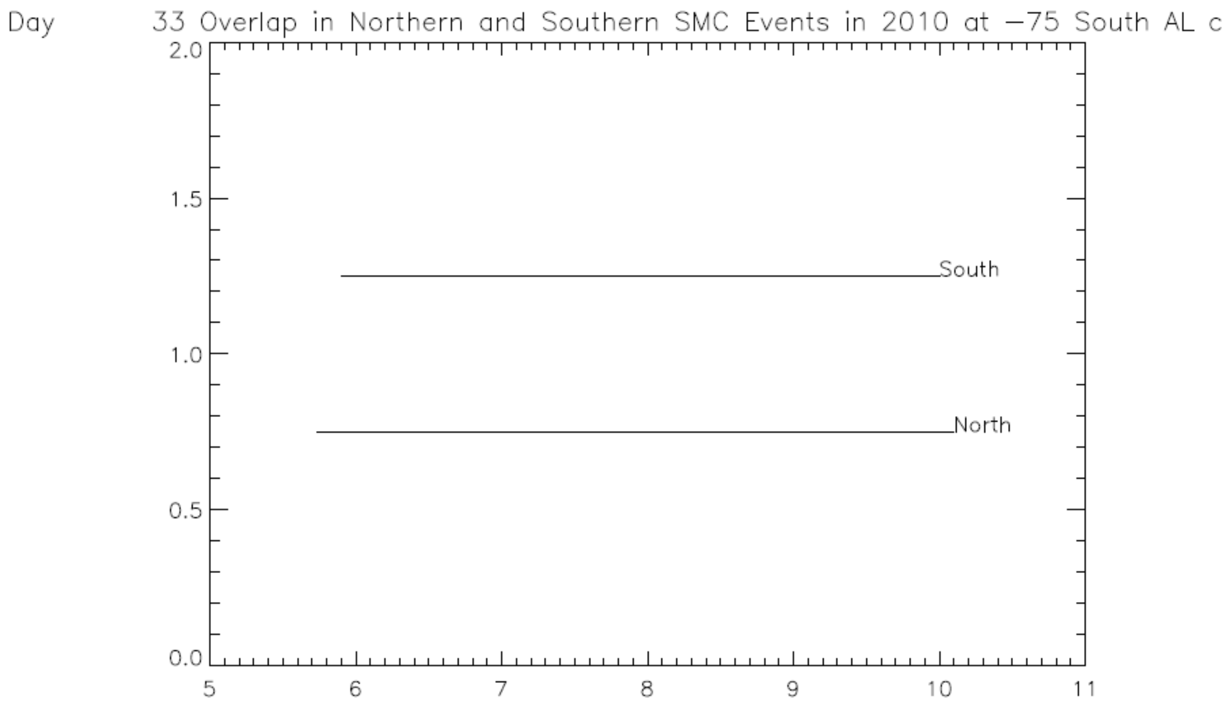
After these events were tabulated in an IDL save file, the second code was used to find the overlap between the northern and southern events. This was done by finding where the two event arrays had events that were between 15 minutes of each other's beginning times. If this was true then the onset, duration, and overlap of time between the events was saved into another array.

The third code was used to plot the overlap data in graphs to show exactly how the events overlapped. These graphs were made for each event specifically and were saved for reference. The minute of year time stamp was changed into day of year and time in UT to make the graphs easier to read and refer to.

In addition to the graphs made for each event, statistics were also produced to show the percentages of the events in both hemispheres and how they related to the different AL cut offs. The data is tabulated in the next section.

Data:

Due to problems gathering data in the southern hemisphere, during 2007 there was no data taken. Also, during the hours of around 15 – 19 UT the southern data was not reliable because of a continual misreading of the southern magnetometers. A sample graph of an event is shown below.



The outlined statistics are tabulated below.

NORTH	Year				
AL	2005	2006	2008	2009	2010
-75	17	39	78	^	111

SOUTH	Year				
AL	2005	2006	2008	2009	2010
-45	24	48	84	2	94
*-55	16	33	70	2	82
-65	12	26	58	2	71
-75	9	21	50	1	63

Total SMC	Year				
AL	2005	2006	2008	2009	2010
-45	41	87	162	2	205
-55	33	72	148	2	193
-65	29	65	136	2	182
-75	26	60	128	1	174

# of	Correlated	Events		
AL	2005	2006	2008	2010
-45	1	7	16	17
-55	1	5	14	14
-65	1	5	10	12
-75	0	3	7	11

2005	South	North
-45	0.585366	0.414634
-55	0.484848	0.515152
-65	0.413793	0.586207
-75	0.346154	0.653846

2006	South	North
-45	0.551724	0.448276
-55	0.458333	0.541667
-65	0.4	0.6
-75	0.35	0.65

2008	South	North
-45	0.518519	0.481481
-55	0.472973	0.527027
-65	0.426471	0.573529
-75	0.390625	0.609375

2010	South	North
-45	0.458537	0.541463
-55	0.42487	0.57513
-65	0.39011	0.60989
-75	0.362069	0.637931

^ There were no data points for 2009 in the North. This was either due to an error in the code or an error in the data acquisition.
*55 seems to be an optimal AL cut off for the south since the number of events seem to line up the strongest with the north

Results and Discussion:

From the statistics gathered, we can see that the correlation of the events in both hemispheres is relatively low compared to the number of events overall. This can either mean that the code is in error, or that the theory of SMCs is possibly not sufficient to describe the overall picture. It is also possible that the magnetosphere does not work how we previous think it did, and therefore a revised theory of the magnetosphere might be needed. The currents in the north and south pole seem to, from this study, be very different. Since the overall number of events is relatively close, it may be possible that a SMC event in the northern hemisphere takes a long enough time to for our code not to see them as correlated. Although, this would be an interesting find since part of the time the southern event started first and part of the time the northern event started first. In any case, the data seems to mean that there is an issue in our understanding of SMC events and the magnetosphere as a whole.

The data also shows that if the AL cut off in the southern hemisphere is at -55, there is greater constancy in the number of events in both hemispheres. This could be due to many things, such as the magnetic field being lower in the southern hemisphere or possibly just pure coincidence. A way to find this out would be to investigate the southern magnetometer data more closely to find possible inaccuracies or inconsistencies based on well-known sets of similar data. Also, a code written to optimize the AL cut off would be useful to see what cut off would be useful, instead of the arbitrary factors of ten used in this study.

Besides clarifying the data and analysis used in this study, it would also be interesting to find out how these sets of data correspond with other sets of data taken from different locations around the world and from satellites. The more sets of data used to describe the magnetosphere we use, the easier it will be to come to a more educated guess on how it works. Further analysis of this study and previous studies on SMCs would prove useful to understand the complex system of currents in the magnetosphere.

Works Cited

DeJong, A., Studies of Magnetospheric Convection: Balanced and Unbalanced, University of Michigan Dissertations and Theses

Weygand, J. M., E. Zesta, and O. Troshichev (2014), Auroral electrojet indices in the Northern and Southern Hemispheres: A statistical comparison, J. Geophys. Res. Space Physics, 119, doi:10.1002/2013JA019377.