What is “Space Weather”?

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Space Weather Technology, Research, and Education Center

SmallSat Conference Side Meeting
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Definition of “Space Weather”

For the purposes of this conference, Space Weather is defined as the variation in
- Photon radiation
- Charged particle radiation
- Magnetic fields
- Plasma density
- and Upper atmospheric composition

in near-Earth space, i.e., in all orbits from LEO to GEO and cislunar.

Space Weather is caused by
- Interaction of the Earth’s magnetic field and atmosphere with outputs from the Sun
- Propagation of disturbances from the lower atmosphere

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The Sun is a Magnetic Star

- Magnetic “reconnection” occurs where strong opposite polarity fields are adjacent.
- Reconnection causes magnetic eruption activity.
The “Solar Magnetic Cycle”

Every 11 ± 1 years, the number of sunspots on the Sun peaks

We are here:
- very little sunspot activity
- Occasional solar wind disturbances

1st sunspots of Cycle 25 have arrived in the last few months

The Solar Magnetic Field heats the Corona to $10^6$ K and drives the Solar Wind

Solar corona visible during Solar Eclipse

Supersonic “solar wind” of protons, electrons, ions and magnetic field

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Solar Magnetic Eruptions  ➔  X-ray Flares

NOAA Solar Ultraviolet Imager (SUVI)

extreme ultraviolet light (19 nm)

NOAA Space Weather Prediction Center
X-ray Flare Class

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Flare X-rays cause OTH radio and radar blackouts

X-rays cause excess ionization of Earth’s “ionosphere” Leading to radio wave absorption rather than reflection.

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Flare “radio bursts” can cause GPS and radar blackouts

- Receivers pointing at Sun swamped by solar “noise”
Solar Magnetic Eruptions  ➔ Coronal Mass Ejections (CMEs)

• CMEs can go any direction in the solar system
• Space weather forecasting challenge: determine whether a CME will impact Earth

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CMEs cause radiation storms and Geomagnetic storms

- Radiation storms threaten astronauts in orbit or on the Moon and can damage or permanently disable satellites in any orbit.
- CME impact drives geomagnetic storms which in turn drive electric currents in the ionosphere.
- Ionospheric currents heat the upper atmosphere (thermosphere) causing atmospheric expansion.
- Disturbed geomagnetic field causes Geomagnetically Induced Currents (GICs) in the Earth’s crust.

The Aurora: the only visible effect of space weather. The farther south the aurora is visible, the bigger the geomagnetic storm.
The Van Allen Radiation Belts & “killer electrons”

- Radiation levels fluctuate during CME impact / geomagnetic storm
- Colors indicate flux of relativistic electrons: red is higher

NASA’s Van Allen Probes
Courtesy of Johns Hopkins Applied Physics Lab

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• "Man-made" space weather
• 2/3 of satellites in LEO in 1962 (not many...) damaged or destroyed

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Space Weather from below

Courtesy: Laura Holt and Cora Randall
Space Weather Fault Tree

Solar Magnetic Cycle
- Basal Extreme Ultraviolet & X-ray Radiation
- Solar Magnetic Eruptions
  - Solar Flares
  - Shock Waves
  - Plasma
  - Magnetic Fields
- Solar Wind
  - High Speed Streams & Interactions
  - Coronal Mass Ejections (CMEs)
  - A,B,C,M,X scale
  - EUV / X-rays
- SWPC R-scale
- SWPC S-scale
- SWPC G-scale

Earth Atmospheric Cycles
- Gravity Waves
- Tides
- Polar Vortices

Solar Wind - Coronal Mass Ejections (CMEs)
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- Atmospheric Ionization
- Thermospheric Expansion
- Polar Region Particle Precipitation
- Radiation Belt Enhancement
- Geomagnetically Induced Currents
- Geomagnetic Storm

Radar / GNSS Interference
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HF Comms absorption
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Satellite Track Errors
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Astronaut / Airline Passenger radiation
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False Sensor Readings
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Satellite Surface Charging
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Satellite Internal Charging
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Avionics Single Event Upsets
- Atmosphere Chemistry Changes
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Electrical Grid Destabilization
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GNSS Scintillation
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GNSS Loss of Lock
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Polar Flight Cancellations
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EVA Aborts
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Astronaut Incapacitation
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Launch Aborts
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Unplanned Reentry
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Wide-scale Power Failure
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Autonomous Vehicle Loss
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Air Traffic Shutdown
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SAR Mission Impact
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Satellite-Debris Collisions
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Space Weather Fault Tree

- **Basal Extreme Ultraviolet & X-ray Radiation**
- **Solar Magnetic Cycle**
  - Solar Flares
  - Coronal Mass Ejections (CMEs)
- **Solar Magnetic Eruptions**
- **Solar Wind**
- **High Speed Streams & Interactions**
- **Gravity Waves**
- **Tides**
- **Polar Vortices**

**Earth Atmospheric Cycles**

- **Gravity Waves**
- **Tides**
- **Polar Vortices**

**Solar Magnetic Cycle**

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- **A,B,C,M,X scale**
- **EUV / X-rays**
- **Radio Burst**
- **Shock Waves**
- **Plasma**
- **Magnetic Fields**

**Solar Energetic Particle Radiation Storm**

- **SWPC S-scale**
- **Polar Region Particle Precipitation**
- **Radiation Belt Enhancement**
- **Geomagnetic Storm**
- **Geomagnetically Induced Currents**

**SWPC G-scale**

- **Atmospheric Chemistry Changes**
- **Atmospheric Ionization**
- **Thermospheric Expansion**

**High Speed Streams & Interactions**

- **Travelling Ionospheric Disturbances**
- **Ionospheric Instabilities**
- **Sudden Stratospheric Warming**
- **Ionospheric TEC gradients**

** HF Comms absorption**
**Radar / GNSS Interference**
**SatComm Interference**
**Geolocation Errors**
**Satellite Track Errors**
**Astronaut / Airline Passenger Radiation**
**False Sensor Readings**
**Satellite Surface Charging**
**Satellite Internal Charging**
**Avionics Single Event Upsets**
**Electrical Grid Destabilization**
**GNSS Scintillation**
**GNSS Loss of Lock**

**SAR Mission Impact**
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**Satellite-Debris Collisions**
**Unplanned Reentry**
**Polar Flight Cancellations**
**EVA Aborts**
**Astronaut Incapacitation**
**Launch Aborts**
**Satellite Loss of Function**
**Wide-scale Power Failure**
**Autonomous Vehicle Loss**
**Air Traffic Shutdown**

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Space Climate
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More Information

- https://www.colorado.edu/spaceweather
- https://science.nasa.gov/heliophysics/focus-areas/space-weather
- https://www.swpc.noaa.gov
- https://www.spaceweather.com
- https://www.spaceweatherlive.com
- http://www.spaceweatherwoman.com
- https://solarmonitor.org