
Effects of a Super Storm on Vital Satell
Systems, and other Critical Infrastructu
-
How do we maintain Public Awareness
Improve our Protection?"
TIEMS Oslo Conference 2012: Space Weather and Challenges for Modern Society
22-24 October 2012
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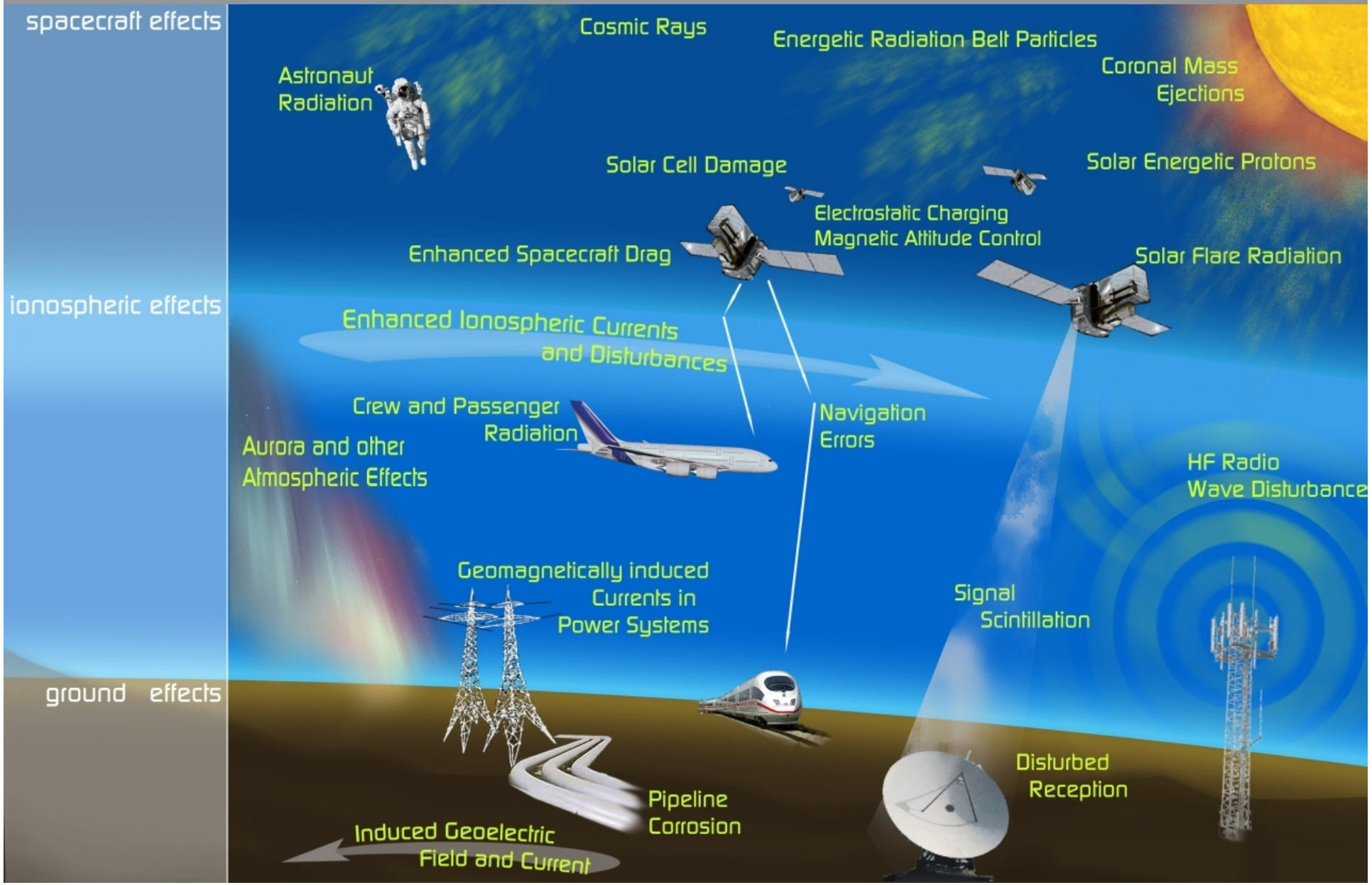
Space Weather Impacts on Infrastructure

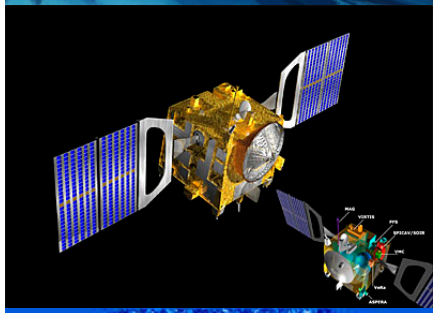


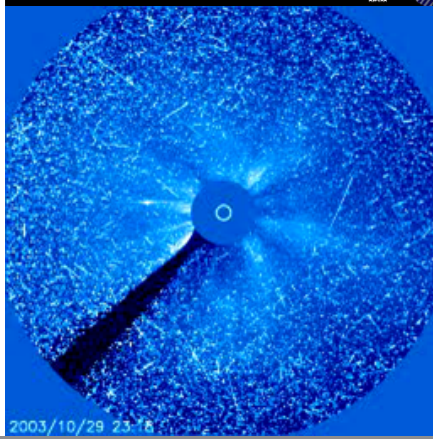
Space weather impacts on satellites

- Space weather can damage a satellite or a spacecraft in many different ways:
  - Degradation of satellite solar panels
  - Charging of the satellite structure causing electrostatic discharges => damage in the structure or electronics
  - Radiation damage to the satellite electronics => Single Event Upsets (SEU) or permanent damage
  - Disturbances in the satellite sensors (telemetry and payload)
  - Disturbances in the satellite operations, especially onboard software patching
- These impacts can happen individually or in combination

Examples of Space weather impacts

- Space weather damage is very difficult to verify
  => correlation of SWE events with anomalies
- Cases of total loss of a mission:
  - INSAT 2D
  - ADEOS-2
- Substantial anomalies
  - Loss of MetOp-A power amplifier
  - Loss of control of Galaxy 15
  - Anik E1 and E2 anomalies with E2 out for 5 months
- Frequent disturbances
  - Venus Express star sensors blurred by solar protons
  - ACE solar wind monitor saturated by solar protons
  - SOHO coronagraph image disturbances
  - SEUs in many other satellite missions

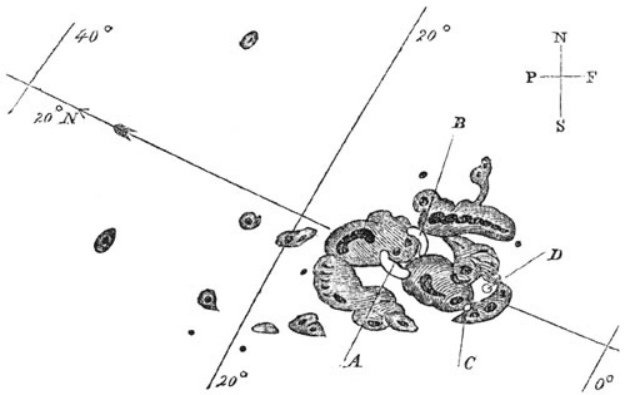


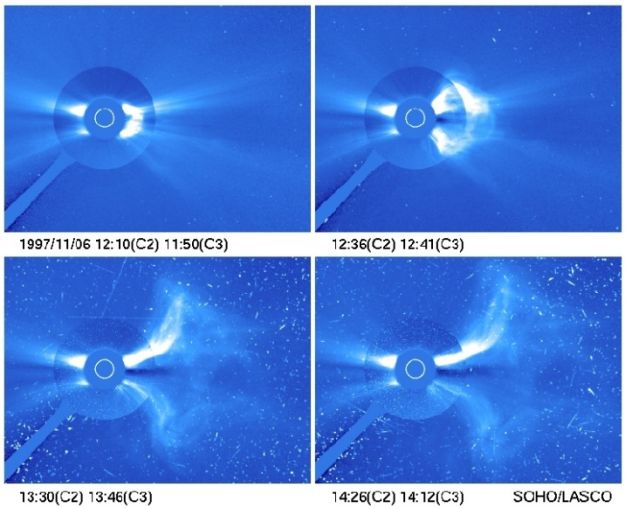


What would be a solar super storm?

- 1859 Carrington event is usually considered as a major solar storm
- Some characteristics of the storm reverse engineered
  - Flare >X10 [Cliver and Svalgaard, 2005], while 4 November 2003 flare was X28
  - Most significant solar proton event (SPE) of the last 450 years [McCracken et al., 2001]
  - Very fast CME (arrival within 17.6 hours)

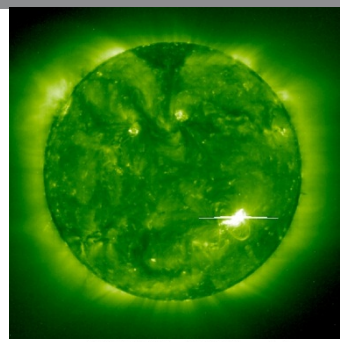
  => a good super storm candidate
- A storm like this would certainly impact satellite systems
- Several statistical assements of the potential impact published [e.g. Odenwald et al., 2005]

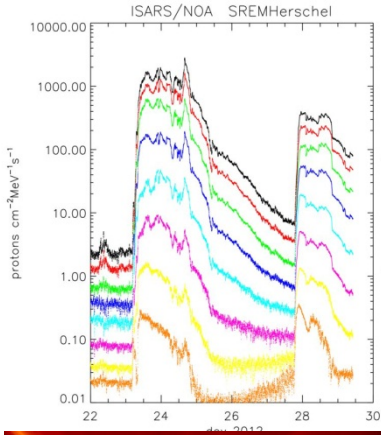


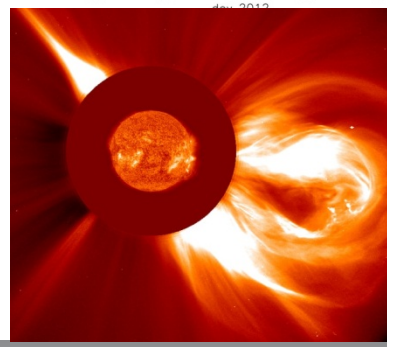


Solar storm: satellite operator perspective

1) Flare
   - We can not forecast flares well => detected by monitoring
   - Impact on Earth space at the time of detection
2) SEP
   - Forecasting an SEP is a challenge
   - Models can provide about 5 hour warning time
   - From detection in L1 the warning time is a few minutes
3) CME
   - Detectable by a coronagraph (if available)
   - Warning time for a fast CME less than 20 hours
   - From verification in L1 the impact will come in 10 minutes
4) Potental extended storm period
   - Repeated flares, SPEs and CMEs <=> 2003 Halloween storm

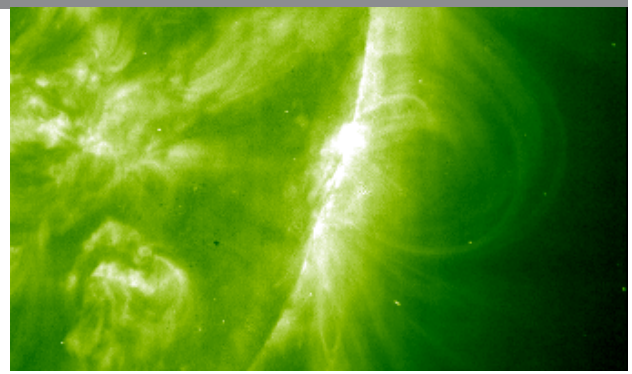






Spacecraft impacts of a solar flare

- Direct impact of a flare on space systems is limited
  - ➢ Solar cell degradation beyond normal levels
    => can push older satellites to EoL
  - ➢ X-ray or (E)UV sensitive sensors can be damaged
  - ➢ Increased atmospheric drag impacts on LEO missions
- Ionospheric disturbances can make space systems temporarily non-accessible
  => especially an issue for repeated flares
  => main impact on dayside at low-mid latitudes
  => impact of a single flare disappears in 2-3 hours



Empirical scintillation index (~1000 GPS stations) – 29 Oct.2003 – 17:00

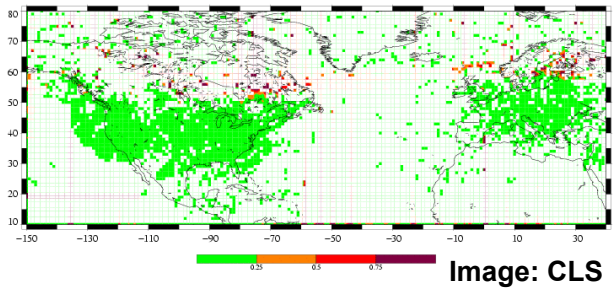
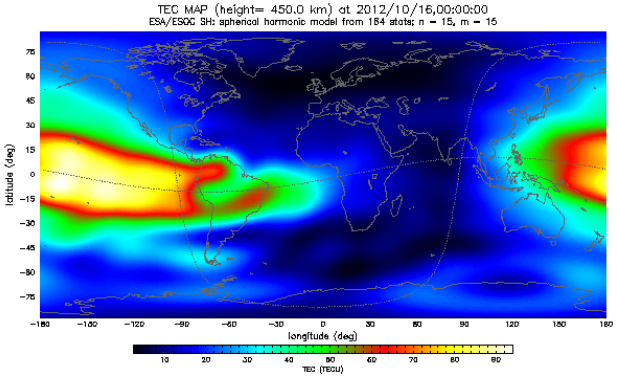
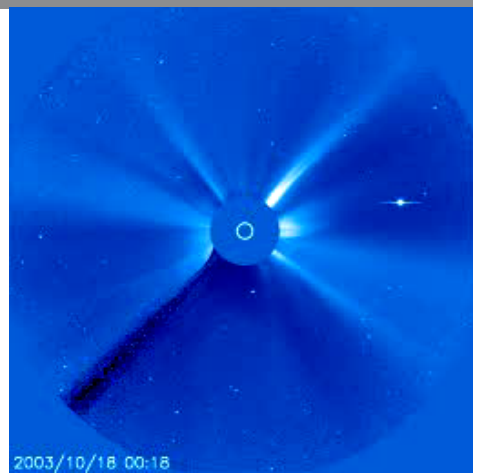


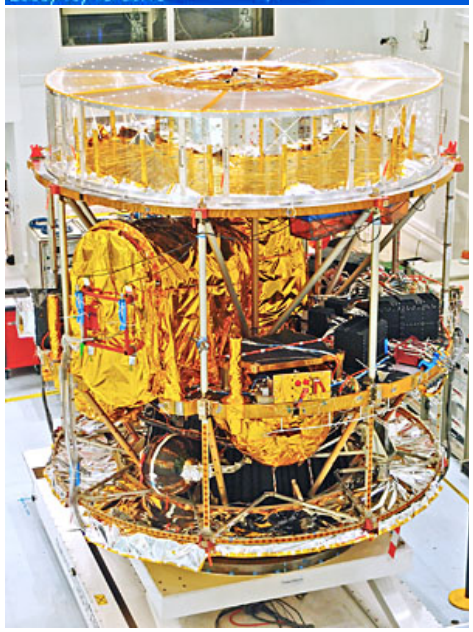
Image: CLS



SEP event impacts on spacecraft

- Damage predominantly by high energy protons
  => GEO and interplanetary space most vulnerable
- Small SEP events interfere with satellite sensors
  => additional maintenance due SEUs,
  => potential safe modes
  => risk of loss of control of the spacecraft
- Major SEP events can cause permanend damage and a loss of a mission
  - Increase of the frequency of SEUs to non-maintenable levels
  - Solar cell degradation comparable to 1 year with single event
  - Radiation damage to electronics and semiconductors also due to secondary particles inside the satellite
  - SEPs with very hard spectrum can also impact MEO and LEO
- Increased risk when combined with flares and CMES



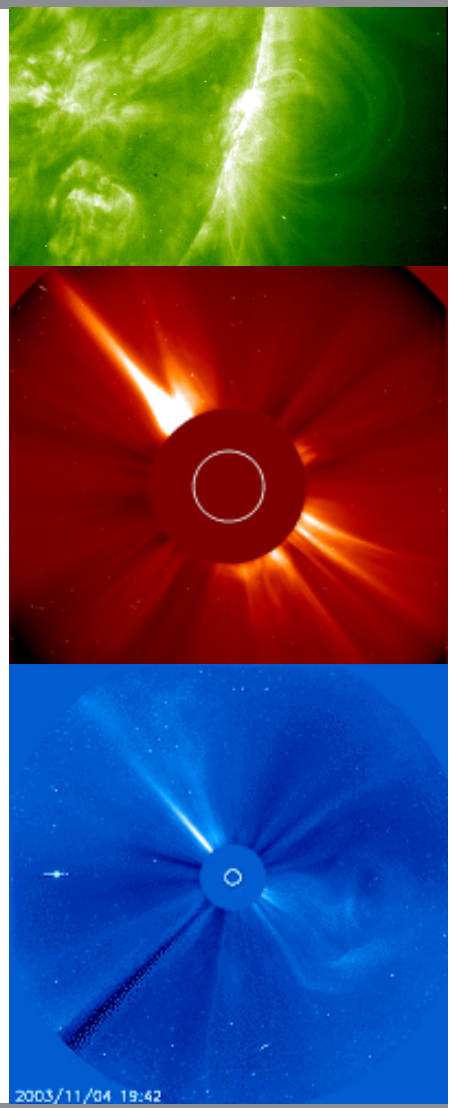


Impacts from a fast CME

- Two impacts in space:
  - Energetic electrons in GEO and LEO
  - Increased atmospheric drag in LEO
- Energetic (killer) electrons
  - SEUs, logic errors, data corruption, phantom commands, ...
  - Charging of the spacecraft materials => risk of electrostatic discharges
- Combined impact of SEP and CME

  => multiple mission critical anomalies/satellite/day

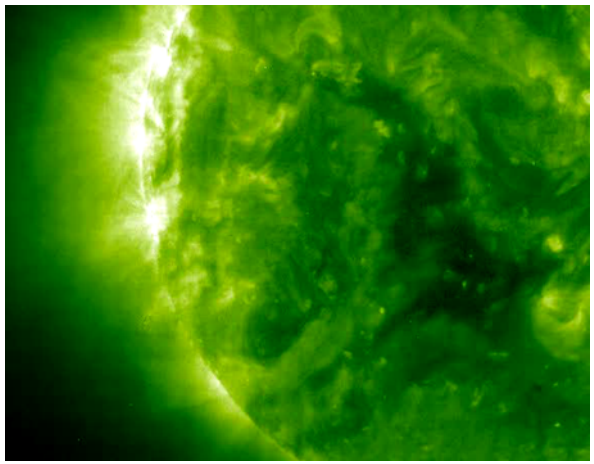
  => challenging battle for operators
- Orbit decay
  - impacts on orbits below 600 - 700 km
  - satellites below 300 km could risk an imminent re-entry

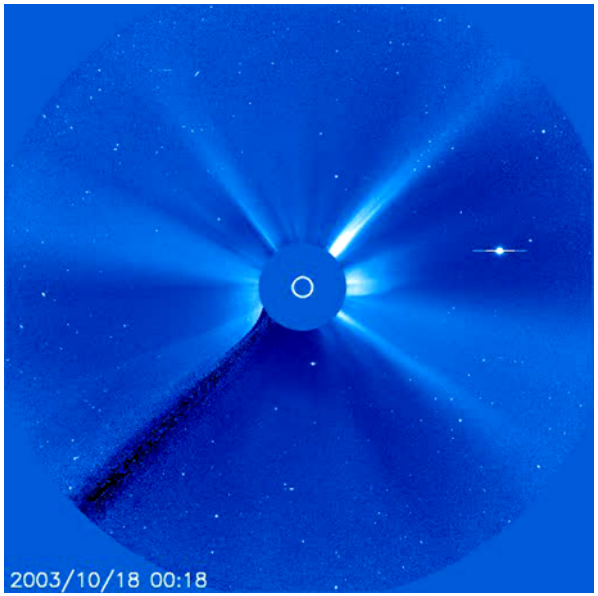


What if there is more than one event?

- Each individual element of a major storm is dangerous
- Combination of impacts including ionospheric disturbances make satellite operations and recovery very challengin
- Halloween storm 19 Oct – 5 Nov 2003
  - 18 X-ray events: M5.0 – X28.0
  - 18 radio blackout events: R1 – R5
  - 5 CMEs with geoimpacts: Kp 6 – 9
  - 5 > 10 MeV proton events

  => approaching a super storm
- Continuing disturbances will cause
  - accumulated damage e.g. on solar arrays
  - increasing risk of permanent radiation damage
  - complications in the satellite recovery
  - secondary effects on satellite depending ground systems



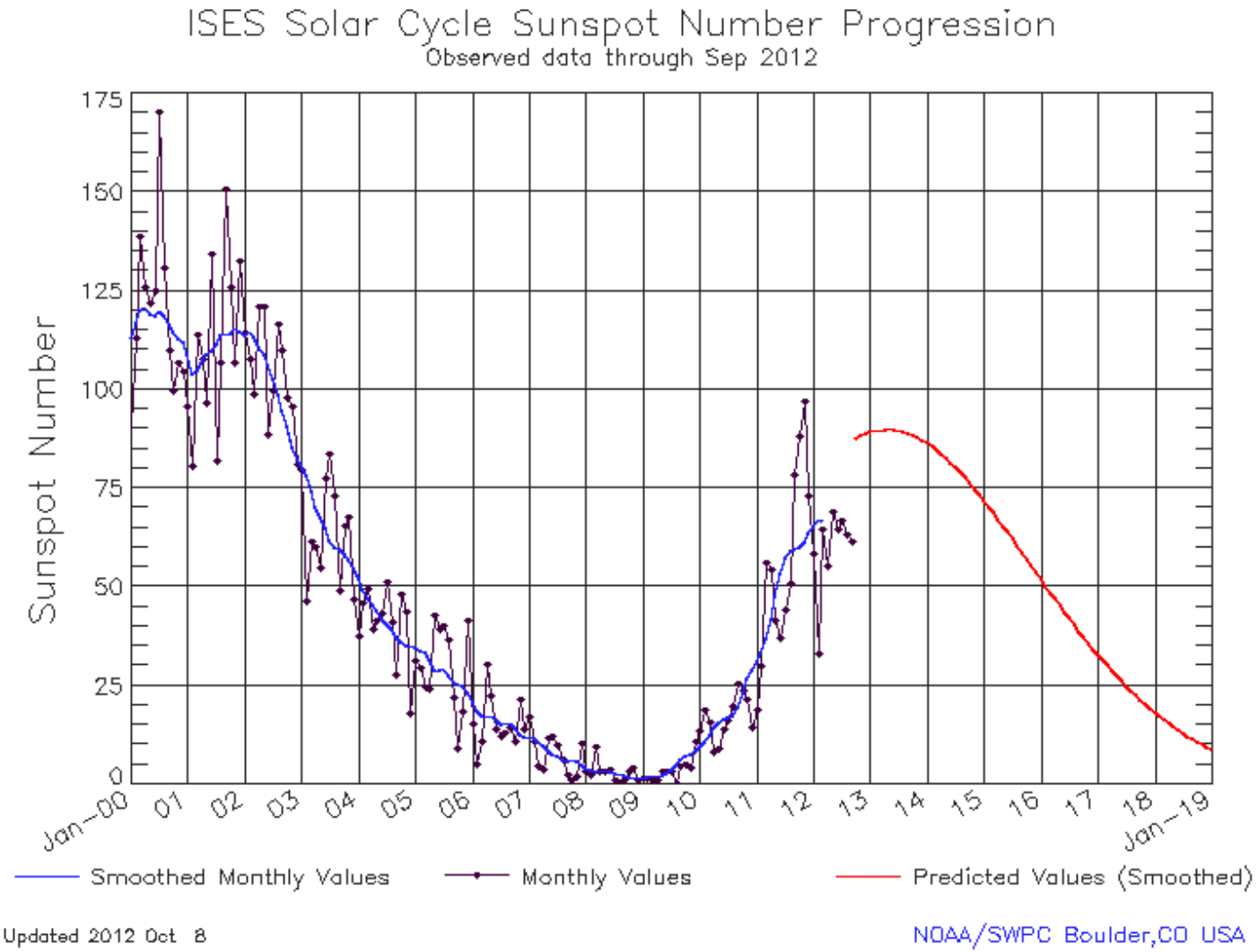


Satellite impacts during Halloween storm

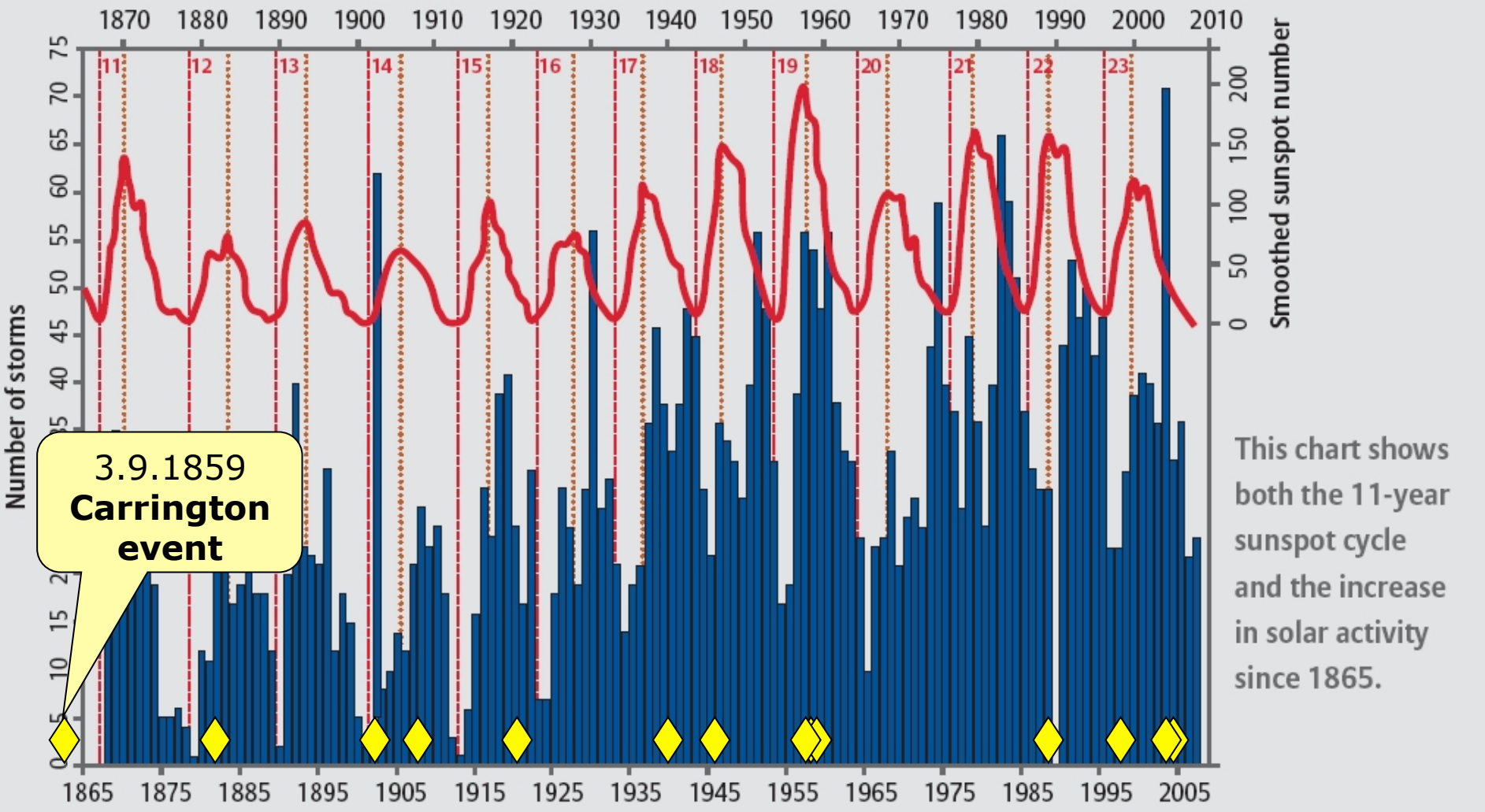
- Mars Odyssey: Safe mode during radiation storm. Memory error and loss of MARIE instrument
- Stardust: Safe mode due to read errors
- SMART-1: Automatic shutdown due to high radiation levels
- Mars Explorer Rover: “Sun Idle” mode due to excessive star tracker error
- Mars Express: Gyroscope stabilization due to blinded star tracker
- ADEOS-2: Satellite lost
- ACE: EPAM instrument permanently damaged
- SOHO: Instrument in safe mode, CDS/GIS anomalies
- CHIPS: Computer offline and contact lost for 18 hours
- DMSP F16: SSIES sensor lost data twice, microware sounder damaged
- GOES-9, 10 and 12: High bit error rates (9,10) and magnetic torguers disabled (12)
- Inmarsat: two satellites had momentum wheel anomalies, one had CPU offline
- More anomalies: TV and Pay Radio satellites, US DoD satellite operatons, ...

[Source: NOAA Technical Memorandum OAR SEC-88]

Where are we in the solar cycle now?



Major Geomagnetic Events since 1865



Source: British Geological Survey

Why are we concerned now?

- Space weather has not become more dangerous that it has been in the past => not a direct danger to any form of life on Earth
- However, our infrastructure has become more sophisticated and more dependent on space based systems
  - Satellite telecommunication
  - Earth observation
  - Satellite navigation including a global time reference
  - Ground based system depending on satellite links
- A major solar storm could
  - disable temporarily a large number of satellites
  - damage permanently or push to EoL up to 80 satellites due to ACS or EPS failures [Odenwald et al., 2005]

  => recovery would take from days (recovery of disabled satellites) to years (replacements) and cost several billions of Euros

What can we do to mitigate the risks

- Space weather monitoring
  - Right information to right people at the right time
  - Reliable and timely warnings and alerts
  - Databases and tools for anomaly analysis and design of future space systems
- Space weather forecasting
  - Scientific challenge
- Maintaining Awareness
  - Awareness should not follow the solar cycle
  - Both operational actors and public
- Analysis of the risk for new infrastructure
  - New systems are more efficient, but sometimes increasingly sensitive to disturbances
- Long term planning to maintain capability and assets
  - Replacement of aging assets with sufficient overlaps – especially in space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THANK YOU FOR YOUR ATTENTION
European Space Agency