Solar wind, IMF data Analysis and Interpretation

George Omondi

Maseno University

Department of Physics and Materials Science

Space Weather and Upper Atmospheric data analysis workshop for East Africa Community-Muni, Arua Uganda, 25 to 29 September, 2023

OUTLINE

1. Solar wind: Basics

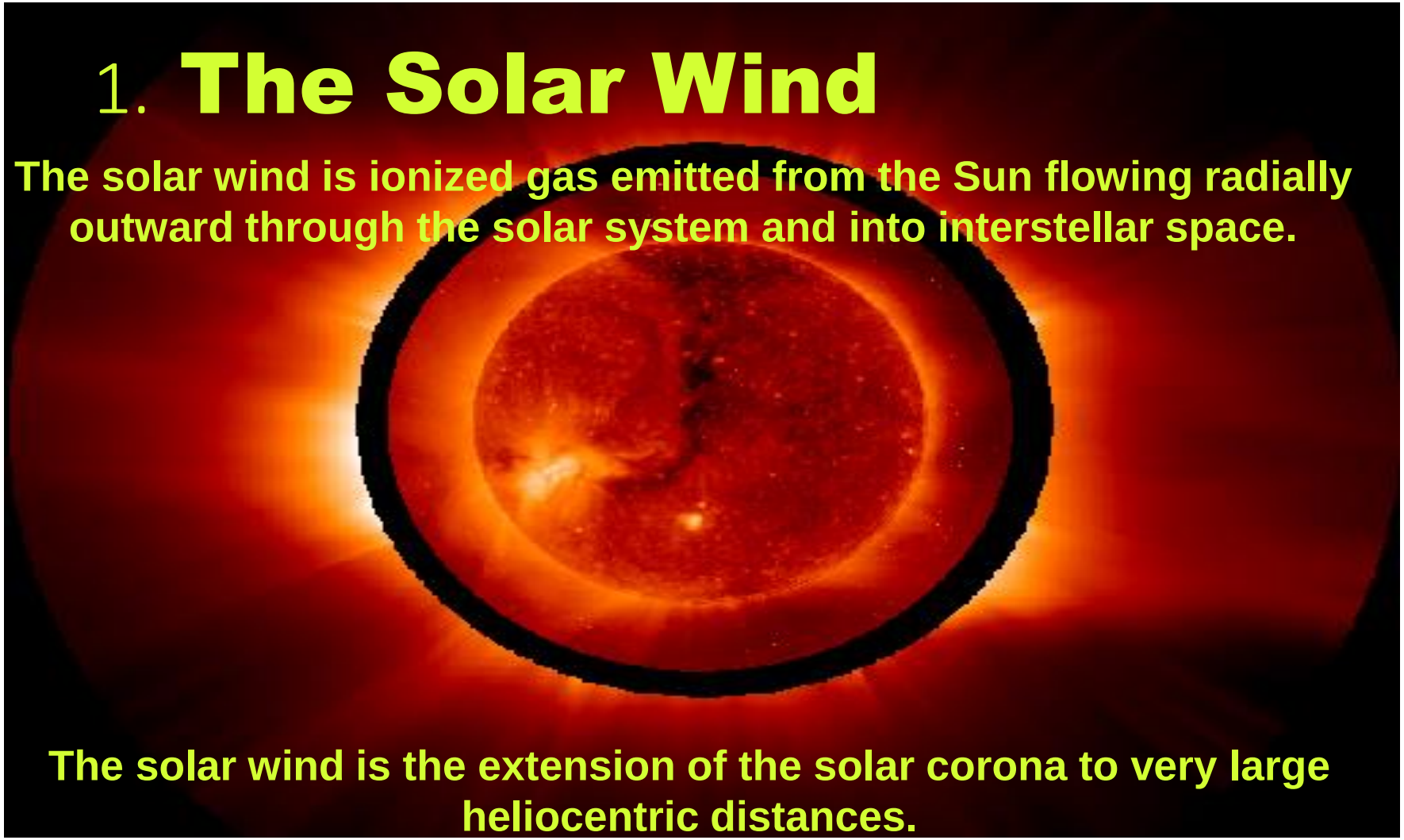
2. Interplanetary Magnetic Field: Basics

3. Coordinate systems based on Sun-Earth line

4. Data sources, Analysis and Interpretation

1. The Solar Wind

The solar wind is ionized gas emitted from the Sun flowing radially outward through the solar system and into interstellar space.

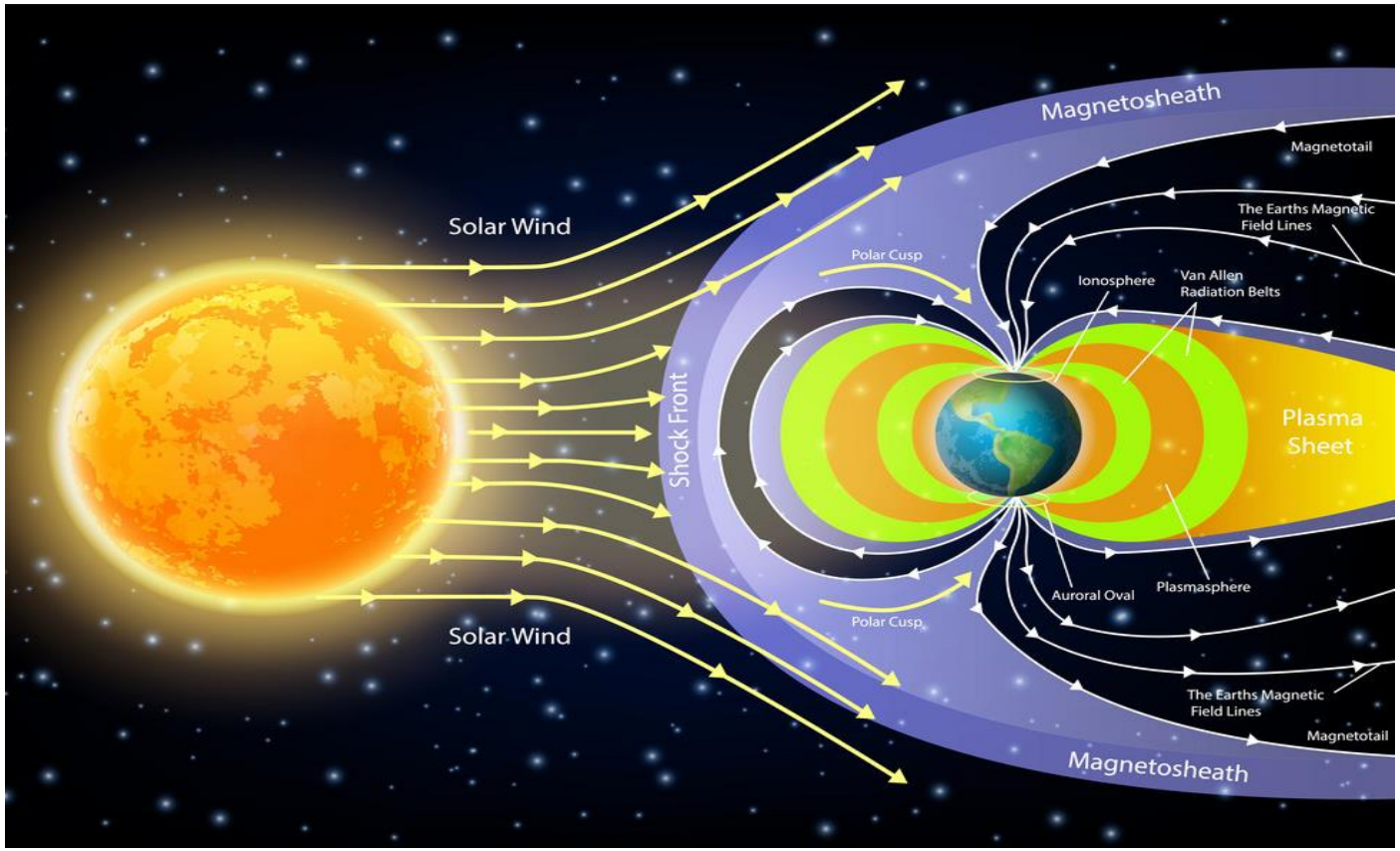


The solar wind is the extension of the solar corona to very large heliocentric distances.

- Solar wind forms as a result of the huge pressure difference between the solar corona and the interstellar space
- The pressure difference means the existence of a resultant force directed outwards from the sun despite the restraining influence of solar gravity. This resultant force is the driver of plasma outward into the interstellar space.

- The solar wind which consists mainly of electrons and protons extends tenuously for more than a hundred astronomical units and surrounds the Earth and all of the planets.

- On average, solar wind blows past the Earth at a speed of 400 km/s



- Assuming hydrostatic equilibrium, then

$$\frac{\partial p}{\partial r} = -g\rho = -\frac{GM_{\oplus}}{r^2}\rho, \text{ and substitute } \rho = \frac{p}{\tilde{R}T},\ \tilde{R} \approx \frac{2k_B}{m_p}$$

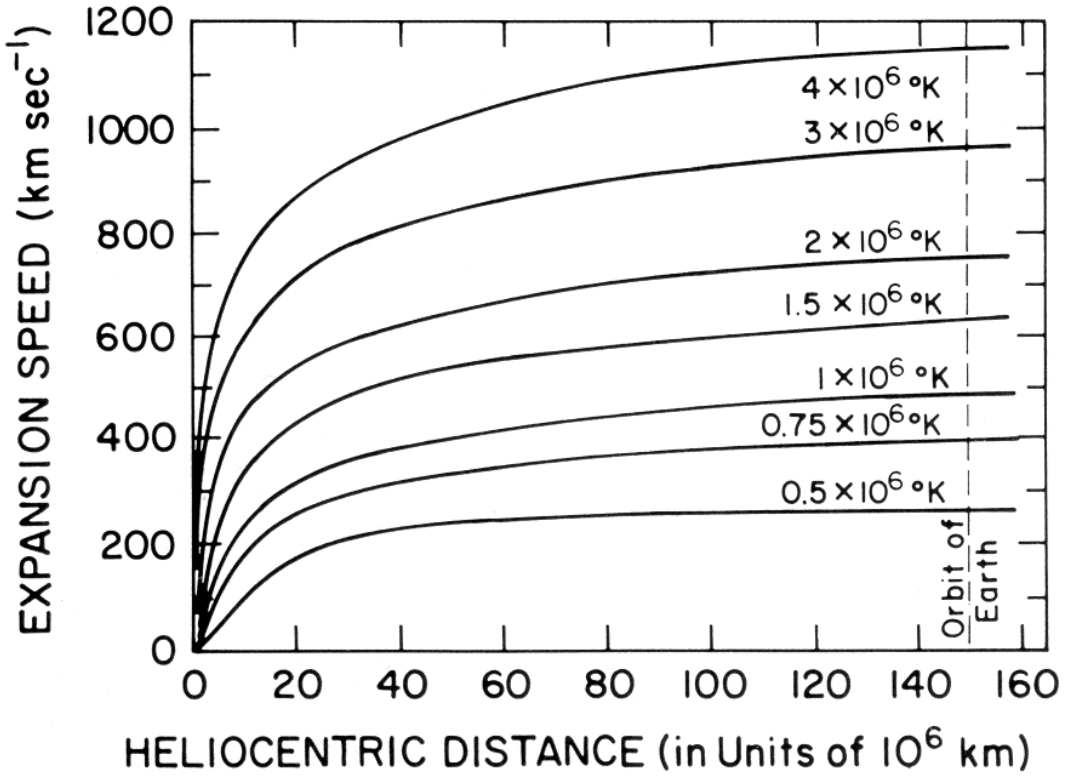
$$\frac{dp}{p} = -\frac{GM_{\oplus}}{\tilde{R}}\frac{dr}{r^2 T(r)}$$

$$p = p_{\oplus} \exp\left(-\frac{GM_{\oplus}}{\tilde{R}}\int_{R_{\oplus}}^{r}\frac{dr}{r^2 T(r)}\right)$$

$\oplus$ refers to the base of the corona

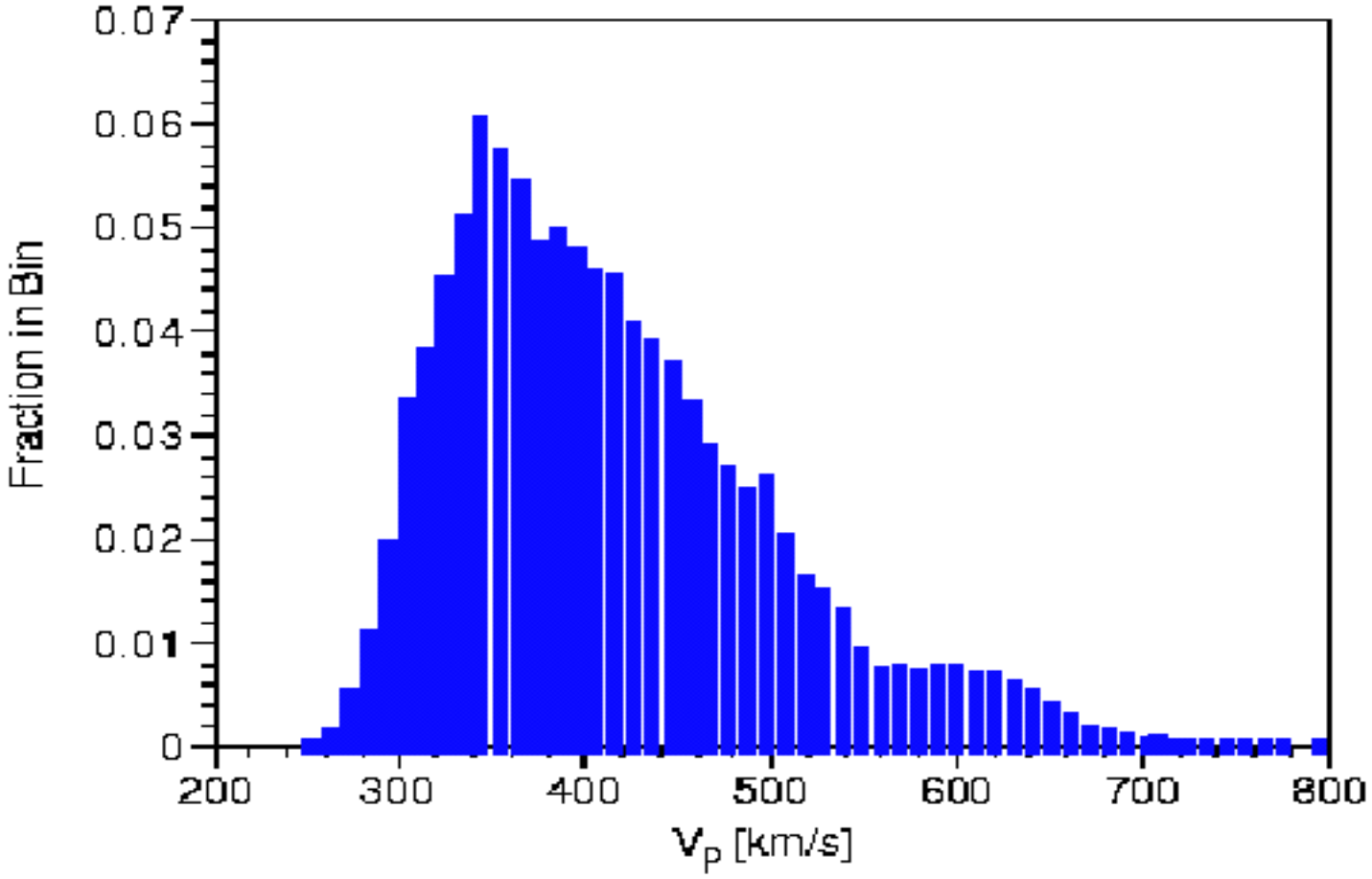
- The solar wind exists because the Sun maintains a $2x10^6$K corona as its outermost atmosphere.
- The Sun's atmosphere "boils off" into space and is accelerated to high velocities (> 400 km s^{-1}).

- *Parker* (1958) proposed that the solar wind was the result of the **high temperature corona** and developed a hydrodynamic model to support his idea. From Parker's model, the following quantitative solutions for solar wind were obtained



For the solar wind to continue to accelerate then the mean thermal energy must exceed the gravitational energy.

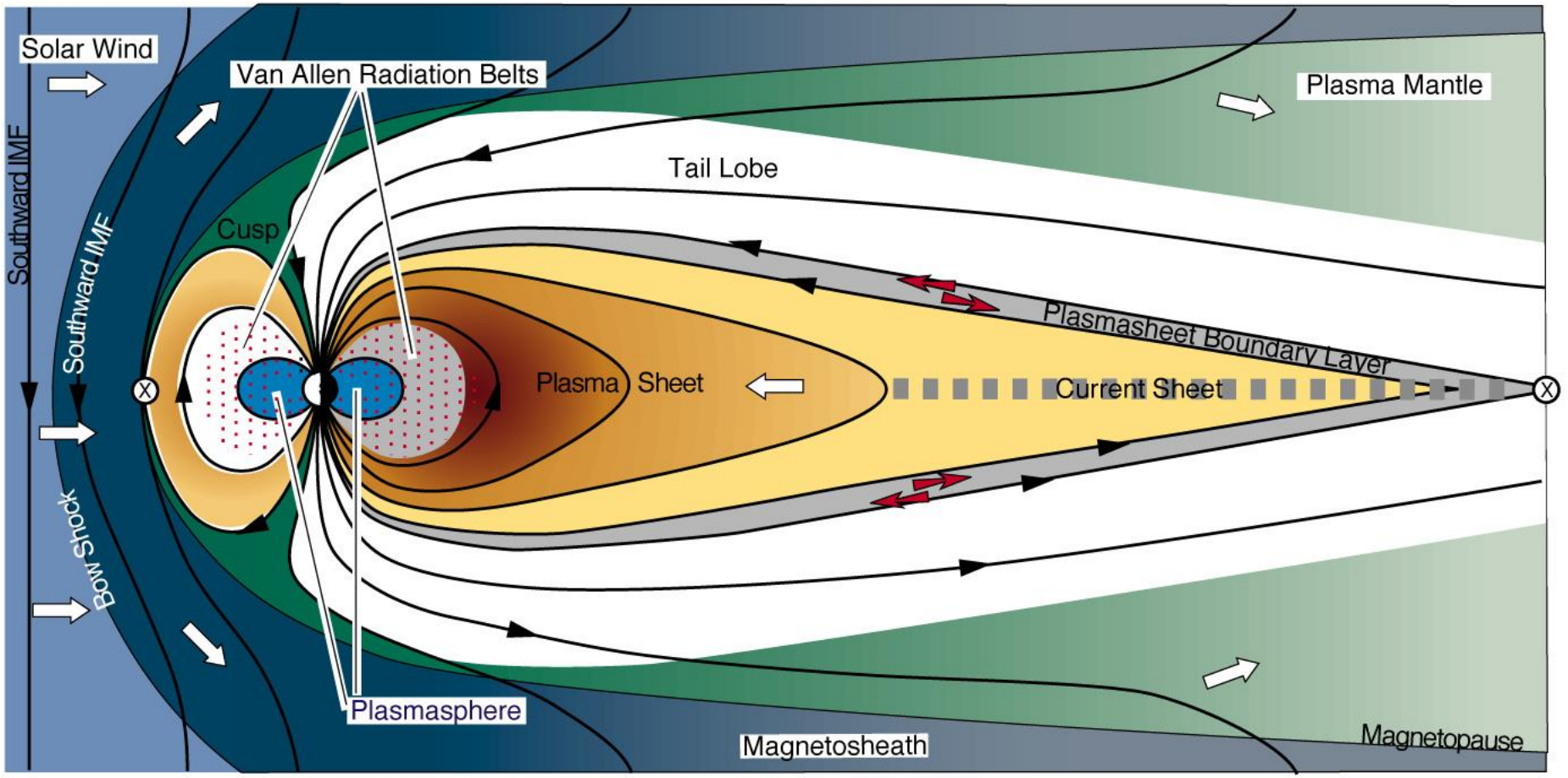
• Solar wind statistics

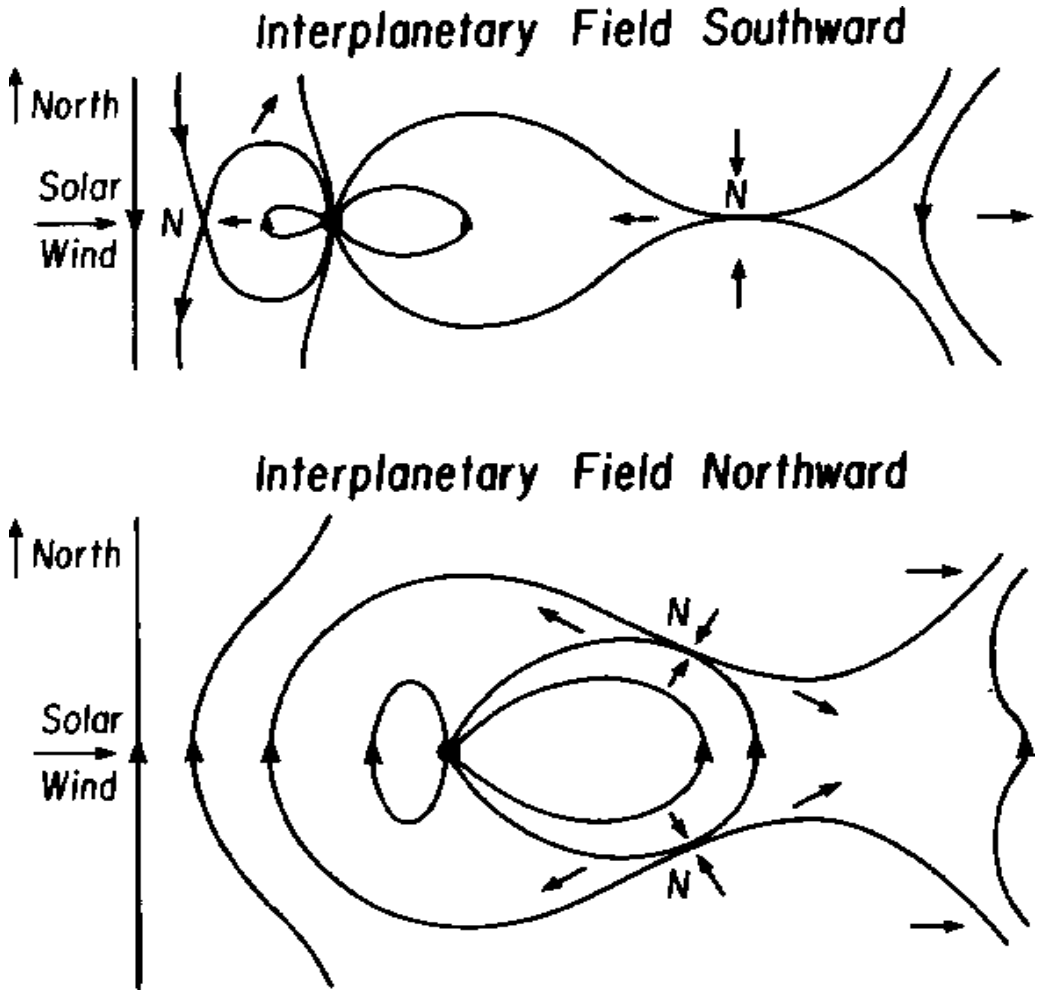


2. Interplanetary Magnetic Field

- The IMF is part of the Sun's magnetic field that is carried by the solar wind. Due to the frozen-in-flux condition, the IMF travels outward in a spiral pattern originating from the regions on the Sun where open magnetic field lines emerging from do not return to a conjugate region but instead extend indefinitely into space. The frozen-in-flux condition implies that if at a given time t_0 an element of particles exists on a particular field line, then at a later time, t this element will still be on the same field line.
- The interaction of the IMF with the Earth's magnetic field is responsible for the shape of the magnetosphere and is one of the important conditions that **determine the processes that yield geomagnetic storms.**

- The IMF is described by three orthogonal component directions B_X,
- B_Y , B_Z. The directions of the IMF are important for the study of the interaction of solar wind with magnetosphere. When B_Z is positive, it is said to be northward and when negative it is referred **to as southward.**
- The accepted model for the IMF supposes that when the southward directed IMF encounters the northward directed magnetic field of the Earth then the field lines interconnect, distorting the Earth's dipole field and providing entry for the solar wind particles into the magnetosphere through the process of magnetic reconnection. This results in a geomagnetic storm.

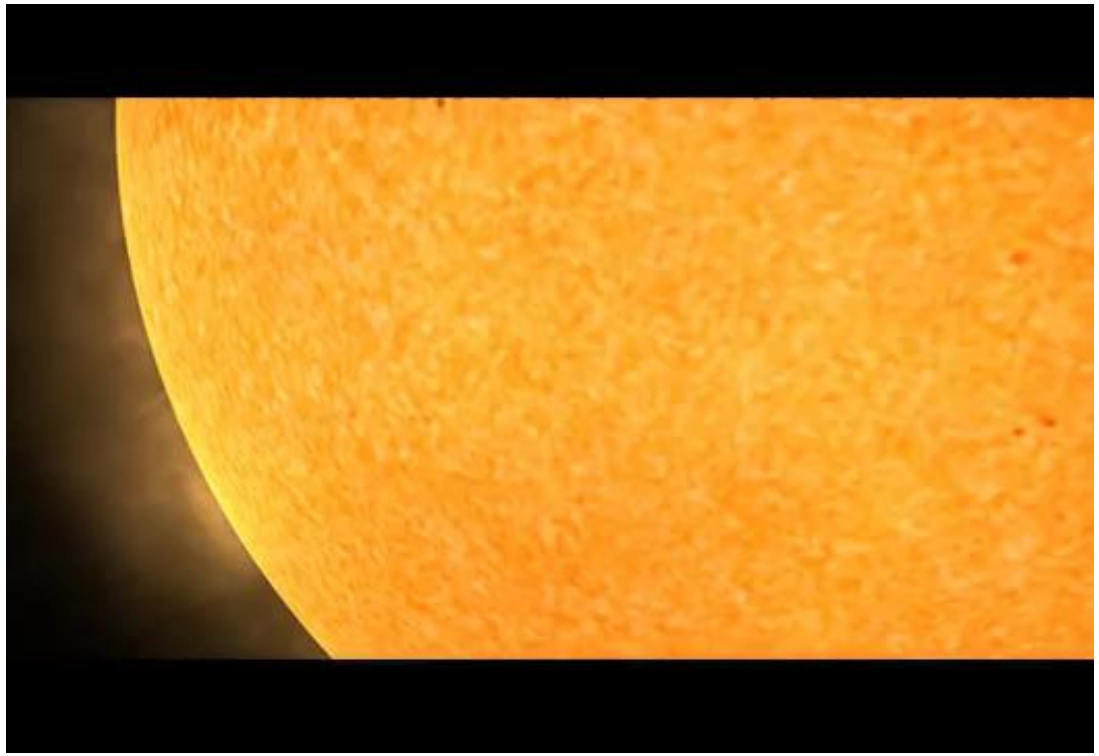

Solar Wind
Van Allen Radiation Belts
Plasma Mantle
Tail Lobe
Southward IMF
Southward IMF
Cusp
Plasmasheet Boundary Layer
Plasma Sheet
Current Sheet
Bow Shock
Plasmasphere
Magnetosheath
Magnetopause



- Structure and dynamics of the magnetosphere is strongly dependent on orientation of magnetic field in solar wind (Interplanetary Magnetic Field – IMF) with respect to the Earth's dipole field

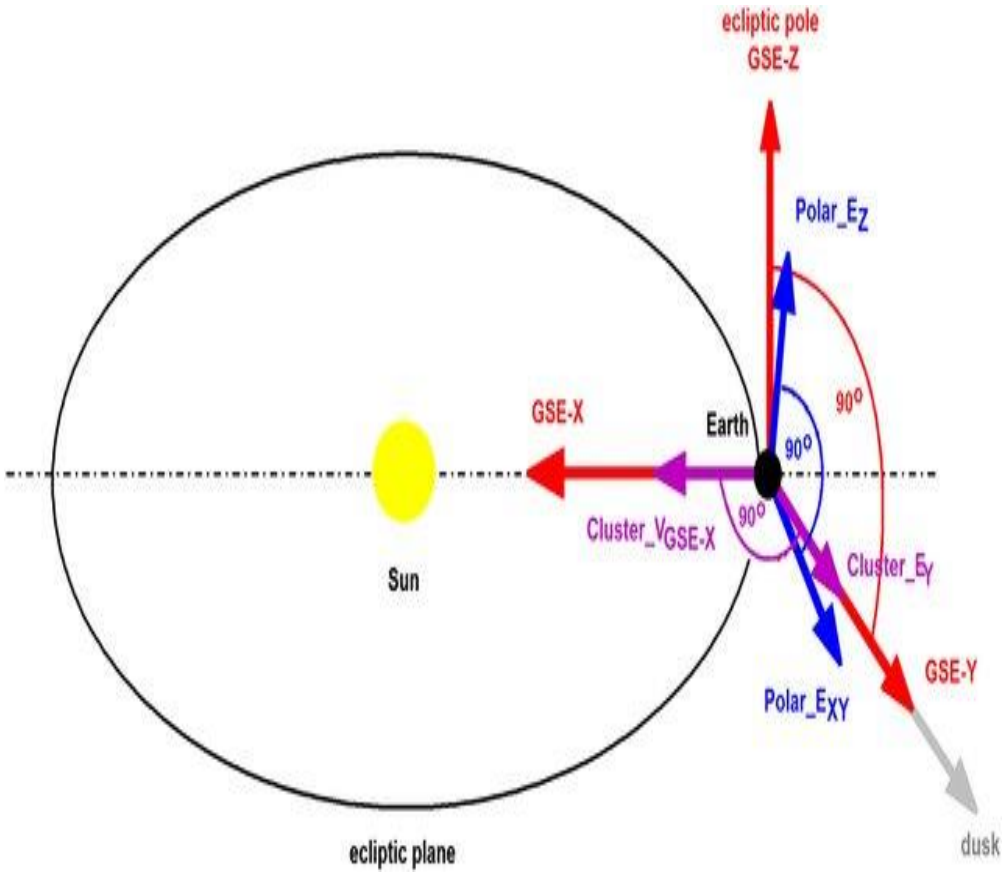
- A geomagnetic storm is a major disturbance of Earth's magnetosphere that occurs when there is **efficient exchange of energy from the solar wind into the space environment surrounding the Earth.**

- The solar wind conditions that are effective for creating geomagnetic storms are sustained (for several hours) periods of high-speed solar wind, and most importantly, **a southward directed Interplanetary Magnetic Field at the dayside of the magnetosphere**

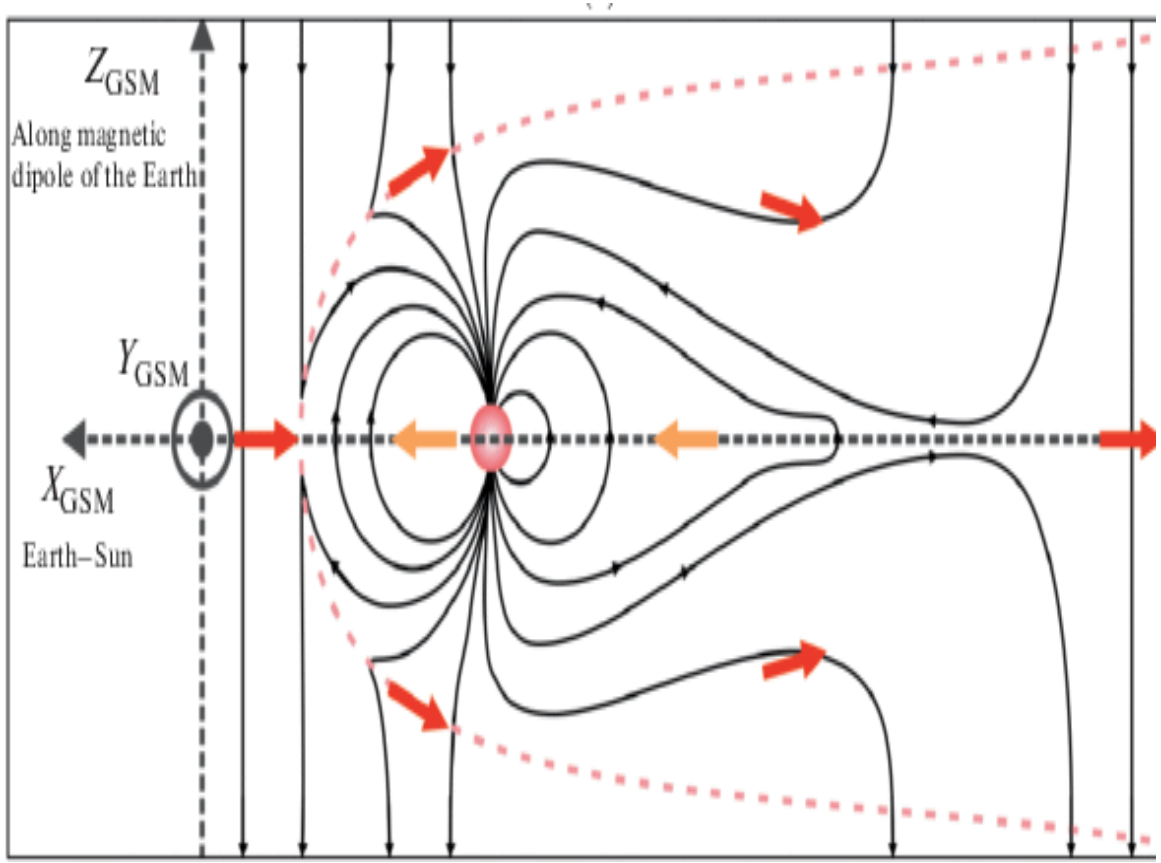


3. Coordinate Systems based on the Earth-Sun line

- **3.1 Geocentric solar ecliptic (GSE)**
- This system has its X axis towards the Sun and its Z axis perpendicular to the plane of the Earth's orbit around the Sun (positive North). This system is fixed with respect to the Earth-Sun line. It is convenient for specifying magnetospheric boundaries. It has also been widely adopted as the system for representing vector quantities in space physics databases.

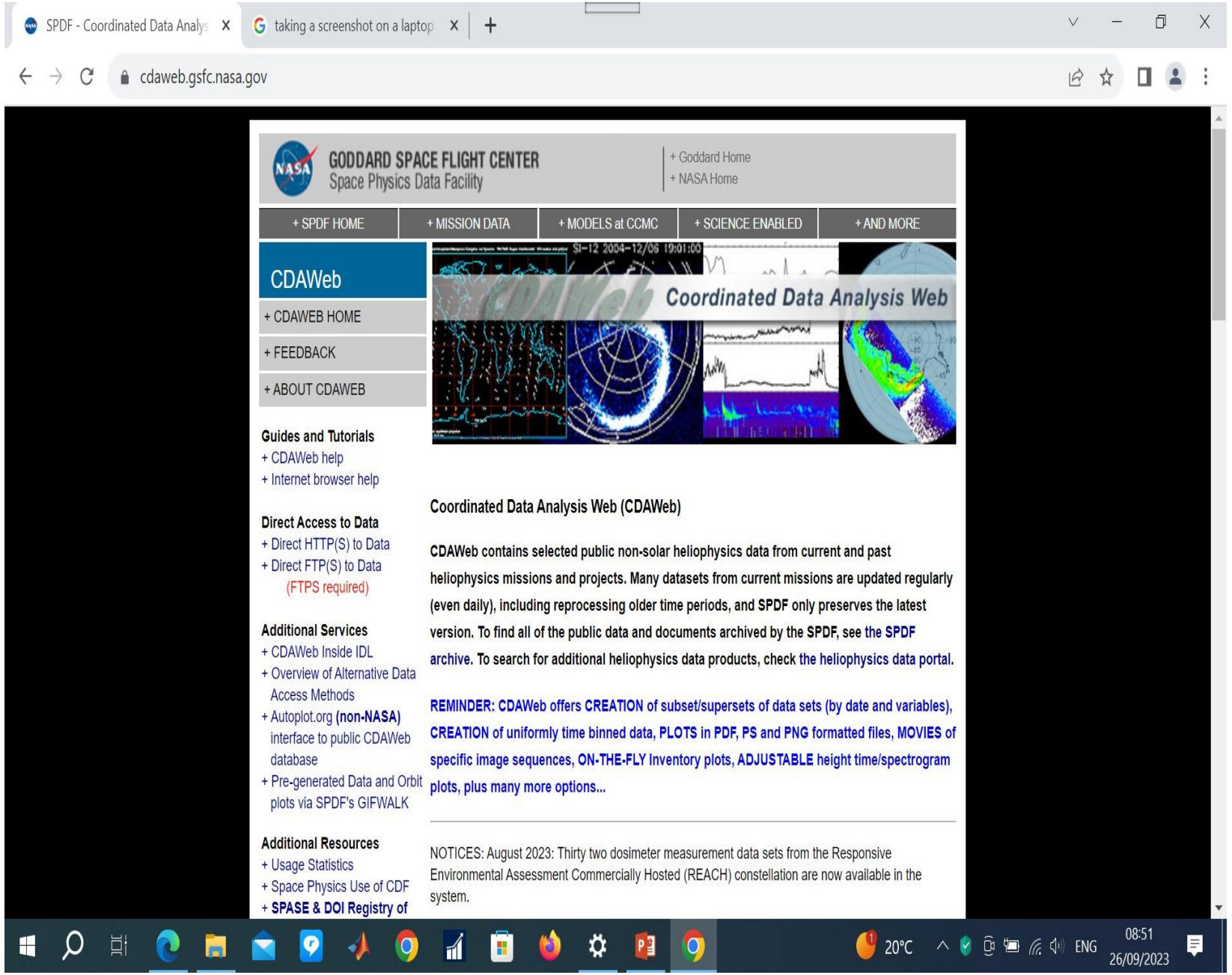


- **3.2 Geocentric solar magnetospheric (GSM)**
- This system has its X axis towards the Sun and its Z axis is the projection of the Earth's magnetic dipole axis (positive North) on to the plane perpendicular to the X axis. The direction of the geomagnetic field near the nose of the magnetosphere is well-ordered by this system. Thus it is considered the best system to use when studying the effects of interplanetary magnetic field components (e.g. B_z) on magnetospheric and ionospheric phenomena.



4. Data sources, Analysis and Interpretation

- Solar wind parameters and IMF values are measured by instruments onboard spacecrafts orbiting at L1 lagrange point. For example NASA Advanced Composition Explorer (ACE).
- These data are archived by different sites such as Coordinated Data Analysis (Workshop) Web (CDA Web).
- https://cdaweb.gsfc.nasa.gov/


SPDF - Coordinated Data Analys
taking a screenshot on a laptop
cdaweb.gsfc.nasa.gov
GODDARD SPACE FLIGHT CENTER
Space Physics Data Facility
+ Goddard Home
+ NASA Home
+ SPDF HOME
+ MISSION DATA
+ MODELS at CCMC
+ SCIENCE ENABLED
+ AND MORE
CDAWeb
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Coordinated Data Analysis Web
Guides and Tutorials
+ CDAWeb help
+ Internet browser help
Direct Access to Data
+ Direct HTTP(S) to Data
+ Direct FTP(S) to Data
(FTPS required)
Additional Services
+ CDAWeb Inside IDL
+ Overview of Alternative Data Access Methods
+ Autoplot.org (non-NASA) interface to public CDAWeb database
+ Pre-generated Data and Orbit plots via SPDF's GIFWALK
Additional Resources
+ Usage Statistics
+ Space Physics Use of CDF
+ SPASE & DOI Registry of
Coordinated Data Analysis Web (CDAWeb)
CDAWeb contains selected public non-solar heliophysics data from current and past heliophysics missions and projects. Many datasets from current missions are updated regularly (even daily), including reprocessing older time periods, and SPDF only preserves the latest version. To find all of the public data and documents archived by the SPDF, see the SPDF archive. To search for additional heliophysics data products, check the heliophysics data portal.
REMINDER: CDAWeb offers CREATION of subset/supersets of data sets (by date and variables), CREATION of uniformly time binned data, PLOTS in PDF, PS and PNG formatted files, MOVIES of specific image sequences, ON-THE-FLY Inventory plots, ADJUSTABLE height time/spectrogram plots, plus many more options...
NOTICES: August 2023: Thirty two dosimeter measurement data sets from the Responsive Environmental Assessment Commercially Hosted (REACH) constellation are now available in the system.
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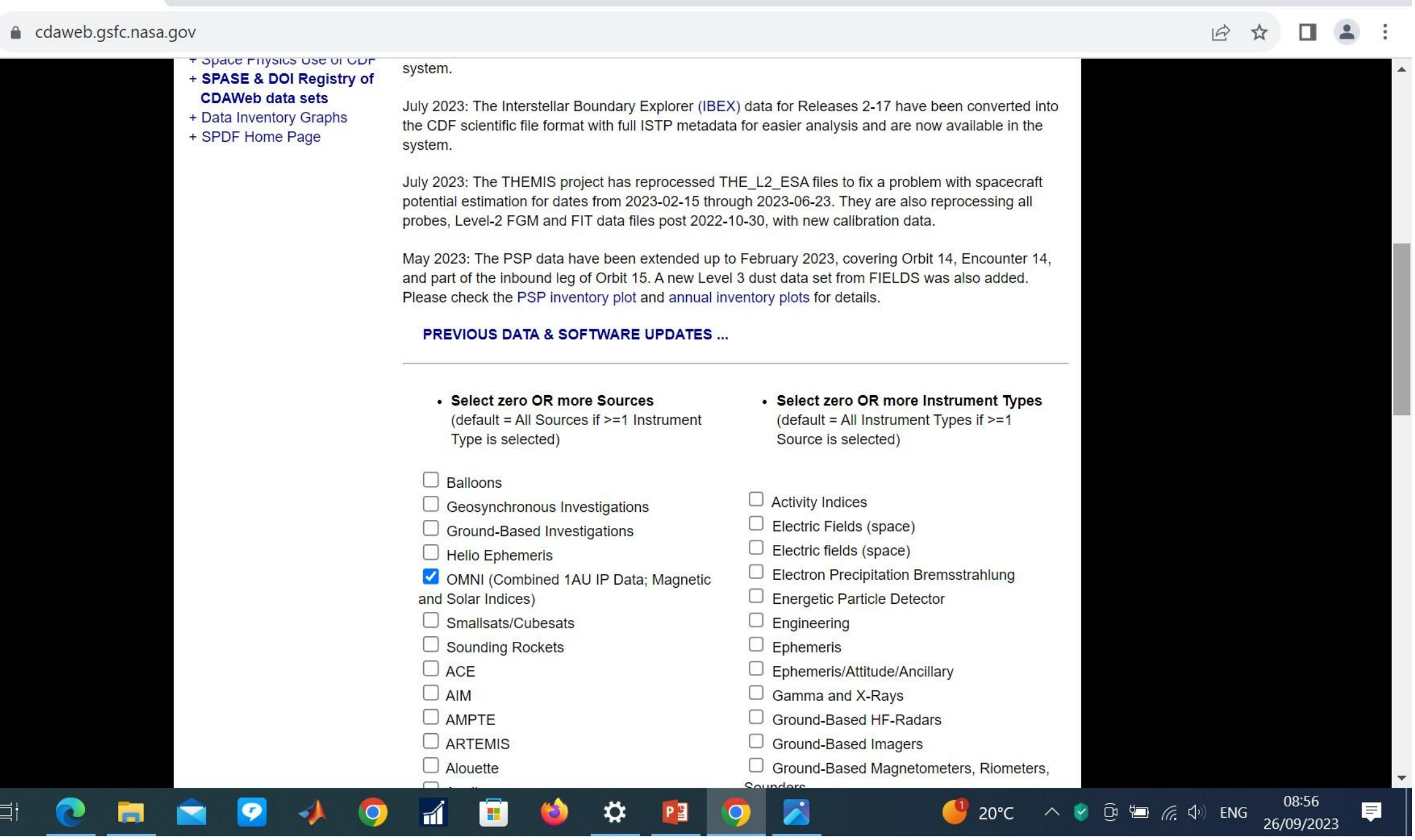
26/09/2023


cdaweb.gsfc.nasa.gov
+ Space Physics Use of CDF
+ SPASE & DOI Registry of CDAWeb data sets
+ Data Inventory Graphs
+ SPDF Home Page
system.
July 2023: The Interstellar Boundary Explorer (IBEX) data for Releases 2-17 have been converted into the CDF scientific file format with full ISTP metadata for easier analysis and are now available in the system.
July 2023: The THEMIS project has reprocessed THE_L2_ESA files to fix a problem with spacecraft potential estimation for dates from 2023-02-15 through 2023-06-23. They are also reprocessing all probes, Level-2 FGM and FIT data files post 2022-10-30, with new calibration data.
May 2023: The PSP data have been extended up to February 2023, covering Orbit 14, Encounter 14, and part of the inbound leg of Orbit 15. A new Level 3 dust data set from FIELDS was also added. Please check the PSP inventory plot and annual inventory plots for details.
PREVIOUS DATA & SOFTWARE UPDATES ...
Select zero OR more Sources (default = All Sources if >=1 Instrument Type is selected)
Balloons
Geosynchronous Investigations
Ground-Based Investigations
Helio Ephemeris
OMNI (Combined 1AU IP Data; Magnetic and Solar Indices)
Smallsats/Cubesats
Sounding Rockets
ACE
AIM
AMPTE
ARTEMIS
Alouette
Select zero OR more Instrument Types (default = All Instrument Types if >=1 Source is selected)
Activity Indices
Electric Fields (space)
Electric fields (space)
Electron Precipitation Bremsstrahlung
Energetic Particle Detector
Engineering
Ephemeris
Ephemeris/Attitude/Ancillary
Gamma and X-Rays
Ground-Based HF-Radars
Ground-Based Imagers
Ground-Based Magnetometers, Riometers,
20°C
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26/09/2023

cdaweb.gsfc.nasa.gov/cgi-bin/eval1.cgi

+ FEEDBACK

CDAWeb Data Selector

SELECT AT LEAST ONE DATA SET below before pressing the "Submit" button to continue.

SELECT ALL checkboxes
CLEAR ALL checkboxes

Submit

- [ ] **OMNI_HRO_1MIN:** OMNI Combined, Definitive, 1-minute IMF and Plasma Data Time-Shifted to the Nose of the Earth's Bow Shock, plus Magnetic Indices - J.H. King, N. Papatashvilli (AdnetSystems, NASA GSFC)
  [Available Time Range: 1981/01/01 00:00:00 - 2023/08/31 23:59:00] Info Metadata
- [x] **OMNI_HRO_5MIN:** OMNI Combined, Definitive, 5-minute IMF and Plasma, and Energetic Proton Fluxes, Time-Shifted to the Nose of the Earth's Bow Shock, plus Magnetic Indices - J.H. King, N. Papatashvilli (AdnetSyst NASA GSFC)
  [Available Time Range: 1981/01/01 00:00:00 - 2023/08/31 23:55:00] Info Metadata
- [ ] **OMNI_HRO2_1MIN:** OMNI Combined, Definitive 1-minute IMF and Definitive Plasma Data Time-Shifted to the Nose of the Earth's Bow Shock, plus Magnetic Indices - J.H. King, N. Papatashvilli (AdnetSystems, NASA GS
  [Available Time Range: 1995/01/01 00:00:00 - 2023/08/31 23:59:00] Info Metadata
- [ ] **OMNI_HRO2_5MIN:** OMNI Combined, Definitive 5-minute IMF and Definitive Plasma, and Energetic Proton Fluxes, Time-Shifted to the Nose of the Earth's Bow Shock, plus Magnetic Indices - J.H. King, N. Papatashvilli (AdnetSystems, NASA GSFC)
  [Available Time Range: 1995/01/01 00:00:00 - 2023/08/31 23:55:00] Info Metadata
- [ ] **OMNI2_H0_MRG1HR:** OMNI Combined, Definitive, Hourly IMF and Plasma Data, and Energetic Proton Fluxes, Time-Shifted to the Nose of the Earth's Bow Shock, plus Solar and Magnetic Indices - J.H. King, N. Papitas (ADNET, NASA GSFC)
  [Available Time Range: 1963/01/01 00:00:00 - 2023/09/18 12:00:00] Info Metadata
- [ ] **OMNI_COHO1HR_MERGED_MAG_PLASMA:** OMNI Combined merged hourly magnetic field, plasma and ephermis data - J.H. King, N. Papatashvilli (AdnetSystems, NASA GSFC)
  [Available Time Range: 1963/01/01 00:00:00 - 2023/09/13 00:00:00] Info Metadata

Submit Reset

NASA Official: Robert M. Candey
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cdaweb.gsfc.nasa.gov/cgi-bin/eval2.cgi

DAWeb Data Explorer

Select start and stop times from which to GET or PLOT data:

tart time (YYYY/MM/DD HH:MM:SS.mmm): 2001/04/10 00:00:00.000

top time (YYYY/MM/DD HH:MM:SS.mmm): 2001/04/14 00:00:00.000

Compute uniformly spaced binned data for scalar/vector/spectrogram data (not available with noise filtering)

Use spike removal to filter data without binning (not available with noise filtering)(Warning: Experimental !!).

Select an activity:

Data Availability Chart : *Generate a chart showing when data is available for the selected data set(s) and time range (Select > 1day).*

Plot Data : *select one or more variables from list below and press submit.*

- **Also create PS and PDF best quality outputs** (all plot types except images and plasmagrams).
  Many panels per dataset are allowed but <=4 panels optimal for standard Y-axis height and single page display.
- **Use coarse noise filtering** to remove values outside 3 deviations from mean of all values in the plotted time interval.
- **Change the X-axis width** for time-series and spectrogram PNG plots (NEW default=3). NEW
- **Change the Y-axis height** for time-series and spectrogram plots (NEW default=2). NEW
- **Combine all time-series and spectrogram plots**, for all requested datasets, into one plot file.
- **Plot overlay options.**

List Data (ASCII/CSV): *select one or more variables from list below and press submit. (Works best for < 31 days)*

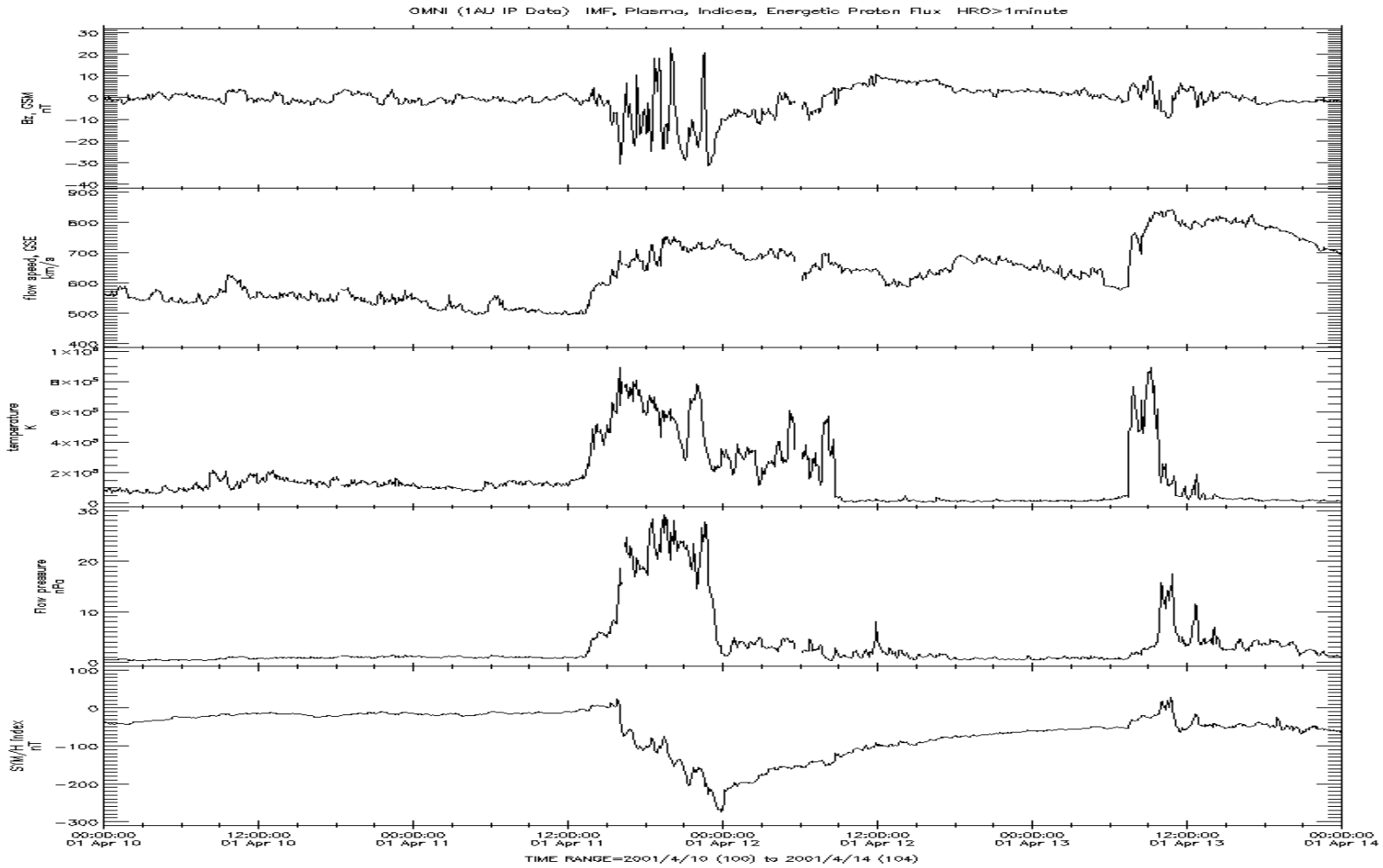
Download original files : *press submit button to retrieve list of files. (Max. 200 days - use HTTPS site for larger requests)*

Create V3.9 CDFs for download: *select one or more variables from the list below and press submit.* NEW

Create audio files based on data from selected variables. *More information about audification.*

Note: CDF patch required for reading Version 3.9 CDFs in IDL or MATLAB.
Get CDFX - IDL GUI plotting/listing toolkit software. To be used with either the daily or "created" CDF files available above.

Geomagnetic storm time



CDAWeb Data Explorer

Select start and stop times from which to GET or PLOT data:

Start time (YYYY/MM/DD HH:MM:SS.mmm): 2001/04/10 00:00:00.000

Stop time (YYYY/MM/DD HH:MM:SS.mmm): 2001/04/14 00:00:00.000

☐ **Compute uniformly spaced binned data for scalar/vector/spectrogram data (not available with noise filtering)**

☐ **Use spike removal to filter data without binning** (not available with noise filtering)(Warning: Experimental !!).

Select an activity:

○ Data Availability Chart : *Generate a chart showing when data is available for the selected data set(s) and time range (Select > 1day).*

○ Plot Data : *select one or more variables from list below and press submit.*

◉ List Data (ASCII/CSV): *select one or more variables from list below and press submit. (Works best for < 31 days)*

- ☐ Output listing times as year and seconds of year (Default is dd-mm-yyyy hh:mm:ss)
- ☐ **CSV options.**

○ Download original files : *press submit button to retrieve list of files. (Max. 200 days - use HTTPS site for larger requests)*

○ Create V3.9 CDFs for download: *select one or more variables from the list below and press submit.* NEW

○ Create audio files based on data from selected variables. *More information about audification.*

Note: CDF patch required for reading Version 3.9 CDFs in IDL or MATLAB.
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GSFC)

Available dates: 1981/01/01 00:00:00 - 2023/08/31 23:55:00
(Continuous coverage not guaranteed - check the inventory graph for coverage)

- [ ] OMNI ID code for the source spacecraft for time-shifted IMF values (see OMNI documentation link for codes)
- [ ] OMNI ID code for the source spacecraft for time-shifted IP plasma values (see OMNI documentation link for codes)
- [ ] Number of fine time scale points in IMF averages
- [ ] Number of fine time scale points in plasma averages
- [ ] Percent interpolated
- [ ] Timeshift (seconds)
- [ ] RMS Timeshift (seconds)
- [ ] Time between observations (seconds)
- [ ] Magnitude of avg. field vector (nT) (last currently-available OMNI B-field data Aug 29, 2023)
- [ ] Bx (nT), GSE
- [ ] By (nT), GSE
- [ ] Bz (nT), GSE
- [ ] By (nT), GSM, determined from post-shift GSE components
- [x] Bz (nT), GSM, determined from post-shift GSE components
- [ ] RMS SD B scalar (nT)
- [ ] RMS SD field vector (nT)
- [x] Flow Speed (km/s), GSE
- [ ] Vx Velocity (km/s), GSE
- [ ] Vy Velocity (km/s), GSE
- [ ] Vz Velocity (km/s), GSE
- [ ] Proton density (n/cc) (last currently-available OMNI plasma data Aug 29, 2023)
- [x] Temperature (K)
- [x] Flow pressure (nPa)
- [ ] Electric Field (mV/m)
- [ ] Plasma beta

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CDAWeb
+ FEEDBACK

Available CDAWeb data from 2001/04/10 00:00:00.000 to 2001/04/14 00:00:00.000

Select dataset listings to view/download:

OMNI_HRO_5MIN

(click here for) Combined Dataset Listing (tar/gzip, all times and all datasets selected)

OMNI_HRO_5MIN_65197.txt (111K)

gzip listing (21K)

Combined Listing (tar/gzip, all times and all datasets selected) (21K)

Notes:

- Click on the hyperlinked words above to view/download the listings for the selected datasets.
- Listings are often wider than the screen, so listings saved to disk must be saved as **"source"** (AS IS) and not as **"text"** to avoid wrapping the lines.
- Very wide listings (many variables or variables with many dimensions) may not correctly display with all browsers, even once downloaded as a file. Listings of this nature can only be viewed when they are downloa and then opened with a text or word processing editor.
- Listings and plots are automatically deleted after 8 hours (DO NOT SAVE THE URLs TO THESE FILES) **-- save these files to your computer now**.

<< Previous time range | Next time range >> NEW

>> Zoom IN time range << | << Zoom OUT time range >> NEW

< Pan left | Pan right > NEW

NEW

```
#     CDFMAJOR                        COL_MAJOR
#
#              ***********************************
#              ****  RECORD VARYING VARIABLES  ****
#              ***********************************
#
#  1. Epoch Time
#  2. Bz (nT), GSM, determined from post-shift GSE components
#  3. Flow Speed (km/s), GSE
#  4. Temperature (K)
#  5. Flow pressure (nPa)
#       NOTES:  Derived parameters are obtained from the following equations. Flow pressure = (2*10**-6)*Np*Vp**2 nPa (Np in cm**-3, Vp in km/s, subscript p for proton)
#  6. SYM/H - 5-minute SYM/H index,from WDC Kyoto (1981/001-2023/243)
#
EPOCH_TIME                    BZ,_GSM FLOW_SPEED,_GSE   TEMPERATURE FLOW_PRESSURE SYM/H_INDEX
dd-mm-yyyy hh:mm:ss.ms             nT            km/s             K           nPa          nT
10-04-2001 00:00:00.000     -0.920000         567.400       76474.0      0.520000         -36
10-04-2001 00:05:00.000     -0.120000         559.600       80357.0      0.480000         -37
10-04-2001 00:10:00.000     -0.780000         560.400       83030.0      0.460000         -38
10-04-2001 00:15:00.000      -1.39000         558.500       77326.0      0.480000         -40
10-04-2001 00:20:00.000      0.300000         557.000       102082.      0.450000         -41
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10-04-2001 00:30:00.000    -0.0700000         557.800       93375.0      0.440000         -43
10-04-2001 00:35:00.000      -1.98000         573.800       61681.0      0.560000         -42
10-04-2001 00:40:00.000      -1.52000         571.500       70887.0      0.510000         -42
10-04-2001 00:45:00.000     -0.820000         556.500       84724.0      0.450000         -43
10-04-2001 00:50:00.000     -0.950000         558.200       78901.0      0.440000         -43
10-04-2001 00:55:00.000     -0.960000         558.200       72968.0      0.470000         -43
10-04-2001 01:00:00.000      -1.40000         567.800       83915.0      0.550000         -42
10-04-2001 01:05:00.000      -1.42000         584.600       79118.0      0.680000         -42
10-04-2001 01:10:00.000     -0.940000         585.600       85871.0      0.530000         -41
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10-04-2001 01:50:00.000     -0.790000         549.100       75600.0      0.420000         -44
10-04-2001 01:55:00.000      1.28000         558.100       69656.0      0.570000         -44
```
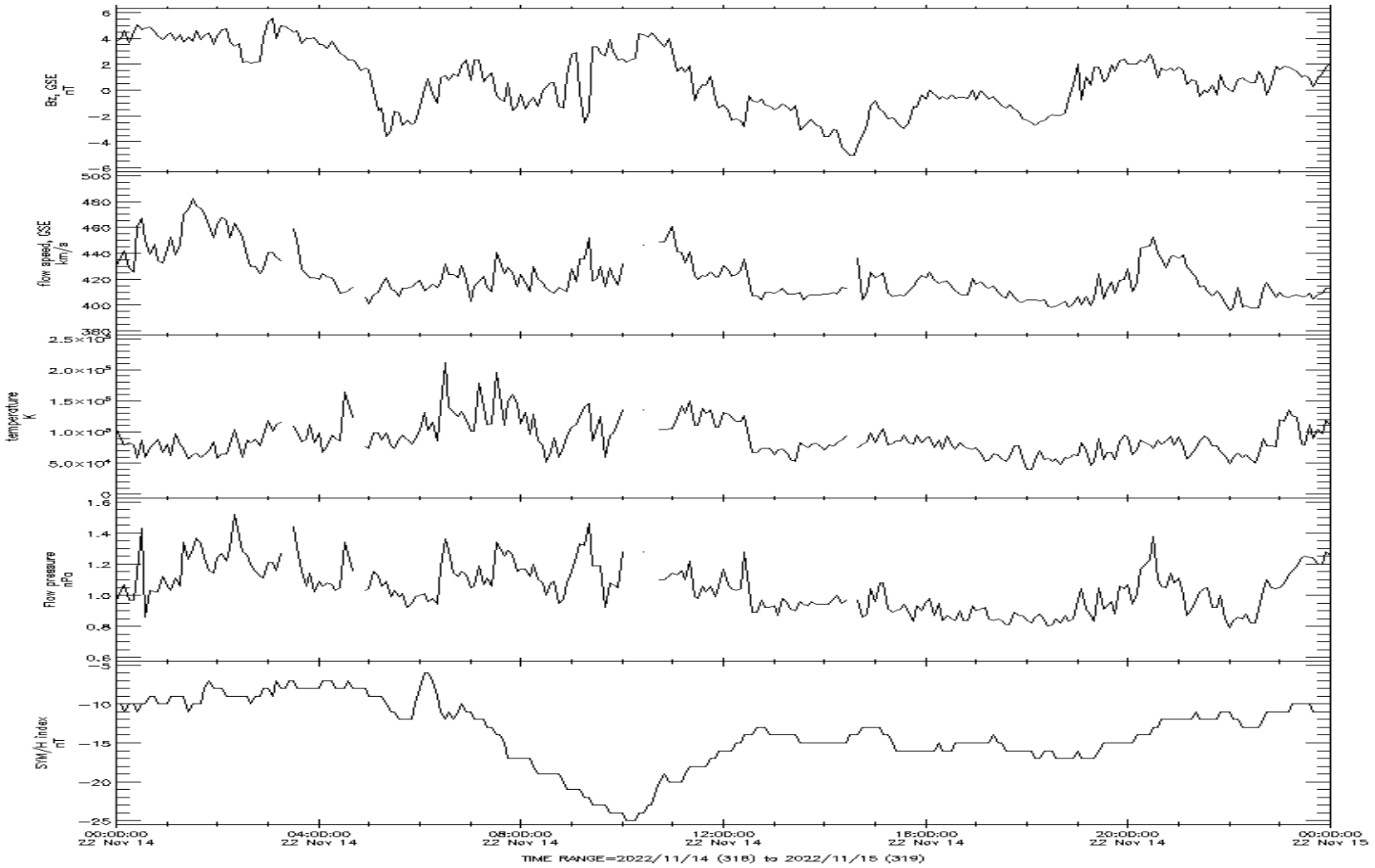

Quiet time


Bz, GSE
nT
flow speed, GSE
km/s
temperature
K
Flow pressure
nPa
SYM/H index
nT
00:0D:00
22 Nov 14
04:0D:00
22 Nov 14
08:0D:00
22 Nov 14
12:0D:00
22 Nov 14
16:0D:00
22 Nov 14
20:0D:00
22 Nov 14
00:0D:00
22 Nov 15
TIME RANGE=2022/11/14 (318) to 2022/11/15 (319)

Assignment

a) Identify quiet time and geomagnetic storm time

b) Using an MATLAB or python plot the IMF Bz and solar wind speed for the quiet time and geomagnetic storm

c) Interpret the two results.

THANK YOU