
Panamá Seminars 2018

Space Weather Social and Economic Impacts

El tiempo espacial.

Impactos sociales y económicos



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Co-authored by Dr. Clezio Denardin

- **Electric Power**

- **Aviation**

- **GNSS**

- **Satellite**

Severe space weather events are low probability, but with high consequences by interrupting services and damaging technologies.

Electric grids, airplanes, pipelines, trains, satellites, GNSS, ...



Some preliminary analyses

Extreme events may have high consequences (National Research Council, 2008; Baker and Lanzerotti, 2016).

However, more **moderate events** that is less intense but occurs more frequently is also known to cause adverse impacts (Allen et al., 1989; Lopez et al., 2004).

Too few studies

Despite such risks and our growing dependencies on these technologies for almost all aspects of daily life, there have been a limited number of studies on space weather's social and economic impacts (Eastwood et al., 2017).

The ongoing Service

Better understanding of the social and economic impacts of space weather therefore represents an important but formidable problem at the intersection of science, engineering, economics, and the social sciences (Baker, 2019).

The lack of direct experience of our society today about a severe event → **Poses theoretical and analytical challenges that require many assumptions, simplifications, extrapolations, and inferences.**



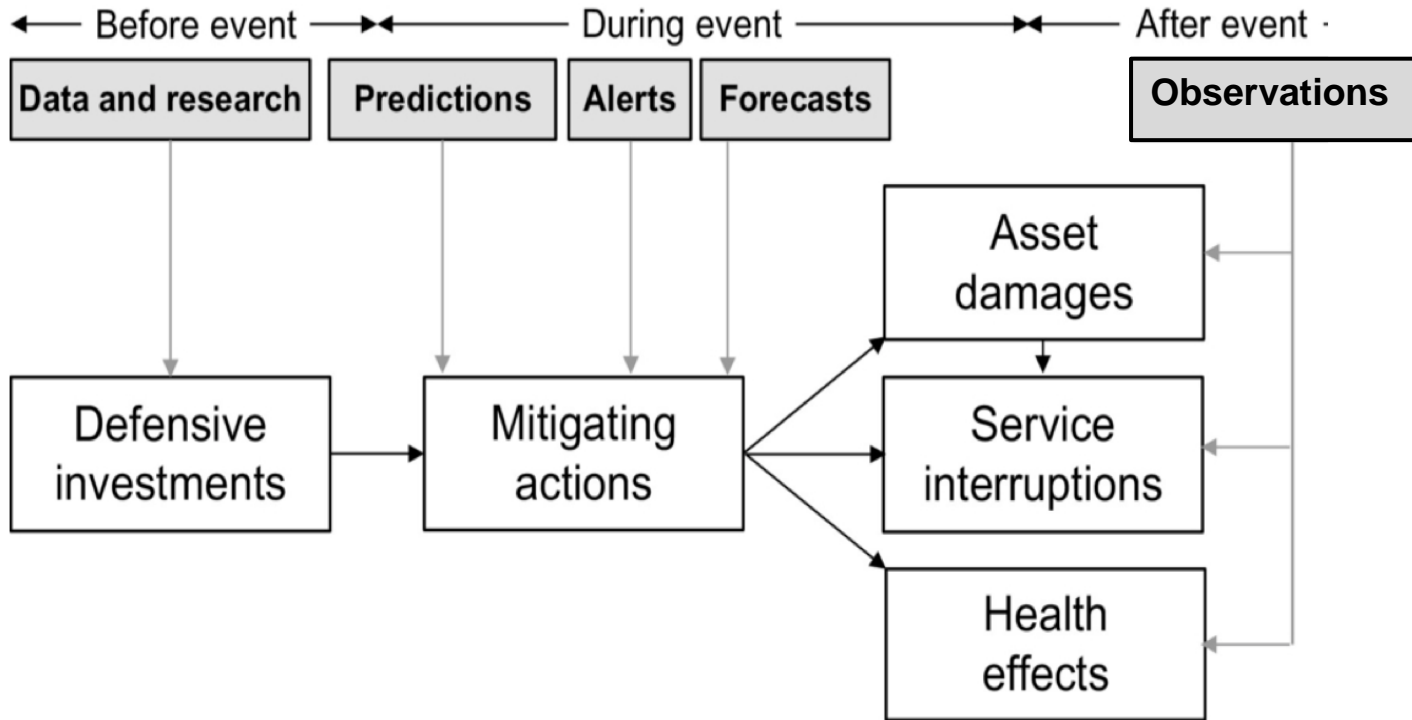
The science job

- Impacts are not simply directly proportional to storm magnitude but are affected by a number of other factors such as geography, the time of day, or the season of the year that affect demand on the electric power grid (e.g., Forbes and Cyr, 2012).
- The definition of a “severe” event is debated and scientifically uncertain, and when studying impacts, is furthermore dependent and relative to the specific technology and impact pathway of interest (Cannon et al., 2013; Hapgood et al., 2016).

How deep the impact can go?

- The response of various technologies (e.g., power grids, satellites, airplanes, and GNSS) to severe events is furthermore largely unknown because they fall beyond engineering standards and operational experiences.
- Further complications arise from economic and social processes that are complex, interconnected, and rapidly overcoming these inherent challenges is essential for better understanding the potential socioeconomic impacts so that we can enhance preparedness and strategically reduce risks.

Impact categories



The Superstorm of July 2012



Extreme geomagnetic event $Dst < -1182$ nT

- **This event would correspond larger than Carrington ($Dst < -880$ nT) if the July 2012 was Earth directed.**
- **A potential impact of a severe storm on the power grid**
 - ✓ Direct costs \Rightarrow \$ 220 billion - \$1.2 trillion (Baker et al., 2013)
 - ✓ Including supply-chain interruptions \Rightarrow \$500 billion - \$2.7 trillion (Oughton et al., 2016)

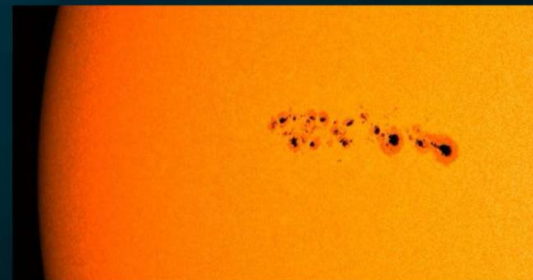
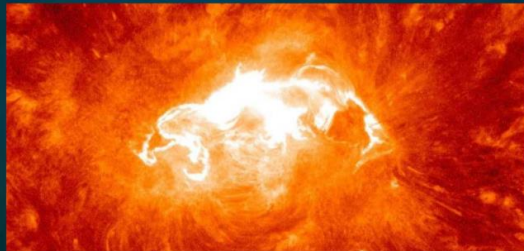
Focusing on satellites

- **A worst case storm (solar proton event – SPE with a fluence $\sim 5.6 \times 10^{10}$ particles/cm²) = 3 times larger than 1859 Carrington.**
- **Costs => \$84 billion without accounting for services interruption (Odenwald et al., 2006)**

Societal and economic impacts – Nov 2015

The screenshot shows the top portion of a news article. At the top, there are navigation links for 'SECTIONS', 'HOME', and 'SEARCH', followed by the 'The New York Times' logo. The main headline reads 'Solar Storm Knocks Out Flight Control Systems in Sweden'. Below the headline, there is a weather widget from 'The Weather Channel' showing temperatures for Anchorage (29°), Vilnius (46°), and Patanga (84°). The article is categorized under 'Science' and has the sub-headline 'Massive Solar Storm Halts Air Travel in Sweden'. It is dated 'Published Nov 5 2015 09:09 AM EST' and attributed to 'The Associated Press'.

“Flights disappeared from radar screens in Swedish air traffic control towers during the blackout, which lasted about an hour”



Comparing disasters

Disaster	Cost \$
1989 Québec Storm	13.2 million
July 2012 Earth directed	1,000,000 million (1 trillion)
Proton event 3 times Carrington	84,000 million (84 billion)
Hurricane Katrina (2005)	125,000 million (125 billion)
Japan Tsunami (2011)	235,000 million (235 billion)

Social and Economic Categories

The presence (or absence) of a filled circle denotes where we were able (or unable) to connect a given physical effect to a particular impact category based on detailed discussions with experts.

“Stacey Worman”

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	Communication	●	●	○	●	
	Navigation	●	●	○	●	○
	Human Exposure		●		○	○
	Avionic Upsets	●	○	○	○	○
Satellites	Cumulative Dose	●		○	○	
	Anomalies	●	●	●	●	
	Link Disruptions	●	●		●	
	Loss of Orientation	●	●	●	●	
	Loss of Altitude	●	●	●	○	
GNSS Users	Loss of Lock	●	○		●	
	Ranging Errors	●	○		●	

Geomagnetic Storm Effects March 1989

Hydro Quebec Loses Electric Power for 9 Hours

A blackout that
happens in Canada in
March 1989

Electric Power
Transformer



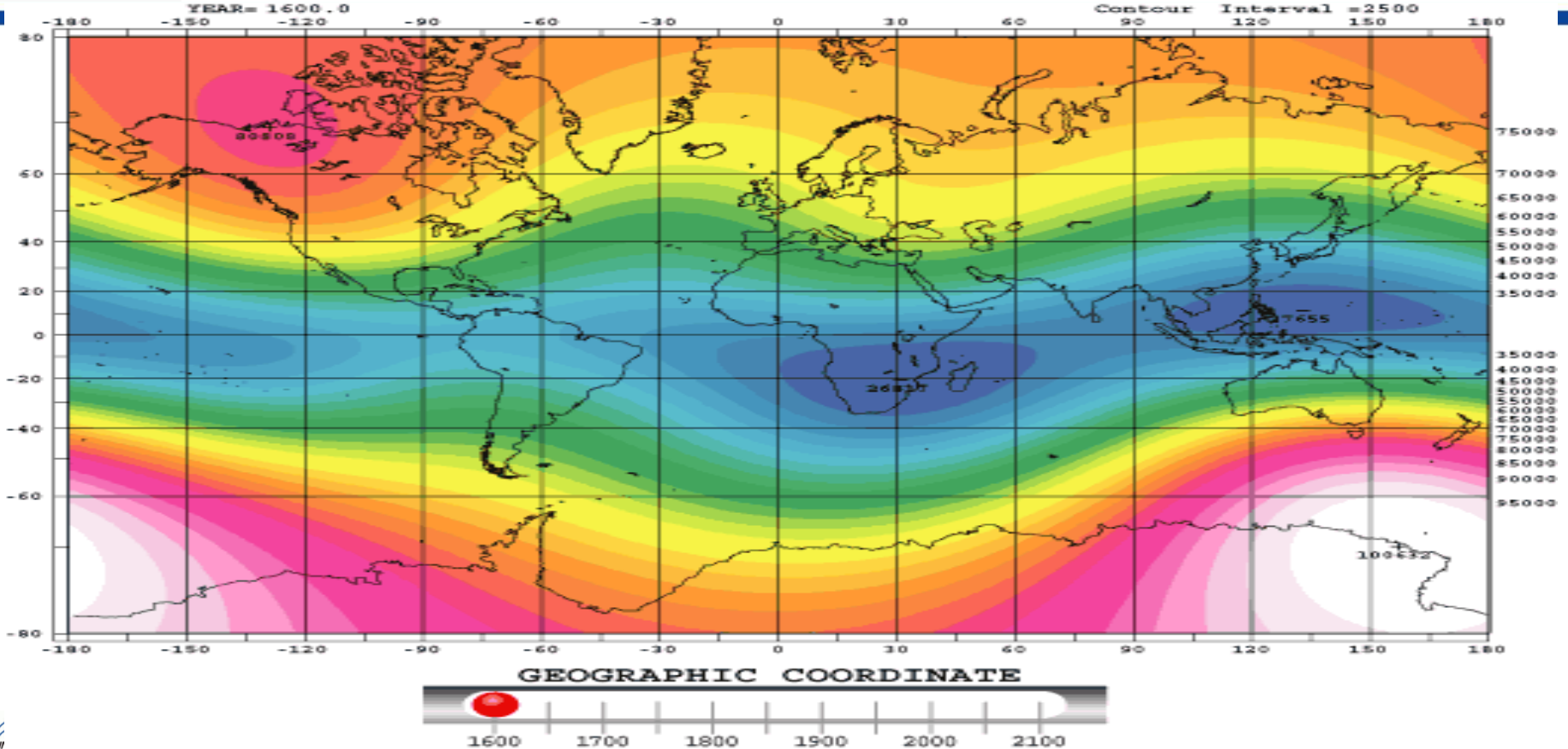
Transformer Damage

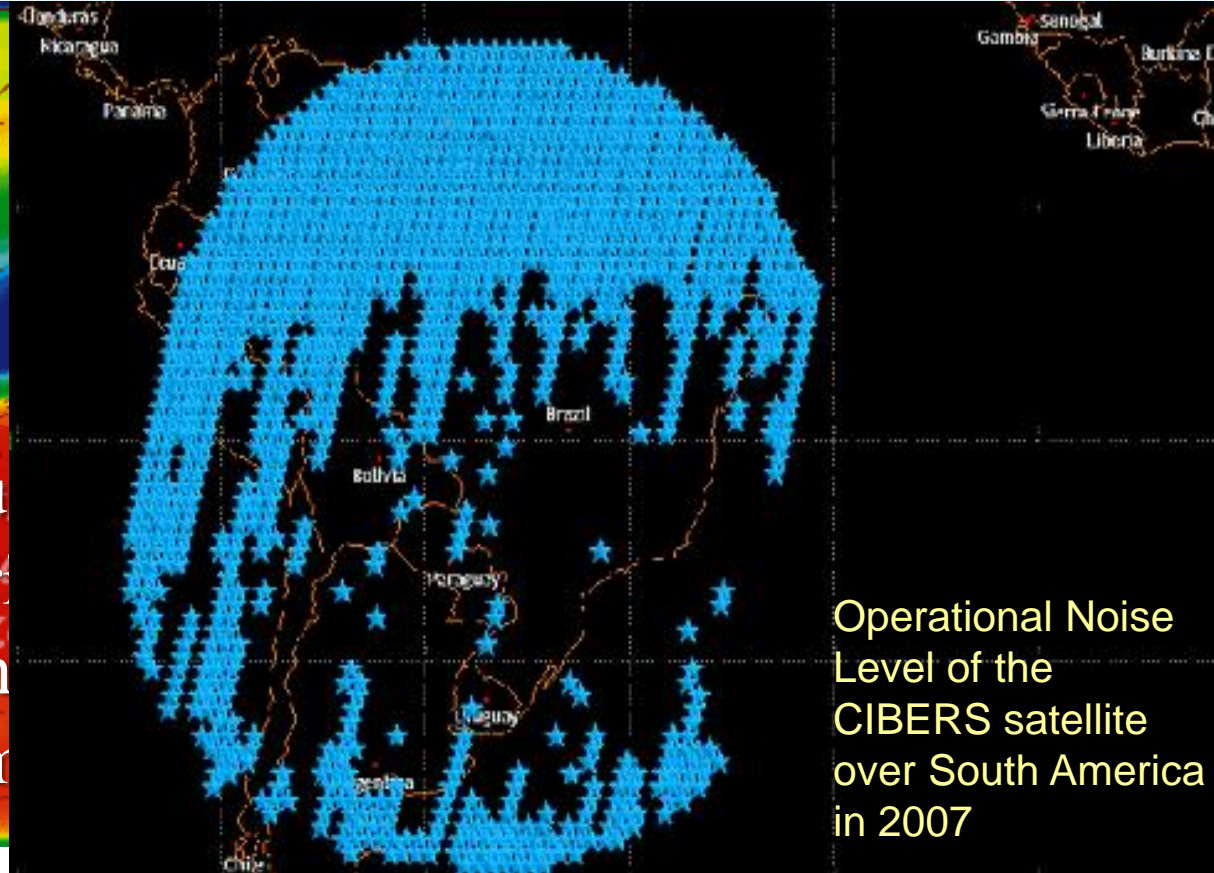
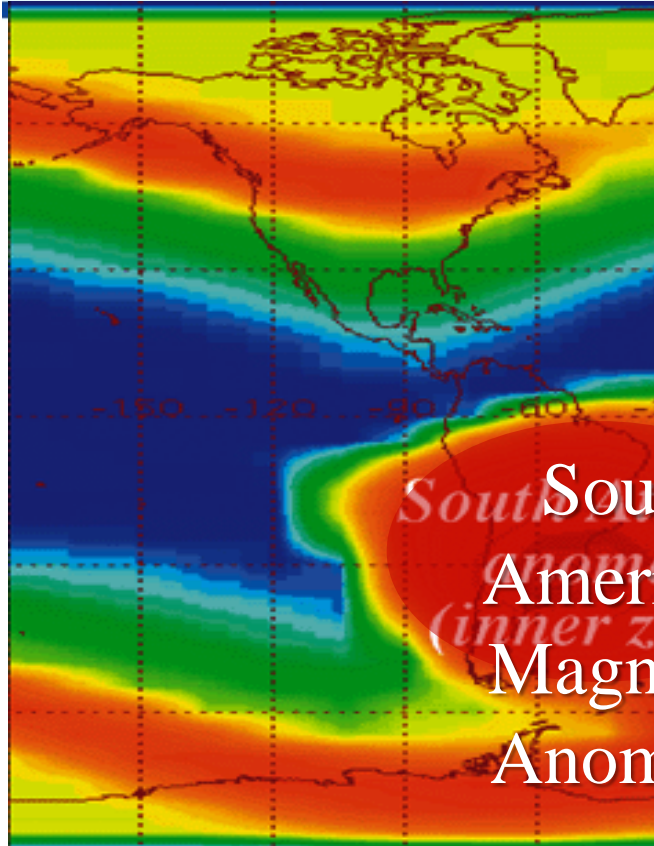


The cost of Québec power failure

- **The transformer was burned**
- **6 million people lost electricity by 9 hours**
- **The estimated cost was \$13.2 million (Bolduc, 2002)**

That impact us ?







Software Error Doomed Japanese Hitomi Spacecraft

JAXA Space Agency declares the astronomy satellite a loss

By Alexandra Witze, Nature magazine on April 29, 2016.

Japan's flagship astronomical satellite Hitomi, which launched successfully on February 17 but tumbled out of control five weeks later, may have been doomed by a basic engineering error. **Confused about how it was oriented in space and trying to stop itself from spinning, Hitomi's control system apparently commanded a thruster jet to fire in the wrong direction** - accelerating, rather than slowing, the craft's rotation.

On 28 April, the Japan Aerospace Exploration Agency (JAXA) declared the satellite, on which it had spent ¥31 billion (**US\$286 million**), lost. At least ten pieces — including both solar-array paddles that had provided electrical power — broke off the satellite's main body.

Hitomi had been seen as the future of X-ray astronomy. "It's a scientific tragedy," says Richard Mushotzky, an astronomer at the University of Maryland in College Park.

The satellite managed to make one crucial astronomical observation before the accident, capturing gas motions in a galaxy cluster in the constellation Perseus. The instrument that made the observation, a high-resolution spectrometer, had been in the works for three decades. Two earlier versions of it were lost in previous spacecraft failures.

Hitomi's troubles began in the weeks after launch, with its 'star tracker' system, which is one of several systems on board that are designed to keep the satellite oriented in space. **The star tracker experienced glitches whenever it passed over the eastern coast of South America, through a region known as the South Atlantic Anomaly.** Here, the belts of radiation that envelop Earth dip relatively low in the atmosphere, exposing satellites to extra doses of energetic particles.

By itself that should not have been a fatal problem. But the star tracker issue kicked off a series of cascading failures.

NOTE: The Japan Aerospace Exploration Agency is investigating the factors that led to Hitomi's demise. Credit: STR/AFP/Getty Images

Schrijver et al (2015) ASR n55 p2745-2807 JASR12190 S0273-1177(15)00225-1



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**ADVANCES IN
 SPACE
 RESEARCH**
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Understanding space weather to shield society: A global road map for 2015–2025 commissioned by COSPAR and ILWS

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Risk Analysis

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

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Space weather describes the way in which the Sun, and conditions in space more generally, impact human activity and technology both in space and on the ground. It is now well understood that space weather represents a significant threat to infrastructure resilience, and is a source of risk that is wide-ranging in its impact and the pathways by which this impact may occur. 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. Here, we provide an initial literature review to gather and assess the quality of any published assessments of space weather impacts and socioeconomic studies. Generally speaking, there is a good volume of scientific peer-reviewed literature detailing the likelihood and statistics of different types of space weather phenomena. These phenomena all typically exhibit “power-law” behavior in their severity. The literature on documented impacts is not as extensive, with many case studies, but few statistical studies. The literature on the economic impacts of space weather is rather sparse and not as well developed when compared to the other sections, most probably due to the somewhat limited data that are available from end-users. The major risk is attached to power distribution systems and there is disagreement as to the severity of the technological footprint. This strongly controls the economic impact. Consequently, urgent work is required to better quantify the risk of future space weather events.

KEY WORDS: Geomagnetic storms; power grids; space weather



What is the likelihood ?

The probability of a Carrington-like event occurring in the next decade is estimated to be 12%⁽⁵⁵⁾ (50% in the next 50 years).⁽¹⁷⁾

Geomagnetic storm statistics are more complex because likelihood depends on both the solar wind driver (typically, but not exclusively, a CME) and the magnetospheric response. The probability of a Carrington-like event occurring in the next decade is estimated to be 12%⁽⁵⁵⁾ (50% in the next 50 years).⁽¹⁷⁾ The probabilities of a superstorm event (worse than Carrington) and a 1989 event are calculated as $0 < 6.3\% < 23\%$ and $3.4\% < 17.8\% < 38.6\%$ in the next 10 years, respectively (95.4% Bayesian C2 confidence interval).⁽⁵⁸⁾ Finally, although weaker storms are correlated with the strength of the solar cycle, strong storms are not, and so could arise even in epochs where the Sun was quieter, as was the case for both the Carrington event and the 2012 event.⁽⁹³⁾

How much ?

1. The total loss varies between \$ 0.5 and **2.7 trillion** with disruption of the global supply chain.
2. Estimated losses for US GDP vary between **\$ 136 and \$ 613 billion**.

Report on the ESA Space-Weather Socio-Economic Study

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Space Weather Manager
ESA SSA Programme Office

Space Weather Workshop, 2-5 May 2017, Broomfield, Colorado

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European Space Agency

Qualitative benefits from SSA SWE development

Macro categories	Qualitative benefits
Strategic	<ul style="list-style-type: none">• Increase in autonomy with independent SWE data• Equal partner in data exchange agreements internationally• Coordinate design and development of an operational SWE system• Push for advances in solar science and Sun-Earth interaction understanding• Development of end-to-end modelling capability
Economic	<ul style="list-style-type: none">• Positive impact on European economy• Enabling of downstream third-party business opportunities
Societal	<ul style="list-style-type: none">• Improved safety of the European infrastructure and services (space systems, human space flight, aviation, transport, power systems...)• Improved safety of human life (navigation, radiation environment,...)• Reduction of morbidity and mortality due to prolonged electrical blackouts• Reduced loss of time in road and rail transport, aviation, ...
Environmental	<ul style="list-style-type: none">• Reduced risk and faster recover from spill-over from underwater oil wells• Reduced green house gas emissions from alternate flight routes and levels

Do nothing scenario:

- No investment to ESA SSA SWE system
- No substantial improvements over service status today
- No coordinated development of measurement system

Do ESA SSA Programme:

- Coordinated development and validation of end-to-end models and applications
- Improved SWE forecasting capability
- Ensured availability of the measurement data
- Development of new capability through international collaboration:
 - combination of L1 and L5 data

How much ?



Results of the CBA for the SWE segment

Cost/Benefit	Do nothing scenario	Do ESA scenario	Value added of ESA services
User domain benefits			
Satellite operations	- €293 M	- €267 M	€26 M
Launch operations	- €0.3 M	- €0.1 M	€0.2 M
Resource exploitation	- €327 M	- €135 M	€192 M
Power grids operations	- €5,771 M	- €4,546 M	€1,225 M
Aviation	- €3,312 M	- €3,066 M	€246 M
Logistic/Road transport	- €3,432 M	- €2,888 M	€544 M
Investment benefits			
GDP impact	None	€952 M	€952 M
Total Benefits (b)	- €13,135 M	- €9,950 M	€3,185 M
Programme Costs (c)	None	- €529 M	- €529 M
Total Net Benefits	- €13,135 M	- €10,479 M	€ 2,656 M

Benefit / Cost ratio (b/c)

6

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Luca del Monte | Headquarters | July 2017 | Slide 12



European Space Agency

In case of extreme storms (G/R/S5+) all flight are expected to be grounded for 3 hours in average
Benefit: 1/3 reduction of delay time for grounded aircrafts

Number of flights per year
6.4 M

Average cost of a 3h flight delay
0.05 M€

Number of passenger per year
958M

Do Nothing Scenario	
Impact	- €1,369 million
Do ESA Programme	
Impact	- €1,123 million
Do ESA Programme benefits	
Benefit	€246 million

Example of benefits: Aviation

Impact	'Do nothing scenario'	'Do ESA scenario'	Benefits of ESA services for Aviation
Increased financial cost (delayed flight)	- €973 M	- €804 M	€169 M
Value of time (delayed flight)	- €396 M	- €319 M	€77 M
Total Net Benefits	- €3,312 M	-€3,066 M	€246 M

How much ?

1. Today, the economy with the forecast of the Space Weather is **€ 2.656 Billion** in the European Community.
2. Given the current economic growth, an economy of:
 - a. **€ 3.5 Billion** in 2024
 - b. **€ 5.0 Billion** in 2032

Focus: GIC Risk !!!

Lightner et al (2017) Space Weather v15 n1 p65-83 doi10.1002-2016SW.01101

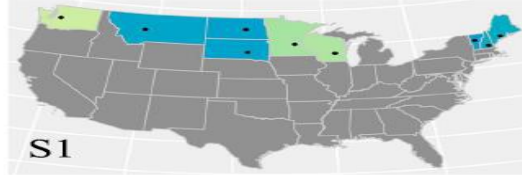


Direct Economic Impact

Blackout Zone



Daily Customer Disruptions



Daily Direct Loss

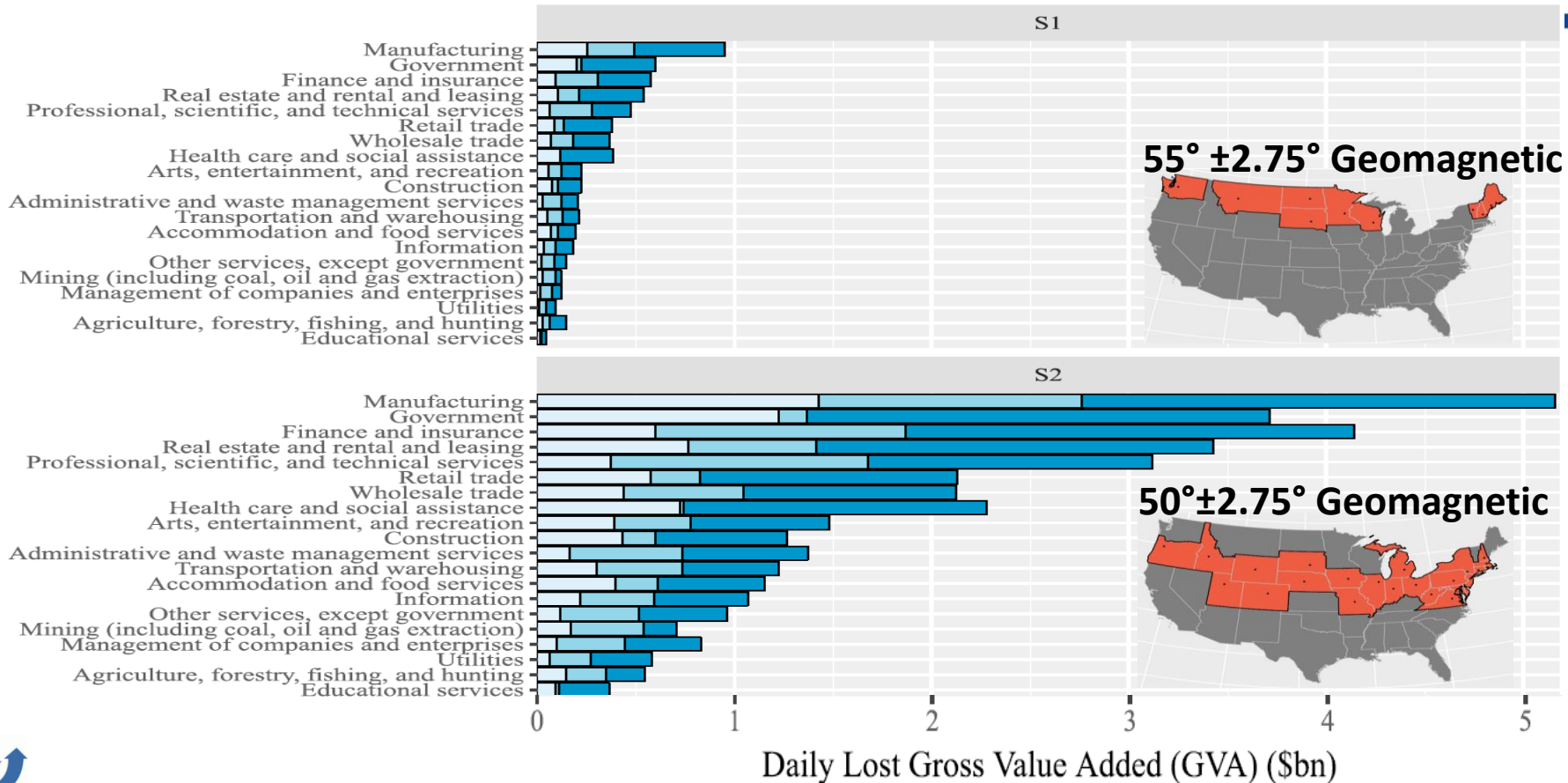


Lichten et al (2017) Space Weather v15 n1 p65-83 doi:10.1002-2016SW001101



Direct Economic Impact

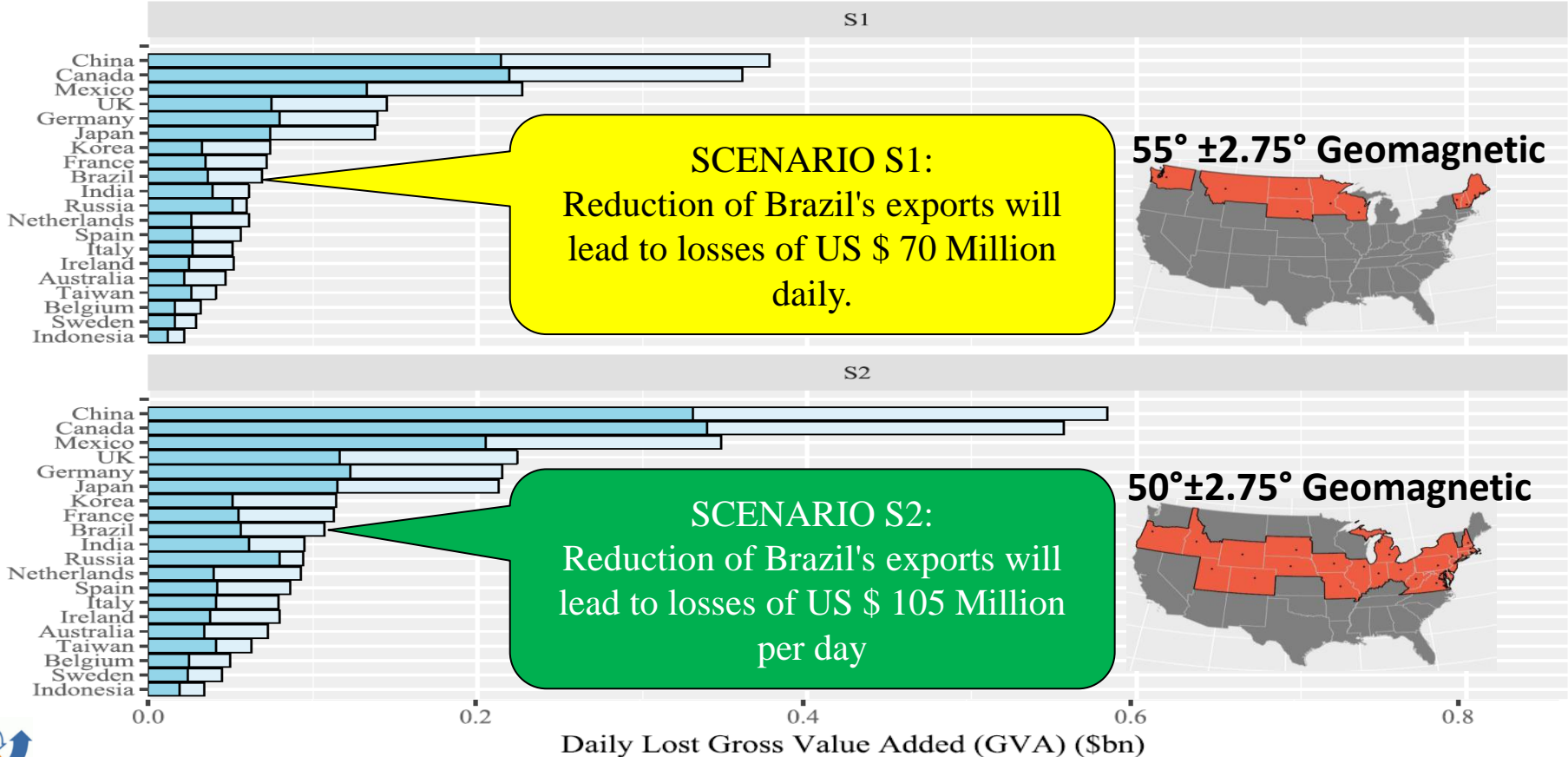
Light et al (2017) Space Weather v15 n1 p65-83 doi:10.1002-2016SW.01101



Daily Lost Gross Value Added (GVA) (\$bn)

Direct Economic Impact

Sughton et al (2017) Space Weather v15 n1 p65-83 doi10.1002-2016SW00149



OTHER RECENT SIGNIFICANT EVENTS

- **Oct 2003 – Loss of \$600 million ADEOS II satellite**
- **Apr 2010 – Galaxy-15 satellite failure**
 - Recovered 8 months later
- **Mar 2012 – Skyterra-1 satellite knocked out for 3 weeks**
- **July 2012 – “What could have been”**

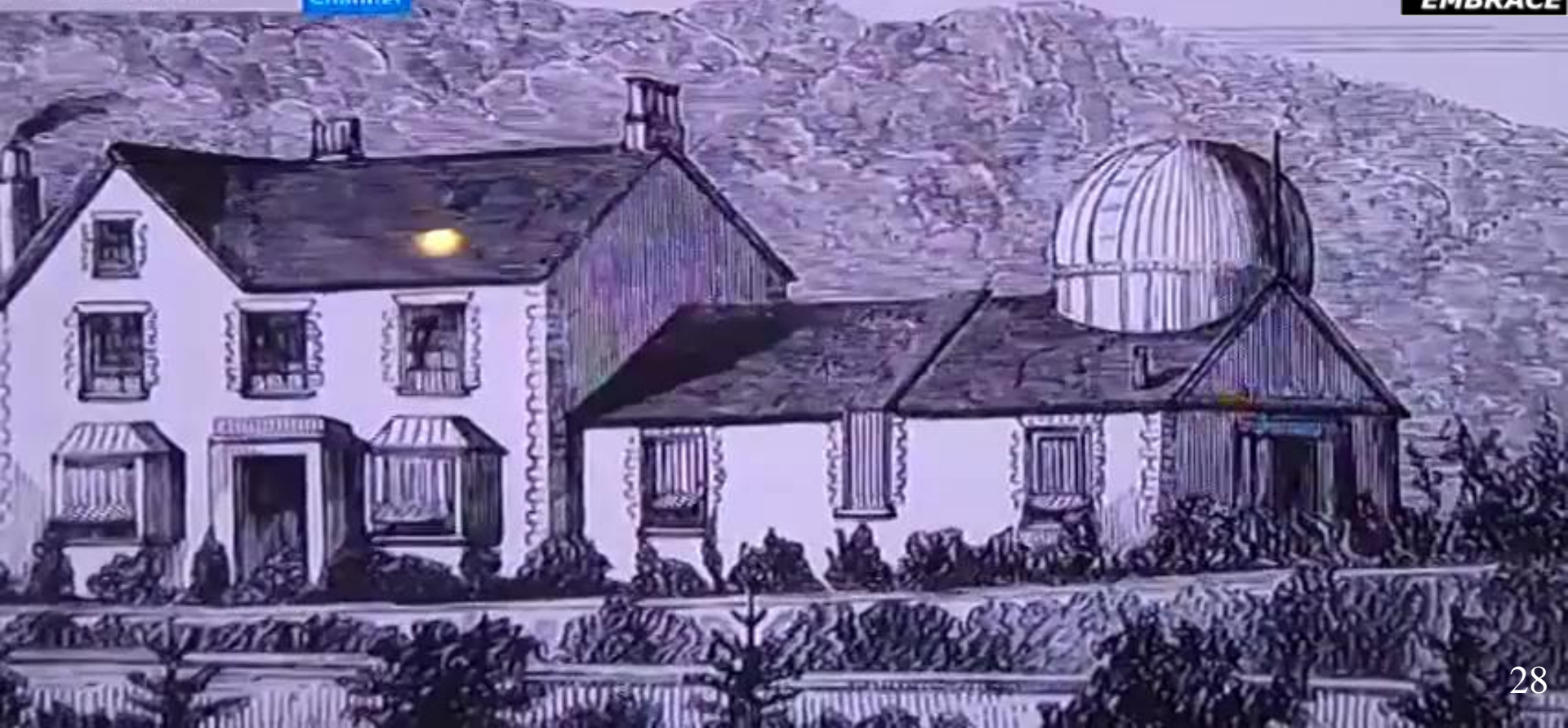


*AN HOUR OF OUTAGE FOR A SATELLITE CAN COST
AS MUCH AS \$150,000*

THE EVOLVING LANDSCAPE OF
CATASTROPHIC MANAGEMENT

SECRETS
OF THE EARTH

Extreme event occurred in 1959



If you think
research is
expensive imagine
Ignorance!

“Alex Hands (Un.Surrey) in Who
Cares about Space Weather”

Si crees que
la
investigación
es costosa,
imagina
¡Ignorancia!

Thank you
Gracias

<http://www.inpe.br/climaespacial>

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