

Exploring the Structure of the Solar Wind

Introduction (10 minutes)

In this lab we will examine the structure and properties of the solar wind out to ~1 AU by visualizing results from the ENLIL 3-D MHD solar wind model that is initialized (at an inner boundary $R = 30 R_s$) by the MAS model. We will examine the structure of the solar wind in two situations: at the beginning of the last solar cycle near solar minimum (CR2070), and near solar maximum (CR2150) of the last cycle. You will look at how the plasma parameters vary in space throughout the inner heliosphere, and how the magnetic field lines and flow velocities are related.

When you are finished with this lab you will have reviewed the:

- variation in solar wind plasma parameters as a function of distance from the sun
- the variation in solar wind plasma parameters as a function of solar latitude
- difference in the overall structure of the solar wind from the solar minimum case to the solar maximum case
- the relationship between plasma flow and the magnetic field line topology
- the interaction of fast and slow solar wind flows and how they affect the solar wind structure

Before You Begin: (5 minutes)

The DSCOVR spacecraft is a joint NOAA, NASA, and USAF mission to monitor the solar wind just upwind of Earth (<https://solarsystem.nasa.gov/missions/DSCOVR/in-depth/>). Solar Wind data from the DSCOVR spacecraft can be found at [Real Time Solar Wind](#)

What plasma parameters are provided in the above link?

Make a table of the ranges of the plasma parameters measured by DSCOVR at (near) Earth along with their units. (Add rows as needed.)

<i>Plasma Parameter</i>	<i>Units</i>	<i>Range</i>
density		

Part I: An Overview of the Solar Wind (30 minutes)

Introduction (10 minutes)

The iSWA layout below shows simulation results from the solar wind Enlil model. A brief description of the Enlil model can be found here,

<https://ccmc.gsfc.nasa.gov/models/ENLIL~2.8f>

Load this link showing an example of Enlil Output: http://bit.ly/Enlil_Example

- ***What solar wind variables are you viewing in the iSWA layout? What range of values do they take?***
- ***What other features are represented in the plots?***
- ***What other variables might you expect from the Enlil model?***
- ***What other information would you like from the model?***
- If you like, use the “global date” button at the top of the screen to get the most recent version.

Cut Planes (5 minutes)

The two cygnets in the layout above show cut planes through a 3-D volume of simulation results for a given variable - density and velocity.

- ***On your group's whiteboard, sketch the 3-D simulation volume showing the cut planes. (If you have trouble with this, ask an instructor)***
- ***Can you describe the volume?***
- ***Why do you think this volume was chosen by the model developers?***

Each cut plane is painted with a variable that is derived from the simulation results.

- ***What is the scale (range) of the velocity variable?***
- ***How is the “density” plotted? What simulation results are used to calculate it?***
- ***What is the range of density values? What is the expected density at 1 AU (Earth's orbit)?***

Part II: A Second Look (60 Minutes)

Getting Started (5 minutes)

In this section you will look at the solar wind density and velocity variations in more detail. This page ([Cycles in the Solar Wind](#)) has a series of runs for Carrington Rotations during Solar Minimum and Solar Maximum. Click on one of these runs from the solar minimum cases.

These are simulation results from the Enlil solar wind model for Carrington Rotations (CR) 2066 through 2070 (approximately January to June 2008). This is a period of low solar activity near “solar minimum”.

- Choose one of the Carrington Rotations and click the link.
- Click on the “3D Data” link. This links to a form page that allows the user to plot the simulation results in a variety of formats.
- To start with, click “Update Plot”. You should see a plot very similar to the plots you just looked at.
- **How large would the Sun be in this image
(look up the diameter of the Sun and the distance of 1 AU)?
How large would the Earth’s magnetosphere be?**

Each cut plane is painted with a plasma parameter labeled on the legend. The solar wind parameters depicted here are simulation results for CR 2070, which is near solar minimum. The other window has a plot of the parameter as a function of distance from the Sun along a line that is indicated in the cut plane window. The radial distance is in AU’s [one AU or Astronomical Unit is the mean distance from the Earth to the Sun].

Activity 1:

Exploring the Global Structure of the Solar Wind

(45 minutes)

Direction of the Solar Wind Velocity

- Scroll down a little on the page till you find the “**Quantity**” section. **Choose ‘V’** (the velocity magnitude) from the “Q1” drop down menu and then **click “update plot”**.
- **What is the range of velocities shown?**
- Now choose different components of the velocity - “Vr”, “V_lat”, and “V_lon” (for the components of velocity represented in spherical coordinates) - and plot each.
- Create a table of the range of the velocity magnitude and its components?
- **What is the dominant component of the solar wind velocity vector?**

- ***What is the general direction of the solar wind plasma velocity at 1 AU? At 2 AU?***
- ***What conclusion can you draw about the flow of the solar wind?***

Variations in Density

- Keep the window above open and switch the quantity back to “V” for velocity magnitude. Open a second window and open the same case and plot “N” for the plasma density.
- **How much variation can you see in the plot of density?**

You can look at the variation in the parameters along a line.

- Scroll down the form and choose the following settings.
From the “Plot Mode” drop down menu choose “Line 1D”
- From the “quantities” drop down menu choose “2” for “number of quantities”.
- Choose Q1: “N” and Q2: “V”
- In the “Choose Plot Area”, set “Lon1”, “Lon2”, “Lat1”, and “Lat2” to “0”.
- Hit the “Update Plot” button.

You should now have a line plot showing the variation of the density and magnetic field strength along a radial line in the solar equatorial plane.

- ***Where is this line in the 2D equatorial plane that you plotted previously?***
- ***How much variation is there in the density? Note the range.***
- ***Compare the variation in the magnetic field to the density. Do they appear to be related?***
- ***Can you tell how the density varies with distance from the Sun? What functional form would you guess?***

Rescaled Density and Compared to Velocity

Finally, let’s look at a rescaled density and compare it to the velocity

- Choose “Q1: Nr^2 ” and “Q2: V”
- ***How would you describe this plot?***
How does the density vary with distance from the Sun?
“...velocity...”
Is the variation particularly strong with distance? Make note of the scales for each.
- ***How does the variation with density compare to the variation with velocity?***
- ***What general conclusions can you draw about how the density varies with distance from the Sun?***
- Verify your conclusions by choosing a different longitude and reviewing those

plots.

Variations in Solar Wind with Latitude

Let's return to the 2-D view of the model, but now looking at the latitudinal variation.

- Open another window and navigate back to the case you have been using.
- Under "Plot Mode" select "ColorContour (2D)".
- For Q1 select "Nr²" to show the scaled plasma density.
- In the "Choose Plot Area" section select the "Lon=constant" button.
- Click on "Update Plot"
- **Observe the range of values for the plasma density at low latitude and high latitude. Record your observations below.**
- For Q1 choose the "V" variable to display the plasma velocity.
- **Record what you observe below.**

Latitude	Range of plasma densities	Range of plasma speeds
Low latitude		
High latitude		

- **What general conclusions can you make about the variation of density and velocity with latitude?**

Summary Solar Minimum Case

Review the categories on this Jamboard. Choose one of the views you used above that satisfies one of the categories and paste an image into the Jamboard.

(You will work on "Solar Max Case" next).

Solar Maximum Case

Return to this page ([Cycles in the Solar Wind](#)) and change the Carrington Rotation to a solar max case such as 2150, 51, or 52. Look at the global structure and compare it to the solar minimum case.

- ***Are the velocity and the density related to each other in the same way as in the solar minimum case?***
- ***How does the velocity and density change as you go to higher latitudes? How does this compare to the solar minimum case?***
- ***On the paper provided, sketch a solar minimum and solar maximum case***

highlighting the differences.

- *Are the similarities and differences between solar minimum and solar maximum consistent with spacecraft data presented in the lectures?*

Summary: Comparing Models with Data

Compare these visualizations to the visualize presented here:

<https://www.swpc.noaa.gov/products/wsa-enlil-solar-wind-prediction>

Below in image from the Ulysses mission. You can find a full size version at

<http://sci.esa.int/science-e/www/object/index.cfm?fobjectid=33482> Are the findings from

your study of these simulation results consistent with this data? Discuss, draw pictures and save images.

