Tracking a Solar Storm: An Expert-Jigsaw Analysis

One way to describe a solar storm is to follow how it evolves in the different domains of the space environment, and how each domain affects the other domains in the system. These domains are broadly divided into four main categories: the solar corona, solar wind/heliosphere, magnetosphere, and ionosphere. In this each member of your group will become an "expert" in one of these domains, and then you will come back to the group and put the pieces of the "puzzle" together.

Audience: advanced undergraduates or graduate students in a specialized course on space physics.

Goals:

- Explore a broad overview of the space weather system
- Explore the various data sets and simulation results available in a particular domain
- Understanding how the space physics community organizes itself into specialized domains
- practice working with others across space physics domains to develop a systems view of the event

Expert Groups

Divide up into "Expert Groups" to analyze one set of data detailed in the links below.

Date	Solar Corona	Solar Wind	Magnetosphere	Ionosphere
2022-2-01 (Starlink)	Solar Surface Solar Corona	Solar Wind Data at L1 Solar Wind Models	Kp Index and GOES Data Global Simulation Results	TEC Maps Ionosphere Models

Divide up into "Expert Groups" to analyze one of the layouts.
Each "Expert Group" will analyze one layout.

- **Does the cygnet show observational data or simulation results?**
  - **If it is data, how is it collected? What spacecraft or ground station was used? Where is the spacecraft located? What kind of instrument is collecting it?**
  - **If it is simulation results, what model was used? What are the inputs to the model?**
- **What are the axes plotted? What is the scale?**
  - **Does the scale change if you are looking at multiple time steps?**
- **What is this data used for? How do you interpret the data shown in the cygnet?**
- **What other data do you think would be helpful?**

- **What predictions can you make about what the other expert groups will see?**
- **Summarize your findings in a document that includes *a sketch* and *a table*.**

Specific Questions for the Expert Groups

Solar Surface and Coronagraphs Groups

Solar Chromosphere Images

- You can find a summary of these instruments here https://aia.lmsal.com/public/instrument.htm

SOHO Coronagraphs

- More about these instrument here https://lasco-www.nrl.navy.mil/index.php?p=content/about_lasco

1) See this chart for X-Ray classification.
2) Do all sunspots have active regions associated with them?
3) Are all active regions associated with sunspots?
4) How would you define a solar active region? What characteristics does it have?
5) Identify possible solar flare events.
   What criteria do you use to define the solar flare event?
   Is there more than one event?
6) Identify the times when CME's first appear.
   Are all the coronagraph images consistent from one to the other?
   Are all the solar flares associated with a CME?
7) Is the CME Earthbound? How can you tell? (You will want to check the position of the STEREO space craft https://stereo-ssc.nascom.nasa.gov/cgi-bin/make_where_gif) Can you tell if it is traveling towards or away from the observers location (Earth or STEREO)
8) What else can you learn or explain from this data?

Solar Wind Groups
ACE & DSCOVR Data:
(Note the location of ACE and DSCOVR)

- The three panels on the left show the plasma parameters of density, bulk speed, and temperature. The top panel on the right shows the magnetic field (Which components are plotted?)
- The bottom panel on the right shows the energetic particle (protons) flux.

Solar Wind Models

- The model results shown are from the Enlil Solar Wind model. You can find some details about this model here. https://ccmc.gsfc.nasa.gov/models/ENLIL~2.8f

1) Is there evidence for the passage of a CME or a CIR in this data?
2) In terms of the solar wind plasma parameters, what are the signatures of the passage of a CME (Coronal Mass Ejection)? Note the date and time.
3) Based on the model results describe the global shape of the CME? How does this change the global magnetic field structure of the Heliosphere?
4) Based on the model results, roughly what solar angle of the heliosphere is affected by the CME?
5) Compare the model results timeline plot of the density and velocity to the ACE/DSCOVR measurements of the solar wind. What does the model get right? Where are the model and the data inconsistent? Which do you trust more?
6) What does the GOES Proton data indicate?

Magnetosphere

GOES Data:

- The top left panel shows the Global KP derived from ground magnetometers and the top right panel shows the magnetic field measured by one of the GOES satellites in geosynchronous orbit. (see the "details" tab at this site: https://www.swpc.noaa.gov/products/goes-magnetometer)
- The bottom panel shows the energetic radiation belt electrons at GOES orbit.

1) *Identify the quiet time and disturbed time in this data.*
2) *Based on this data, how many CME's do you think impacted the magnetosphere? What are the indicators?*
3) *What drives the high energy electron flux?*
4) *What drives the high energy proton flux? (Included in the solar wind data)*

Models:

- The top panel shows the global magnetosphere simulation painted with plasma density. Selected field lines are traced throughout the magnetosphere. Note that these are projections of 3-D field lines so they may appear to cross, but do not.
- The lower left panel shows a close-up of a similar simulation painted with magnetosphere current. The white line indicates the location of the magnetopause.
- The lower right panel shows a plot of the distance of the magnetopause from the Earth.

5) *What are the indicators in the model results of the passage of the CME?*
6) *What are the effects on the magnetosphere when the CME passes?*
7) *Why might spacecraft in geosynchronous orbit be affected?*
8) *Is there any reason to question what the simulation is telling you?*

Ionosphere:

GNSS GPS derived TEC "Data":

This "data" is derived from GPS errors caused by changes in signal propagation due to dispersion by the ionosphere. More information can be found here https://cddis.nasa.gov/Data_and_Derived_Products/GNSS/gnss_ionodctec.html

1) What day-to-day changes do you see?
   Record times and locations (particularly latitude) of daily variations.
2) Are the differences positive or negative?
3) When do you think the event started?
4) Is there anything surprising about these images?
   https://www.aurorawatch.ca/content/view/213/64/

Models:

5) Do you see significant changes from day to day in the structure of the ionosphere as shown by these results?
6) Does the structure of the ionosphere change significantly at any given time?
   (Pay careful attention to the color scales for the animation.
   Are they fixed or do they change?)

7) Can you interpret parameters plotted? What do they represent? What could cause these changes and what effects might you expect there to be?

Jigsaw Groups

Your jigsaw groups are now made up of one person from each of the expert groups.

- Each expert should explain their findings to the rest of the group.
- *How do the findings of each expert group relate to each other?*
- Devise a way to organize your findings and present it to the other groups. You may try one of the following:
    - Time Line
    - Event Concept Map
    - Summary of Storm Impacts
    - Some other approach?
- *Consider the following questions as you organize the data:*
    - *What are the initiators of the event?*
      Which data sources indicate those?
    - *What are the impacts of the event?*
      Which data sources indicate those impacts?
    - *How do the initiators connect to the impacts?*