FEMA

Extreme Space Weather

Considerations for Telecommunications Impact and Mitigation

For the Space Weather Enterprise Forum
27 June 2017

Worst Natural Disaster in U.S. History

- **August 30, 1900** – Hurricane spotted in the Eastern Caribbean.
- **September 4, 1900** – Hurricane passes over Cuba.
- **September 6, 1900** – Hurricane reaches northeast of Key West. Warnings issued for eastern gulf states, Florida, and the southern Atlantic Coast.
- Without weather satellites or even ship-to-shore radio, location, path, and strength of hurricane is a mystery.
- **September 7, 1900** – Galveston Weather Station Chief Isaac M. Cline notices unusual swell in Galveston Bay. Advises residents to seek high ground. High ground is 8.7 feet.
- **September 8, 1900** – Category 4 hurricane makes landfall. Storm surge is 15 feet. 8,000 people die (official). Account courtesy of NOAA.

What the Galveston Hurricane Teaches Us about Space Weather

What they didn't know:

- Probable location(s) of impact
- Estimated time of impact at those locations
- Severity of impact
- Duration of impact

- The same is currently true for extreme space weather

Space Weather is <u>not</u> Nuclear EMP

Electromagnetic Pulse (EMP) from nuclear explosions produces a high frequency (E1) component, which can damage consumer electronics, and a low frequency (E3) component that can damage large-scale conductors such as the electric power grid.

Space weather has no E1 component and will not directly damage consumer electronics on the Earth.

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 se		
		Radio Blackouts		
R 5	Extreme	**HF Radio:**Complete HF (high frequency**) rad sunlit side of the Earth lasting for a number of ho radio contact with mariners and en route aviators **Navigation:** Low-frequency navigation signals u aviation systems experience outages on the sunli hours, causing loss in positioning. Increased sate positioning for several hours on the sunlit side of into the night side.		
R 4	Severe	**HF Radio:** : HF radio communication blackout Earth for one to two hours. HF radio contact lost **Navigation:** Outages of low-frequency navigatio error in positioning for one to two hours. Minor navigation possible on the sunlit side of Earth.		
R 3	Strong	**HF Radio:** Wide area blackout of HF radio com contact for about an hour on sunlit side of Earth. **Navigation:** Low-frequency navigation signals d		
R 2	Moderate	**HF Radio:** Limited blackout of HF radio comm of radio contact for tens of minutes. **Navigation:** Degradation of low-frequency navig minutes.		
R 1	Minor	**HF Radio:** Weak or minor degradation of HF ra side, occasional loss of radio contact. **Navigation:** Low-frequency navigation signals d		

* Flux, measured in the 0.1-0.8 nm range, in $W \cdot m^{-2}$. Based on th considered.
** Other frequencies may also be affected by these conditions.

Radio Blackouts

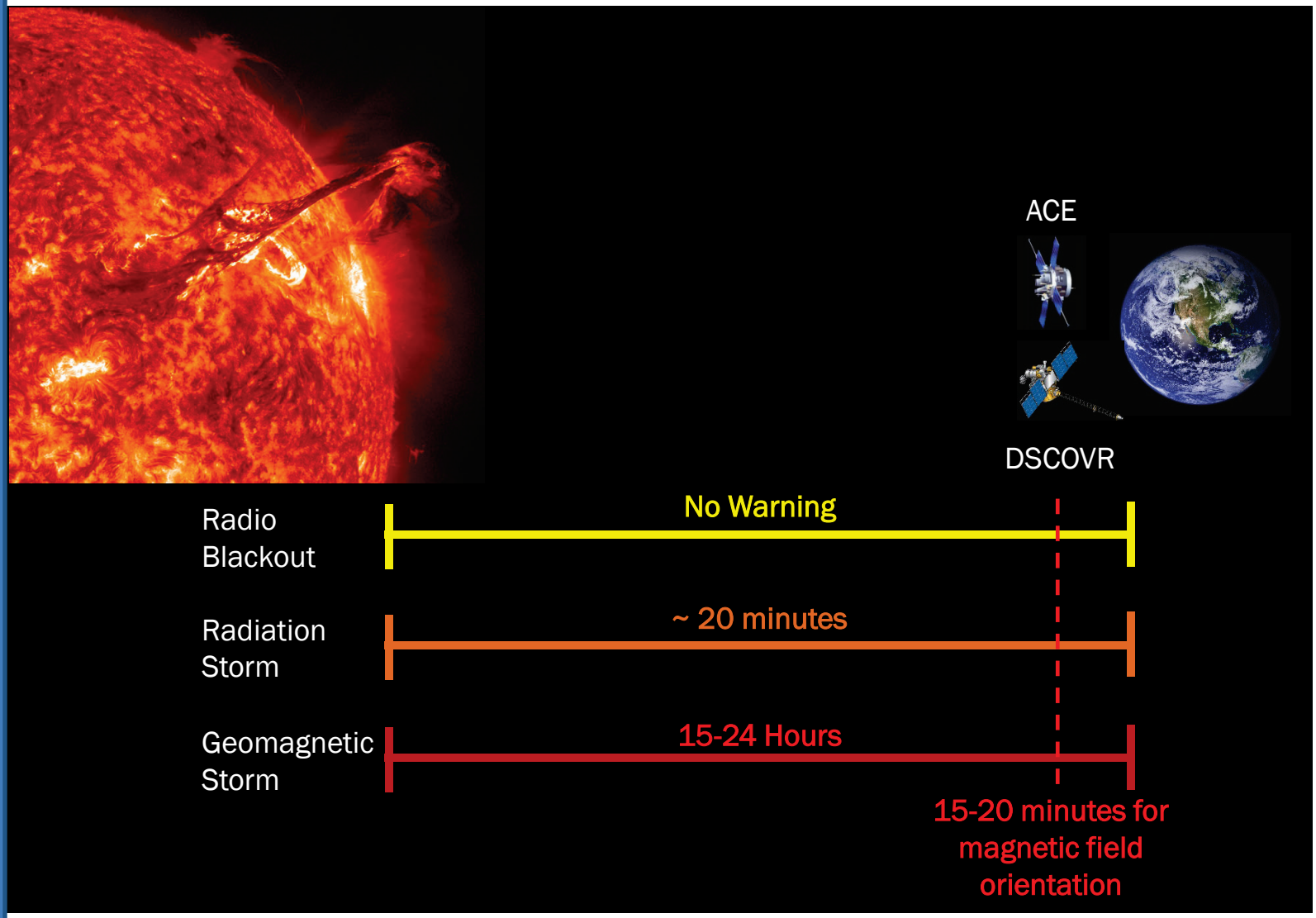
Category		Effect	Physical measure	Average Freq. (1 cycle = 11 yr)
Scale	Descriptor	Duration of event will influence severity of effects		
		Solar Radiation Storms	Flux level of >= 10	Number of events when
S 5	Extreme	**Biological:** unavoidable high radiation hazard to astr vehicular activity); high radiation exposure to passer commercial jets at high latitudes (approximately 100 **Satellite operations:** satellites may be rendered usel cause loss of control, may cause serious noise in ima be unable to locate sources; permanent damage to so **Other systems:** complete blackout of HF (high freq possible through the polar regions, and position erro operations extremely difficult.		
S 4	Severe	**Biological:** unavoidable radiation hazard to astronau radiation exposure to passengers and crew in comme (approximately 10 chest x-rays) is possible. **Satellite operations:** may experience memory devic imaging systems; star-tracker problems may cause o solar panel efficiency can be degraded. **Other systems:** blackout of HF radio communicatio regions and increased navigation errors over several		
S 3	Strong	**Biological:** radiation hazard avoidance recommende passengers and crew in commercial jets at high latitu radiation exposure (approximately 1 chest x-ray). **Satellite operations:** single-event upsets, noise in im reduction of efficiency in solar panel are likely. **Other systems:** degraded HF radio propagation thro navigation position errors likely.		
S 2	Moderate	**Biological:** none. **Satellite operations:** infrequent single-event upsets **Other systems:** small effects on HF propagation thr navigation at polar cap locations possibly affected.		
S 1	Minor	**Biological:** none. **Satellite operations:** none. **Other systems:** minor impacts on HF radio in the po		

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)

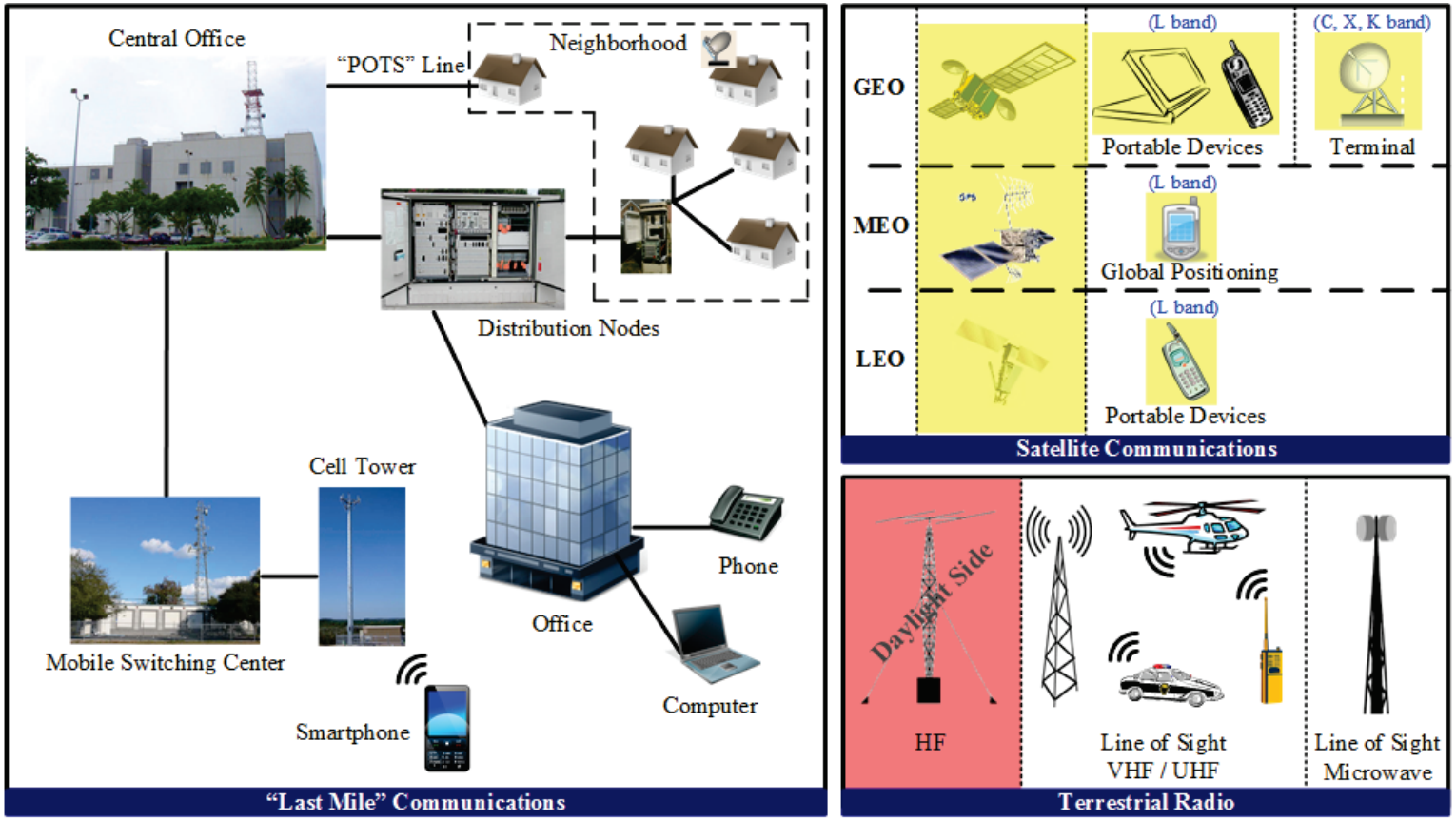
Geomagnetic Storms

Extreme Event Warning Times



R5 Radio Blackout Event

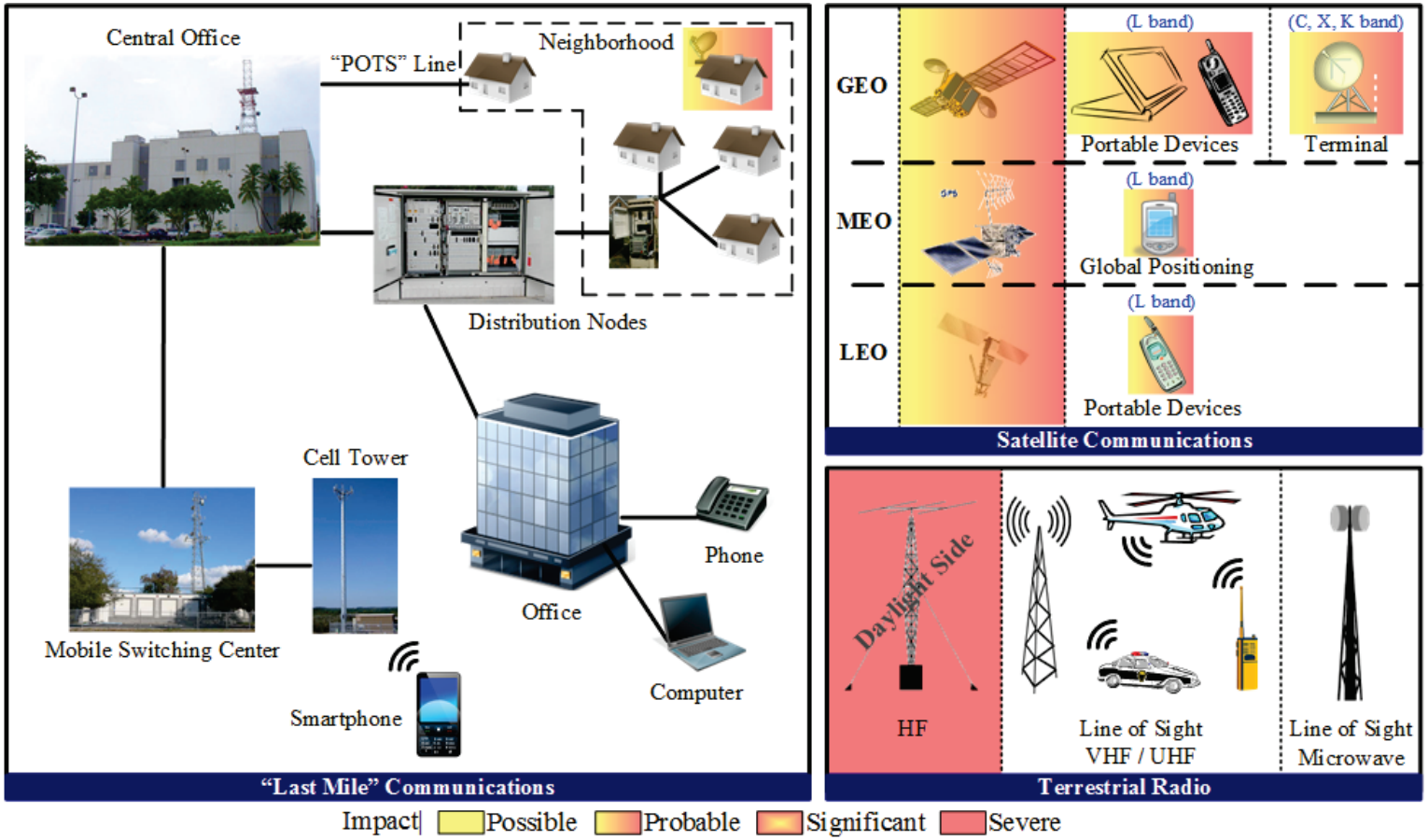
- A radio blackout event ***will not*** blackout all radio communications.
- Can degrade or prevent over-the-horizon communications in the 5-35 MHz range.
- Radiation at microwave frequencies may degrade satellite communications for up to an hour.
- Line-of-sight radio communications, to include cellular, should see little or no impact .



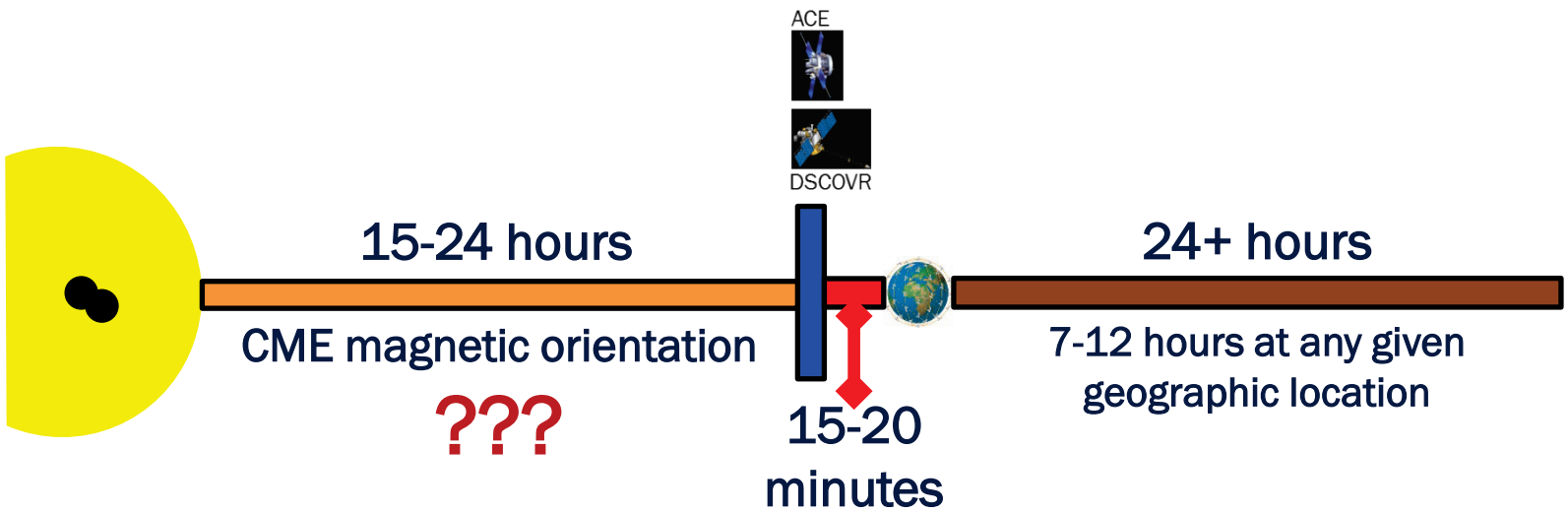
Impact | Possible | Probable | Significant | Severe

S5 Solar Radiation Storm

- Could result in the temporary or permanent loss of between 10%-15% of the satellite fleet.
- Significantly increase operational anomalies that would create a challenging environment for ground controllers.
- HF Radio in polar regions and satellite navigation may be degraded.



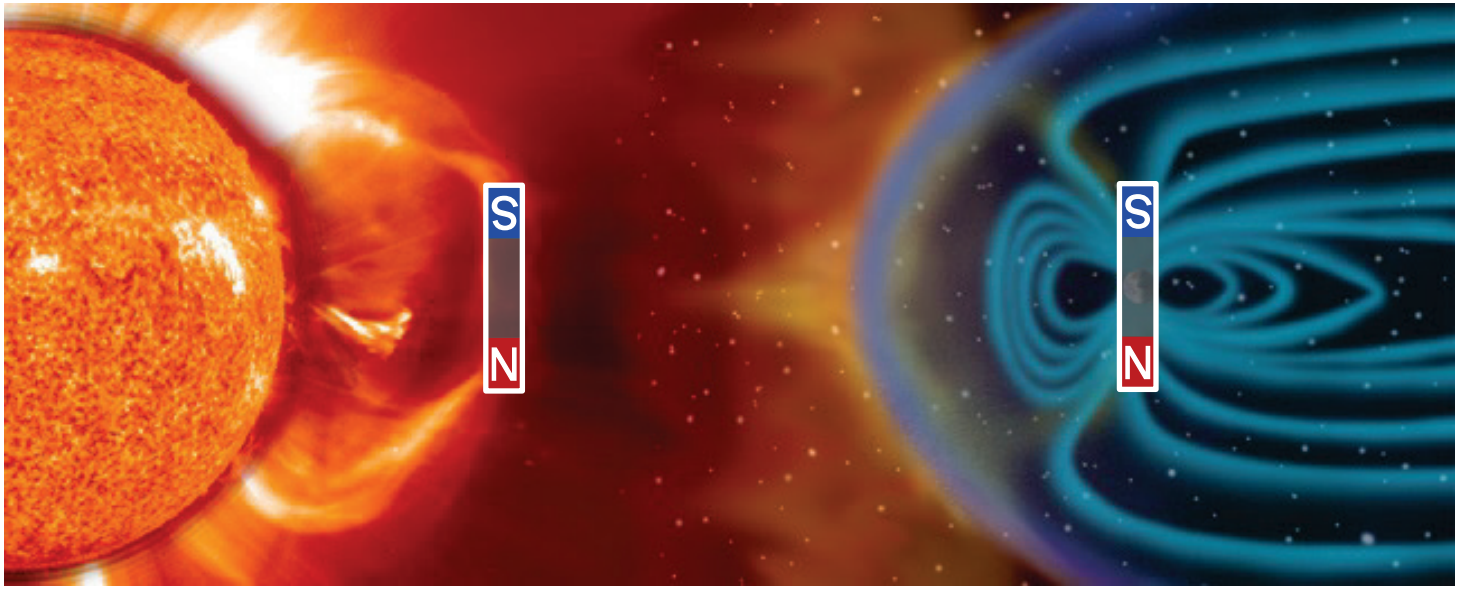
Timeline of an Extreme Geomagnetic Storm

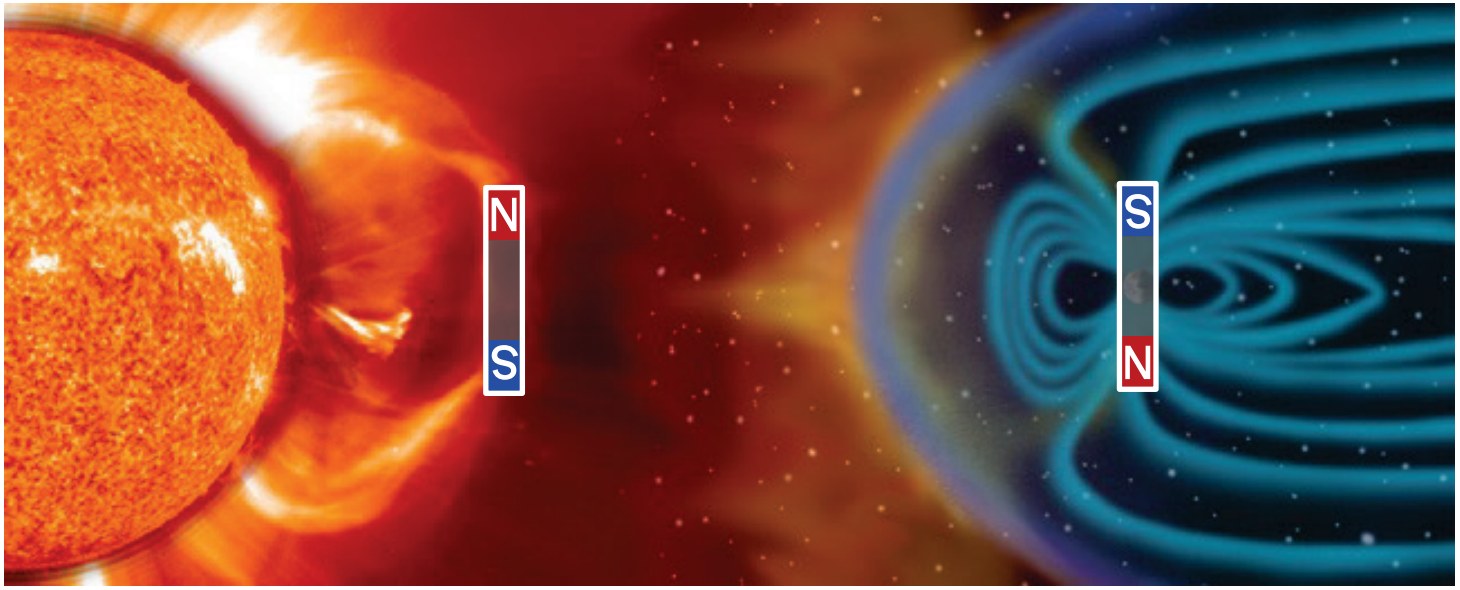


What we won't know up front:

- Geographic location(s) of physical impact (includes Earth orbit)
- Timing of physical impact at those locations
- Severity of physical impact
- Duration of physical impact

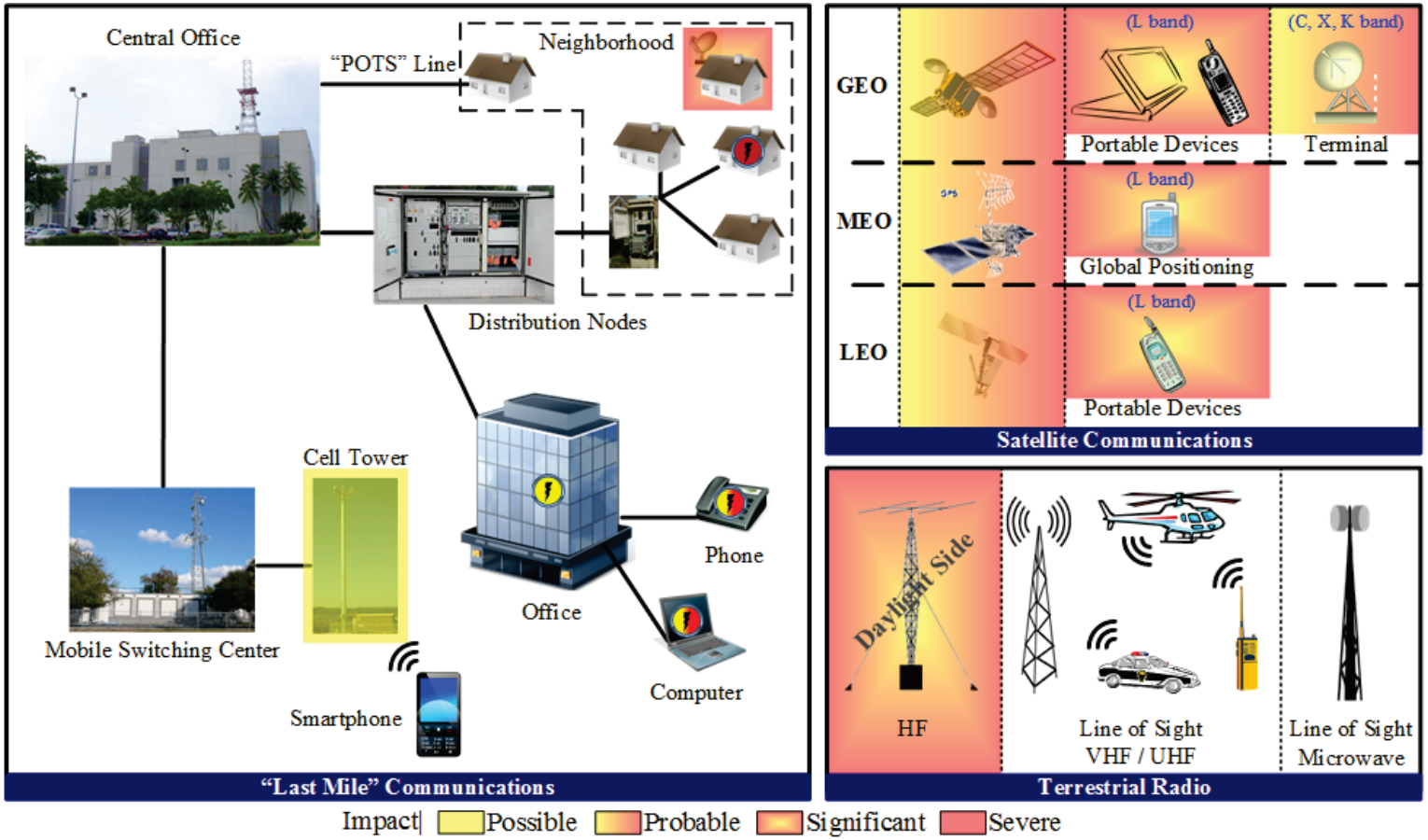
Interplanetary Magnetic Field (-Bz)





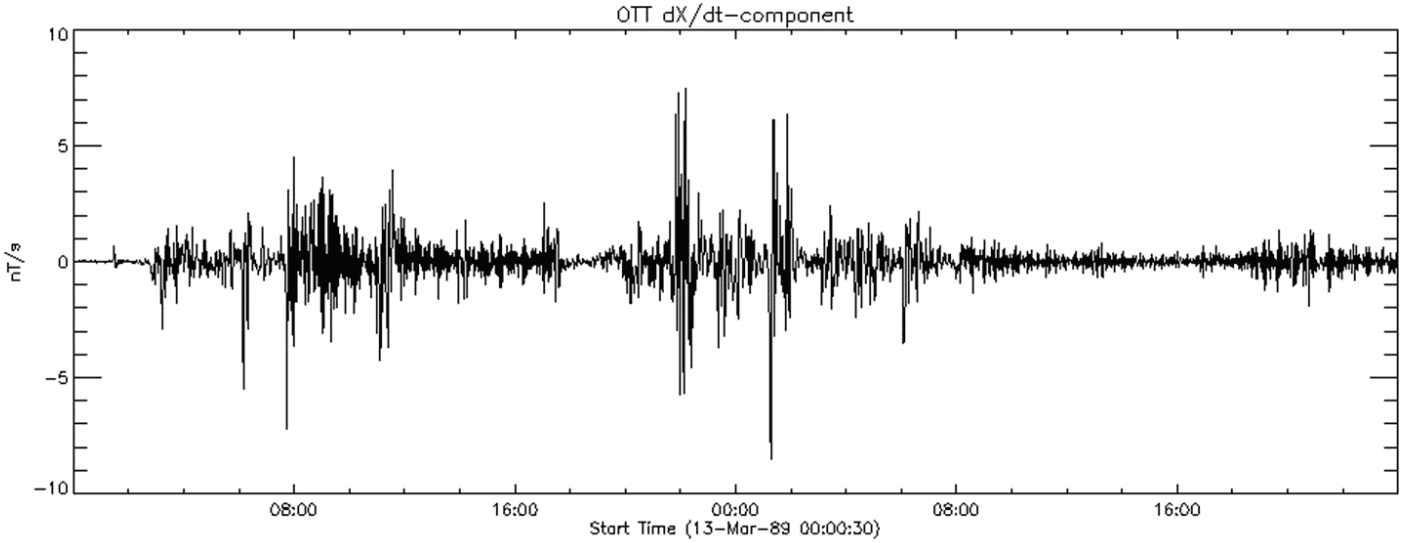
G5 Geomagnetic Storm

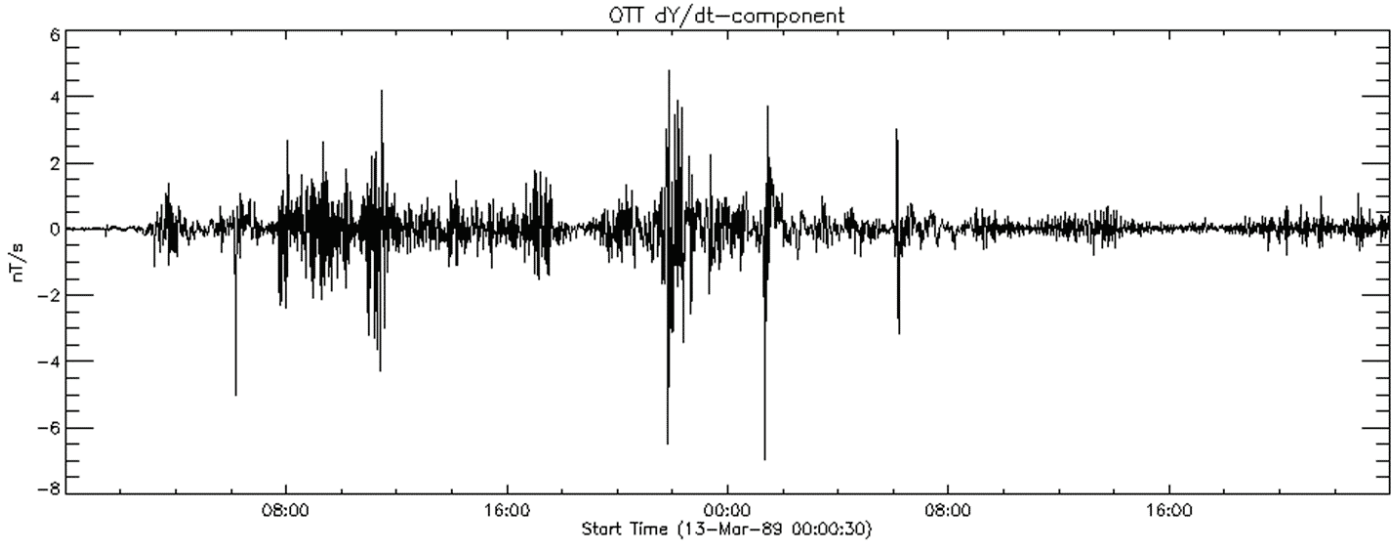
- HF radio on the daylight side may initially be possible due to enhancement of the ionosphere F layer, but would quickly become unusable for 1-3 days.
- L-band is highly susceptible to scintillation; higher frequencies less effected.
- If power goes out, anything without backup power will fail.



It's More Complicated Than That

Strength and magnetic orientation vary throughout the geomagnetic storm





Intermittent Impact

A curious thing about the telegraphers' experience is that it has been intermittent. For some periods the wires and instruments worked normally and then would start on a dance that puzzled the operators.

The phenomenon was first noticed in Western France late on Friday evening and gradually spread eastward. All lines were not affected similarly, neighboring ones behaving normally or eccentrically from no known reason.

One feature was that while earth currents were disturbed, the wireless apparatuses remained unaffected.

The New York Times

Published: May 18, 1921

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This will be true for electric power systems and telecommunications

Extreme Events Can Bring Friends

TABLE.

Day.	Magnetic Range in Minutes of Arc. Dn.	H.	V.	Character.	Sun-Spots. Mean Daily Disc-area.	Mean Co-ordinates. Centre of Group. Lat.	Long.	Heliographic Co-ordinates. Centre Sun's Disc. D.	L.	Angular Distance. Spot from Central Meridian.
						°	°	°	°	°
May 12	21	34	5	2	14·9	+0·8	2·7	−2·9	32·2	29·5
13	40	40	>67	2	15·6	,,	,,	−2·8	19·0	16·3
14	50	64	56	2	16·5	,,	,,	−2·7	5·7	3·0
15	>129	...	>75	2	14·3	,,	,,	−2·5	352·5	10·2
16	47	70	>64	2	13·0	,,	,,	−2·4	339·3	23·4
17	21	29	8	2	11·3	,,	,,	−2·3	326·0	36·7
18	11	19	2	1	7·4	,,	,,	−2·2	312·8	49·9
19	58	30	21	2	...	,,	,,	−2·1	299·6	63·1
20	26	61	27	2	1·6	,,	,,	−2·0	286·4	76·3
21	26	20	11	2	0·3	,,	,,	−1·8	273·1	89·6

In the three columns giving the ranges of the magnetic elements, these ranges, Dn, H, V, are expressed in minutes of arc, in order the more easily to compare the magnitudes of the movements as measured on the curves. To reduce the numbers in the columns under H and V to units of force, γ, where $1\gamma \equiv 10^{-5}$ C.G.S. unit, the factors are 4·7 for H, and 6·4 for V. The values for V are very notably high. The international character figures for magnetic disturbances are 0 (quiet), 1 (disturbed), 2 (highly disturbed). Every day except one, May 18, is marked by the figure 2. This storm is remarkable for the number of days over which it extended. To find a parallel we must go back to the protracted storm, 1882 November 11–21, which also accompanied the passage of a great spot across the sun's disc. That storm was the greatest recorded up to that date at the Stonyhurst Observatory, where the photographic magnetographs had then been in constant action for fourteen years.*

In the columns concerned with solar data, the first gives the

* *Stonyhurst Observatory Report*, 1882, pp. 64–65.

The "Great Storm" of 1921 was the largest of several storms over a period of almost two weeks.

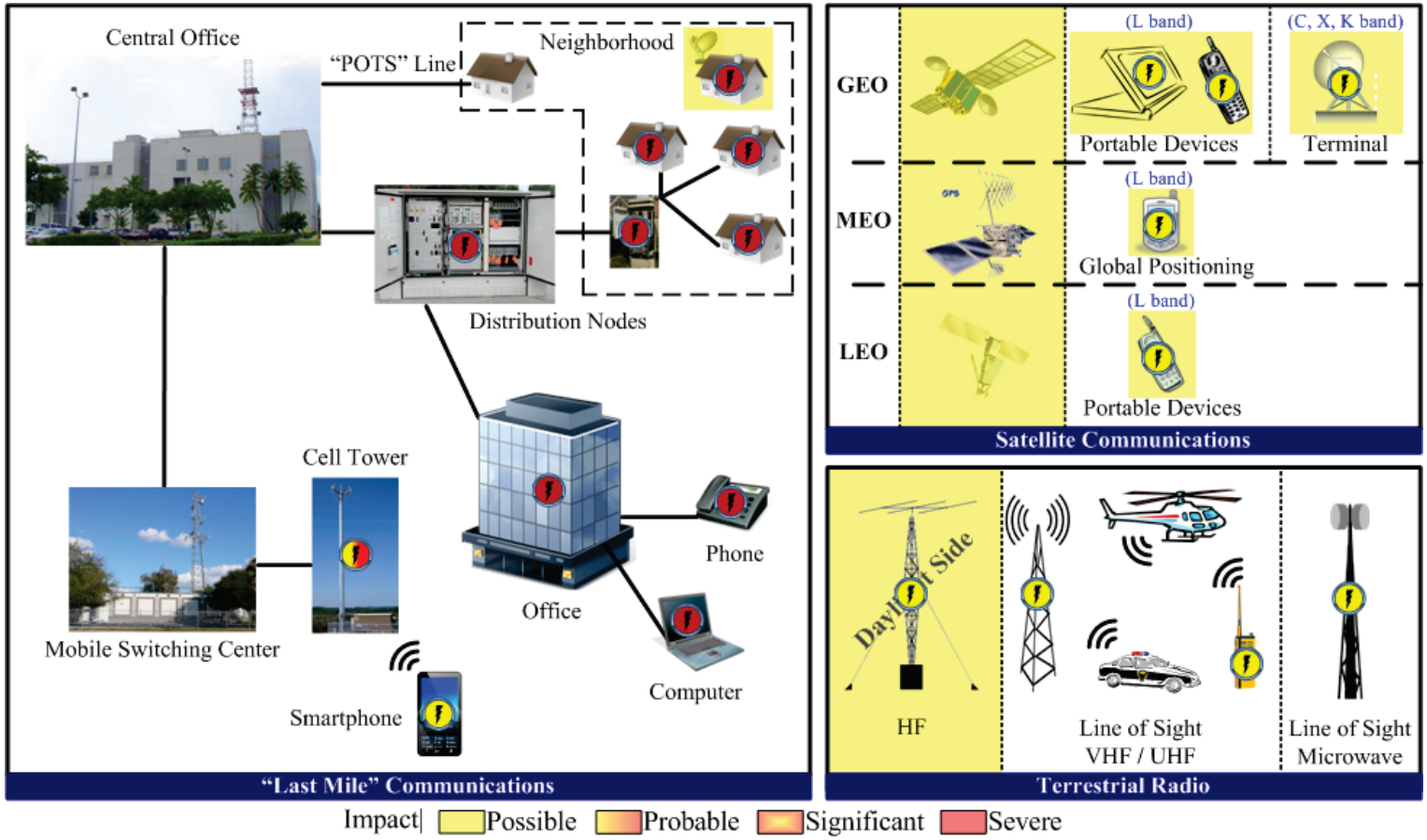
The "Carrington Event" of 1859 was the second and largest of two extreme events.

The "Halloween Storms" of 2003 saw 17 major flares over roughly two weeks.

© Royal Astronomical Society • Provided by the NASA Astrophysics Data System

8-24 Hours Without Power

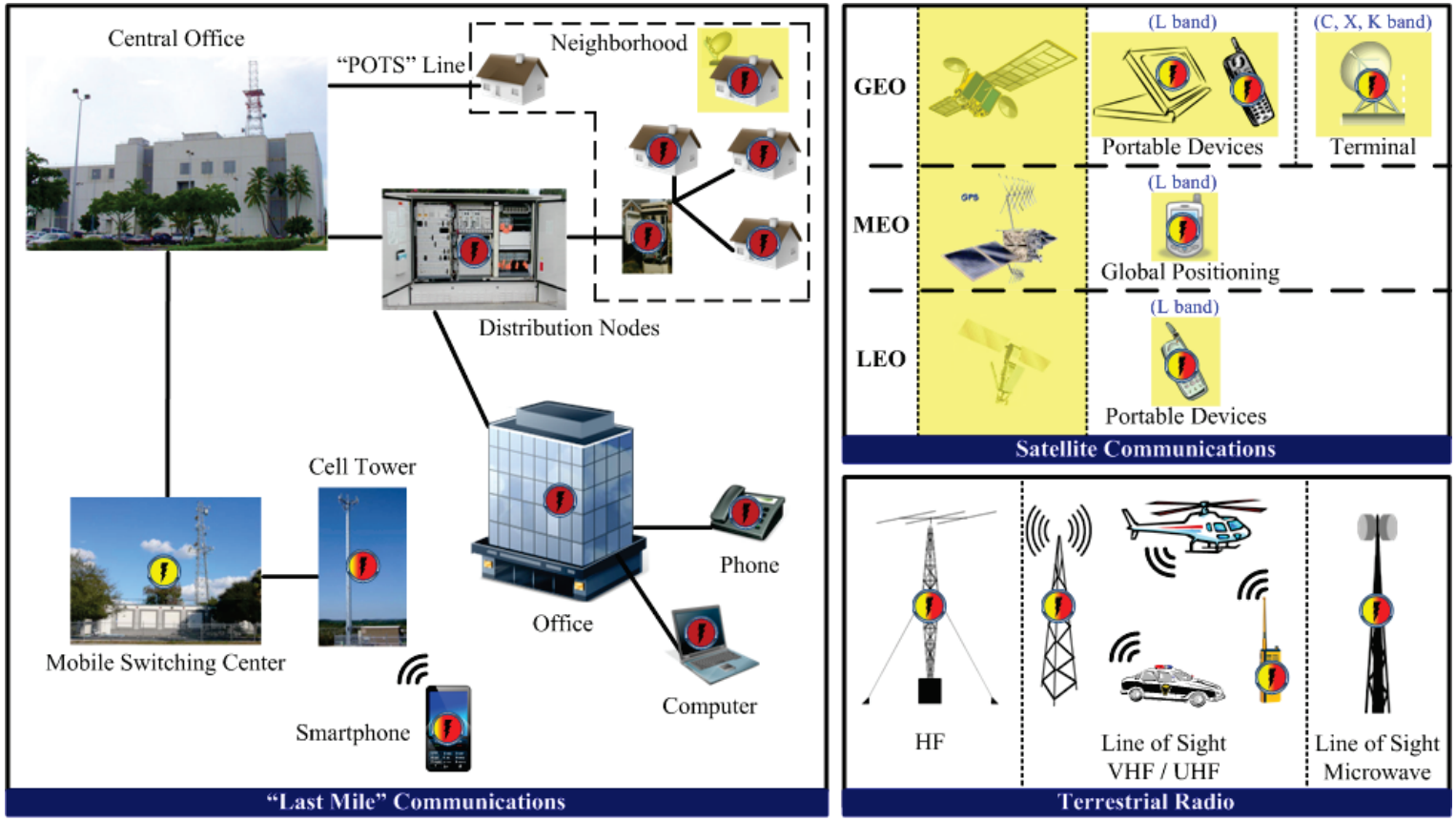
- About 60% of communications towers have backup power for only 2-8 hours.
- Landline/cable distribution nodes have 2-24 hours of backup power.
- Device batteries generally last about 4-8 hours.
- 1 Day is a common planning factor for smaller generator backup.



Impact | Possible | Probable | Significant | Severe

72 Hours Without Power

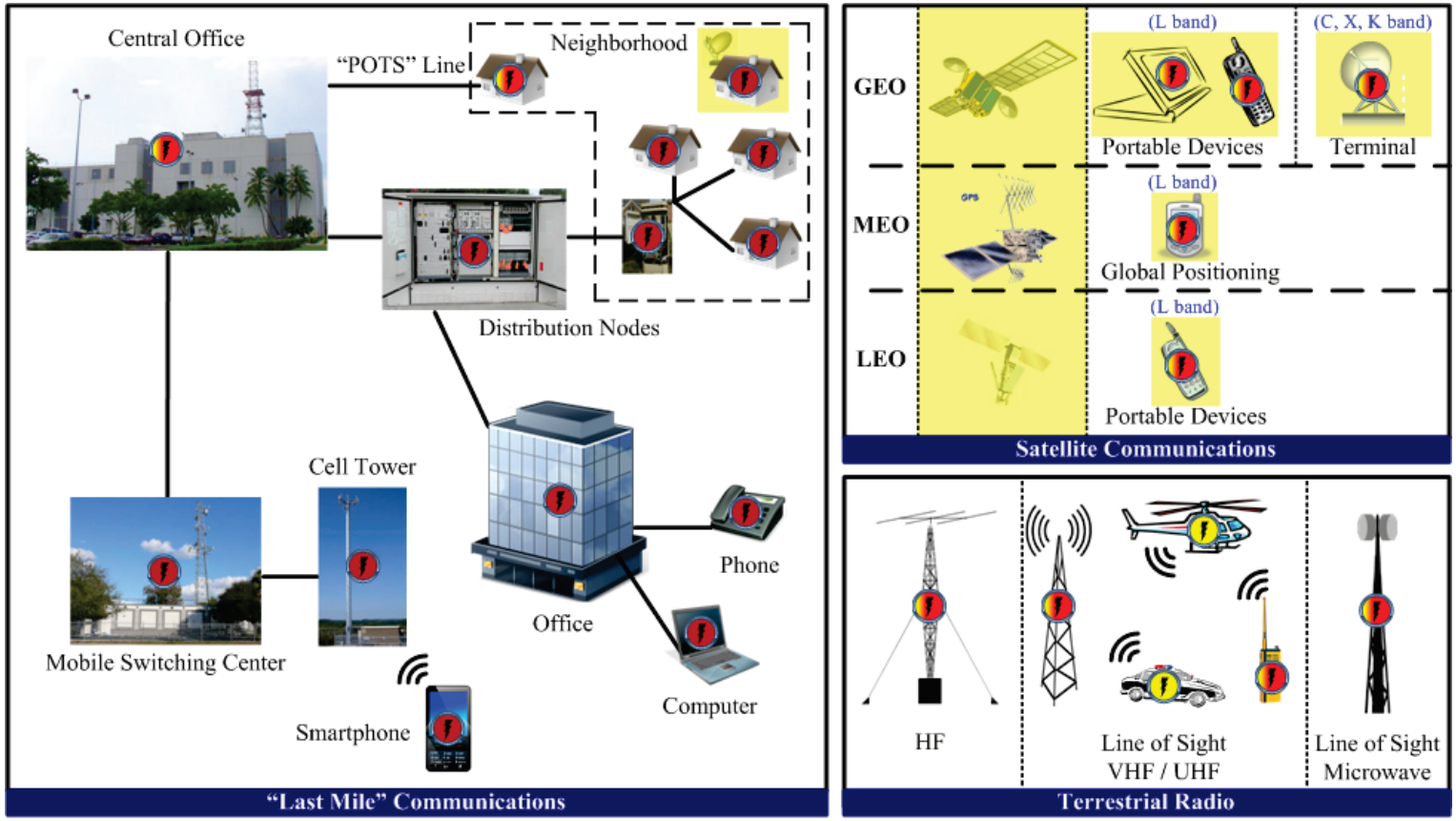
- 3 Days is a common planning factor for medium sized generators.
- If power is out over a wide area, getting fuel for generators may be difficult. Fuel contracts may not be able to meet demand.
- Transportation disruptions could delay or prevent fuel deliveries.



Impact | Possible | Probable | Significant | Severe

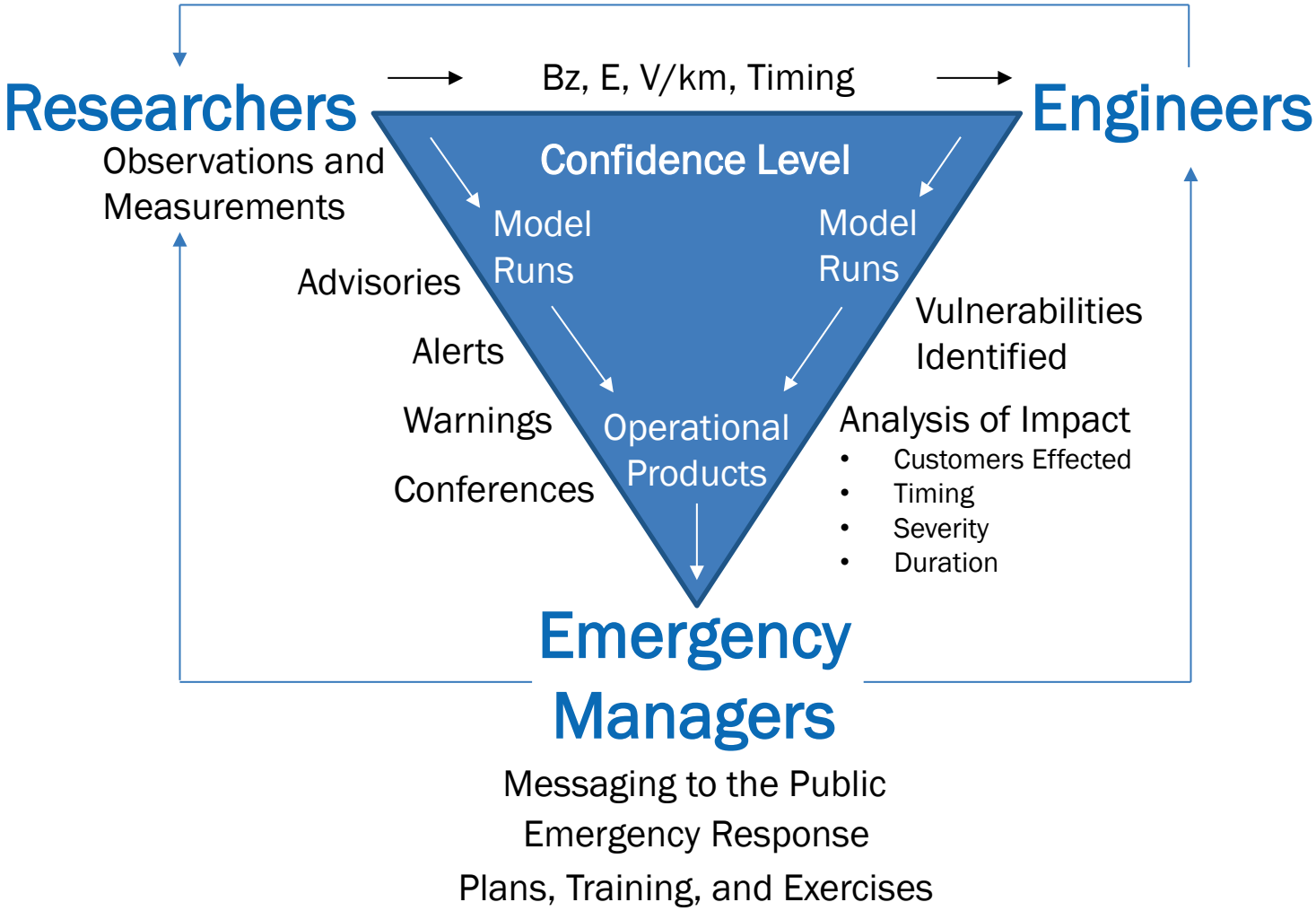
7+ Days Without Power

- 7 Days is a common planning factor for large generators.
- If power is out over a wide area, getting fuel for generators may be difficult. Fuel contracts may not be able to meet demand. Transportation disruptions could delay or prevent fuel deliveries.
- After 7 days, major failures of telecommunications infrastructure possible without refueling.



Impact| Possible Probable Significant Severe

Whole Space Weather Community



Ready
Prepare. Plan. Stay Informed.

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Prepare

- Have reliable backup power and test it regularly. Know where and how to get fuel, water, and other consumables. (Be aware of contracts that promise the same services to many users). Don't forget your people!
- Multiple means of communications and, if practicable, multiple service providers can provide redundancy and resiliency in an extreme solar event.

Plan

- Know what communications systems will work and when they will work in an extreme event. Most organizations already have emergency and/or continuity plans. Add space weather.

Stay Informed

- Research is ongoing and information is constantly being updated.
- During an event information sharing, flexibility, and gaining and maintaining situational awareness will be key.

Ready.gov