Solar storms and their impacts on power grids - Recommendations for (re)insurers

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Club APREF, 20 May 2014

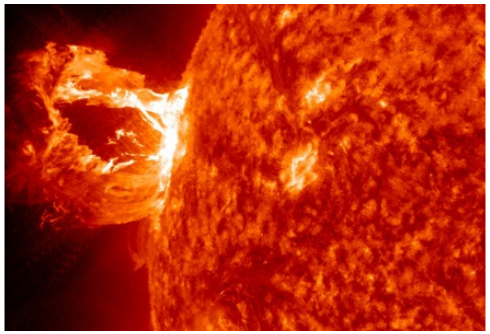
Solar storms: an issue which is hard to grasp for (re)insurers

- ‘Exotic’ nature (vs well-known perils such as hurricanes or earthquakes)
- ‘Emerging’ risk (even though solar storms have arguably existed long before any human being was there to watch)
- Low probability, high severity event. Similar to meteorites?

Solar storms: a credible threat?

A multi-faceted physical phenomenon

	Solar flares	Solar energetic particles	Coronal mass ejections (CMEs)
Physical nature	X-rays, extreme UV, gamma rays, radio burst	Energetic protons and ions (typically 10 to 100 MeV, but up to 20 GeV)	Vast clouds of seething gas, charged plasma of low to medium energy particles with imbedded magnetic field
Time needed to reach the Earth	8 minutes (speed of light)	15 minutes to 24 hours	1 to 4 days
Duration of the interaction with Earth	Minutes to hours	Several days	One day or two

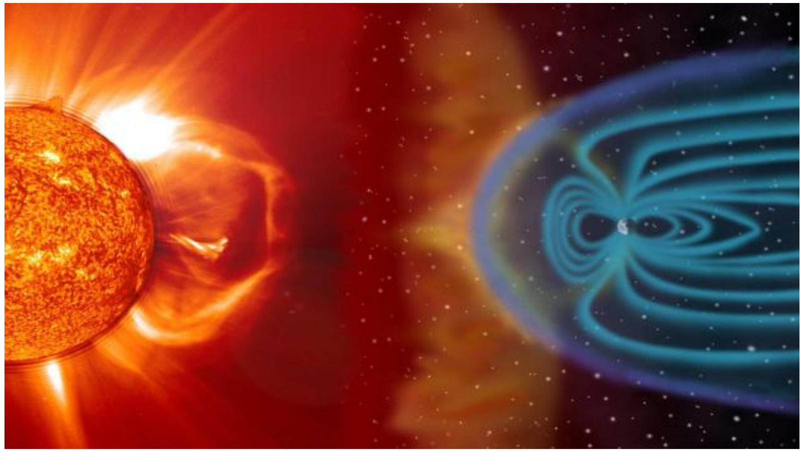


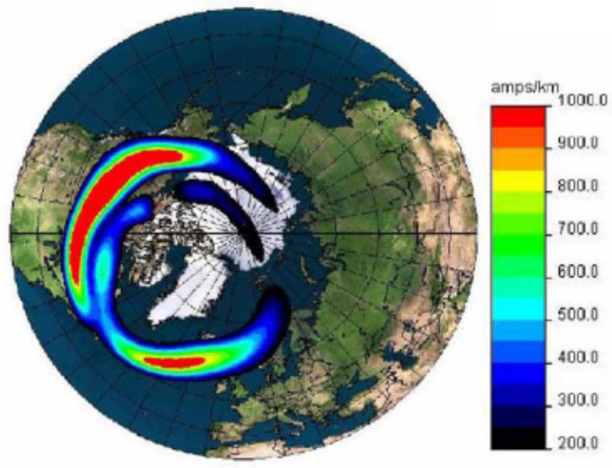
coronal mass ejection.mp4

Direct impacts on human activities

- The modification of the characteristics of the ionosphere caused by solar storms affects electromagnetic signals going through it. This may result in disruptions to:
  - Radio communications (including GPS signals).
  - Radar systems
- Solar energetic particles and nuclear radiation associated with them may hurt:
  - Solar panel arrays of satellites
  - Electronics
  - Spacecraft and aircraft crew and passengers
- Geomagnetic field distortions may affect systems using compasses, notably:
  - Spacecraft
  - Ships
- Electric currents induced in the ground by CMEs may cause disruptions to:
  - Power grids, potentially resulting in outages
  - Railway signalling systems
  - Oil and gas pipelines

From CMEs to GICs (Geomagnetically induced currents)

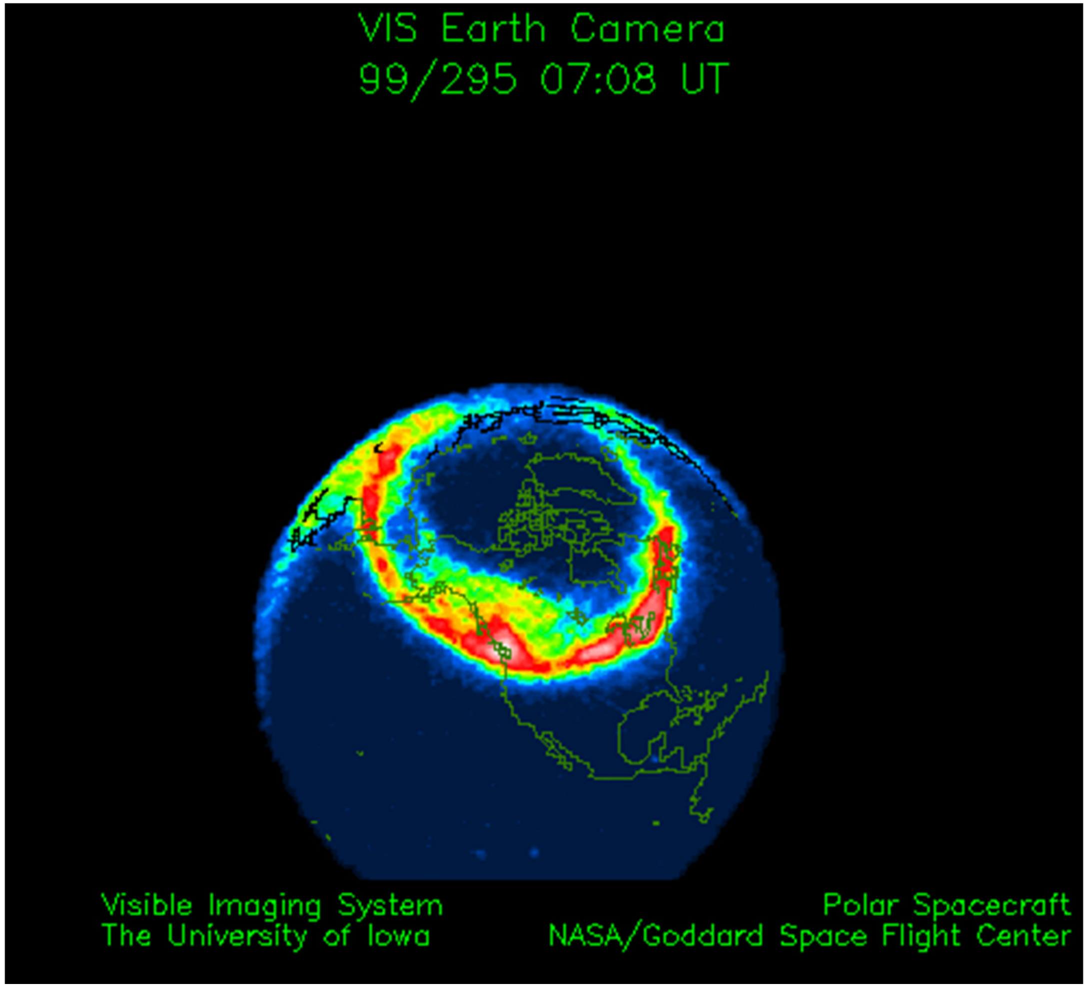




- Ground electric fields in the UK may rise to 5 to 10 V per km during solar storms.

- Thus the difference of electric potential at the ground between the two endpoints of a 100 km transmission line can typically reach 1 000 V.

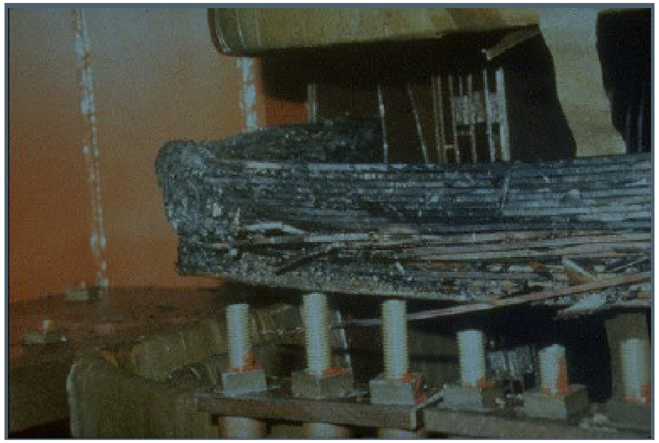
From CMEs to GICs (Geomagnetically induced currents)



Impact on power grids

- GICs in electric grids may reach high values (300 A measured in a transformer neutral in Sweden in 2000)

- Possible impact on power grids:
  - Overheating of transformers, damaging them up to the point of failure



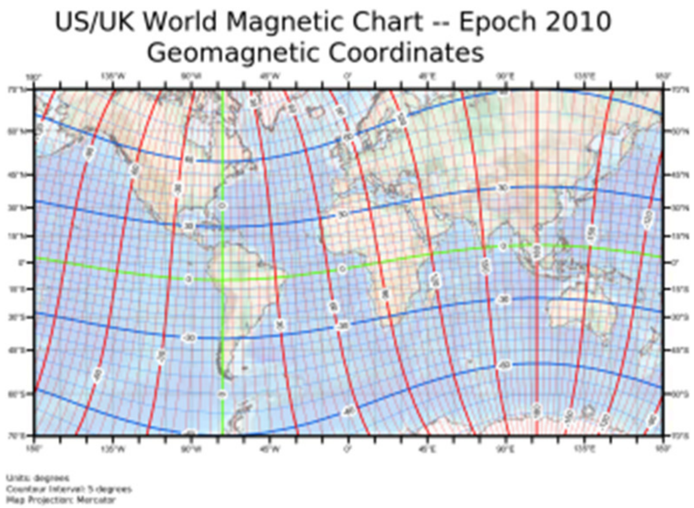
  - Increase of the reactive power consumption of transformers => voltage collapse
  - Harmonic currents may cause the tripping of protective systems on the grid => voltage collapse

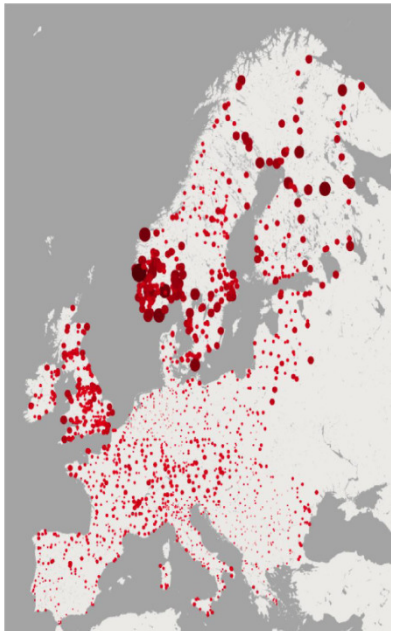
Real-life examples from past events

- 1859: Carrington event
  - Auroras turning night to day as far south as Panama
  - Unusable telegraph systems across Europe and North America
- May 1921
  - The entire signal and switching system of the New York Central Railroad below 125th street put out of operation
- March 1989
  - Loss of electric power to more than 6 million people for 9 hours in Quebec
- 2003 'Halloween' storm
  - Blackout of less than an hour in Sweden affecting around 50,000 customers
  - Damage to twelve transformers in South Africa necessitating their removal from service

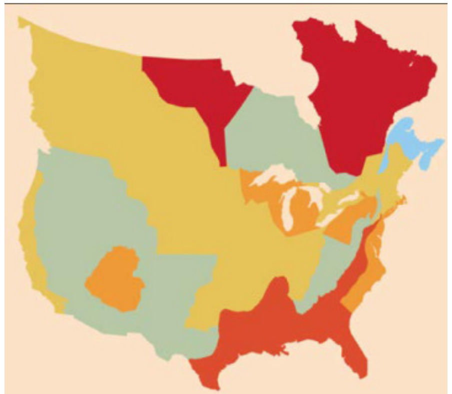
Some of the (many) factors influencing the impact of solar storms on power grids

- Geomagnetic latitude

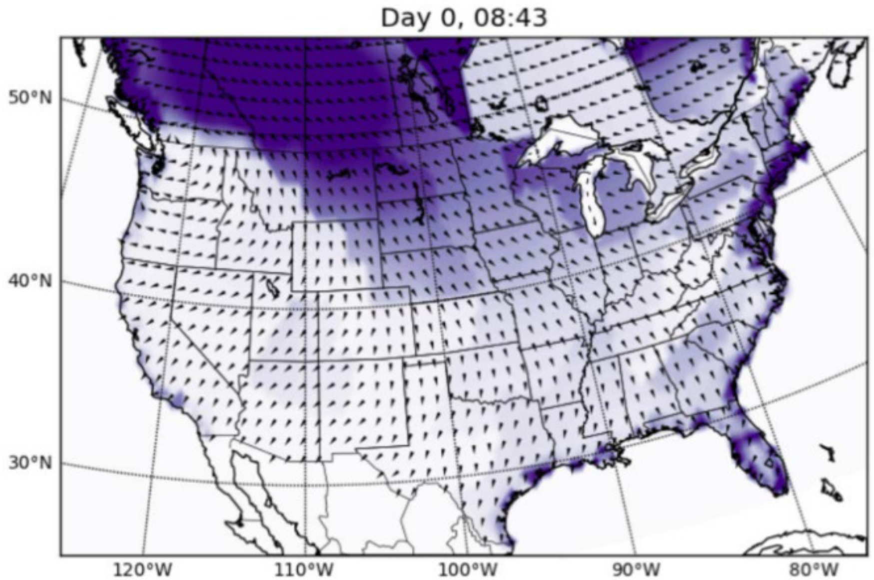


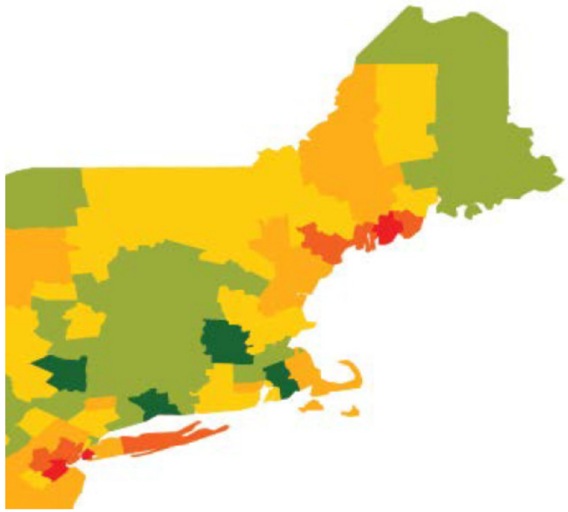


- Ground conductivity

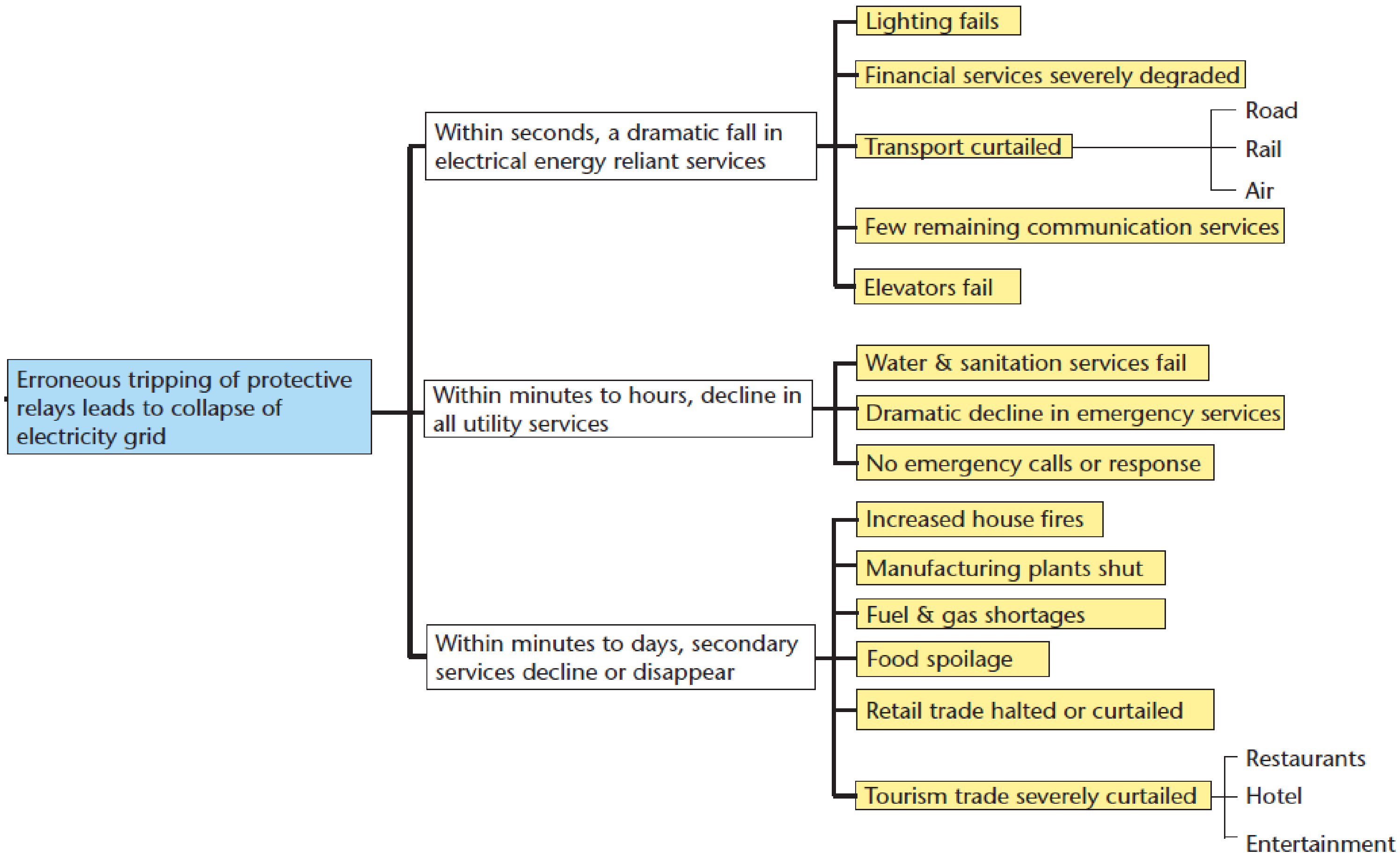


The picture resulting from the combination of all risk factors is complex





The consequences of a prolonged blackout scenario



The severe blackout scenarios

- 2004 report from the US National Academy of Sciences:
  - a repeat of the May 1921 solar storm would leave 130 million people without power in the US for an extended period of time, with economic costs skyrocketing to USD 2 trillion for the first four years and recovery taking up to ten years.

- 2013 study by AER :
  - a Carrington-level storm would deprive between 20 and 40 million people of electricity in the US, with durations of 16 days to one to two years, with economic costs estimated at $0.6-2.6 trillion

- Figures presented by Swiss Re in 2012:
  - Economic losses from a Carrington-like event affecting the US and Canada would range between USD 129 bn (best case) and USD 163 bn (worst case)

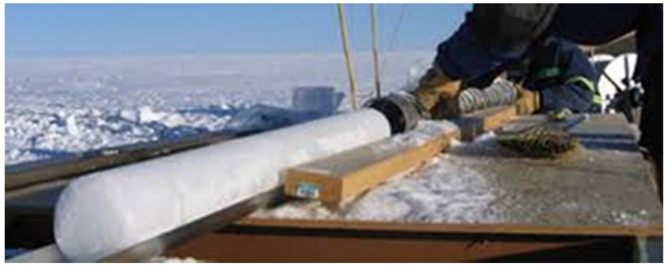
Milder scenarios

- 2012 study by the UK National Grid :
  - a Carrington-like solar storm, would only result in “temporary localized power interruptions”. Around six super grid transformers in England and Wales and a further seven grid transformers in Scotland could be damaged and could fail.

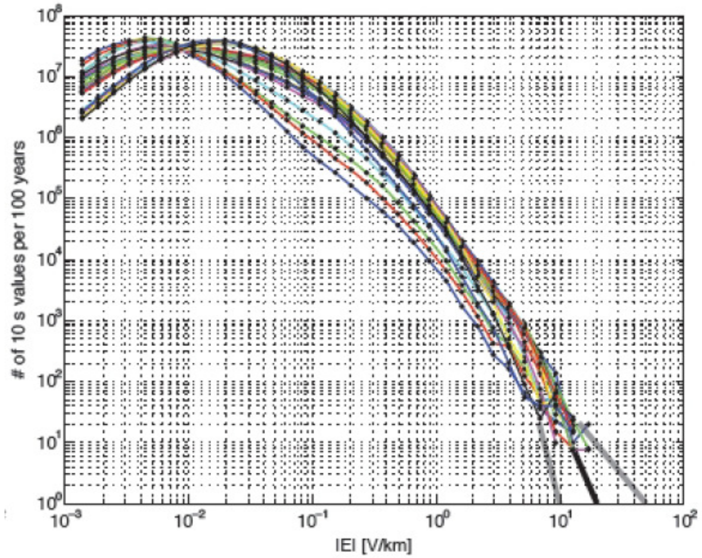
- February 2012 report from NERC:
  - “NERC recognizes that other studies have indicated a severe GMD event would result in the failure of a large number of EHV transformers. Based on the results of this chapter, the most likely worst-case system impact from a severe GMD event and corresponding GIC flow is voltage instability caused by a significant loss of reactive power support and simultaneous to a dramatic increase in reactive power demand”.

How to evaluate the return period of a Carrington-like solar storm?

- Physical model of solar eruptions
- Ice cores studies



- Extrapolation from smaller events



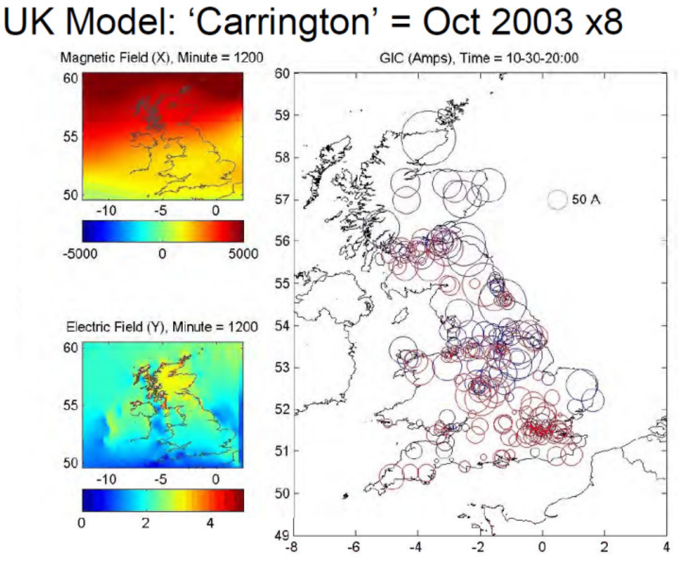
- Use of historical records of visual observations of aurora borealis

Solar storms and their impacts on power grids
Recommendations for (re)insurers

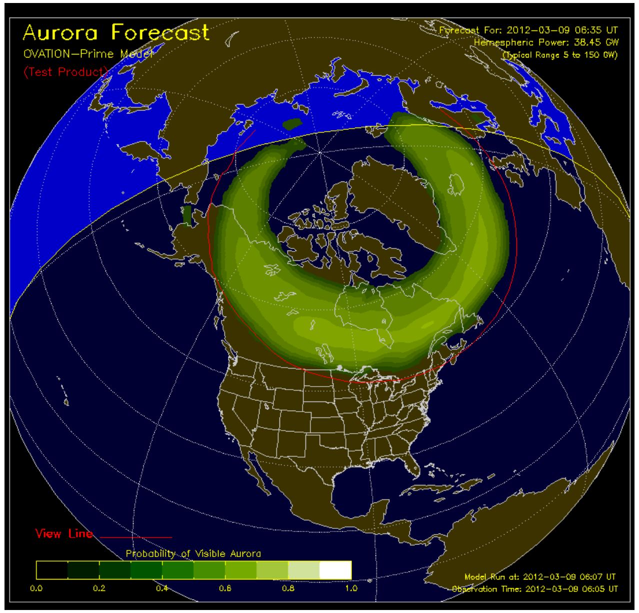
Long-term measures to reduce the vulnerability of power grids

- Replace transformers with more resilient ones
- Increase spare holdings
- Fit devices in order to block the propagation of DC currents in the grid
- Adjust protection systems against harmonics in order to avoid unnecessary tripping

Modelling tools are essential in order to identify vulnerability hotspots and focus on them



Forecasting and mitigating



- Operational mitigation strategy of National Grid:
  - all circuits returned to service and switched in
  - all supergrid transformers connected in order to spread the load
  - substations run solid in order to maximise the connectivity of the grid
  - extra generation instructed to synchronise
  - extra reactive support made available

Public authorities' awareness

Industry Advisory

Preparing for Geo-Magnetic Disturbances

Initial Distribution: May 10, 2011

NERC and Regional Entities are monitoring the threat to bulk power system reliability caused by damaged equipment from Geo-Magnetic Disturbances. This Advisory provides industry with a set of operational and planning actions to prepare for the effects of severe Geo-Magnetic Disturbances on the bulk power system.

143 FERC ¶ 61,147
UNITED STATES OF AMERICA
FEDERAL ENERGY REGULATORY COMMISSION

18 CFR Part 40

[Docket No. RM12-22-000; Order No. 779]

Reliability Standards for Geomagnetic Disturbances

(Issued May 16, 2013)

Solar storms and their impacts on power grids
Recommendations for (re)insurers

Solar storms are largely absent from insurance policy wording

- Insurance contracts "are unlikely to have been drafted with any degree of consideration for a loss occurrence of the type initiated by extreme solar weather" (AON Benfield, January 2013).

- Consequently:
  - Solar storms would arguably be covered by 'all risks' policies
  - Solar storms would arguably not be covered by 'named perils' policies, unless they indirectly provoke one of the perils named in the contract (fire, explosions, etc.).

Impact on property covers

- Property insurance policies may be triggered by a major solar storm. In that case they may cover:
  - Physical damage incurred by the insured
    - TSO: USD 10 million per transformer
    - Large corporate: e.g. aluminium melting furnaces
  - Business interruption caused by such damage
  - Business/service interruption caused by physical damage incurred by a supplier/service provider/client
    - Accumulation risk
    - Waiting period hurdle may be easily overcome
    - However, the limit is typically 10% to 15% of the limit applicable to property and BI
- Wider impacts in case of a prolonged blackout:
  - Looting
  - Fires spinning out of control, etc.

Impact on liability covers

- At first glance, ‘Force majeure’: unforeseeable and extraordinary event beyond the reasonable control of anyone.

- However:
  - Plaintiffs may try to show that the risks posed by solar storms to power grids were well known and that mitigation measures were available
  - They may challenge the idea that solar storms are unpredictable by pointing at existing space weather forecasts. They may point at deficiencies in operational procedures.
  - They may refer to the Advisory issued by NERC in May 2011, even if it is non-binding. In the future, they may refer to binding standards.

- Risks for (re)insurers limited by two factors:
  - small number of generating companies and TSOs in a given area (exposure capped by limit x number of insureds).
  - liability insurance policies for generating companies and TSOs usually only cover liability arising from bodily injury, personal injury and property damage.

Recommandations for (re)insurers: risk management

- Include solar storms in the list of emerging risks to be monitored.
- Map your exposure / Build extreme scenarios
- Prepare for the fact that in the future supervisors may ask reinsurance companies to consider a one in 200-year solar storm as part of Solvency 2-compliant internal models / Engage in a dialogue with modelling firms.
- Monitor new results coming out of ongoing research.

Recommandations for (re)insurers: underwriting (1)

- When underwriting insurance policies covering generating companies or TSOs in countries above a certain geomagnetic latitude:
  - Check that they have taken measures to reduce their vulnerability to solar storms.
  - Check whether they have developed modelling tools.
  - Check that they receive and check space weather forecasts.
  - Check that they have operational procedures in place in case a major solar storm should approach the Earth.
  - In the US, as soon as NERC Reliability Standards are applicable, make sure that coverage is subject to the respect of these standards by operators.

Recommandations for (re)insurers: underwriting (2)

- When underwriting property insurance covers for manufacturers with high potential physical damage in case of a prolonged power blackout, encourage them to receive space weather forecasts and set up operational procedures.
- Monitor and manage the accumulation risk linked to service interruption extensions.
- When assessing the risk of cascade triggering of CBI covers along supply chains, take prolonged blackout scenarios into account.
- Review insurance policy wording. In particular:
  - clarify the ‘physical damage’ requirement clause, especially with reference to a scenario where the grid would collapse without incurring any physical damage in the strict sense.
  - clarify the notion of ‘supplier’ in service interruption extensions.

Recommandations for (re)insurers: Governmental affairs

- Draw the attention of governments to the importance of maintaining current forecasting capabilities.
- Draw the attention of governments to the importance of funding research.
- Promote awareness of solar storms by non-US governments and power grid regulators of countries above a certain geomagnetic latitude. Promote the inclusion of risks from solar storms in grid reliability standards.

To find out more…

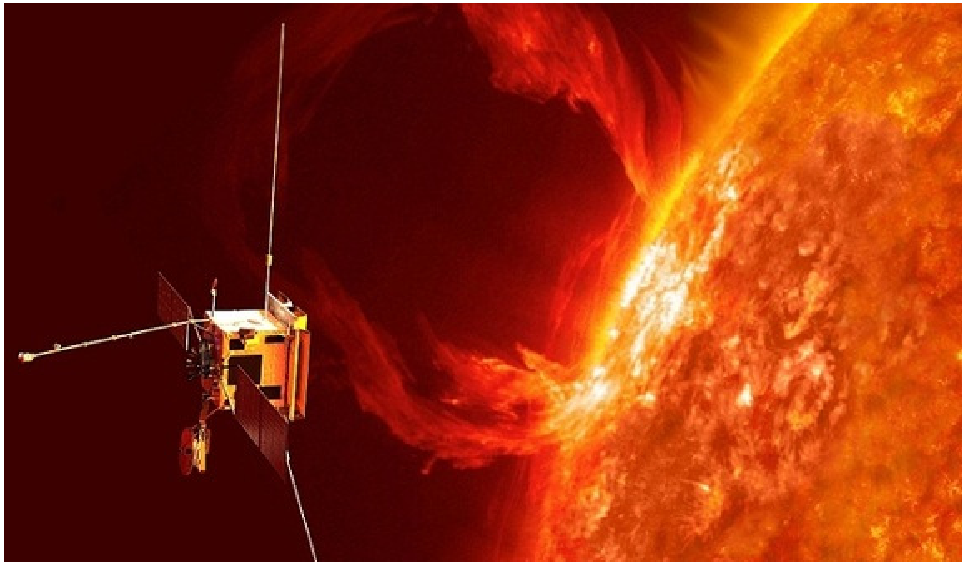
- SCOR Paper n°28: http://www.scor.com/images/stories/pdf/scorpapers/sp28.pdf

Bibliography:

- Aon Benfield (January 2013). *Geomagnetic storms.*
- CRO Forum (November 2011). *Power blackout risks.*
- FERC (May 16, 2013). *Reliability Standards for Geomagnetic Disturbances.*
- LLoyd's, & AER. (2013). *Solar storm Risk to the north American electric grid.*
- Marusek, J. A. (2007). Solar storm threat analysis. *Impact*.
- NERC (February 2012). *Effects of Geomagnetic Disturbances on the Bulk Power System.*
- NERC (May 2011). *Industry Advisory: Preparing for Geo-Magnetic Disturbances.*
- Royal Academy of Engineering (February 2013). *Extreme space weather: impacts on engineered systems and infrastructure.*

Solar storms and their impacts on Satellites

Club APREF
May 20, 2014



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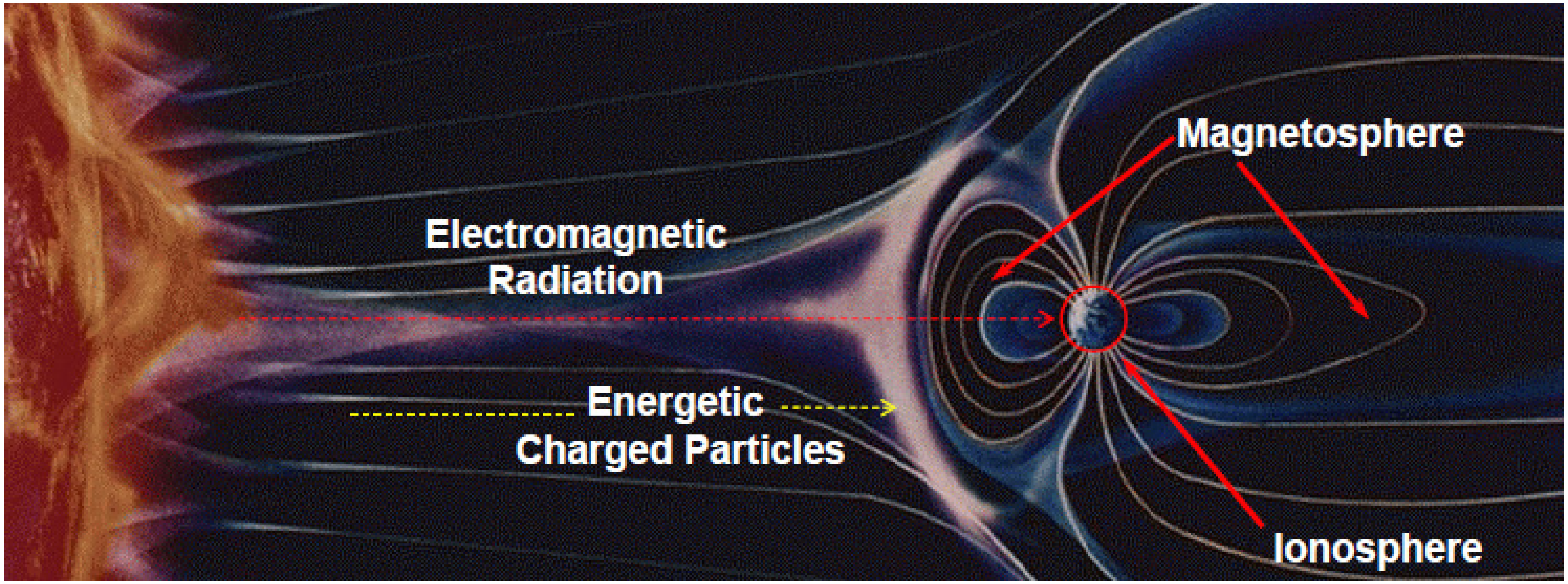
SCOR

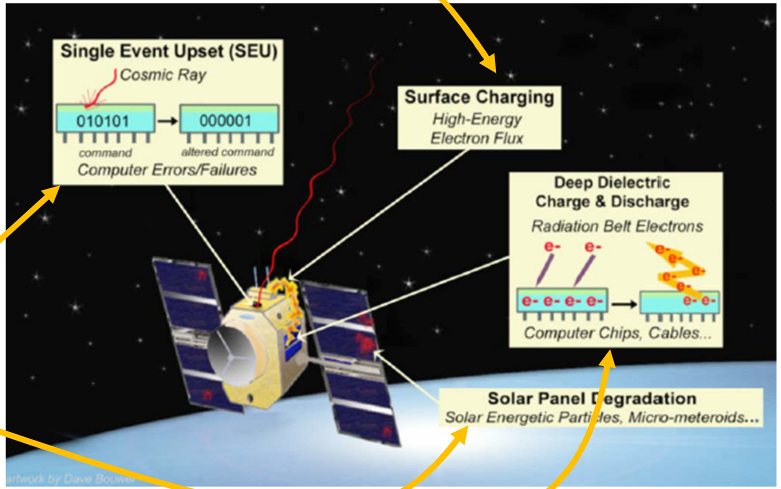
Solar Weather: Various phenomena



Phenomenon	Typical solar event	Description	Impact on	Scale
Geomagnetic Storms	CME, solar wind	Disturbances in the geomagnetic field caused by gusts in the solar wind that blows by Earth.	Power systems, Spacecraft operations, Satellite navigation, low-frequency radio navigation	G1 (Minor) to G5 (Extreme)
Solar Radiation Storms	CME, Solar flares	Elevated levels of radiation that occur when the numbers of energetic particles increase.	Biological (high exposure for astronauts, crew and passengers of high-flying aircraft) Satellite operations and HF communication	S1 (Minor) to S5 (Extreme)
Radio Blackout	Solar flares	Disturbances of the ionosphere caused by X-ray emissions from the Sun.	HF communications, Low-frequency navigation signals	R1 (Minor) to R5 (Extreme)

Solar Storms & Hazards on Satellites & Space activities

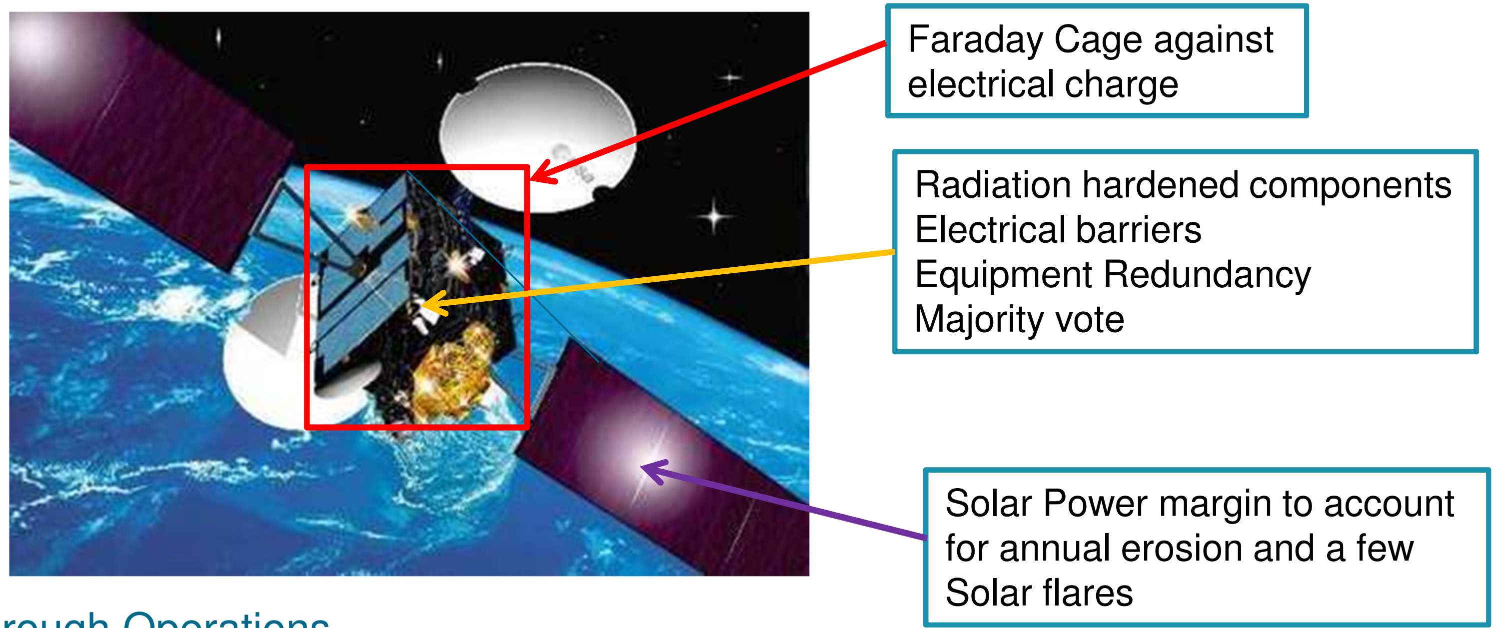
solar event	Manifestation	Impact
Coronal Mass Ejection (CME) or Solar wind	Low energy Electrons (KeV)	Electrostatic Discharge (ESD) outside of Spacecraft Arcing of Solar Array Upset of Spacecraft operations ("phantom" commands)
Solar flares	High proton & ion fluxes	Single Event Upset (SEU) Solar Array performance Degradation (3-5% in a day) Fogging of optical sensors
	Long period of High Flux penetrating high energy electrons (MeV - GeV)	Charging and internal ESD Damage to electronics Insulation failure
	Elevated levels of radiation	Biological impact to Astronauts, especially during Extra-vehicular Activities (EVA)
	Disturbances of the ionosphere caused by X-ray emissions from the Sun.	Erroneous GPS signals for navigation and other GPS-related services



Effects on satellite services range from temporary outage to partial or total failure

Mitigation Measures

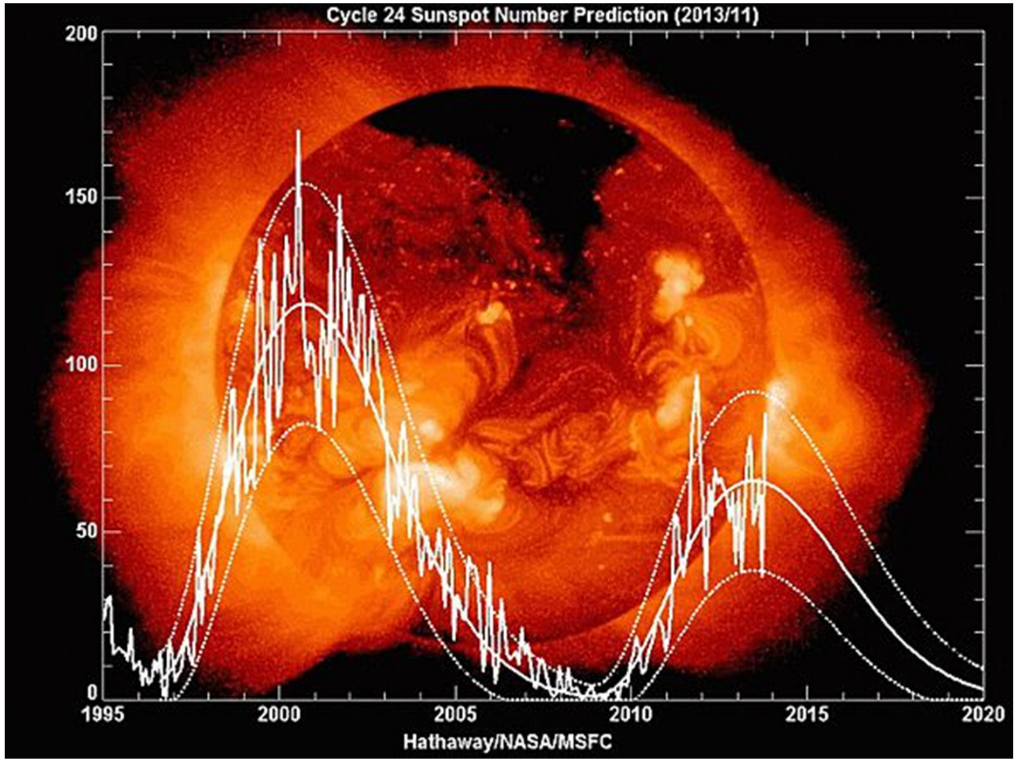
- At the difference of ground systems, satellites are expected to experience severe environment in space and are designed accordingly
- Mitigation by Design



- Mitigation through Operations
  - Early warning (few hours to few days) provided by NOAA / ESA
  - Turn-off non-critical systems onboard satellite
  - Reorient Solar panels to minimize solar flux impact

Low Peak doesn't mean low Risk

- Solar cycle 24 peak (2013) much lower than prior one
- Solar peak is more a measure of frequency than severity of events
- Particles / Radiation emissions are not necessarily phased on peak



Solar storm impact on Satellites / Space-based operations: Consequences on human activities

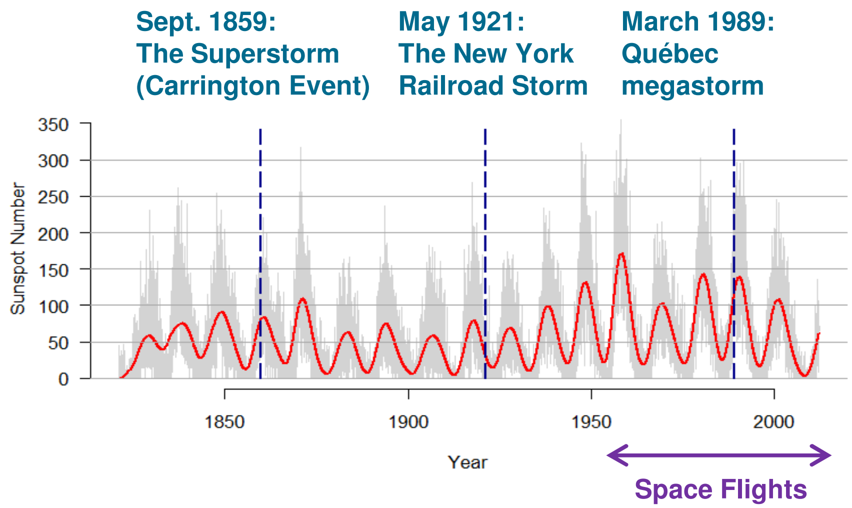
- **Disruptions of satellite communication services**
  - Telecommunication services
  - TV and Radio broadcasting
  - Direct-to-home TV

- **Disruption or alteration of Navigation signals (GPS)**
  - Aircraft navigation including precision landings
  - Road/maritime navigation services
  - Oil & gas: offshore platforms positioning
  - Financial transactions relying on GPS signals for time-stamping

- **Radiations**
  - Health of Astronauts

Risk Assessment

- Satellites & Space operations are a relatively new activity with limited experience on extreme solar events



- Carrington Event

  A repeat of the 1859 event could produce a potential economic loss of USD 44 billion for lost satellite transponder revenues plus about USD 24 billion for the replacement of geosynchronous satellites (oldenwald et al., 2006)

Space Insurance & solar storms

- Space Policies
  - "Launch plus one year" Policies : cover launch, commissioning and initial In-orbit operations
  - "In-orbit life" Policies: renewable 12 months policies covering operations over the satellite lifetime (typically 15 years)
  - Due to the nature of space operations (no repair, potential catastrophic failures), cover is a true "all risks" Policy covering damage, physical loss, failure, faulty design, loss of performance, etc.
  - Solar storms are in the realm of expected events for a satellite and as such are not excluded
- In-orbit experience

  Solar storm origin always difficult to prove – A few examples:
  - 1994: Intelsat K, Anik E1 & Anik E2 all experienced failure on same day.
  - 1996: Anik E1 power loss (USD 142m claim)
  - 1997: Telstar 401 (USD 132m claim)
- Lloyd's RDS scenarios (2013 revision – under evaluation in 2014)
  1) Solar energetic Event (assumed to be a 1-in-100 years event)
     - large solar flare impacting solar arrays performance of all live insured satellites
     - Calculated as 5% of aggregate value of all GEO satellites
     - Current insured value in orbit ca. USD 24,5 Billion => scenario value: ca. USD 1.2 Billion
  2) Space weather design deficiency (assumed to be a 1-in-50 years event)
     - Add four largest lines for a given satellite type among predetermined satellite types
     - Estimated market cost for this scenario: ca. USD 1.7 billion

Conclusion

- Satellite operations are a relatively new activity with limited return of experience as regard severe solar events
- Satellites are designed to sustain severe space environment, including solar storms up to a certain degree
- Given their greater reliance on satellites, terrestrial activities and our way of life would be significantly impacted by any severe disruption of satellite systems
- Insurance is covering losses due to Solar storms with no limitation
- Cat Exposure assessment is currently done through rather simple aggregation scenarios (no stochastic model) - According to these scenarios, an extreme event would largely exceed the Space Market annual premium
- Increased awareness of solar events impact on ground risks should allow to improve modeling, benefiting to the space insurance market as well