The Office of Infrastructure Protection

National Protection and Programs Directorate
Department of Homeland Security

Risk Analysis of Severe Space Weather Events to U.S. Critical Infrastructure

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Critical Infrastructure Protection

- One of the primary mission areas at the U.S. Department of Homeland Security is critical infrastructure protection
- There are 18 critical infrastructure sectors including Energy, Communications, and Food and Agriculture
- Both manmade and natural events can affect critical infrastructure, potentially disrupting the functioning of government and business that could have cascading effects far beyond the initially impacted sector and location
- The National Infrastructure Protection Plan (NIPP) is the unifying structure that integrates a wide range of protective security efforts into a single national program

Analytics and Infrastructure Protection

- To support the mission of protecting critical infrastructure, DHS produces timely and technically defensible risk analysis on a number of potentially adverse events to U.S. infrastructure while also identifying risk management options for consideration for homeland security partners
- DHS takes an all hazards approach and examines manmade threats and natural hazards
- The risks from many natural disasters to U.S. infrastructure can be extrapolated from historical frequency and consequence data
- Analytical techniques are applied based on the data available and the mission need

Space Weather Phenomena and Potential Impacts

- Space weather is an always present, naturally-occurring, solar-based phenomenon that includes solar flares, radiation storms, and coronal mass ejections (CMEs), which can produce geomagnetic storms
- Solar flares may disrupt infrastructure radio transmissions, navigational satellite positioning and timing signals, and global positioning system reception
- Radiation storms impact satellites and aviation, particularly Polar routes
- CMEs can affect transmission lines and the electricity grid

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Focus on Geomagnetic Storms

- Geomagnetic storms are of particular interest due to the potential impacts to critical infrastructure
  - Geomagnetic storms are produced by CMEs – large, violent eruptions of plasma from the Sun
  - Take 1 to 3 days to reach the Earth and affect Earth's geomagnetic field
  - Severe geomagnetic storms can damage the bulk power grid, specifically extra high voltage (EHV) transformers, leading to electrical outages that may have major human and economic consequences
  - Northern latitude countries are particularly vulnerable, but a geomagnetic storm has the potential to cause significant damage across the globe with a single event
  - Though geomagnetic storms are infrequent compared to other natural hazards – the last extreme geomagnetic storm occurred in 1921– a major storm could be a high-consequence event that poses a systemic risk to the Nation

Critical Infrastructure Potentially Affected by Space Weather

- Ground-Based Critical Infrastructure
  - High-voltage transmission lines vulnerable to severe geomagnetic storms
  - Large transformers and other electric power infrastructure may be vulnerable to damage from severe geomagnetic storms
- Satellites
  - Degradation in strength or distortion of signals emitted by GPS satellites
  - Potential to damage satellites

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Historical Context

- One in 100 year storms (of ~4,800+ nT/min level over the USA)
  - In the last 150 years, only the 1859 and 1921 solar storms reached this level
  - 62 years between these storms…91 years have passed since
- One in 30 year storms (of ~2,400+ nT/min level over the USA)
  - 1972 (and perhaps 1940 and 1958) solar storm(s) approached this level over the USA
  - 1989 Hydro Quebec storm was at a lower level (~900 nT/min)
    - This storm caused transformer damage at one nuclear plant site in NJ
    - Caused complete collapse of Quebec's power grid
    - The US power grid is generally more vulnerable to these effects today
- The next solar sunspot maximum will occur in ~2013

Strategic Analysis Challenges

1. **Data**
   The quality, availability, and traceability of data varies across studies, models, and assessments

2. **Likelihood and Consequence (Risk) Measurement**
   Lack of consensus and overall difficulty in assessing low probability, high consequence concerns

3. **Threat Assessment**
   Identification of onset and intensity of geomagnetic storms

4. **Cascading Effects Analysis**
   Indirect consequences and interdependencies are challenging to assess

5. **Quantitative and Qualitative Analysis**
   Analytical approaches will impact findings and outcomes

6. **Time Horizon**
   A reasonable time horizon for which to plan against

Data

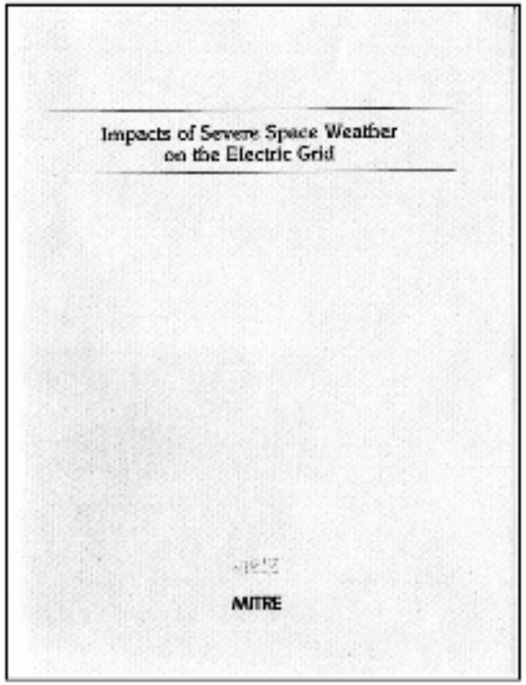
- The dataset on geomagnetic storms is small making it difficult to estimate frequency and strength
  - Only two extreme storms are known to have occurred in the past 150 years (1859 and 1921)
  - Past studies typically describe an 11-year solar cycle that gives some insight of peak solar activity, but no accurate method exists to assess frequency, and major geomagnetic storms do not necessarily occur during peak activity
    - the last extreme storm in 1921 occurred three years after the solar cycle peak
  - Jeffrey Love and Jennifer Gannon, 2009, modeled data from 1958 to 2007 to develop estimated frequencies for geomagnetic storms of different magnitudes, but they note that it is difficult to say whether the estimates are reasonable without a longer time span

Likelihood and Consequence Measurement

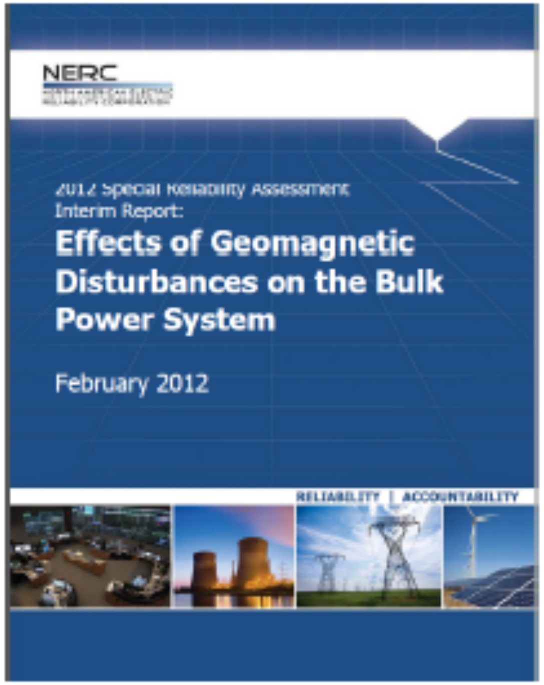
- The small dataset makes measuring likelihood difficult
  - John Kappenman has called severe space weather events “not a zero probability event,” but this is unhelpful for risk analysis
- There is little consensus concerning the consequences of an extreme geomagnetic storm
  - A 2008 study by the Metatech Corporation estimates that a repeat of the 1921 storm would affect more than 130 million people with sudden and lasting ramifications across U.S. social and technical infrastructure
  - A 2010 Lloyd’s report stated “A loss of power could lead to a cascade of operational failures that could leave society and the global economy severely disabled.”
  - A 2011 DHS-funded JASON Study disagreed with the severity of the Metatech worst-case scenario but concluded that severe electric grid damage was possible
  - A 2012 North American Electric Reliability Corporation (NERC) Task Force concluded that a full recovery would occur within a few days

Studies Predict a Range of Consequences

NAS 2008



JASONS 2011



NERC 2012

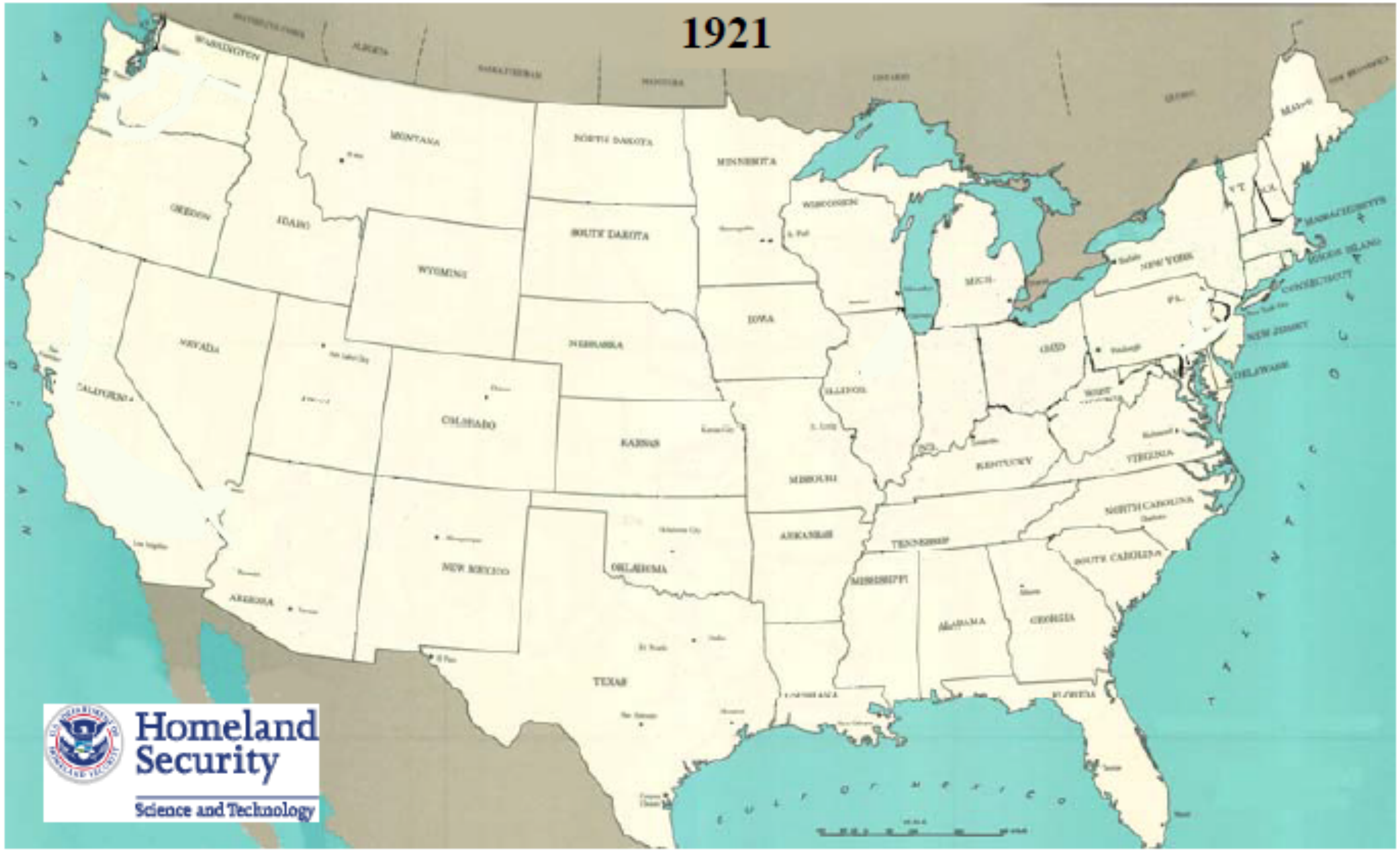
Threat Assessment

- Threat Assessment
  - Studies estimate the threat based on solar cycle activity, but no method is currently available to accurately predict either onset or severity
    - The National Oceanic and Atmospheric Administration (NOAA) can detect CMEs a day before impact but cannot predict intensity until the CME reaches the Advanced Composition Explorer (ACE) satellite positioned 99% of the distance from the Sun to the Earth, limiting alert time
  - Storm severity alone proves to be a poor indicator of the effect on electric utility systems
    - Other factors include ground conductivity, latitude and EHV line characteristics

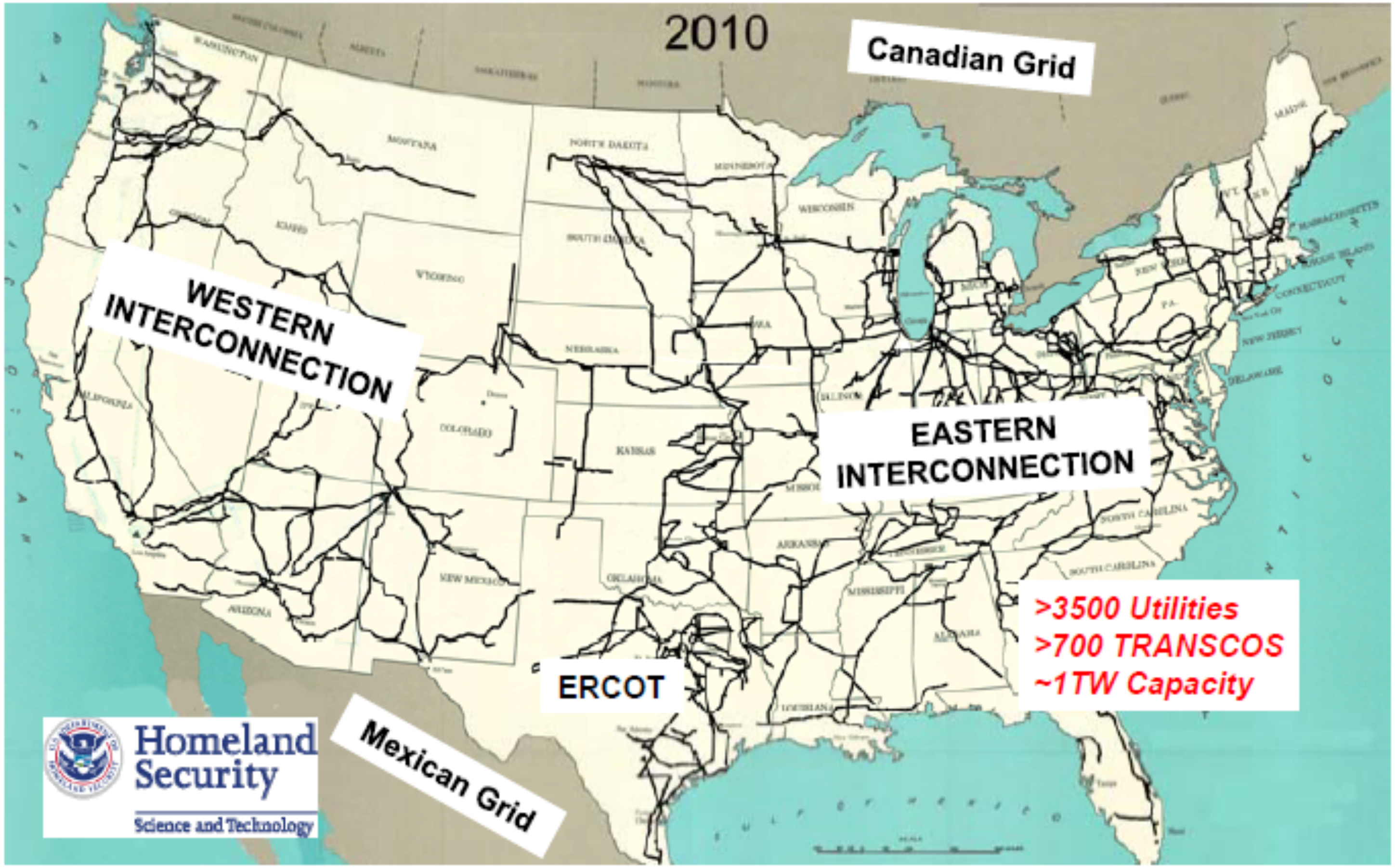
Cascading Effects Analysis

- The scenario developed by Metatech predicts more dire consequences due to cascading effects stemming from transformer failure
  - The report predicts that an extreme geomagnetic storm would destroy or damage transformers which can require a year or more to replace
  - This would result in long-term power outages lasting months to years and would negatively impact nearly all critical infrastructure sectors
- The NERC Task Force concluded that a severe geomagnetic storm would produce a system collapse and blackouts that would preclude transformer overheating damage
  - If transformers do not need to be replaced, the long-term effects would be greatly decreased
- Regardless of long-term effects, it is extremely difficult to predict what short-term impacts an extreme geomagnetic storm would have on critical infrastructure sectors not directly affected

345KV+ Transmission Growth



345KV+ Transmission Growth



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Predicted Impacts from a 1921-equivalent Geomagnetic Storm

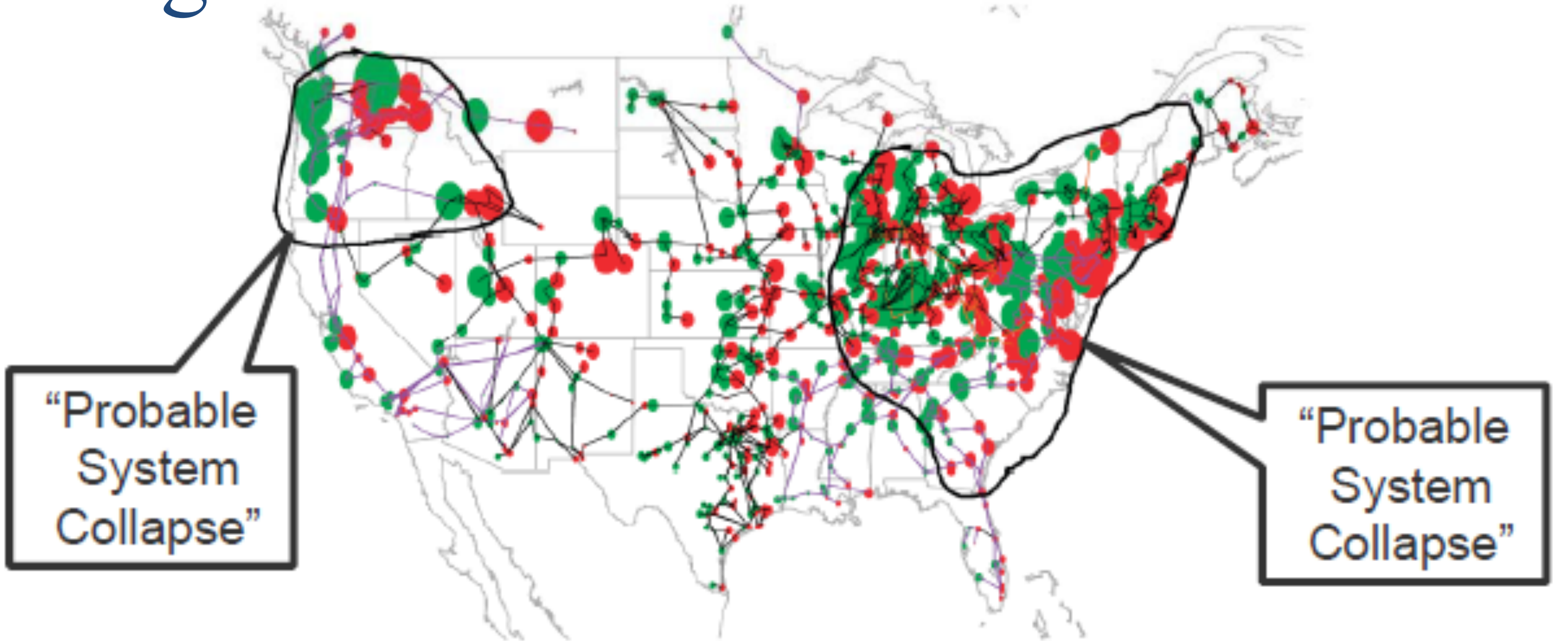

Figure 5. Regions susceptible to power grid collapse during a 4800 nT/min geomagnetic field disturbance at 50° geomagnetic latitude, where the densest part of the U.S. power grid lies. The affected regions are outlined in black. Analysis of such an event indicates that widespread blackouts could occur, involving more 130 million people. A disturbance of such magnitude, although rare, is not unprecedented: analysis of the May 1921 storm shows that disturbance levels of ~5000 nT/min were reached during that storm. (Image courtesy of John Kappenman, Metatech Corporation.)

\- *National Academies 2008 Report*

Quantitative and Qualitative Analysis

- No framework exists to assign a value or relative assessment to geomagnetic storms
- Quantitative analysis is difficult due to the lack of data and measurement inconsistencies
  - Multiple scales are used for estimating the strength of geomagnetic storms
    - Ap, K scale, G scale
  - Multiple units can be used to measure magnetic disturbance
    - nanoTeslas (nT), nT/min, or disturbance storm time (Dst) - Mega-electron Volt
- Quantitative analysis is difficult because there is little to which to compare
  - An extreme geomagnetic storm has not occurred since the United States and international partners have built long distance, EHV transmission grids

Time Horizon

- Because likelihood, frequency, and consequences are poorly understood, the time horizon for which to plan is unknown
- A 2012 FEMA Federal Interagency Response Plan (FIRP) developed a 10% downscale from one possible worst-case scenario
  - 100% of the extent (1/3 of the U.S.) x 10% of the duration =
  - The results were an estimated timescale of power restoration that matches mostly-statewide outages from big hurricanes or snowstorms
  - Study assumes few if any transformers are burnt out and therefore does not address the long-term failures predicted in worst case scenarios
- Other current studies and plans include:
  - OECD Geomagnetic Storms Case Study for Future Global Shocks
  - DHS Risk Management Issue Brief on Geomagnetic Storms
  - Draft Federal Interagency Operation Plan for Space Weather Mitigation

Strategic Policy Challenges and Targeted Efforts

1. **Anticipation and Resilience**
   Causal knowledge of failures in comparison to "preparing for the worst" by hardening systems and infrastructure

2. **EMPs and Geomagnetic Storms**
   Conflation of threats, vulnerabilities, and consequences of electromagnetic pulses and geomagnetic storms

3. **Informing Decision-Making**
   Assurance that findings and data help decision-makers

4. **Risk Appetite**
   Identification of the level of risk that decision-makers and practitioners will take and employ for mitigation determination

5. **Cost Effectiveness and Tradeoffs**
   Comparison of two or more alternatives based on value delivered. Deciding what is optional and what is essential

6. **Infrastructure and Homeland Security**
   Industry ownership of infrastructure and how it harmonizes with homeland security

Anticipation and Resilience

- Due to the potentially catastrophic risk to electrical infrastructure, several projects are underway at DHS to harden the electrical grid and mitigate the threat from an extreme geomagnetic storm
  - The Recovery Transformer Project is developing a prototype EHV transformer that can be quickly delivered, installed, assembled, and energized in seven days as compared to several weeks or even months for traditional transformers
  - The Resilient Electric Grid program is developing an inherently fault-current (power surge) limiting, high temperature, super conducting cable to help prevent cascading blackouts and permanent damage to electrical equipment

EMPs and Geomagnetic Storms

- The E3 component of an EMP is comparable to a geomagnetic storm with the magnitude of the E3 component varying greatly based on the type of EMP including weapon payload, vehicle, and location of detonation
- The E1 and E2 components of an EMP could weaken the electrical grid, making it more susceptible to the E3 component and causing more damage than a geomagnetic storm of equivalent strength
- Hardening the grid against one threat helps mitigate the risks of the other

Informing Decision-Making

- Many of the current and recent space weather studies and projects are being conducted or funded by government agencies
  - DHS, FERC, NERC, FEMA, etc
- Recent committee hearings in both the House and Senate have focused on vulnerabilities to the electric grid, and though not focused specifically on space weather, illustrate the concerns of policy-makers
- Continued government involvement will promote coordination between researchers and decision makers

Risk Appetite, Cost Effectiveness and Tradeoffs

- Decision makers and practitioners must decide what level of risk is acceptable while balancing cost effectiveness and tradeoffs
- The Deep Space Climate Observatory (DSCOVR) satellite will be launched in 2014 to build in redundancy and bolster the detection capabilities of ACE
  - Satellites may be the best detection tool for CMEs and geomagnetic storms but they are expensive
- It is more cost efficient to design and build EHV transformers to withstand an extreme geomagnetic storm than it is to retrofit the electric grid

Infrastructure and Homeland Security

- Much of the critical infrastructure that would be most affected by an extreme geomagnetic storm is owned by private industry
  - It therefore becomes difficult to impose standards
- The government continues to work with private industry to mitigate risks as well as develop procedures to respond to and recover from an extreme space weather event
  - The U.S. power industry has developed procedures to operate the grid in other modes when the Space Weather Prediction Center (SWPC) relays watches, warnings, and alerts
  - Transformer manufacturers have been established in the United States to help produce EHV transformers and shorten the lead time for replacements

DHS Space Weather Task Force

The Task Force is conducting a three-phase operation designed to address many of the previously mentioned challenges

Phase 1: Collection

Collect studies, assessments, and models to create a geomagnetic storms library and POC directory

Potential Results:

- Geomagnetic Storms Library
- Geomagnetic Storms POC Directory
- Information that can be shared with interagency and private sector partners

Phase 2: Assessment and Analysis

Synthesize collected information using a risk-based approach

Potential Results:

- Likelihood and consequence results based on structured analysis
- Findings and results that can be shared with interagency and industry

Phase 3: Policy

Use information or analysis to develop agreed-upon statements about geomagnetic storms

Potential Results:

- "Threshold" identification for planning and preparedness
- "Risk Range" for planning and preparedness

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For more information visit:
www.dhs/gov/criticalinfrastructure

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