Outline

- The Sun/Solar Cycle
- Sequence of Events
- Phenomena/Impacts
- Potential NERC Changes
- Product Improvements
- Measurements/Observations Update
What is space weather?

Space weather refers to the variable conditions on the Sun and in the space environment that can influence the performance and reliability of space and ground-based technological systems, as well as endanger human health.
Sunspots and the Solar Cycle

The Sun at Solar Maximum

The Sun Today

~27 day full rotation
Solar Cycle 24 Predictions

Solar Cycle 24 Sunspot Number Prediction
Data Through 31 Mar 07

High Prediction

Low Prediction
Solar Cycle 24 Predictions

D. Pesnell, 2008
Solar Cycle Update

- Cycle 23 began in May 1996
- Peak in April 2000 with SSN = 120
- Solar Minimum in December 2008
- Solar Cycle 24 Underway
Periods with $Kp \geq 6$

October 2014
(Month 71)
Periods with Kp $\geq 8$
October 2014
(Month 71)

Comparison of Cycles at current month in cycle

- Cycle 17: Sep 1933 - Jan 1944
  - Solar Max (Apr 1937)
  - Solar Min (Feb 1944)
- Cycle 18: Feb 1944 - Mar 1954
  - Solar Max (Jun 1947)
  - Solar Min (Apr 1954)
- Cycle 19: Apr 1954 - Sep 1964
  - Solar Max (Mar 1958)
  - Solar Min (Oct 1964)
  - Solar Max (Nov 1968)
  - Solar Min (Jun 1976)
  - Solar Max (Dec 1979)
  - Solar Min (Sep 1986)
  - Solar Max (Jul 1989)
  - Solar Min (Aug 1996)
  - Solar Max (Apr 2000)
  - Solar Min (Dec 2006)
- Cycle 24: Dec 2008 -
Periods with Kp >= 9
October 2014
(Month 71)
Periods with Kp >= 90

October 2014

(Month 71)

Comparison of Cycles at current month in cycle

Number of Kp >= 90 per month

Cycle 17: Sep 1933 - Jan 1944
  Solar Max (Apr 1937)
  Solar Min (Feb 1944)

Cycle 18: Feb 1944 - Mar 1954
  Solar Max (Jun 1947)
  Solar Min (Apr 1954)

Cycle 19: Apr 1954 - Sep 1964
  Solar Max (Mar 1958)
  Solar Min (Oct 1964)

  Solar Max (Nov 1968)
  Solar Min (Jun 1976)

  Solar Max (Dec 1979)
  Solar Min (Sep 1986)

  Solar Max (Jul 1989)
  Solar Min (Aug 1996)

  Solar Max (Apr 2000)
  Solar Min (Dec 2008)

Cycle 24: Dec 2008 -
• Large geomagnetic storms can occur with smaller cycles

• The largest geomagnetic storms on record occurred during smaller than average cycles (no causality implied)
Sequence of Events

Conditions are Favorable for Activity (Probabilistic Forecasts) → Event Occurs → Coronal Observations
Sequence of Events
### NOAA Space Weather Scales

**Radio Blackouts**

<table>
<thead>
<tr>
<th>Category</th>
<th>Effect</th>
<th>Average Freq. (1 cycle = 11 yrs)</th>
<th>Physical measure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>R5</strong> Extreme</td>
<td>HF Radio: Complete HF (high frequency)**) radio blackout on one side of the Earth lasting for a number of hours. This results in radio contact with mariners and marine aviation in this sector.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>R4</strong> Severe</td>
<td>HF Radio: HF radio communication blackout on most of the Earth for one to two hours. HF radio contact lost during this time.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>R3</strong> Strong</td>
<td>HF Radio: Wide area blackout of HF radio communication, lost contact for about an hour on each side of Earth.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>R2</strong> Moderate</td>
<td>HF Radio: Limited blackout of HF radio communication on one side of Earth for ten minutes.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>R1</strong> Minor</td>
<td>HF Radio: Weak or minor degradation of HF radio communication, occasional loss of radio contact.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* ^This measure is for 0.1-0.8 mm range, in W m⁻². Based on this measure, be considered.

**Other frequencies may also be affected by these conditions.

### Radiation Storms

<table>
<thead>
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<th>Physical measure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>S5</strong> Extreme</td>
<td>Biological: unavoidable high radiation hazard to astronauts on Earth (high altitude). High radiation exposure to passengers and crew in commercial jets at high lattitudes.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>S4</strong> Severe</td>
<td>Biological: unaviodable radiation hazard to astronauts on Earth. Radiation exposure to passengers and crew in commercial jets at high lattitudes.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>S3</strong> Strong</td>
<td>Biological: radiation hazard recommended for astronauts passengers and crew in commercial jets at high lattitudes. Satellites may experience single-event upset failures.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>S2</strong> Moderate</td>
<td>Biological: special single-event upset possible.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>S1</strong> Minor</td>
<td>Biological: special single-event upset possible.</td>
<td></td>
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</tbody>
</table>

### Geomagnetic Storms

<table>
<thead>
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<th>Category</th>
<th>Effect</th>
<th>Average Freq. (1 cycle = 11 yrs)</th>
<th>Physical measure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>G5</strong> Extreme</td>
<td>Power systems: widespread voltage control problems and protective system issues.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>G4</strong> Severe</td>
<td>Power systems: possible widespread voltage control problems and protective system issues.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>G3</strong> Strong</td>
<td>Power systems: voltage corrections may be required, false alarms may occur on some protection devices.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>G2</strong> Moderate</td>
<td>Power systems: high latitude power systems may experience voltage sprints.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>G1</strong> Minor</td>
<td>Power systems: weak power grid fluctuations are possible.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Kp values determined every 3 hours

4 per cycle (4 days per cycle)
Event-Driven Product Definitions

- Watches: The conditions are favorable for occurrence
- Warnings: disturbances that are imminent, expected in the near future with high probability
- Alerts: observed conditions meeting or exceeding thresholds
Solar Flares (Radio Blackouts – R Scale)

- Arrival: 8 minutes, photons
- Duration: Minutes to 3 hours
- Daylight-side impacts
- Probabilistic 1, 2, 3-day forecasts
- Alerts for exceeding R2 (only)
- Summary messages post-event
March 2012
Impacts on Aviation Comms

7 March 2012: INCERFA was issued for Air Canada 003 (Vancouver to Tokyo) until communications were established with the flight.

(INCERFA is issued when there is uncertainty as to the safety of an aircraft and its occupants.)

6-7 March 2012: “Severe impact at 2249Z initially affecting CWP [Central West Pacific] but by 2400Z, impact peaked and was affecting all communications. 25 ATC messages were delayed.”

- Air Traffic Communications
Solar Flare (Radio Burst) Impact on GPS – 6 Dec 2006

IGS Network, 6 December 2006

19:14:46 UTC
- Failure
- Operational

Owens Valley Solar Array RHCP SRB Power (1.6 GHz)

~10 mins
Solar Radiation Storms (S Scale)

- Arrival: 10’s of minutes to several hours
- Duration: hours to days
- Short-term warnings pre-onset
- Alert for threshold crossing
- Summary post-event
"UPDATE 1 03/07/2012 @ 0943 EST - LightSquared is currently experiencing a satellite network outage over our SkyTerra 1 satellite. Preliminary investigation reveals that a solar event has created an automatic system safeguard as a measure to protect the satellite. The recovery procedures are underway which could take from 4 to 24 hours. As soon as we know more, we will provide you with updates. Ground communication with the satellite is intact. Engineers, along with partners at Boeing and Telesat are engaged in resolving the issue. We will provide additional updates as the situation progresses."

"UPDATE 9 03/09/2012 @ 0945 hours EST: - Per the previous communication, LightSquared continues to work the key procedures to restore Skyterra 1 to service. Based on LightSquared's current progress they now estimate that they will return customers to service by 1200 EST (1600 UTC) on Sunday. LightSquared understands that this is a significant extension of the previous timeline estimate. However, there are technical reasons why the schedule has been adjusted. LightSquared understands that this delay of the previous timeline will cause concern for customers and end users. However, the level of commands involved in the overall restoration procedure have taken longer than originally anticipated."

Should emergency managers in Florida be worried about this storm?
**Geomagnetic Storms (G Scale)**

- Coronal Mass Ejections (CMEs) create geomagnetic storms
- Arrival: ~18 – 96 hours
- Duration: Hours to a day or two
- Creates ionospheric storms, geomagnetically induced currents, aurora

- 1-2 Day watch products based on coronagraph observations and modeling (Highest Expected K)
- Short-term (15 -60 min) warnings based on measurement at ACE spacecraft
GPS IMPACT – U.S. Federal Aviation Administration (FAA)
Wide Area Augmentation System (WAAS)

- Intense geomagnetic and ionosphere storms occur on 29 and 30 Oct, 2003
- Acceptable vertical error limits were exceeded for 15 and 11-hour periods
Impacts on Electric Power Grid

- CME impacts Earth’s magnetic field
- Fluctuations generate electric fields on Earth. These geomagnetically induced currents (GIC) can flow into power lines and transformers
- Leads to transformer saturation and over-heating, voltage drops, transformer damage, or protective device trips
Media Release: Loss of Reactive Power, Voltage Instability Most Likely Outcome from GMD, NERC Report Finds
February 29, 2012

ATLANTA – Loss of reactive power is the most likely outcome from a severe solar storm centered over North America, a report released by the North American Electric Reliability Corporation (NERC) finds. Significant losses of reactive power could lead to voltage instability and, if not identified and managed appropriately, power system voltage collapse could occur.....
Extreme Event?

Initiate telecon with RCs through NERC Bulk Power System Awareness group

When this would have happened – Oct 2003

When it may not have happened – Mar 1989!
In partnership with USGS, introducing Web-based map showing electric field magnitude as a function of location.

- Provides options for viewing the electric field vectors (similar to wind field display), electric field magnitude, or individual surface components
- Updates in real-time (new calculation every minute)
- Continuous color scaling to indicate magnitude

Collaborating with the research community

*Transition complete by 2015*
Sun to Earth Modeling – Current Plans

- Solar /Solar Wind
- Magnetosphere/Ionosphere
- Ionosphere/Atmosphere
- Earth’s surface

WSA-Enlil
Space Weather Modeling Framework - Geospace
Whole Atmosphere Model
Electric Field Model

Location of 1D Earth Resistivity Models with respect to Physiographic Regions of the USA
NOAA Space Weather Prediction Center
Boulder, Colorado

www.spaceweather.gov
Thank You

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