Space Weather and its Societal Impacts

Dr. Sten Odenwald
NASA / ADNET

Heliophysics Summer School
June 1, 2012
Space Weather - Origins

Impacts – Radio Communication
  Submarine Cables
  Computer Systems
  Satellite Systems
  Cellular and Mobile Phones
  GPS Systems
  Electric Power Grids
  Aviation and Passengers
Space Weather Forecasting
Solar Flares
Coronal Mass Ejections
The Sunspot Cycle

Modeling the Societal Impacts
Satellite Systems
Electric Power Grid
Commerce

Worst Case Preparedness is now in-Vogue
Basic Physics of the Sun-Wind-Earth System

The Sun
    Volume 1, Chapter 7, 12

Earth’s Magnetosphere
    Volume 1, Chapters 10, 11

Radiation Belts
    Volume 2, Chapter 11

The Ionosphere
    Volume 1, Chapter 12
    Volume 3, Chapter 13
Solar Flares

Courtesy – SDO
Atlantic Communications Broken
By Largest Solar Flare in Years

Coast Guard officials in New York said
that the flare had already knocked out
maritime communications in the Atlantic
for an hour and 45 minutes this morning.

New York Times...April 29, 1978
Space Weather

'Bad Hair Days'
- Solar Wind
- Coronal Holes
- Cosmic Rays

Solar Storms
- Solar Flares
  - X-rays
  - Energetic Particles
    - 8 min.
    - ~1-hr
  - Ionosphere disruption and Heating

- Coronal Mass Ejections
  - Plasma + magnetic field
    - 14-hr to 4 days
  - Geomagnetic Storms
    - No SPEs
    - SPEs
      - Satellite Anomalies
        - GPS problems
        - Satellite drag
        - Satellite Anomalies
          - Power Grid problems
          - GLEs

Milder Geomagnetic Storms
## The Most Severe Geomagnetic Storms

<table>
<thead>
<tr>
<th>Date</th>
<th>Cycle</th>
<th>Dst</th>
</tr>
</thead>
<tbody>
<tr>
<td>March 13, 1989</td>
<td>22</td>
<td>-589</td>
</tr>
<tr>
<td>July 15, 1959</td>
<td>19</td>
<td>-429</td>
</tr>
<tr>
<td>November 20, 2003</td>
<td>23</td>
<td>-465</td>
</tr>
<tr>
<td>February 11, 1958</td>
<td>19</td>
<td>-426</td>
</tr>
<tr>
<td>May 25, 1967</td>
<td>20</td>
<td>-387</td>
</tr>
<tr>
<td>March 31, 2001</td>
<td>23</td>
<td>-387</td>
</tr>
<tr>
<td>October 29, 2003</td>
<td>23</td>
<td>-363</td>
</tr>
<tr>
<td>November 13, 1960</td>
<td>19</td>
<td>-339</td>
</tr>
<tr>
<td>February 8, 1986</td>
<td>22</td>
<td>-307</td>
</tr>
<tr>
<td>July 15, 2000</td>
<td>23</td>
<td>-301</td>
</tr>
<tr>
<td>November 6, 2001</td>
<td>23</td>
<td>-292</td>
</tr>
<tr>
<td>April 7, 2000</td>
<td>23</td>
<td>-288</td>
</tr>
<tr>
<td>July 8, 1958</td>
<td>19</td>
<td>-286</td>
</tr>
<tr>
<td>May 4, 1998</td>
<td>23</td>
<td>-205</td>
</tr>
<tr>
<td>August 4, 1972</td>
<td>20</td>
<td>-125</td>
</tr>
</tbody>
</table>
The Most Severe Geomagnetic Storms (Ap Index)

Most Intense Geomagnetic Storms Since 1932
# The Most Severe X-class Flares

<table>
<thead>
<tr>
<th></th>
<th>Date</th>
<th>Cycle</th>
<th>X-class</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>04/11/03</td>
<td>23</td>
<td>X45</td>
</tr>
<tr>
<td>2</td>
<td>02/04/01</td>
<td>23</td>
<td>X20.0</td>
</tr>
<tr>
<td>2</td>
<td>16/08/89</td>
<td>22</td>
<td>X20.0</td>
</tr>
<tr>
<td>3</td>
<td>28/10/03</td>
<td>23</td>
<td>X17.2</td>
</tr>
<tr>
<td>4</td>
<td>07/09/05</td>
<td>23</td>
<td>X17</td>
</tr>
<tr>
<td>5</td>
<td>06/03/89</td>
<td>22</td>
<td>X15.0</td>
</tr>
<tr>
<td>5</td>
<td>11/07/78</td>
<td>21</td>
<td>X15.0</td>
</tr>
<tr>
<td>6</td>
<td>15/04/01</td>
<td>23</td>
<td>X14.4</td>
</tr>
<tr>
<td>7</td>
<td>24/04/84</td>
<td>22</td>
<td>X13.0</td>
</tr>
<tr>
<td>7</td>
<td>19/10/89</td>
<td>22</td>
<td>X13.0</td>
</tr>
<tr>
<td>8</td>
<td>15/12/82</td>
<td>21</td>
<td>X12.9</td>
</tr>
<tr>
<td>9</td>
<td>06/06/82</td>
<td>21</td>
<td>X12.0</td>
</tr>
<tr>
<td>9</td>
<td>01/06/91</td>
<td>22</td>
<td>X12.0</td>
</tr>
<tr>
<td>9</td>
<td>04/06/91</td>
<td>22</td>
<td>X12.0</td>
</tr>
<tr>
<td>9</td>
<td>06/06/91</td>
<td>22</td>
<td>X12.0</td>
</tr>
<tr>
<td>9</td>
<td>11/06/91</td>
<td>22</td>
<td>X12.0</td>
</tr>
<tr>
<td>9</td>
<td>15/06/91</td>
<td>22</td>
<td>X12.0</td>
</tr>
<tr>
<td>10</td>
<td>17/12/82</td>
<td>21</td>
<td>X10.1</td>
</tr>
<tr>
<td>10</td>
<td>20/05/84</td>
<td>21</td>
<td>X10.1</td>
</tr>
</tbody>
</table>

Total Cycle 23:
- 122 X-class
- 14,500 total

Recent Cycle 24:
- 3/6/2012 X5.4
- 8/10/2011 X6.9

Cycle 21=5
Cycle 22=9
Cycle 23=5
<table>
<thead>
<tr>
<th>Date</th>
<th>Cycle</th>
<th>pFU</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/23/1991</td>
<td>Cycle 22</td>
<td>43,000</td>
</tr>
<tr>
<td>10/19/1989</td>
<td>Cycle 22</td>
<td>40,000</td>
</tr>
<tr>
<td>11/4/2001</td>
<td>Cycle 23</td>
<td>31,700</td>
</tr>
<tr>
<td>10/28/2003</td>
<td>Cycle 23</td>
<td>29,500</td>
</tr>
<tr>
<td>7/14/2000</td>
<td>Cycle 23</td>
<td>24,000</td>
</tr>
<tr>
<td>11/22/2001</td>
<td>Cycle 23</td>
<td>18,900</td>
</tr>
<tr>
<td>11/8/2000</td>
<td>Cycle 23</td>
<td>14,800</td>
</tr>
<tr>
<td>9/24/2001</td>
<td>Cycle 23</td>
<td>12,900</td>
</tr>
<tr>
<td>2/20/1994</td>
<td>Cycle 22</td>
<td>10,000</td>
</tr>
<tr>
<td>8/12/1989</td>
<td>Cycle 22</td>
<td>9,200</td>
</tr>
<tr>
<td>1/23/2012</td>
<td>Cycle 24</td>
<td>6,300</td>
</tr>
<tr>
<td>1/16/2005</td>
<td>Cycle 23</td>
<td>5,000</td>
</tr>
<tr>
<td>3/9/1992</td>
<td>Cycle 22</td>
<td>4,600</td>
</tr>
</tbody>
</table>
## Worst-case storm events

<table>
<thead>
<tr>
<th>Year</th>
<th>1859</th>
<th>1921</th>
<th>1941</th>
<th>1960</th>
<th>2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>Aug-Sept</td>
<td>May 5</td>
<td>July 5</td>
<td>Nov. 13</td>
<td>Oct 29</td>
</tr>
<tr>
<td>Duration</td>
<td>8 days</td>
<td>7 days</td>
<td>1 day</td>
<td>1 day</td>
<td>3 days</td>
</tr>
<tr>
<td>Sunspot phase</td>
<td>-1 year</td>
<td>+4 years</td>
<td>+4 years</td>
<td>+3 years</td>
<td>+3 years</td>
</tr>
<tr>
<td>Transit Time</td>
<td>17.6 hrs</td>
<td>&lt; 24 hrs</td>
<td>&lt; 72 hrs</td>
<td>&lt; 48 hrs</td>
<td>20.3 hrs</td>
</tr>
<tr>
<td>SPE (P/cm²)</td>
<td>18.8</td>
<td>1.0</td>
<td>0</td>
<td>9.0</td>
<td>3.3</td>
</tr>
<tr>
<td>AA*</td>
<td>&gt; 500</td>
<td>257</td>
<td>277</td>
<td>352</td>
<td>298</td>
</tr>
<tr>
<td>Sunspot size (millionths Hemi)</td>
<td>1600</td>
<td>805</td>
<td>2101</td>
<td>5286</td>
<td>2808</td>
</tr>
</tbody>
</table>
| Technological Impacts | **Telegraph** | **Telegraph** | **Telephone** | **Radio** | **Radio**
| | Wireless | Telephone | Radio | Satellites | Pwr Grid |
## Human and Technology Impacts

<table>
<thead>
<tr>
<th>Year(s)</th>
<th>Event Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1851, 1852, 1858, 1859, 1870, 1872, 1877, 1882, 1894, 1921, 1926, 1938, 1940</td>
<td>Telegraph outages</td>
</tr>
<tr>
<td>1919, 1921, 1930, 1938, 1940, 1941, 1946, 1958, 1960, 1972</td>
<td>Radio or TV interference</td>
</tr>
<tr>
<td>1832, 1837, 1859, 1882, 1926, 1938, 1960, 1989</td>
<td>Severe psychic anxiety, mass panic, 'Doomsday'</td>
</tr>
<tr>
<td>1903, 1918, 1989, 1991, 2003</td>
<td>Electrical system failures or disruptions</td>
</tr>
<tr>
<td>1835, 1837, 1859, 1872, 1946</td>
<td>Compass and navigation problems</td>
</tr>
<tr>
<td>1859, 1882, 1921, 1940</td>
<td>Fires and equipment damage.</td>
</tr>
<tr>
<td>1859, 1860, 1882, 1903, 1909, 1921, 1940, 1958</td>
<td>Electrical shocks and high-voltage conditions</td>
</tr>
<tr>
<td>1938, 1940, 1946, 1989</td>
<td>Air Travel issues</td>
</tr>
<tr>
<td>2003</td>
<td>GPS positioning errors</td>
</tr>
</tbody>
</table>
The most intense storms usually get reported.
Since ca 1945, the location in the paper has dramatically shifted
...and the news stories are significantly shorter.

Newspaper Reportage

Halloween 2003
MAGNETIC STORMS BOMBARD RADIO

Sun Spots Blamed for Blasts of Static That Rip European Waves on the Way to America for Rebroadcasting
Radio Communication

Space Weather Impact – SW fadeouts

Ionization in D-Region increases SW signal absorption
Radio Communication

Who cares? ---- Dramatic decline in short-wave stations and usage, worldwide
Radio Communication

Ham Operators Save the Day!!!!

Ham radio operators to the rescue after Katrina
Amateur radio networks help victims of the hurricane

By Gary Krakow
Columnist

Ham radio operators tune in hurricane help

By Barbara W. Carleton, Contributor to The Christian Science Monitor / September 15, 2005

NEWINGTON, CONN.

Richard Webb, an amateur radio operator, was asleep on his air mattress at University Hospital in New Orleans during the aftermath of hurricane Katrina when he was awakened at 5 a.m. by a hospital administrator.

Ham operations work when phones, Web won’t

• Weekend event explains how older technology works when other systems fail
By Naomis Klouda
Homer Tribune

When Hurricane Katrina struck, phone lines went down, cell towers toppled and Internet connections were nonexistent. But the ham operators kept going.

This band of men who make earnest practice keeping their citizen’s band radio tuned, were able to communicate with the outside world.

Telephones, cell phones, Internet, trunk lines, satellite phones – they all have to go through many “vulnerable choke points” and need electric power to operate, said

HOMER TRIBUNE/Naomi Klouda - Ham radio operators George VanLone, Dale Hershberger, Ed Beck and Kris Kere make contact for the refuge.
Submarine Cables – Fiber and copper

Repeaters and amplifiers every 10 km.
Submarine Cables

Like telegraph systems, cable HV supplies are grounded

GICs enter system, cause ‘repeater’ malfunctions
Excess charge causes gate state change
Computer Systems

Single Event Effects – SEEs

Single Event Upsets - SEU
- state change in binary gate ‘0 to 1’
- reset by power cycling or re-boot

Single Event Latch Up - SEL
- Permanent state change
- May not be resetable

Single Event Transient – SET
- Excess charge travels through circuit
- May dissipate w/o intervention
Mitigation

Error Detection and Correction (EDAC)

Parity bits - software correction

Watchdog timer – normal operation resets timer.
- if timer runs out, hard reset

Redundancy - polling before action among independent microprocessors
Radiation-Hardening is expensive

Catastrophic 'latch-up' due to heavy ion impact
Figure provided by Aerospace Corporation
http://www.aero.org/

A six-transistor latch, commonly used as the storage element in a static memory circuit, is shown alongside a design-hardened 12-transistor variant. (Courtesy Aerospace Corp)
# The Economic Real Estate

<table>
<thead>
<tr>
<th>Location</th>
<th>Commercial</th>
<th>Military</th>
<th>Research</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEO</td>
<td>273</td>
<td>94</td>
<td>70</td>
<td>437</td>
</tr>
<tr>
<td>MEO</td>
<td>19</td>
<td>101</td>
<td>12</td>
<td>132</td>
</tr>
<tr>
<td>GEO</td>
<td>308</td>
<td>51</td>
<td>8</td>
<td>367</td>
</tr>
<tr>
<td><strong>Totals:</strong></td>
<td><strong>600</strong></td>
<td><strong>245</strong></td>
<td><strong>91</strong></td>
<td><strong>936</strong></td>
</tr>
</tbody>
</table>

- Total Satellite Fleet (ca Dec, 2004)............. ~ 936
- Total hardware + launch cost....................... ~ $230 billion
- GEO Transponder Capacity......................... ~ 6,800
- GEO industry annual revenue....................... $87 billion
- LEO + MEO satellite annual revenue............. $10 billion
- Satellite Industry annual revenue.............. $225 billion
# 23rd Cycle Satellite Outages (1997-2004)

<table>
<thead>
<tr>
<th>Satellite</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telstar 401</td>
<td>$250 million</td>
</tr>
<tr>
<td>Tempo-2</td>
<td>$150 million</td>
</tr>
<tr>
<td>Adeos</td>
<td>$474 million</td>
</tr>
<tr>
<td>PAS-6</td>
<td>$150 million</td>
</tr>
<tr>
<td>Equator-S</td>
<td>$12 million</td>
</tr>
<tr>
<td>ASCA</td>
<td>$100 million</td>
</tr>
<tr>
<td>Midori-II</td>
<td>$640 million</td>
</tr>
</tbody>
</table>

Total = $1.8 billion to $2.95 billion
Physical Effects of Space Environment

- Low energy electrons - surface charging (ESD)
- High energy electrons - internal charging (IESD)
- Solar flare protons - solar array degradation
- Ionizing dose - electronics, materials aging
- Non-ionizing dose - CCD’s, optical couplers
- Heavy ions/cosmic rays - single event effects
- Ultraviolet - cover glass darkening, surface degradation
MMT Observatory 1-hour dark frame with GCR tracks

Exposed imaging CCD on SOHO during SPE event after CME
Particle fluences are large but satellite anomalies are rare

GCR fluence through satellite.................. $10^{12}$ particles / year

Single Event Upsets............................. $10^6$ events / year

Anomalies........................................... 1 – 10 / year

Mean Time to Failure............................. 250 years

Satellites are reliable 364 days of year, but to get 100% on that last day can be cost-prohibitive.
Satellite Anomalies at GEO
A Few Examples

- Telstar-401 13 January 1997 Satellite Failure
- GALAXY-VII 13 June 1998 Satellite Control Processor
- BRAZILSAT 9 April 2000 Transponder Amplifier
- SOLIDARIDAD-I 27 Aug 2000 Satellite Control Processor
- ECHOSTAR-IV 31 Oct 2000 Transponders lost
- INSAT-2B 4 Nov 2000 Service outage
- GALAXY-VII* 22 Nov 2000 Satellite Control Processor
- ECHOSTAR-VI April 2001 Service outage
- GALAXY-IIIR 21 April 2001 Satellite Control Processor
- TELSTAR-6 22 April 2001 Satellite Control Processor
Relatively Harmless Problem with Power Loss

2% per year decline from GCRs
6% from SPEs
By 2010 67% of human population have cell phones
Cellular and Mobile Phones

Space Weather Vulnerability

A high-frequency Type II burst observed on 2005 November 14 (NRAO)

Dropped-call rate 1 every 3 days during solar max.

Lanzerotti, et al, 2005 ‘Noise in wireless systems from solar radio bursts’
1.0 TECU = $10^{16}$ e/m$^2$

5 TECU = 1 meter GPS pos. error
Electric Power Grids - GICs

Impacts – Geomagnetically-Induced Currents

David Boteler (Helio III, June 6)

Top = GIC in 400 kV transformer ground – southern Sweden
Bottom – GIC in natural gas pipeline – southern Sweden

Courtesy – Lund Space Weather Center (www.lund.irf.se)
Electric Power Grids

Transformer damage
Mitigation

Adding resistors to ground lines

$500 million

Total amperes to US grid using various resistor values
The normal total dose rate is \( 0.41 \text{ microSv/hr} \).
Cosmic Rays

Cosmic Ray background varies with elevation

High = 0.1 microSieverts/hr
Low = 0.03 microSieverts/hr

The normal Total dose rate is 0.41 microSv/hr
Air Travel – Cosmic Rays
Passengers flying polar routes
Amateur Scientist Peter Jaeger (2003) in a flight from Madrid to Miami. This is a non-Polar flight. Typical = 7 microSieverts/hr

On the ground, the normal dose rate is 0.41 microSv/hr.

For a few hours you get 20 times normal dose rate
900 hrs x 7 microSv/hr = 6.3 milliSv  
Annual = 3.6 milliSv
Polar Cap Absorption and HF Communication blackouts

Image Credit: M. A. Shea, Geophysics Directorate, Phillips Laboratory

Courtesy: SpaceWeather.org
Space Weather  Forecasting and Modeling
Solar Flares
Coronal Mass Ejections
The Sunspot Cycle
Sunspot Cycle

Cycle 24 Sunspot Number Prediction (May 2012)

Hathaway/NASA/MSFC
Sunspots

Sunspot Cycle 1600–2000

Number of sunspots

Year

1600 1650 1700 1750 1800 1850 1900 1950 2000

Maunder

Dalton

1900 Minimum
Physics-based Modeling

Maxwell’s Equations

\[ \nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \quad (1) \]
\[ \nabla \times \mathbf{H} = \frac{\partial \mathbf{D}}{\partial t} + \mathbf{J}_f \quad (2) \]
\[ \nabla \cdot \mathbf{B} = 0 \]
\[ \nabla \cdot \mathbf{D} = \rho_f \]

Magnetohydrodynamics Equations:
Conservation of mass, energy, momentum for neutrals and ions

\[ \frac{\partial \rho_n}{\partial t} = -\nabla \cdot (\rho_n \mathbf{v}_n), \quad (1) \]
\[ \frac{\partial \rho_i}{\partial t} = -\nabla \cdot (\rho_i \mathbf{v}_i), \quad (2) \]
\[ \rho_n \frac{\partial \mathbf{v}_n}{\partial t} = -\rho_n (\mathbf{v}_n \cdot \nabla) \mathbf{v}_n - \nabla P_n - \gamma_{AD} \rho_i \rho_n (\mathbf{v}_n - \mathbf{v}_i), \quad (3) \]
\[ \rho_i \frac{\partial \mathbf{v}_i}{\partial t} = -\rho_i (\mathbf{v}_i \cdot \nabla) \mathbf{v}_i - \nabla P_i - \gamma_{AD} \rho_i \rho_n (\mathbf{v}_i - \mathbf{v}_n) \]
\[ \quad + \frac{1}{4\pi} (\nabla \times \mathbf{B}) \times \mathbf{B}, \quad (4) \]
\[ \frac{\partial \mathbf{B}}{\partial t} = \nabla \times (\mathbf{v}_i \times \mathbf{B}), \quad (5) \]
\[ \nabla \cdot \mathbf{B} = 0, \quad (6) \]
Modeling
Solar Modeling
Solar Rotation and Plasma Flows
Sunspot Modeling
Sunspot Cycle Modeling
Sunspot Cycle Modeling

ISES Solar Cycle Sunspot Number Progression

Sunspot Cycles: Past and Future
Solar Flare Modeling

\[ E_h = \frac{j \times B}{ne\epsilon} \]

DOUBLE ELECTRIC LAYERS

X-RAYS
\[ H_\alpha \]

PEDERSEN CURRENT

S

N
CME Modeling
Cosmic Ray Modeling
Integrated Space Weather Analysis System is a web-based dissemination system for NASA-relevant space weather information.

Space Weather Awareness at NASA space weather information portal.

LWS Supported Tools and Methods

Kameleon software: model output from different models can now be stored uniformly in a common science data format. Users can request the CDF-formatted output for a CCMC run.

Movies on Request: you can now request to generate a movie, images and ASCII data files for each time step of a model run.

CCMC Space Weather on Google Earth: CCMC is now providing space weather-related Google Earth overlays.
CCMC - Products

Community Coordinated Modeling Center
Real Time Simulation

SWMF Magnetosphere

Solar Wind from Ace

Tue, 23 Jan 2007 19:59:33 GMT
Radiation Modeling – SPENVIS

http://www.spenvis.oma.be/
NOAA/SWS Space Weather Prediction Service
http://www.swpc.noaa.gov/
The Sun Today
http://www.swpc.noaa.gov/

http://www.swpc.noaa.gov/SolarCycle/

http://sdowww.lmsal.com/
...and yes there’s an App for that!!
Modeling the Societal Impacts
Satellite Systems
Electric Power Grid
Commerce
Large economic events…

San Francisco Earthquake……. 1906………… $ 500 billion

Hurricane Katrina……………… 2005………… $ 120 billion

North American Power Grid Blackout…………$ 30 billion/day
  GEO satellite revenue loss……………………………$ >25 billion

Blackout of East Coast………… 1965………… $ 10 billion

Mt Lassen Volcanic Eruption… 1915………… $ 5 billion

Quebec Blackout………………. 1989………… $ 2 billion

Typical Large Annual Storm…………………………… $ 1 billion
Kappenmann (1997) has an extensive record of modeling the US power grid with increasingly more sophisticated models of the electrodynamics of GICs and exhaustive studies of the North American electric grid network at the component level.

Currently, his efforts use historical geomagnetic storms (e.g. 1921 event) and their impact on the contemporary electric power grid. Among the forecasts are for year-long recovery periods costing over $1 trillion in GDP.
“Establishing the Economic Impact of Space Weather: The case of electricity”

Kevin Forbes (Helio III, June 7)


Space weather disrupts the system that transmits the power from where it is generated to where it is distributed to customers. Between June 1, 2000, through Dec. 31, 2001, solar storms increased the wholesale price of electricity by approximately 3.7 percent or approximately $500 million over 19 months.
Economic losses to commercial satellites

Odenwald and Green (2007)

Monte-Carlo simulation using realistic GEO satellite population and transponder transactions. An 1859-scale ‘superstorm’ near sunspot maximum

$50 billion in lost revenue and assets.
Worst Case Preparedness Becomes Political

October 2003 – ‘What is Space weather and who should forecast it?’

Congressional Hearing on Space Weather held before the Subcommittee on Environment, Technology, and Standards, Committee on Science, House of Representatives, One Hundred Eighth Congress, first session, October 30, 2003, (Congress, 2003)

Debate over who should fund SEC
December 2005, Idaho National Laboratory and NRC published ‘Reevaluation of Station Blackout Risk at Nuclear Power Plants--Analysis of Station Blackout Risk.’

The executive summary from this report reads in part: The availability of alternating current (ac) power is essential for safe operations and accident recovery at commercial nuclear power plants. (INL, 2005)

The US Congress funded a vulnerability assessment research under the National Defense Authorization Act to evaluate the impact of an electromagnetic pulse (EMP) from a high altitude nuclear detonation by a terrorist event on the nation's critical infrastructure including the electric grid.

The same study also discussed geomagnetically - induced currents. (EMP Commission, 2008)

208 pages!
Worst Case Preparedness – Doomsday Scenarios

2008 ‘Severe Space Weather Events—Understanding Societal and Economic Impacts Workshop Report’.

The National Academy of Sciences determined that severe geomagnetic storms have the potential to cause long-duration outages to widespread areas of the North American grid. (NAS, 2008)

jointly sponsored by NERC and the Department of Energy, NERC now concedes that the North American power grids have significant reliability issues in regard to High-Impact, Low-Frequency events such as severe space weather.

The NERC report explains commercial grid vulnerability to space weather (NERC, 2010)

The commercial power grids in two large areas of the continental United States are vulnerable to severe space weather. The replacement lead time for extra high voltage transformers is approximately 1-2 years. (Oak Ridge Labs, 2010)
Worst Case preparedness is now in-Vogue
…but now the stakes seem higher!!!!

The Telegraph

Nasa warns solar flares from 'huge space storm' will cause devastation

Exclusive: Britain could face widespread power blackouts and be left without critical communication signals for long periods of time, after the earth is hit by a once-in-a-generation “space storm”, Nasa has warned.

May 30, 2012
Dire warning: U.S. unprepared for massive solar flare storm; could lose power, communications

BY SHERRY MAZZOCCHI
DAILY NEWS WRITER
Thursday, June 24, 2010

It may sound like the premise for the next Michael Bay, big-budget action extravaganza -- but scientists say a storm from space could change life on Earth as we know it.

And the United States is woefully unprepared for such a disaster, according to a new report.

The potential threat, detailed in a National Academy of Sciences, Severe Space Weather Events report, said radiation bombarding the planet from powerful solar flares could result in the loss of power, water and communications on a global scale.
How a solar flare could send us back to the Stone Age

A powerful enough solar flare could knock out our power grids, disrupt our GPS satellites, and bring the global economy to a halt, warns a British scientists.

By Amina Khan, Los Angeles Times / May 9, 2012

This image provided by NASA shows the sun releasing a M1.7 class flare in April 2012. This image was taken by the Solar Dynamics Observatory. This visually spectacular explosion occurred on the sun's Northeastern limb (left) and was not Earth directed.

NASA/SDO/AIA/AP/Files