Space Weather and Technological Impacts

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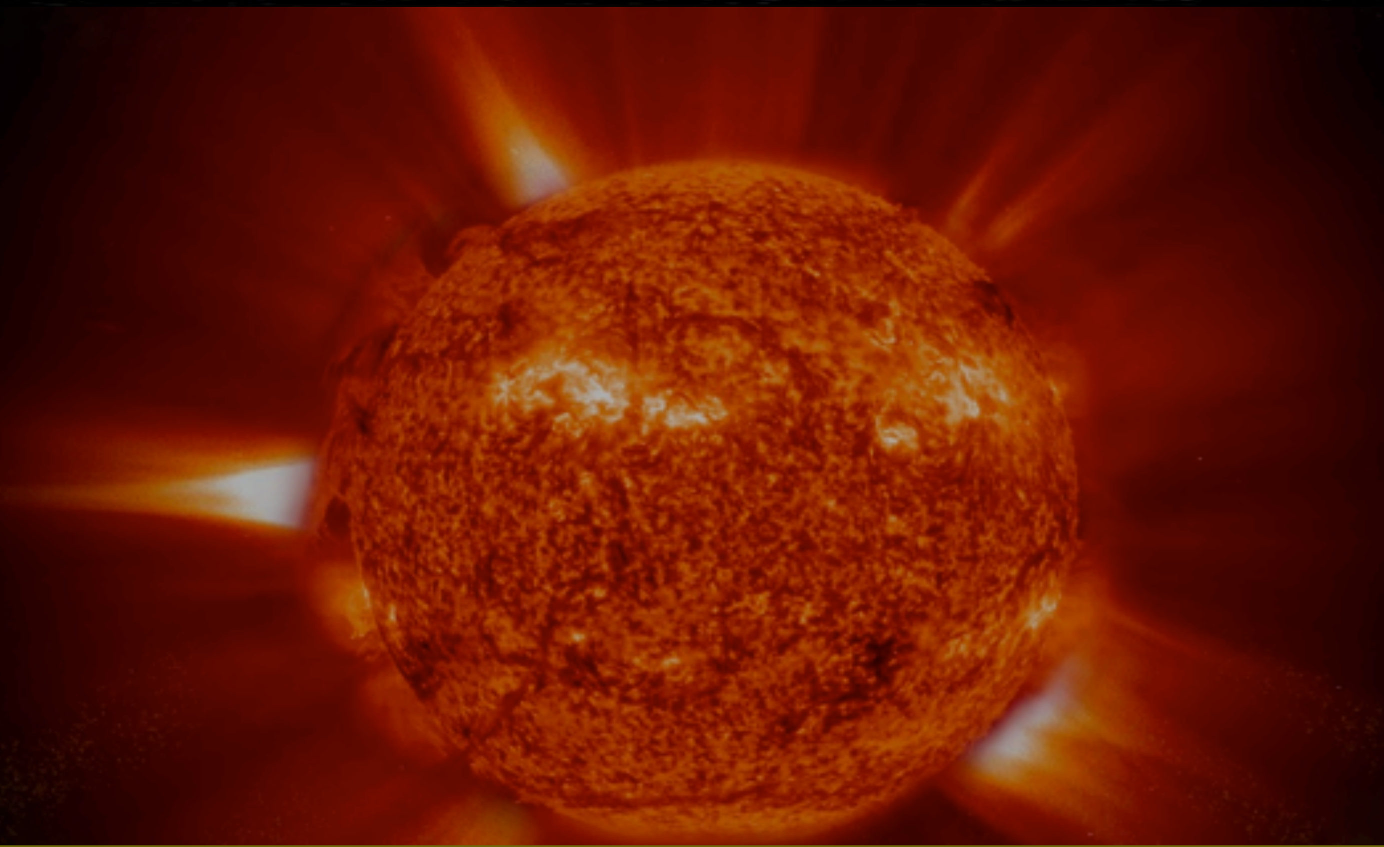


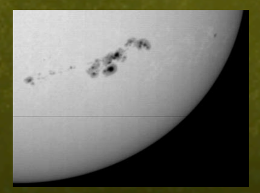
Introduction

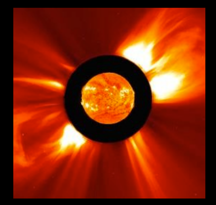
- The National Space Weather Program defines space weather as "conditions on the sun and in the solar wind, magnetosphere, ionosphere, and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human life or health."
- As we approach Solar Maximum in 2013-2014, society is at risk due to impacts space weather storms have on our heavily reliant technological infrastructure.
- The Global Positioning System (GPS)-based technologies which society's become extremely dependent on since the last solar cycle will be fully tested for the first time.
- The NOAA Space Weather Prediction Center (SWPC) navigation customer list was analyzed to investigate the types of companies reliant on GPS.
- The AMS held a policy workshop titled, "Satellite Navigation & Space Weather: Understanding the Vulnerability & Building Resilience," that led to recommendations on how to best characterize satellite navigation's vulnerability to space weather and how to build resilience for the future.

Overview of space weather

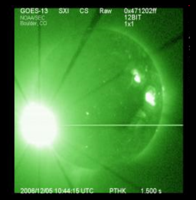
Space Weather is a consequence of the behavior of the Sun and the nature of Earth's magnetic field and atmosphere. The Sun, like Earth, experiences seasons that occur on a period of 11 Earth years, solar maximum and minimum. During solar max, activity on the Sun is high and numerous events occur.

- Sunspots are dark areas on the solar surface and contain strong magnetic fields that are constantly shifting. An average-sized sunspot is about as large as the Earth and groups of sunspots are often identified as sites of flares.

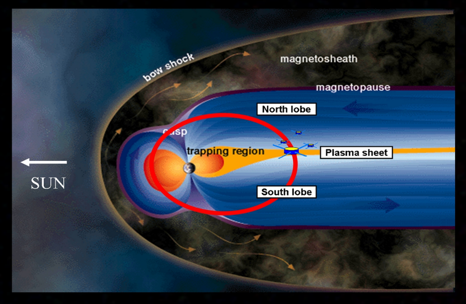




- Solar flares are intense, short-lived releases of energy. They are seen as bright areas on the Sun in optical wavelengths and as bursts of noise in radio wavelengths and can last from minutes to hours. Flares are our solar system's largest explosive events.
- Coronal Mass Ejections (CME) are sudden and violent releases of bubbles of gas and magnetic fields. A large CME can contain 10^{16} grams (a billion tons) of matter that can be accelerated to several million miles per hour in a spectacular explosion impacting any planet or spacecraft in its path



- Solar Radio Bursts (SRB) are emissions of the Sun in radio wavelengths from centimeters to dekameters, under both quiet and disturbed conditions. Radio waves produced during solar flare eruptions on the Sun can cripple the GPS and other communication technologies by acting like noise interfering with used frequencies.
- The region between the Sun and Earth, the interplanetary medium, is a turbulent region dominated by the solar wind, flowing at velocities of approximately 250-1000 km/s (about 600,000 to 2,000,000 miles per hour). Characteristics of the solar wind, such as density, composition, and magnetic field strength, vary with changing conditions on the Sun.



- Aurora is a visual, solar-induced geomagnetic storm. The solar wind energizes electrons and ions in the magnetosphere entering the Earth's upper atmosphere near the polar regions. When the particles strike the molecules of the thin, high atmosphere, some of them start to glow in different colors. As a storm intensifies, the aurora spreads equator-ward.

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Background Image Credit: ESA/NASA - SOHO/EIT; GPS image credit: Kintner, 2008; Earth's magnetosphere image credit: ESA; Aurora image credit: E.J. Peiker; Tsunami amplitude prediction image credit: NASA/JPL-Caltech

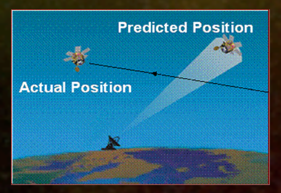
Technological impacts

Adverse conditions in the space environment can cause disruption of the electric power industry, aviation, navigation and communication systems, satellite operations, and space flight leading to a variety of socioeconomic losses.

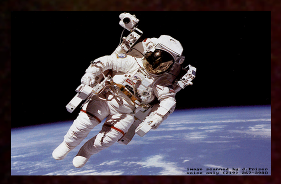
- Electric power industry - power companies transmit alternating current to their customers via long transmission lines. Direct currents induced in these lines from geomagnetic storms are harmful to electrical transmission equipment. In 1989 a geomagnetic storm trigged the collapse of the Hydro-Quebec power grid, leaving 6 million Canadians without power for 9 hours.

- Aviation – the airline industry faces risks during high latitude and polar routes which includes disruptions in High Frequency (HF) communications, GPS errors and radiation hazards to humans and avionics.

- Navigation and Communication Systems - ionospheric storms are space weather induced instabilities that can affect HF communications and for GPS signals, ionospheric irregularities can create a timing error or a signal that scintillates causing a receiver to lose lock on the signal.



- Satellite Operations – geomagnetic storms and increased solar UV emission heat Earth's upper atmosphere, causing it to expand, which increases drag on satellites in space, causing them to slow and change orbit. Energetic solar particles can cause single event upsets which often cause physical damage to microchips and change software commands in satellite-borne computers. Bulk charging occurs when energetic particles, primarily electrons, penetrate the outer covering of a satellite and deposit their charge in its internal parts.



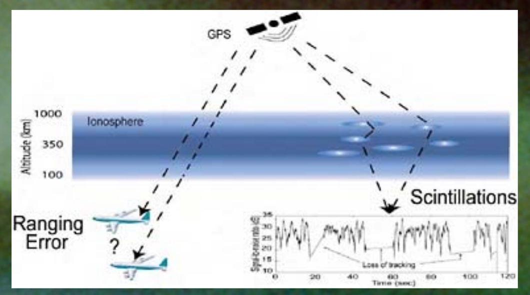
- Space Flight - astronauts in space can be subjected to potentially lethal dosages of radiation. The penetration of high-energy particles into living cells, radiation dose, leads to chromosome damage and, potentially, cancer. Large doses can be fatal immediately.

Closer look at GPS

Since the last solar max, our society has become extremely dependent on GPS often referred to as the "4th utility" behind electricity, water, and natural gas. Precision GPS is now required by numerous applications--railway control, highway traffic management, precision agriculture, emergency response, commercial aviation, and marine navigation. With such widespread and critical usage, GPS-reliant industries are now concerned about space weather impacts on the once thought "all weather proof" GPS system.

There are 3 primary effects of space weather on GPS:

- propagation delay of signals caused by the presence of the ionosphere resulting in increased errors in position and navigation
- loss of signal due to scintillation effects caused by small-scale irregularities in the ionosphere resulting in increased errors due to decreased number of useable satellites and possibly inability to navigate
- Solar radio burst impacts on receivers



Examples of GPS impacted space weather events:

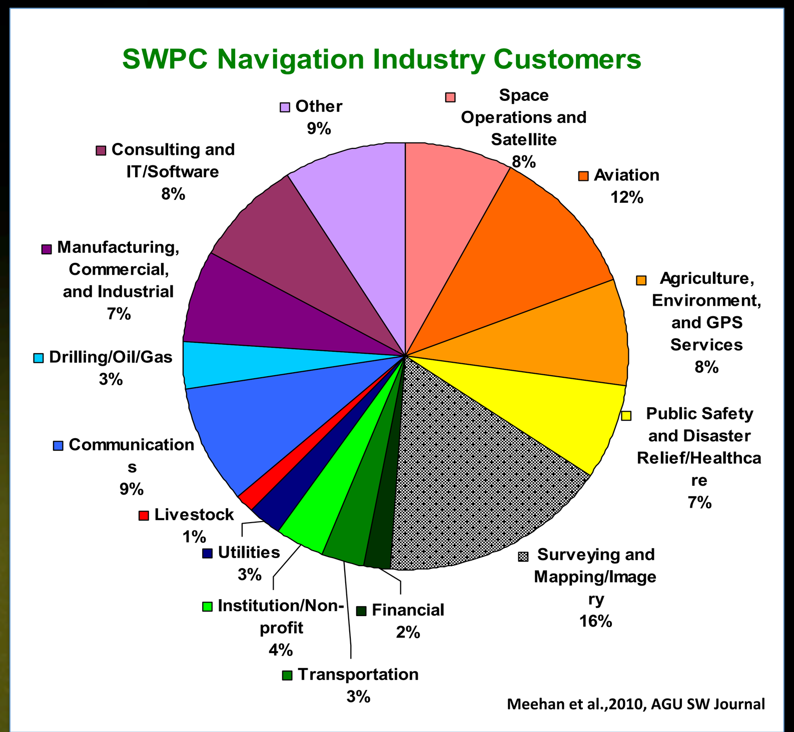
- Oct 29-31, 2003 (Halloween Storms): a CME required precise GPS users to delay operations. For 15 hrs on Oct 29 and 11 hrs on Oct 30 the FAA's WAAS system was severely impacted. The ionosphere was so disturbed that the vertical error limit was exceeded which rendered WAAS unusable.
- Dec 6, 2006: an extremely large SRB affected GPS receivers over the entire sunlit side of the Earth. There was widespread loss of GPS in the Mountain States region, specifically around NM & CO. Several aircraft reported losing lock on GPS.

GPS industry

The NOAA SWPC navigation customer list was analyzed to investigate the types of companies reliant on GPS. 644 out of 733 customers were identified and categorized into military (9%), civil government (14%), academia (10%), and industry (67%).

SWPC Navigation Industry Customers chart shows industry organizations as a percentage of type of company.

- Wide-ranging company categories
- All categories include individuals and companies, domestic and international
- A majority of the industries provide GPS services and could experience tremendous economical impacts during signal errors or interruptions
- Some companies use GPS to improve safety and efficiency of systems, i.e. emergency response groups
- Some companies use GPS for the economic value, whether it be the money making business (consulting) or the money saving business (precision agriculture)

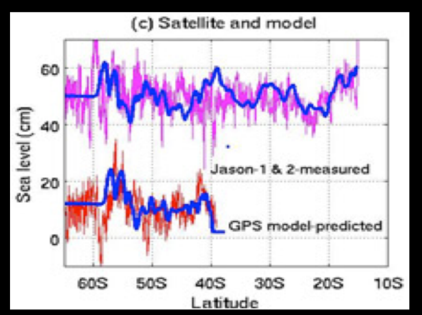


Critical GPS usage

- National Security
  - GPS used to enable DoD forces worldwide to strategically maneuver into a militarily advantageous position
  - GPS provides critical services to deployed forces around the globe from the infantrymen walking the streets of Fallujah, to ships combating piracy off the coast of Somalia, to the aircraft patrolling our country's borders
- Oil Drilling
  - GPS used for very precise location requiring near pinpoint accuracy
  - Space Weather impacts could result in a $1 million loss in a single oil drilling operation in the Gulf
- Aviation
  - GPS used for navigation; NextGen requires GPS for all navigational uses
  - Could save up to $10 billion in fuel cost by the year 2025
- Banks
  - GPS satellites used to time-stamp financial transactions; GPS provides precise time signals for synchronization and fault detection
  - During bank robberies, GPS tracking devices are thrown into bags of money for tracking and recovering

Unique GPS application

In 2007, NASA scientist Tony Song discovered a Tsunami prediction method using GPS. It was successfully demonstrated during the Feb. 27, 2010 magnitude 8.8 Chilean earthquake earning number 84 of Discover magazine's top 100 scientific stories of 2010.



Song's prediction method estimates the energy an undersea earthquake transfers to the ocean to generate a tsunami. It relies on data from coastal GPS stations near an epicenter, along with information about the local continental slope. When the Feb. 27 earthquake struck, its ground motion was captured by the NASA GDGPS network's station in Santiago, Chile, with data made available to Song within minutes of the earthquake, enabling him to derive the seafloor motions. Based on GPS data, Song calculated the tsunami's source energy, ranking it as moderate: a 4.8 on the system's 10-point scale based on the fact that the ground motion detected by GPS indicated the slip of the fault transferred fairly minimal kinetic energy to the ocean.

AMS Policy Workshop

Held in Fall 2010 participants included GPS government and industry leaders, space weather scientists and information providers, and policymakers. By better understanding the risks and preparing the GPS community with strategies for mitigation, potential disasters can be avoided.

Key points for building resilience: science and engineering

- conduct further research on understanding space weather and its effects
- develop and maintain observational capabilities
- understand user requirements
- develop better space weather products

Key points for building resilience: policy

- investment in research
- create and strengthen partnerships
- international collaboration
- develop education and outreach to users
- strengthen integrity and robustness of the system