INTRODUCTION

MAGNETOSPHERE:

The region which surrounds the earth and earth magnetic field is dominant is known as Magnetosphere. The solar wind pressure compresses the Earth's magnetic field on the dayside and extends it into a long tail on the night side. On the day side, the magnetic field is confined within 10RE and on the night side, it extends to the hundreds of Earth's radii.

MAGNETOPAUSE:

The boundary of Earth magnetic field and the magnetosphere is known as Magnetopause which constantly changes with a change in the Solar wind. The Position of magnetopause can be determined by the dynamic pressure of solar wind and magnetic field pressure of earth. As the dynamic pressure changes, the magnetopause moves inward and outward accordingly.

CLUSTER SATELLITE:

The cluster consists of four identical satellites in a tetrahedral formation and studies the sun activity in Earth's environment. The spinning rate of the satellite is 15 rotations per minute. Each satellite has 11 instruments to study solar wind, bow shock, magnetopause, polar cusps, magneto tail, plasma pause boundary layer and over the polar caps and the auroral zones of small-scale plasma scale.

EXERCISE – 1 PERFORM THE EXAMPLE FOR GIVEN VALUES, THAT IS FIND THE MAGNETOPAUSE NORMAL FOR THE MAGNETOPAUSE DATA.

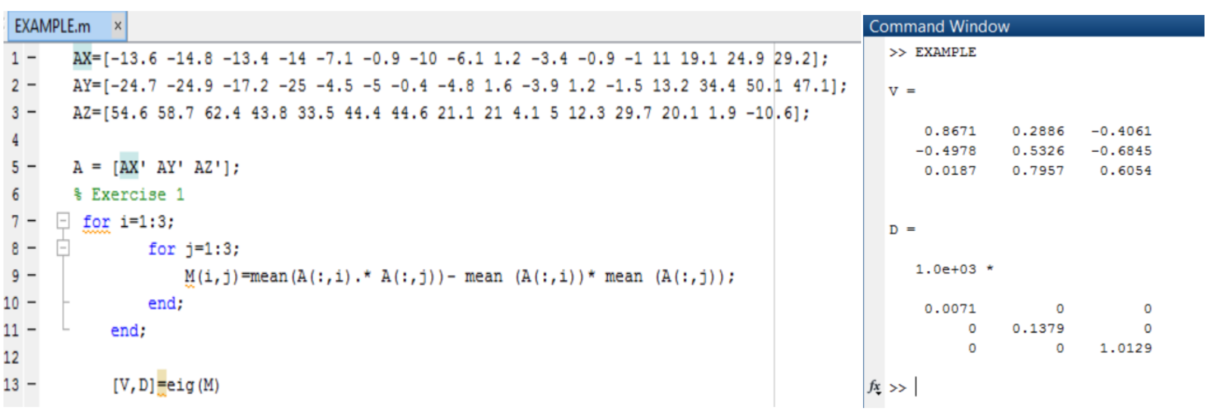
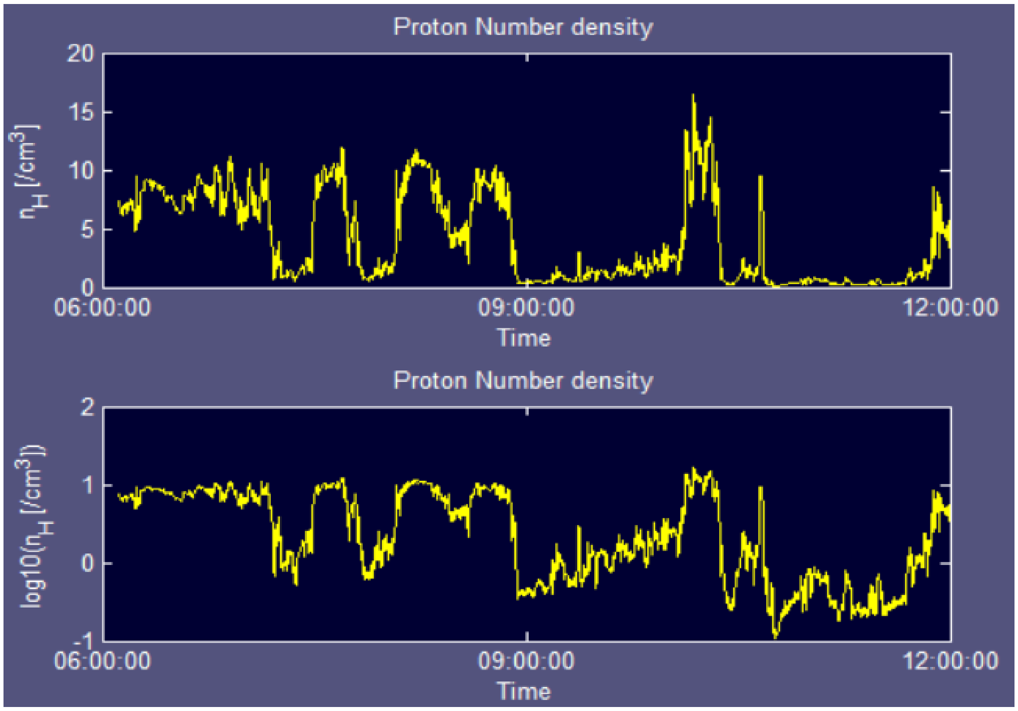


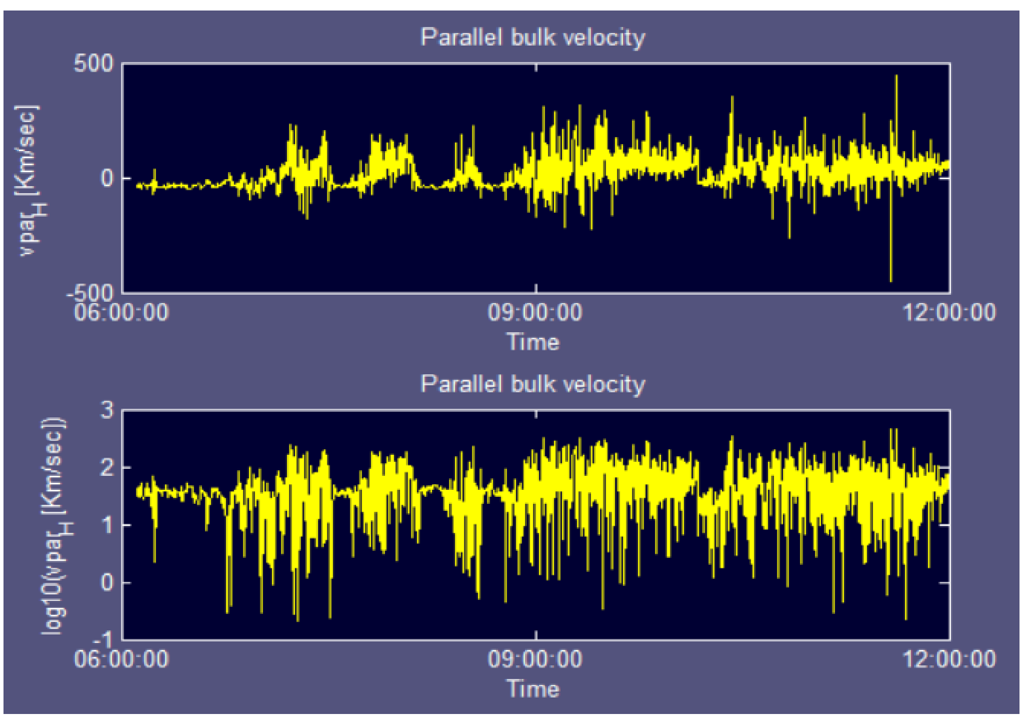
Figure 1: Example of Lars---Göran Westerberg (LGW)

For the given values, we are getting n= [0.8671 -0.4978 0.0187] with respect to the minimum Eigen value e = 7.1 which is correct according to the given solution in exercise.

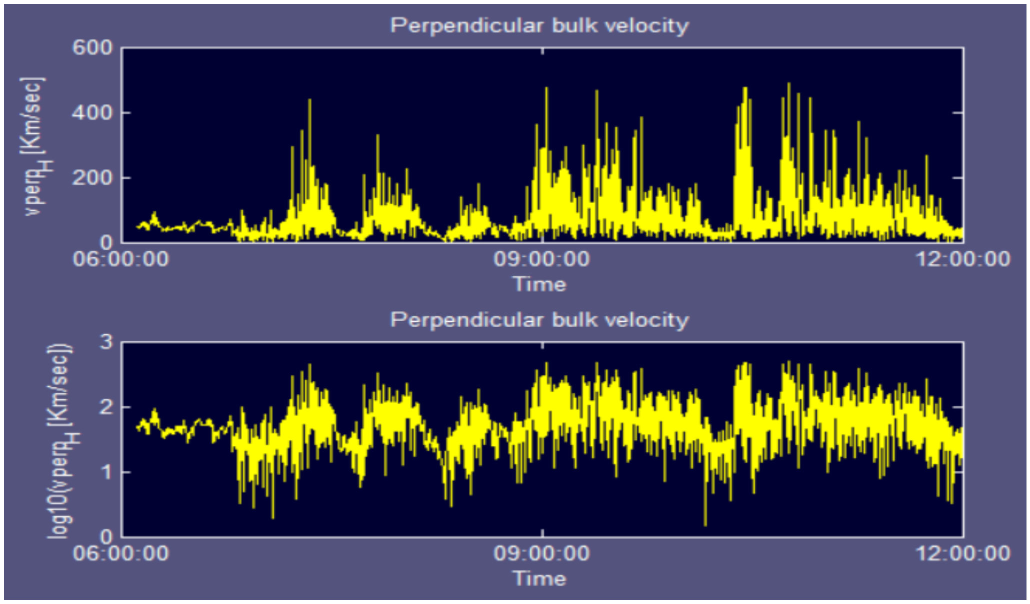
EXERCISE – 2 PLOT TIMES SERIES OF PROTON DATA (NUMBER DENSITY, VELOCITY, TEMPERATURE, PLASMA BETA) AND MAGNETIC FIELD DATA.



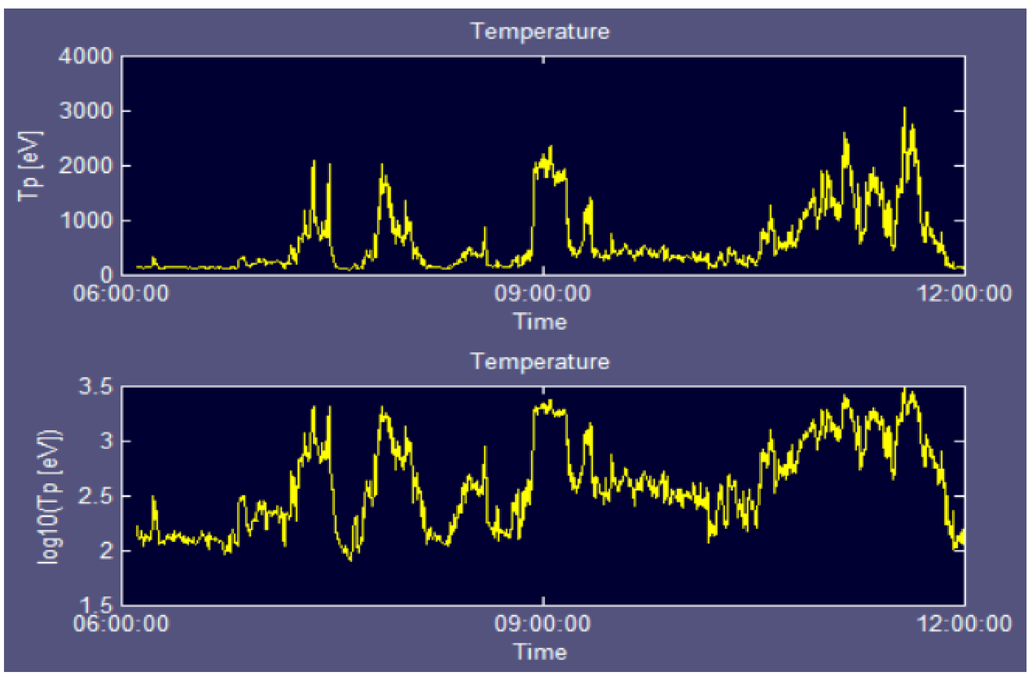
(a)



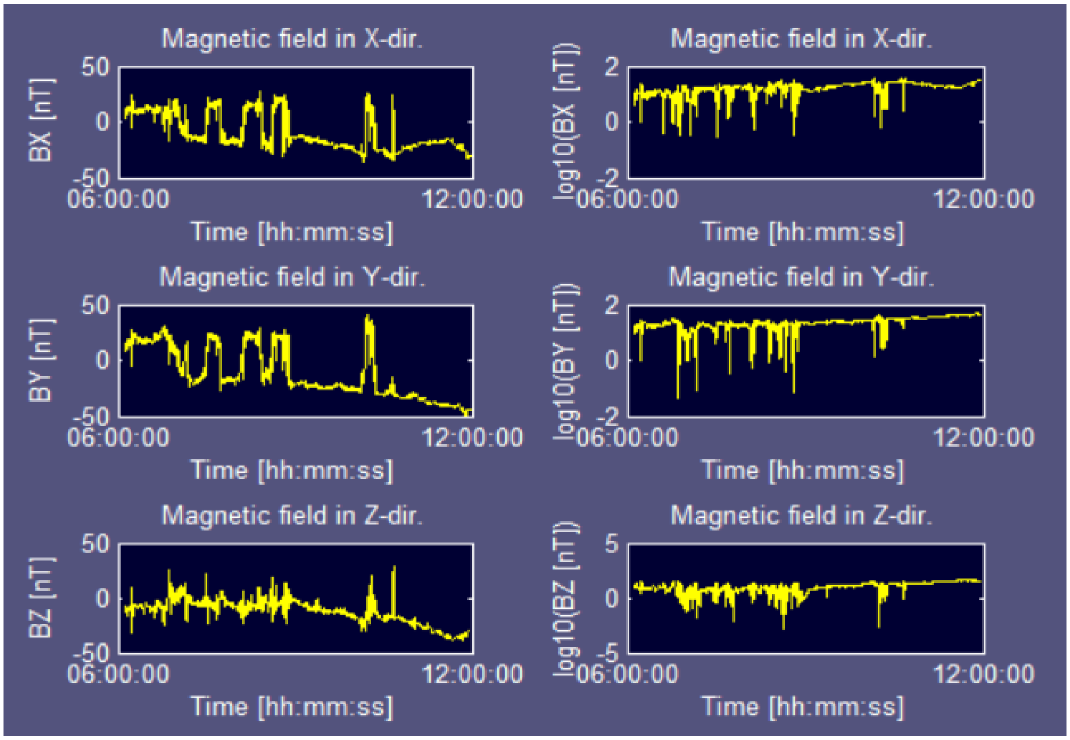
(b)


Perpendicular bulk velocity
vperp$_H$ [Km/sec]
600
400
200
0
06:00:00
09:00:00
12:00:00
Time
Perpendicular bulk velocity
log10(vperp$_H$ [Km/sec])
3
2
1
0
06:00:00
09:00:00
12:00:00
Time

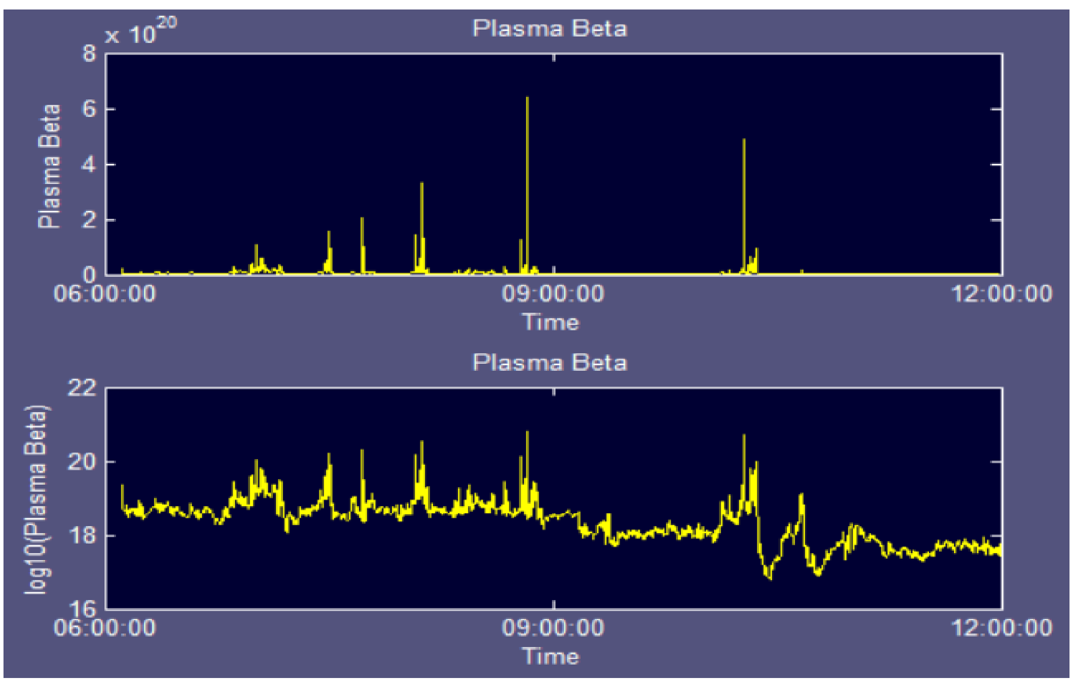
(c)


Temperature
Tp [eV]
4000
3000
2000
1000
0
06:00:00
09:00:00
12:00:00
Time
Temperature
log10(Tp [eV])
3.5
3
2.5
2
1.5
06:00:00
09:00:00
12:00:00
Time

(d)



(e)



(f)

Figure 2: Plot of proton data (a) Proton number density, (b) Parallel Bulk Velocity, (c) Perpendicular Bulk Velocity, (d) Temperature, (e) Magnetic field (x, y & z direction)and (f) Plasma Beta with respect to the time.

2.1 CAN YOU DISTINGUISH THE MAGNETOSPHERE REGION FROM THE MAGNETOSHEAT REGION? DISCUSS AND MOTIVATE.

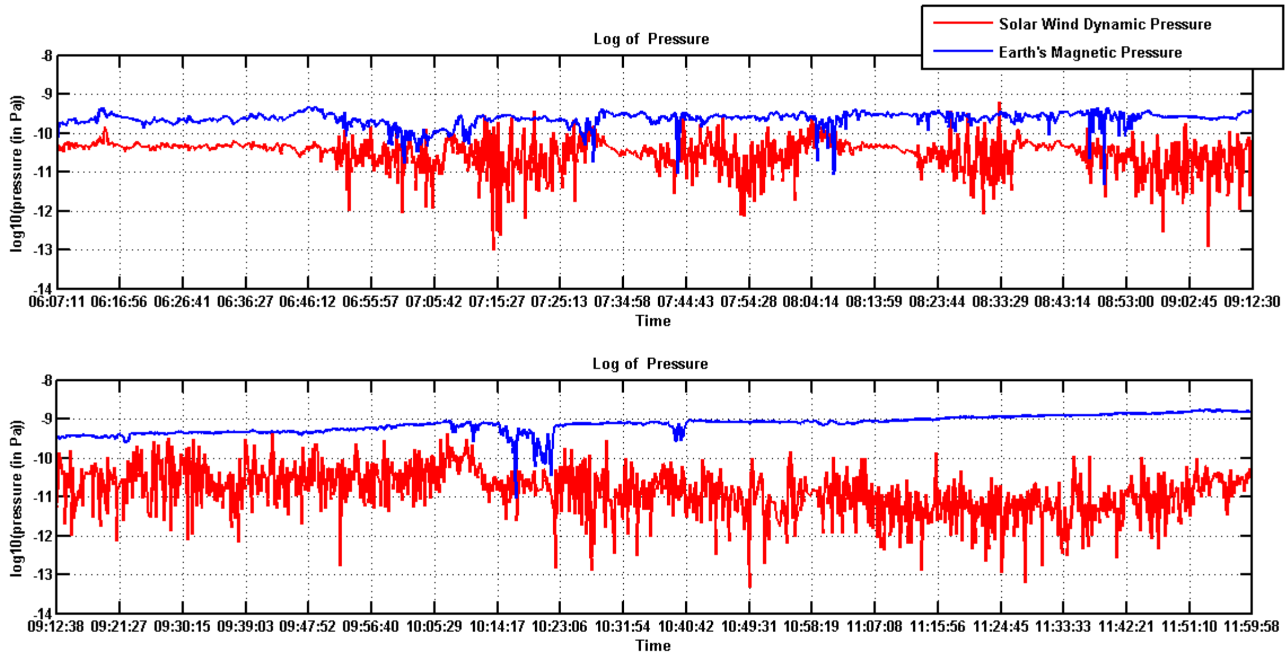


Figure 3: Plot of Solar wind dynamic pressure and Earth's magnetic pressure with respect to time

We plotted solar wind dynamic pressure and Earth's magnetic field pressure. From the plots it is easy to differentiate magnetosphere region from magnetosheath region. Time intervals where Earth's magnetic pressure (blue line) is more than solar wind dynamic pressure (red line) is the region when Cluster satellites are in Earth's magnetosphere. Regions where solar wind dynamic pressure is more than Earth's magnetic pressure is the region when satellites are in magnetosheath. Regions where the two pressures are equal is the region of magnetopause. From the above plots, it can be observed that the Cluster satellites are travelling within Earth's magnetosphere most of the time. There are few instances when the satellites skim through magnetopause or travel for a short duration in magnetosheath.

2.2 HOW MANY MAGNETOPAUSE TIMINGS DO YOU OBSERVE? AND AT WHAT TIMES DO THEY (APPROXIMATELY) OCCUR? (IN ORDER TO DO THAT YOU WILL NEED TO PLOT FOR SMALLER TIME INTERVALS)

We observe a total of 26 magnetopause timings at time instants:

1. 6:59:41
2. 7:01:01
3. 7:01:48
4. 7:03:38
5. 7:04:23
6. 7:07:45
7. 7:13:25
8. 7:13:45
9. 7:21:12

10. 7:27:13
11. 7:28:35
12. 7:28:46
13. 7:29:49
14. 7:30:26
15. 7:43:26
16. 7:43:43
17. 8:04:56
18. 8:05:07
19. 8:06:29
20. 8:07:23
21. 8:07:48
22. 8:25:37
23. 8:28:20
24. 8:33:15
25. 8:49:28
26. 10:16:40

For Cluster satellites, if multiple magnetopause crossing occur within 10 min, then there is a possibility that the spacecraft is skimming the magnetopause [5]. Therefore, we considered only the first event to represent crossing location.

Therefore, we could narrow down the magnetopause timings to:

1. 6:59:41
2. 7:13:25
3. 7:27:13
4. 7:43:26
5. 8:04:56
6. 8:25:37
7. 8:33:15
8. 8:49:28
9. 10:16:40

2.3 USE THE MVAB METHOD AND ESTIMATE THE MAGNETOPAUSE NORMAL FOR EACH MAGNETOPAUSE CROSSING. IN GENERAL, ARE THE ESTIMATED NORMAL DIRECTIONS WHAT YOU EXPECTED, CONSIDERING THE SPACECRAFT POSITION IN RELATION TO EARTH AND AN IDEAL TEXTBOOK MAGNETOPAUSE?

Magnetopause normal for each magnetopause crossing were determined. A plot of magnetopause normal along with spacecraft position in relation to Earth, is given below:

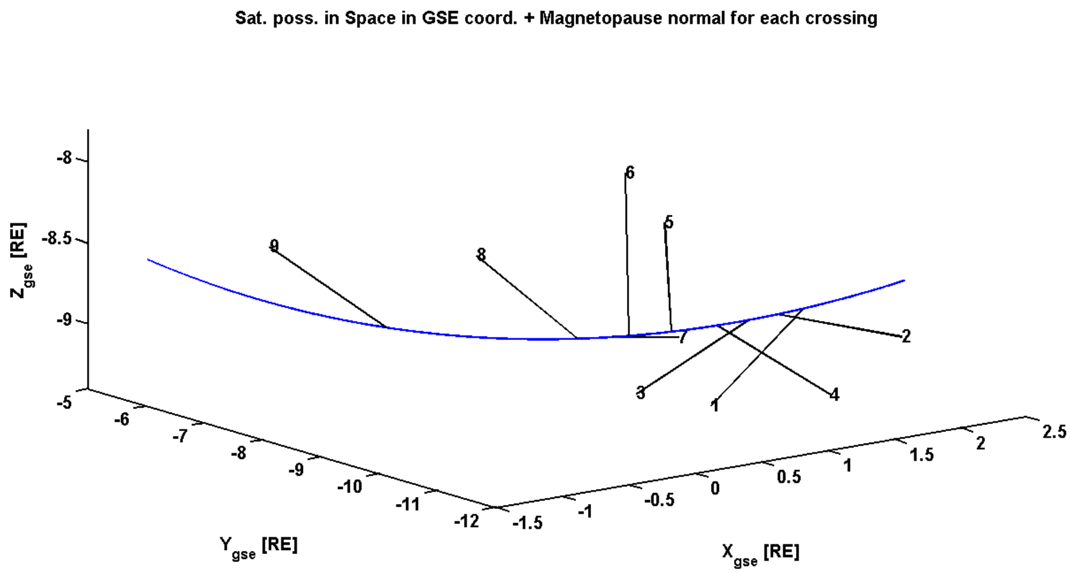


Figure 4: Satellite position in GSE coordinates & Magnetopause normal for each crossing

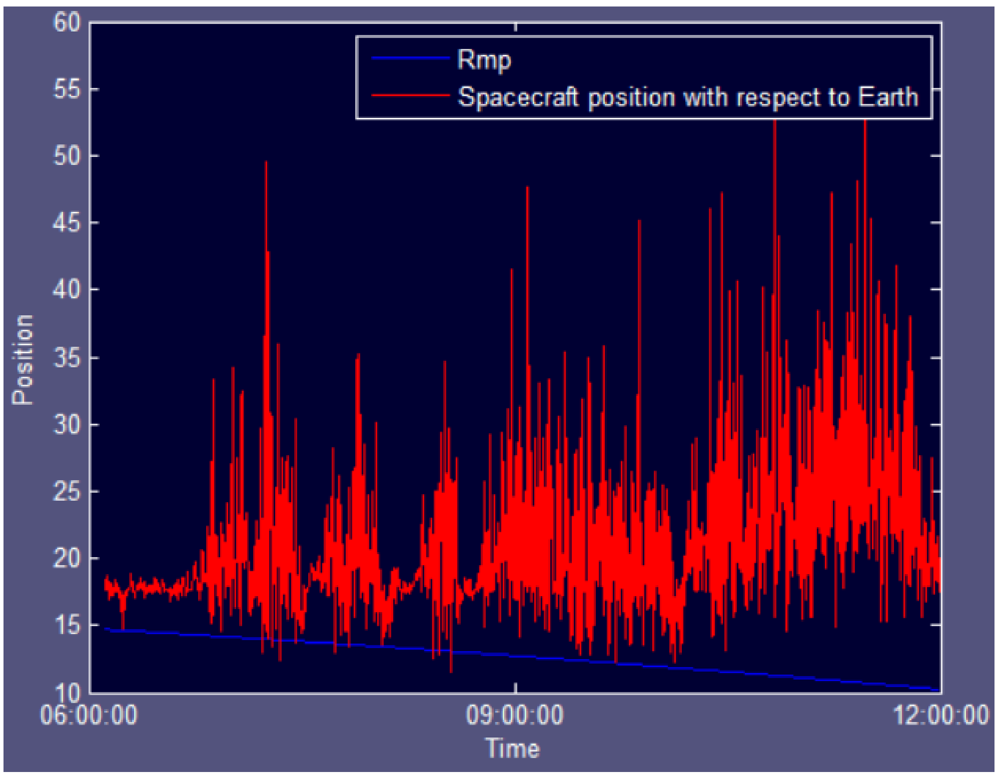


Figure 5: Satellite position with respect to Earth and R_{mp} with Time

$$R_{mp} = (KB_o^2/2\mu_o m_p n v_{sw}^2)^{\frac{1}{6}}\, R_E$$

Where, R_{mp} defines the contour of the magnetopause in GSE coordinate system
$B_o = 3E - 05\ T$, is the dipole magnetic field at Earth's surface
μ_o, Permeability of vacuum
m_p, Mass of proton

n, Proton number density
v_{sw}, Velocity of solar wind
R_E, Radius of Earth

At magnetopause crossings R_{mp} will be equal to spacecraft position with respect to Earth.

From Figure 5, it can be seen that there are nine instant of time where spacecraft crosses magnetopause. These instant of time approximately the same as predicted in 2.2.

2.4 ESTIMATE THE CURRENT DENSITY FOR EACH CROSSING AND REPORT. COMPARE TO TYPICAL MAGNETOPAUSE CURRENTS. ARE YOUR RESULTS REASONABLE?

Magnetopause current density, J, is calculated from Ampere's Law.

$$J = \frac{\nabla X B}{\mu_o}$$

The current density for each crossings are:

1. 0.476E-06
2. 0.012E-06
3. 0.209E-06
4. 1.575E-06
5. 0.512E-06
6. 2.139E-06
7. 0.116E-06
8. 1.624E-06
9. 3.875E-06

The average calculated value is 1.1711E-06 A/m^2.

The current density of magnetopause is estimated to be about 10^{-6} A/m^2 [2]. From this comparison we can say that our results are reasonable.

REFRENCES

[1]. http://www.swpc.noaa.gov/phenomena/earths-magnetosphere

[2]. Basic Space Plasma Physics, by Wolfgang Baumjohann, Rudolf A. Treumann, Page 191

[3]. http://www.physics.usyd.edu.au/~cairns/teaching/lecture14/node3.html (Equation 14.11)

[4]. Espen Lyngdal Olsen and Egil Leer, A study of solar wind acceleration based on gyrotropic transport equations, Journal of geophysical research, vol. 104, NO. A5, Pages 9963-9973, May 1, 1999 (Equation 11).

[5]. N. A. Case & J. A. Wild, The location of the Earth's magnetopause: A comparison of modeled position and in situ Cluster data, Journal of geophysical research, Space Physics, The location of the Earth's magnetopause: A comparison of modeled position and in situ Cluster data (Point [29]).

MATLAB CODE

```
close all;
clear all;
load('20020509_data.mat')
% Magnetic field matrix (Tesla)
B = [BX' BY' BZ']/ (10 ^ 9);
% Proton number density wrt time
figure
subplot (2, 1 ,1);
plot(matlab_time,n_H);
datetick('x','HH:MM:SS');
xlabel('Time');
ylabel('n_H [/cm^3]');
title('Proton Number density')
subplot (2, 1 ,2);
plot(matlab_time,log10(n_H));
datetick('x','HH:MM:SS');
xlabel('Time');
ylabel('log10(n_H [/cm^3])');
title('Proton Number density')

% velocity wrt time
%Parallel bulk velocity & Perpendicular bilk velocity
figure
subplot (2, 1, 1);
plot(matlab_time,vpar_H);
datetick('x','HH:MM:SS');
xlabel('Time');
ylabel('vpar_H [Km/sec]');
title('Parallel bulk velocity')
subplot(2,1,2);
plot(matlab_time,log10(vpar_H));
datetick('x','HH:MM:SS');
xlabel('Time');
ylabel('log10(vpar_H [Km/sec])');
title('Parallel bulk velocity')

figure;
subplot (2, 1, 1 );
plot(matlab_time,vperp_H);
datetick('x','HH:MM:SS');
xlabel('Time');
ylabel('vperp_H [Km/sec]');
title('Perpendicular bulk velocity')
subplot(2,1,2);
plot(matlab_time,log10(vperp_H));
datetick('x','HH:MM:SS');
xlabel('Time');
ylabel('log10(vperp_H [Km/sec])');
title('Perpendicular bulk velocity')
```

```
% Temperature Plot (T =(2*TPerpendicular + TParallel)/3)
Tp = (Tpar_H + (2*Tperp_H))/3;
% Kb = 1.38e-23;
% e = 1.602e-19;
% Tp = (Tp / Kb)*e;
figure
subplot(2,1,1);
plot(matlab_time,Tp);
datetick('x','HH:MM:SS');
xlabel('Time');
ylabel('Tp [eV]');
title('Temperature')
subplot(2,1,2);
plot(matlab_time,log10(Tp));
datetick('x','HH:MM:SS');
xlabel('Time');
ylabel('log10(Tp [eV])');
title('Temperature')

%Magnetic field
figure
subplot(3,2,1);
plot(matlab_time,BX);
datetick('x','HH:MM:SS');
xlabel('Time [hh:mm:ss]');
ylabel('BX [nT]');
title('Magnetic field in X-dir.')
subplot(3,2,2);
plot(matlab_time,log10(BX));
datetick('x','HH:MM:SS');
xlabel('Time [hh:mm:ss]');
ylabel('log10(BX [nT])');
title('Magnetic field in X-dir.')
subplot(3,2,3);
plot(matlab_time,BY);
datetick('x','HH:MM:SS');
xlabel('Time [hh:mm:ss]');
ylabel('BY [nT]');
title('Magnetic field in Y-dir.')
subplot(3,2,4);
plot(matlab_time,log10(BY));
datetick('x','HH:MM:SS');
xlabel('Time [hh:mm:ss]');
ylabel('log10(BY [nT])');
title('Magnetic field in Y-dir.')
subplot(3,2,5);
plot(matlab_time,BZ);
datetick('x','HH:MM:SS');
xlabel('Time [hh:mm:ss]');
ylabel('BZ [nT]');
```

```
title('Magnetic field in Z-dir.')
subplot(3,2,6);
plot(matlab_time,log10(BZ));
datetick('x','HH:MM:SS');
xlabel('Time [hh:mm:ss]');
ylabel('log10(BZ [nT])');
title('Magnetic field in Z-dir.')

% Plasma_Beta = (n * K_b * T) /((B^2)/2u)
B_total_sqr = (BX .^ 2) + (BY .^ 2) + (BZ .^ 2);
B_total_sqr = B_total_sqr * 1e-18;
u = 1.256637061e-6; % Permeability of vacuum
Plasma_Beta = (n_H *10^6.* Tp)./(B_total_sqr  /( 2 * u));
figure
subplot(2,1,1);
plot(matlab_time,Plasma_Beta);
datetick('x','HH:MM:SS');
xlabel('Time');
ylabel('Plasma Beta');
title('Plasma Beta')
subplot(2,1,2);
plot(matlab_time,log10(Plasma_Beta));
datetick('x','HH:MM:SS');
xlabel('Time');
ylabel('log10(Plasma Beta)');
title('Plasma Beta')

%DYNAMIC PRESSURE OF SOLAR WIND AND MAGNETIC PRESSURE
figure;
dynpr=1.6726*10^(-6)*n_H.*(vpar_H.^2+vperp_H.^2)*10^(-9);
magpr=(B_total_sqr)/(2*u);
subplot(2,2,1);
plot(matlab_time,dynpr);
datetick('x','HH:MM:SS');
xlabel('Time');
ylabel('dynamic pressure (in Pa)');
title('Dynamic Pressure of Solar Wind')
subplot(2,2,2);
plot(matlab_time,magpr);
datetick('x','HH:MM:SS');
xlabel('Time');
ylabel('magnetic pressure (in Pa)');
title('Magnetic Pressure of Earth')

startDate=matlab_time(1);
endDate=matlab_time(1100);
xdata=linspace(startDate, endDate, 20);
figure
subplot (2, 1, 1)
plot(matlab_time,log10(dynpr),'r');
hold on;
```

```
plot(matlab_time,log10(magpr),'b');
grid on;
set(gca,'XTick',xdata)
datetick('x','HH:MM:SS','keepticks')
xlabel('Time');
ylabel('log10(pressure (in Pa))');
title('Log of  Pressure ')

startDate1=matlab_time(1101);
endDate1=matlab_time(2209);
xdata1=linspace(startDate1, endDate1, 20);

subplot (2, 1, 2)
plot(matlab_time,log10(dynpr),'r');
hold on;
plot(matlab_time,log10(magpr),'b');
grid on;
set(gca,'XTick',xdata1)
datetick('x','HH:MM:SS','keepticks')
xlabel('Time');
ylabel('log10(pressure (in Pa))');
title('Log of  Pressure ')


T= ['06:59:41'; '07:13:25'; '07:27:13'; '07:43:26';'08:05:07'; '08:25:37'; '08:33:15'; '08:49:28'; '10:16:40'];
Time=datestr(matlab_time,'HH:MM:SS')
g=[]
for i=1:9
   for j=1:2209
if (Time(j,:)==T(i,:))
   g=[g j]
end
   end
end

G = [220 225; 310 320; 410 420; 500 510; 665 670;  780 790;  840 845; 935 945; 1530 1535];
s= size(G);
for k=1:s(1)
for i=1:3;
      for j=1:3;
          M(i,j)=mean(B(G(k,1):G(k,2),i).*B(G(k,1):G(k,2),j))-
mean(B(G(k,1):G(k,2),i))*mean(B(G(k,1):G(k,2),j));
      end;
   end;

   [V,D]=eig(M)
   f(1)=D(1);
   f(2)=D(5);
   f(3)=D(9);
   eigen=min(f);
   Index=find(f==eigen);
```

```
    switch(Index)
        case 1
            Normal(k,1)=V(1);
            Normal(k,2)=V(2);
            Normal(k,3)=V(3);
        case 2
            Normal(k,1)=V(4);
            Normal(k,2)=V(5);
            Normal(k,3)=V(6);
        case 3
            Normal(k,1)=V(7);
            Normal(k,2)=V(8);
            Normal(k,3)=V(9);
    end;
end

for i=1:s
    Lt(i,1)=X_gse(round(mean(G(i,:),2)));
    Lt(i,2)=Y_gse(round(mean(G(i,:),2)));
    Lt(i,3)=Z_gse(round(mean(G(i,:),2)));
end

figure
plot3(Y_gse,X_gse,Z_gse,'LineWidth',2)
hold on
xlabel('Y_{gse} [RE]');
ylabel('X_{gse} [RE]');
zlabel('Z_{gse} [RE]');
title('Sat. poss. in Space in GSE coord. + Magnetopause normal for each crossing')

for i=1:s
    plot3([Lt(i,2),Lt(i,2)+Normal(i,2)],[Lt(i,1),Lt(i,1)+Normal(i,1)],[Lt(i,3),Lt(i,3)+Normal(i,3)])
    nmbr=num2str(i);
    text(Lt(i,2)+Normal(i,2),Lt(i,1)+Normal(i,1),Lt(i,3)+Normal(i,3),nmbr);
end

figure
plot3(X_gse,Y_gse,Z_gse,'LineWidth',2), hold on
xlabel('X_{gse} [RE]');
ylabel('Y_{gse} [RE]');
zlabel('Z_{gse} [RE]');
title('Sat. poss. in Space in GSE coord. + Magnetopause normal for each crossing')

for i=1:s
   plot3([Lt(i,1),Lt(i,1)+Normal(i,1)],[Lt(i,2),Lt(i,2)+Normal(i,2)],[Lt(i,3),Lt(i,3)+Normal(i,3)])
    nmbr=num2str(i);

    text(Lt(i,1)+Normal(i,1),Lt(i,2)+Normal(i,2),Lt(i,3)+Normal(i,3),nmbr);
end
```

```
% J calculation
u = 1.256637061e-6;

for i=1:s(1)
    Bf(i,1) = (((BZ(G(i,2))-BZ(G(i,1)))/10^9)/((Y_gse(G(i,2))-Y_gse(G(i,1)))*6870e+03))-(((BY(G(i,2))-
BY(G(i,1)))/10^9)/((Z_gse(G(i,2))-Z_gse(G(i,1)))*6870e+03));
    Bf(i,2) = (((BX(G(i,2))-BX(G(i,1)))/10^9)/((Z_gse(G(i,2))-Z_gse(G(i,1)))*6870e+03))-(((BZ(G(i,2))-
BZ(G(i,1)))/10^9)/((X_gse(G(i,2))-X_gse(G(i,1)))*6870e+03));
    Bf(i,3) = (((BY(G(i,2))-BY(G(i,1)))/10^9)/((X_gse(G(i,2))-X_gse(G(i,1)))*6870e+03))-(((BX(G(i,2))-
BX(G(i,1)))/10^9)/((Y_gse(G(i,2))-Y_gse(G(i,1)))*6870e+03));
    J(i)=sqrt(Bf(i,1).^2+Bf(i,2).^2+Bf(i,3).^2)/u;

end
J'
mean(J')

%Rmp = ((K* B^2)/(2*u*mp*n_H*(vel^2) *6870e+03))^(1/6)
vel = vpar_H.^2+vperp_H.^2;
Rmp = 313619.9902 *((( 3*10^(-5))^2./(n_H .* vel*(10^12))).^(1/6));
x = sqrt (X_gse .^2 + Y_gse.^2+Z_gse.^2);
figure
plot(matlab_time,x,'b')
hold on;
plot(matlab_time,Rmp,'r')
datetick('x','HH:MM:SS');
xlabel('Time');
ylabel('Position');
legend('Rmp', 'Spacecraft position with respect to Earth')
```