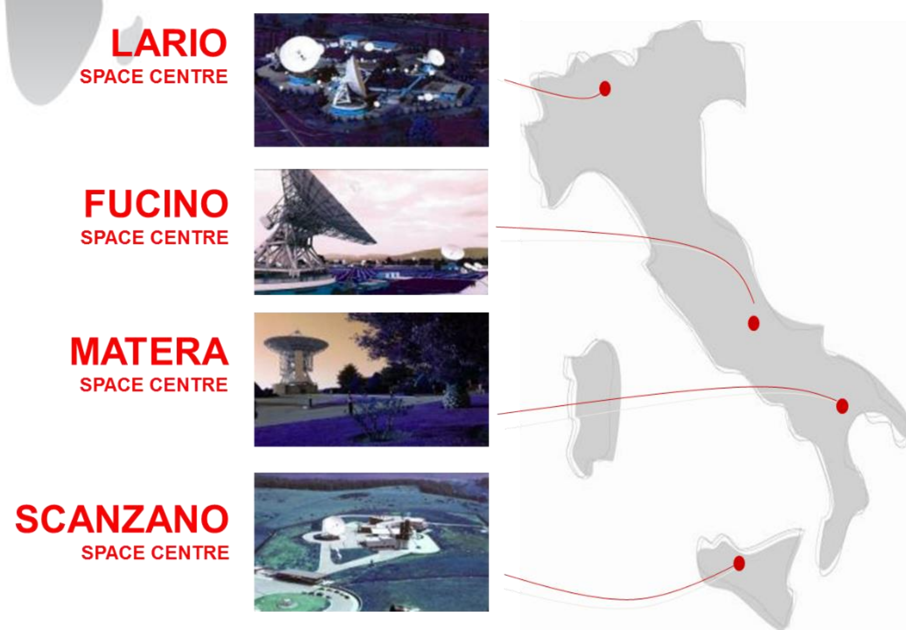
Space Weather Services

ISSS School - L'Aquila June 6-10 2016

TELESPAZIO
a LEONARDO and THALES company

Telespazio

Telespazio, is a joint venture between Leonardo Finmeccanica- (67%) and Thales (33%)



TELESPAZIO ORGANIZATION

SYSTEM ENGINEERING AND OPERATIONS

- Satellite Operations (SO)
- Space Systems and Applications (SSA)
- Science & Navigation

SERVICE PROVIDER

- Networks & Connectivity (N&C)
- Geo Information (GI)

…..and main programmes

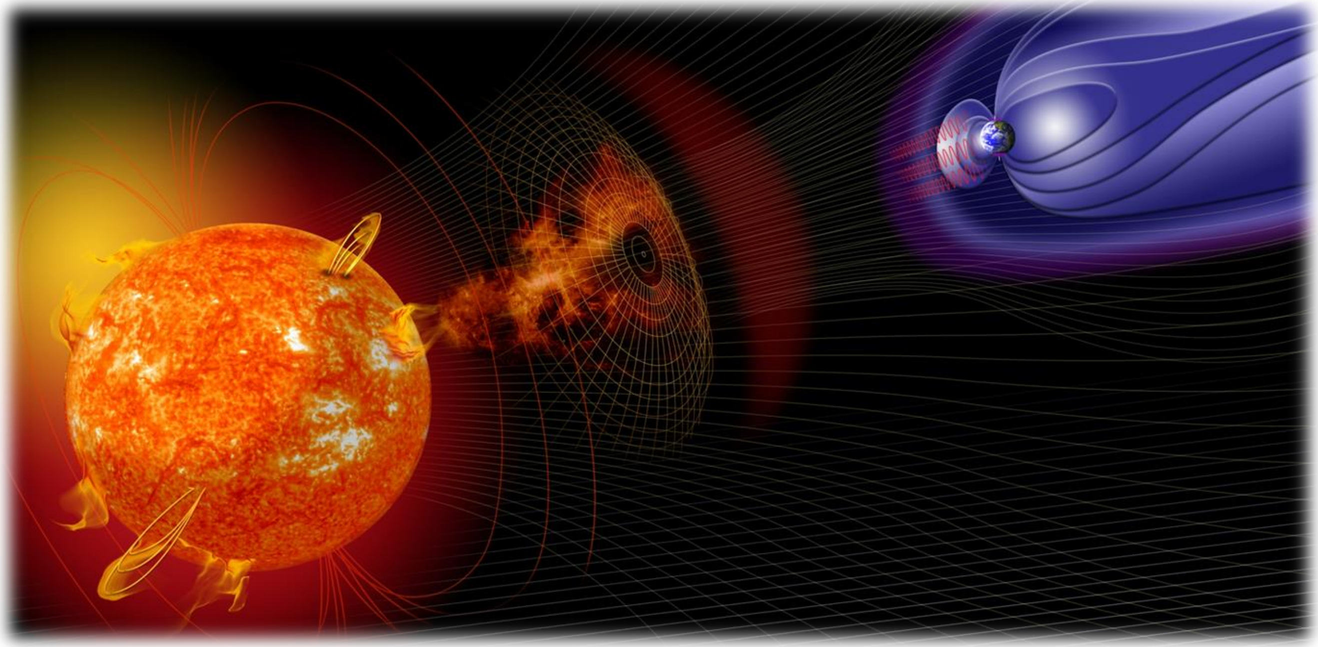
Galileo operations and Mission Control Centre at Fucino Space Station

EGNOS Operations in EGNOS Service Provider contract

Copernicus Programme (Earth observation)

COSMO-SkyMed satellite constellation

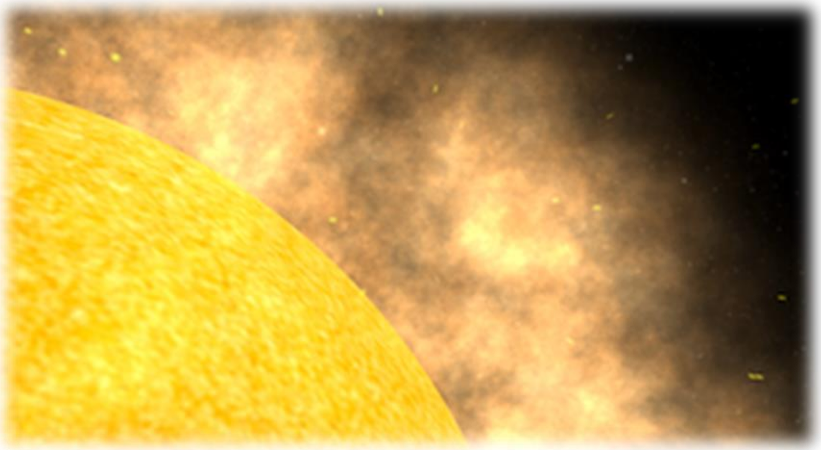
SICRAL and Athena Fidus TLC programmes



Space weather refers to changes in the space environment and the effects that those changes have on mankind's activities.

The primary source of space weather is the Sun. Variation in the electromagnetic and particulate output of the Sun is the main cause of changes in the Earth's upper atmosphere and surrounding regions such as the magnetosphere.

SOLAR ACTIVITY

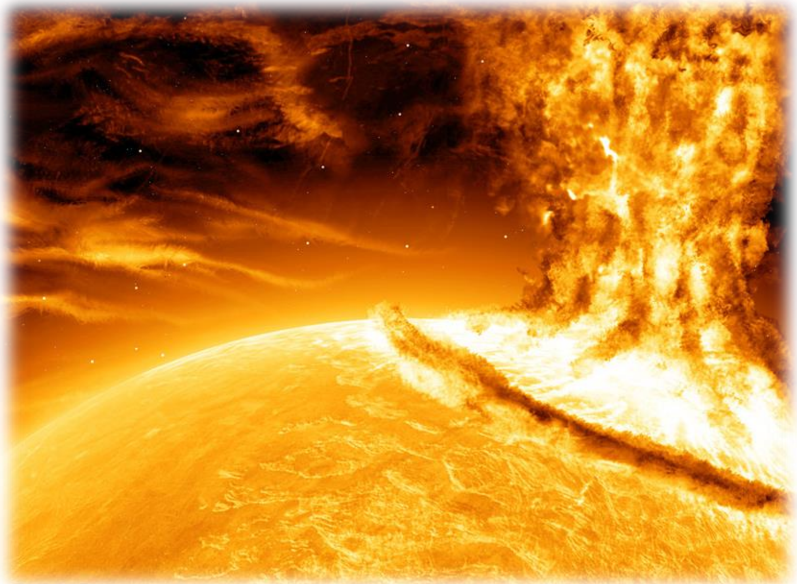


Background activity - Quiet sun

- Solar Irradiance (radiation) and
- Solar Wind (mass)

Peak activity - Active sun

- Solar flares,
- Coronal mass ejections (CME),
- High-speed solar wind,
- Solar energetic particles



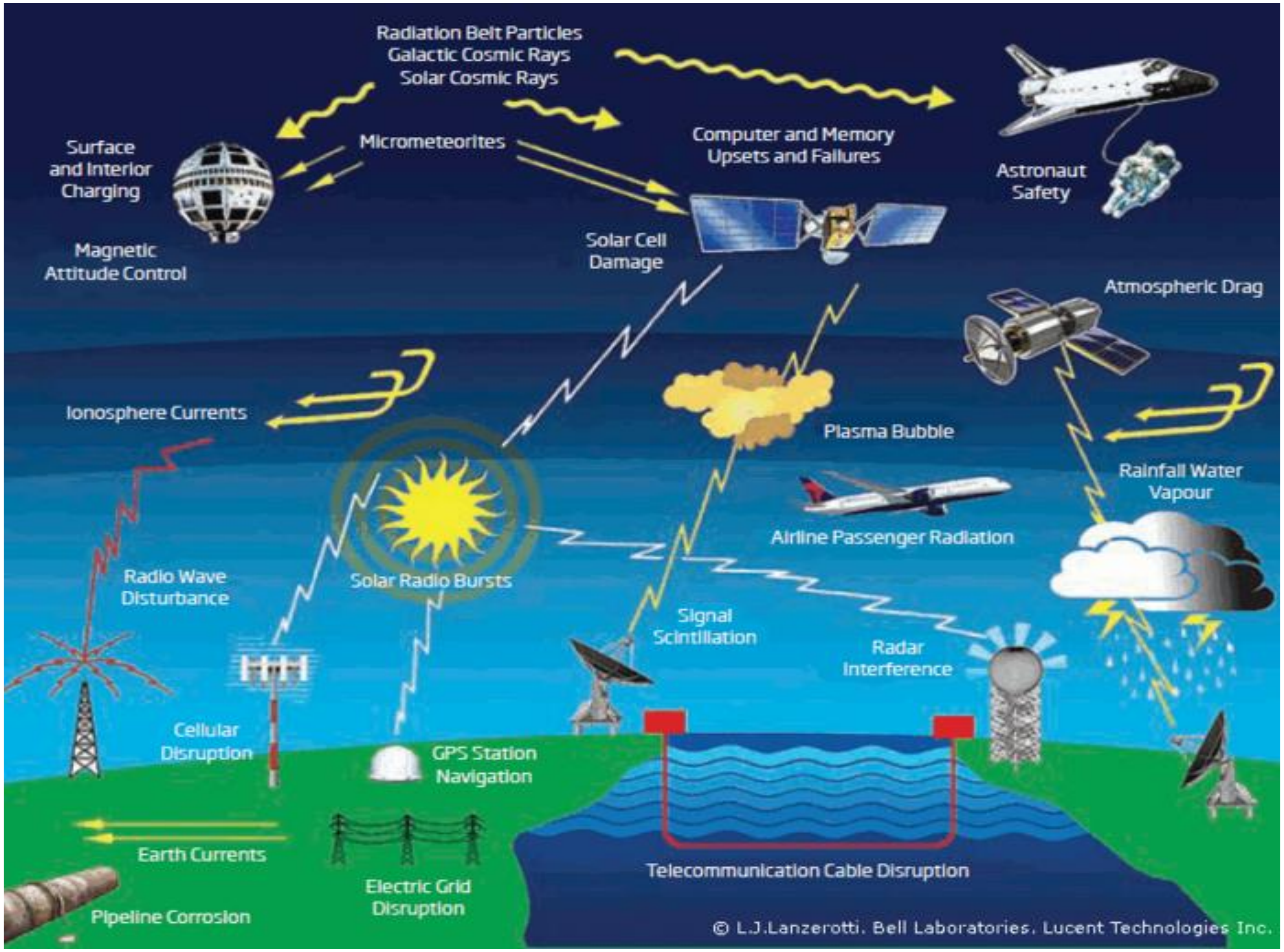
- All solar activity is driven by the global and local solar magnetic field.
- The **Peak** activities are the major responsible of space weather **effects on technology**

Solar Flares
Coronal Holes
Sunspots/Solar Cycle
F10.7 cm Radio Emissions
Solar EUV Irradiance
Coronal Mass Ejections
Solar Radiation Storm
Solar Wind
Magnetosphere
Geomagnetic Storms
Aurora
Ionosphere
Total Electron Content
Ionospheric Scintillation
Ground Induced Currents
Steele Hill/NASA

Solar Phenomena and Impacts

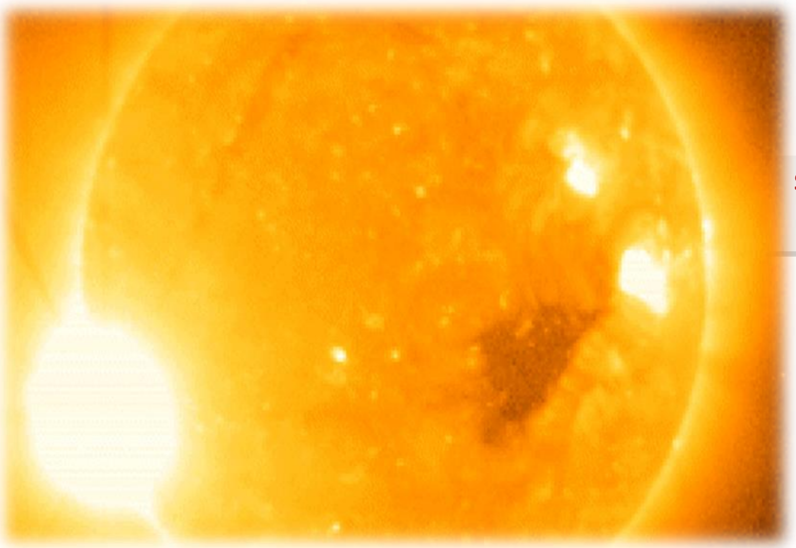
Solar phenomena	Travel time to Earth	Phenomena@Earth	Impacts
Coronal Holes→High speed solar wind	Hrs/days	Particle fluxes (SEP)	surface charging on satellites, damages on the electronics, single event upset causing errors within the computer systems, solar panel degradation
Coronal Mass Ejections (CMEs)	Hrs/days	Geomagnetic Storms→ GIC	Degradation of power grid operations, transformers damages degradation of power supply for transoceanic TLC cables pipelines consumption (corrosion phenomena)
		Geomagnetic Storms	Ionospheric interaction (scintillation): impact on radio navigation signal (GNSS) satellite and HF communications
		Geomagnetic Storms	Thermospheric interaction: atmospheric drag modulation for LEO satellites
		Geomagnetic Storms and particle fluxes → Auroral electrojets	Radio Blackouts and Radiation dose in Polar regions
		Particle fluxes	surface charging on satellites, damages on the electronics, single event upset causing errors within the computer systems, solar panel degradation, Human body exposure (astronauts and air crew/passengers in polar regions)
Solar Flares	8 min	EM Radiation Bursts→radio blackouts	Ionosphere interaction (scintillation): absorbing HF communications signals and causing radio blackouts on the sun-lit. Disruption of VHF communications, satellite communications and GNSS signal.
	30 min	solar radiation storms (high speed particles)	Increased exposure for human bodies (air crew, passengers and astronauts) Block radio communications at high latitudes in during Solar Radiation Storms
		solar radiation storms(high speed particles)	Surface charging on satellites, damages on the electronics, single event upset causing errors within the computer systems, solar panel degradation
		solar radiation storms (high speed particles)	Ionosphere interaction: absorbing HF communications signals and causing radio blackouts on the sun-lit. Disruption of VHF communications and GNSS signal

Impact on Technology

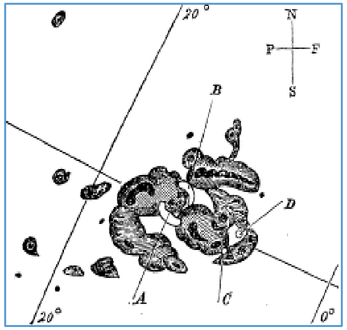


Carrington event – 1859

September 1st 1859: Richard Carrington observed a large flare, which caused a major Coronal Mass Ejection to travel directly toward Earth, reaching it in 17.6 hours.



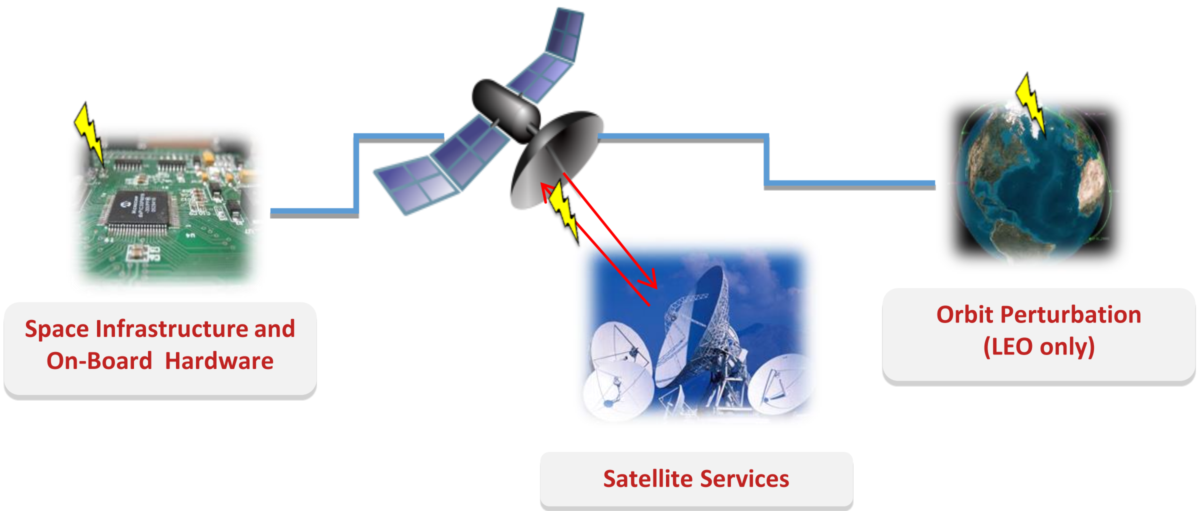
Sunspots sketched by Richard Carrington
Copyright: Royal Astronomical Society



- Events like this can happen “once a century”
- Impact on Society: Not relevant impact because of low technological level and complexity of 19th century society
- The increase of the social complexity and dependence on technology represents today a relevant risk factor

Satellites can be differently exposed depending on the orbit:

- MEO & GEO : more intense exposition to Space Weather: High energy particles ejected by the sun may hit satellites and cause failure.
- LEO : minor exposition due to Geomagnetic shielding/ major exposition to atmospheric drag variation induced by space weather



Impact on TLC:

- Hi-Frequency Telecommunication systems (both satellites and ground) are very sensitive to Space Weather. A minor event can cause a fair degradation of service and some occasional loss of radio contact. Severe and Extreme events can cause Telecommunications Blackout and heavy loss of radio contact. Effects can last from a few seconds to several hours, according with the Event intensity.

Impact on GNSS:

- GNSS systems are more robust than communication systems. In fact minor sun activity. Have no impact on GNSS signal, while severe events can cause minor disruption. An extreme event can cause positioning errors for several hours on the sunlit side of Earth, which may spread into the night side

Direct Impact on Ground Based Critical Infrastructures

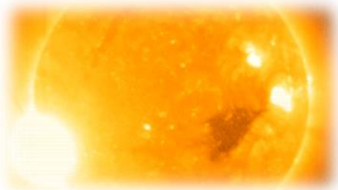
Satellites are directly exposed to Space weather, but Ground Critical Infrastructures are exposed too:

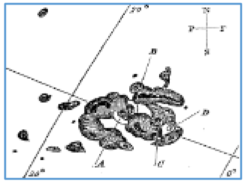
- **Powergrid**: very sensitive to space weather, due to inducted currents. Safety systems can react to relevant events switching power plants in stand-by mode, causing blackout. Extreme events can also damage components of the Powergrid.
- **Ground Communications** (Radio&Mobile) Like Satellite communications, they are very sensitive to space weather noise. Heavier events can cause blackout for many hours on the sunlit side of Earth.
- **Aviation&Radar**: Radar systems can have effects similar to Radio Communications. Even in a case of moderate event, passengers and crew in high-flying aircraft at high latitudes may be exposed to elevated radiation risk.

Carrington Event Today?

ESTIMATED IMPACTS

Carrington event – 1859: September 1st 1859: Richard Carrington observed a large flare, which caused a major Coronal Mass Ejection to travel directly toward Earth, reaching it in 17.6 hours.





Sunspots sketched by Richard Carrington
Copyright: Royal Astronomical Society

- 80 satellites (LEO, MEO, GEO) could be disabled as a consequence of a superstorm event.
- Possible failure of many of the GPS/GLONASS/Galileo satellite systems in MEO.
- Shorten de-orbit period of about 100 LEO satellites, from decades to about nine years, due to the temporarily increased atmospheric drag.

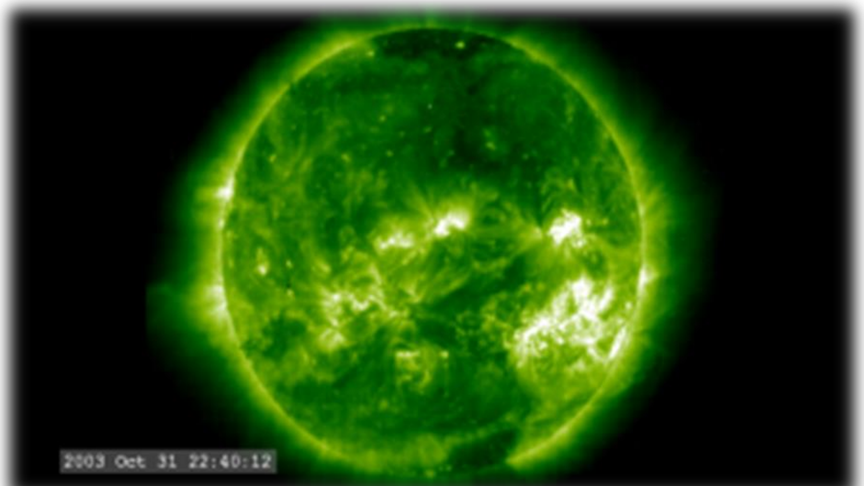
Potential economic loss

- Total loss~ $70 billion
- lost revenue (~$44 billion) and satellite replacement for GEO satellites (~$24 billion)

(Sten F. Odenwald and James L. Green, Space Weather (2007) 5: 1-16.)

The Hallowen 2003 Solar Storm

- October and November 2003 (Halloween storm): the Sun produced a significant display of solar activity and one of the most intense solar flares ever recorded was observed.
- The arrival of transient solar wind from Earth-directed CMEs produced extreme geomagnetic storming.
- Its effects included prolonged high-frequency (HF) communication outages, fluctuations in power transmission systems, and minor to severe impacts on space satellite systems.
- This solar Storm was less powerful than a Carrington Event



SOHO Oct. 31 2003

Wisconsin Oct. 22, 2003
(Copyright Chris VenHaus)

Impact on Satellites Hardware
(The The Hallowen 2003 Solar Storm)

data	mission	device/instrument	events	recovery
29 October	Mars Odyssey	spacecraft	automatic shutdown because memory errors	yes, 31 October
28 October	Mars Odyssey	MARIE	temperature red alarm	no
-	Stardust			yes
-	SMART-1		multiple shutdowns	yes
-	Mars Explorer Rover		excessive star tracker error events	yes
-	Microwave Anisotropy Probe		star tracker reset	yes
-	Mars Express		stabilization with gyroscopes because of SEPs blocked star tracking (**15 hours**)	yes
24 October	ADEOS-2		lost contact	no
-	ACE	EPAM - Low Energy Magnetic Spectrometer	damaged	no
28-30 October	SOHO	CDS and UVCS	manually safed due to elevated proton levels	yes
4 November	SOHO	CDS/GIS	excessive count rates	yes
29 October	DRTS		automatic safe mode	yes, 7 November
29 Oc				yes, 27 hours
28 C				yes
-				yes, but **switched to a redundant system**
-			several occasions	yes
-			and disabled magnetic	yes
-			tion because gyroscopes fline CPU	yes
-			utdowns for 29 hours, manual n	
29 C			off or safed	yes
29 O			off or safed	yes
29 Octo			ed off or safed	yes
29 October	TOMS		spacecraft turned off or safed	yes
29 October	TRMM		spacecraft turned off or safed	yes
-	SIRTF		turned off due to high proton fluxes. **Four days of operations lost.**	yes
-	UARS/HALOE		delayed activation of the instrument	yes

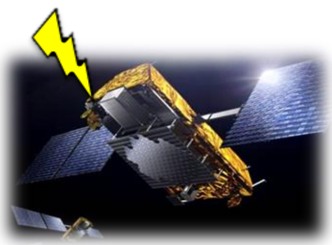
23 satellites impacted,
4 permanent damages
3 loss of functionality

NOAA Technical Memorandum OAR SEC-88

Manage complexity

Increased Technology
&
Systems Complexity

Increased Vulnerability — **Impact** — **Increased Wellness**

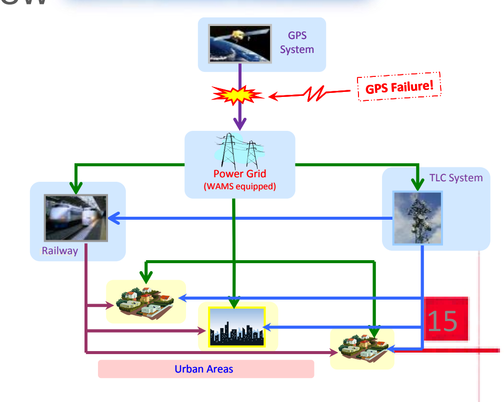


Space infrastructures and services (Communications, positioning, navigation and timing)

Aircraft passengers and crew

Ground Systems:

- power grids
- avionics and ground systems
- radio communication systems



Propagated Impacts

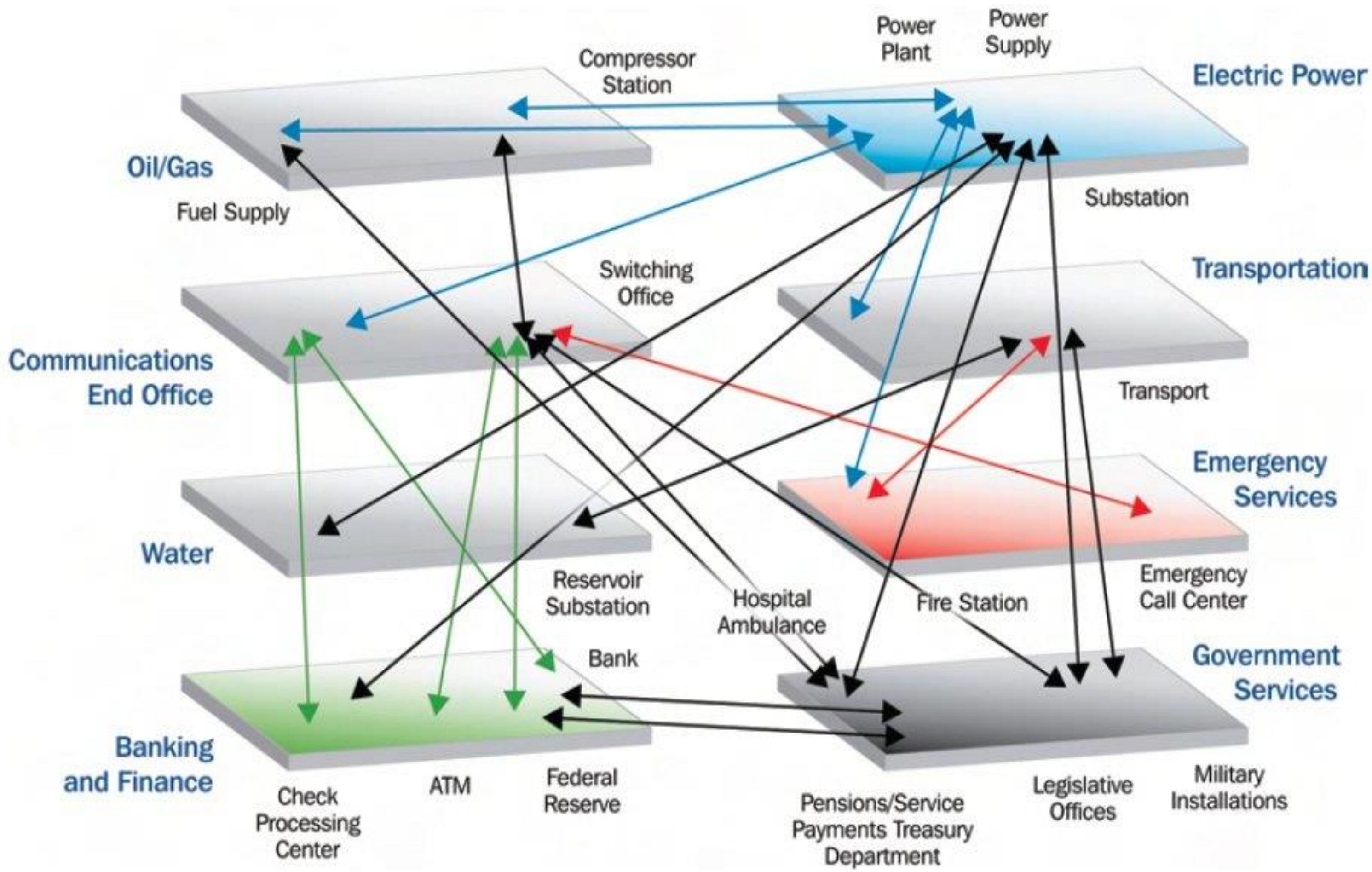


FIGURE 3.1 Connections and interdependencies across the economy. Schematic showing the interconnected infrastructures and their qualitative dependencies and interdependencies. SOURCE: Department of Homeland Security, National Infrastructure Protection Plan, available at http://www.dhs.gov/xprevprot/programs/editorial_0827.shtm.

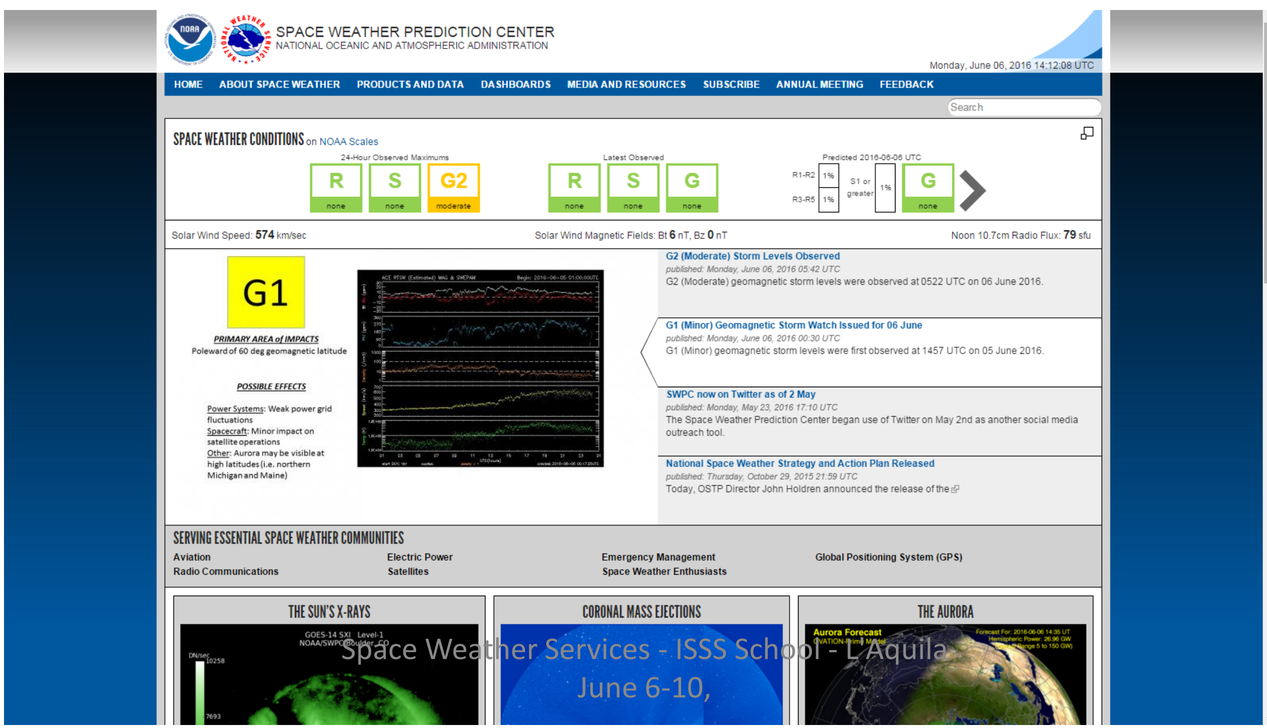
NOAA Space Weather Prediction Centre

The Space Weather Prediction Center is one of the nine National Centers for Environmental Prediction (NCEP) and provides real-time monitoring and forecasting of solar and geophysical events, conducts research in solar-terrestrial physics, and develops techniques for forecasting solar and geophysical disturbances. The SWPC Forecast Center is jointly operated by NOAA and the U.S. Air Force and is the national and world warning center for disturbances that can affect people and equipment working in the space environment.

SWPC works with many national and international partners who contribute data and observations.

NOAA Serving Essential Space Weather Communities

- Aviation
  - U.S. Air Force operational support
  - Commercial airline industry
  - Federal Aviation Administration
- Electric Power
  - U.S. power grid infrastructure
- Emergency Management
- Global Positioning System (GPS)
  - Department of Transportation
- Radio Communications
- Space & Satellites
  - Satellite launch and operations
  - NASA human space flight activities (NASA relies on SWPC data to protect the $1 billion arm on the International Space Station
- Commercial and public users (more than half a million hits per day on SWPC web sites)
- Space Weather Enthusiasts



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NOAA SWPC - Products and Data

SPACE WEATHER PREDICTION CENTER
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Tuesday, June 07, 2016 13:37:14 UTC

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FORECASTS
- 27-Day Outlook of 10.7 cm Radio Flux and Geomagnetic Indices
- 3-Day Forecast
- 3-Day Geomagnetic Forecast
- Forecast Discussion
- Predicted Sunspot Numbers and Radio Flux
- Report and Forecast of Solar and Geophysical Activity
- Solar Cycle Progression
- Space Weather Advisory Outlook
- USAF 45-Day Ap and F10.7cm Flux Forecast
- Weekly Highlights and 27-Day Forecast

REPORTS
- Forecast Verification
- Geoalert - Alerts, Analysis and Forecast Codes
- Geophysical Alert
- Solar and Geophysical Event Reports
- USAF Magnetometer Analysis Report

MODELS
- Aurora - 30 Minute Forecast
- D Region Absorption Predictions (D-RAP)
- Relativistic Electron Forecast Model
- STORM Time Empirical Ionospheric Correction
- U.S. Total Electron Content
- WSA-Enlil Solar Wind Prediction
- Wing Kp

OBSERVATIONS
- ACE Real-Time Solar Wind
- Boulder Magnetometer
- GOES Electron Flux
- GOES Magnetometer
- GOES Proton Flux
- GOES Solar X-ray Imager
- GOES X-ray Flux
- LASCO Coronagraph
- Planetary K-index
- Real Time Solar Wind
- Satellite Environment
- Solar Synoptic Map
- Space Weather Overview
- Station K and A Indices

SUMMARIES
- Solar & Geophysical Activity Summary
- Solar Region Summary
- Summary of Space Weather Observations

ALERTS, WATCHES AND WARNINGS
- Alerts, Watches and Warnings
- Notifications Timeline

EXPERIMENTAL
- Aurora - 3 Day Forecast
- CTIPe Total Electron Content Forecast
- Predicted Solar Wind at Earth
- Solar Wind Transit Time

DATA ACCESS

Communication of the risk: Impact Scale

NOAA Space Weather Scales

Category		Effect	Physical measure	Average Frequency (1 cycle = 11 years)
Scale	Descriptor	Duration of event will influence severity of effects		
Solar Radiation Storms			Flux level of ≥ 10 MeV particles (ions)*	Number of events when flux level was met**
S 5	Extreme	Biological: unavoidable high radiation hazard to astronauts on EVA (extra-vehicular activity); passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk. *** Satellite operations: satellites may be rendered useless, memory impacts can cause loss of control, may cause serious noise in image data, star-trackers may be unable to locate sources; permanent damage to solar panels possible. Other systems: complete blackout of HF (high frequency) communications possible through the polar regions, and position errors make navigation operations extremely difficult.	10^5	Fewer than 1 per cycle
S 4	Severe	Biological: unavoidable rad… high latitudes may be expos… Satellite operations: may ex… problems may cause orienta… Other systems: blackout of… over several days are likely.	10^4	3 per cycle
S 3	Strong	Biological: radiation hazard… aircraft at high latitudes ma… Satellite operations: single-… panel are likely. Other systems: degraded HF…		
S 2	Moderate	Biological: passengers and… risk.*** Satellite operations: infrequ… Other systems: effects on H… possibly affected.		
S1	Minor	Biological: none. Satellite operations: none. Other systems: minor impac…		

* Flux levels are 5 minute averages. Flux in particles·s^{-1}·ster…

** These events can last more than one day.

*** High energy particle (>100 MeV) are a better indicator of…

NOAA Space Weather Scales

			GOES X-ray	Number of events when
Radio Blackouts				
R 5	Extreme	HF Radio: Complete HF (high freque… number of hours. This results in no H… Navigation: Low-frequency navigatio… on the sunlit side of the Earth for man… positioning for several hours on the s…		
R 4	Severe	HF Radio: HF radio communication … contact lost during this time. Navigation: Outages of low-frequenc… hours. Minor disruptions of satellite …		
R 3	Strong	HF Radio: Wide area blackout of HF … of Earth. Navigation: Low-frequency navigatio…		
R 2	Moderate	HF Radio: Limited blackout of HF ra… of minutes. Navigation: Degradation of low-frequ…		
R 1	Minor	HF Radio: Weak or minor degradatio… radio contact. Navigation: Low-frequency navigatio…		

* Flux, measured in the 0.1-0.8 nm range, in W·m^{-2}. Based on this measu…

** Other frequencies may also be affected by these conditions.

NOAA Space Weather Scales

Category		Effect	Physical measure	Average Frequency (1 cycle = 11 years)
Scale	Descriptor	Duration of event will influence severity of effects		
Geomagnetic Storms			Kp values* determined every 3 hours	Number of storm events when Kp level was met; (number of storm days)
G 5	Extreme	Power systems: widespread voltage control problems and protective system problems can occur, some grid systems may experience complete collapse or blackouts. Transformers may experience damage. Spacecraft operations: may experience extensive surface charging, problems with orientation, uplink/downlink and tracking satellites. Other systems: pipeline currents can reach hundreds of amps, HF (high frequency) radio propagation may be impossible in many areas for one to two days, satellite navigation may be degraded for days, low-frequency radio navigation can be out for hours, and aurora has been seen as low as Florida and southern Texas (typically 40° geomagnetic lat.).**	Kp=9	4 per cycle (4 days per cycle)
G 4	Severe	Power systems: possible widespread voltage control problems and some protective systems will mistakenly trip out key assets from the grid. Spacecraft operations: may experience surface charging and tracking problems, corrections may be needed for orientation problems. Other systems: induced pipeline currents affect preventive measures, HF radio propagation sporadic, satellite navigation degraded for hours, low-frequency radio navigation disrupted, and aurora has been seen as low as Alabama and northern California (typically 45° geomagnetic lat.).**	Kp=8	100 per cycle (60 days per cycle)
G 3	Strong	Power systems: voltage corrections may be required, false alarms triggered on some protection devices. Spacecraft operations: surface charging may occur on satellite components, drag may increase on low-Earth-orbit satellites, and corrections may be needed for orientation problems. Other systems: intermittent satellite navigation and low-frequency radio navigation problems may occur, HF radio may be intermittent, and aurora has been seen as low as Illinois and Oregon (typically 50° geomagnetic lat.).**	Kp=7	200 per cycle (130 days per cycle)
G 2	Moderate	Power systems: high-latitude power systems may experience voltage alarms, long-duration storms may cause transformer damage. Spacecraft operations: corrective actions to orientation may be required by ground control; possible changes in drag affect orbit predictions. Other systems: HF radio propagation can fade at higher latitudes, and aurora has been seen as low as New York and Idaho (typically 55° geomagnetic lat.).**	Kp=6	600 per cycle (360 days per cycle)
G 1	Minor	Power systems: weak power grid fluctuations can occur. Spacecraft operations: minor impact on satellite operations possible. Other systems: migratory animals are affected at this and higher levels; aurora is commonly visible at high latitudes (northern Michigan and Maine).**	Kp=5	1700 per cycle (900 days per cycle)

* Based on this measure, but other physical measures are also considered.

** For specific locations around the globe, use geomagnetic latitude to determine likely sightings (see www.swpc.noaa.gov/Aurora)

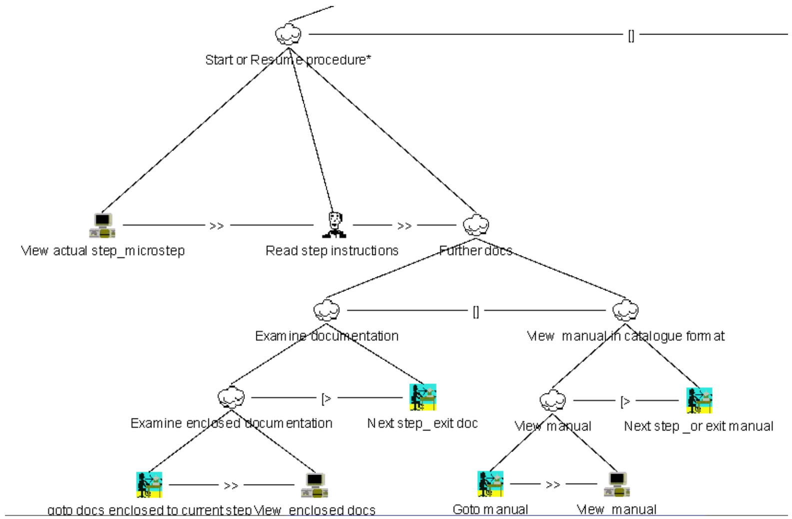
Objective: is to model users and their interaction with complex systems.

The user model will include:

- User's mental attitudes & preferences
- User's environment knowledge
- User's expectations (soft goals)
- User's domain knowledge and objectives related to the knowledge domain

Interaction analysis

- It aims to the formalization and evaluation of the interaction flow between human and machine agents in operating procedures



Task Tree for HCI

Telespazio has been involved in development of a lot of Human Computer Interfaces for Space and Ground applications. They have been designed on the basis of measured usability criteria

The Met Office Space Weather Operations Centre

- The Met Office has been working in collaboration with National Oceanic and Atmospheric Administration (NOAA) since 2011 to build knowledge and capability to forecast space weather in the UK, and at the end of 2013 received £4.6 million funding from the Department for Business, Innovation & Skills (BIS) for an operational Space Weather prediction service.

- MOSWOC was created in October 2014, and it provides the vital information to help build the resilience of UK infrastructure and industries in the face of space weather events, thereby supporting continued economic growth.
- The Met Office is also set to become a member of International Space Environment Services(ISES) - international body for space weather - and will become a designated Regional Warning Centre.

- The Met Office provides operational 24/7 forecasts and warnings of the impacts of space weather on UK services and infrastructure into Government and responder communities, and will continue to develop the level of capability the UK requires.

International Space Evironment Service (ISES)

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The International Space Environment Service (ISES) is a collaborative network of space weather service-providing organizations around the globe. The objective is to improve, to coordinate, and to deliver operational space weather services. ISES is organized and operated for the benefit of the international space weather user community.

ISES currently includes 16 Regional Warning Centers, four Associate Warning Centers, and one Collaborative Expert Center. ISES is a Network Member of the International Council for Science World Data System (ICSU-WDS) and collaborates with the World Meteorological Organization (WMO) and other international organizations.

ISES has been the primary organization engaged in the international coordination of space weather services since 1962. ISES members share data and forecasts and provide space weather services to users in their regions. ISES provides a broad range of services, including: **forecasts, warnings, and alerts of solar, magnetospheric, and ionospheric conditions; space environment data; customer-focused event analyses; and long-range predictions of the solar cycle.**

Members | Space Weather Now

- IPS (Australia)
- KSO (Austria)
- SIDC (Belgium)
- EMBRACE (Brazil)
- CSWFC (Canada)
- SEPC (China)
- SAPC (China)
- IAP (Czech Republic)
- NPL (India)
- NICT (Japan)
- KSWC (Republic of Korea)
- SCiESMEX (Mexico)
- SRC (Poland)
- IAG (Russia)
- SANSA (South Africa)
- LSWC (Sweden)
- MOSWOC (UK)

Services:

- Forecasting for Early Warning:
  - From Earth (solar surface and light observation)
  - From Near-sun probes (Sentinels)
- Analysis and design: Exposure simulation and risk assessment
- …

Candidate End Users:

- Satellite industry (satellite owners and operators)
- Critical Infrastructures directly exposed to space weather and/or satellite service users
- Institutional Users

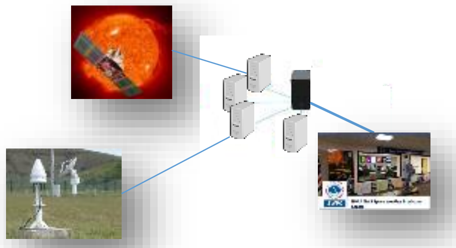
Downstream Countermeasures:

- Space Hardware Shielding,
- Service response (i.e.) :
  - Performance reduction
  - Backup solutions,
  - Scheduled service shut down (i.e. Satellite in stand-by mode)

data are relevant and they can be obtained from different kinds of sources (i.e. space- or ground based sensors, forecasting models, reuse of existing sources). After their acquisition, data shall be handled, compared, processed and stored, in order produce information for alert systems and decision makers.

A data collecting and processing centre is fundamental to properly obtain and route information according to the different end-user needs.

Data processing, based on scientific models, shall drive to nowcasting and forecasting services, in order to be prepared to face space weather **events.**



Telespazio interests and expertise

- Customers / end users Requirement analysis
- System Requirement analysis
- Survey of existing assets
- System Architecture
- Networking
- Data Integration and Exploitation
- Service Center Design and development
- System management & Operations

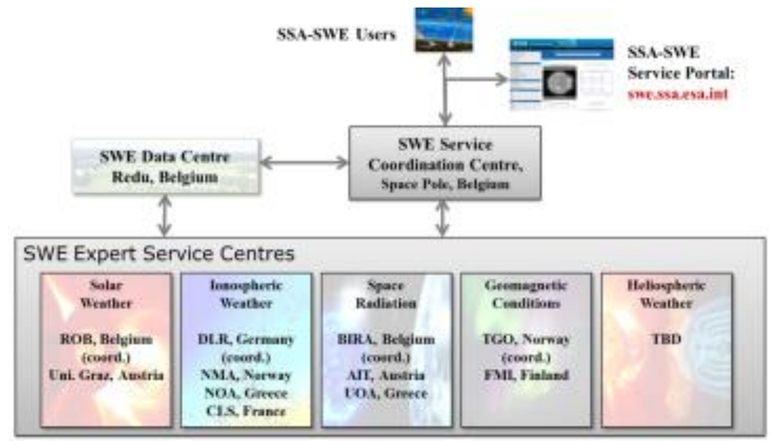
Contribution from the science community

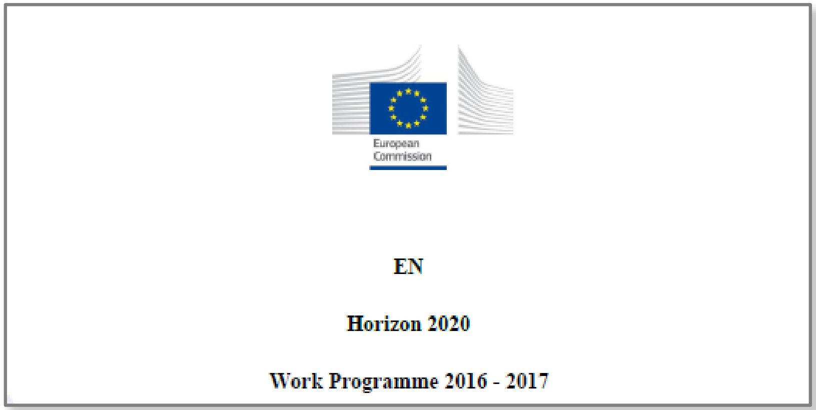
- Sensors
- Data
- Phenomenon Physical Modelling
- Models for Forecasting and Early Warning
- Potential Impact assessment
- ….

- Italy has a full set of expertise and assets to be part in the different domain of SSA European road map and projects

- It implies to consoldiate and to build a national capability based on integration of assets (existing and new), data fusion, simulation, modelling and processing tools

- Specific for SW segment it’s mandatory a qualified participation to future ESA opportunities (SWE mission to the Lagrange point (L1/L4/L5)) and ESA GSTP programme in support




European Commission

EN

Horizon 2020

Work Programme 2016 - 2017

THANK **YOU** FOR YOUR ATTENTION

TELESPAZIO
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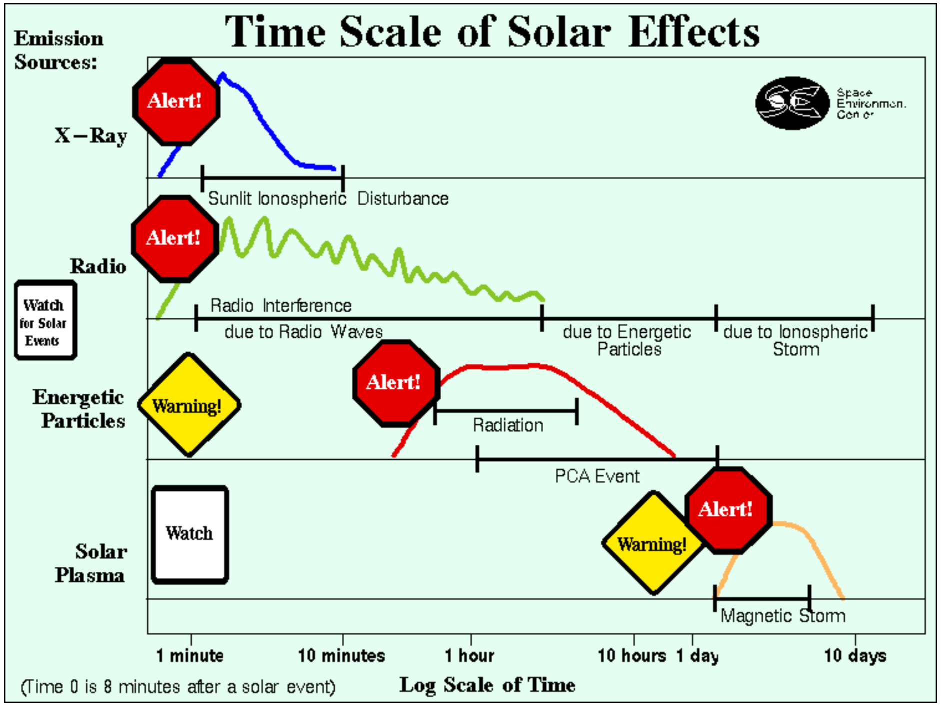
...TO BETTER PREVENT

- The best and most practical way to decrease GIC risks and to avoid problems is developing FORECASTING methods based on observations of Solar winds by satellites at L1 point located at about 1.5 million Km from the Earth towards the Sun.
- Such a forecast would typically provide a time of order of 30 to 60 minutes for taking counter measures against a coming GIC event.



- Most SW forecasting models do not provide adequate information or are accurate enough to be of practical use for operators of space systems
- To be effective tools , warnings need to have spatial and spectral resolution and provide information about the level of severity.
- An important need is for increased communication between research, application and user communities

Communication of the Risk: Impact Scale

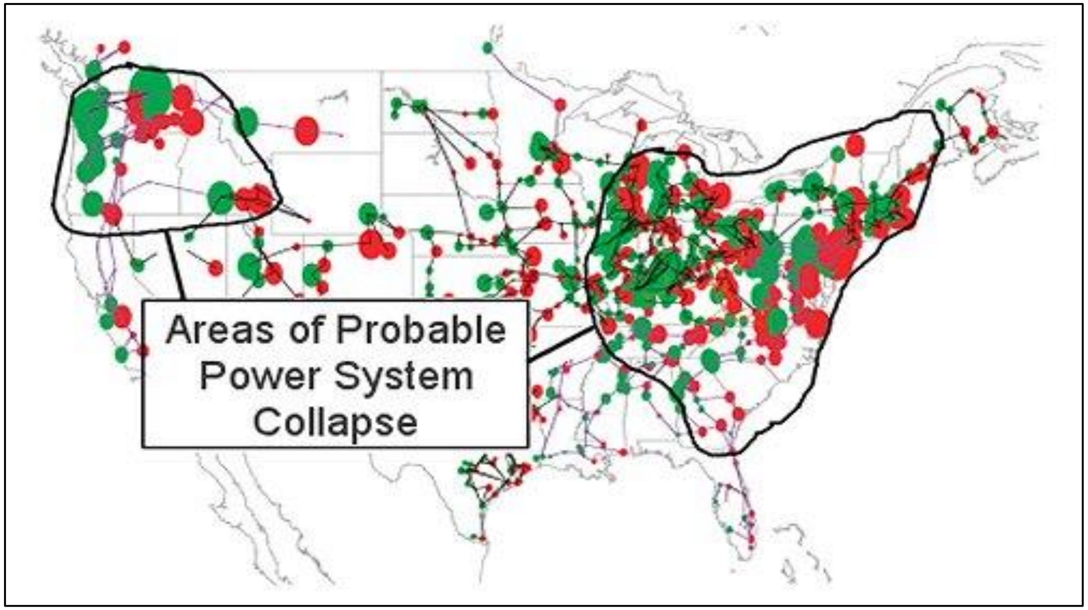
NOAA Space Weather Scales

Category: Scale	Category: Descriptor	Effect Duration of event will influence severity of effects	Physical measure	Average Frequency (1 cycle = 11 years)
Solar Radiation Storms			Flux level of ≥ 10 MeV particles (ions)*	Number of events when flux level was met**
	Extreme	Biological: unavoidable high radiation hazard to astronauts on EVA (extra-vehicular activity); passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk. *** Satellite operations: satellites may be rendered useless, memory impacts can cause loss of control, may cause serious noise in image data, star-trackers may be unable to locate sources; permanent damage to solar panels possible. Other systems: complete blackout of HF (high frequency) communications possible through the polar regions, and position errors make navigation operations extremely difficult.	10^5	Fewer than 1 per cycle
S 4	Severe	problems may cause orientation problems, and solar panel efficiency can be degraded. Other systems: blackout of HF radio communications through the polar regions and increased navigation errors over several days are likely.		
S 3	Strong	Biological: radiation hazard avoidance recommended for astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk.*** Satellite operations: single-event upsets, noise in imaging systems, and slight reduction of efficiency in solar panel are likely. Other systems: degraded HF radio propagation through the polar regions and navigation position errors likely.	10^3	10 per cycle
S 2	Moderate	Biological: passengers and crew in high-flying aircraft at high latitudes may be exposed to elevated radiation risk.*** Satellite operations: infrequent single-event upsets possible. Other systems: effects on HF propagation through the polar regions, and navigation at polar cap locations possibly affected.	10^2	25 per cycle
S1	Minor	Biological: none. Satellite operations: none. Other systems: minor impacts on HF radio in the polar regions.	10	50 per cycle

* Flux levels are 5 minute averages. Flux in particles·s^{-1}·$ster^{-1}$·cm^{-2} Based on this measure, but other physical measures are also considered.
** These events can last more than one day.
*** High energy particle (>100 MeV) are a better indicator of radiation risk to passenger and crews. Pregnant women are particularly susceptible.

Impact On Powergrids

«…transmission systems have developed to become more meshed and more heavily loaded. They now have a greater dependence on reactive compensation equipment such as static variable compensators and mechanically switched capacitors for ensuring robust voltage control”



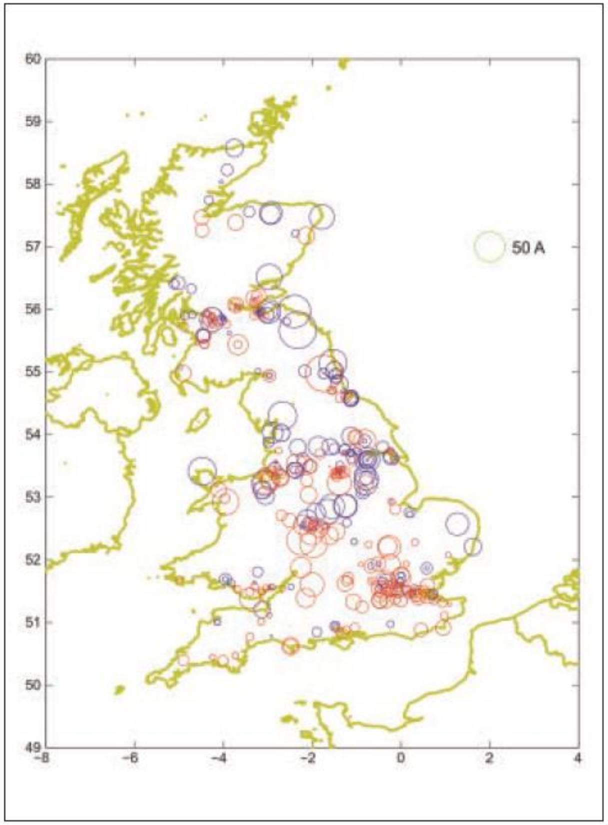


Figure 9: Simulation of GIC flow across a simplified model of the UK 400 and 275 kV transmission system at 21:21 UT on 30 October 2003. A reference 50 Amp spot size is also shown. Red and blue denote GIC flowing to/from the Earth at major transformer substation nodes
© British Geological Survey

Simulation of effects of a geomagnetic storm equivalent to the May 14-15, 1921 event on electrical systems.
Heavy black lines: *areas of system collapse lasting months or years. Impact: 130 million people, cost of $1-2 trillion in the first year after the event.*
Thin black lines *80 000 miles long-distance heavy-hauling 345kV, 500kV and 765kV transmission lines.*
Circles *indicate magnitudes of geomagnetically-induced current (GIC).*
Image credit: John Kappenman, Metatech Corp., The Future: Solutions or Vulnerabilities?, presentation to the space weather workshop, May 23, 2008.

Le supertempeste Magnetiche nella storia

• 1847 – Una “Corrente anomala” viene rilevata nella linea telegrafica Derby-Birmingham. prima rilevazione di un effetto di space weather sulla tecnologia.

• 28-29.08.1859 – servizio telegrafico interrotto a livello mondiale da una supertempesta geomagnetica.

• 1-2.09.1859 – la supertempesta di Carrington-Hodgson è la più intensa degli ultimi 500 anni.

• 16.05.1921 – la “grande tempesta” ha interrotto il servizio telegrafico, causato incendi, bruciato cavi. tempeste simili possono avvenire ogni 100 anni.

• 13.03.1989 – la tempesta geomagnetica mette fuori uso la rete elettrica del Quebec. La rete nel nordest e centro ovest degli usa seguono in pochi secondi.

• 19.10-07.11.2003 – le “tempeste di halloween” creano interruzioni nei GPS, sopprimono le comunicazioni ad onde corte, rendono necessarie procedure di emergenza negli impianti nucleari in Canada e negli USA nord-orientali, distruggono molti trasformatori di potenza in Sudafrica.

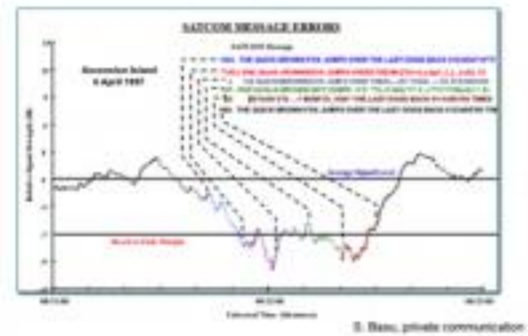
Impact of Space Weather

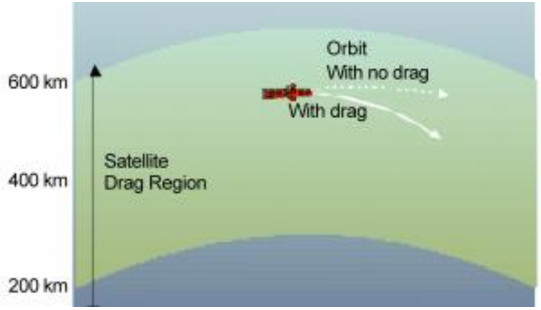
ELECTRIC POWER TRANSMISSION

HF RADIO COMMUNICATIONS

SATELLITE COMMUNICATIONS

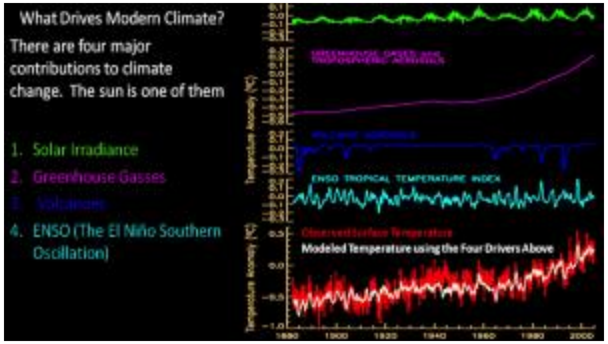
ACTUAL SATCOM MESSAGES





SATELLITE DRAG

SPACE WEATHER AND GPS SYSTEMS



SPACE WEATHER IMPACTS ON CLIMATE

IMPACT ON POWERGRIDS : GIC (GEOMAGNETICALLY INDUCED CURRENTS)

Rapid variations of the geomagnetic field on time scales of a few seconds to a few tens of minutes, caused by space weather, induce an electric field in the surface of the Earth (GIC). This electric field, in turn, induces electrical currents in the power grid and in other grounded conductors. These currents can cause power transmission network instabilities and transformer burn out.

For example, severe space weather caused damage to two UK transformers during the 13 March 1989 storm [Erinmez et al., 2002], the same storm that caused much disruption to the operation of the Hydro-Quebec grid [Bolduc, 2002].

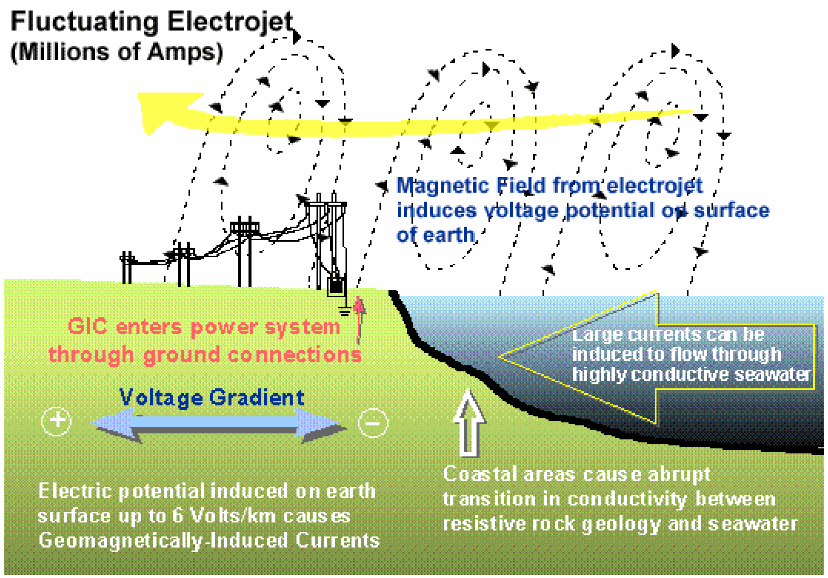


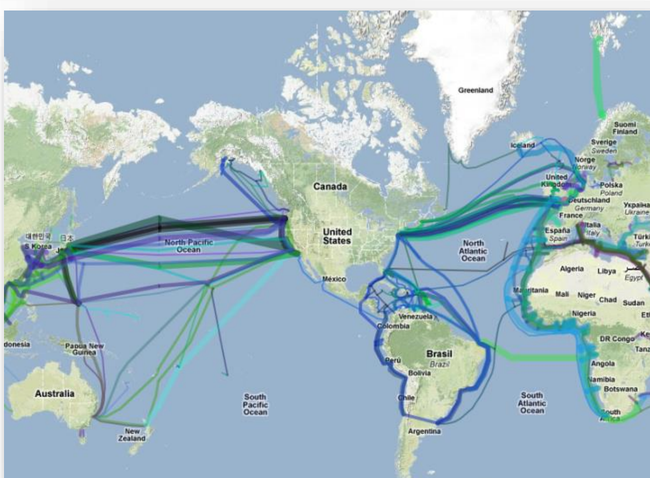
Image from METATECH CORPORATION
(http://www.metatechcorp.com/aps/electro_.html)

IMPACT ON TLC (2/2)

Satellite and terrestrial broadcasting

Satellite broadcasting will be not affected of a Severe space weather event, due to the higher frequencies involved (minor ionosferic effect)

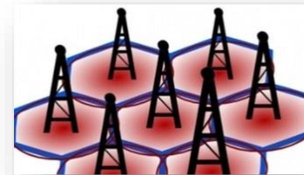
Terrestrial broadcasting would be vulnerable to secondary effects, such as loss of power and GNSS timing



Trans-oceanic communications Cables

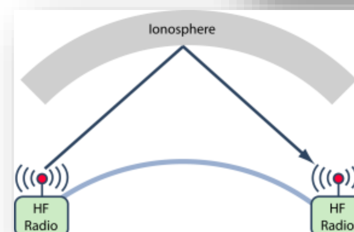
Optical fibre cables are the backbone of the global communications networks. electric power is required to drive optical repeaters distributed along the transoceanic fibres and this is supplied by long conducting wires running alongside the fibre. These wires are vulnerable to GIC effects.

IMPACT ON TLC (1/2)



Terrestrial mobile communications networks:

- Commercial cellular networks not necessarly GNSS dependent
- TETRA emergency communications network is dependent on GPS timing



HF communications and international broadcasting:

- long distance aircraft HF communications are likely to be rendered inoperable for several days during a solar superstorm. Extreme case could induce the closing of the airspace

Mobile satellite communications:

- L-band satellite communications (i.e. Iridium and aircraft satellite communications) might be unavailable, or provide a poor quality of service, for between one and three days owing to scintillation

IMPACT AVIATION DOMAIN (1)

Degradation of radio/satellite communication:

During solar events, some disturbance may happen on the HF and satellite communication. However, line of sight VHF communication may not be impacted.

On board system failure due to radiation:

During a radiation storm, when striking a sensitive node, radiation may induce shortcuts, change of state or burnout in on-board electronic devices. Its impact may vary from unnoticeable to a complete failure of the system.

Radiation doses:

During radiation storms, unusually high levels of ionizing radiation may lead to an excessive radiation dose for air travellers and crew. The dose received is higher at higher altitudes and latitudes.

IMPACT AVIATION DOMAIN (2)

GNSS based aviation operation:

High energy particles and radiation ejected by the sun may cause strong disturbances in the ionosphere affecting GNSS radio signals producing unexpected position and timing errors at user level.

In extreme cases, the GNSS receiver can lose reception of the satellites altogether and the position can no longer be computed. As a side effect, GNSS based surveillance applications can be unavailable.

SBAS or GBAS augmented services, used for approach and landing, are more demanding in terms of accuracy and integrity than En-Route/TMA GNSS based navigation. The safety monitors of those systems are also more sensitive to space weather events, and the unavailability of these services would be more frequent.

- The increase of the social complexity and dependence on technology represents today a relevant risk factor in itself
- One needs to consider not only the impact on the single systems, but the strong interdependency among systems, distinguishing between primary impacts and propagated impacts.
- Most of the added values of offered services consists in the capability to interconnect systems and compose complex services starting from simple building blocks.
- Nevertheless the connections and interdependency represents a vulnerability factor

CRITICAL INFRASTRUCTURES

"Critical Infrastructures are a growing Issue. The security of Critical Infrastructures is one of the challenges for the next years. They are an essential asset for the functioning of a modern society and economy. Originally designed separately, they are now **interconnected** and **interdependent**. Therefore, a single failure could sometimes trigger a "**domino effect**" with unpredictable impacts. Critical Infrastructures work through a high-level of interdependence among each other, composing a very complex super-system. Space assets are not excluded. It is fundamental to consider all possible threats for the whole super-system, to better stop or mitigate direct and propagated effects of these threats." *(SPARC project)*

In EU, Critical infrastructures are grouped in the following categories (2013): ***Energy, Nuclear industry, ICT, Water, Food, Health, Financial, Transportation, Chemical industries, Space, Research Facilities***

Mitigation Strategies

Three approaches to dealing with the space weather risks :

- Understanding the risks through modelling.
- Implementing appropriate engineering or hardware solutions, such as increasing the spares holding and installing GIC blocking devices.
- Implementing forecasting and operational procedures, similar to those for other severe risk events such as terrestrial weather.