

Investigating the Magnetosphere

Introduction

In this investigation, you will explore the properties of the regions of the magnetosphere using simulation results from the BATS-R-US model from the magnetosphere (see <http://ccmc.gsfc.nasa.gov/models/modelinfo.php?model=BATS-R-US>). During this lab you will explore:

- regions of the magnetosphere and their characteristics as shown by plasma parameters
- the global structure of the magnetosphere magnetic field under varying solar wind conditions
- methods for visualizing Magnetohydrodynamics simulation results

First Viewing

1. Open the Space Weather Explorer program by clicking on the 'SWX' icon.
2. A blank window will appear. Click on the file menu and navigate to the desktop Data folder and look for the 'lab 1' data under that. Choose the 'Northward IMF' data file. This is Run Number "HSS2011_SWMF_053111_4" at CCMC.

This simulation result is one time step from a run using 'Idealized' solar wind, a solar wind input at the front boundary of the simulation with constant density (5 amu/cc), constant velocity (400 Km/sec), and a constant IMF (5 NT) that is Northward (parallel to the Earth's magnetic field at the equator).

1. The window is still blank. Click the '+' sign and a tab window appears with a set of axis, but it is still blank.
2. Let's fill this window. Click the wrench icon on the tab and a dialog window will appear. Set:
 - 'Variable' to 'N' for plasma density
 - minimum and maximum value of X to -125 and 25
 - choose the "Component" to be "Y". This chooses the cut plane with the y-axis as its normal. This is the meridian or "noon-midnight" cut plane. Choosing "Z" would set an equatorial cut plane. Choosing "X" would choose the "dawn-dusk" cut plane.
1. Select 'OK' . The screen is now painted with the plasma density. Notice that it is a constant negative value at the front boundary, positive being defined as towards the Sun. The Earth is at the (0,0) point and there often is a simulation inner boundary around it of 3 Earth radii. You can resize the window any way you like.

Structures in the Magnetosphere

2. Hover the cursor over a point on the image. The coordinates and value at that point should appear.

- ***Can you find the position of the bow shock this way? What is the position and what criteria did you use to find it?***
 - ***Can you find the magnetopause? What characteristic did you use to find it?***
 - ***What values for the density do you see in the tail?***
1. Click on the tab tool again to get the dialog menu and change the 'Variable' to 'Vx' for speed in the x-direction. Based on the values you see, which direction is positive x?

2.

- **Can you find all of the features below in this view? Record the position and criteria for both in the table below.**

Feature	Position	Criteria
Bow Shock (velocity)		
Bow Shock (density)		
Magnetopause (velocity)		
Magnetopause (density)		
Magnetotail (velocity)		
Magnetotail (density)		

Another Cut-plane

1. Choose the “+” sign in the upper left corner to add another tab window. Click on the new tab (which will be blank) and click on the tool icon to get a dialog box.
 2. In the dialog box, choose the same settings as above. Choose the same variable that you have displayed in the other cut plane. Then in the “Component” pull down menu choose “Z”. This choose the cut plane normal to the “Z” axis. Use the same scaling you used above. Hit ‘Ok’ and observe the new cut plane.
- **Confirm all the values you found above. Are they consistent with what you found?**

3-D View

In order to get a better sense of how the two cut planes relate to each other, they can be viewed together in 3-D. Choose “3D-View” from the “View” menu. A window appear with the two cut planes plotted together in it.

- Expand the window to suit you.
- Use the mouse wheel to zoom out
- Hold the left mouse button down and move the mouse to rotate
- Use “Esc” to reset the view.

Tracing Field Lines

1. In the original window, choose the “Y” cut plane and click on a point. A field line should appear both on the cut plane window and in the 3-D window.
 2. Click on a few more points and observe the field lines.
- **What happens to field lines that start near the Earth? What happens to field lines that start out in the Solar Wind near the boundaries of the simulation**
1. Chose the other cut plane can click on a few points there. Choose points in the magnetosheath (between the Magneto-pause and the bow shock).

2. In either cut plane choose some field lines in the magneto tail.
3. View the results in the 3D window.
 - **What can you say about the structure of the magnetosphere in this idealized northward IMF case?**
4. You can also import a series of field line seed points. Choose the “Seed Position” option from the “View” menu and click on “Import”. Use the file browser to find the “Global.csv”. Choose this and click ok. Close the “Seed” window and click “Go” on the 2D view window and a series of new lines should appear. You will need to reopen the 3D window.
 - **Refine your answer from above. Does the solar wind have access to the inner magnetosphere? If so where? Is reconnection occurring?**
5. Click on areas that are not covered to see the field lines in that region.
 - **Based on the field lines you have chosen, how many classes of field lines are there in the case of a northward IMF.**
 - **Describe the characteristics of the magnetic field lines for the various regions of the magneto-sphere in the table below**

Region	Field line Characteristics
Outside the Bowshock	
In the magnetosheath	
Inside the magnetopause	
Near the poles	
On the night side	
Far in the tail	
Others?	

- **Where are the reconnection regions (x-points) for this field configuration?**

Southward IMF

Now you will explore how the field configuration changes when the solar wind IMF is southward.

1. Start a new instance of SWX and open the file for the southward configuration (Run HSS2011_SWMF_053111_2 at CCMC).
2. Set the cut plane settings in the same way as before and view the 3-D configuration.
 - *To save time you, use the “Load State” option in the “File” menu and choose the “SouthwardState-2012” file.*
3. Identify the same magnetosphere features as with the other case.
 - ***Can you find all of the features below in this view? Record the position and criteria for both in the table below.***

Feature	Position	Criteria
Bow Shock (velocity)		
Bow Shock (density)		
Magnetopause (velocity)		
Magnetopause (density)		
Magnetotail (velocity)		
Magnetotail (density)		

4. And do the same for field lines.

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Region	Field line Characteristics
Outside the Bowshock	
In the magnetosheath	
Inside the magnetopause	
Near the poles	
On the night side	
Far in the tail	
Others?	

- **Discuss the qualitative differences between the magnetosphere under conditions of northward and southward IMF. Consider the following:**
 - **How does the field configuration at the nose compare?**
 - **Which has more Earth originating field lines that are “open”?**
 - **Compare the features and field configuration of the tail for the two cases.**

Plotting the Magnetosphere.

Two dimensional cut planes and 3-D renderings of computer models can often provide a good conceptual picture of the global structure of a system, but calculations and line plots are needed to carefully explore issues. The CCMC online tools allow for line plots

In a web browser, open

http://ccmc.gsfc.nasa.gov/database_MHD/HSS2011_SWMF_053111_2.php

This is the page for the run that generated the **southward** IMF simulation results you were looking at in the Space Weather Explorer (leave SWX open for reference).

- Scroll down and click on the “View Magnetosphere” link. A plotting page will appear with a variety of settings on it. Click on “Update Plot” and a plot of the plasma density should appear.
 - **Be sure you can identify the sun direction, the north and south poles, the bow shock, and the magnetopause.**
- Scroll down to the “Plot Mode” pull down menu and choose “Line(1D)” plot. Also choose the density (N) and x component of velocity (Vx) in the “Q1” and “Q2” “quantity” pull down menus next to it.
- Scroll back up and hit “update plot”. A line plot should appear that shows Vx and N as a function of position along a line. If you look at the bottom axis the positions of the line are given. It runs from one corner of the simulation region to another. This is complicated to interpret so let’s plot a simpler line.
- Scroll down past the previous menu to “Choose Plot Area”. Set the “Y” and “Z” positions to zero so that you just have a line along the X-axis running through the simulation region. Set the minimum value of “X” to zero and click on “update plot”.
- You should now see a line plot of the two variables along a line running from the Earth, through the nose of the magnetosphere directly towards the Sun. Notice that there is a vertical line at the inner boundary of the simulation.
- **Can you identify the bow shock and magnetopause? Use the “X_2” value to zoom in and refine your estimate. Is this consistent with what you found for the Southward case at the beginning of the lab.**
- Add the B_z variable to the plot using the “Q3” menu next to plot mode.
- **Does this help identify the magnetopause? Is it consistent with what you saw above in the data visualizer used earlier?**
- **What do strong gradients in the magnetic field indicate?**

Now let’s look at the **Northward** case. In another browser window open

http://ccmc.gsfc.nasa.gov/database_MHD/HSS2011_SWMF_053111_4.php

- **Use the techniques settings above to verify the position of the bow shock and magnetopause you found in the first part of the lab for the Northward IMF case.**
- **How does it compare to the positions in the southward case?**

- Finally, let's look at what happens when we move off axis. Move the plot line up to 5 by setting "Z1" and "Z2" to "5".
- **Is the bow shock and magnetopause still well defined?
Where is it located now?**
- **Make a table of the locations as you increase the Z-position.**
- **Make a similar table for locations in the y direction.**