Social & Economic Impacts of Space Weather (US Project)

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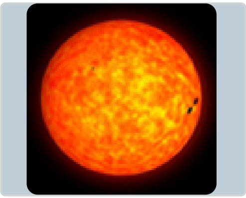

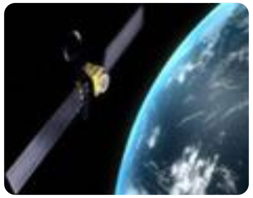


Space Weather Workshop – Westminster, CO – April 17, 2018

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Perspective

The Economic Impact of Space Weather: Where Do We Stand?

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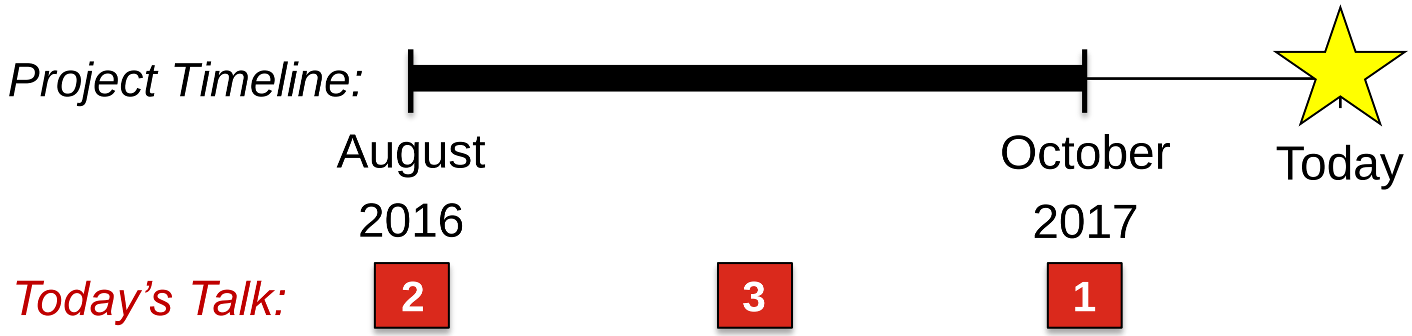
"Although space weather is growing rapidly as a field, work rigorously assessing the overall economic cost of space weather appears to be in its infancy."

Overview

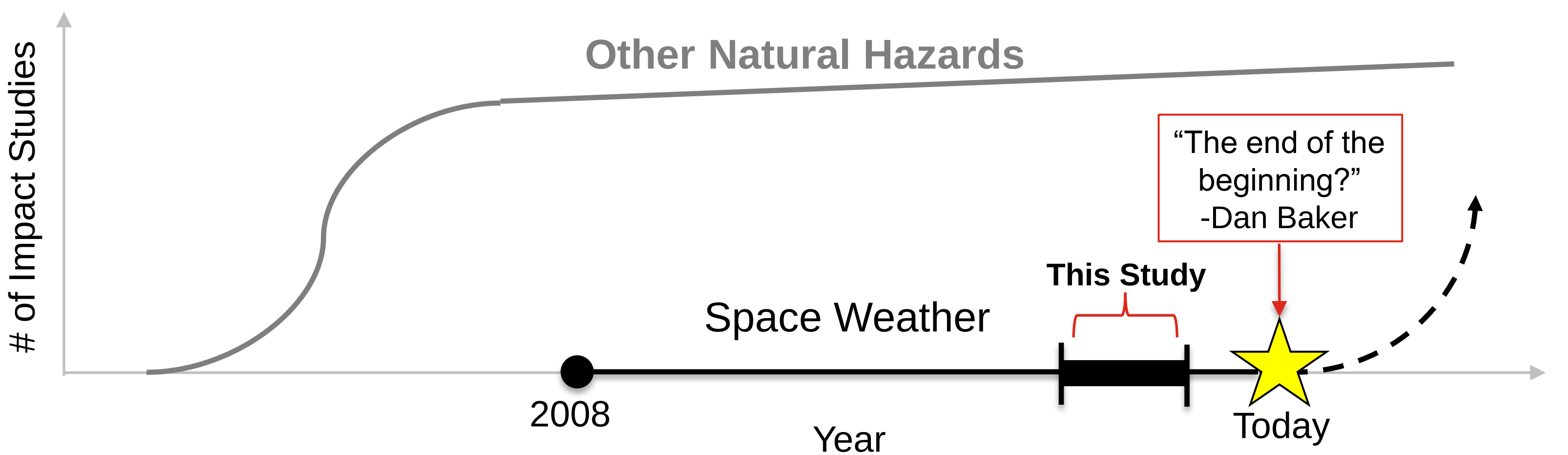
Project Timeline:

August 2016 — October 2017 — Today

Today's Talk: **2** **3** **1**



Takeaway Message



1. Final Report

FINAL REPORT

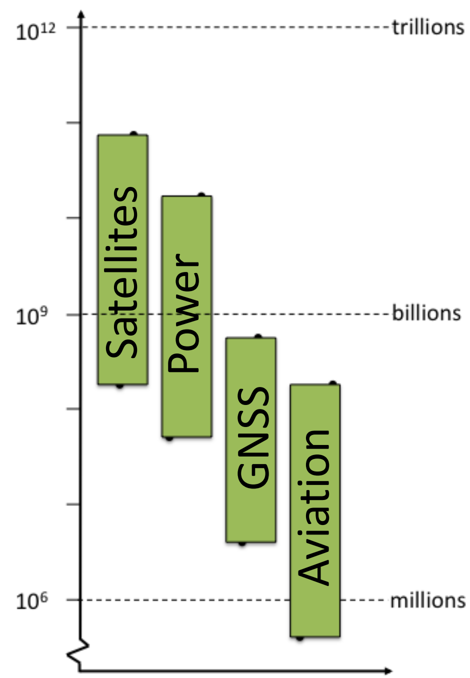
Social and Economic Impacts of Space Weather in the United States

September 2017

Abt Associates
Bethesda, Maryland

Written under contract for the NOAA National Weather Service
www.nws.noaa.gov

www.weather.gov/news/171212_spaceweatherreport

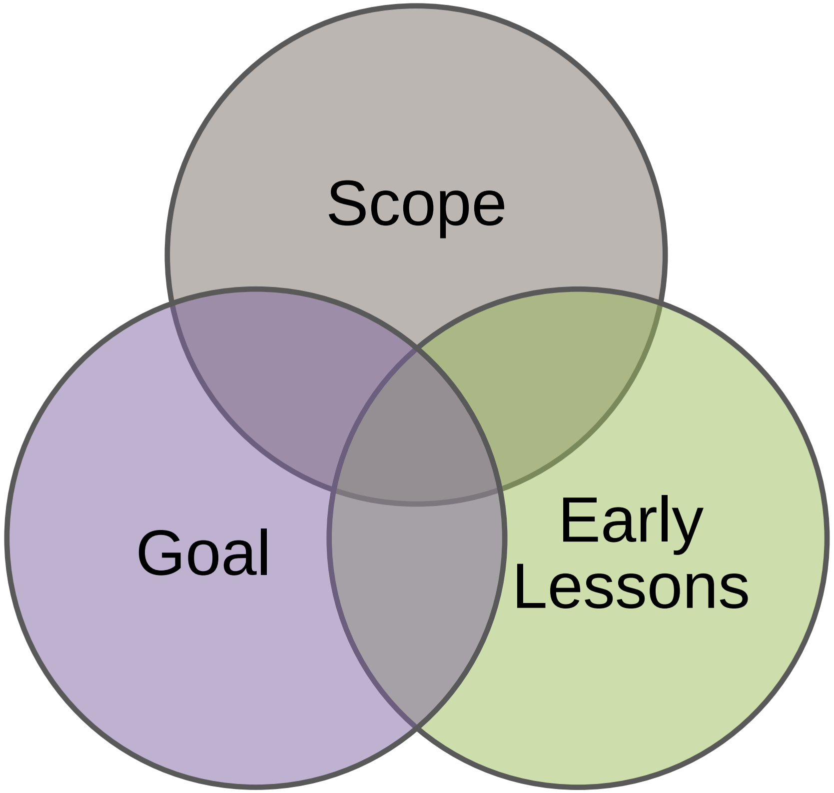


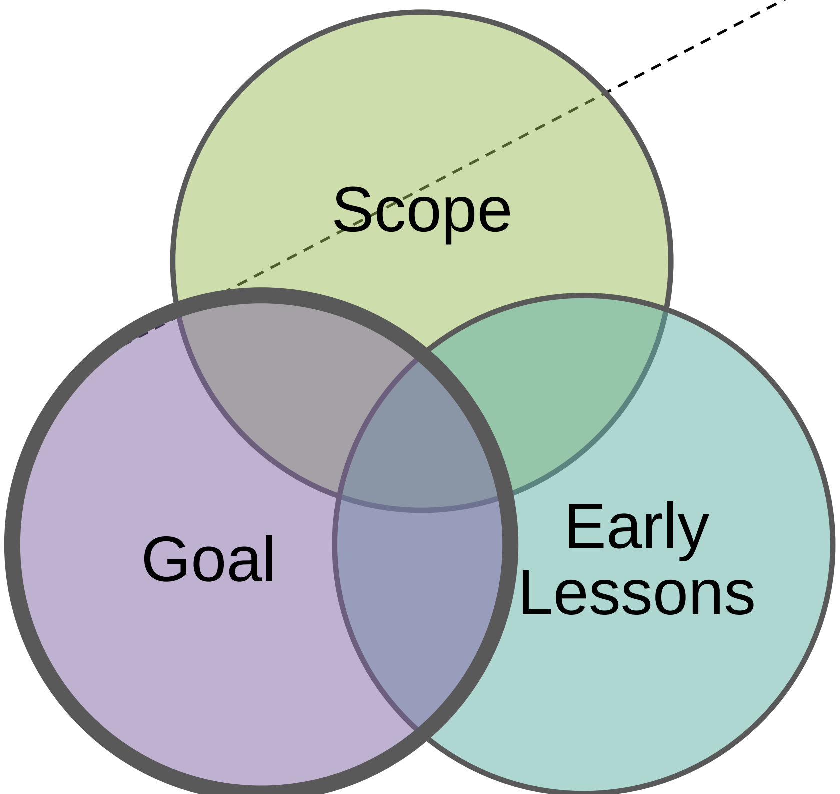
Key Findings

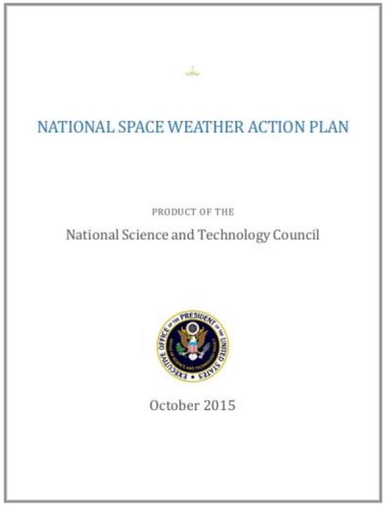
- Impacts are a real concern
- Stakeholders are interested
- Topic is complex
- Mitigation may be inexpensive
- Help value NOAA investments

"The cost estimates provided in this report represent first pass estimates that should not be taken out of context or quoted without the appropriate caveats. Readers are urged to consider the qualitative information synthesized from the literature and industry stakeholders and the quantitative framework established from this information to be the more important contribution of this effort." p. 2

2. Beginning



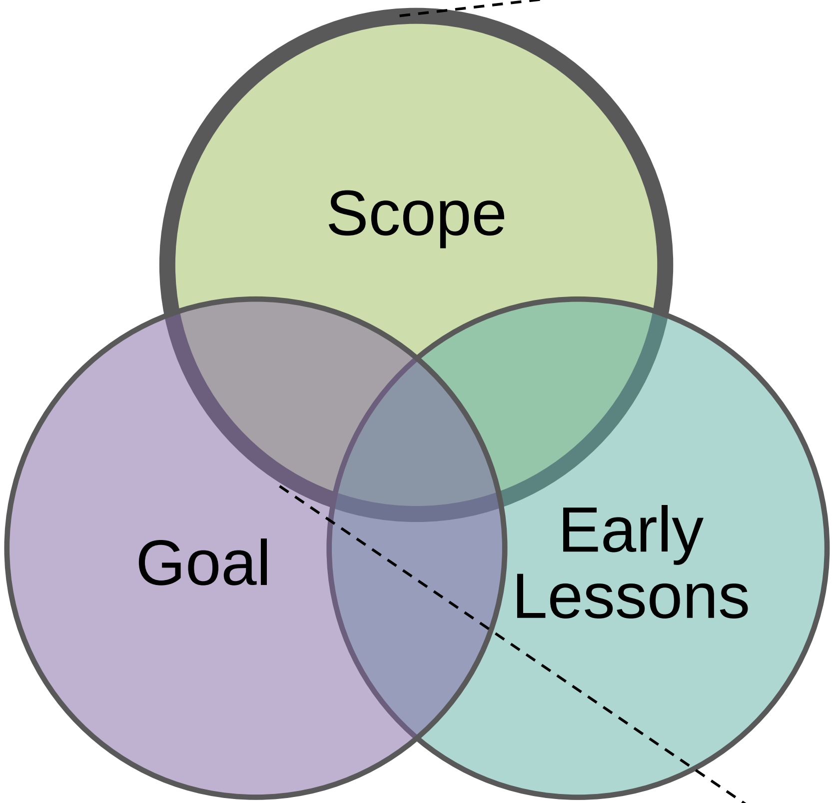



NATIONAL SPACE WEATHER ACTION PLAN

PRODUCT OF THE
National Science and Technology Council

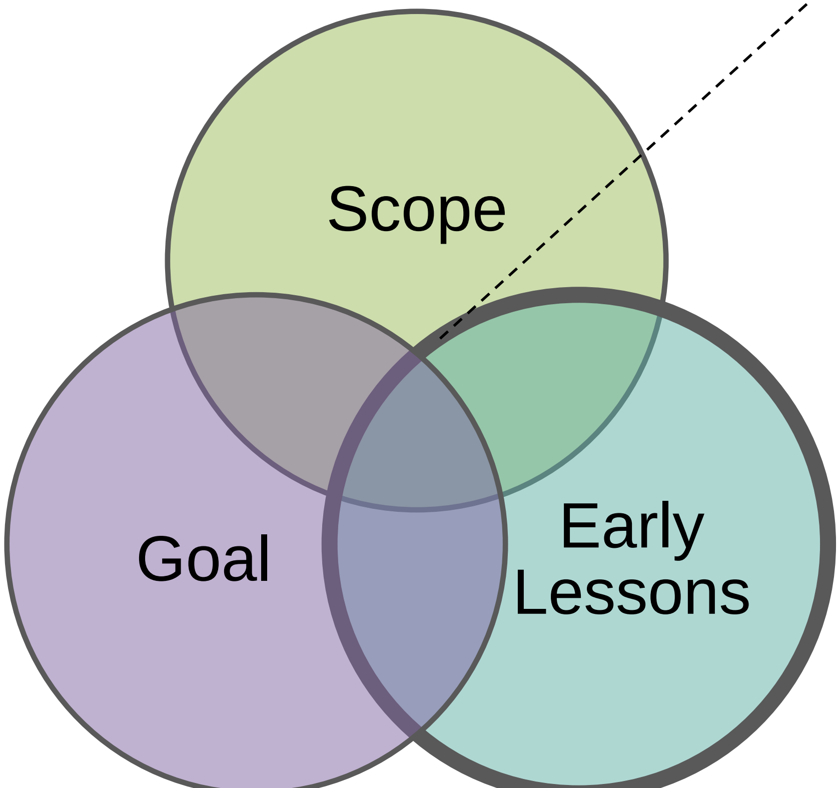
October 2015

GOAL 4.5.2:
"Initiate studies on the economic impact of SW_x events"



Identify • Describe • Quantify

Moderate & Extreme Events



- Complex
- Multidisciplinary
- Few existing studies
- Scenarios ill defined
- Many uncertainties
- Strong opinions

3. Study Details

Identify	Describe	Quantify
Literature Review	Stakeholder Outreach	Tractable Estimates

Impact Matrix

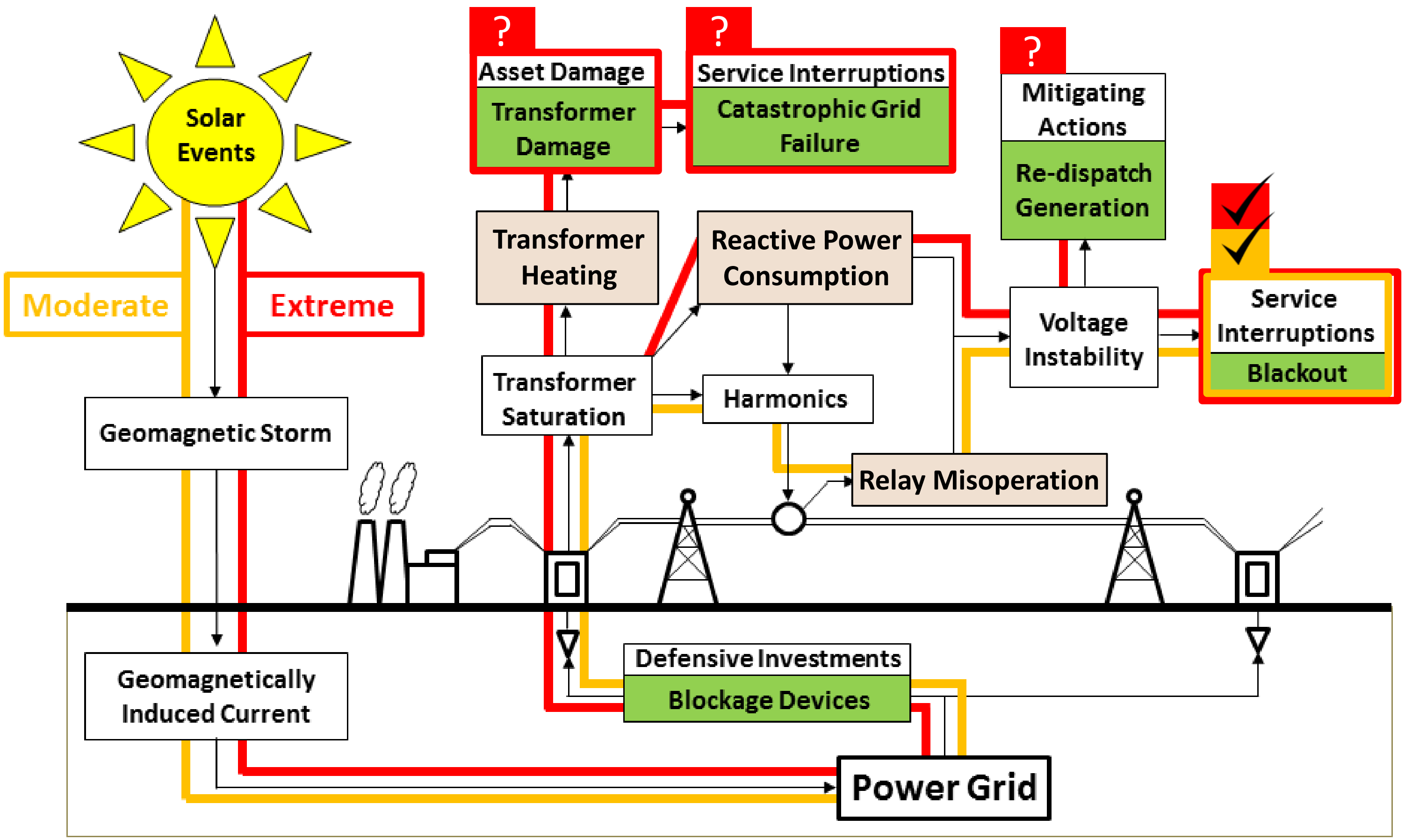
		Impact Categories				
Sector	**Physical Effects**	Defensive Investments	Mitigating Actions	Asset Damages	Service Interruptions	Health Effects
Power Grid	Reactive Power Loss	●	●		●	
	Transformer Heating	●	●	●	●	
	Relay Misoperation	●	●		●	
	Power Imbalances		●		●	
	Generator Tripping	●	●		●	
	Precision Timing	●	●		○	
Aviation	Communications	●	●	○	●	
	Navigation	●	●	○	●	○
	Human Exposure		●		○	○
	Avionic Upsets	●	○	○	○	○
Satellites	Cumulative Dose	●		○	○	
	Anomalies	●	●	●	●	
	Link Disruptions	●	●		●	
	Loss of Orientation	●	●	●	●	
	Loss of Altitude	●	●	●	○	
GNSS Users	Loss of Lock	●	○		●	
	Ranging Errors	●	○		●	

Stakeholder Outreach

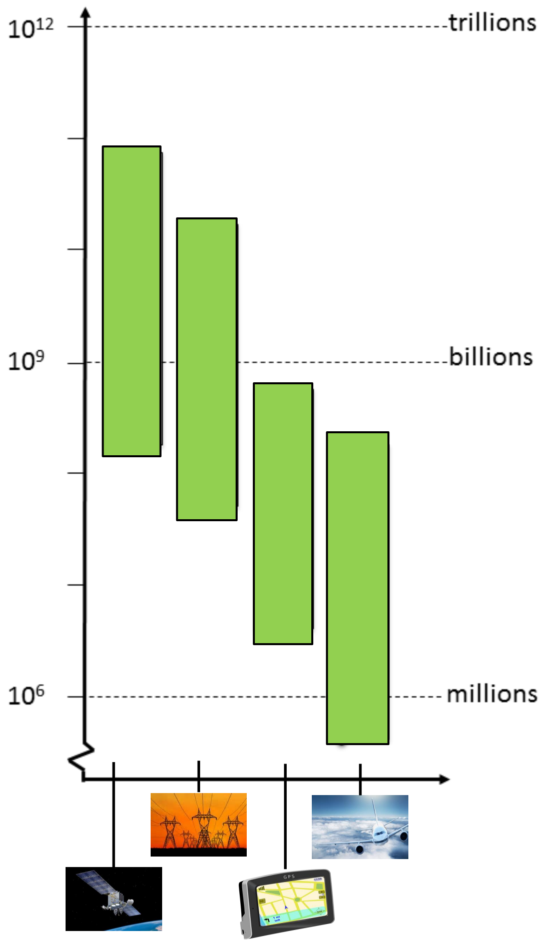
Physical Effect	Definition	Notes from Stakeholder Outreach
Reactive Power Consumption	Reduction in amount of reactive power flowing through grid due to the increased consumption of reactive power by transformers.	• This is problematic because it depresses the system voltage and may lead to voltage collapse. • Reactive power losses occur at transformers but "VAR loss" is a grid metric. • Voltages are controlled within tight bands. When system gets to ~10-20% of normal voltage, this triggers a concern for blackouts. • Reactive power does not like to travel so highest vulnerability in areas farthest away from generation and highest loads. Eastern part of PJM Grid? Kevin says biggest in the spring? • Increasing problem as we rely on higher voltage power lines (long distance transfers) • Relying more heavily on local generation can help mitigate but trend is for it to be shut down in favor of long distance transfers. • Renewables, which tend to be local and more distributed, may be helpful for these reasons.
Transformer Heating	Substantial heating of internal transformer components that can cause accelerated asset aging and perhaps even transformer damage.	• Probability of damage depends on design, age, use history, etc. • FERC's recently approved threshold based on potential transformer heating is 75 amps. Transformers can take more than this but it is a trigger for attention to be paid. The relationship between heating and damage is transformer specific so FERC standard is conservative in order to covered potential differences across nation in transformer designs. • Industry is dissatisfied with previous economic analyses because they grossly overstate potential failures by assuming currents magically get into transformers. Before failure occurs, it is likely that transformers will be disconnected. This negative feedback could cause a blackout and protects system from catastrophic failures in a way that is not captured by current economic analyses. Utility perspective on probability of transformer damage will be known when studies related to TPL-007-1 are complete, in ~2 to 4 years from now. • Diagnostic equipment is being installed on transformers in order to optimize maintenance cycle, to move from maintaining on an as needed basis rather than on a time schedule. Although not installed for space weather events per say, it will allow any transformer heating to be rapidly assessed.
Improper Operation of Protective Relaying Equipment	Improper functioning of relay systems that are designed to protect grid by detecting electrical aberrations (e.g. faults, surges, over/under voltages) and then isolating the impacted area from the rest of the network.	• Infrequently observed but it does happen and when it does, not clear what the cause is. It will likely be attributed to SWx only if they know an event is expected or underway. • Older relays tend to be more effected by harmonics, modern relays not very susceptible. • Most often trip capacitors banks offline. This increases reactive power losses, depressing system voltage and introducing blackout threat. This is what triggered the 1989 Quebec blackout and the outage in Sweden during the Halloween 2003 storm.
Real power imbalances	Difference in real-time supply and demand for power that must be managed by operators to maintain grid stability.	• Caused by many things in addition to SWx such as hot weather, etc. • Industry is aware of statistical relationship but physical basis is unclear and most likely attributable to operator actions that occur during a SWx event.
Generator Tripping	Space weather related harmonics can also send erroneous commands to generators, tripping them offline.	• One stakeholder brought this to our attention as niche but real issue.
Loss of precision timing	Loss of satellite enabled technology that provides precise timing information that is used to improve grid synchronization.	• When satellite signals are lost, substation clocks will continue to operate and remain accurate for several hours. • Not clear how SWx threat compares to spoofing threat but addressing spoofing concerns makes grid less vulnerable to SWx interruptions. The spoofing threat has been well studied by the industry and they find the threat to be small. • This could become more problematic in the future if we over rely on these systems. • Dependence on precision timing may be bigger trend in U.S. power sector than abroad. Other countries are required to maintain traditional timing devices at substations.

Impact Categories	Examples	Definition	Notes from Stakeholder Outreach
Defensive Investments	Infrastructure hardening	A range of engineering and design modifications that reduce grid vulnerability such as installing GIC absorbing or blocking devices (e.g. neutral ground connections, series line capacitors) or replacing aging or vulnerable transformers.	• Understanding what to do requires many analyses. Installing blocking device, for example, can reroute current in unexpec and devastating ways. • This is the subject of the new FERC regulations. The types c investments that need to be made are understood but unclear how widely or where they will be required.
	Situational Awareness & Preparedness	Utilizing a range of data and tools to stay aware of current and anticipated future conditions. Data can come from GIC monitoring networks (e.g. magnetometers, internal-instruments within transformers) or transformer monitors and be fed into grid simulators and management systems. This information can then be used to inform what operational procedures should be enacted as various situations arise.	• This Defensive Investment is critical to being able to implem real-time Mitigating Actions. • Operators have training to prevent key downstream impacts b they need to be made aware of the situation, day ahead SWx warnings are most important. • Operators monitor SWx products and pay extra attention to o data when they receive alerts at the upper end of scales (K7 c greater).
Mitigating Actions	Re-dispatch Generation	Deciding to utilize generators that will enhance grid stability rather than those that will maximize profits.	• Relatively low cost action. One stakeholder mentioned that c SWx event may cost ~$1s million but re-dipatching costs the ~$100s million per year so the one event is drop in the bucke • This is a relatively easy action for operators and almost alwa impacts the price of electricity.
	Emergency Procedures	A set of operating procedures that can be enacted in extreme cases and might include, for example, generator or equipment curtailment, voltage reductions, and load shedding as a last resort.	• Different grid operators have different sets of emergency procedures and different triggers for enacting them in place.
Asset Damages	Transformer Aging	Accelerated aging of transformer caused, for example, by degradation and gas generation within insulation materials.	• Logic of argument makes sense but the empirical data is not significant enough for industry to believe that moderate even "add up" and, among all else, play a big role in transformer aging.
	Transformer Failure	Any damage to a transformer that renders it permanently inoperable and cannot be repaired and so requires a replacement transformer.	• Probability and extent of damage requires long GIC duration and scale with duration of GIC. • Most likely to happen to older transformer that are near the e of their lifetime.
Service Interruptions	Degradation in Power Quality	Voltage instabilities lead to a reduction in power quality that may harm industrial equipment.	• Different customers have different quality requirements so impact of quality degradation will be customer specific.
	Blackouts	Loss of power to electricity users.	• Storms have to be particularly extreme for this to happen (K8 K9). NOAA scales need to be refined to better discriminate l differences between large events. • More permanent loss of service that would result if a large number or certain critical transformers permanently fail, but probably of this occurring is thought to be very low. • Costs of outages depend on where and when an outage occur something that is almost impossible to know in advance of ar event occur.

Impact Mechanism Diagrams

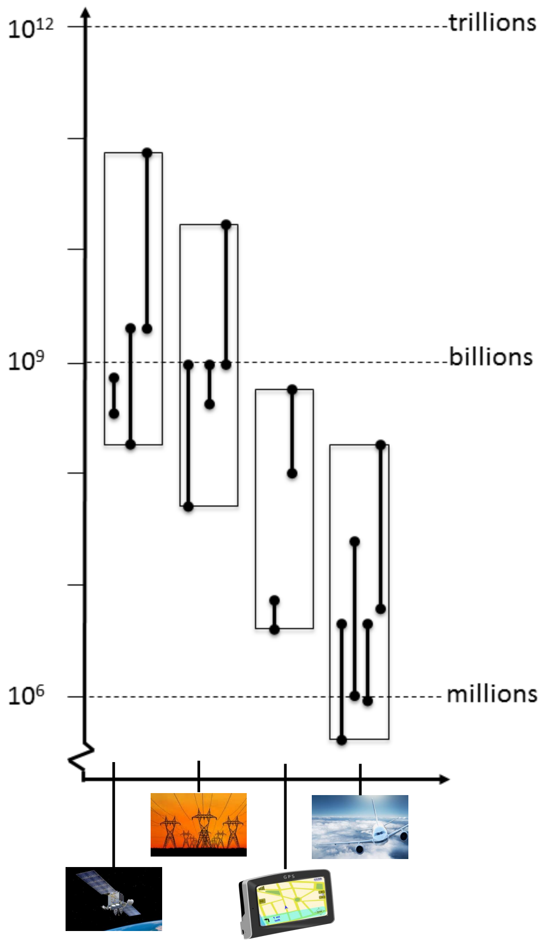


Findings



- Estimates span many orders of magnitude
- Compare across sectors cautiously

Findings

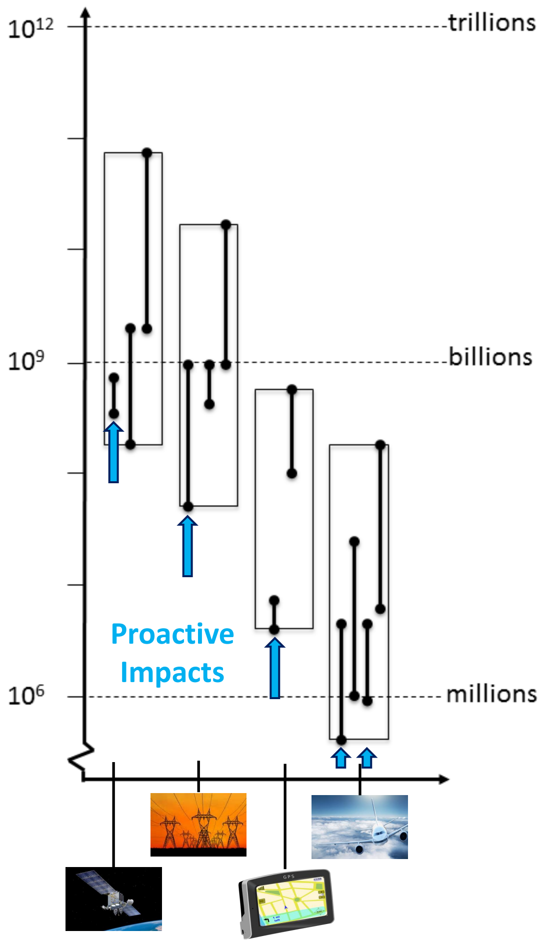


- Estimates span many orders of magnitude
- Compare across sectors cautiously
- Many different impacts to estimate

Impacts estimated in this study

Sector	Physical Effects	Impact Categories: Defensive Investments	Mitigating Actions	Asset Damages	Service Interruptions	Health Effects
Power Grid	Reactive Power Loss	•	•		•	
	Transformer Heating	•	•	•	○	
	Relay Misoperation	•	•		•	
	Power Imbalances		•		•	
	Generator Tripping	•	•		•	
	Precision Timing	•	•		○	
Aviation	Communications	•	•	○	•	
	Navigation	•	•	○	•	○
	Human Exposure		•		○	○
	Avionic Upsets	•	○	○	○	○
Satellites	Cumulative Dose	•		○	○	
	Anomalies	•	•	•	•	
	Link Disruptions	•	•		•	
	Loss of Orientation	•	•	•	•	
	Loss of Altitude	•	•	•	○	
GNSS Users	Loss of Lock	•	○		•	
	Ranging Errors	•	○		•	

Findings

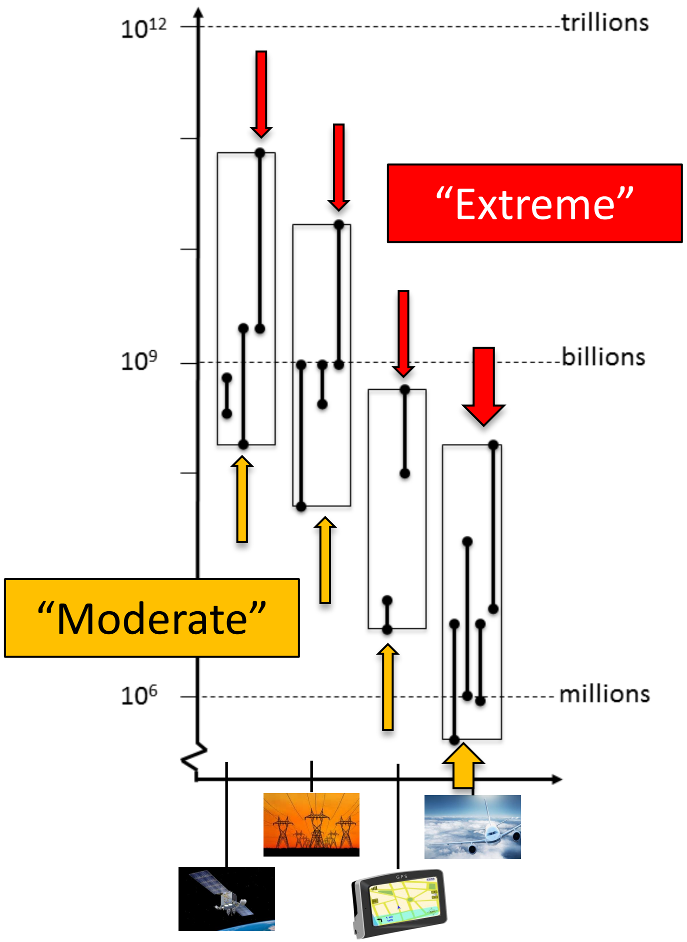


- Estimates span many orders of magnitude
- Compare across sectors cautiously
- Many different impacts to estimate
- Mitigation may be relatively inexpensive

Impacts estimated in this study

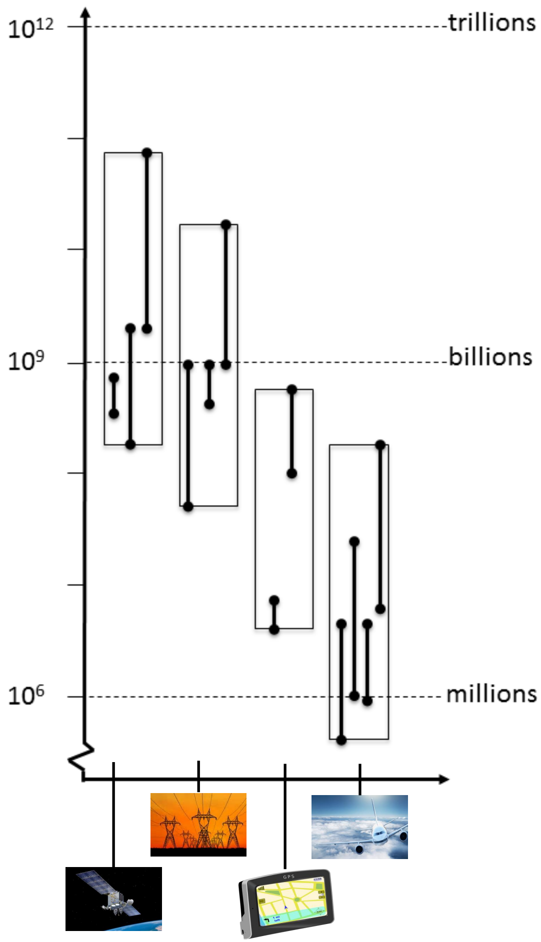
Sector	Physical Effects	Defensive Investments	Mitigating Actions	Asset Damages	Service Interruptions	Health Effects
		Proactive		**Reactive**		
		Impact Categories				
Power Grid	Reactive Power Loss	•	•		•	
	Transformer Heating	•	•	•	○	
	Relay Misoperation	•	•		•	
	Power Imbalances		•		•	
	Generator Tripping	•	•		•	
	Precision Timing	•	•		○	
Aviation	Communications	•	•	○	•	
	Navigation	•	•	○	•	○
	Human Exposure		•		○	○
	Avionic Upsets	•	○	○	○	○
Satellites	Cumulative Dose	•		○	○	
	Anomalies	•	•	•	•	
	Link Disruptions	•	•		•	
	Loss of Orientation	•	•	•	•	
	Loss of Altitude	•	•	•	○	
GNSS Users	Loss of Lock	•	○		•	
	Ranging Errors	•	○		•	

Findings



- Estimates span many orders of magnitude
- Compare across sectors cautiously
- Many different impacts to estimate
- Mitigation may be relatively inexpensive
- Costs escalate with storm size

Findings



- Estimates span many orders of magnitude
- Compare across sectors cautiously
- Many different impacts to estimate
- Mitigation may be relatively inexpensive
- Costs escalate with storm size
- Simple and transparent first pass estimates

Annual cost of engineering

“Moderate” → 1 lost satellite

“Extreme” → 10 to 100 satellites

One time cost of TPL-007-1

“Moderate” → Quebec 1989 scale

“Extreme” → 9 hours, US power markets

Users efficiencies (benefits) reduced

User susceptibilities are differ

“Moderate” → 1 hour outages

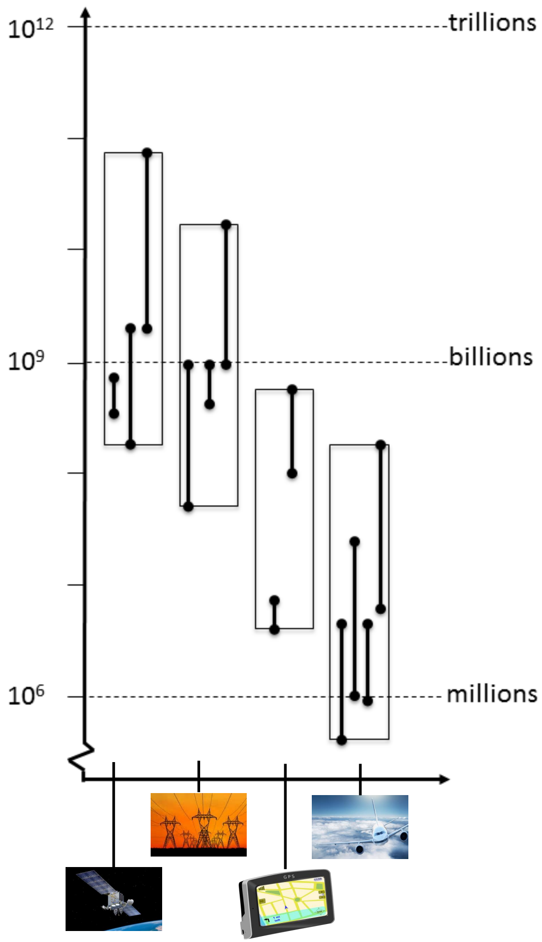
“Extreme” → 1-3 day outages

Cost to airlines and passengers

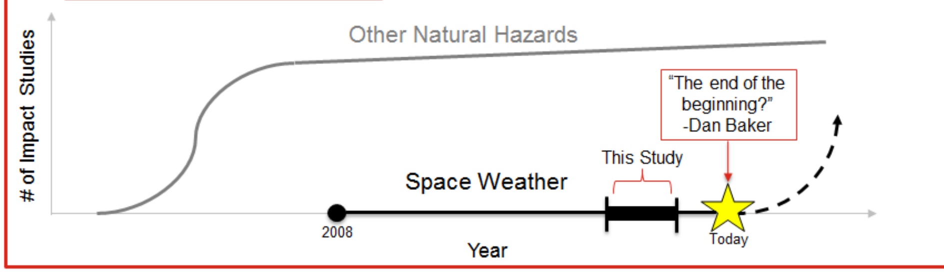
“Moderate” → 1 day, polar flights

“Extreme” → 1-3 days, 1-10% of US flights

Summary



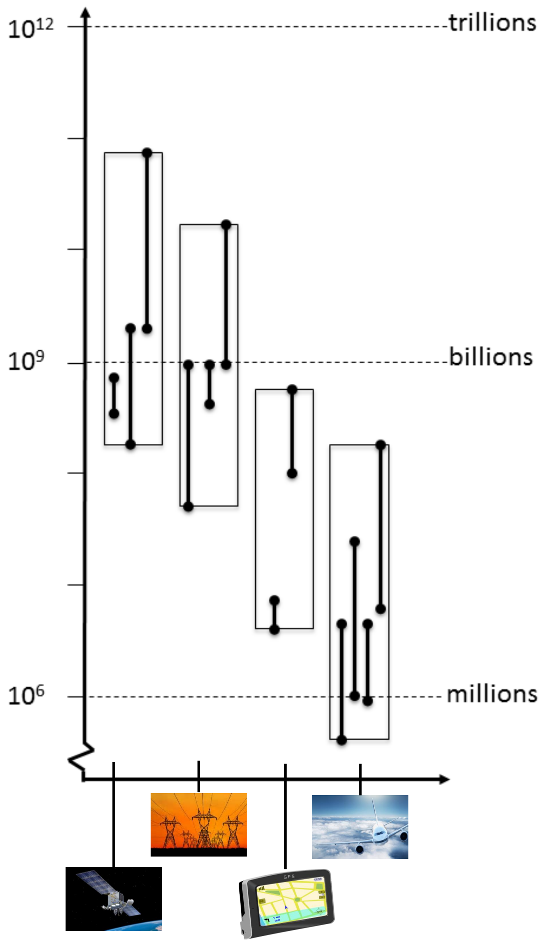
Takeaway Message



Recommended Next Steps

- Critical Review
- Discuss Findings
- Establish Best Practices
- Conduct Case Studies
- Analyze Sensitivity
- Add Context
- Update Estimates
- Explore Interdependencies

Summary



Recommended Next Steps

- Critical Review
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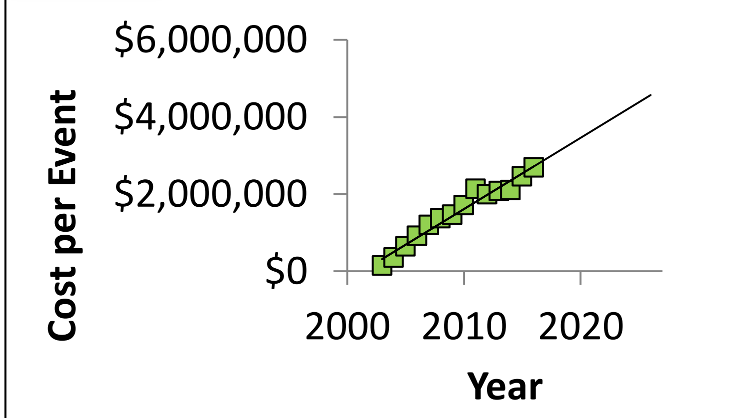
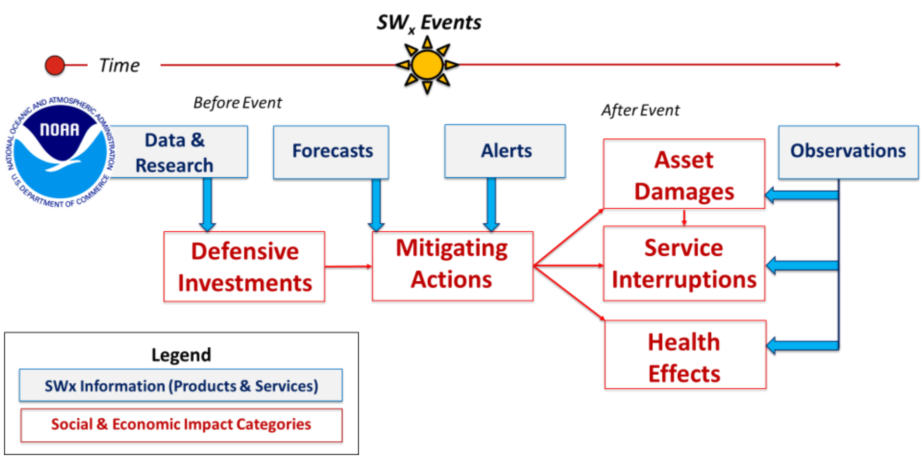
Impacts change with the world



Ongoing Work

SWAP Actions 4.4.1 & 5.1.1

- *Improve operational impact forecasting and communications*
- *Improve understanding of user needs for SWx forecasting to establish lead-time and accuracy goal*



Motivation: Information about Space Weather is key to mitigating impacts with engineering & operational actions

Outreach to engineers & operators in each sector to identify:

- Key technological impacts
- Steps industries take to mitigate impacts
- Additional steps that could be taken to further reduce vulnerabilities
- Attributes of SWx information needed (e.g. lead time, cadence, granularity) to achieve these further reductions
- Recommended improvements to existing products and services
- Desired format for SWx Information

Final report available at NOAA's website:

www.weather.gov/news/171212_spaceweatherreport

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BOLD
THINKERS
DRIVING
REAL-WORLD
IMPACT