Space Weather Forecasting and Research

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Abstract

The Space Weather Research Center (SWRC) provides experimental research forecasts and analysis for NASA robotics missions operators. Using tools and models developed at the Community Coordinated Modeling Center (CCMC), space weather forecasters monitor space weather conditions to provide advance warning and forecasts based on observations and modeling, as well as contribute to DONKI, a database logging space weather events and impacts. Space weather events include solar flares, coronal mass ejections (CMEs), radiation belt enhancements, and solar energetic particle events (SEPs). These can impact robotics missions by causing surface charging, internal charging, thermal drag, orbit decay, and communications disruptions, as well as impacts on Earth such as geomagnetically induced currents and aurora. Ongoing multidisciplinary research is being done to understand space weather drivers, introduce new methods and models, and produce more accurate forecasts.

Overview

There are several different solar events and space weather drivers

- Coronal mass ejections (CME)
- Solar flares
- Solar energetic particle (SEP) events
- High-speed streams

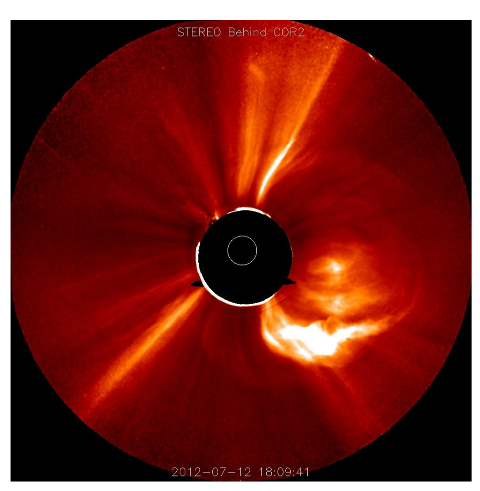
These events can interact with spacecraft, the Earth's magnetosphere, and the atmosphere

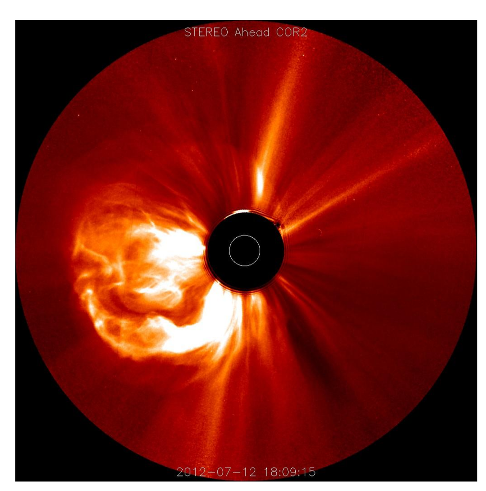
- Interplanetary shock
- Geomagnetic storm
- Magnetopause crossing
- Radiation belt enhancement
- Surface charging
- Satellite drag

Space Weather Events

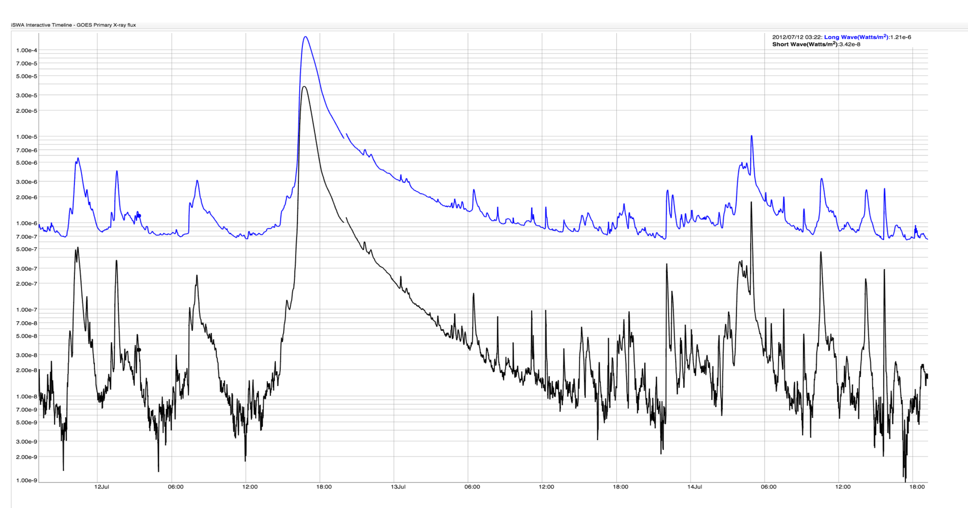
Methods of detection of space weather events vary widely with each particular event:

- Coronal mass ejections (CMEs) are massive expulsions of plasma and magnetic field from the solar corona.
- CMEs are categorized by speed using the SCORE typification system (S-type with speed less than 500 km/s, C-type with speed less than 1000 km/s, etc.)
- CMEs are typically detected in SOHO and STEREO A coronagraphs, with CME arrivals detected using ACE magnetic field and solar wind velocity monitors.

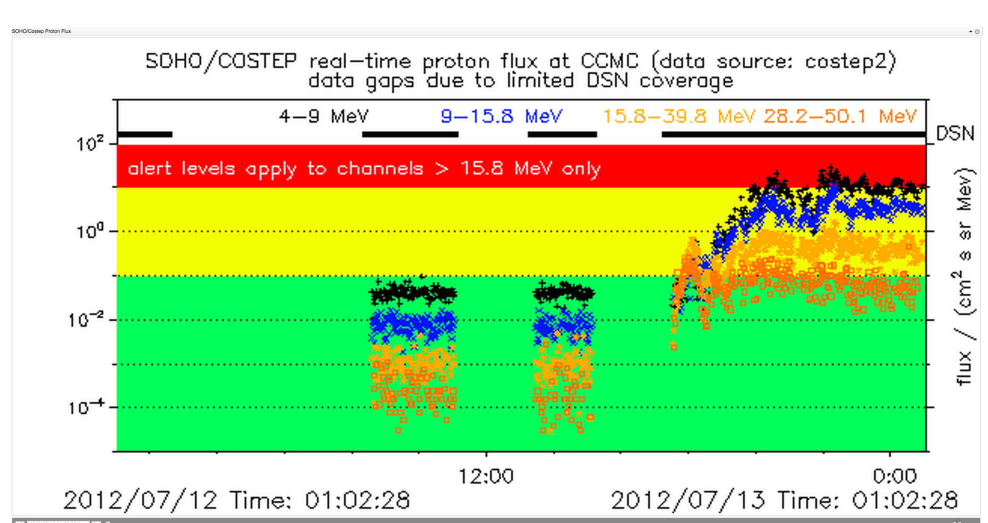




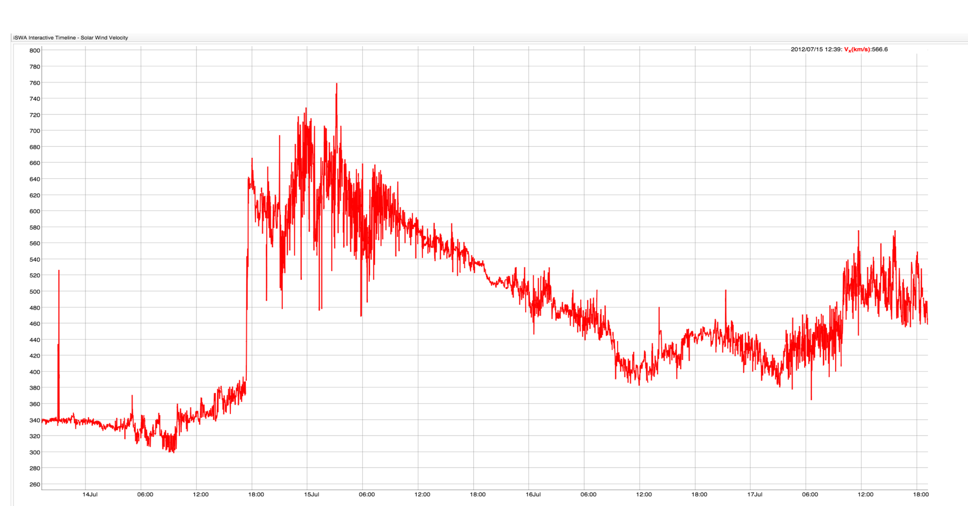
- Solar flares are periods of intense brightening on the surface of the Sun, lasting anywhere from minutes to hours.
- Flares, especially long-duration ones, often precede CMEs.
- Flares are classified by x-ray flux, with X being the highest and corresponding to a flux of greater than 10^{-4} W/m^2.
- Solar flares are both seen in SDO imagers and detected using GOES X-Ray flux monitors.



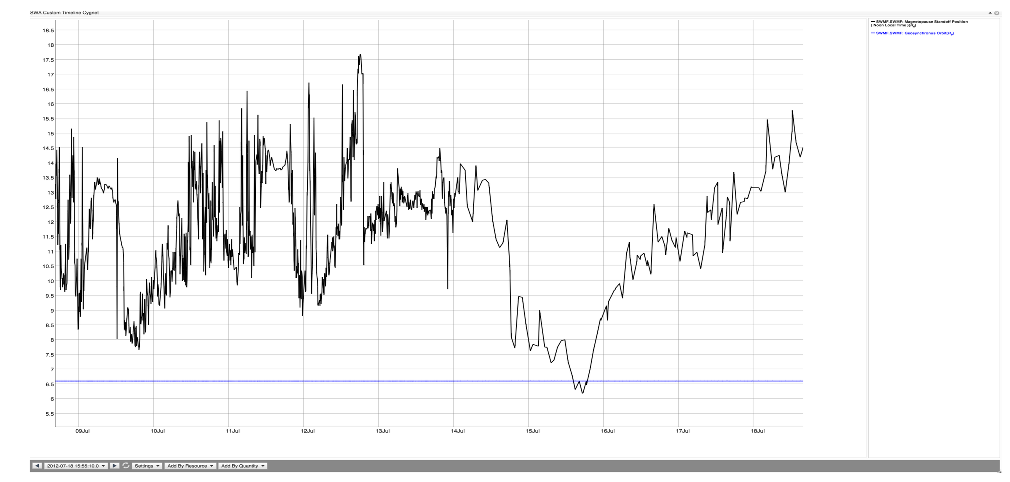
- Solar energetic particles are high-energy protons and ions originating in the Sun and are generally associated with solar flares and CMEs.
- SEPs travel along magnetic field lines, unlike CMEs, which travel roughly radially.
- SEP events are detected using either GOES or SOHO/COSTEP proton flux monitors.



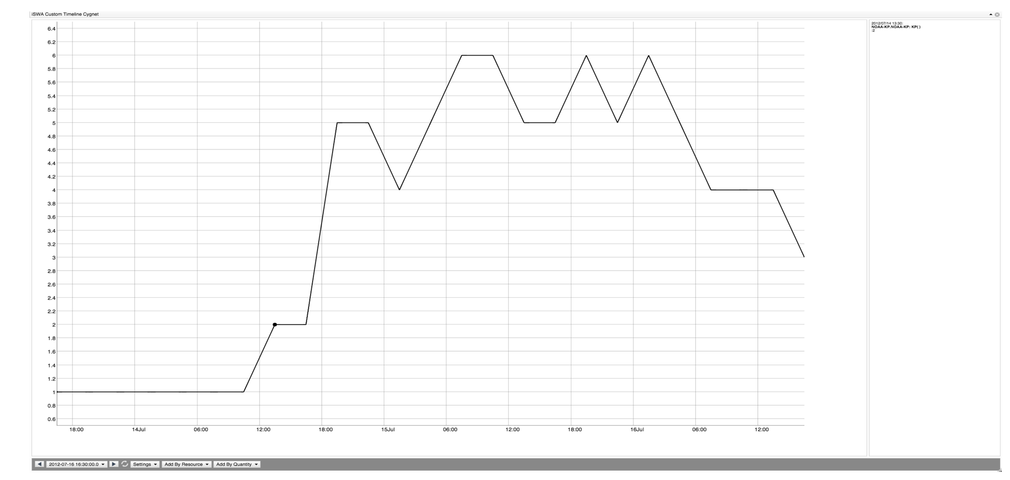
- High speed streams are regions of solar wind with velocity greater than the ambient solar wind.
- High speed streams typically originate from coronal holes on the solar disk.
- Interplanetary shocks result from the arrivals of both CMEs and high speed streams.
- High speed streams and interplanetary shocks are typically detected using ACE magnetic field, solar wind velocity, and ion density monitors.



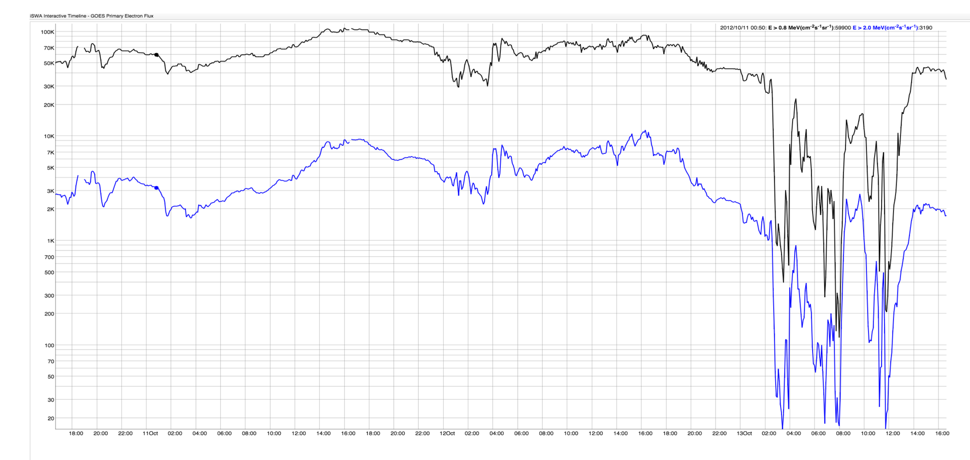
- The magnetopause is the interface between the ambient solar wind and Earth's magnetic field.
- Magnetopause crossings occur when the Earth's magnetopause is compressed past the geosynchronous orbit (6.6 R_{Earth}).
- Magnetopause crossings are detected using the SWMF (Space Weather Modeling Framework) magnetospheric model.



- Geomagnetic storms are a state of excitation and rapid energy release in the Earth's magnetosphere.
- There are a variety of effects of geomagnetic storms, including increased auroral activity and ground-induced currents (GIC).
- The KP index (ranging from 0 to 9) is one way to measure geomagnetic storms, and a geomagnetic storm is classified as a time with KP greater than or equal to 6.



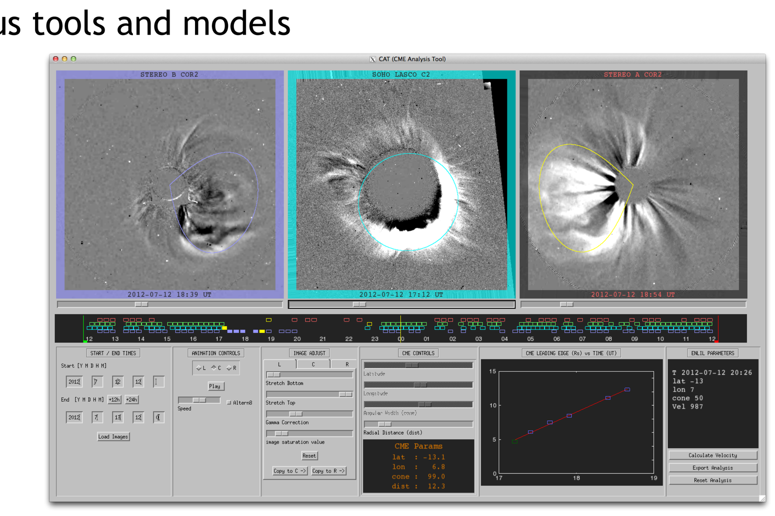
- Radiation belt enhancements occur when electrons in Earth's magnetotail are propelled through the magnetosphere, usually following the arrival of a CME or high speed stream.
- Radiation belt enhancements are known to occur days after arrivals of CMEs or high speed streams.
- One measurement of radiation belt enhancements is conducted using GOES electron flux monitors.

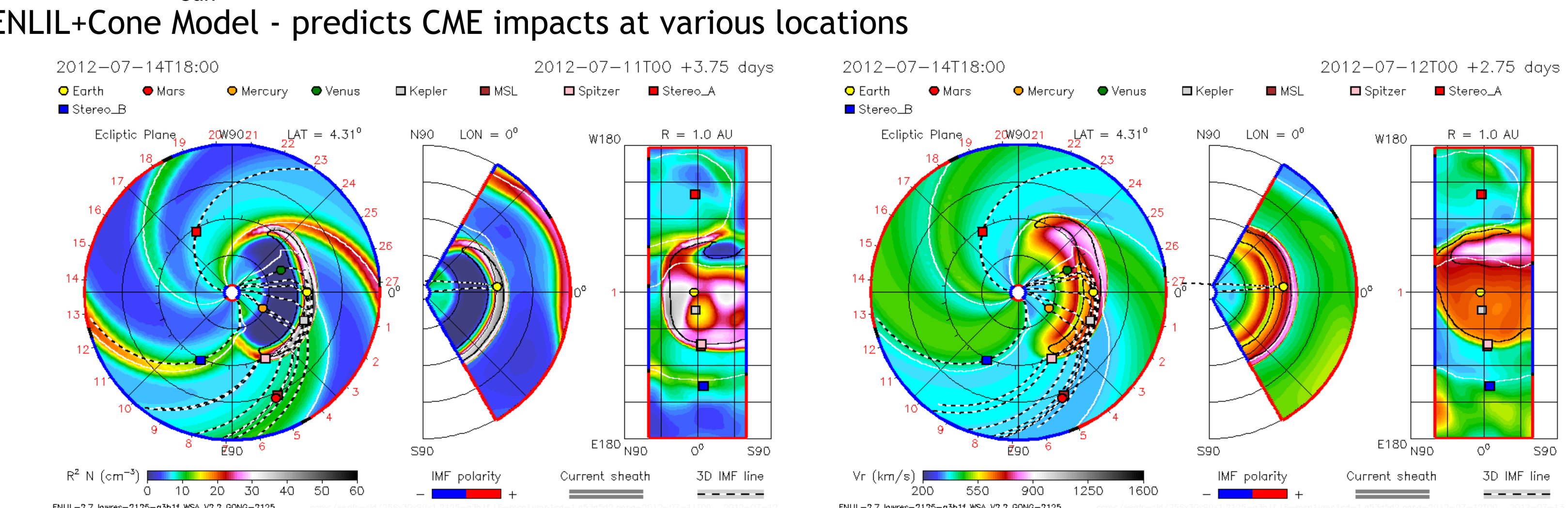


Tools and Models

Space weather forecasters measure and analyze SWx events using various tools and models

- iSWA (iNtegrated Space Weather Analysis System) - available to the public, allows forecasters to look at various graphs and figures (called cygnets) at once
- SWPC_CAT and Stereo_CAT (CME Analysis Tools) - measures parameters of CMEs to enter into simulations
  - Longitude
  - Latitude
  - Half-angle
  - Velocity
  - Time at 21.5 R_{Sun}
- WSA-ENLIL+Cone Model - predicts CME impacts at various locations





Space Weather Impacts

- Surface charging is probably the most common cause of space weather-related anomalies in spacecraft. This is often caused by high-energy electrons in the radiation belts.
- Single event effects can be caused by galactic cosmic rays, solar flares/CMEs, trapped protons in the inner radiation belt, and high-energy neutrons.
- Satellite drag can affect spacecraft at low Earth orbit (LEO) and is caused by heating of the upper atmosphere by energetic particles.
- Data scintillations can be caused by geomagnetic storms.
- Aurora are caused by radiation belt enhancements and are correlated with geomagnetic storms.

Acknowledgements

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References

SWPC_CAT session from SWPC_CAT: See Millward, G., et al. (2013), Space Weather, 11, 57-68, doi:10.1002/swe.20024.
All other images can be found on iSWA: http://iswa.ccmc.gsfc.nasa.gov/IswaSystemWebApp/