CTU Presents

The Wonderful World of Space Weather

Dr. Tamitha Mulligan Skov
The Aerospace Corporation
Who is Impacted by Space Weather?
What is Space Weather?

Essentially Space Weather is:
A planet’s interaction with its host star and the surrounding space environment.
What is Space Weather?

More generally, it occurs at planets, moons, comets, asteroids, and other celestial bodies in the universe.

In our solar system

- We see aurora at Jupiter, Saturn, and recently at Uranus and Mars
- Effects are studied at Io, Europa, Ganymede, and Titan to name a few
- Highlight **Sun-driven processes**
- Will not cover other sources of space weather
  - Galactic and anomalous cosmic rays
  - Micrometeoroids & interstellar dust
  - Space junk
Our Star

- Giant fusion reactor: Drives Space Weather
- Energy output in the form of:
  - Electromagnetic radiation (from X-rays through radio)
  - Solar wind plasma & magnetic fields
  - Flares
  - Solar Energetic Particles (SEPs) (aka solar radiation storms)
  - Coronal Mass Ejections

What do Space Telescopes See?

5700 °C → 6.3 Million °C
Four Basic Types of Solar Phenomena Affecting Earth

- **Solar Flares**
- **Solar Storms (a.k.a. CMEs)**
- **Solar Radiation Storms**
- **Coronal Holes (Fast Solar Wind)**
...So how bad can Space Weather be?

3 Categories:

- **Geomagnetic Storms** (CMEs and fast solar wind)
- **Solar Radiation Storms** (Particle Events)
- **Radio Blackouts** (Solar Flares)

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**NOAA Space Weather Scales**

<table>
<thead>
<tr>
<th>Category</th>
<th>Effect</th>
<th>Physical measure</th>
<th>Average Frequency (1 cycle = 13 years)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Geomagnetic Storms</strong></td>
<td>Power systems: widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage. Spacecraft operations: may experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. Other systems: pipeline cameras can reach hundreds of amps, HF (high frequency) radio propagation may be impossible in many areas for one to two days, satellite navigation may be degraded for days, low-frequency radio navigation cannot be used for hours, and aurora has been seen as far as Florida and southern Texas (typically 45° geomagnetic lat.)***.</td>
<td>Kp rating* determined every 3 hours</td>
<td>Number of events: when Kp level was met, number of times range</td>
</tr>
<tr>
<td>G 0 Extreme</td>
<td>Power systems: possible widespread voltage control problems and some protective systems will continuously trip out key assets from the grid. Spacecraft operations: may experience extensive charging and tracking problems, connections may be needed for orientation problems. Other systems: induced current pipelines affect preventive measures, HF radio propagation sporadic, satellite navigation degraded for hours, low-frequency radio navigation impossible, and aurora has been seen as far as Alabama and northern California (typically 45° geomagnetic lat.)***.</td>
<td>Kp9, including a 9-</td>
<td>100 per cycle (60 days per cycle)</td>
</tr>
<tr>
<td>G 1 Moderate</td>
<td>Power systems: High latitude power systems may experience voltage fluctuations, long duration storms may cause transmission damage. Spacecraft operations: corrective actions to orientation may be required by ground control, possible changes in drug effect orbit predictions. Other systems: HF radio propagation can fail at higher latitudes, and aurora has been seen as far as New York and Ohio (typically 50° geomagnetic lat.)***.</td>
<td>Kp6</td>
<td>600 per cycle (360 days per cycle)</td>
</tr>
<tr>
<td>G 2 Minor</td>
<td>Power systems: weak power grid fluctuations can occur. Spacecraft operations: minor impact on satellite operations possible. Other systems: aurora commonly visible at higher latitudes (northern Michigan and Maine)**.</td>
<td>Kp5</td>
<td>1,500 per cycle (900 days per cycle)</td>
</tr>
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**Solar Radiation Storms**

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<td>S 0 Extreme</td>
<td>Biological: unavoidable high radiation hazard to astronauts on EVA (extra-vehicular activity); high radiation exposure to passengers and crew in commercial jets at high latitudes (approximately 100 km x/c a) is possible. Satellite operations: satellites may be rendered useless, memory impacts can cause loss of control, may cause serious injury in space, star-trackers may be unable to locate sources, permanent damage to solar panels possible. Other systems: blackout of HF (high frequency) communications possible through the polar regions, and ionization zones makes navigation operations extremely difficult.</td>
<td>Flux level of 10^-30 MeV particles/cm²</td>
<td>Number of events: when flux level was met**.</td>
</tr>
<tr>
<td>S 1 Moderate</td>
<td>Biological: unavoidable radiation hazard to astronauts on EVA; elevated radiation exposure to passengers and crew in commercial jets at high latitudes (approximately 100 km x/c a) is possible. Satellite operations: may experience memory device problems and noise in imaging systems; star-trackers problems may cause orientation problems, and solar panel efficiency can be degraded. Other systems: blackout of HF radio communications through the polar regions and increased navigations errors over several days are likely.</td>
<td>Flux level of 10^-30 MeV particles/cm²</td>
<td>Number of events: when flux level was met**.</td>
</tr>
<tr>
<td>S 2 Severe</td>
<td>Biological: radiation hazard avoidance recommended for astronauts on EVA; passengers and crew in commercial jets at high latitudes may receive low-level radiation exposure (approximately 0.1 x/c a). Satellite operations: single-event upsets, noise in imaging systems, and slight reduction of efficiency in solar panel are possible. Other systems: degraded HF radio propagation through the polar regions and navigation position error likely.</td>
<td>Flux level of 10^-30 MeV particles/cm²</td>
<td>Number of events: when flux level was met**.</td>
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<tr>
<td>S 3 Strong</td>
<td>Biological: radiation hazard avoidance recommended for astronauts on EVA; passengers and crew in commercial jets at high latitudes may receive low-level radiation exposure (approximately 0.1 x/c a). Satellite operations: single-event upsets, noise in imaging systems, and slight reduction of efficiency in solar panel are possible. Other systems: degraded HF radio propagation through the polar regions and navigation position error likely.</td>
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**Radio Blackouts**

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<tr>
<td>R 0 Extreme</td>
<td>HF Radio: Complete HF (high frequency) radio blackout on the entire earth side of the Earth lasting for a number of hours. This results in no HF radio contact with satellites and no control issues in satellites. Navigation: Low-frequency navigation signals used by ground and general aviation systems experience outages on the earth side of the Earth for many hours, causing loss in positioning. Increased satellite navigation errors in positioning for several hours on the earth side of Earth, which may spread into the right side.</td>
<td>X20</td>
<td>Number of events when flux level was met**.</td>
</tr>
<tr>
<td>R 1 Moderate</td>
<td>HF Radio: Weak blackout of HF radio communications, loss of radio contract for about an hour on earth side of Earth. Navigation: Low-frequency navigation signals degraded for about an hour.</td>
<td>X1</td>
<td>Number of events when flux level was met**.</td>
</tr>
<tr>
<td>R 2 Severe</td>
<td>HF Radio: Long blackout of HF radio communications, loss of radio contact for tens of minutes. Navigation: Degradation of low-frequency navigation signals for tens of minutes.</td>
<td>X0</td>
<td>Number of events when flux level was met**.</td>
</tr>
<tr>
<td>R 3 Strong</td>
<td>HF Radio: Complete HF radio blackout on the entire earth side of the Earth for one to two hours. Radio contacts lost during this time. Navigation: Outages of low-frequency navigation signals cause increased error in positioning for one to two hours. Minor disruptions of satellite navigation possible on the earth side of Earth.</td>
<td>X0</td>
<td>Number of events when flux level was met**.</td>
</tr>
</tbody>
</table>

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*** Based on cycle average, but other physical measures are also considered.
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CONTEST UNIVERSITY
What Can a Typical Solar Storm Event Do?

Source of all official forecasting data is the NOAA Space Weather Prediction Center (SWPC)

January 23-30, 2012 solar storm series of events caused

- 2 radio blackouts
- 2 radiation storms
- 1 geomagnetic storm

Reprinted courtesy of NOAA
FAA Radio Communications Center reported that the CEP (Central East Pacific) and CWP (Central West Pacific) regions were:
“impacted severely by solar activity between 1830Z and 1930Z on 27 Jan due to the R3 solar flare radio blackout. Thirteen requests were received from ATC for overdue position reports.”

Several polar flights altered due to S3 Radiation Storm (23-25 Jan)

Major airline report: “…some of our polar flights (but not all) have reported HF comm outages/issues over the past 3 nights.”

Reprinted courtesy of NOAA
What Can a Super Solar Storm Event Do?

- March 6-15, 1989
  - X-15 Flare followed by a CME
  - Weather Satellites lost images for hours
  - TDRS-1 com sat had over 250 anomalies
  - Space Shuttle Discovery fuel sensor failed
  - Radio Free Europe disrupted thinking it was Soviet Jam Event
  - Quebec Hydro-Quebec Power Grid shutdown
  - James Bay Network, serving 6 million people, offline for 9 hours
  - Caused Toronto Stock Market to close
  - Brilliant Auroral Displays as far at Texas and Florida (aurora pic by DOD F9 weather sat)
  - Many other examples of super storms in space age: 1998 Telstar 401, Anik 1,2, “Halloween Events” 2003
What is the Ionosphere?

- Ionosphere is a charged plasma layer above the atmosphere comprised of ions and electrons.
- It would be neutral but it gets charged from exposure mainly to the Sun’s UV radiation.
- This charged nature facilitates radio propagation.
- During geomagnetic storms, extra energy caught in the Earth’s magnetic shield gets dumped into the ionosphere.
- This energy (flow of charged particles) lights-up the plasma in the Earth’s ionosphere similar to a fluorescent lamp or neon sign.
- Result is the aurora borealis (northern lights) and aurora australis (southern lights).
Space Weather Effects on Propagation

- Waves in neutral and charged particle regions
- Atmospheric heating instabilities
- Signal reflection
- Signal refraction
- Currents in charged particle regions
- Signal scintillation
- Signal amplitude and phase modulation (signal fading)
Space Weather Audible Interference

**Solar flare:** Solar radio bursts cause radio blackouts over a wide frequency range
[https://www.wired.com/2013/02/radio-solar-outburst/](https://www.wired.com/2013/02/radio-solar-outburst/)

**Dawn Chorus:** Radio Waves due to energetic particles in the magnetosphere

**Sferics and Tweeks:** Radio waves caused by lightning nearby

**Whisters:** Radio waves caused by lightning far away
What about Solar Variability?

- Sun’s activity cycle has a quasi 11-year periodicity
- Solar magnetic field constantly reversing orientation
- Activity increases for few years around field reversal (solar maximum) and decreases when field becomes ordered again (solar minimum)
- Other competing cycles cause deviations from 11-years and modulate the strength of the cycle over the long-term
- Sunspot numbers are used as a proxy for solar activity
Solar Cycle: Where are We Now?

- Recent solar cycles are showing dramatic changes, making predictions more complicated
- Consensus is we are in a new Dalton-like Minimum
  - Cycle is slower, up to 14 years
  - Lower luminosity, slower currents beneath Sun’s surface, lower magnetic field
  - Lower activity at maximum
- Solar maximum double-peaked

Recent Sunspot Number Predictions
Space Weather Forecasting: A Return to the Sixties

Space Weather Prediction Centers
- Developed mainly as a response to super storms
- Models that predict solar fields, CME transit, magnetospheric responses → solar storm alerts
- Radio blackouts, solar radiation storms → FAA alerts
- Space and ground telescopes for 24/7 monitoring of Sun, even on the backside
- “Spaceship Earth” networks

~1960
Harry Volkman: Broadcast Meteorologist

Today
Tamitha Skov: Broadcast Space Meteorologist
Space Weather Forecasting: A Return to the Sixties

October 16, 2016
Solar Storm Forecast
by Tamitha Skov
Our Future Relies on Predicting Space Weather

Reliance on Space is advancing:

- Wireless technologies
  - 6 Billion mobile phones in world today
  - GPS/GNSS receivers
  - Satellite service providers exploding
- Self-driving cars
  - CA law passed in 2012 Google car can share public roads
- Unmanned Aerial Vehicles (UAVs)
  - FAA allows GPS/GNSS enabled drones to share commercial airspace in 2015
- Space Tourism
  - World View to launch manned balloon test flights in 2017
- National Power Grids

For more information visit:
TamithaSkov on SpaceWeatherWoman.com and on YouTube for weekly forecast videos: (http://www.youtube.com/user/SpWxfx)
@TamithaSkov on Twitter for daily forecasts and often hourly updates
SpaceWeatherWoman@gmail.com