Solar Wind Driving of Magnetospheric Substorms

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Abstract

Solar Wind Driving of Magnetospheric Substorms is a data analysis project using Interactive Data Language to examine the triggers of magnetospheric substorms ending Steady Magnetic Convection (SMC) to gather data about the By and Bz components of the Interplanetary Magnetic Field (IMF). The project was designed to sort triggered and untriggered substorms for further research and further our knowledge of processes in the magnetotail of the Earth. The resulting percentage break down of triggered and untriggered substorms was similar to previous research in the field.

Introduction

A substorm is a brief disturbance in the Earth's magnetosphere that releases energy stored in the tail of the magnetosphere (called the magnetotail) and accelerates charged particles along the Earth's magnetic field lines to the poles of the planet. The substorms examined will occur after Steady Magnetospheric Convection where the magnetosphere was in an active steady state. These periods can end by an induced substorm (also called a triggered substorm) or by internal magnetospheric processes. When an abrupt change in the driving of the solar wind is identified near the onset (plus or minus 20 minutes) of the substorm, it is considered the trigger. Triggers are often found in the Bz component of the IMF because it has greater influence on the state of the magnetosphere system, and fewer triggers the By component since it has less effect on the system. This project will be mostly concerned with substorms with no trigger indicated in the data.

Once a substorm was identified in the Auroral Lower index (AL) it was sorted by trigger. Into either a Bz, By, or no apparent trigger, including possible slope caused triggers. After being sorted, the 30 minute slope, 5 minute slope, and average By and Bz field strengths were calculated for each of the substorms. Then the percentage of SMCs ended by each type of substorm was compared to previous findings. The expected result of the project was to have an IDL program to identify a substorm, find its trigger, then set aside untriggered substorms for further study, and then calculate pertinent data. However, this technique was revised and visual inspection became the preferred method of inspection.

Theory

When the Interplanetary Magnetic Field is oriented such that it is anti-parallel to Earth's magnetic field (Bz negative), plasma and energy from the solar wind can enter the magnetosphere. The magnetosphere can then transfer this energy to the inner magnetosphere and ionosphere via different modes of energy transport. It can store (load) energy in the magnetotail and then release the energy (unload) into the inner magnetosphere and ionosphere. If this process is an isolated event and localized near midnight in magnetic local time (MLT), then it is considered an isolated substorm. If the energy is not stored and released, but rather continuously diverted, then convection is enhanced and quasi-steady, the dayside and nightside reconnection rates are balanced, and the magnetosphere enters a steady magnetospheric convection (SMC) mode. DeJong 2014

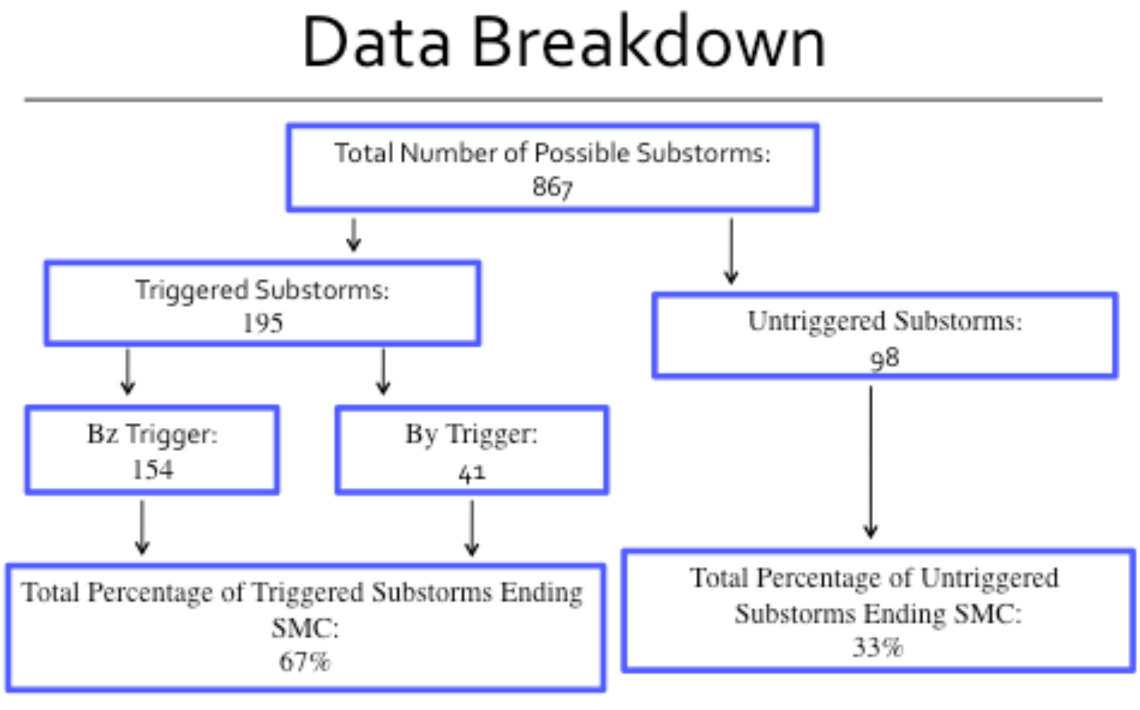
There are triggered and untriggered substorms that can end steady magnetic connection. Triggered substorms are straightforward because the reason for the releasing of the energy from the magnetotail can be easily seen in the data. However, this project was concerned more with untriggered substorms. An untriggered substorm is when steady magnetic reconnection is ended with a substorm without a trigger. Untriggered substorms are more interesting because they could have many causes, yet none of them are seen in the data, nor are they understood. This project was designed to find untriggered storms by finding the triggered storms and separating the two types to examine the untriggered substorms and compare trends in each type's data.

Methods

The data received from Dr. DeJong was a list of possible substorms ending SMC. Each file included By, Bz, and AL data readings formatted for IDL (.EPS files). Every substorm was graphed and saved as its own pdf file (Figure 1, Appendix 1). Then the AL index of each file was visually inspected to see if the event met the criteria to be considered a good substorm. The definition used to pick useful events was an obvious substorm occurring in the AL index that ends SMC. When a substorm met this criteria it was sorted into a Bz, By, or no apparent cause folder. Next, the pdf files in the good folder were converted back to IDL files to use IDL to investigate the data (Figure 2). An IDL program was then written to examine the total slope, five minute slope average, thirty minute slope average, and the average field strength of the Bz and By during the event (also Figure 2). This program also tallied the substorms based on trigger to find the percentages of SMCs ended by each type of trigger or nontriggered substorms.

Data

Below is the final break down of substorm triggers:



On Appendix 2, in the Figure labeled Bz Trigger, the onset of the substrom can be seen in the AL right at the dark line that crosses all three graphs with the trigger occuring around the arrow in the Bz. In the Figure labeled By Trigger (Appendix 2), the onset occurs at the dark line again with the trigger occuring somewhere between the arrow and the onset of the storm. Lastly, in the Figure labeled No Trigger (Appendix 2), around the onset of the substorm there are no trigger signitures in the Bz or the By so this is an untriggered substorm. These are the type of substorms that motivated this project. Examples of some slope calculations can be seen on Appendix 3.

Discussion

The original aim of this capstone was to develop and code a program in IDL that would find a substorm trigger in the By or Bz component of the IMF, and set aside substorms that are untriggered. It is important to note that there are currently no programs that do this. IDL was chosen because it was developed for graphing and it deals with NANs (empty data points) in the data easily. This project was much more ambitious and complicated than we realized. The program would need to essentially mimic the steps a persons brain would go through to sort the data.

In essence, the program would need to evaluate the data by first delineating SMC and checking to be sure the magnetosphere is not too active (both can seen by looking at the graph of the AL index readings). Once the first criteria are met, the program would need to determine if a substorm ends the SMC (this can also be seen in the AL index). Next, the Bz and By index need to be examined (triggers are seen in their respective indices) to verify that this data is also not too active, if it is not too active then the data can be useful. Next, the trigger (if there is one) must be picked out. This is also difficult because there often are signatures of a trigger in the Bz and By around the onset of the substorm, so the program must decide where the trigger actually is. Last of all the program would sort the events into Bz, By, and untriggered events, this would be the easy part. The complexity of the program comes from the fact that each step must include the ability for the program to make a judgment call and each substorm is different from the rest.

Conclusion

This project entailed more programming skills and knowledge than I had to meet the requirements of such a program. After analyzing all of the data, the percentage of triggered and untriggered substorms was obtained. Hsu and McPherron's data and claims 60% of substorms are triggered, while my data came to 66%, and they claim 40% of substorms were untriggered, while my findings say 34%. Hsu 2003. This difference in percentage is most likely due to errors while sorting through the data visually since I was not as familiar with the data. Secondly, the data I kept was strictly limited to obvious substorms that end SMC, if the event did not match my criteria it was removed and not examined. Despite these differences of how the data was examined and sorted, this data tends towards and supports Hsu and McPherron's conclusions.

Time permitting, the next logical steps for this project would be to examine the Bz and By index using a best fit line obtained using a Least-Squares Regression Line or a Fourier Transform to minimize noise in the data. Reducing this noise in the would be a first step towards writing the program to pick out substorms from data and the trigger without needing to visually inspect each data set. The ultimate goal would be to use this program and the data to understand the physics and processes in the magnetosphere.

Appendix 1

Figure 1- Graphing files

```
files=file_search(dir+'*.sav',count=nfiles)
;setting up the postscript file
set_plot,'ps'
;set up 4 plots per page
!p.multi=[0,1,3]
;set up a time array that starts at -120 minutes and 0 is the end of the SMC
times=findgen(181)-120.
!x.style=1
;save one graph/page
;plot,times,al_end,ytitle='AL (nT)',yrange=[-1000,0],xrange=[-120,60],title=files(0)+".ps",xcharsize=0.001
;".pdf"
dates=strmid(files,59,11)
;access all files one at a time
for i=0,nfiles-1 do begin
  device,filename=dates(i)+'.eps',/portrait
  restore,files(i)
  ;look at the file string and cut out the 11 that are the date
  ;date=strmid(files(i),53,11)
;setting up graphs
  plot,times,al_end,ytitle='AL (nT)',yrange=[-1000,0],xrange=[-120,60],title=files(i)+".ps",xcharsize=0.001
  plot,times,bz_end,ytitle='Bz (nT)',yrange=[-15,10],xrange=[-120,60],xcharsize=0.001
  plot,times,by_end,ytitle='By (nT)',yrange=[-15,10],xrange=[-120,60],xcharsize=1.2
 oplot,[0,0],[0,1000],linestyle=2
 ; plot,times,press_end,ytitle='Pressure ',xrange=[-120,60],xtitle='Time from End',charsize=1.2
;close the ps file
device,/close
endfor
end
```

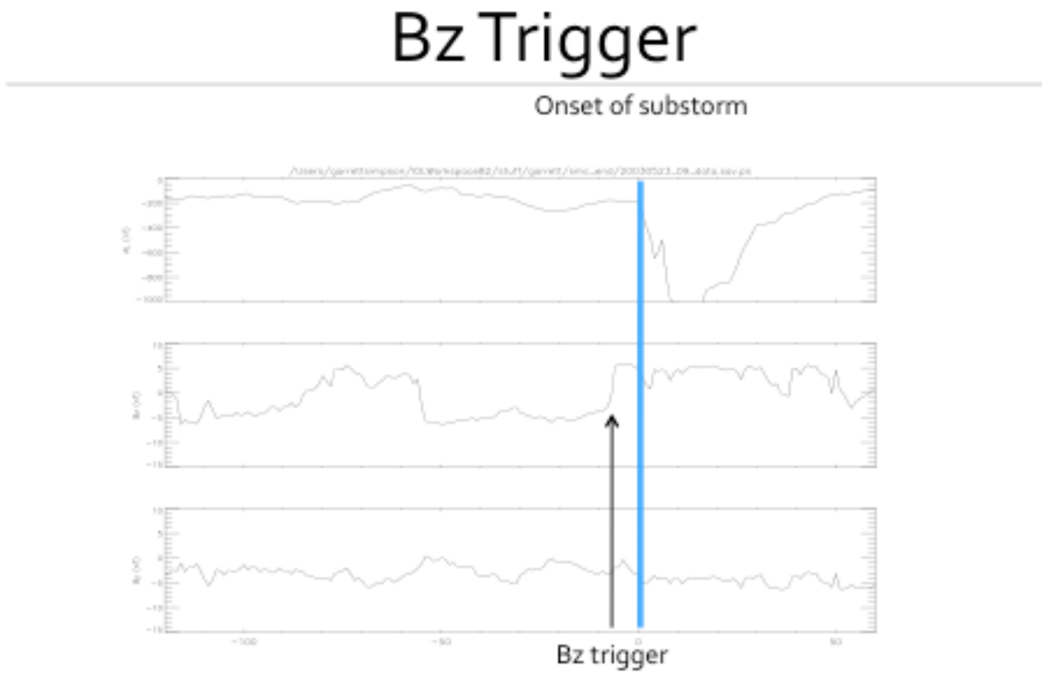
Figure 2- Code to convert files back to IDl, calculate slopes and averages (.eps file)

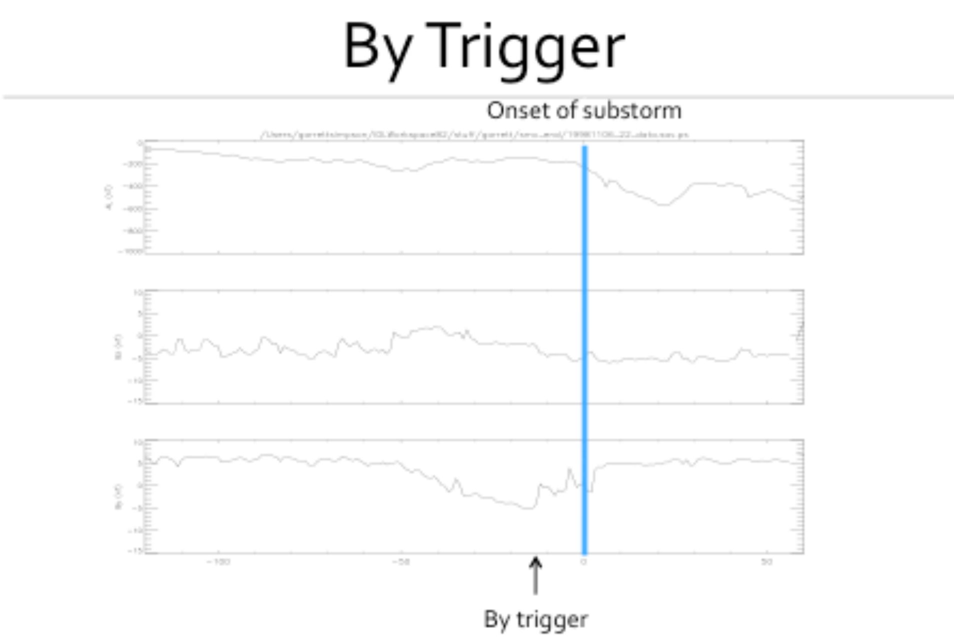
```
;file locations
dir_by='/Users/garrettsimpson/Desktop/Capstone/Sorted_Data/Whoa_wee_wa/By_trigger/'
dir_bz= '/Users/garrettsimpson/Desktop/Capstone/Sorted_Data/Whoa_wee_wa/Bz_trigger/'
dir_slope='/Users/garrettsimpson/Desktop/Capstone/Sorted_Data/Whoa_wee_wa/Slope_trigger/'
;very large substorms
files_whoawaweeway =file_search(dir_by+'*',count=nfilesy)
files_whoawaweewaz =file_search(dir_bz+'*',count=nfilesz)
files_whoawaweewas =file_search(dir_slope+'*',count=nfiless)
;bz,by
file_namey=strmid(files_whoawaweeway,74,11)
file_namez=strmid(files_whoawaweewaz,74,11)
file_names=strmid(files_whoawaweewas,77,11)
;master directory
master_dir='~/IDLWorkspace82/stuff/garrett/smc_end/'
;*****ALL THE IMPORTANT INFORMATION
ave_by=list()
bytotslope=list()
ave_bz=list()
bztotslope=list()
ave_al=list()
altotslope=list()
thirtslopy=list()
thirtslopz=list()
thirtslopa=list()
fiveslopy=list()
```

```
fiveslopz=list()
fiveslopa=list()
;unused al_ls_slope=list()
;unused by_ls_slope=list()
;unused bz_ls_slope=list()
;***EVERYTHING THAT IS ANYTHING
for y=0,nfilesy-1 do begin
;restore files for BY
 valy = file_namey[y]
 valy = valy + '_data.sav'
 restore, (master_dir + valy)
 ave_by_total=0
 ;to calculate the average
 for i=0,n_elements(by_end)-1 do begin
  ave_by_total = ave_by_total + by_end(i)
  endfor
 ave_by.add,(ave_by_total/180.)
 ;calc 30 min slope up to about begin of sub
 avesl=0
 for i=0,5 do begin
  x=i+1
  avesl = (by_end(30*x) - by_end((30*i)))/30.
 endfor
 thirtslopy.add, avesl
 ;calc total slope
 slopebytot = (((by_end(180))-(by_end(0))))/180.)
 bytotslope.add,(slopebytot)
 ;calc 5 min slop ave
 avefive=0
 for i=0,24 do begin
  x=(5*i)+5
  avefive = (by_end(x) - by_end((i)))/5.
 endfor
 fiveslopy.add, avefive
endfor
;restore files for Bz
for z=0,nfilesz-1 do begin
 valz = file_namez[z]
 valz = valz + '_data.sav'
 restore, (master_dir + valz)
 ave_bz_total = 0
 ;to calculate the average
 for i=0,n_elements(bz_end)-1 do begin
  ave_bz_total = ave_bz_total + bz_end(i)
 endfor
 ave_bz.add,(ave_bz_total/180.)
 slopebztot = (((bz_end(180))-(bz_end(0))))/180.)
 bztotslope.add,(slopebztot)
 ;calc 30 min slope up to about begin of sub
 avesl=0
 for i=0,5 do begin
  x=i+1
  avesl = (bz_end(30*x) - bz_end((30*i)))/30.
 endfor
 thirtslopz.add, avesl
 ;calc 5 min slop ave
 avefive=0
 for i=0,24 do begin
  x=(5*i)+5
  avefive = (bz_end(x) - bz_end((i)))/5.
 endfor
 fiveslopz.add, avefive
endfor
;restore files for AL
for s=0,nfiless-1 do begin
 vals = file_names[s]
```

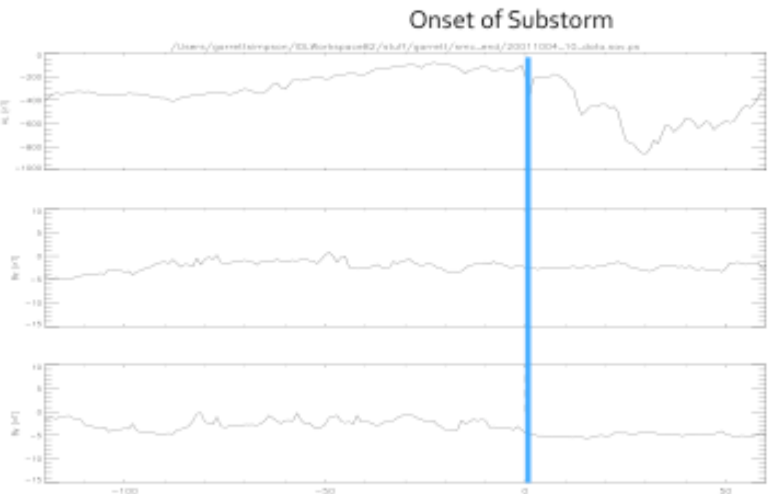
```
  vals = vals + '_data.sav'
  ave_al_total =0
  restore, (master_dir + vals)
  for i=0,n_elements(al_end)-1 do begin
    ave_al_total = ave_al_total + al_end(i)
  endfor
  ave_al.add,(ave_al_total/180.)
  slopealtot = (((al_end(180))-(al_end(0))))/180.)
  altotslope.add,(slopealtot)
  ;calc 30 min slope up to about begin of sub
  avesl=0
  for i=0,5 do begin
    x=i+1
    avesl = (al_end(30*x) - al_end((30*i)))/30.
  endfor
  thirtslopa.add, avesl
  ;calc 5 min slop ave
  avefive=0
  for i=0,24 do begin
    x=(5*i)+5
    avefive = (al_end(x) - al_end((i)))/5.
  endfor
  fiveslopa.add, avefive
endfor
;print out final counts
print,'by caused: ',nfilesy
print,'bz caused: ', nfilesz
;slope caused = untriggered storm
print,'slope caused: ', nfiless
end
```

Appendix 2


Bz Trigger
Onset of substorm
Bz trigger


By Trigger
Onset of substorm
By trigger

No Trigger



No apparent trigger in Bz or By

Appendix 3

Below are some values for the average Bz in Bz triggered substorms (nT):

-0.0341667
0.0315000
-0.0293889
0.0280556
-0.0295000
0.00783333
0.00922222
0.0227778
0.00338889
-0.00255556

Below are some values for the average By in By triggered substorms (nT):

-1.52361
-3.12589
-3.45417
-0.397333
-0.846722
-0.0807775
-6.36011
3.10811
-2.73117

Below are some values for the average 5 minute slope of Bz in Bz triggered substorms (nT/min):

-0.0780000
0.802000
0.0300000
-0.116000
0.576000
1.12000
0.780000
-1.28400
-1.1580

Below are some values for the average 5 minute slope of Bz in Bz triggered substorms (nT/min):

-0.584000
0.368000
0.202000
0.722000
-0.306000
-0.276000
0.572000
0.332000
0.164000

Bibliography

- DeJong, A. D. Steady magnetopsheric convection events: How much does steadiness matter? J. Geophys. Res. doi:10.1029/2013JA019220R, 2014 (In revision)
- Hsu, T., and R. L. McPherron, Occurrence frequencies of IMF triggered and nontriggered substorms, J. Geophys. Res., 108(A7), 1307, doi:10.1029/2002JA009442, 2003