Original by M. Hamrin and P. Norqvist
Division of Physics,
Umeå University,
Sweden

Modified by R. Slapak, Nov. 2015
Div. of Space Technology, LTU

The Halloween Storm

In this exercise you will use provided data as well as publicly available data and overview plots from the web for an interesting events in late October, 2003 (Halloween).

Introduction

It is well-known that solar eruptions can cause severe disturbances on Earth. For example, electronic navigation can be erroneous due to variations in the geomagnetic field and due to changes in the propagation of radio waves. Moreover, power grids can overload during geomagnetic storms and substorms. Modern society is increasingly dependent on our space environment, and it is important to construct methods of predicting when and where large solar eruptions may affect our technological society.

The Halloween storm in late October, 2003, is a typical example of how the so called *space weather* can affect our society. As a consequence of some large solar eruptions when huge CMEs (Coronal Mass Ejections) were released into interplanetary space, large disturbances were at a later time observed in Earth's magnetosphere and on the ground. These physical phenomena caused a lot of disturbances in our technology. They disrupted communications, GPS systems and the United States defense operation. There was a loss of electric power for 50 000 people in the south of Sweden late on October 30. There were also

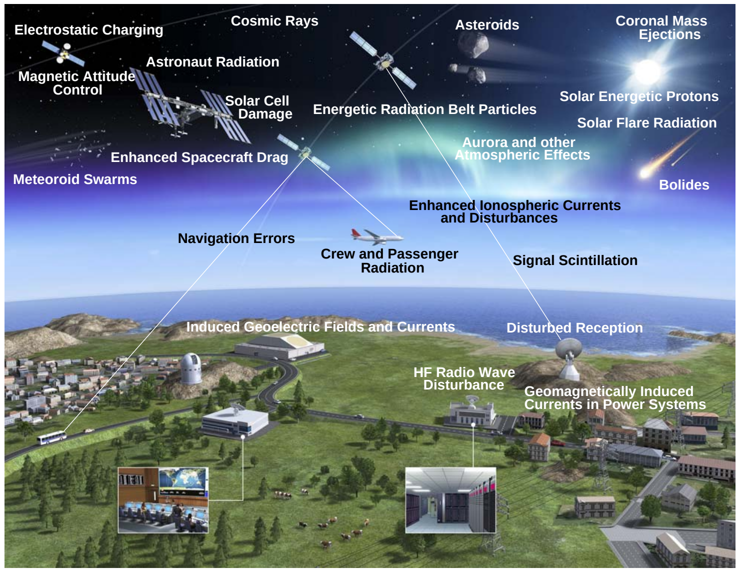

Figure 1: Space weather effects. Adapted from ESA (spaceimages.esa.int).

reported problems on many spacecraft, and the $450 Midori-2 research satellite was lost in the storm. During the storm, grand auroras were also seen at many places.

Data

The solar-wind data is provided in *ACE_MAGSWE_Data.txt*, which you will find in Fronter. Read the header in the data file carefully since it explains what data the file contains. Note especially what 'Fill Values' are used to indicate missing data or not operational instruments (data gaps). You will need to remove these 'Fill Values' to make a decent plot (see for example the matlab routine `find`). You need to make a .mat-file to be able to use the data in MatLab. Also remember that MatLab uses a special time format: days since year 0. Therefore you need to reformat the time given in the file to this format somehow. MatLab commands like `datenum`, `datestr`, `datetick` may be useful in order to make this work.

Exercise a)

In this exercise you will study the Halloween storm and analyze the chain of events starting with the solar eruptions and ending with disturbances on the Earth. You will analyze data from the sun, from the solar wind, and in the Earth's magnetosphere. The purpose is to obtain an understanding of the course of events during this famous storm.

Start by looking at some electromagnetic disturbances observed at Earth. For this purpose you will use the AE (Auroral Electrojet) and the Dst (Disturbance Storm Time) indices. Dst measures the strength of the ring current around the Earth, and AE measures the auroral electrojet (see for example `https://wiki.oulu.fi/display/SpaceWiki/Magnetic+activity+indices;`). Both indices are based on measurements from several ground based magnetometers. Start by browsing overview plots of Dst and AE indices in October and November 2003, and try to localize the time interval associated with the major disturbances, i.e., the Halloween storm as observed on Earth. When does the storm start as observed from the indices? Overview plots of the indices can be obtained from `http://wdc.kugi.kyoto-u.ac.jp/wdc/Sec3.html` where you click on 'Dst index' ('Final Dst index [1957–2009]') and 'AE index' ('Provisional AE index') respectively. The click your way to the desired overview plots for the relevant dates. It might be wise to compare AE and Dst data in October and November 2003 with other times to obtain a feeling for the typical range of variation in the indices.

The next step is to analyze some solar wind data from the ACE (Advanced Composition Explorer) satellite. ACE is a NASA spacecraft launched in 1997, and it is still operational (the fuel will last until 2024). ACE continuously monitors the solar wind by measuring the magnetic field and plasma moments. It orbits close to the *L1 Lagrange point*, which is situated between the sun and the Earth. Note the ACE consequently observes the solar wind a while before it reaches Earth and its bow shock and magnetopause.

Plot the interplanetary magnetic field (IMF), the proton density and the proton velocity, as well as the ACE position with the provided data. Can you identify the passing of the CME responsible for the Halloween storm observed on Earth? What are the signatures in the data? Do the measured magnetic field, proton density, and proton velocity differ from typical values in the solar wind? Note that there is an apparent data gap in the proton data. What could be the cause for this?

Try to make a rough estimate of how long time it takes for the huge CME investigated in this exercise to propagate from the surface of the Sun to the position of ACE. Note that you can obtain a rude estimate (interpolate by eye) on the lower limit of the earthward solar wind speed even though there is a data gap. Compare the resulting propagation time with the typical time for the solar wind to propagate from the Sun to ACE.

Also make a rough estimate of the time lag between ACE observing the huge CME and the CME hitting the Earth's magnetopause. How long do we have to prepare ourselves for the CME hitting the Earth's magnetosphere after ACE has observed it? What is the typical propagation time for the solar wind? Is it possible to identify any corresponding signatures in AE or Dst which are consistent with your estimated time lag?

Exercise b)

Search through scientific litterature (journals) for an article (or similar) that studies this particular Halloween event. Compare the results presented there with your estimates from this simple lab exercise (one or two examples at least). Discuss any similarities or disparities.

Exercise c)

The CMEs observed by ACE come from the sun. You can see them yourself in movies from the SOHO spacecraft (Solar and Heliospheric Observatory), which is a joint NASA-ESA mission designed to study the sun. SOHO was launched in 1995 and it is still operating (extended mission until 2016). SOHO orbits the sun at a distance of about $150 \cdot 10^6$ km. Using the 'SOHO Movie Theater' you can observe how a set of CMEs were launched from the sun in late October: `http://sohodata.nascom.nasa.gov/cgi-bin/soho_movie_theater`. There are various 'Image Types' in the theatre. On `http://soho.nascom.nasa.gov/data/realtime/mpeg/` you get a quick guide to the different types. If you like horror movies, you should definitively watch the CME that caused the Halloween storm. Discuss shortly what you observe, and if you can connect it somehow to the provided data.