Severe Space Weather NATO Relevance

Civil Emergency Planning Operational Relationships Focus on Communications

Contents

- What is NATO
- Functions of NATO in International Emergency Management
- Why NATO is needed for Communications recovery
- Solar weather Impacts to NATO Operations
- What matters – language of Interoperability
- Communications Disaster Planning tools

NATO MEMBER AND PARTNERSHIP COUNTRIES

NATO member countries

Twenty-eight members contribute to promoting security and stability through diplomatic, political and military means. They are committed to the principle of collective defence, which means that an attack against one member or more is considered as an attack against all. NATO also develops partnerships with non-NATO countries and is involved in crisis management operations and missions.

Partnership for Peace countries

Partnership with non-NATO countries started as early as 1991 to help often newly independent states build a solid democratic environment, maintain political stability and modernise armed forces. Discussions on security issues of common interest take place within a multilateral forum called the Euro-Atlantic Partnership Council and practical cooperation is organised with individual partner countries through NATO's Partnership for Peace programme. NATO also maintains a special relationship with Russia and with Ukraine.

Mediterranean Dialogue countries

These countries participate in a security dialogue with NATO to improve mutual understanding and contribute towards regional security through stronger practical cooperation. At present, there are seven participating countries, which can consult collectively and individually with NATO.

Istanbul Cooperation Initiative countries

This initiative offers countries of the broader Middle East region practical bilateral security cooperation with NATO so as to contribute to global and regional security. To date, four countries have joined.

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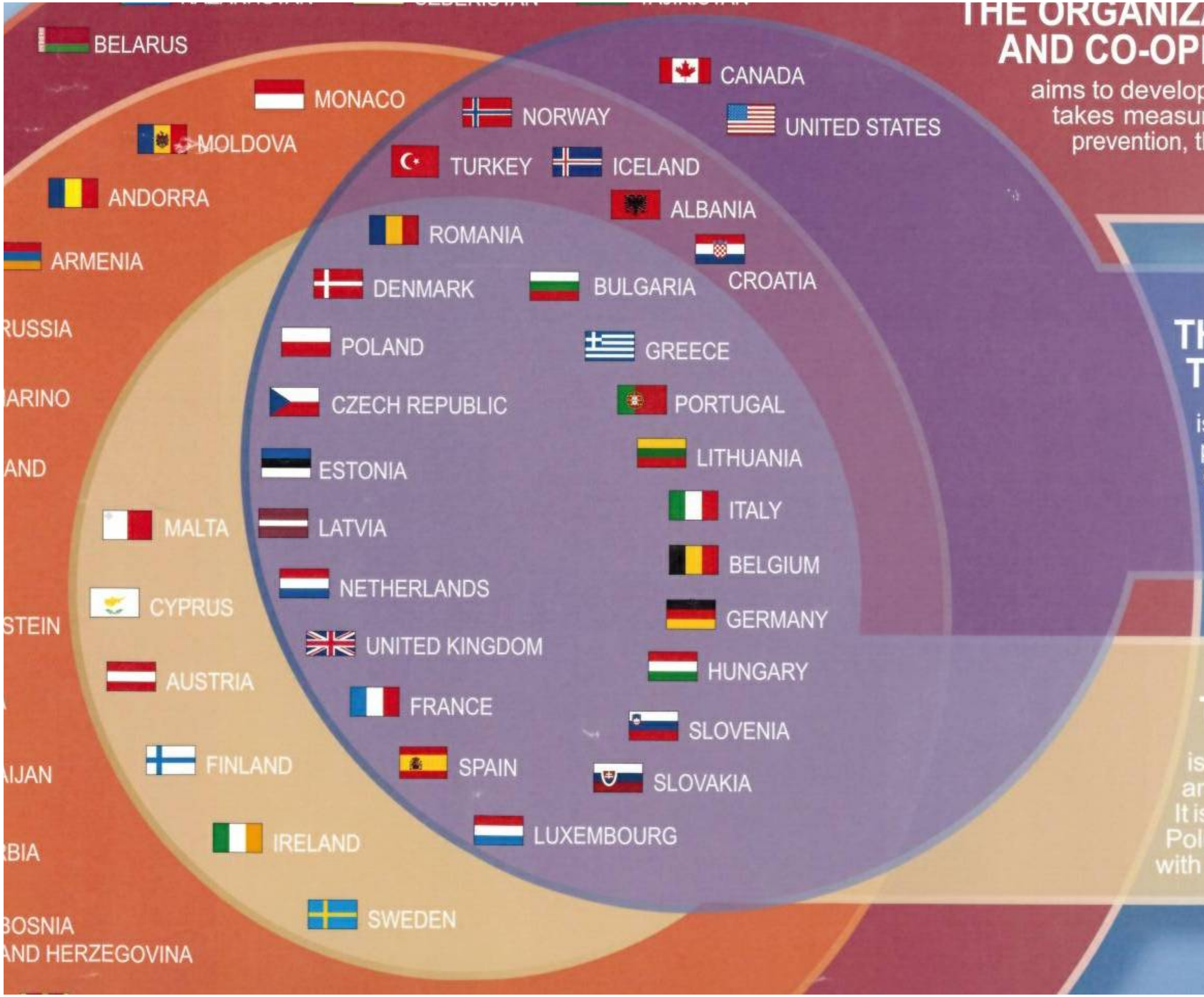
[1] Turkey recognises the Republic of Macedonia with its constitutional name.

[2] The State of Israel has designated Jerusalem as its capital. The position of the United Nations on the question of Jerusalem is contained in several Resolutions of the General Assembly and the Security Council concerning this question.

www.nato.int



BELARUS

MONACO

MOLDOVA

ANDORRA

ARMENIA

RUSSIA

ARINO

AND

STEIN

IJAN

BIA

BOSNIA
AND HERZEGOVINA

CANADA

UNITED STATES

NORWAY

TURKEY

ICELAND

ALBANIA

CROATIA

ROMANIA

DENMARK

BULGARIA

POLAND

GREECE

CZECH REPUBLIC

PORTUGAL

ESTONIA

LITHUANIA

LATVIA

ITALY

BELGIUM

NETHERLANDS

GERMANY

UNITED KINGDOM

HUNGARY

FRANCE

SLOVENIA

SPAIN

SLOVAKIA

LUXEMBOURG

MALTA

CYPRUS

AUSTRIA

FINLAND

IRELAND

SWEDEN

THE ORGANIZATION FOR SECURI
AND CO-OPERATION IN EUROP

aims to develop democracy and human right
takes measures to encourage preventive
prevention, the peaceful resolution of conflic

THE NORTH ATLANTI
TREATY ORGANIZAT

is committed to protecting its
political and military means. I
consultation and cooperatio
countries in a wide range of se
and undertakes crisis manag

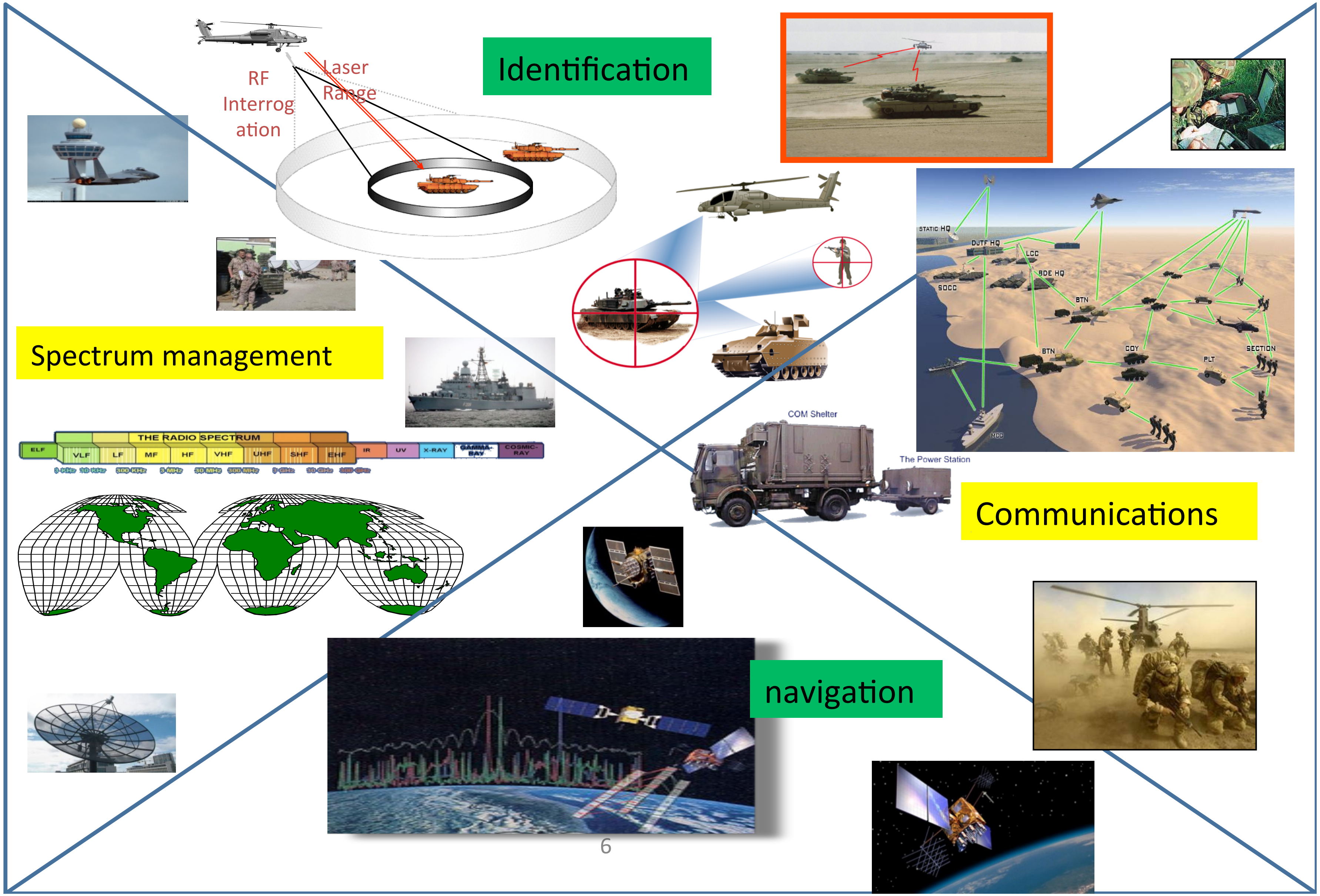
THE EUROPEAN UN

is striving for closer political, e
and social integration of its me
It is developing the European Se
Policy using the strategic partn
with NATO on security issues.

NATO supports Nations civil-military engagement for emergencies in sectors necessary for defense of populations.

NATO prepares for disasters requiring interoperability with civil support for Alliance operations and Crisis Response operations.

NATO Networks Use Space



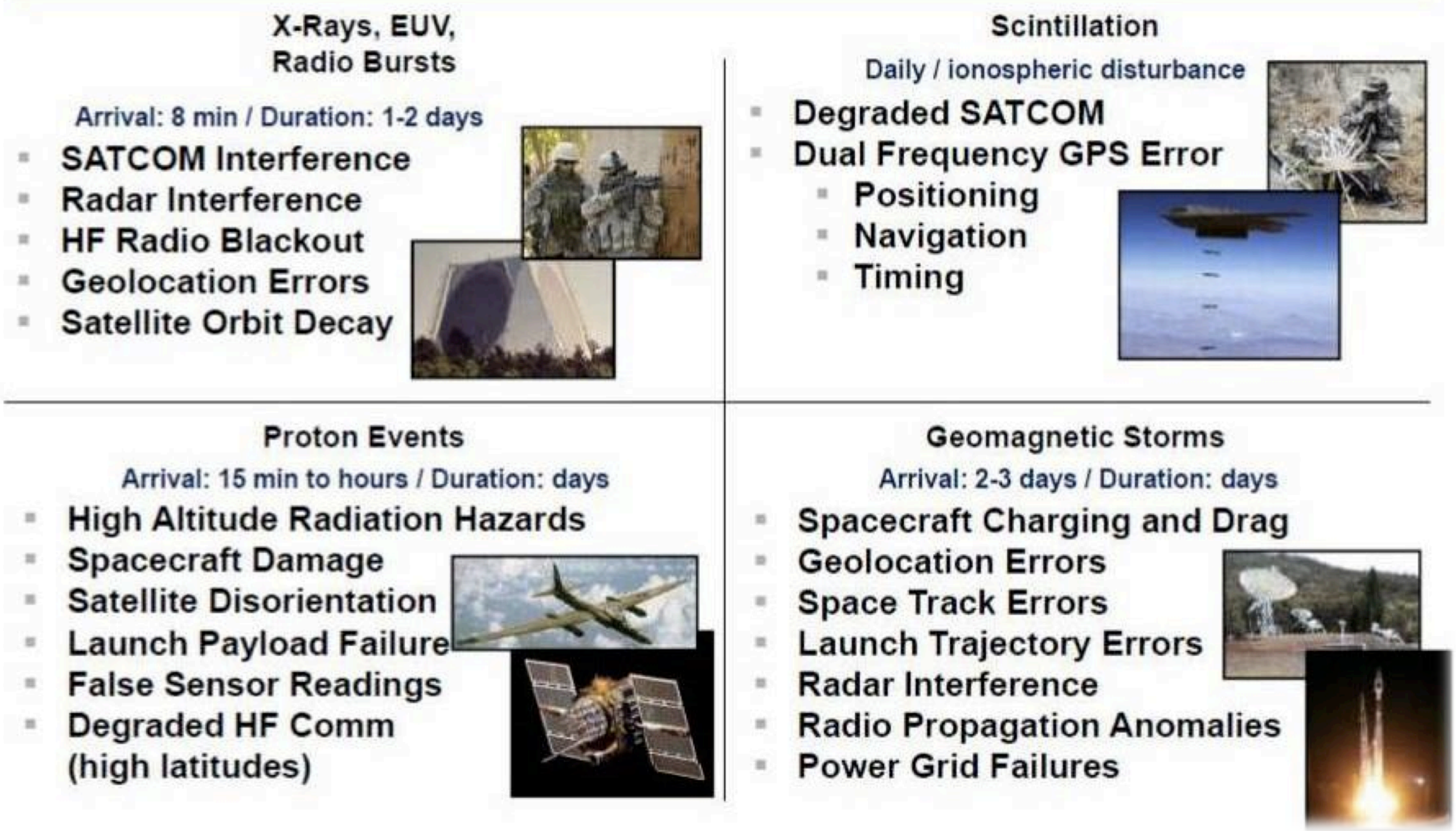
Identification

Spectrum management

Communications

navigation

Military and Civil Planners Need to Time Space Weather Impacts



X-Rays, EUV, Radio Bursts

Arrival: 8 min / Duration: 1-2 days

- SATCOM Interference
- Radar Interference
- HF Radio Blackout
- Geolocation Errors
- Satellite Orbit Decay

Scintillation

Daily / ionospheric disturbance

- Degraded SATCOM
- Dual Frequency GPS Error
  - Positioning
  - Navigation
  - Timing

Proton Events

Arrival: 15 min to hours / Duration: days

- High Altitude Radiation Hazards
- Spacecraft Damage
- Satellite Disorientation
- Launch Payload Failure
- False Sensor Readings
- Degraded HF Comm (high latitudes)

Geomagnetic Storms

Arrival: 2-3 days / Duration: days

- Spacecraft Charging and Drag
- Geolocation Errors
- Space Track Errors
- Launch Trajectory Errors
- Radar Interference
- Radio Propagation Anomalies
- Power Grid Failures

Civil Disaster Roles NATO Supports

Planning Operations reduce damage and loss of life in the **common phases of a disaster**.

- Communications are necessary for all activities.

- Warning
- Mitigation
- Response
- Recovery

Necessary for Disaster Recovery

These three **requirements are mandatory** for **emergency recovery** by all **communications service providers.**

- Access
- Security -> NATO’s function and value
- Fuel

Civil Emergency Planning Structures

EADRCC (Euro-Atlantic Disaster Response Coordination Centre)

- Located at NATO HQ, Brussels
- Partnership instrument (MD/ICI countries can use the tool)
- Liaison arrangements (UN-OCHA; National Military Authorities)
- Role:
  - Coordination of Allied and partner nations' assistance (68 total) to each other in case of natural or technological disaster.
  - Not command and control

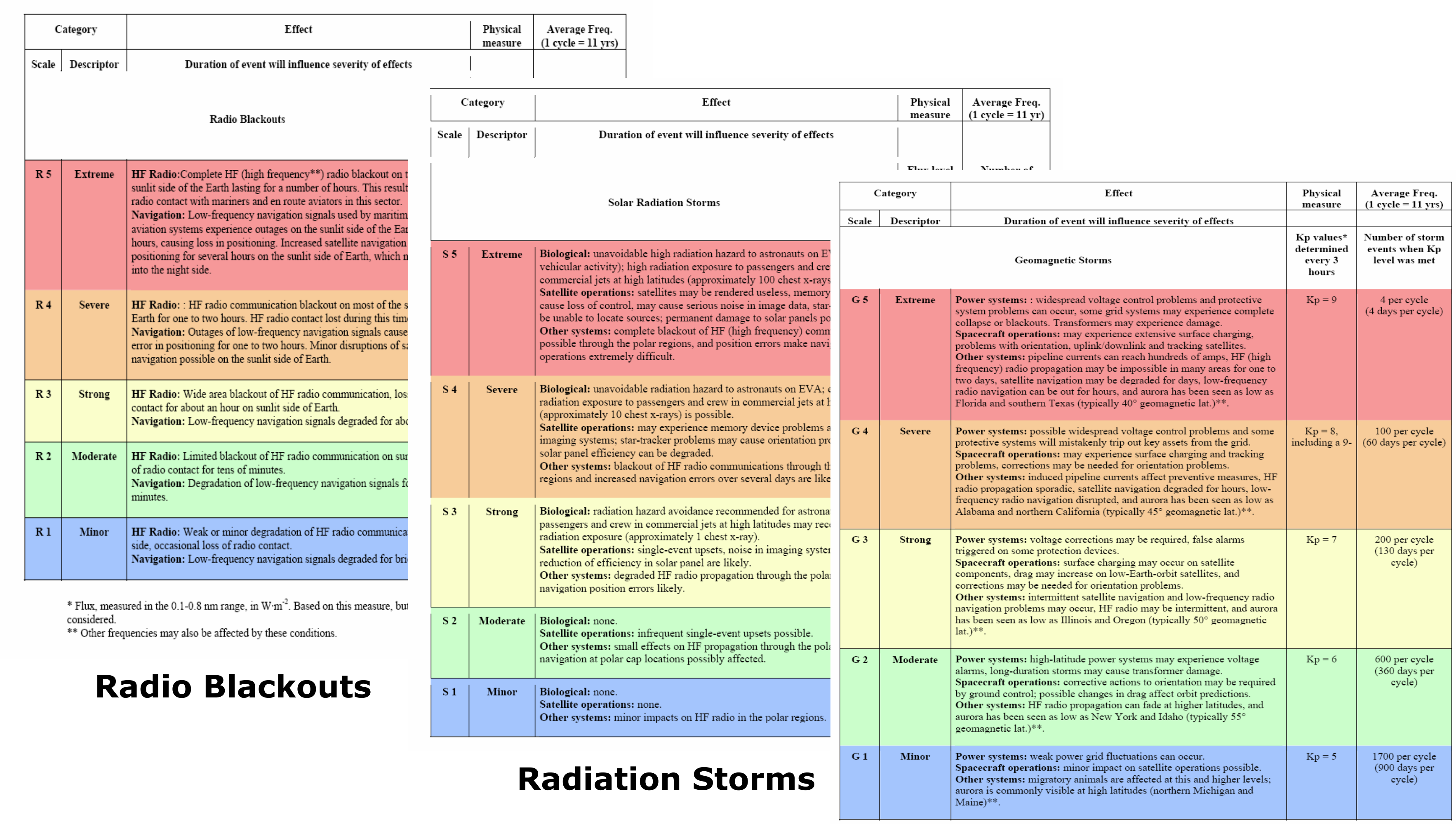
Common threats - Solar extremes

- Interoperability requires **common terms** for communication.

- Space Weather types
  - Solar Flares Radio Blackouts *(R Scale)*
  - Radiation Storms *(S Scale)*
  - Geomagnetic Storms *(G Scale)*

NOAA Space Weather Scales

http://www.swpc.noaa.gov/NOAAscales/



Category		Effect	Physical measure	Average Freq. (1 cycle = 11 yrs)
Scale	Descriptor	Duration of event will influence severity of effects		
Radio Blackouts				
R 5	Extreme	**HF Radio:**Complete HF (high frequency**) radio blackout on t sunlit side of the Earth lasting for a number of hours. This result radio contact with mariners and en route aviators in this sector. **Navigation:** Low-frequency navigation signals used by maritim aviation systems experience outages on the sunlit side of the Ear hours, causing loss in positioning. Increased satellite navigation positioning for several hours on the sunlit side of Earth, which n into the night side.		
R 4	Severe	**HF Radio:** : HF radio communication blackout on most of the s Earth for one to two hours. HF radio contact lost during this tim **Navigation:** Outages of low-frequency navigation signals cause error in positioning for one to two hours. Minor disruptions of sa navigation possible on the sunlit side of Earth.		
R 3	Strong	**HF Radio:** Wide area blackout of HF radio communication, los contact for about an hour on sunlit side of Earth. **Navigation:** Low-frequency navigation signals degraded for abo		
R 2	Moderate	**HF Radio:** Limited blackout of HF radio communication on sun of radio contact for tens of minutes. **Navigation:** Degradation of low-frequency navigation signals fo minutes.		
R 1	Minor	**HF Radio:** Weak or minor degradation of HF radio communica side, occasional loss of radio contact. **Navigation:** Low-frequency navigation signals degraded for bri		

* Flux, measured in the 0.1-0.8 nm range, in W·m^{-2}. Based on this measure, but
considered.
** Other frequencies may also be affected by these conditions.

Radio Blackouts

Category		Effect	Physical measure	Average Freq. (1 cycle = 11 yr)
Scale	Descriptor	Duration of event will influence severity of effects		
Solar Radiation Storms			Flux level	Number of
S 5	Extreme	**Biological:** unavoidable high radiation hazard to astronauts on EV vehicular activity); high radiation exposure to passengers and cre commercial jets at high latitudes (approximately 100 chest x-rays **Satellite operations:** satellites may be rendered useless, memory cause loss of control, may cause serious noise in image data, star- be unable to locate sources; permanent damage to solar panels po **Other systems:** complete blackout of HF (high frequency) comm possible through the polar regions, and position errors make navi operations extremely difficult.		
S 4	Severe	**Biological:** unavoidable radiation hazard to astronauts on EVA; radiation exposure to passengers and crew in commercial jets at h (approximately 10 chest x-rays) is possible. **Satellite operations:** may experience memory device problems a imaging systems; star-tracker problems may cause orientation pro solar panel efficiency can be degraded. **Other systems:** blackout of HF radio communications through th regions and increased navigation errors over several days are like		
S 3	Strong	**Biological:** radiation hazard avoidance recommended for astrona passengers and crew in commercial jets at high latitudes may rec radiation exposure (approximately 1 chest x-ray). **Satellite operations:** single-event upsets, noise in imaging syster reduction of efficiency in solar panel are likely. **Other systems:** degraded HF radio propagation through the pola navigation position errors likely.		
S 2	Moderate	**Biological:** none. **Satellite operations:** infrequent single-event upsets possible. **Other systems:** small effects on HF propagation through the pola navigation at polar cap locations possibly affected.		
S 1	Minor	**Biological:** none. **Satellite operations:** none. **Other systems:** minor impacts on HF radio in the polar regions.		

Radiation Storms

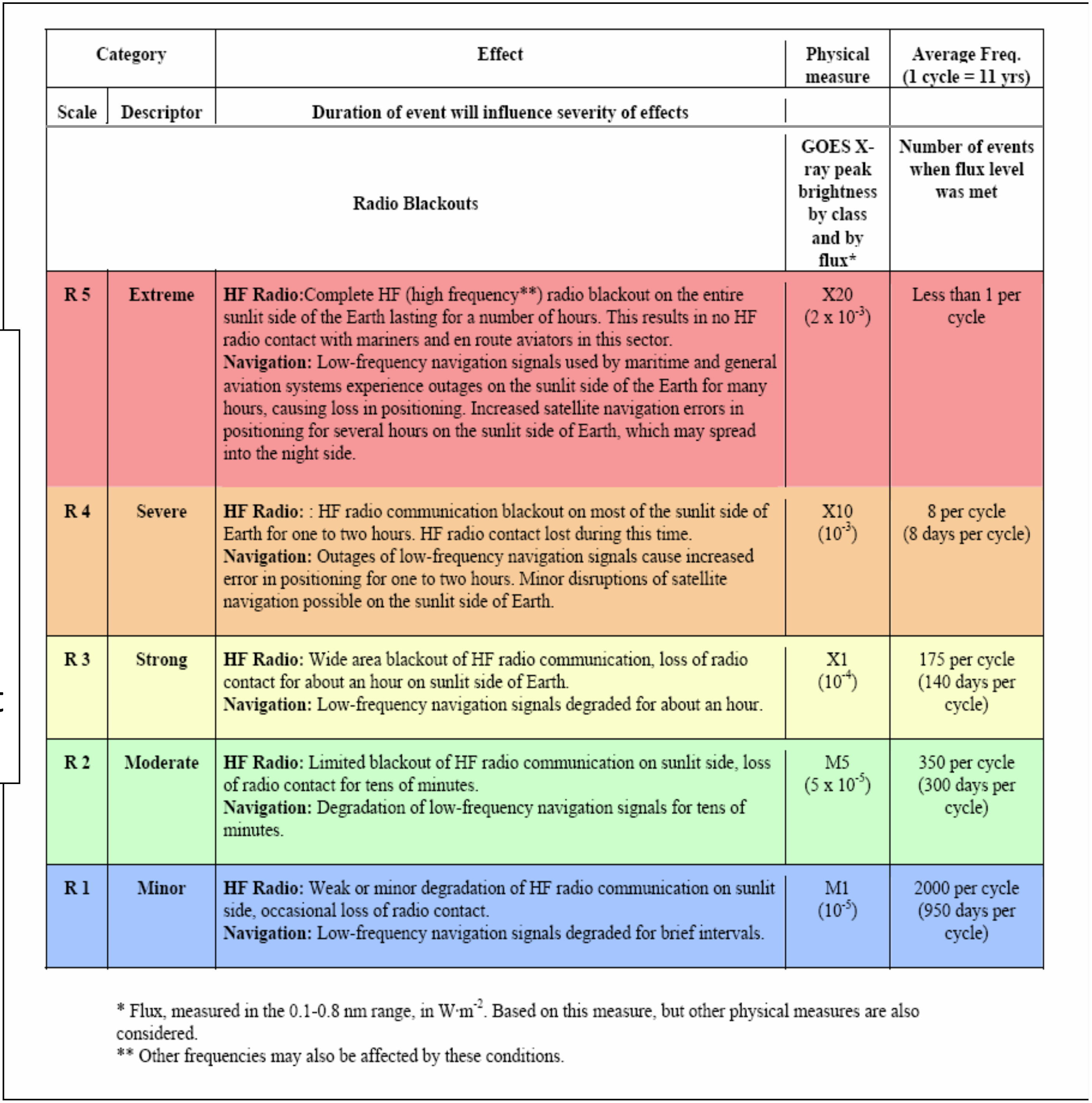
Category		Effect	Physical measure	Average Freq. (1 cycle = 11 yrs)
Scale	Descriptor	Duration of event will influence severity of effects		
Geomagnetic Storms			Kp values* determined every 3 hours	Number of storm events when Kp level was met
G 5	Extreme	**Power systems:** : widespread voltage control 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)

Geomagnetic Storms

Solar Flare Radio Blackouts

R-scale

- Arrival: 8 minutes from Sun to Earth *(speed of light)*
- Duration: minutes to 3 hours
- Daylight-side impact <u>only</u>

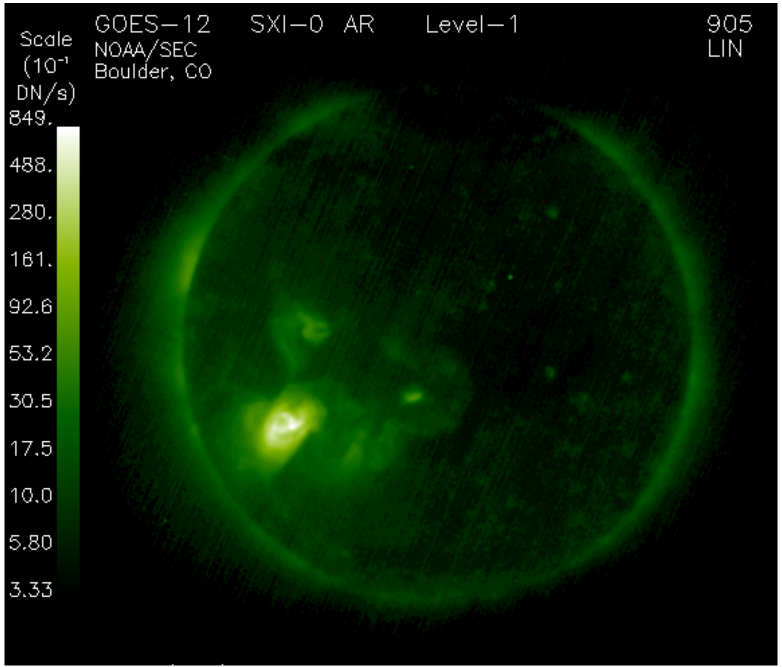


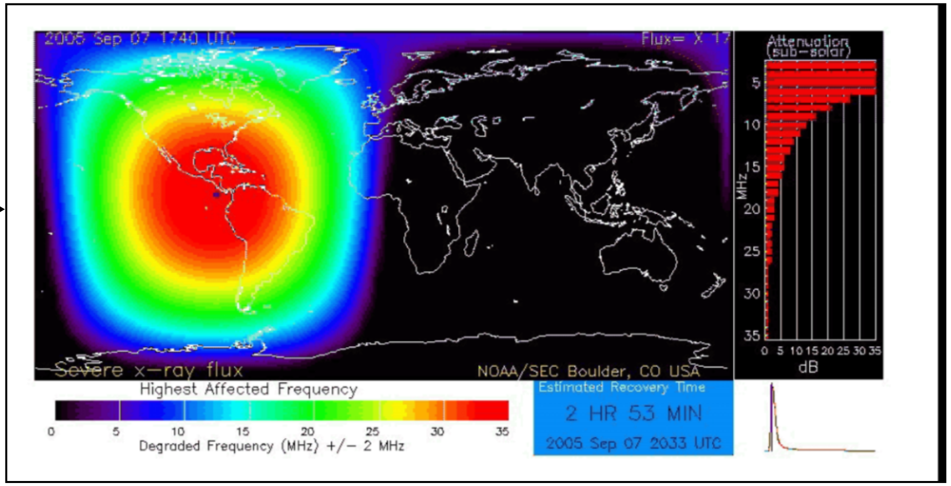
Category		Effect	Physical measure	Average Freq. (1 cycle = 11 yrs)
Scale	Descriptor	Duration of event will influence severity of effects		
Radio Blackouts			GOES X-ray peak brightness by class and by flux*	Number of events when flux level was met
R 5	Extreme	**HF Radio:**Complete HF (high frequency**) 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 x 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 x 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)

* Flux, measured in the 0.1-0.8 nm range, in W·m^{-2}. Based on this measure, but other physical measures are also considered.

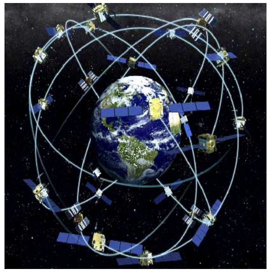
** Other frequencies may also be affected by these conditions.

Solar Flare Radio Blackouts

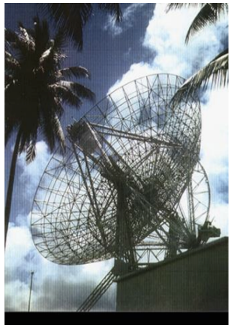




ALERT: X-ray Flux exceeded M5
Issue Time: 2005 Sep 11 1710 UTC
Threshold Reached: 2005 Sep 11 0915 UTC
Location: S17E90
Region Number: UNK
NOAA Scale: R4 - Severe



GPS Network



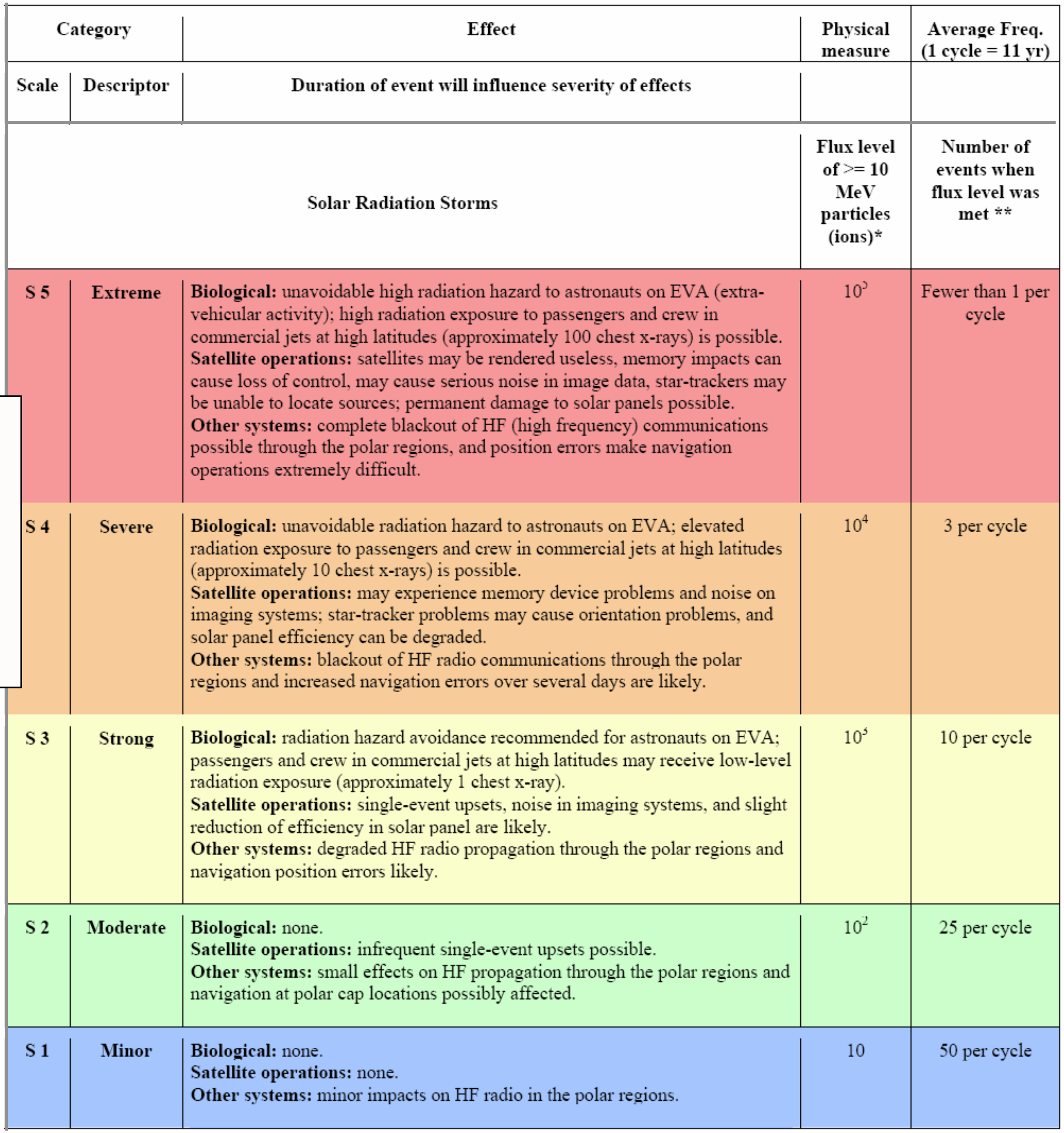
Communications

Radar

Radiation Storms

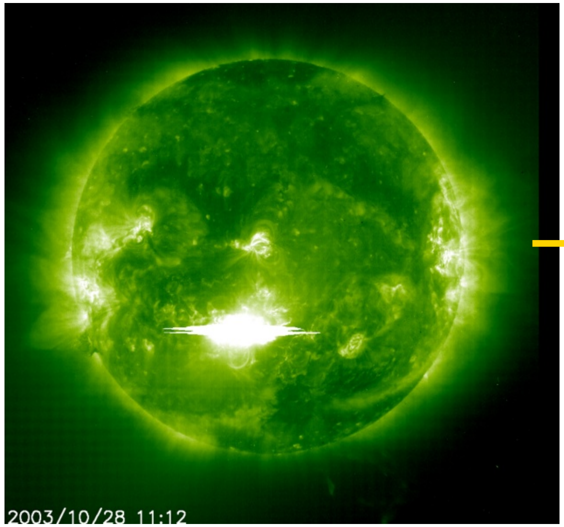
S-scale

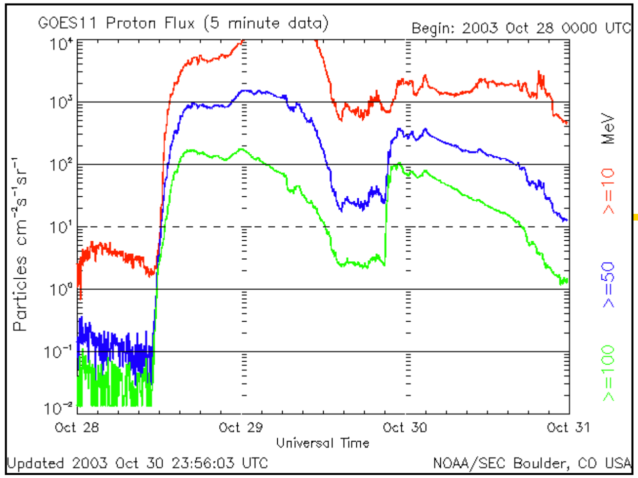
- Arrival: 30 minutes to several hours
- Duration: hours to days

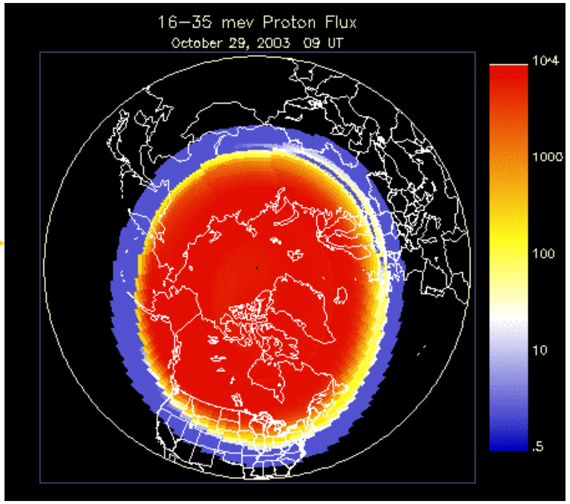


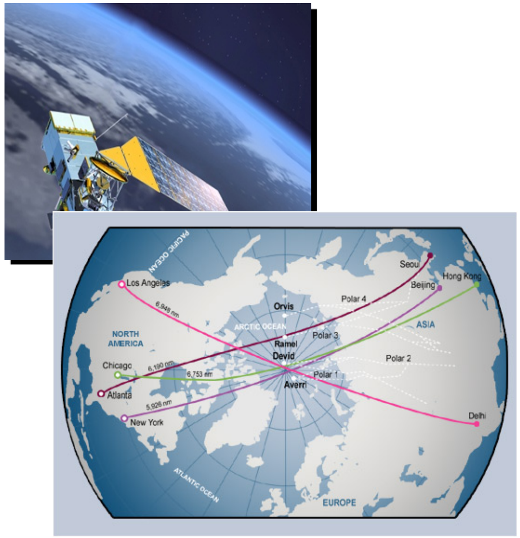
Category		Effect	Physical measure	Average Freq. (1 cycle = 11 yr)
Scale	Descriptor	Duration of event will influence severity of effects		
		Solar Radiation Storms	Flux level of >= 10 MeV particles (ions)*	Number of events when flux level was met **
S 5	**Extreme**	**Biological:** unavoidable high radiation hazard to astronauts on EVA (extra-vehicular activity); high radiation exposure to passengers and crew in commercial jets at high latitudes (approximately 100 chest x-rays) is possible. **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; elevated radiation exposure to passengers and crew in commercial jets at high latitudes (approximately 10 chest x-rays) is possible. **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 commercial jets at high latitudes may receive low-level radiation exposure (approximately 1 chest x-ray). **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.	10^5	10 per cycle
S 2	**Moderate**	**Biological:** none. **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

Radiation Storms – Systems Impacted







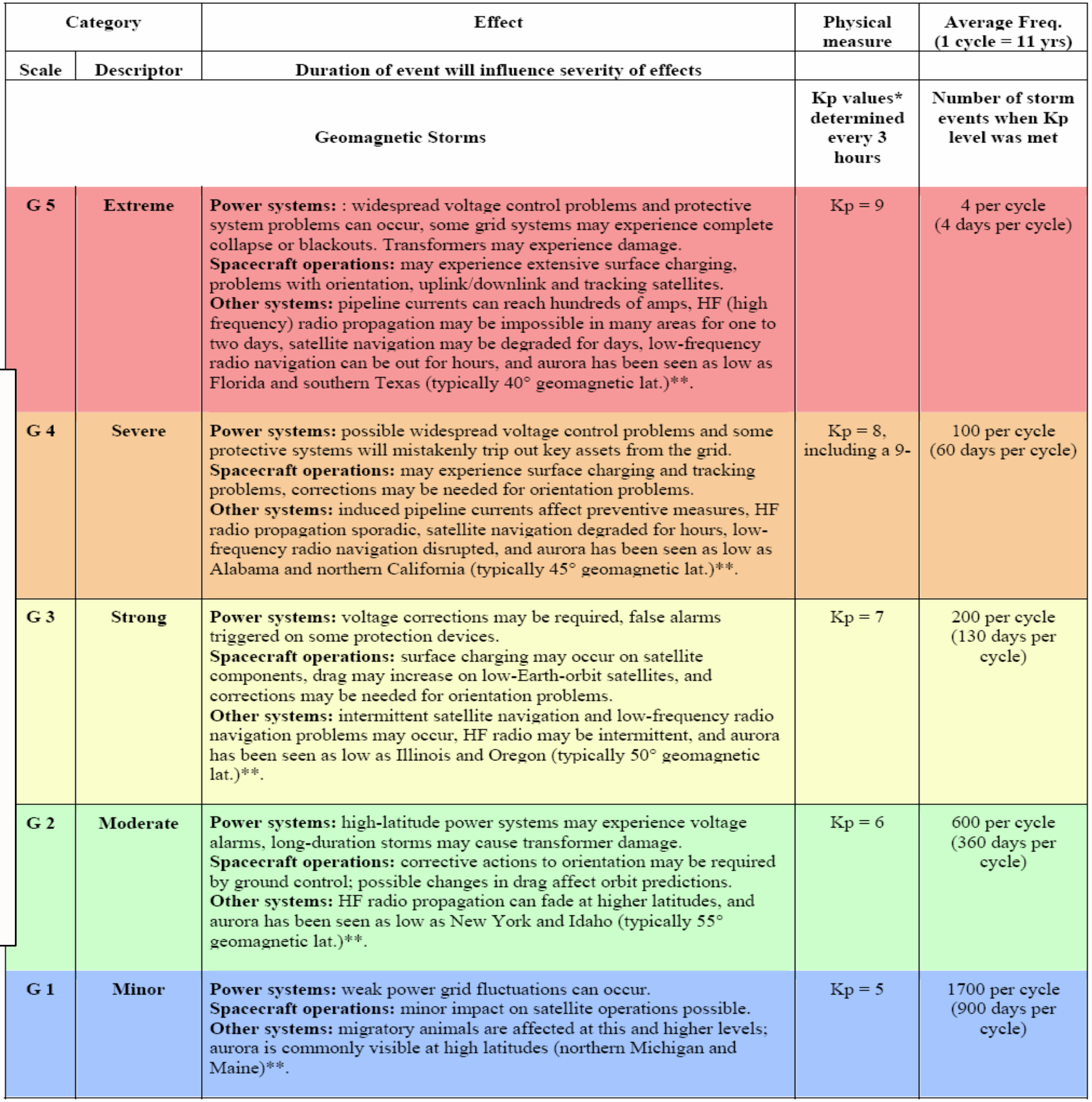


- Satellite Operations (range from loss of data to loss of satellite)
- HF Outage at high latitudes
- Aviation (communications and exposure concerns)

Geomagnetic Storms

G-scale

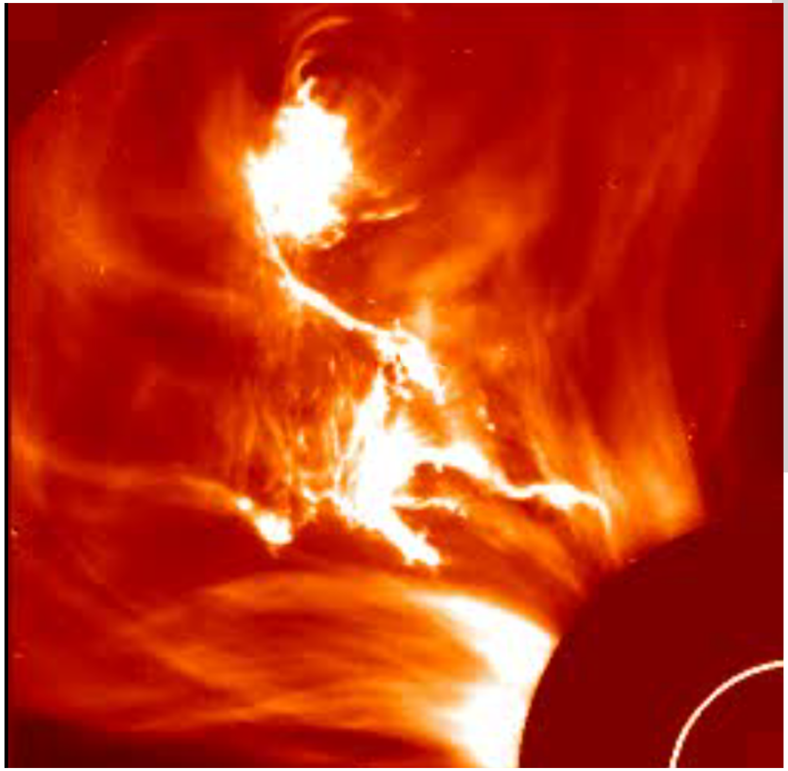
- Arrival: 18 - 90 hours
- Duration: hours to 1-2 days
- NOTE: High levels of solar activity can produce prolonged periods (several days) of geomagnetic storming.

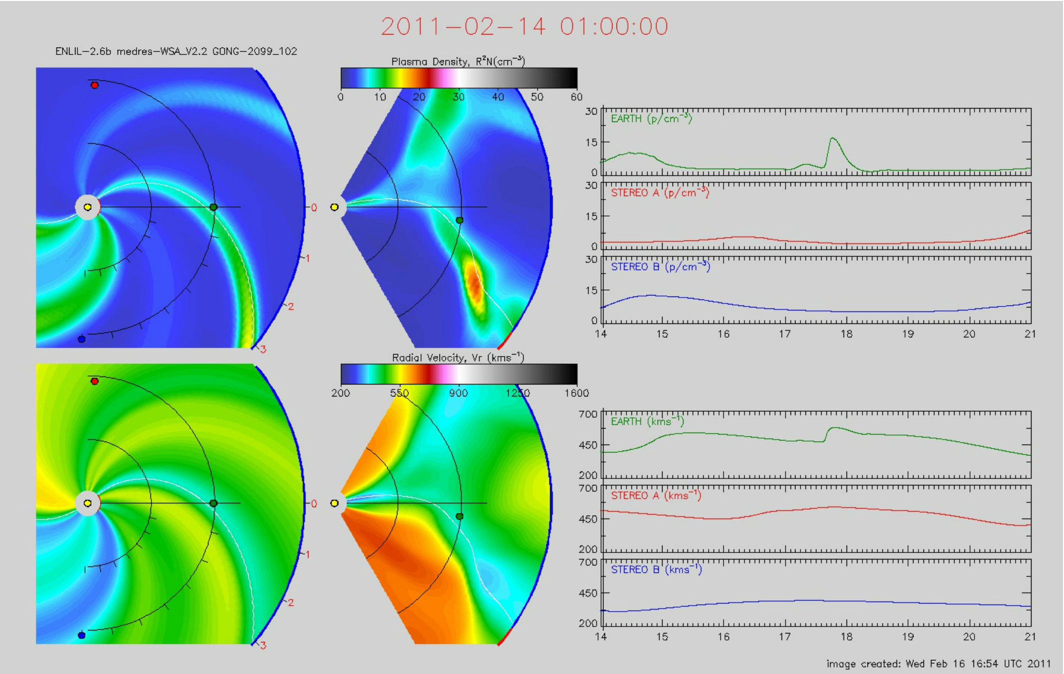


Category		Effect	Physical measure	Average Freq. (1 cycle = 11 yrs)
Scale	**Descriptor**	**Duration of event will influence severity of effects**		
Geomagnetic Storms			**Kp values* determined every 3 hours**	**Number of storm events when Kp level was met**
G 5	**Extreme**	**Power systems:** : widespread 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)

Geomagnetic Storms (G Scale)

Coronal Mass Ejections (CMEs) create geomagnetic storms





WATCH: Geomagnetic A-index of 50 or greater predicted

<u>NOAA Scale: Periods reaching the G3 (Strong) Level Likely</u>

Earth-directed CMEs result in Geomagnetic Storms

Impacts from geomagnetic storms are wide-ranging with potentially significant consequences.

Satellite Operations

Manned Spaceflight

GPS

Power Grid Operations

Aircraft Operations

The aim of civil emergency planning in NATO is to collect, analyse and share information on national planning activity to ensure the most effective use of civil resources for use during emergency situations, in accordance with Alliance objectives.

It enables Allies and Partner nations to assist each other i preparing for and dealing with the consequences of crisis, disaster or conflict.

In a rapidly changing world, populations in NATO and Partn countries are threatened by many risks including the possil use of chemical, biological, radiological weapons by terrorists. However, terrorism is not the only challenge. Natural disasters, such as earthquakes or floods and man-made disasters continue to pose a serious threat to civilian populations.

Civil emergencies: a threat to security and stability

CEP's decision-making bodies

Because civil emergency planning is a multi-dimensional effort, its management requires extensive coordination within the Alliance, as well as with national civil emergency planning personnel and other international organization

The principal body in the area of civil emergencies is the Civil Emergency Planning Committee (CEPC). The operational tool at its disposal is the Euro-Atlantic Disaster Response Coordination Centre (EADRCC).

Civil Emergency Planning Committee

The day-to-day business of the Alliance's civil emergency planning is guided by the Civil Emergency Planning Committee (CEPC) – formerly known as the Senior Civil Emergency Planning Committee (SCEPC) –, which is composed of national representatives who provide oversight to the work conducted at NATO.

Under the authority of the North Atlantic Council, this Committee meets semi-annually in plenary session and hold regular meetings in permanent session. These meetings are chaired by the Assistant Secretary General for Operations and the Deputy Assistant Secretary General for Planning, Civil Emergency Planning and Exercises.

Given the strong interest of Partner countries in civil emergency planning, CEPC meetings are held in the format of the Euro-Atlantic Partnership Council twice-yearly in plenary, encompassing all NATO and Partner countries. Permanent meetings with Partners are held approximately once per month. .

Country representation at plenary level is drawn from heads of national civil emergency planning organizations in capitals. At permanent level, members of national delegations at NATO Headquarters normally attend but may be reinforced from capitals.

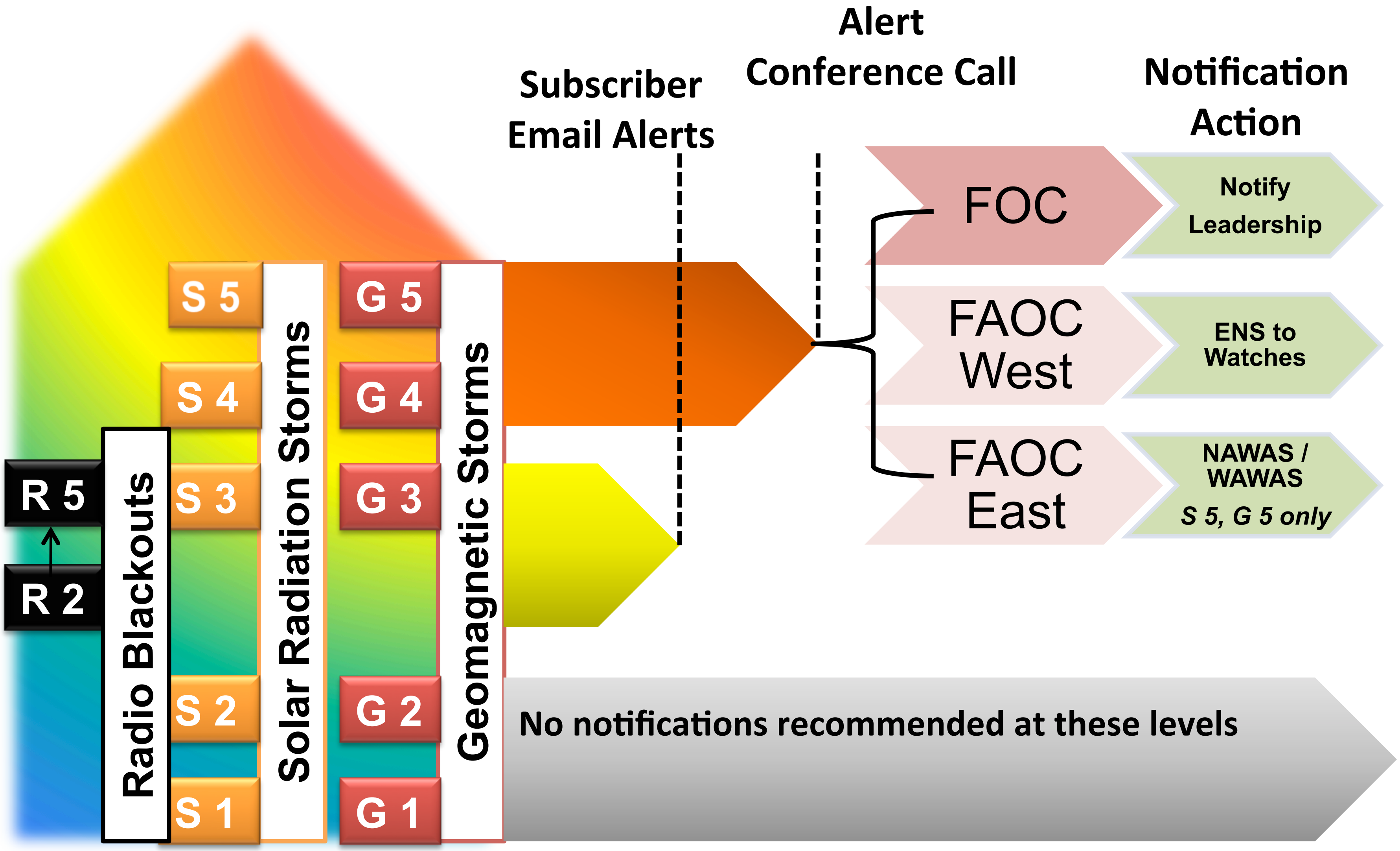
Planning Groups

Under CEPC's direction, four technical Planning Groups bring together national government experts, industry expe and military representatives to coordinate planning in various areas of civil activity. These areas are:

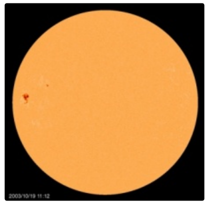
- Civil protection
- Transport (civil aviation, ocean shipping and inland surface)
- Public Health, Food and Water
- Industrial resources and communications

These bodies advise CEPC on crisis-related matters and assist NATO military authorities and countries to develo and maintain arrangements for effective use of civil resources.

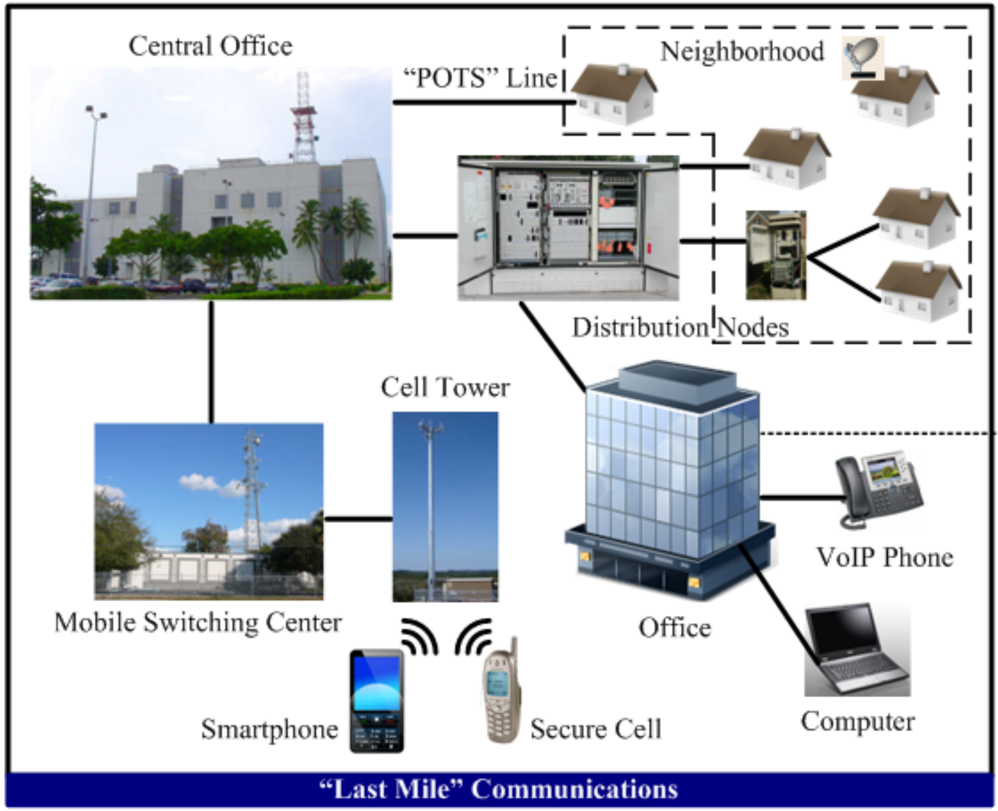
Space Weather Alerts and Notifications

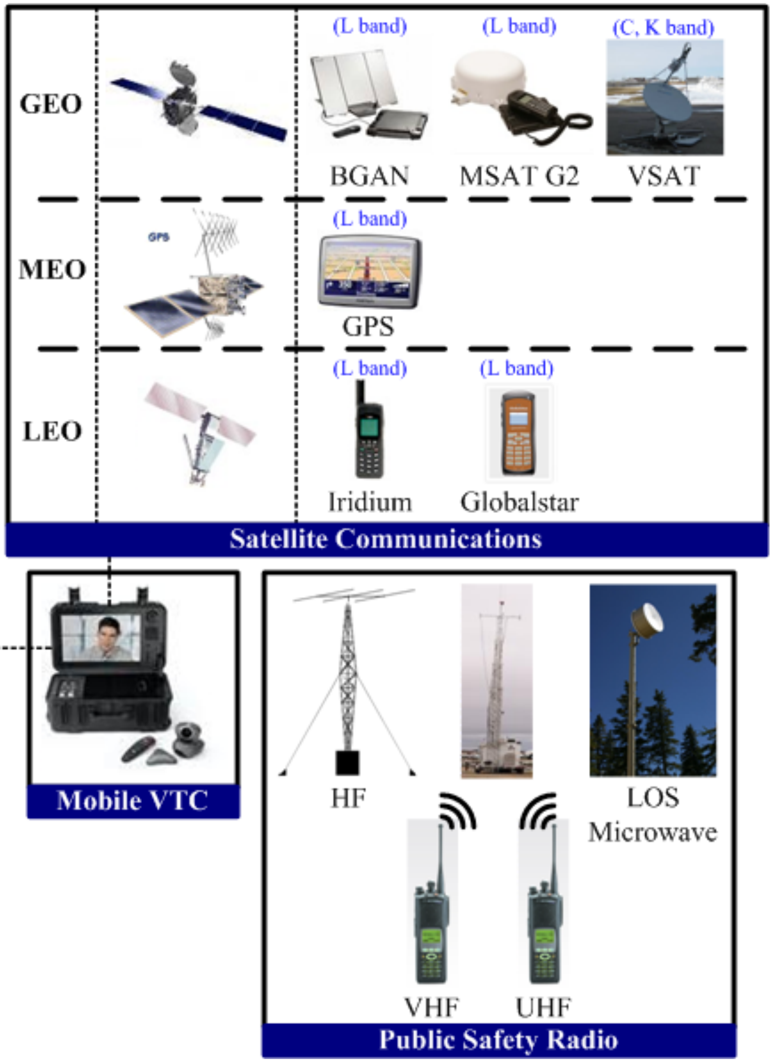


Scenario: (Baseline)



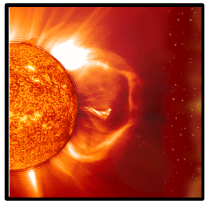
A very large, complex sunspot group emerges near the solar equator





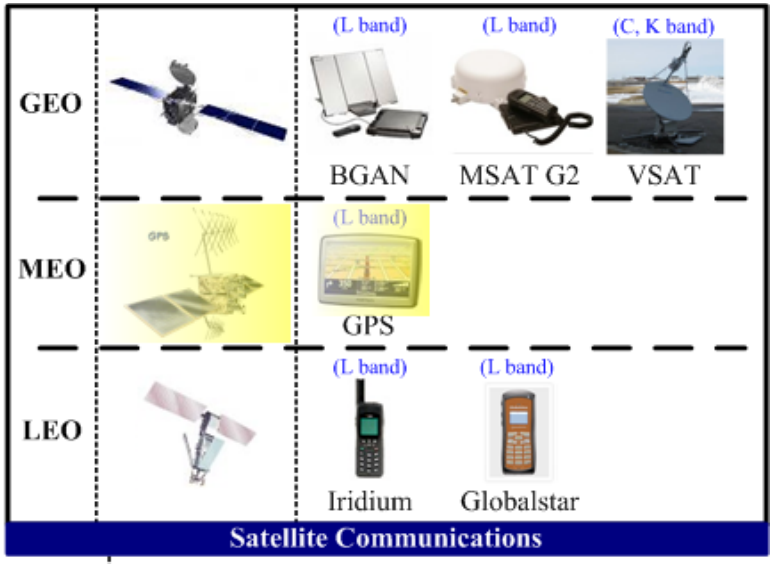
"Last Mile" photos courtesy of AT&T

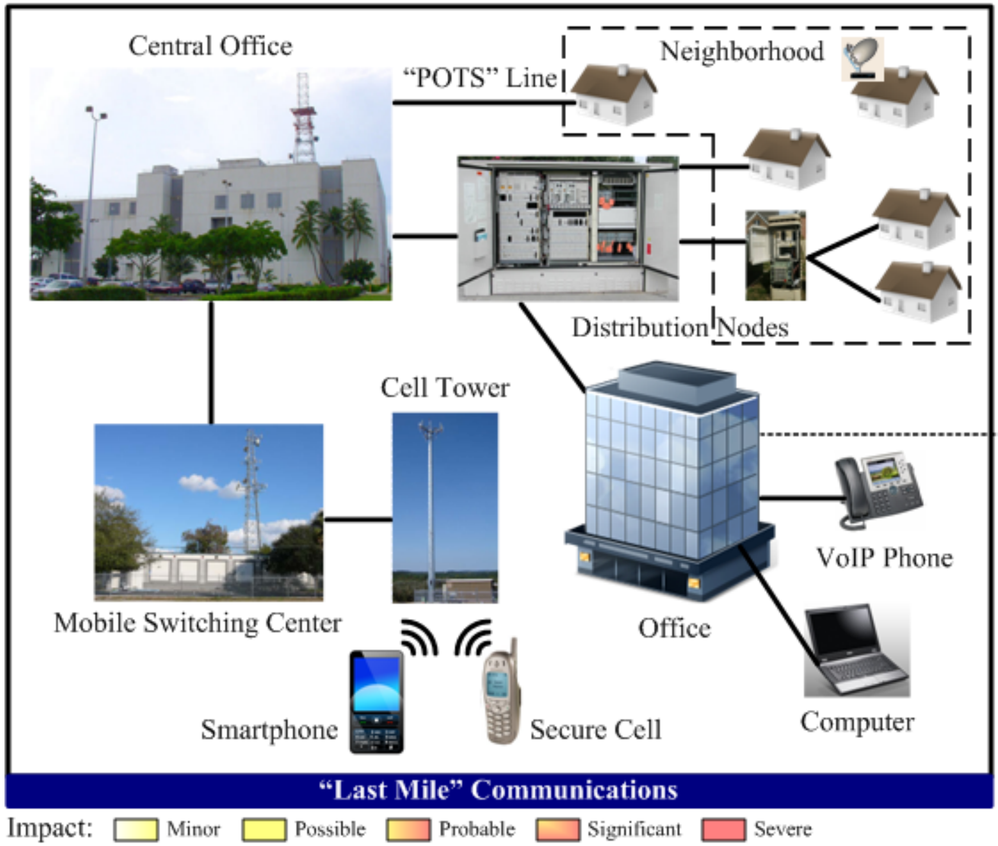
Scenario: R5 Radio Blackout Event



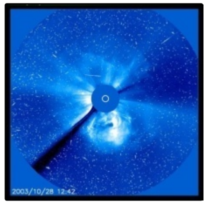
Massive solar flare erupts above near-center-disk sunspot group.

- HF: Several hours (daylight side)
- GPS: Seconds to 15 Minutes





Scenario: S5 Solar Radiation Storm

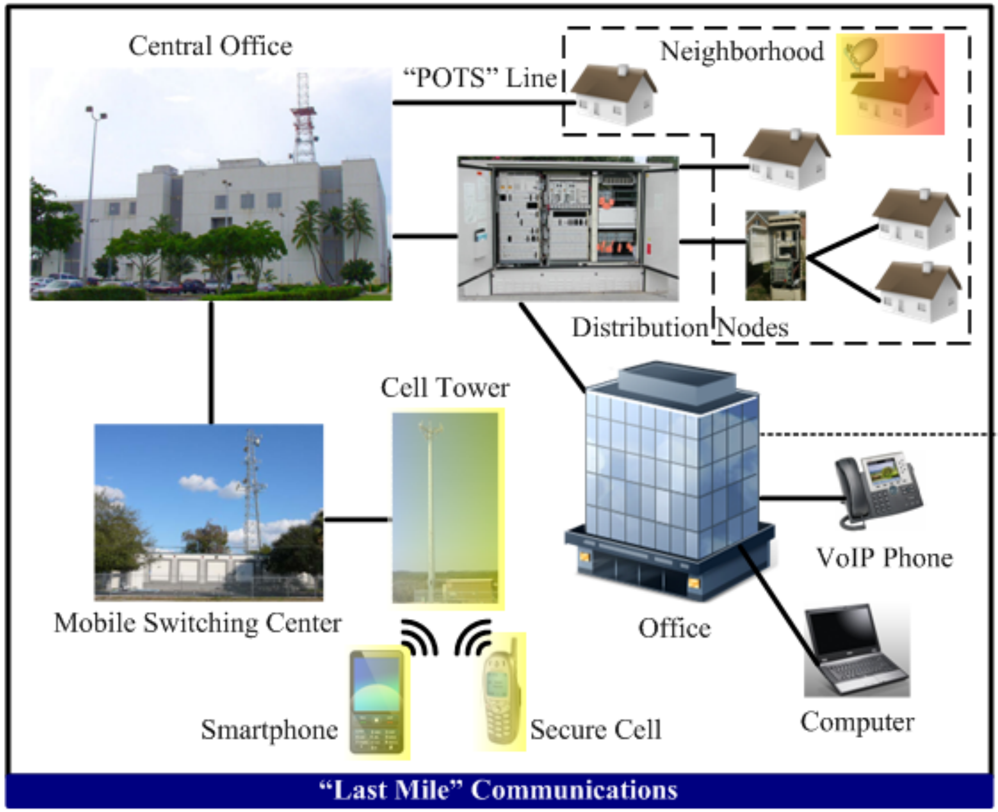


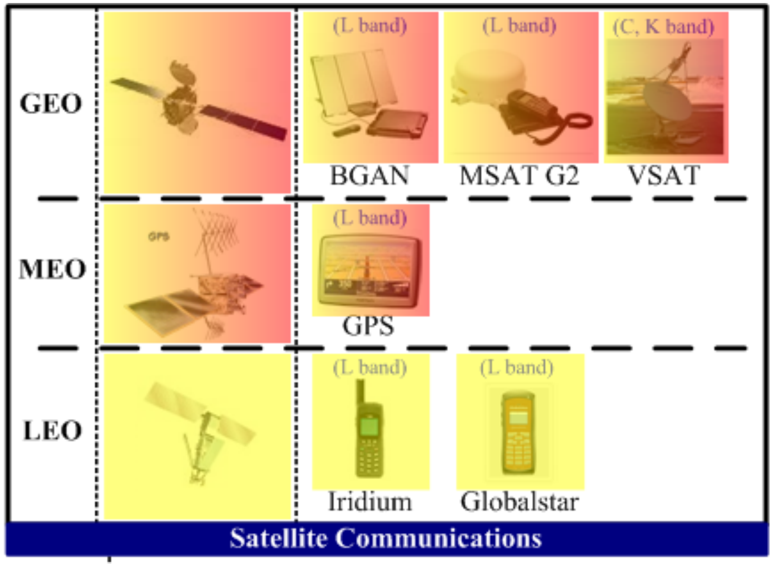
Solar radiation storm arrives twenty minutes after solar flare. Radio blackout event continues.

- 3-24 hours (various effects)

≈ 15% of satellite fleet lost due to solar panel damage

≈ 50 times normal satellite anomalies





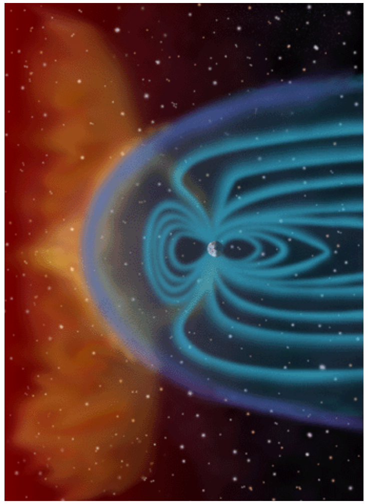
Impact: ☐ Minor ☐ Possible ☐ Probable ☐ Significant ☐ Severe

Power is the fundamental for NATO

- Almost all modern technology relies on the reliable delivery of electric power
- Communications networks and Information transactions cut across all critical sectors.

(Credit: K. Turnbull / J. Wild / ESA)

Scenario: G5 Geomagnetic Storm

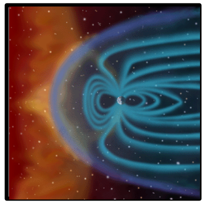


- NASA ACE satellite provides approximately 15 minutes warning of the southward interplanetary magnetic field orientation of the coronal mass ejection.

- Approximately 17 hours after the initial solar flare, the massive, fast-moving CME arrives at the Earth.

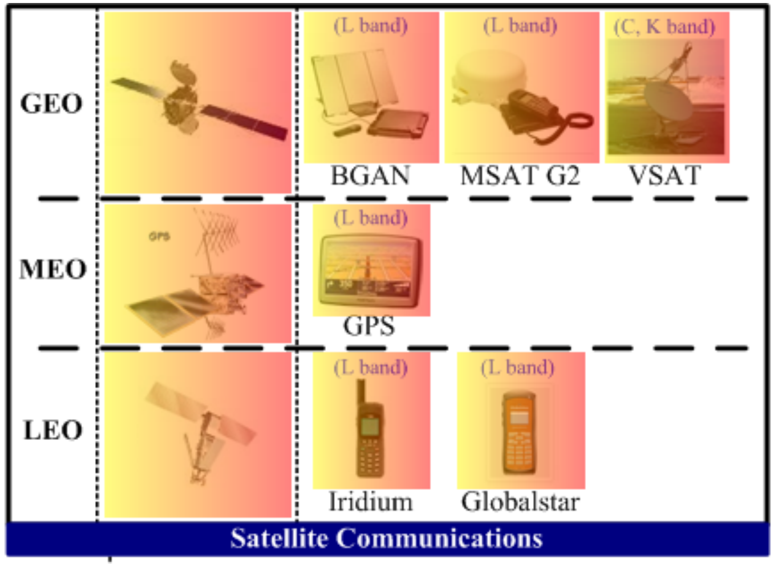
- The physical shock of the CME pushes the daylight side of the magnetosphere inside the geostationary orbit, exposing GEO satellites on the daylight side directly to the solar plasma.

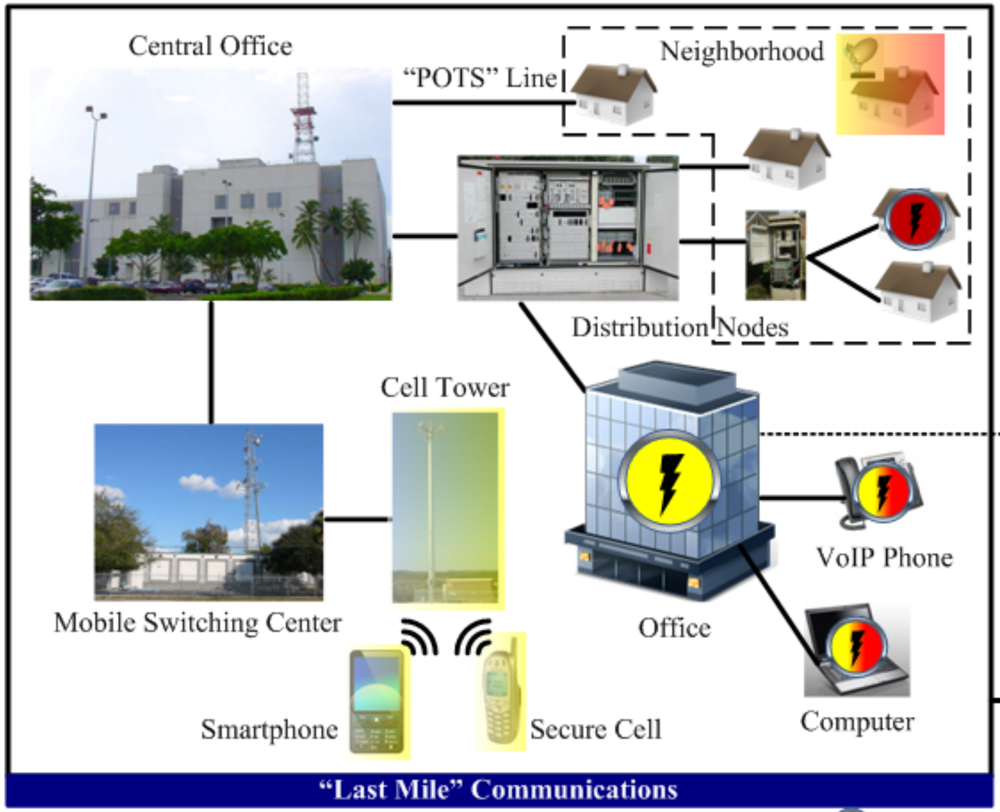
Scenario: G5 Geomagnetic Storm



CME with southward magnetic orientation arrives at Earth causing extreme geomagnetic storm.

- 12-24 hours (various effects)
- SATCOM/GPS severely disrupted due to scintillation
- HF may be possible



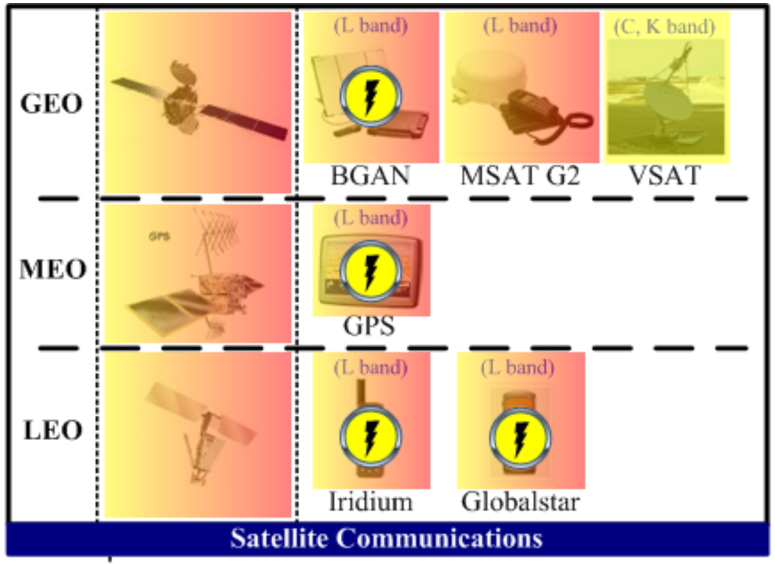
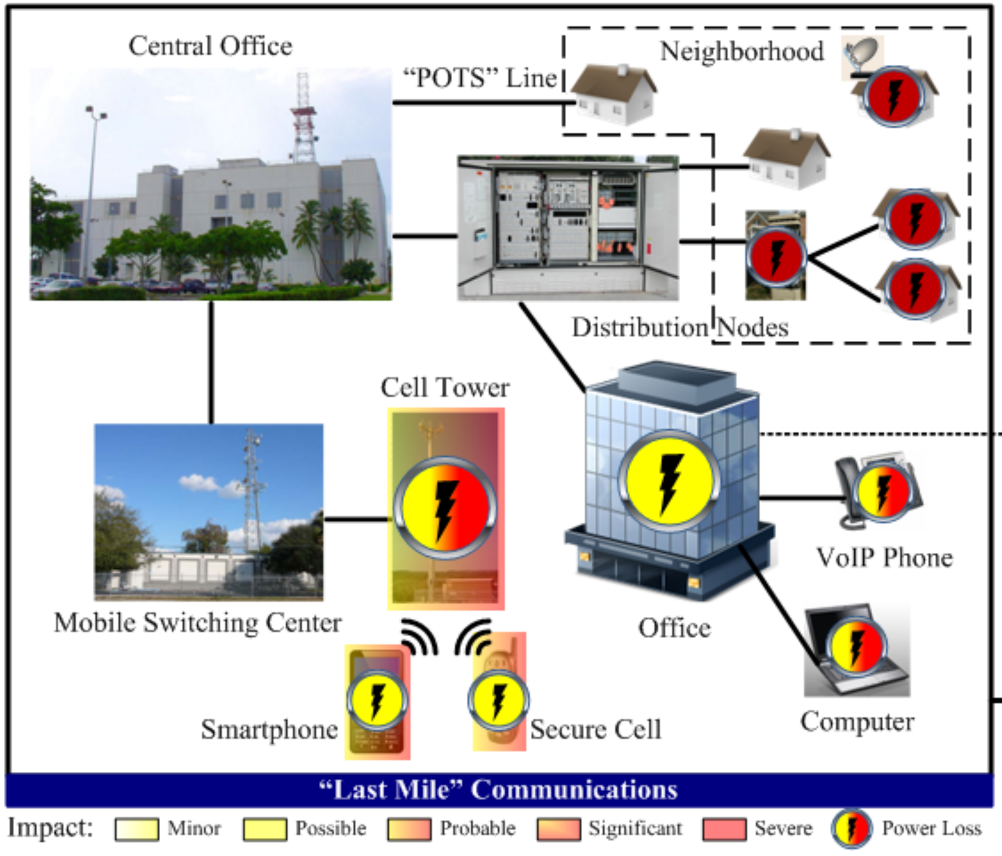
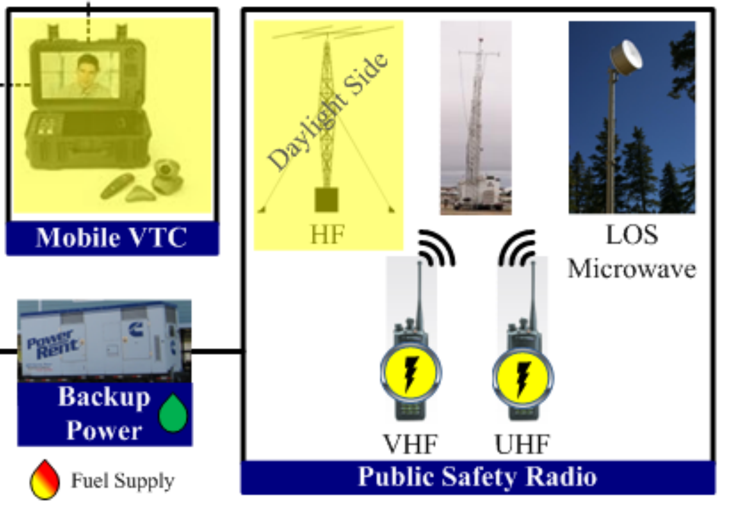


Impact: ☐ Minor ☐ Possible ☐ Probable ☐ Significant ☐ Severe ⚡ Power Loss 🔥 Fuel Supply

Scenario: G + 8 Hours

Loss of power begins to effect "last mile" communications

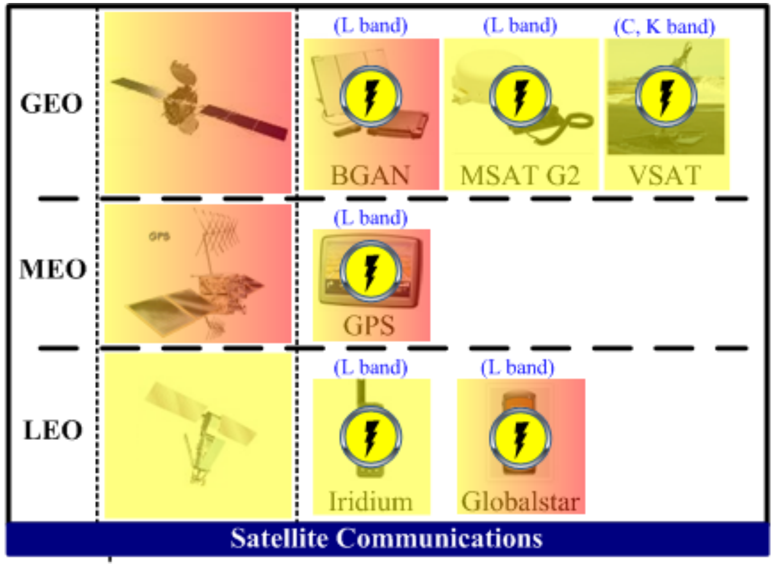
- Numerous cellular towers begin to fail
- Battery backup fails in homes and offices
- HF communications intermittent for next three days

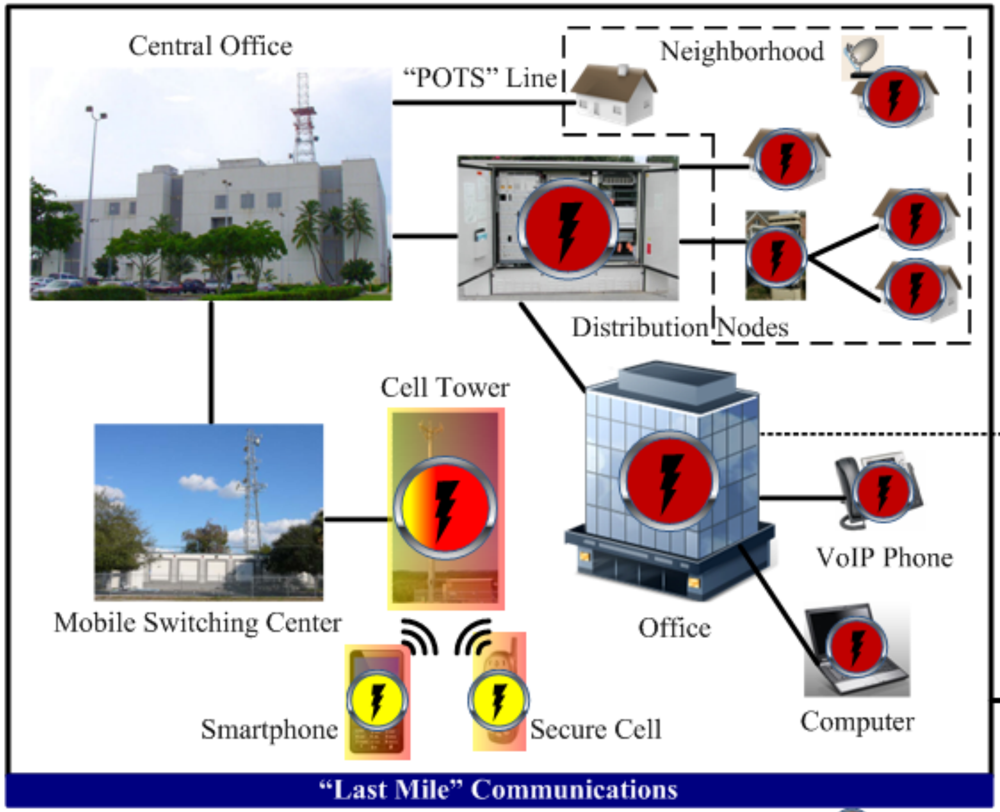




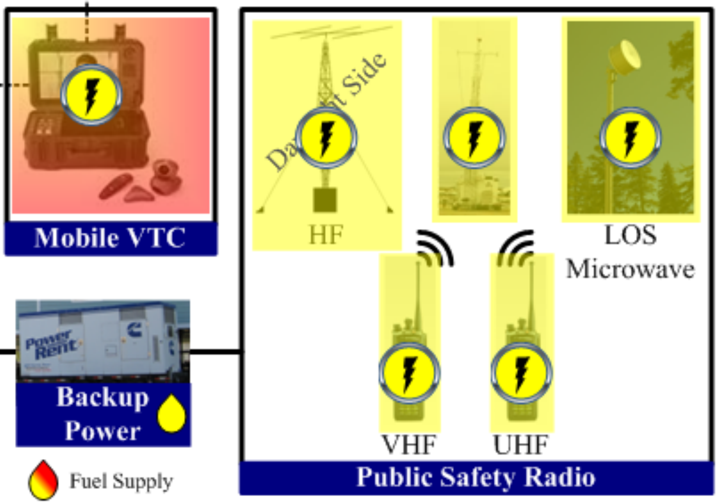
Scenario: G + 24 Hours

Loss of power begins to effect critical systems

- Telecommunications distribution nodes begin to fail; may impact Land Mobile Radio repeater towers
- Power required to recharge equipment batteries





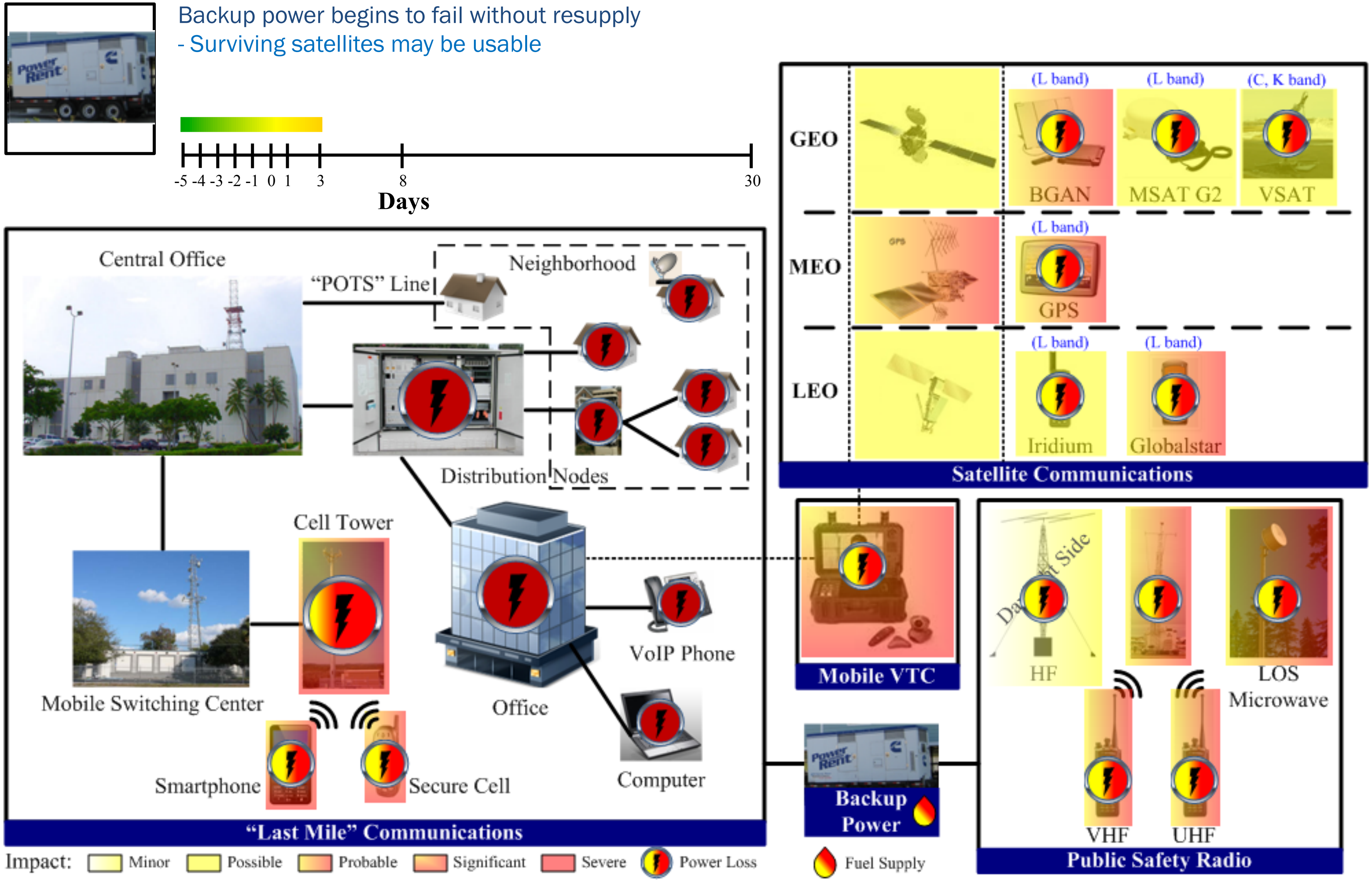


Impact: Minor Possible Probable Significant Severe Power Loss Fuel Supply

Scenario: G +72 Hours

Backup power begins to fail without resupply

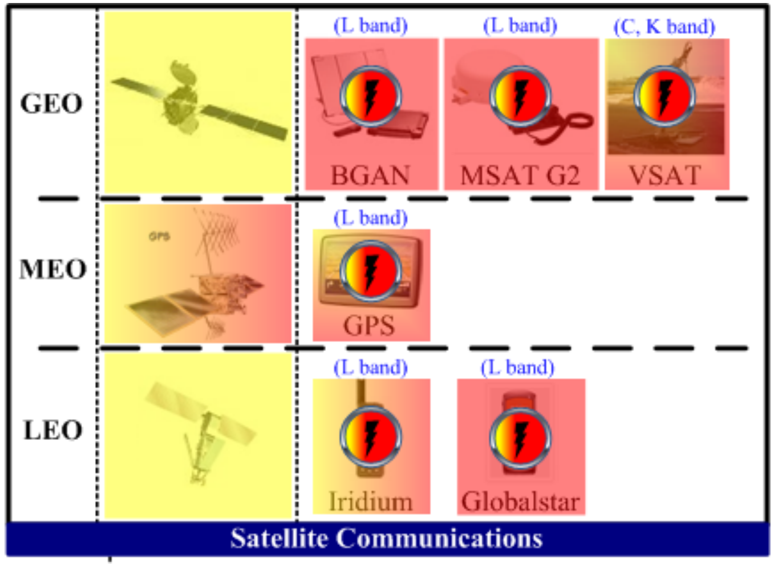
- Surviving satellites may be usable

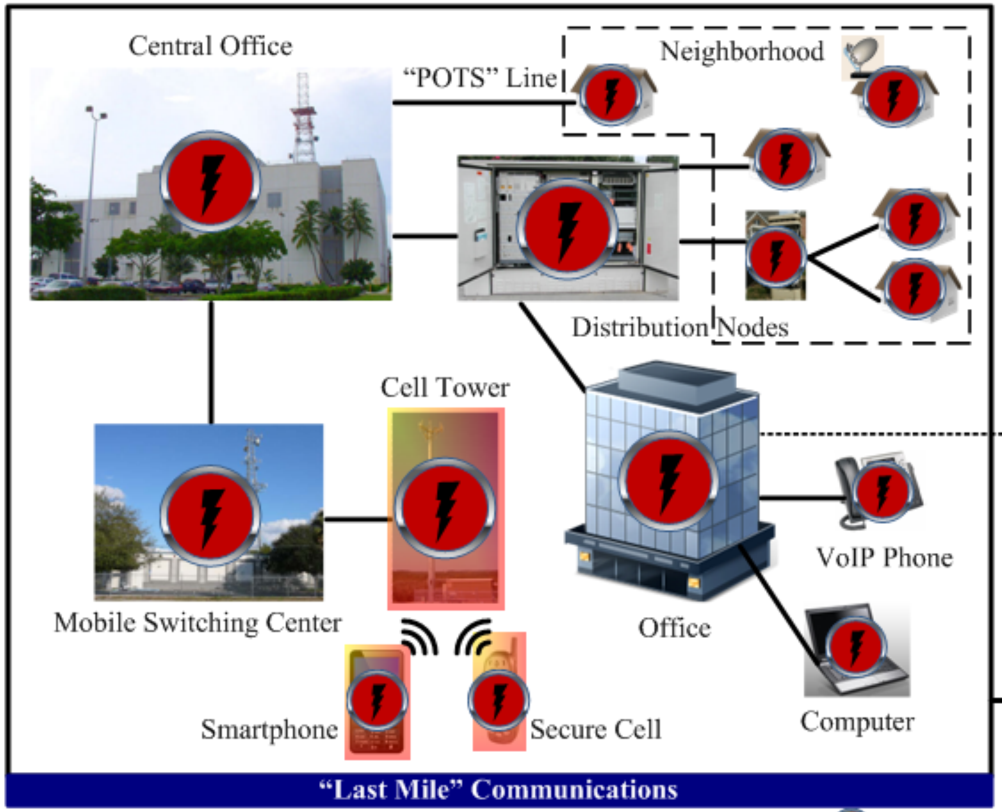


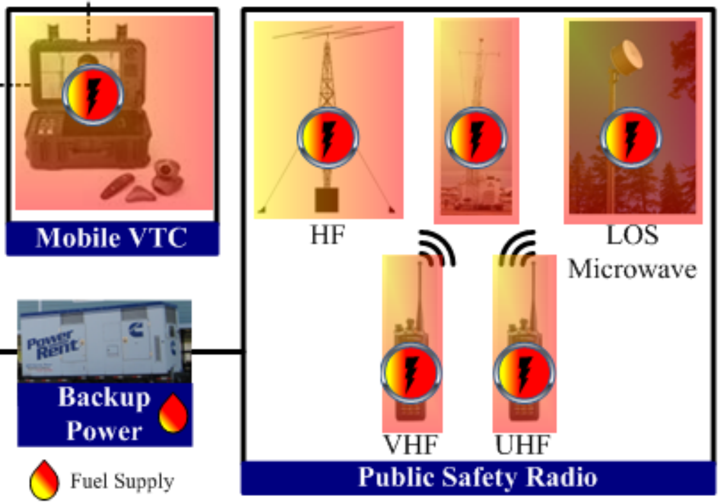
Scenario: G +8 Days

Without fuel and water, the Public Switched Network begins to fail.

- Widespread failure of telecommunications infrastructure; Internet “cloud” fails
- Any system that relies on the PSN cannot talk
- Widespread failure of operations centers







Impact: 🟨 Minor 🟨 Possible 🟧 Probable 🟧 Significant 🟥 Severe ⚡ Power Loss 🔥 Fuel Supply

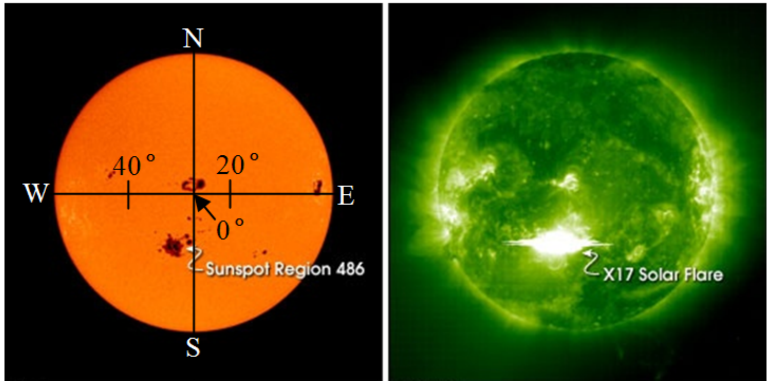
Conclusion

- Diversify
  - Redundant and resilient satellite, radio, and terrestrial communications systems can provide critical communications throughout a superstorm. HF radio could be key to long term critical communications.
- Plan
  - Know what communications systems will work and *when* they will work. Know where and how to get fuel, water, and other consumables. **Don't forget your people.**
- Power, Power, Power
  - Have backup power available—and don't forget that generators need maintenance. If you can, consider renewable sources such as solar, wind, or fuel cells.
- Advocate
  - If you don't, who will. Many solutions to extreme solar weather also solve for other hazards.

Backup Slides for Discussions

- Scenarios
- Systems
- References

What is the worst storm?



SOHO image of 2003 “Halloween Storm” flare

“Solar superstorms cannot be predicted, but the conditions that give rise to them can be foreseen.”

1) Launched from near the center of the Sun onto a trajectory that will cause it to impact Earth’s magnetic field
2) Fast (≥1000 km/s) and massive, thus possessing large kinetic energy
3) Have a strong magnetic field whose orientation is opposite that of Earth’s
4) Contain all three primary types of space weather

Extreme Solar Weather Has Happened Before

Morse Telegraph Table
Photo from www.telegraphlore.com

- 1847 – "Anomalous current" noted on telegraph line between Derby and Birmingham. First recorded impact of solar weather on technology.

- August 28-29, 1859 – Telegraph service disrupted worldwide by geomagnetic superstorm.

- September 1-2, 1859 – Carrington-Hodgson event is largest geomagnetic storm in 500 years.

- May 16, 1921 – The "Great Storm" disrupted telegraph service, caused fires, burned out cables. **Storms like this may occur roughly every 100 years.**

- March 13, 1989 – Geomagnetic storm collapsed Quebec power grid. Northeast U.S. and Midwest power grid came within seconds of collapse.

- October 19 – November 7, 2003 – "Halloween Storms" interrupted GPS, blacked out High Frequency (HF) radio, forced emergency procedures at nuclear power plants in Canada and the Northeastern United States, and destroyed several large electrical power transformers in South Africa.

Scenario: Power

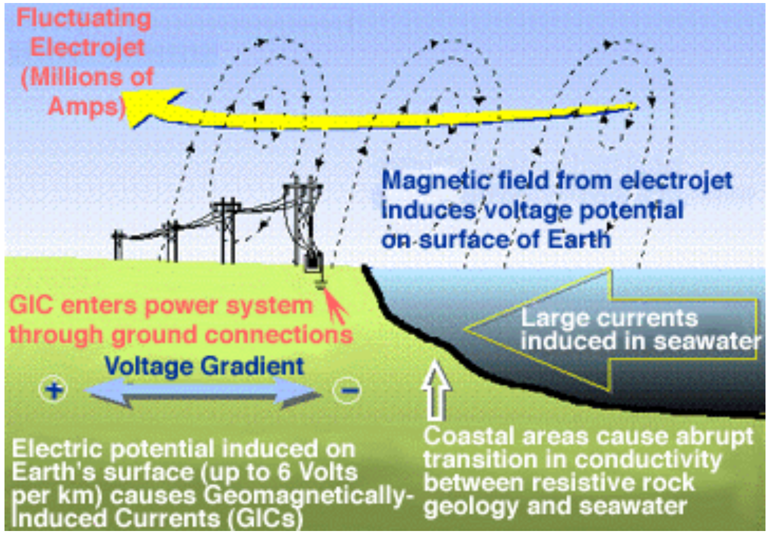


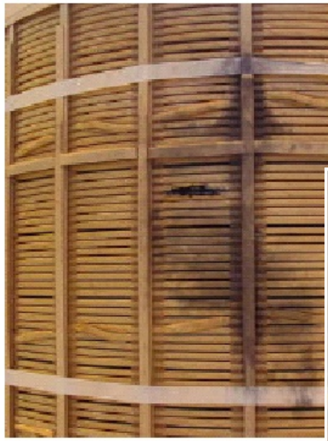
Image courtesy of John G. Kappenman

- Electrojet magnetic fields induce currents in the Earth.
- Geomagnetically-induced currents (GICs):
  - Are quasi-DC currents – effects electrical transformers
  - Can affect power systems at all latitudes
  - Can affect many power transformers simultaneously at multiple points across regional and continental scale power networks
  - Can reach in excess of 1000-2000 amps?
  - Seek “path of least resistance” – high-voltage power lines and pipelines have very low resistance
  - Enter power networks through ground connections

Scenario: ESKOM Transformers Damaged

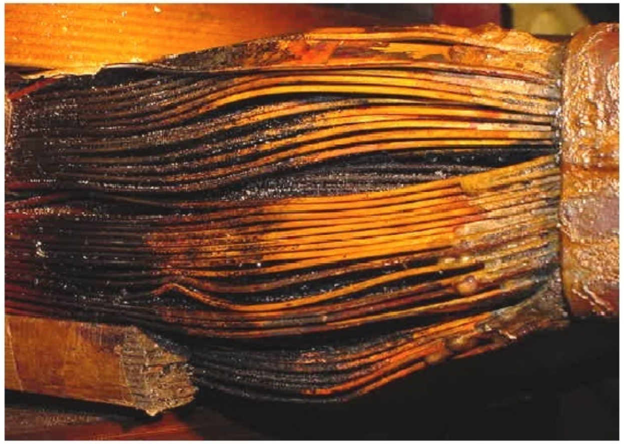
Station 4 Transformer 6 HV winding failure

Station 3 Transformer 6 LV exit lead overheating



Station 5 Transformer 2

Station 3 Gen Transformer 4 damage



Station 3 Gen. Transformer 5 overheating

Scenario: Scintillation

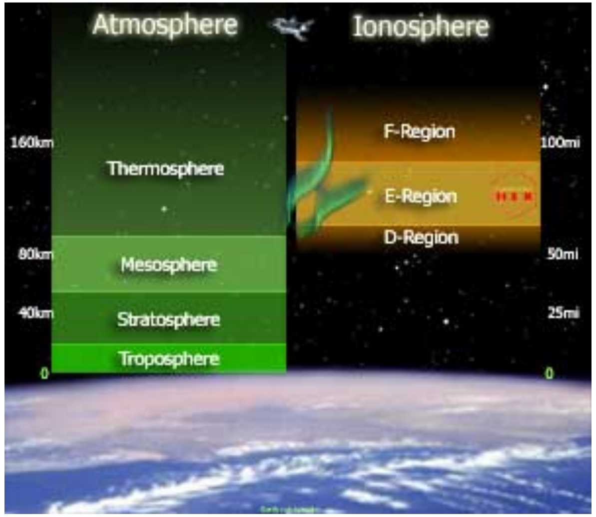


Image courtesy of solar-center.stanford.edu

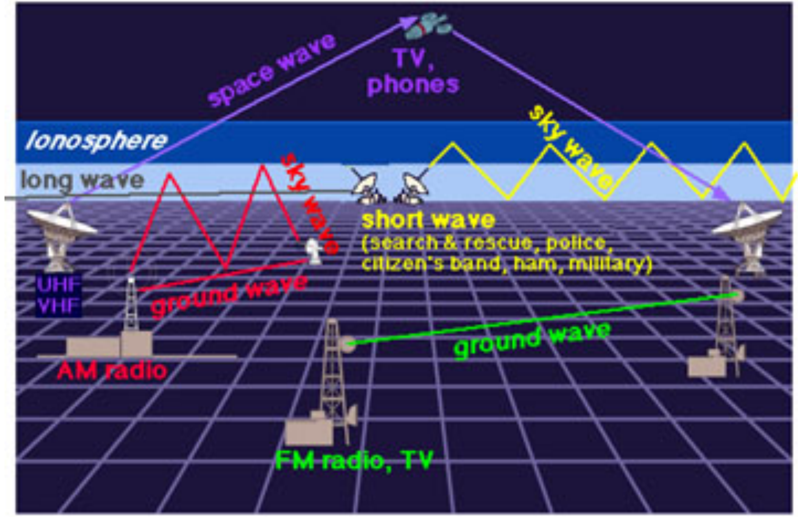


Image courtesy of Windows to the Universe

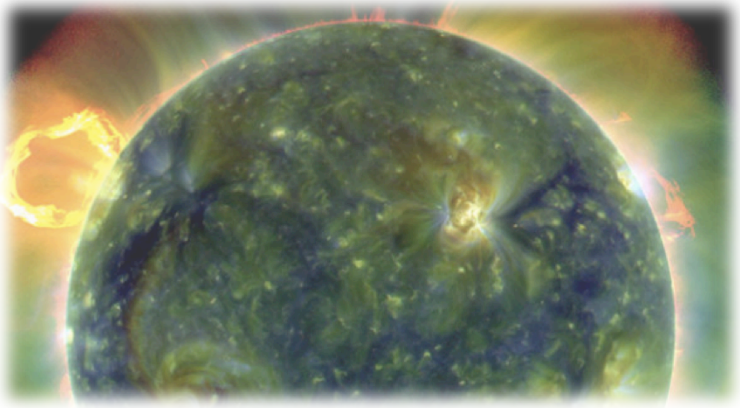
- Southward magnetic orientation of the CME creates immense currents in the ionosphere called “electrojets.”
- These currents cause scintillation, which can change the amplitude, phase, polarization, and angle-of-arrival of signals. Scintillation can become so severe that it represents a practical limitation for communication systems.
- Scintillation can degrade or even prevent signals to and from satellites for 12-24 hours.
- HF communications may be helped during this period due to enhancement of the ionosphere F Layer that could improve reflectivity, though HF will remain spotty for 1-2 more days .

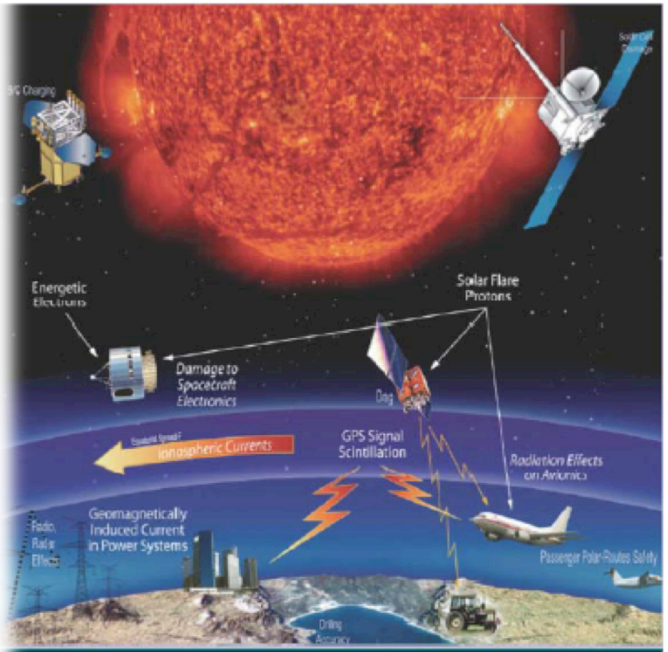
Scenario: Global Positioning System

- The Global Positioning System constellation provides location and timing information for users worldwide and requires a minimum of 24 MEO satellites to provide complete global coverage.
- Current GPS fleet consists of 30 operational satellites.
  - All 11 surviving Block IIA satellites are well past their designed lifetimes.
  - 6 of the 19 Block IIR satellites are now beyond their designed lifetime.
- Block IIF GPS Satellites are 3 ½ years behind schedule.
  - GPS network could fall to 25 usable satellites by the end of 2012 and 24 satellites by late 2014, if no further program.
- Should the network fall below the required 24 satellites, position information may not be available for portions of the day when the requisite 4-6 satellites are not above the horizon for specific geographic locations. Impacts E911.
- Loss of GPS timing could cause some cellular towers to go into “island mode” where they are unable to hand off calls from one cell tower to another, resulting in dropped calls for users moving between tower coverage areas.

Solar Storms Damage Critical Infrastructure

- Satellites
  - 1994: Anik E1 & E2 damaged (TV and data services lost to 1600 communities)
  - 1998: PanAmSat's Galaxy IV satellite (disrupted pager service)
  - 2003: Extensive satellite upsets and damage due to a solar storm
- Power grid (especially Extra High Voltage (EHV) transformers)
  - 1958 & 1972: Transformer failures at British Columbia Hydro and Power Authority
  - 1989: Hydro Quebec power interrupted/damaged; Salem NJ nuclear plant transformers failed
  - 2003: 14 transformers damaged in South Africa
- Long communications lines 1859, 1882, 1909, 1921, 1926: Telegraph lines disrupted, operators shocked, fires started
  - 1940 and 1958: Landline and undersea lines disrupted and/or damaged
  - 1972: US and Canada's telephone system damaged/disrupted
- HF radio paths
  - 1991 upset of HF radio support Gulf War
- Global Positioning System (GPS) (disruption)





Comms on the Move; ISR; Missile Detection, Tracking, Intercept; Precision Engagement; Intell; S/C Anomaly Assessment; Attack Assessment; Power Grid Failures

Civil Emergency Planning vulnerabilities beyond communications

- **Microelectronics at altitude:** computer errors degrade data/control
- **Aviation:** Irradiation of people and equipment, reroute polar flights
- **Telecom long lines**: i.e. sea cables
- **Geographically distributed systems:**
  - Pipelines (gas, oil, water) and pumps
  - Railway signals
  - SCADA systems i.e. water management

Source Acknowledgements

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Federal Emergency Management Agency

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