CSI 662/ PHYS 660 Fall 2009
Introduction to Space Weather

Project: The Chain of Sun-to-Earth Activities of Intense Geomagnetic Storms

Assigning Date: Nov. 5, 2009
Due Date: phase 1 – Nov. 19, 2009
Due Date: Final – Dec. 3, 2009

1. Objective

The objective of this project is to help students comprehend the space weather system that involves energy and mass flow throughout the Sun-Earth connection system. It is a comprehensive end-to-end project that addresses various physical processes and their possible cause-effect relationships in different space weather components, including the surface of the Sun, the Sun's corona, heliosphere, magnetosphere, and ionosphere.

An intense space weather event may have profound impacts on technological system. One recent example is the so called "Halloween storm" occurred in Oct. 2003. The international space station did a ground-commanded power down, and crews onboard took shelters in the service module during the peak exposure times. About 24% of the space missions turned off their instruments or took other protective actions. One Japanese satellite (ADEOS-2) is believed to have failed completely due to this storm. The NASA/ESA's SOHO satellite and the German satellite CHAMP failed temporarily. Some satellite based communication companies (TV and radio) reported several short-lived interruptions. Airlines restricted flight paths on several occasions due to degraded communications. GPS users reported degradation and outages with some applications. A power grid in southern Sweden experienced a one hour blackout.

2. General Requirement

Students are required to observe and study a super intensive geomagnetic storm. The intensity of a geomagnetic storm is indicated by the Dst (Disturbance Storm Time) index, which measures the depression of the horizontal magnetic field on the surface of the Earth. The depression is caused by the ring current enhancement during the storm period. A super intensive storm is classified as Dst minimum < -240 nT.

The entire study consists of five steps, each of which has specific requirements.

Step 1: physical processes on the Sun
Step 2: physical processes in the heliosphere
Step 3: physical processes in the magnetosphere
Step 4: physical processes in the upper atmosphere and ionosphere
Step 5 (optional): space weather effect and numerical simulation

3. Selection of Intense Geomagnetic Storms

During 1995 – 2005, there were in total 12 super intensive storms. These storms were among 88 major storms (Dst <= -100) studied in the Coordinated Data Analysis Workshop (CDAW) held at George Mason University in March 2005. A complete list of these storms is available online at http://solar.gmu.edu/meetings/cdaw/Data_master_table.html.

You are free to study any one of the 12 super intensive storms listed. All needed data for this project are available online through various data providers. The following events are suggested, because these are well-known well studied events. A substantial amount of data for these events has been collected at the CDAW website.

* Famous Halloween storms. Double storms, one peaked at 2003/10/30 01 UT, Dst=-363, the other peaked at 2003/10/30 23:00 UT, Dst=-400 nT

*The largest storm in solar cycle 23: 2003/11/20, Dst=-472 nT

*One largest storm: 2004/11/08 Dst=-373 nT

*One recent super storm: 2005/05/15, Dst=-263 nT

4. Specific Requirements

4.1. Step 1 - Physical Processes on the Sun

4.1.1. Identify and describe the solar sources of the super intensive storm studied

A super geomagnetic storm is always driven by a fast CME originated from the Sun's corona. It takes about 20 to 40 hours for a fast CME to propagate from the Sun to the Earth, depending on the initial speed and the kinematic evolution in the interplanetary space. A fast CME is also often associated with a major flare on the Sun, associated with a strong active region.

You are required to identify the source CME, source flare and surface source region responsive for the storm. You may refer to http://solar.gmu.edu/research/cme_storm/index.html for the source identification.

With the source identified, please study and provide the following information

- One magnetogram image (e..g, SOHO/MDI) indicating the surface source region. Briefly describe the source region.
- One coronal image (e.g., SOHO/EIT) taken at the time during the eruption. Describe what you see, and indicate the eruption feature in the image (e.g., flaring, dimming)
- One coronagraph image (e.g., SOHO/LASCO C2 or C3 image) taken at one time during the eruption. Describe what you see, and indicate the location of the CME in the image.

Note that you may need to use screen capture to extract appropriate images from mpeg movies often provided online.

4.1.2 CME timing: estimate CME onset time based on measurement by LASCO C2/C3

LASCO C2 and C3 have fields of view of 2-6 Rs, and 4-30 Rs, respectively (measured from disk center). Though a CME first appears in the C2 field of view (>2 Rs), it is initiated in an earlier time in the lower corona close to the Sun's surface. Based on the height-time measurement in the LASCO, estimate the CME onset time at the surface of the Sun using linear extrapolation method, assuming (1) CME is initiated at the surface (or at 1 Rs) and (2) CME is instantly initiated and has a constant speed in the inner corona below the C2 occulting disk. The height-time measurement data for CMEs are available at http://cdaw.gsfc.nasa.gov/CME_list/. (for the H-T data file, click on the link in the second column in the monthly event table). In the H-T file, the first three columns indicate the CME height, date and time, respectively. You could do the extrapolation using any software, e.g., IDL, Excel, and Mathematics. A graphic plot of the data points and linear extrapolation are welcome but not required.

4.1.3. CME kinetic energy, velocity and transit time to the Earth

- Assuming the mass of this CME is 10^{16} gram, calculate the kinetic energy of this CME
- Assuming the true radial velocity along the line of sight is the same as the observed projected velocity, calculate the transit time (in unit of hour) of this CME from the Sun to the Earth (distance of 1AU), and estimate the impact time (time and day, in UT format)

Useful links

Major storm list with some solar and geo-space data:
http://solar.gmu.edu/meetings/cdaw/Data_master_table.html

Major storm list with source region identification:
http://solar.gmu.edu/research/cme_storm/index.html

Online CME Catalog by GSFC/NRL
http://cdaw.gsfc.nasa.gov/CME_list/

SOHO LASCO/EIT site by NRL
http://lasco-www.nrl.navy.mil/daily_mpg/

SOHO MDI data
http://soi.stanford.edu/production/mag_gifs.html

4.2. Step 2-- Identify and Study Interplanetary Coronal Mass Ejection (ICME)

Super geomagnetic storms are directly driven by the strong and prolonged southward magnetic field embedded in the interplanetary CMEs, the counterpart of solar CME in the solar wind flow.

You are required to identify and study the ICME driver for the super storm you have chosen, based on ACE in-situ observations of plasma and magnetic field.

- Make solar wind plots (*) for at least the following parameters: magnetic field, southward magnetic field, plasma density, plasma velocity and proton temperature. The plots should be made in a reasonable time window within which the storm was driven.
- Simply describe the features in the plot(s), such as shock or discontinuity, velocity change, magnetic field change and strength, etc.

ICME Velocity and Transit Time

- Identify the timing and velocity of the shock driven by the ICME.
- Find out the true transit time, which is the difference between the onset of CME on the surface of the Sun (from phase 1) to the shock arrival time.
- Calculate the average acceleration (deceleration) of CME from the Sun to the Earth in the unit of m/s^2.

Useful References

*For making solar wind plots with ACE data
(1) Using CDAWEB online tools. Go to http://cdaweb.gsfc.nasa.gov/istp_public/. Select "ACE" (for source) and "Magnetic Fields" and "Plasma and Solar Wind" (for instrument type). Then follow the instructions to plot the data.
(2) or simple use the plots made by Dr. Richardson, available at http://solar.gmu.edu/meetings/cdaw/data/cdaw1/Richardson/ (file name in this directory indicates the date, thus the event)

4.3. Step 3—Process in the Magnetosphere

An ICME and its associated shock have profound effects in the magnetosphere. The purpose of this phase of the project is to demonstrate these effects. The solar wind data you gathered in Phase-2 is used as the necessary input.

4.3.1 The shift of magnetopause

Calculate the positions of the magnetopause (1) just before the arrival of the shock, and (2) just after the shock front. How large is the shift of the magnetopause?

You may need to use the Kallenrode (8.15) formula (page 293) to do the calculation, which is

$$d_{so} = \sqrt[6]{\frac{4B_0^{\ 2}}{2\mu_0 K\rho u^2{}_{sw}}}$$

4.3.2 Solar wind energy input into the magnetosphere

The famous ε formula is often used to estimate the solar wind energy input into the magnetosphere. One variant of it is the following, which calculates the input power

$$\varepsilon = uB_s L^2 R^2{}_E (erg / \mathrm{sec})$$

where u is the solar wind speed, Bs southern oriented magnetic field, L shell number (taken L=7), and R_E Earth radius.

(1) calculate the power at the moment with the highest Bs during the ICME/shock sheath period

(2) calculate the total energy input into the magnetospheric system, assuming the power calculated in (1) continuously lasting for 10 hours

4.4. Step 4— Processes in the ionosphere and thermosphere

The purpose of this phase of the project is to understand the thermosphere and ionosphere conditions during the storm time.

4.4.1. Thermosphere. Calculate the atmospheric N_2, O_2, and O number densities and temperature during and before the geomagnetic storm that you have been studying. The calculation can be made by the MSIS 90 empirical model atmosphere, which can be run on line at: http://omniweb.gsfc.nasa.gov/vitmo/msis_vitmo.html

Geomagnetic Latitude = 70 deg
Geomagnetic Longitude = 0 deg
Altitude = 100 km, 200 km, 1000 km
Optional inputs: default

(1) at the time of storm peak (UT time)
(2) at the same UT time but in the quiet day before the storm arrival
(3) compare the results in (1) and (2), and briefly discuss the differences and/or similarities.

4.4.2. Ionosphere. Calculate the ionospheric N_e, T_n, T_i, T_e, and percentages of O^+, N^+, H^+, O_2^+ and NO^+ ion densities during and before the geomagnetic storm that you have been studying. The calculation can be made by the International Reference Ionosphere (IRI)-2001 model, which can be run on line at:
http://omniweb.gsfc.nasa.gov/vitmo/iri_vitmo.html

Geomagnetic Latitude = 70 deg
Geomagnetic Longitude = 0 deg
Altitude = 100 km, 200 km, 1000 km
Optional inputs: default

(1) at the time of storm peak (UT time)
(2) at the same UT time but in the quiet day before the storm arrival
(3) compare the results in (1) and (2), and briefly discuss the differences and/or similarities.

4.5. Step 5 – space weather effect and numerical simulation

The following two tasks are optional. Extra credits may be given for the extra efforts.

4.5.1 (Optional) Space Weather effects.

Find out the technological and societal impacts of the space weather caused by the geomagnetic storm you are studying. You may look for online resources, e.g., news.

4.5.2 (Optional) Numerical Simulation.

"Blind" Run on CCMC models. There is a suite of numerical space weather models provided in the NASA Community Coordinated Modeling Center (CCMC) (at **http://ccmc.gsfc.nasa.gov/models/index.php**). You are able to request a model run based on the condition that you specify, and model results will be returned to you. However, you are not able to access the source code and modify the processing. You are encouraged to request a test model run from one of the CCMC model and discuss the result. The model calculation should be related to the specific storm you are studying.

5. Submission

You need to submit a project paper in electronic version. The paper shall fulfill the specific requirements for each of the five steps discussed above, and make a succinct summary in the end the paper.

The final project will be due on Dec. 3. However, in order to prevent the crunch in the final moment, you need to submit an interim paper on Nov. 19. This interim paper shall fulfill all requirements specified in Step 1 and Step 2. The final version of the paper shall also include the requirements in Step 3, Step 4 and the optional Step 5.