TRACKING A SOLAR STORM – Part 1
The Process

When a Coronal Mass Ejection (CME) from the Sun is observed, we know there will soon be effects felt here on Earth. These effects are the result of a solar storm. In order to understand the relationships between the events on the Sun and the subsequent effects here on Earth, there are several satellites making continuous observations of the Sun, the Earth and the space environment near Earth. The following set of steps can be used to track the progress of a solar storm:

1. Refer frequently to websites that monitor space weather.
2. When a CME is reported, immediately begin to monitor websites of satellites that observe the solar wind and interplanetary magnetic field.
3. Also begin checking websites of satellites that monitor the region around Earth containing the magnetosphere.
4. Finally, look at websites containing observations made from the surface of Earth.

Each of the preceding steps will be described in detail below, followed by a step-by-step case study of the July 14, 2000 CME and solar storm.

1. Space Weather

One of the best sites for space weather information is **Space Weather Now**:

http://www.sec.noaa.gov/SWN/

This site contains descriptions of current and recent (past 24 hours) conditions for Geomagnetic Storms, Solar Radiation Storms and Radio Blackouts. NOAA Space Weather Scales are given to describe the severity of each type of storm. Recent images of the Sun, active regions on the Sun, a map of the auroral zone and real-time solar wind information are included.

Links are provided to

Today's Space Weather :	satellite data plots showing current conditions
Latest Alert, Warning, or Watch:	latest Magnetic K-Index is given
Last Space Weather Bulletin	the most recent Official Space Weather Advisory issued by NOAA Space Environment Center Boulder, Colorado, USA and an archive of the advisories for the last 6 months is included.

Another good site is **SOHO: THE SOLAR AND HELIOSPHERIC OBSERVATORY**:

http://sohowww.nascom.nasa.gov/

CME events appear as headlines at the top of the home page and the **What's New** link in the upper left leads to further information.

2. Solar Wind Observing Satellites

A good resource for solar wind information is ACE, Advanced Composition Explorer:
ACE orbits in the same region as SOHO, which is the L1 position between Earth and the Sun where the gravitational effects cancel. The L1 position is 1.5 million kilometers from Earth, or about 1% of the distance to the Sun. ACE will detect changes in the solar wind and solar magnetic field minutes before those changes reach the magnetosphere of Earth.

http://helios.gsfc.nasa.gov/ace/ace.html

Select **Online Data**
Select **Real Time**
Select **ACE Real-Time Solar Wind (RTSW) Data**
Select **Dynamic Plots**
Select **24 hrs MAG_SWEP**
This will display five graphs. The top one and the third and forth one down are important for our purposes:
The top graph give magnetic field magnitude (|B|) (white) and the z-component (B_z) (red).
The third one down gives the solar wind density in particles per cm^3.
The fourth one down gives the solar wind speed in kilometers per second.

Over the hours and days after the CME, watch for changes:

1. In magnetic field: the magnitude will increase and the z-component may go negative. (If B_z becomes negative and large, the storm effects will likely be large.)
2. Solar wind density will increase as the plasma nears Earth.
3. Solar wind speed will increase.

3. Impacts on Earth's Magnetosphere

An excellent resource for impacts on Earth's magnetosphere is IMAGE, the Imager for Magnetopause-to-Aurora Global Exploration.

http://image.gsfc.nasa.gov/

Since IMAGE travels in a long, elliptical orbit, it is important to compare views from IMAGE from the same position in its orbit. The best position to get a full-Earth view is from the apogee position, the point in the orbit of IMAGE where it is farthest from Earth. The following procedure will determine the times of apogee.

Select **IMAGE Orbital Plots**
Change the **Date Format to YYYYMMDD** (unless you prefer using **YYYYDDD**)
Under **Dat**e, input the date of the CME
Select **Update Data/Plot type**

From the three position plots, determine the time of apogee to the nearest hour and note it. Use the hour marks on the orbit tracks and estimate the time when IMAGE is farthest from Earth.
Select **Next.** This will display the next orbit.
Again, note the date and time of apogee.
Continue this process for several orbits (each orbit is approximately 14 hours)
Use this list of apogee times when selecting time frames for viewing IMAGE data.

Return to:

http://image.gsfc.nasa.gov/

Under **IMAGE Data and Ancillary Products**
Select **IMAGE CDAWEB**
Under **Select one or more Sources:**, select **IMAGE**
Under **Select one or more Instrument Types**:, select **Imagers (space)**
Submit

This will bring up the **CDAWeb Data Selector** screen listing the instruments on IMAGE. These instruments and the data provided by each are described below. One of the main things of interest to space scientists is the timing and sequence of the various events and impacts of a solar storm. In analyzing the data, these aspects will be emphasized.

FUV – Far Ultraviolet Camera

The **FUV** instrument employs three detectors: **WIC**, **GEO**, and **SI**. We will use data from the most general instrument, WIC.

The Wideband Imaging Camera (**WIC**) is designed to image the whole Earth and the auroral oval from satellite distances greater than 4 Earth radii from the center of the Earth. It selects the spectral range between 140 nm and 160 nm in the ultraviolet part of the optical spectrum. A curved image intensifier is optically coupled to a CCD and the optics provides a field of view of 17x17 degrees. The temporal resolution between two images is 120 s and the size of the final images is 256x256 pixel elements, corresponding to spatial resolutions of less than 100 km at apogee distances. The **WIC** Characteristics are summarized below:

Spectral range	140-160 nm
Field of view	17x17 degrees
Resolution elements of less than	0.1 degrees
Temporal resolution	120 s
Goal sensitivity	100 R in final image

From the **CDAWeb Data Selector** screen, unselect all instruments except **IM_K0_WIC: .**
Submit
Input a **Start time** that is 2 hours before apogee and a **Stop time** 2 hours after apogee starting from the time of the CME
(Note that **Select an activity: Plot data**: is the default selection.)
Select **FUV/WIC LBH Auroral Images (raw…)**
Submit.

This will return a large group of individual images with their times from the WIC instrument. Scan down the images looking for changes. Select any individual image to see an enlarged view. When you find an area of interest, note the times and go **back**.

Change the **Start** and **Stop** times to include the next apogee time and work your way through the next few days looking for changes and noting the dates and times.

EUV – Extreme Ultraviolet Camera

The magnetospheric structure that EUV will study is the plasmasphere, the cold dense plasma near Earth in the inner magnetosphere. The primary component of the plasmasphere is ionized hydrogen, or protons. Atoms and ions give off electromagnetic waves when the electrons change from one energy level to another. Protons, since they have no electrons, do not radiate electromagnetic energy. EUV will examine the ultraviolet radiation given off by singly ionized helium (He^{+}) with a wavelength of 30.4 nm. From this, knowing the proportion of hydrogen to helium in the plasmasphere (H:He = 4:1), an image of the plasmasphere can be formed

Unselect all except **IM_K0_EUV:**
Submit
Input a **Start time** that is 2 hours before apogee and a **Stop time** 2 hours after apogee starting from the time of the CME
Select **---> EUV ion images, as above (large format)** (Second selection down)
Submit.

This will return a group of individual images in the large format with their times from the EUV instrument. Scan down the images looking for changes. Select any individual image to see an enlarged view. When you find an area of interest, note the times and go **back**.

Change the **Start** and **Stop** times to include the next apogee time and work your way through the next few days looking for changes and noting the dates and times.

Again, scan down the images looking for changes. Select any individual image to see an enlarged view. When you find an area of interest, note the times and go **back**.

Neutral Atom Imagers

Neutral atom imagers look at the ring current structure within the plasmasphere. The ring current consists of ions trapped on magnetic field lines drifting around Earth as they oscillate between the polar regions. If these ions pick up an electron they become neutral atoms and they then move inertially away from the ring current region to be counted by the neutral atom imagers. The approach to using the neutral atom imager data will be similar to that described for the ultraviolet cameras: first scan the data for a large time interval looking for changes in the data, then look at smaller time intervals in more detail.

HENA – High energy Neutral Atom Imager

HENA counts neutral atoms in six energy ranges.
From the **CDAWeb Data Selector** screen, unselect all instruments except **IM_K0_HENA.**
Submit
Input a **Start time** that is 2 hours before apogee and a **Stop time** 2 hours after apogee starting from the time of the CME
Select **---> ENA H Images @ 50-60 keV, as above (large format)**
Submit.

This will return a rather large set of images of the ring current.
Change the **Start** and **Stop** times to include the next apogee time and work your way through the next few days looking for changes and noting the dates and times. Note that the unit for the data is in "Counts", so what you are seeing is the relative number of hydrogen atoms in that energy range compared over time.

You can also look at the other HENA energy ranges available in the same way. Two other instruments, MENA and LENA, give information about still more energy ranges of neutral atoms.

RPI – Radio Plasma Imager

RPI acts as a radar to determine the locations of the magnetopause and the plasmapause.

From

http://image.gsfc.nasa.gov/

Select **IMAGE CDAWEB**
Select **IMAGE** and **Radio Plasma Imagers (space)**
Submit
From the **CDAWeb Data Selector** screen, unselect all instruments except **IM_K0_RPI: .**
Submit
Input a **Start time** that is 2 hours before apogee and a **Stop time** 2 hours after apogee starting from the time of the CME
Select **Echo Amplitude images (x=range, y=frequency, no scales)**
Submit.

What you are looking for here first is movement of the magnetopause. Select any image to view an enlargement. Note the distance to the magnetopause and look for changes in position.

4. Impacts Measured from Earth's Surface

One impact on Earth's surface of a solar storm is a change in the magnetic field at the surface. This is monitored at many locations and the results are compiled every three hours to form the **Kp index**. The value of the Kp index ranges from 0 (normal, or quiet, magnetic field) to 9 (very disturbed surface magnetic field. If the magnetopause is pushed in toward Earth, that will cause a disturbance in the surface magnetic field. An archive of Kp values, updated every three hours, can be found at:

http://sec.noaa.gov/ftpmenu/index.html

Select **Plots of Solar-Geophysical Data**
If the date of interest is in the current year, select **3-day Estimated Planetary K-indices Plots**
If the date of interest is in a prior year, use the annual **Plot Files** listed at the bottom of the page.
Select the date of interest in YYYYMMDD format. (Current day is listed first.)

The current Kp plot can also be found from **the Space Weather Now** homepage:

http://www.sec.noaa.gov/SWN/

using the **Today's Space Weather** link:

http://www.sec.noaa.gov/today.html

Several plots of space variables will appear. The Kp Index should be monitored daily (or more often) from the time the CME is reported.

Another impact measurable from Earth's surface is the **Dst Index**. The Dst Index is a measure of the variations in the horizontal component of Earth's magnetic field, the geomagnetic field. The Dst is determined by measuring the horizontal component of the geomagnetic field at several locations and comparing that value with the local value under "quiet" conditions. The Dst index is a good indicator of the progress and severity of the solar storm. The unit for measuring Dst is the nanotesla (nT). The values are typically negative and if the value is large in magnitude, that is an indication of the presence of a solar storm.

Dst values can be obtained in real-time from:

World Data Center for Geomagnetism, Kyoto
http://swdcdb.kugi.kyoto-u.ac.jp/

using the **Data Service** tab:
http://swdcdb.kugi.kyoto-u.ac.jp/wdc/Sec3.html

then, under **Indices**, select **2.Dst index [Since 1957]**
http://swdcdb.kugi.kyoto-u.ac.jp/dstdir/
then, **1.Near realtime Dst monitor**
then, **plot of this month (one month)**
http://swdcdb.kugi.kyoto-u.ac.jp/dstdir/dst1/q/Dstqthism.html

This will bring up a plot of the Dst values and a table of numerical values showing the Dst value for each hour of the current month. Scan these values and looking for large values and changes.