SPACE WEATHER INTRODUCTORY COURSE

SWIC

Collaboration of

Solar-Terrestrial Centre of Excellence

Koninklijke luchtmacht

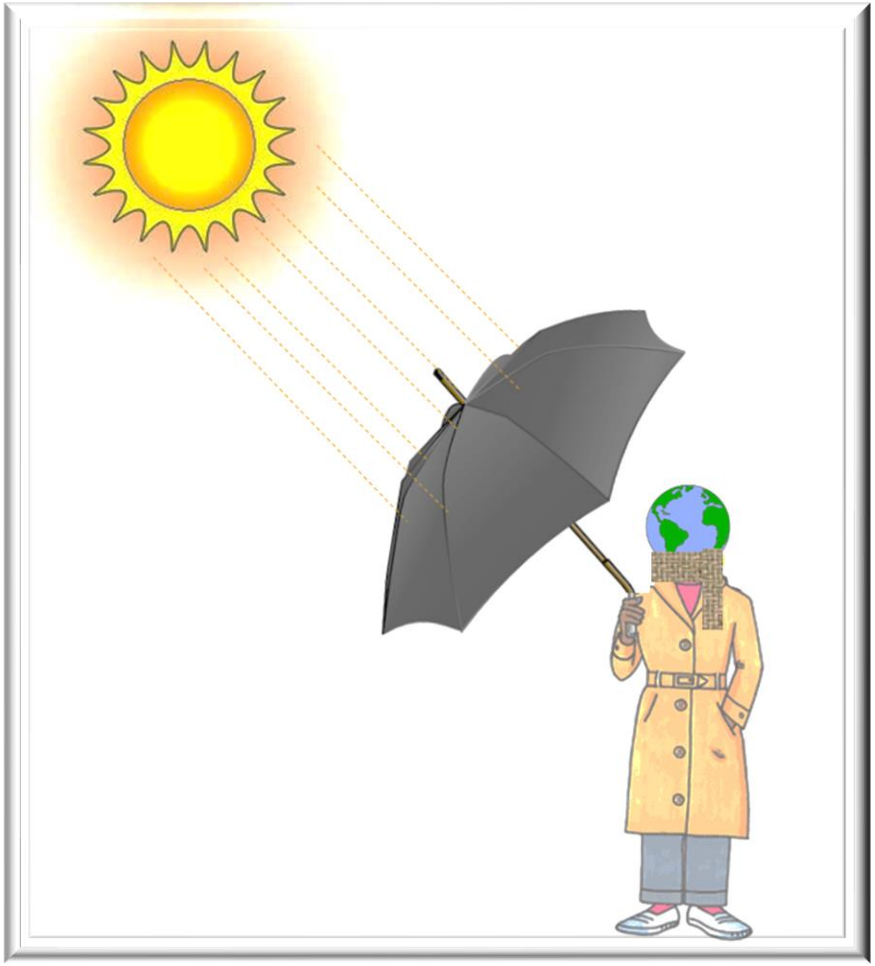
Koninklijk Nederlands
Meteorologisch Instituut
Ministerie van Infrastructuur en Milieu

Space weather effects

Jan Janssens

Space Weather effects (SWx effects)

- ***Introduction***
- *SWx effects from*
  - *Solar flares*
  - *Proton events*
  - *ICMEs*
  - *Coronal holes*



Space Weather (SWx)

- Space weather refers to the environmental conditions in Earth's magnetosphere, ionosphere and thermosphere due to the Sun and the solar wind that can influence the functioning and reliability of spaceborne and ground-based systems and services or endanger property or human health.

NSWP

- Space Weather is the physical and phenomenological state of natural space environments. The associated discipline aims, through observation, monitoring, analysis and modelling, at understanding and predicting the state of the Sun, the interplanetary and planetary environments, and the solar and non-solar driven perturbations that affect them, and also at forecasting and nowcasting the potential impacts on biological and technological systems.

ESA, COST Action 724

NSWP: National Space Weather Program ; ESA: European Space Agency ; COST: (European) COoperation in Science & Technology

Drivers of disturbed space weather

Solar eruptions

Magnetic Reconnection

Radiation

Particles

Solar corona

Solar wind

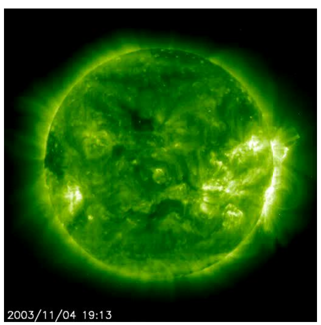
Particles

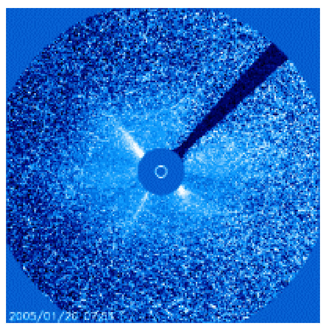
Solar flares

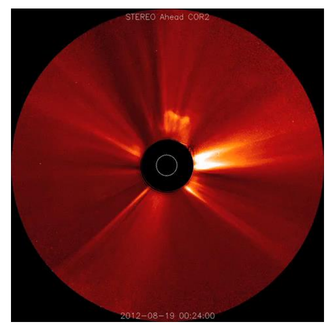
Proton events

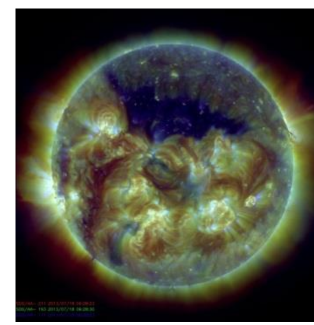
Coronal Mass Ejections

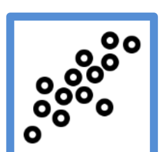
Coronal Hole

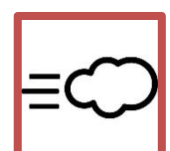






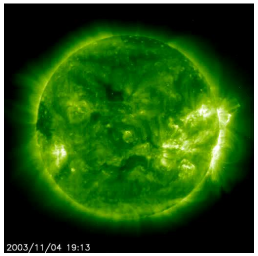
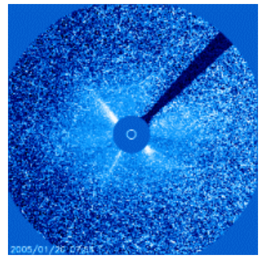
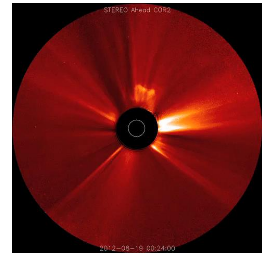
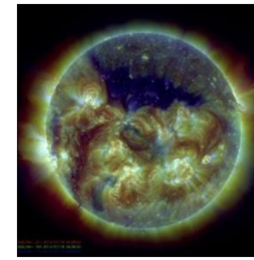






Disturbed Space weather

Causes

Solar flares	Proton events	Coronal Mass Ejections	Coronal Holes
			

	Solar flares	Proton events	Coronal Mass Ejections	Coronal Holes
Arrival	Immediately (8')	15 min to a few hours	20 to 72+ hours	2 to 4 days
NOAA scales	R1 (minor) => R5 (extreme)	S1 (minor) => S5 (extreme)	G1 (minor) => G5 (extreme)	
Parameter	M1 => $\geq$ X20	pfu (>10MeV): 10 => 10^5	Kp = 5 => Kp = 9	
Duration	Minutes to hours	Hours to days	Days	
Protection	Earth's atmosphere	Earth's magnetic field	Earth's magnetic field	

Effects

Radio communications	Satellites	Satellites	
Radar interference	Astronauts & Airplanes	Aurora	
	Communication/Navigation	Communication/Navigation	
	Ozone	Electrical Currents (GIC)	

1 pfu = 1 proton / cm^2 s sr

Space Weather effects (SWx effects)

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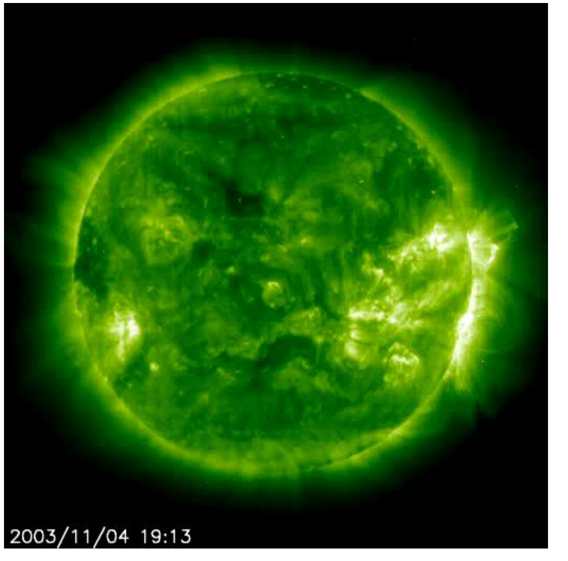
Solar flares



Effects from solar flares

Scale	Description	Effect	Physical measure	Average Frequency (1 cycle = 11 years)
R 5	Extreme	**HF Radio:** Complete HF (high frequency) radio blackout on the entire sunlit side of the Earth lasting for a number of hours. This results in no HF radio contact with mariners and en route aviators in this sector. **Navigation:** Low-frequency navigation signals used by maritime and general aviation systems experience outages on the sunlit side of the Earth for many hours, causing loss in positioning. Increased satellite navigation errors in positioning for several hours on the sunlit side of Earth, which may spread into the night side.	X20 (2×10^{-3})	Less than 1 per cycle
R 4	Severe	**HF Radio:** HF radio communication blackout on most of the sunlit side of Earth for one to two hours. HF radio contact lost during this time. **Navigation:** Outages of low-frequency navigation signals cause increased error in positioning for one to two hours. Minor disruptions of satellite navigation possible on the sunlit side of Earth.	X10 (10^{-3})	8 per cycle (8 days per cycle)
R 3	Strong	**HF Radio:** Wide area blackout of HF radio communication, loss of radio contact for about an hour on sunlit side of Earth. **Navigation:** Low-frequency navigation signals degraded for about an hour.	X1 (10^{-4})	175 per cycle (140 days per cycle)
R 2	Moderate	**HF Radio:** Limited blackout of HF radio communication on sunlit side, loss of radio contact for tens of minutes. **Navigation:** Degradation of low-frequency navigation signals for tens of minutes.	M5 (5×10^{-5})	350 per cycle (300 days per cycle)
R 1	Minor	**HF Radio:** Weak or minor degradation of HF radio communication on sunlit side, occasional loss of radio contact. **Navigation:** Low-frequency navigation signals degraded for brief intervals.	M1 (10^{-5})	2000 per cycle (950 days per cycle)

Effects from solar flares

- From EUV & X-ray radiation
  - Solar flare effect ("magnetic crochet")
    - => Effects from ICMEs
  - Shortwave fadeout ("Radio Blackout")
    - => PECASUS
- From radio emission
  - GNSS disturbances
  - Radar disturbances

EUV: Extreme Ultraviolet ; GNSS: Global Navigation Satellite Systems ; VLF: Very Low frequency ; MF/HF: Medium/High Frequency
PECASUS: Pan-European Consortium for Aviation Space weather User Services

Effects from solar flares

- GNSS disturbance

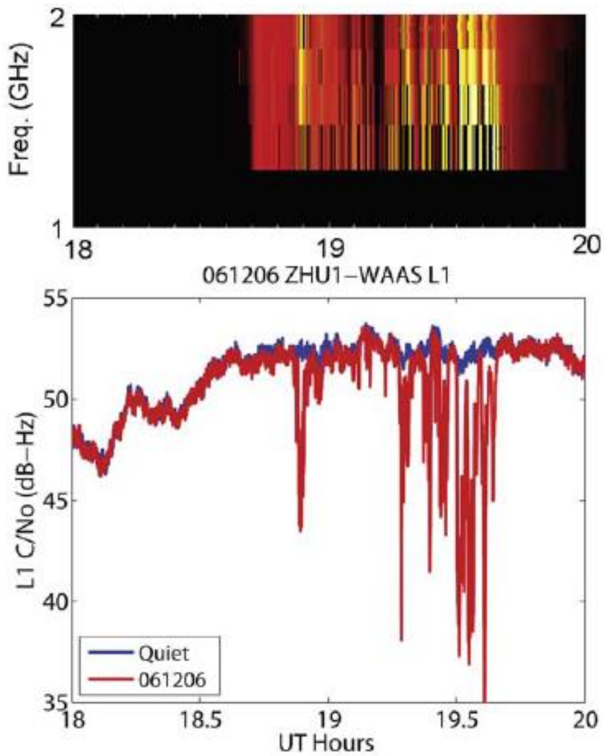


Figure 2. Response of a GPS receiver to the solar radio burst on 6 December 2006. The red line corresponds to C/N_0 on 6 December 2006, and the blue line corresponds to the previous sidereal day.

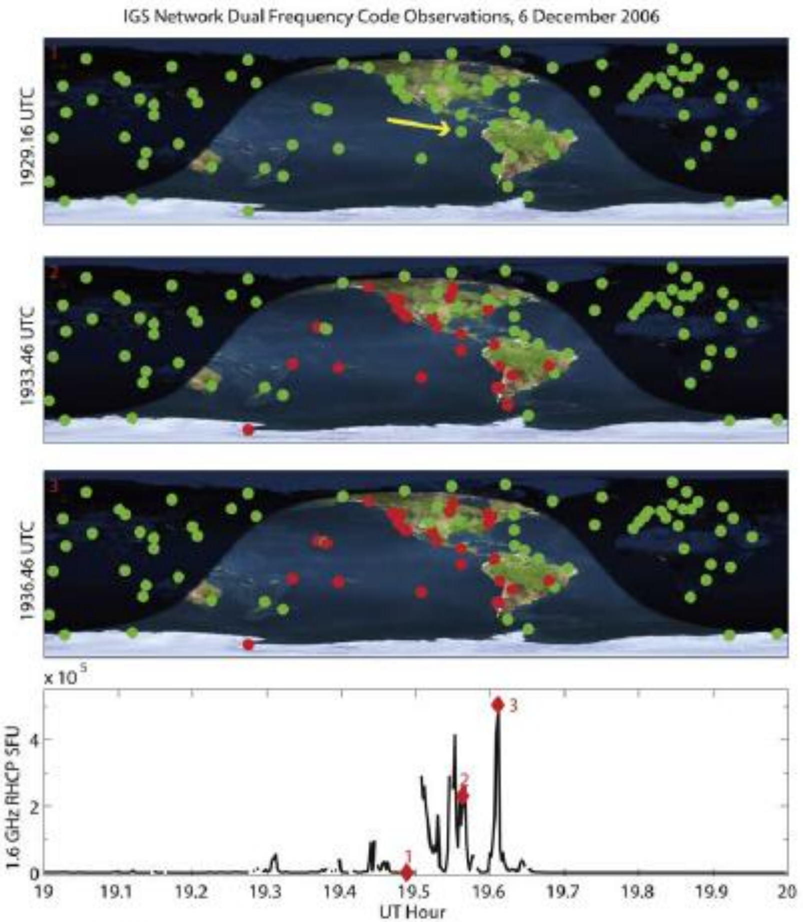
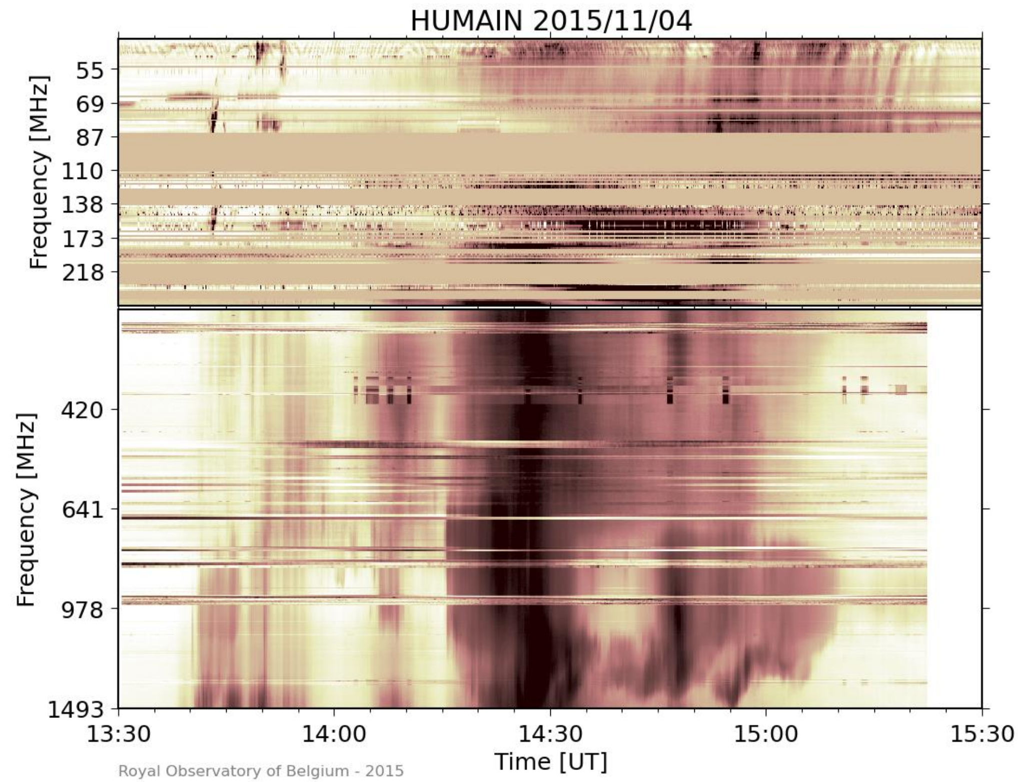
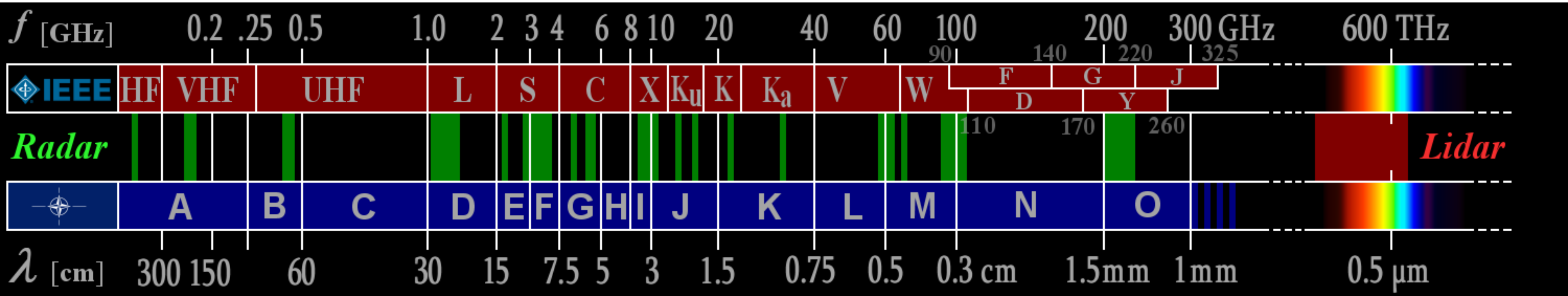


Figure 6. Receivers in the Global GPS Network that were analyzed during the solar radio burst. Green indicates the normal number of satellites being tracked. (fourth panel) During the burst (power at 1.6 GHz), several sunlit receivers tracked fewer than the four satellites needed for a full positioning solution (marked in red). (Image of Earth from the The Living Earth, 1996 and is used here by permission of the publisher. Day/night overlay created using Earth Viewer by J. Walker.)

Effects from solar flares

- Radar disturbance
  - 4 November 2015
    - M3 flare paralyzes Swedish air traffic
  - 23 May 1967
    - BMEWS disturbed
  - Seems to require a set of special conditions





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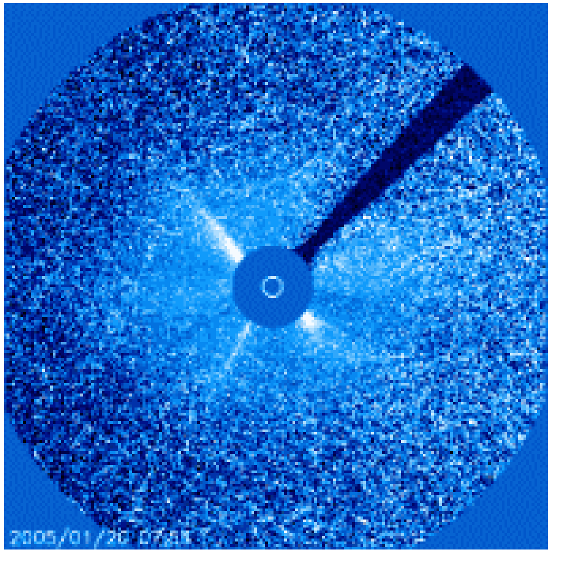
Proton events



Effects from proton events

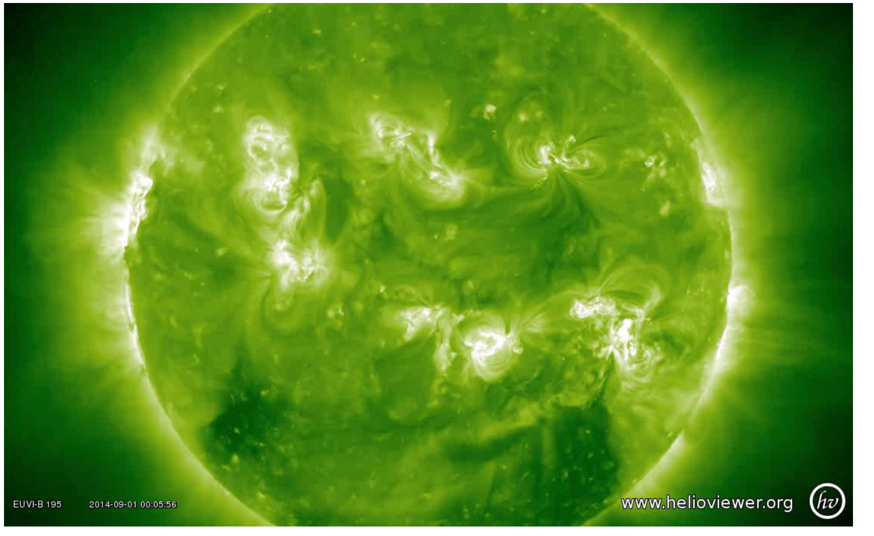
Scale	Description	Effect	Physical measure (Flux level of >= 10 MeV particles)	Average Frequency (1 cycle = 11 years)
S 5	Extreme	**Biological:** Unavoidable high radiation hazard to astronauts on EVA (extra-vehicular activity); passengers and crew in high-flying aircraft at high latitudes may be exposed 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 radiation hazard to astronauts on EVA; passengers and crew in high-flying aircraft at high latitudes may be exposed to radiation risk. **Satellite operations:** May experience memory device problems and noise on imaging systems; star-tracker 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.	10^4	3 per cycle
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:** Small effects on HF propagation through the polar regions and navigation at polar cap locations possibly affected.	10^2	25 per cycle
S 1	Minor	**Biological:** None. **Satellite operations:** None. **Other systems:** Minor impacts on HF radio in the polar regions.	10	50 per cycle

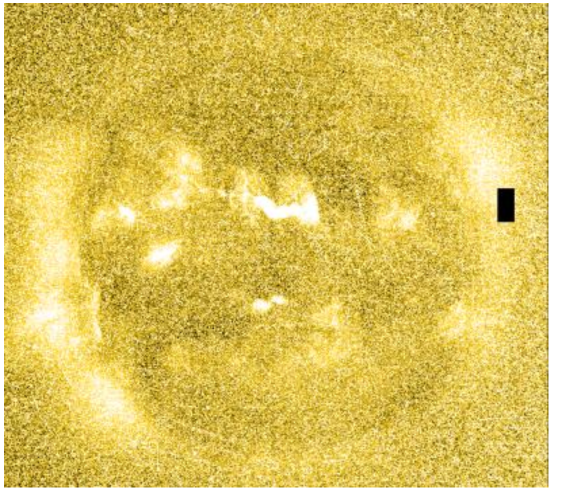
Effects from proton events

- Polar Cap Absorption (PCA)
  - => PECASUS
- Radiation
  - Astronauts, Polar flights
    - => PECASUS
- Satellites
  - Star trackers
  - Single Event Effects (SEE)
  - Solar arrays
- Ground Level Enhancement (GLE)

Effects from proton events

- Satellites
  - Star trackers
    - Spacecraft orientation
    - Photonics noise
      - Proton « impacts »
        - » True stars?
      - Misorientation
        - » Solar panels
          - No energy
        - » Loss sun-lock
      - Data loss
        - » Gravity Probe-B





Effects from proton events

- Satellites
  - Single Event Effect (SEE)
    - Direct hit of an electronic component by an energetic particle resulting in an anomaly
    - Several variations
      - SEU (bit flip), SEL, SEB,…
    - Sources
      - Galactic Cosmic Rays (GCR)
        - » [DSCOVR]
      - Solar proton storms
      - Radiation belts

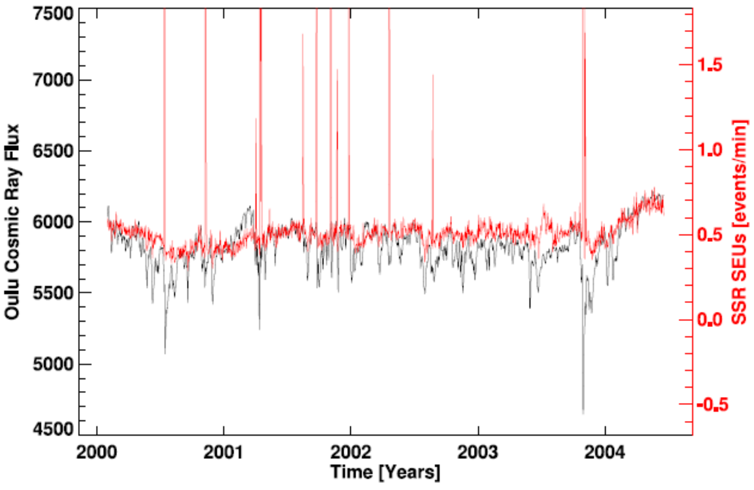
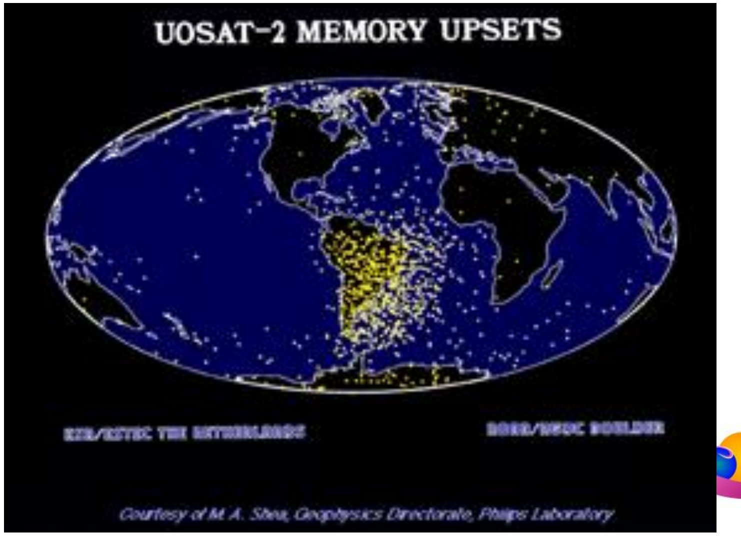


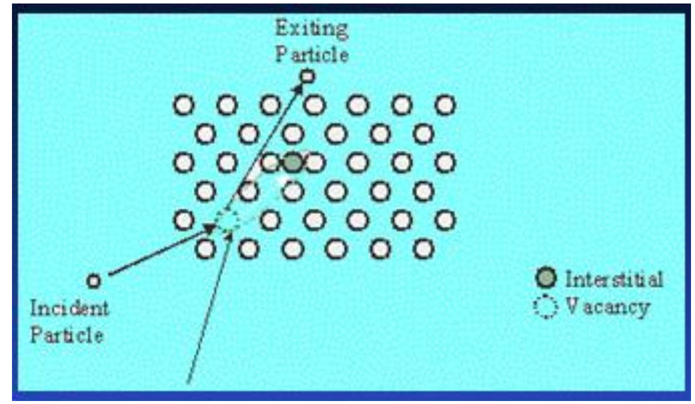
Figure 3: Subset of the data in Fig. 1 during solar maximum. The plot shows a dozen sharp spikes on top of the solar-cycle-modulated background of SSR SEUs triggered by cosmic ray hits. These spikes are caused by isolated strong SEP events. Most of them coincide with a CRF down spike.

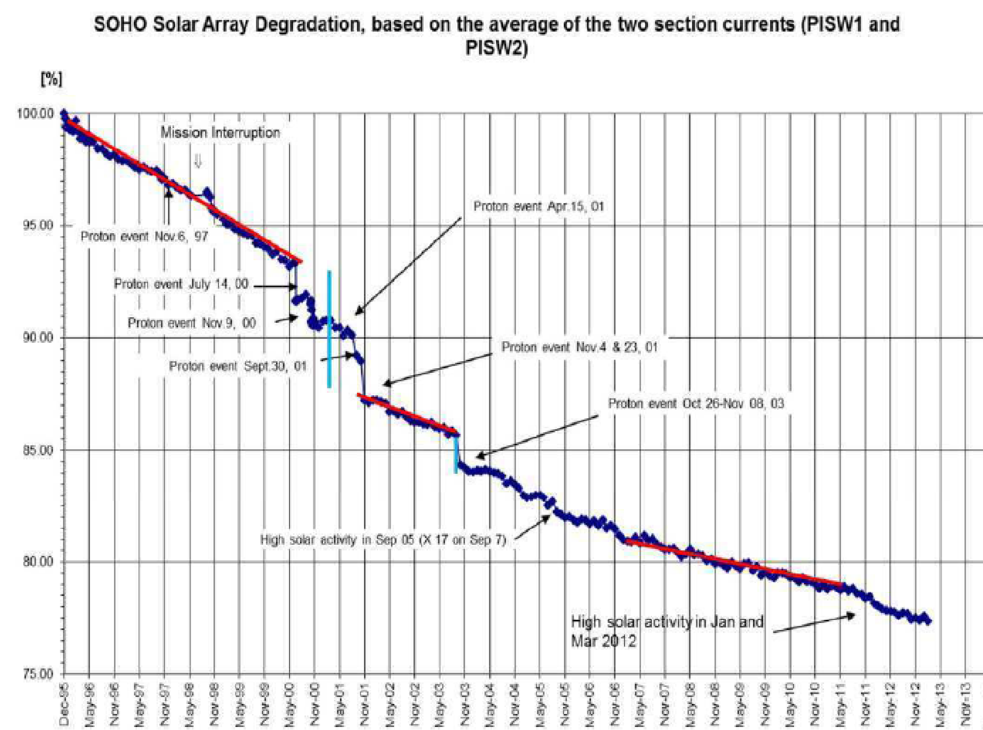


SEU: Single Event Upset
SEL: Single Event Latchup
SEB: Single Event Burnout
DSCOVR: Deep Space Climate Observatory

Effects from proton events

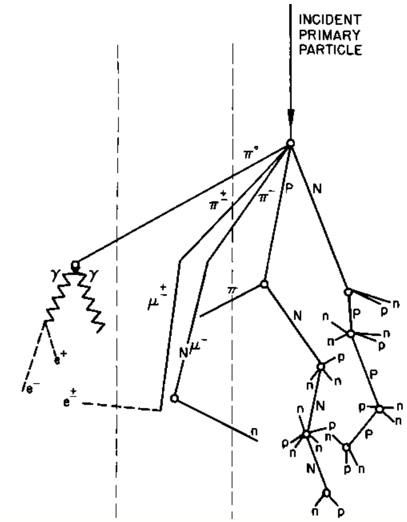
- Satellites
  - Solar Arrays
    - Displacement damage
    - Reduces efficiency in electricity production
    - Several % loss from one proton event is possible
      - 2% loss during Bastille Day event (14 July 00)
      - 5% loss during extreme 4 August 1972 event
  - Overall aging process of satellite and its instruments

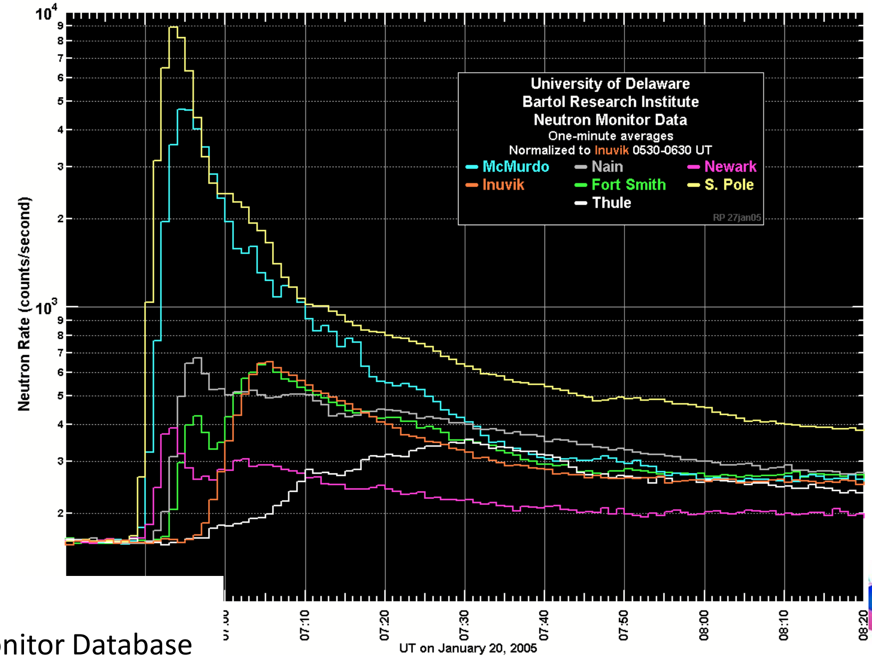




Effects from proton events

- Ground Level Enhancement (GLE)
  - Sharp increase of #neutrons at ground
  - Main source
    - Strong SEPs ~500 MeV/nucleon
      - X-class flares
      - Western hem.
      - Fast halo CMEs
      - => RARE!!
        - » Only 73 GLEs since the 1940s
        - » GLE#73: 28 Oct 2021
  - Thresholds GLE
    - SWPC: 10% above B/Gr GCR
      - Practice: 3% above B/Gr
    - At least 2 independent stations
  - Realtime monitoring
    - https://www.nmdb.eu/
    - List: https://gle.oulu.fi/#/

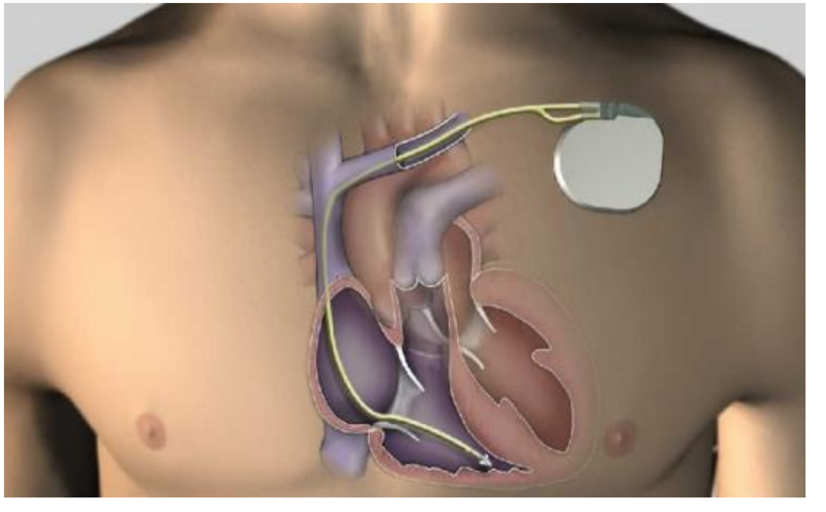




GCR: Galactic Cosmic Rays ; SC: solar cycle ; GeV: Giga electronvolt ;
SEP: Solar Energetic Particles ; B/Gr: Background ; NMDB: Neutron Monitor Database

Effects from proton events

- Ground Level Enhancements
  - Various systems
    - Computer glitches, servers,…
      - Errors increase with altitude
    - Pacemakers, defibrillators, and other medical devices,…
      - SEUs (very low rates)
  - Solar cycle (SC) effect noted
    - More errors during SC <u>min</u> than SC <u>max</u>



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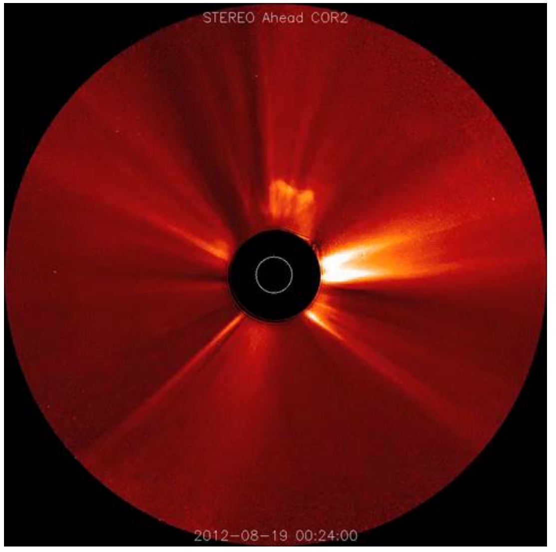
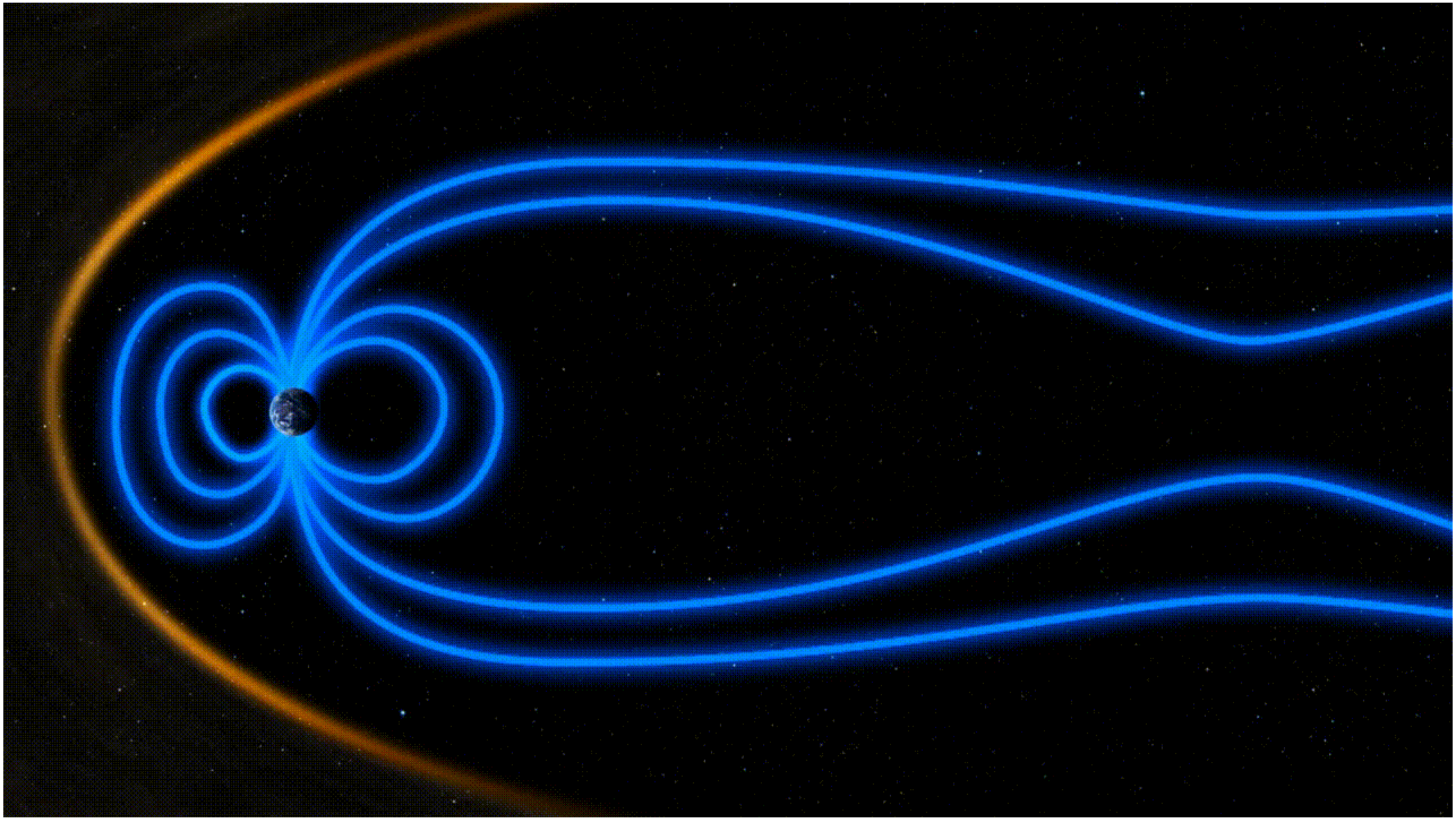
Coronal Mass Ejections



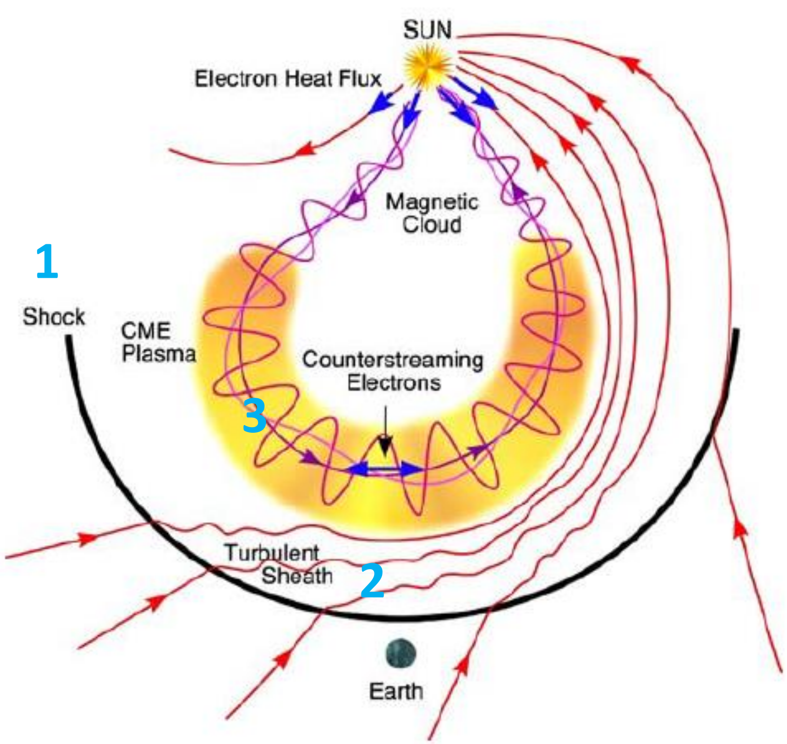
Effects from ICMEs

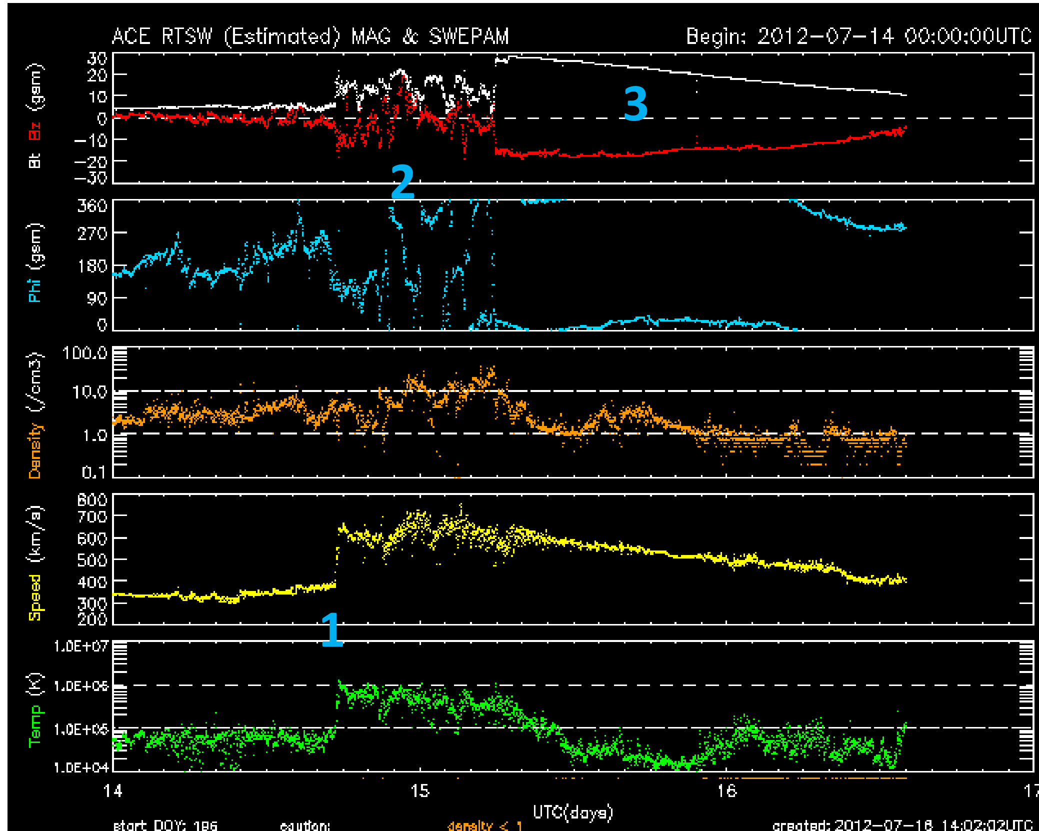


Credits: ESA

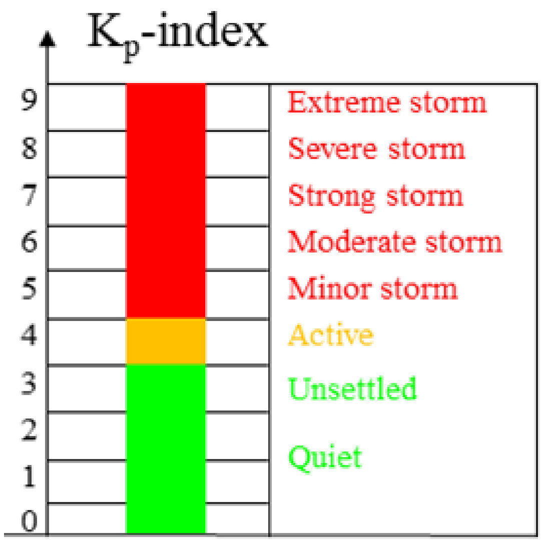
Effects from ICMEs

- Solar wind features

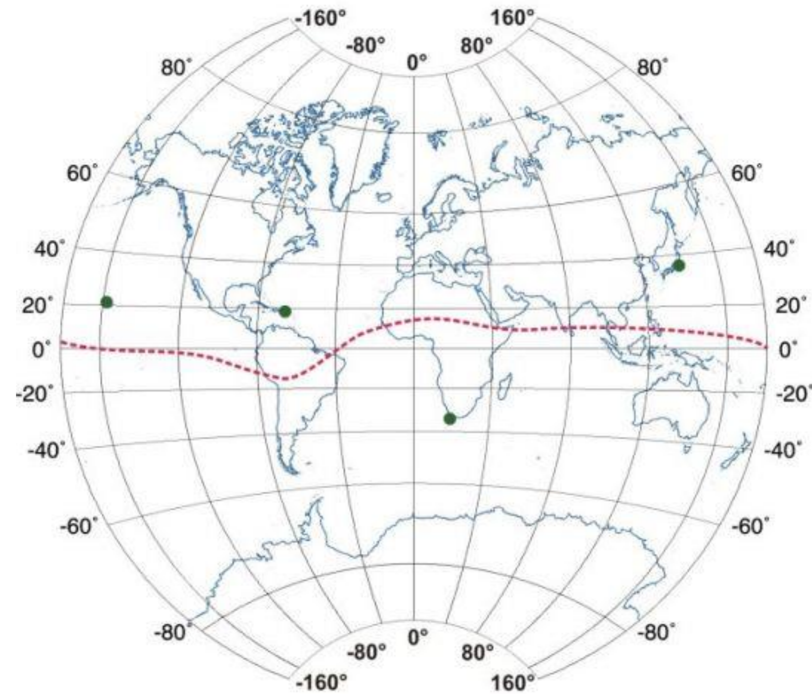


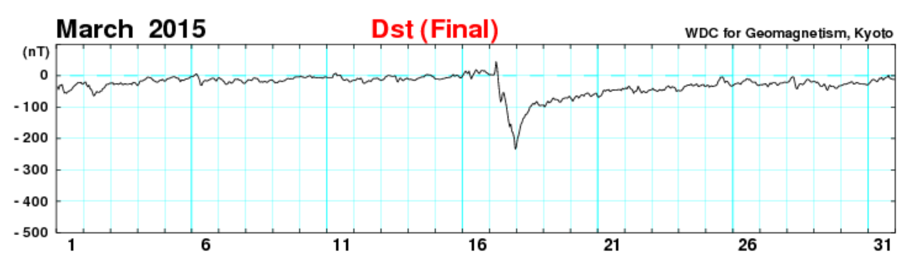


Geomagnetic indices

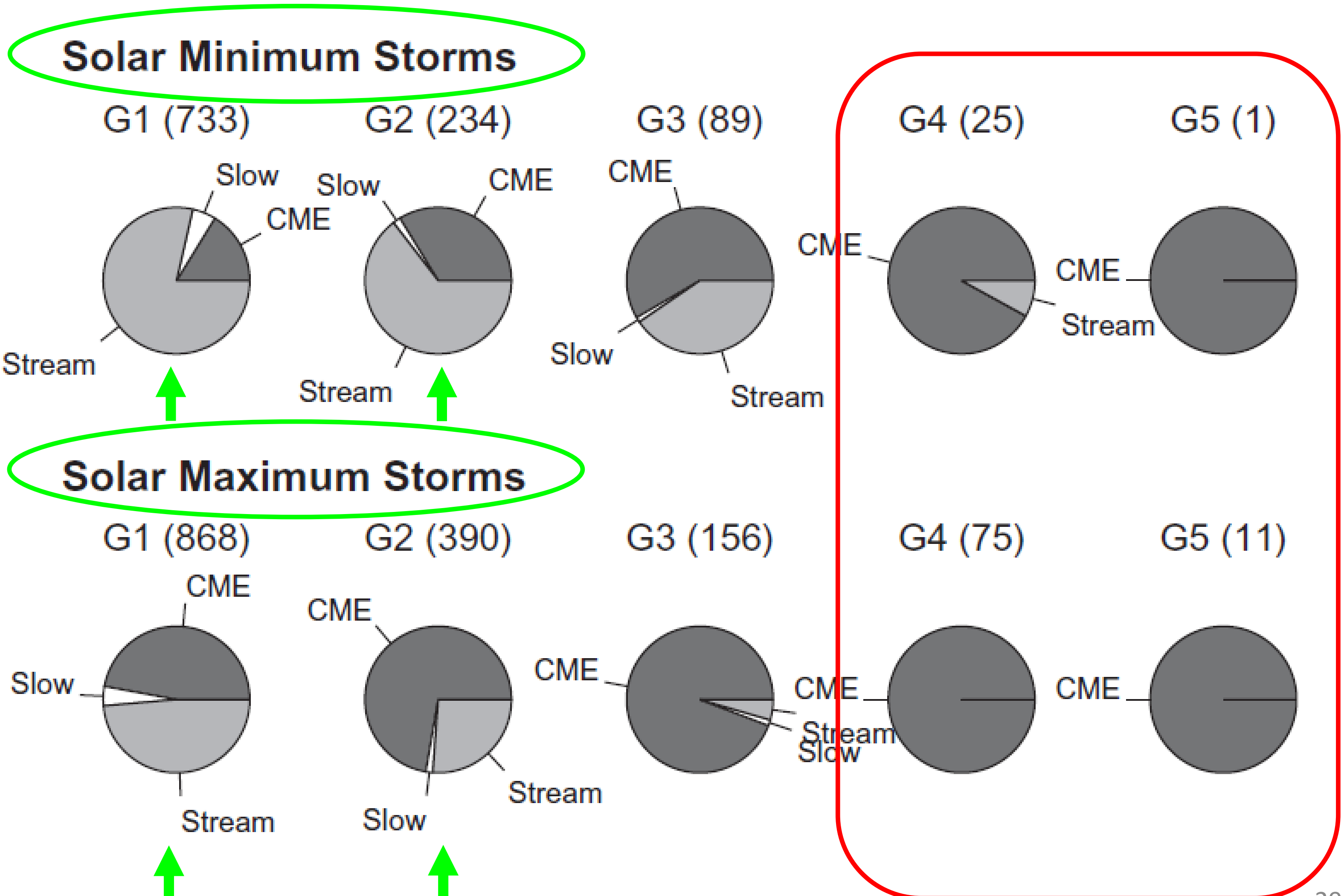


K	a
0	0
1	3
2	7
3	15
4	27
5	48
6	80
7	140
8	240
9	400





Effects from ICMEs



Effects from ICMEs

Scale	Description	Effect	Physical measure	Average Frequency (1 cycle = 11 years)
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, including a 9-	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)

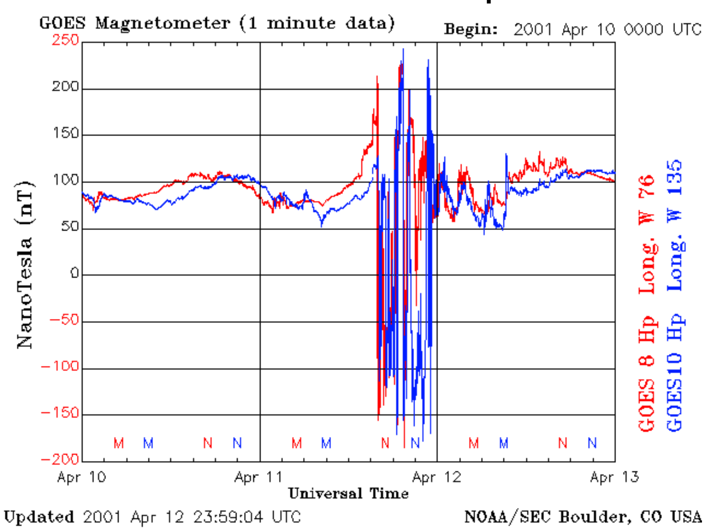
Effects from ICMEs

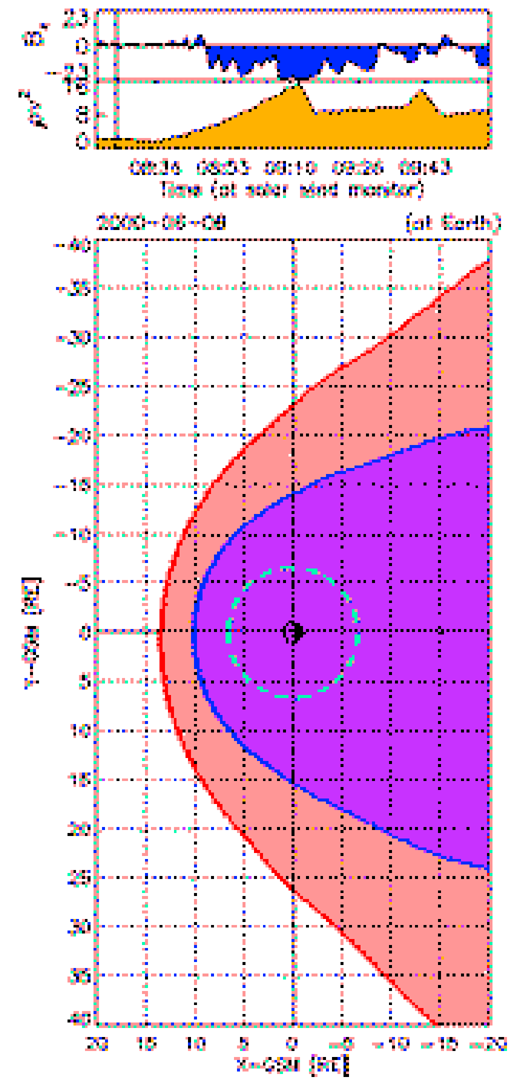
- From magnetic field
  - Satellites
    - Magnetopause crossings
  - High-Precision industry
  - GCR: Forbush decrease
- From particles
  - Satellites
    - Drag
    - Charging effects
    - Satellite-based Comms/Nav applications (GNSS)
      - => PECASUS
  - HF Communication (aviation)
    - => PECASUS
  - Geomagnetically Induced Currents (GIC)
  - Aurora

GCR: Galactic Cosmic Rays ; GNSS: Global Navigation Satellite Systems ; Comms/Nav: Communications/Navigation
PECASUS: Pan-European Consortium for Aviation Space weather User Services ; HF: High Frequency

Effects from ICMEs

- Satellites
  - Magnetopause crossings
    - CME pushes magnetopause inside GEO
    - Satellites directly exposed to solar wind
      - Orientation problem

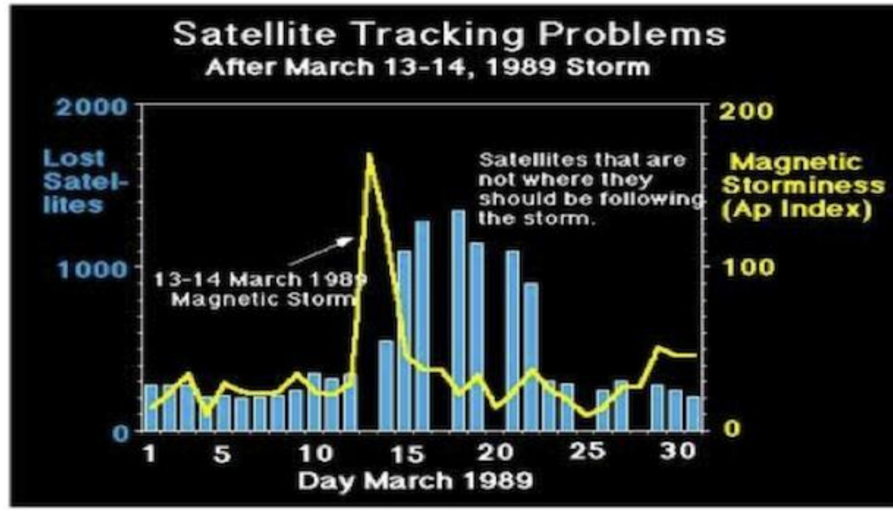


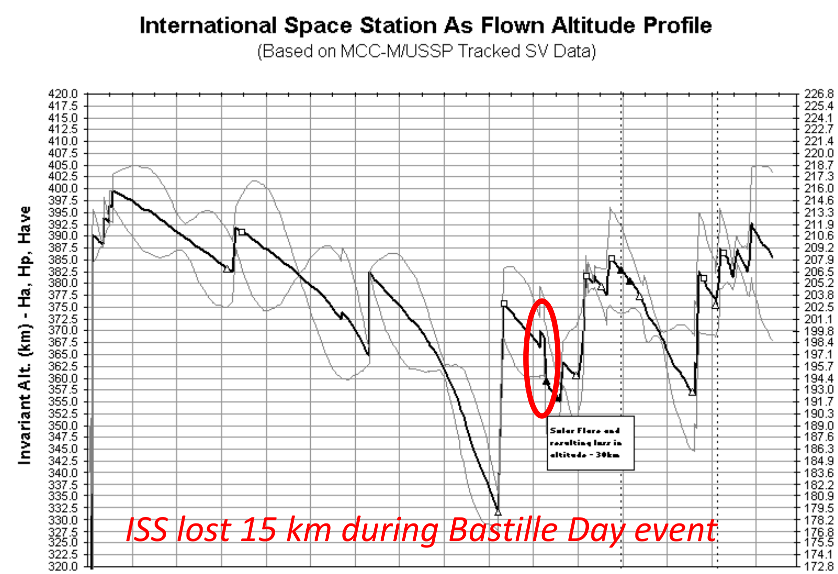


GEO: geostationary (equatorial) orbit

Effects from ICMEs

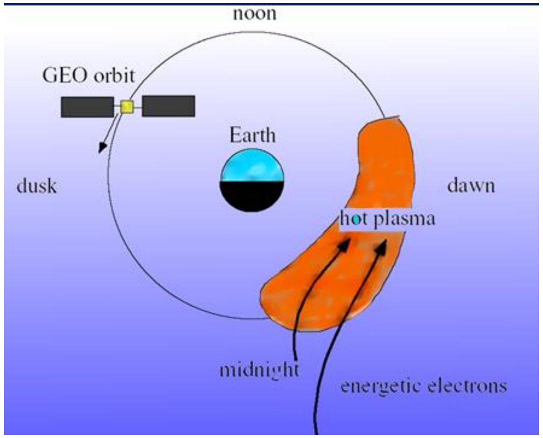
- Satellites
  - Atmospheric drag
    - Low Earth Orbit (LEO)
    - Sources
      - Shortterm: ICME
        - » NOAA: Kp $\geq$ 6
      - Longterm: Solar EUV radiation (solar cycle)
        - » NOAA: $F_{10.7} \geq 250$ sfu
    - Slows down satellite
      - Burns up in atmosphere
    - Examples
      - March 1989
        - » 1000 satellites off-track
      - Premature mission end
        - » Solar Max, Skylab, Starlink
- Space debris
  - Cleaned up by high solar activity
    - » SpaceX Dragon crew capsule trunk
      - Early re-entry (27 April 2023)

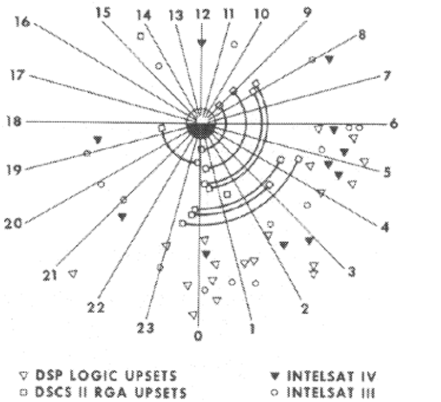




Effects from ICMEs

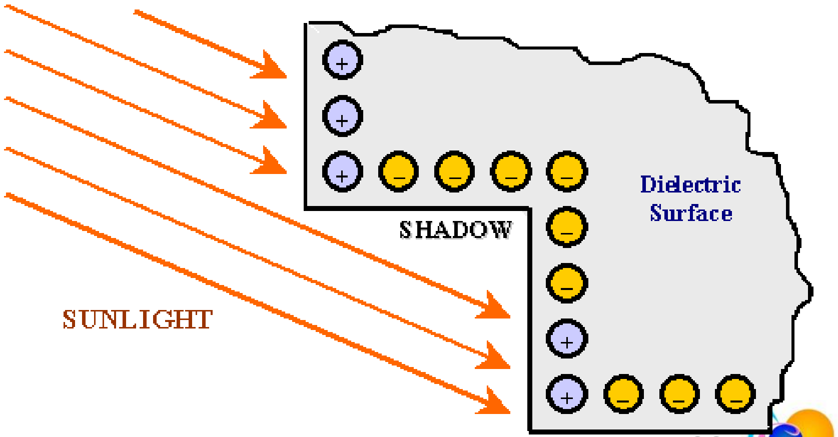
- Satellites
  - **Surface charging**
    - Low energy plasma
      - 0-100 keV electrons
    - Midnight to dawn region
      - Substorm related
      - SWPC: likely if K ≥ 6
    - Differential charging
      - Shadow effect (GEO/HEO)
      - Wake effect (LEO)
    - Electrostatic discharge (ESD)
      - Surface damage
      - Phantom commands
  - **Internal charging**
    - 100s keV electrons
      - More uniform distribution
      - Galaxy 15 outage in April 2010
  - **Accumulation effect**





Local time dependence of anomalies observed geosynchronous satellites.

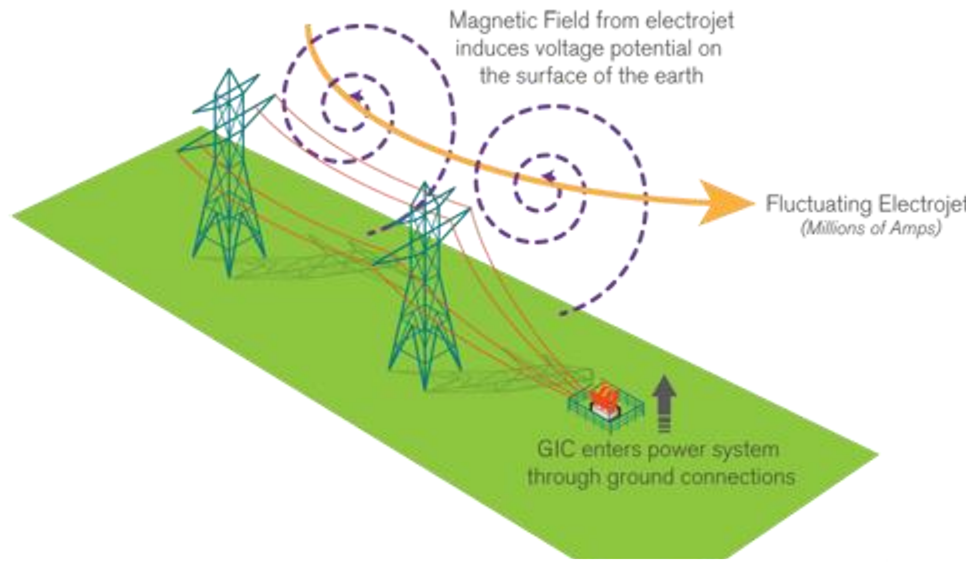
Low Earth orbit (LEO) ; Medium Earth orbit (MEO)
Geosynchronous orbit (GEO) ; High Earth orbit (HEO)

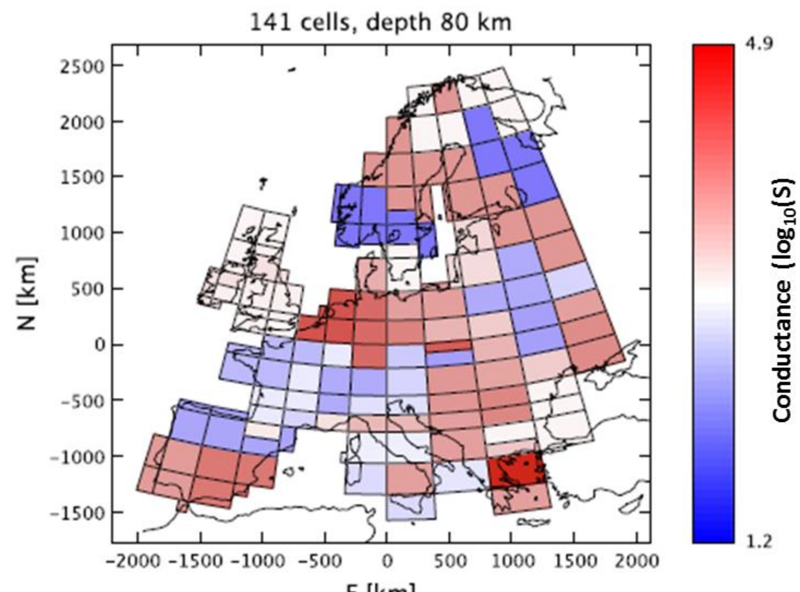


SWPC: Space Weather Prediction Center

Effects from ICMEs

- Geomagnetically Induced Currents (GIC)
  - Electrons from magnetotail => ionospheric currents => Magnetic field => currents in crust surface
  - Affects all long conductors
    - Enters via ground connections
  - GIC depends on
    - Strength ICME
    - Geomagnetic latitude
      - Eq. Latitudes too!
    - Local conductance
    - Network details





Effects from ICMEs

- GICs
  - Power grids
    - Distortions voltage pattern
    - Transformer damage
      - South-Africa, Oct 2003
    - Grid collapse
      - Québec, March 1989
      - Malmö, Sweden, 2003
    - Longterm effects of power loss!

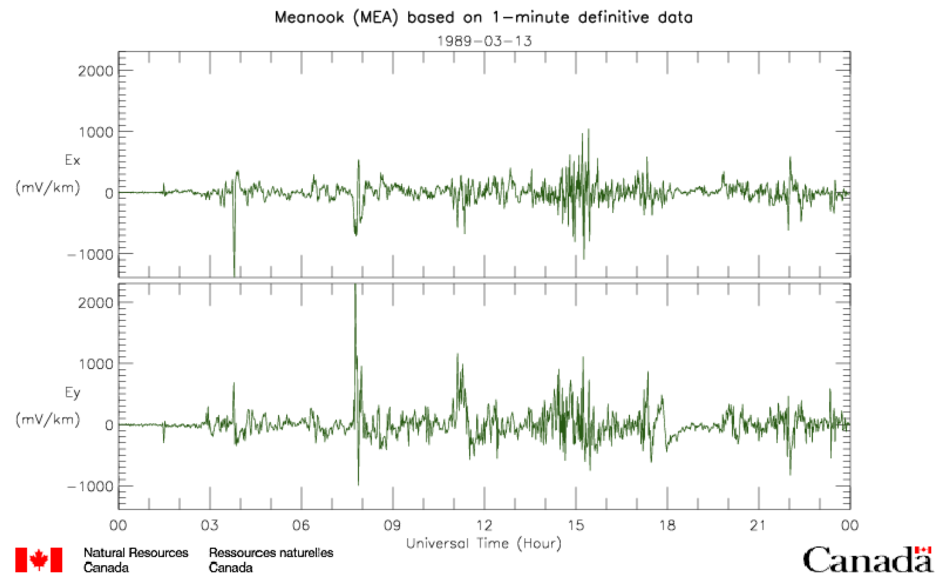


Table 3 Parameters for the GIC emergency alert model. The criterion for each alert level is shown in the second column, and the following columns show the expected extreme dB/dt values for RC-, AE-, and SC-type GICs

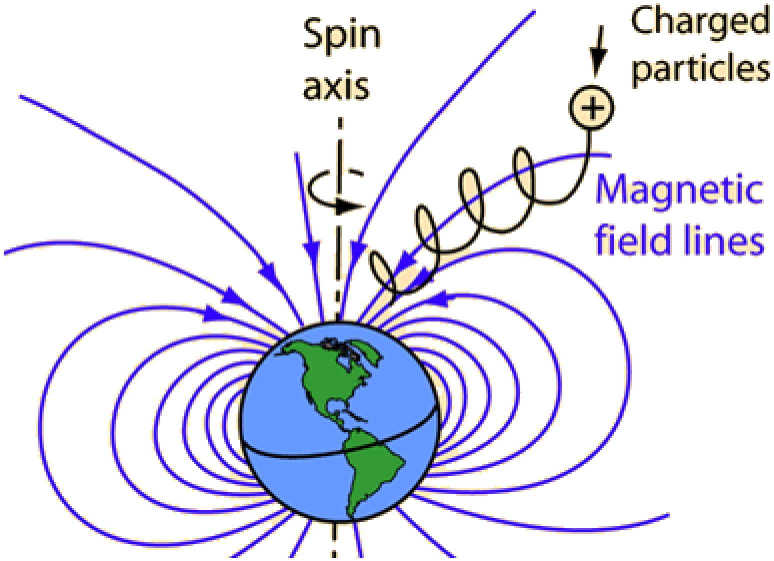
		dB/dt of GICs		
Alert level	Criterion	RC (nT/h)	AE (nT/min)	SC (nT/s)
Caution	Dst < −300 nT	100–150	2000	40–110
Warning	Dst < −600 nT	150–400	4000	40–110
Emergency	Dst < −900 nT	400–1250	6000	40–110
Transient alert	High SEP flux			40–110

Effects from ICMEs

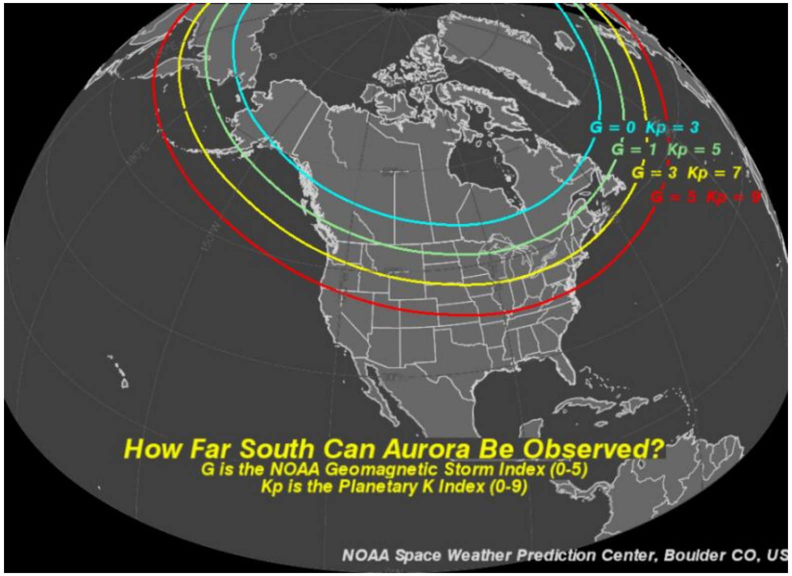
- GICs
  - Railways
    - New York (USA), 14-15 May 1921
    - Sweden, 13-14 July 1982
    - China, 17 March & 23 June 2015
  - Pipelines
    - Corrosion => Oil leaks
  - Telephone/Telegraph
    - Carrington event (1859),…
    - Transcontinental cables
      - 4 August 1972
  - Transatlantic cables
    - Copper to optical fibre
      - But « optical repeaters »!
      - March 1989 event
  - High-precision industry
    - Wellbore drilling
      - Manitoba, Canada, 27 February 2023

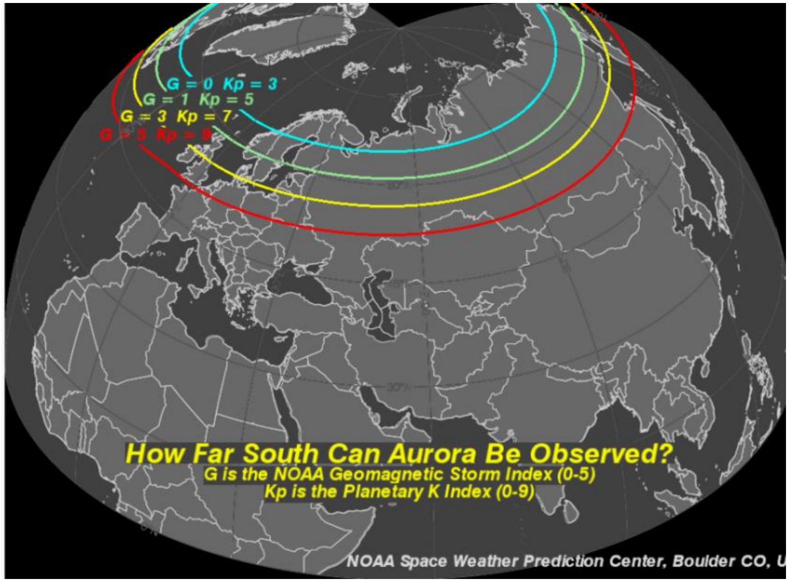
Effects from ICMEs

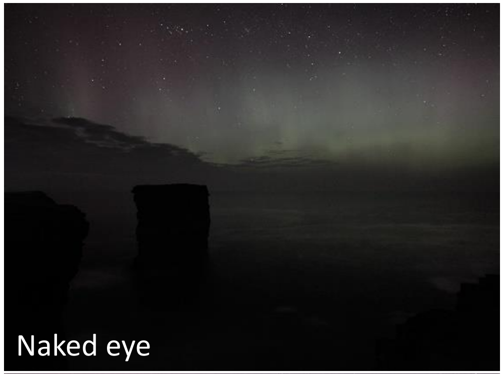
- Aurora

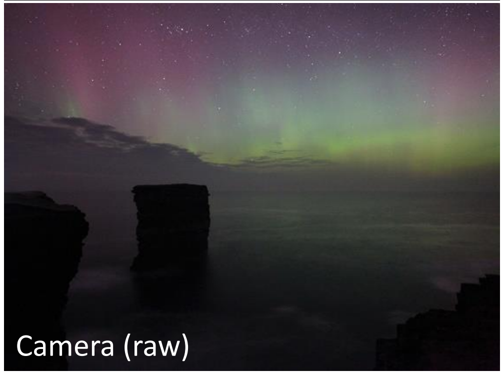


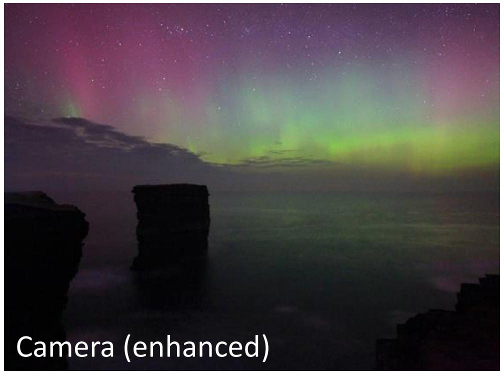
Effects from ICMEs









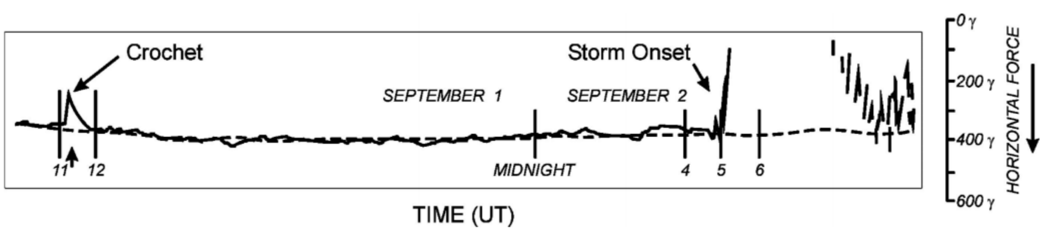


Credits: Phogotraphy - https://phogotraphy.com/2015/10/04/aurora-lies-cameras/

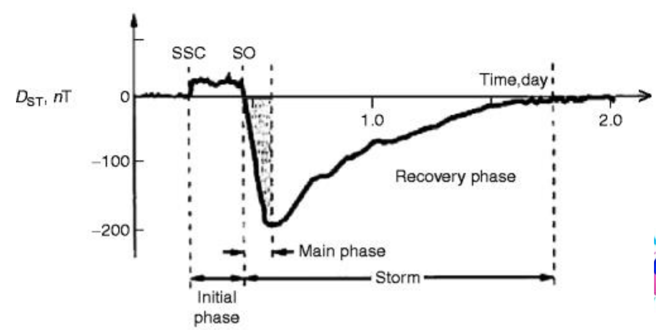
Effects from ICMEs

Rapid geomagnetic variations

- Solar flare effect (SFE)
  - Aka "magnetic crochet"
  - Source
    - Strong solar flare
      - H-α: 2B (30%)
      - X-ray: X1 (50%)
    - f(local time & latitude)
  - Examples
    - 4 Nov 2003: + 115nT
    - 1 Sep 1859: + 110nT

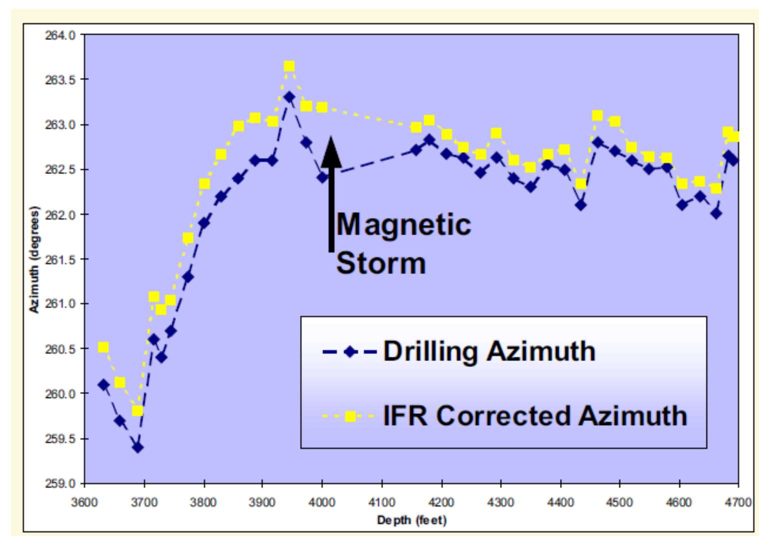


- Storm Sudden Commencement (SSC)
  - Sudden impulse (SI)
    - = no geomagnetic storm
  - Source
    - Dayside compression by strong ICME
    - Global, but f(local sit.)
  - Max. Amplitude: +/- 300 nT



Effects from ICMEs

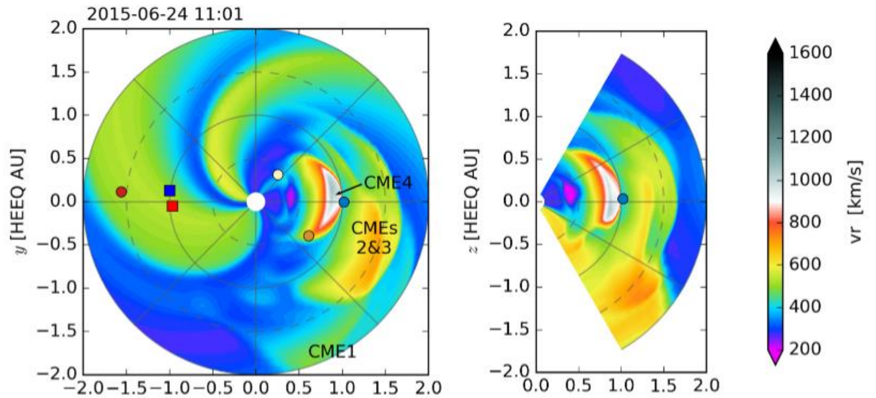
- High-precision industry
  - Industries depending on amplitude of magnetic field
    - magnetic anomaly surveys
    - directional wellbore drilling
  - Performance degradation
    - Mitigation possible
  - 4 August 1972
    - Vietnam: sea mine detonation

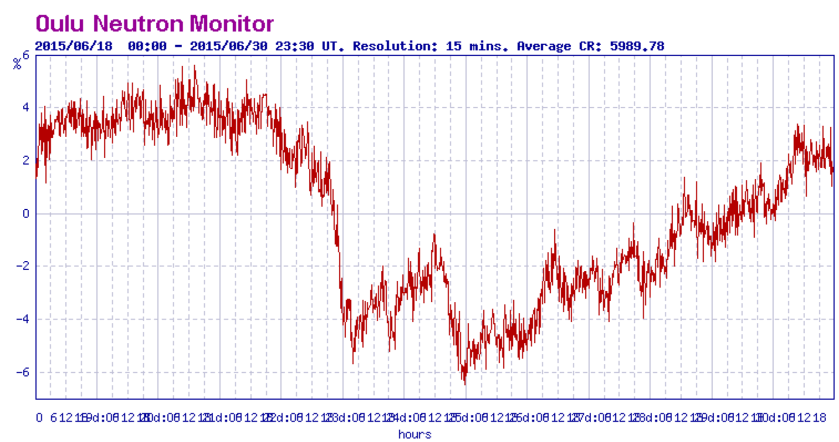


IIFR: Interpolated In-Field Referencing

Effects from ICMEs

- Cosmic rays
  - Forbush decrease
    - Decrease in neutron count over background levels
      - Due to the passage of strong ICME / multiple ICMEs
    - Threshold: > 3%
    - Amplitude:
      - Typical: 3-20%
      - Depends on
        - » Size and # CMEs
        - » B of CME
        - » Proximity CME to Earth
        - » cut-off rigidity (GCR)
    - Gradual recovery
      - 3-10 days



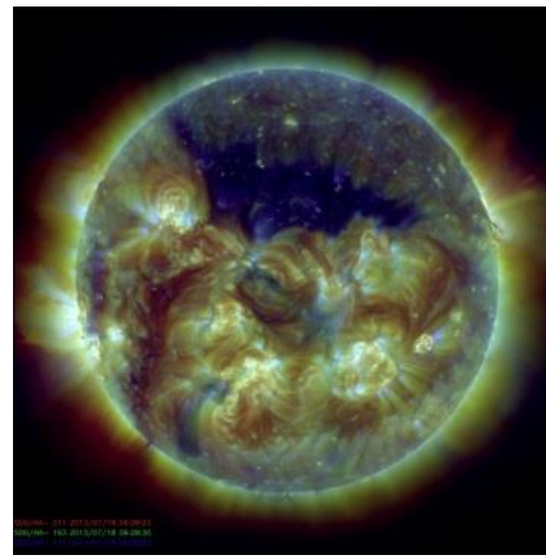


B: magnetic field strength ; GCR: Galactic Cosmic Rays

Space Weather effects (SWx effects)

- *Introduction*
- ***SWx effects from***
  - *Solar flares*
  - *Proton events*
  - *ICMEs*
  - ***Coronal holes***

Coronal Holes



Effects from CHs

Co-rotating interaction regions (CIR)

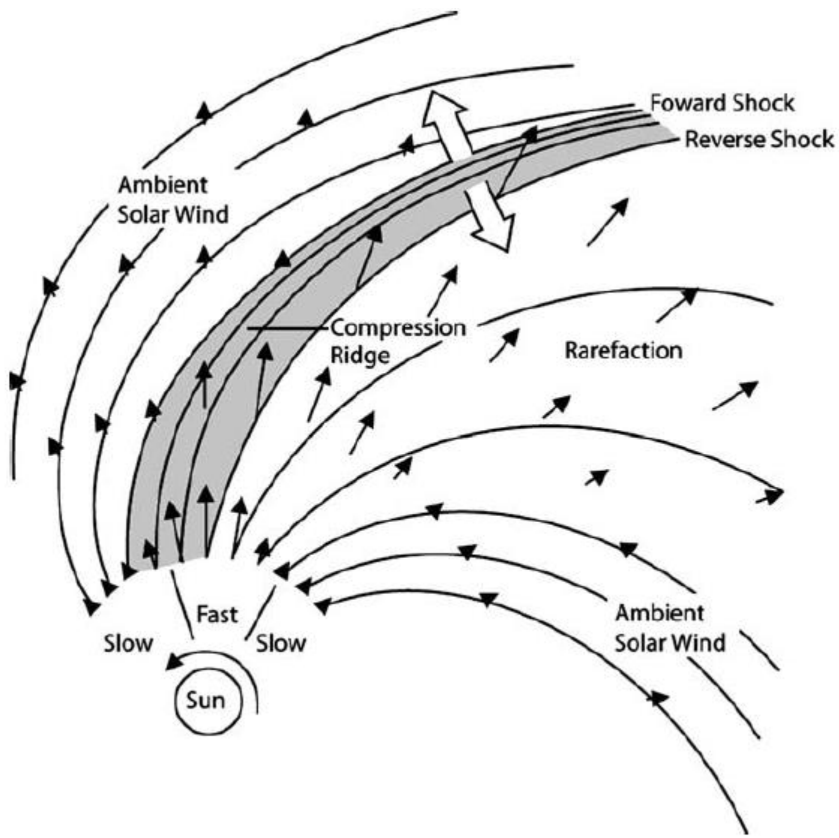


Figure 1. Schematic illustrating 2-D corotating stream structure in the solar equatorial plane in the inner heliosphere (after Pizzo, 1978).

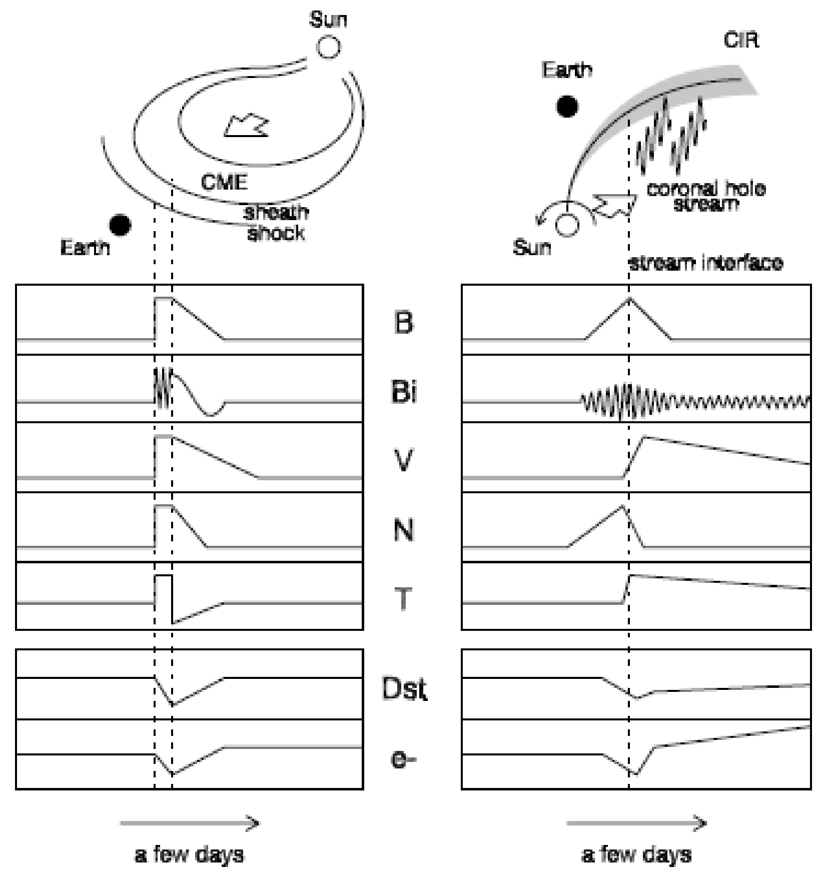
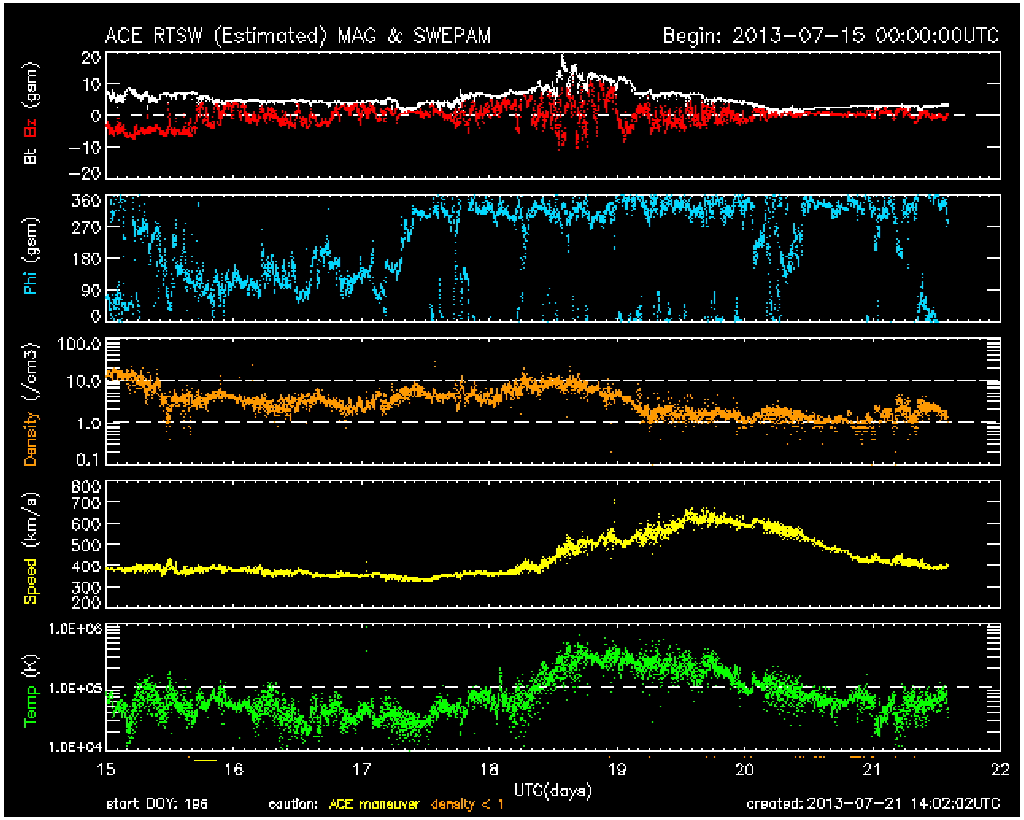


Figure 1. Schematic illustration of typical solar wind structures of coronal mass ejections (CMEs) and corotating interaction regions (CIRs): (top to bottom) magnetic field strength B, one of the Cartesian component B_i, solar wind speed V, density N, temperature T, expected response of the Dst index, and >2.0 MeV electron flux at geosynchronous orbit.

Effects from CHs



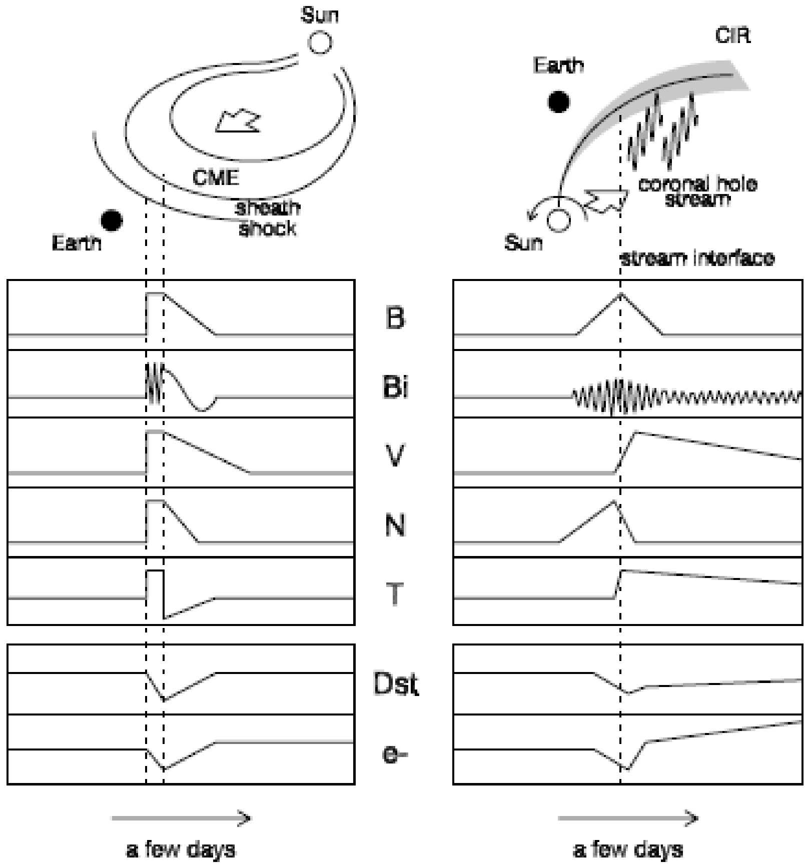
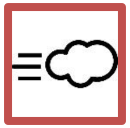
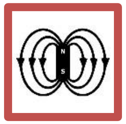


Figure 1. Schematic illustration of typical solar wind structures of coronal mass ejections (CMEs) and corotating interaction regions (CIRs): (top to bottom) magnetic field strength B, one of the Cartesian component B_i, solar wind speed V, density N, temperature T, expected response of the Dst index, and >2.0 MeV electron flux at geosynchronous orbit.

Effects from CHs

Scale	Description	Effect	Physical measure	Average Frequency (1 cycle = 11 years)
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, including a 9-	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)





Effects from CHs

- Similar to effects from ICMEs but less intense

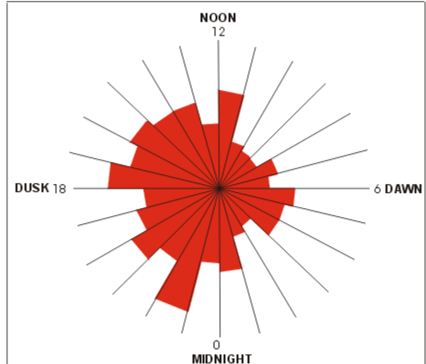
- except…

- From particles
  - Satellites
    - **Deep di-electric charging**

GCR: Galactic Cosmic Rays ; GNSS: Global Navigation Satellite Systems ;
PECASUS: Pan-European Consortium for Aviation Space weather User Services

Effects from CHs

- High-Speed Stream (HSS)
  - Satellite charging
    - Deep di-electric charging
      - Also called « Internal charging »
        - Several 100 keV to a few MeV (e^-)
        - Penetrate S/C
        - Accumulation effect within S/C (ESD)
        - Dayside effect
        - More during equinox
          - SNAP!
    - Fluxes > 2 MeV e^- (GEO)
  - CHs in declining phase SC
    - Also 1-2 days after strong ICME, e.g. 3-4 Nov 2021



Local time distribution of occurrences of static discharges, based on 122 reported events.
Radial extent shows relative number of events in each sector.
After Lam and Hruska, 1991, J. Spacecraft and Rockets

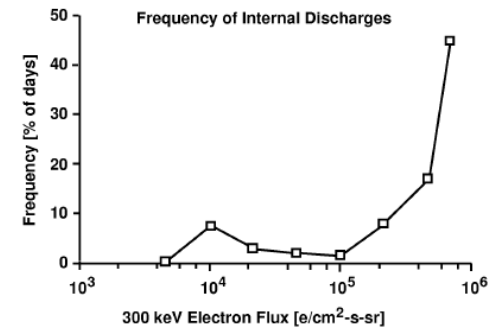
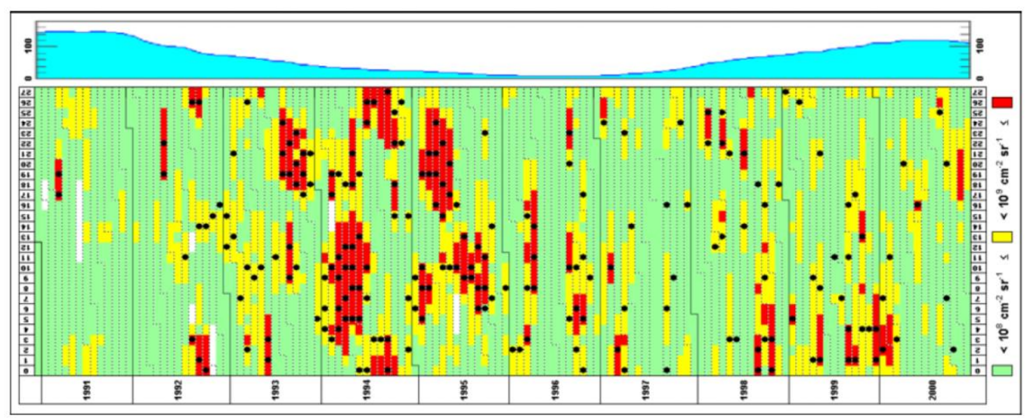


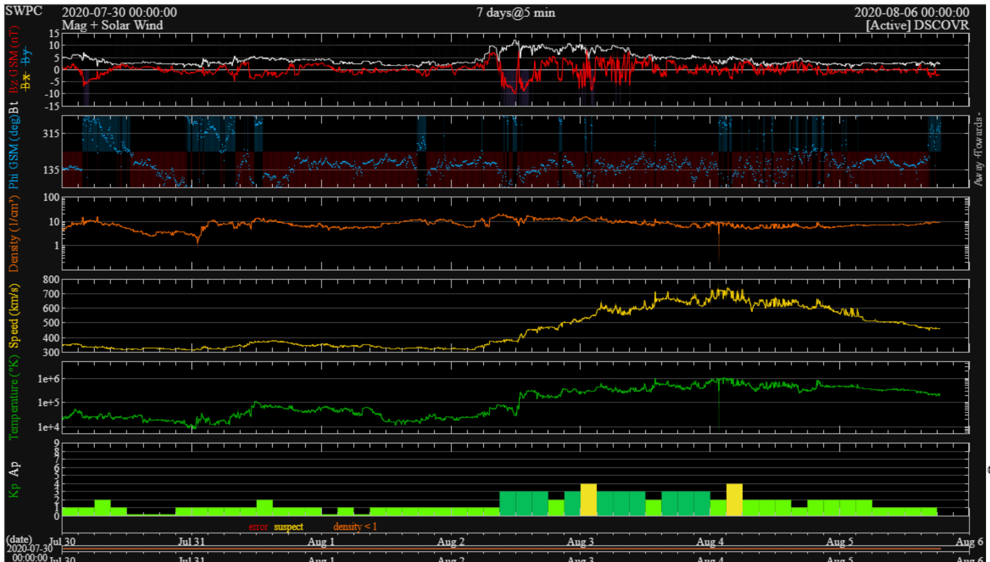
Figure 11. Comparison of SCATHA anomalies with energetic electron fluxes.

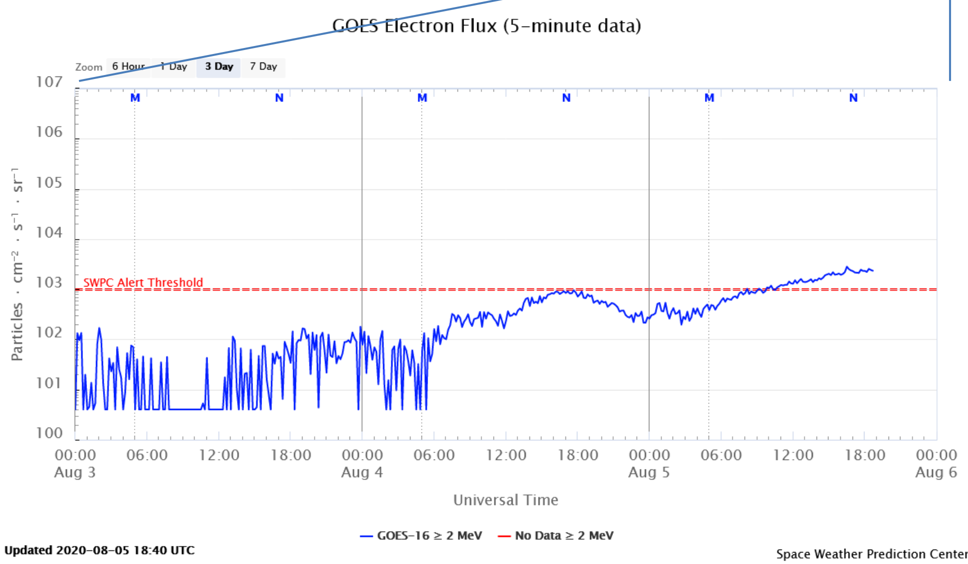


#ESDs on a GEO communications satellite

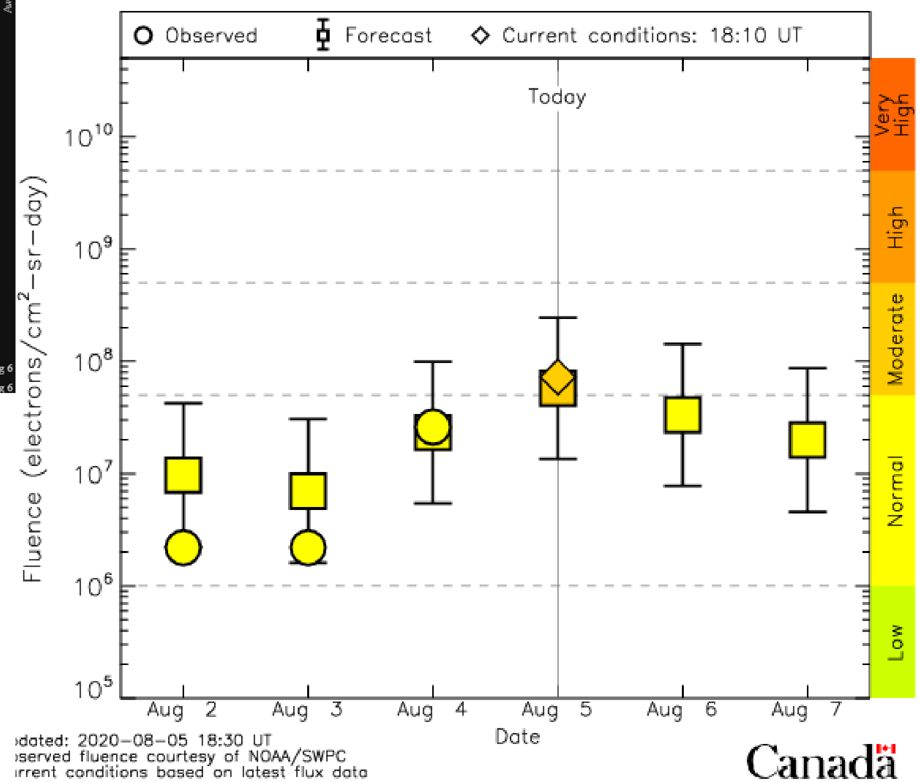
CH: Coronal hole ; e^- : electron ; S/C: spacecraft ; ESD: Electrostatic Discharge ;
SNAP: Spring Negative Autumn Positive ; GEO: Geostationary orbit ; SC: Solar cycle

Effects from CHs





HSS from 2-6 August 2020



Effects from CHs

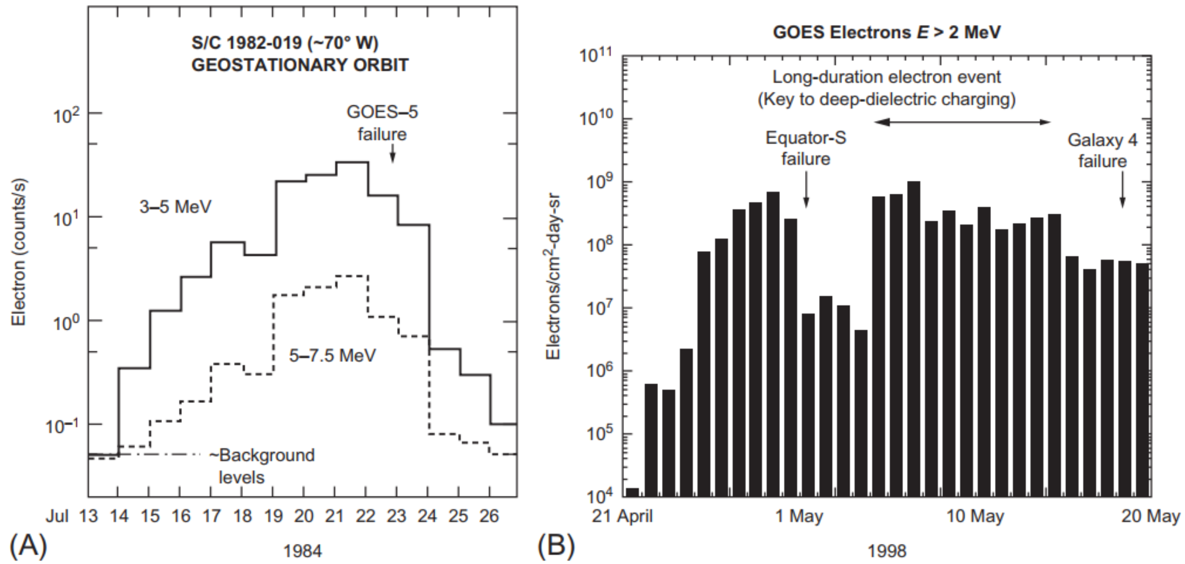
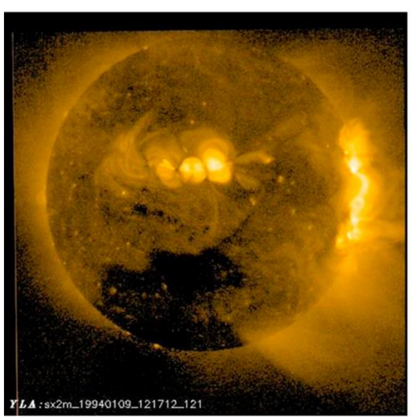
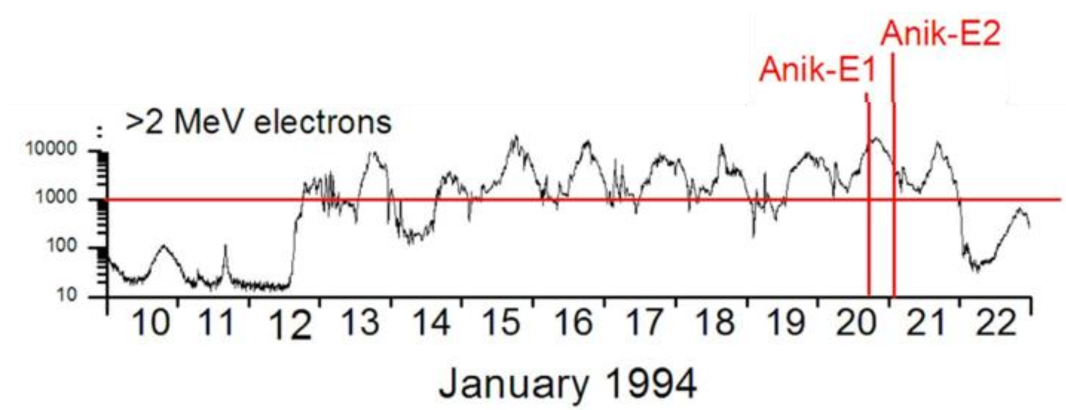
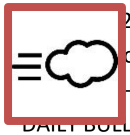
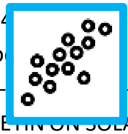


FIG. 7

(A) High-energy electron counts during the period July 13–26, 1984. The satellite GOES-5 failed after, but not during, the peak flux high energy electron flux (Baker et al., 1987).(B) Galaxy-4 and Equator-5 spacecraft failure events showing delays of failures occurring after the peak of the electron fluence (Baker et al., 1998).





24 1 UTC
o at http://www.sidc.be/products/tot
--#
DAILY BULLETIN ON SOLAR AND GEOMAGNETIC ACTIVITY from the SIDC #
#--#

SIDC URSIGRAM 40317
SIDC SOLAR BULLETIN 17 Mar 2024, 1231UT
SIDC FORECAST
SOLAR FLARES : M-class flares expected (probability >=50%)
GEOMAGNETISM : Quiet (A<20 and K<4)
SOLAR PROTONS : Quiet
PREDICTIONS FOR 17 Mar 2024 10CM FLUX: 144 / AP: 007
PREDICTIONS FOR 18 Mar 2024 10CM FLUX: 146 / AP: 007
PREDICTIONS FOR 19 Mar 2024 10CM FLUX: 148 / AP: 007

Solar Active Regions and flaring: There are five active regions visible on the solar disk. They all have simple beta or alpha magnetic field configuration and produced minor C-class flaring. The main activity in the last 24 hours has been observed from active regions behind the east limb, that will rotate into view in the next hours. The strongest was an M3.5 flare peaking at 16:35 UTC on 16 March, from a region not yet visible, located behind the east limb. As these regions rotate into view, we expect more M-class and possible X-class flares in the next 24 hours.

Coronal mass ejections: There was a partial halo CME (angular width about 180 degrees) directed towards the south, first seen at 03:24 UTC by LASCO C2. This CME originates from a filament eruption in the southern hemisphere. Since the filament was located close to the disk center, an ICME may arrive to the Earth on 20-21 March (a better estimation will be given when more data become available).

Solar wind: The Earth is inside slow solar wind, with speeds close to 350 km/s and an interplanetary magnetic field around 5 nT. Similar conditions are expected for the next 24 hrs.

Geomagnetism: Geomagnetic conditions were quiet both global and locally (NOAA_Kp up to 1 and K_BEL up to 1). Similar conditions can be expected for the next 24 hours.

Proton flux levels: The 10 MeV proton flux (measured by GOES-18) has come below the 10 pfu threshold, but remains elevated. It is expected that it will go back to low levels in the next 24 hrs.

Electron fluxes at GEO: The greater than 2 MeV electron flux from GOES 16 was below the threshold level in the last 24 hours. It is expected to remain below the threshold during the next 24 hours. The 24h electron fluence was at normal level and is expected to remain so.

TODAY'S ESTIMATED ISN : 074, BASED ON 10 STATIONS.

SOLAR INDICES FOR 16 Mar 2024
WOLF NUMBER CATANIA : ///
10CM SOLAR FLUX : 144
AK CHAMBON LA FORET : 005
AK WINGST : 002
ESTIMATED AP : 002
ESTIMATED ISN : 058, BASED ON 23 STATIONS.

≥ 2MeV electron flux & fluence

NOTICEABLE EVENTS SUMMARY
DAY BEGIN MAX END LOC XRAY OP 10CM Catania/NOAA RADIO_BURST_TYPES
16 1622 1635 1644 ////// M3.5 ///////
16 2127 2155 2211 ////// M1.1 ///////
END

Summary SWx effects (1/2)

- **Solar flares**
  - NOAA scale (R)
  - From EUV & X-ray radiation
    - Solar flare effect
      - "magnetic crochet"
      - => Effects from ICMEs
  - Shortwave fadeout
    - "Radio Blackout"
    - => PECASUS
  - From radio emission
    - GNSS disturbances
    - Radar disturbances

- **Proton events**
  - NOAA scale (S)
  - Polar Cap Absorption (PCA)
    - => PECASUS
  - Radiation
    - Astronauts, Polar flights
    - => PECASUS
  - Satellites
    - Star trackers
    - Single Event Effects (SEE)
    - Solar arrays
  - Ground Level Enhancement (GLE)

Summary SWx effects (2/2)

- ICMEs
  - NOAA scale (G)
  - From magnetic field
    - Satellites
      - Magnetopause crossings
    - High-Precision industry
    - GCR: Forbush decrease
  - From particles
    - Satellites
      - Drag
      - Charging effects
        - » Electrostatic Discharges (ESD)
      - Satellite-based Comms/Nav applications (GNSS)
        - » => PECASUS
    - HF Communication (aviation)
      - => PECASUS
    - Geomagnetically Induced Currents (GIC)
    - Aurora

- Coronal Holes
  - NOAA scale (G)
    - Impacts similar but less severe than with (strong) ICMEs
    - Especially during the declining phase of Solar Cycle
    - SNAP (Spring - Autumn +)
  - Satellites
    - Deep di-electric charging