SPACE WEATHER EFFECTS ON COMMUNICATIONS SYSTEMS

EFFECTS, OPERATIONAL IMPACTS, AND MITIGATIONS FOR COMMUNICATIONS SYSTEMS

Mark MacAlester
Communications Liaison
May 6, 2021

Who's Right?

Hurricane Watch Net

"While Hurricanes Harvey, Irma, Jose, and Maria tore through the Caribbean region, X-class flares, solar energetic particle (SEP) events, and Earth-directed coronal mass ejections (CMEs) plowed through the heliosphere. Caribbean emergency communication system operators reported **critical impacts to high-frequency (HF) radio links used in disaster response** and aviation tracking."

- Redmon, R. J., Seaton, D.B., Steenburgh,R., He, J., & Rodriguez, J. V. (2018). September 2017's geoeffective space weather and impacts to Caribbean radio communications during hurricane response. Space Weather, 16. https://doi.org/10.1029/2018SW001897

Government Operators

Federal Emergency Management Agency (FEMA) operators, their federal, state, and local emergency management partners supporting operations in the U.S. Virgin Islands and Puerto Rico used HF communications extensively. None reported any space weather related impacts to HF communications.

Premise

What is the *operational impact* caused by a space weather *effect*

- On a specific communications technology
- Operated according to a set of procedures
- At a specific geographical location
- At a specific time during a space weather event

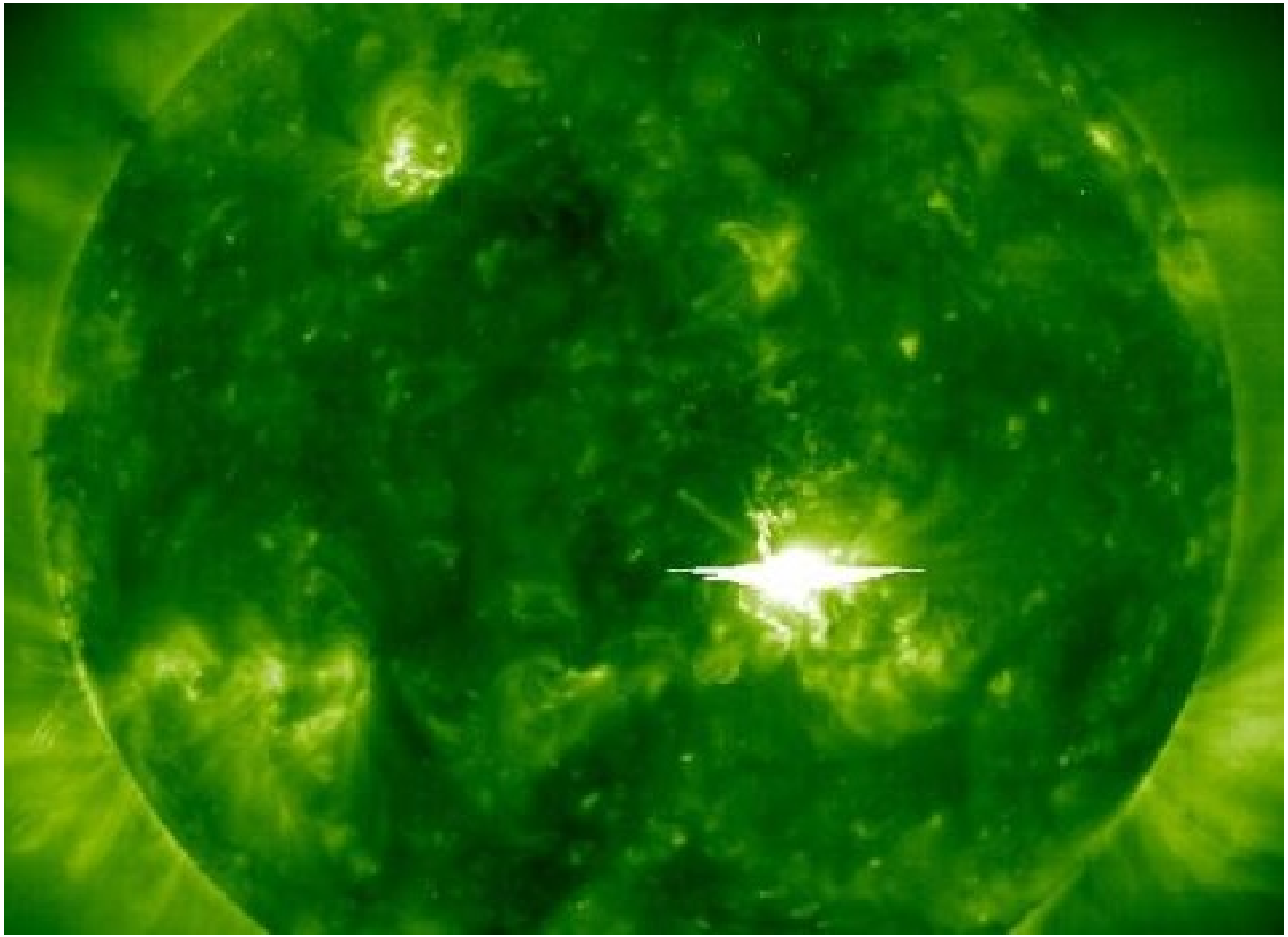
Several slides are animated.

Let's Talk Communications

Communications Basics and Space Weather

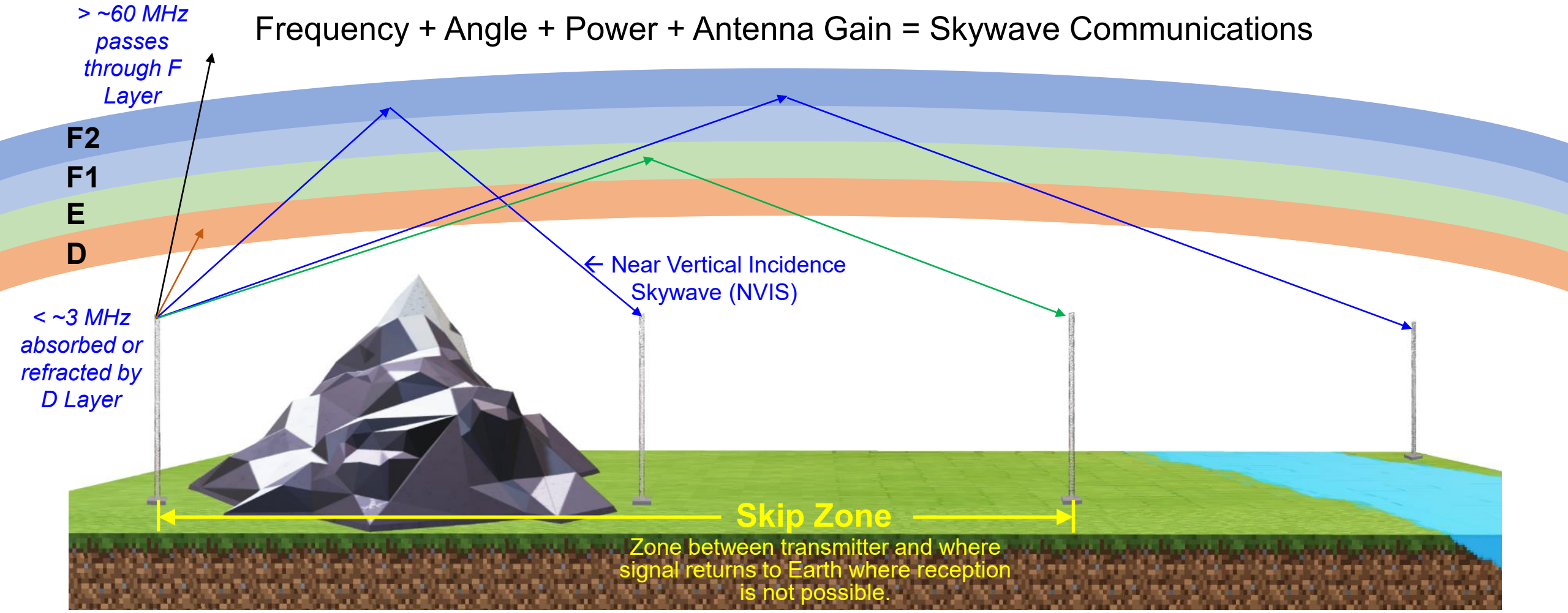
- Radio (a.k.a "wireless")
- Satellite
- Terrestrial Telecommunications Systems (a.k.a. "wireline")

Radio Communications



Ionospheric Skywave Communications

Frequency + Angle + Power + Antenna Gain = Skywave Communications

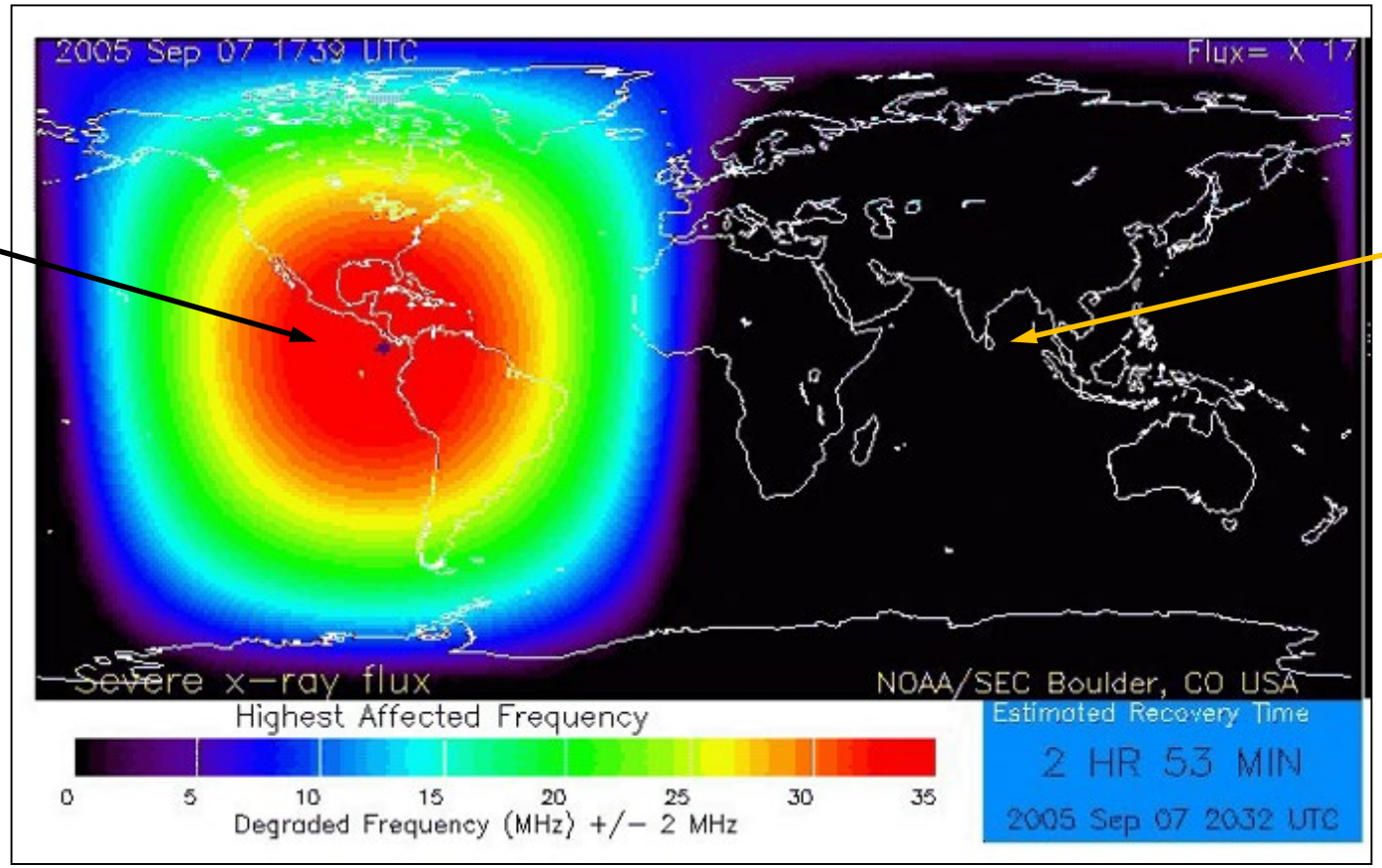


Solar Flare Radio Blackout Effect (Visual)

DAY

X-Rays increase electron density which increases absorption of radio signals from lower frequencies to higher frequencies for ~minutes to 3 hours.

If ultraviolet (UV) light in addition to X-ray, UV increases F layer ionization which can enhance F Layer HF communications.)



NIGHT

No **D** Layer to absorb radio signals.

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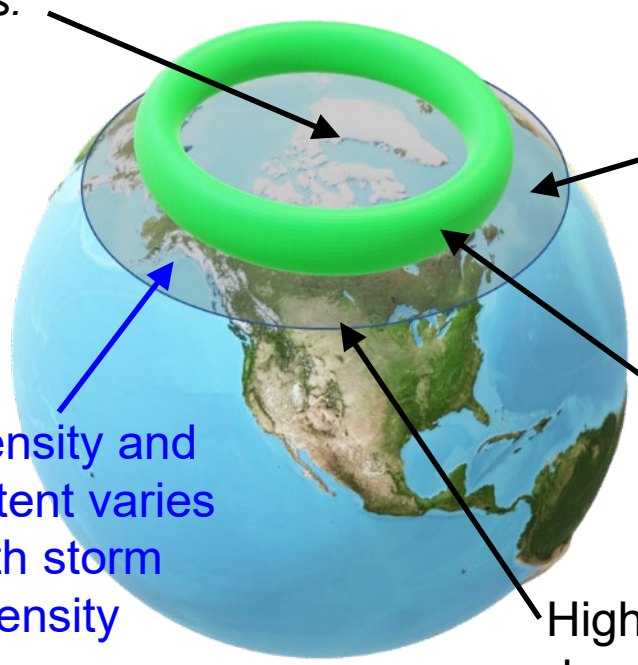
Radiation and Geomagnetic Storms (Visual)

Solar Radiation Storm

Polar Cap Absorption event:

Solar Energetic Protons increase ionization which increases absorption of radio in D and E layers near poles for ~minutes to days.



Full-coverage from pole to equatorward extent

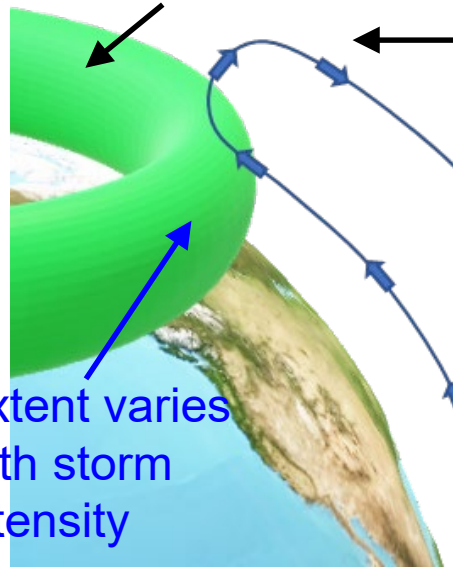
Density and extent varies with storm intensity

Not highly correlated to the visible aurora

Higher ion density on day side (higher absorption)

Geomagnetic Storm

Increased ionization increases absorption at E Layer and above, disrupting communications < 20MHz.



Aurora heats atmosphere:

Molecular neutrals rise to F Layer over all of auroral oval and move toward the equator: Suppresses ion creation, increases ion loss in F Layer. Higher frequencies pass through for ~1-3 days + ~1-2 days near poles.

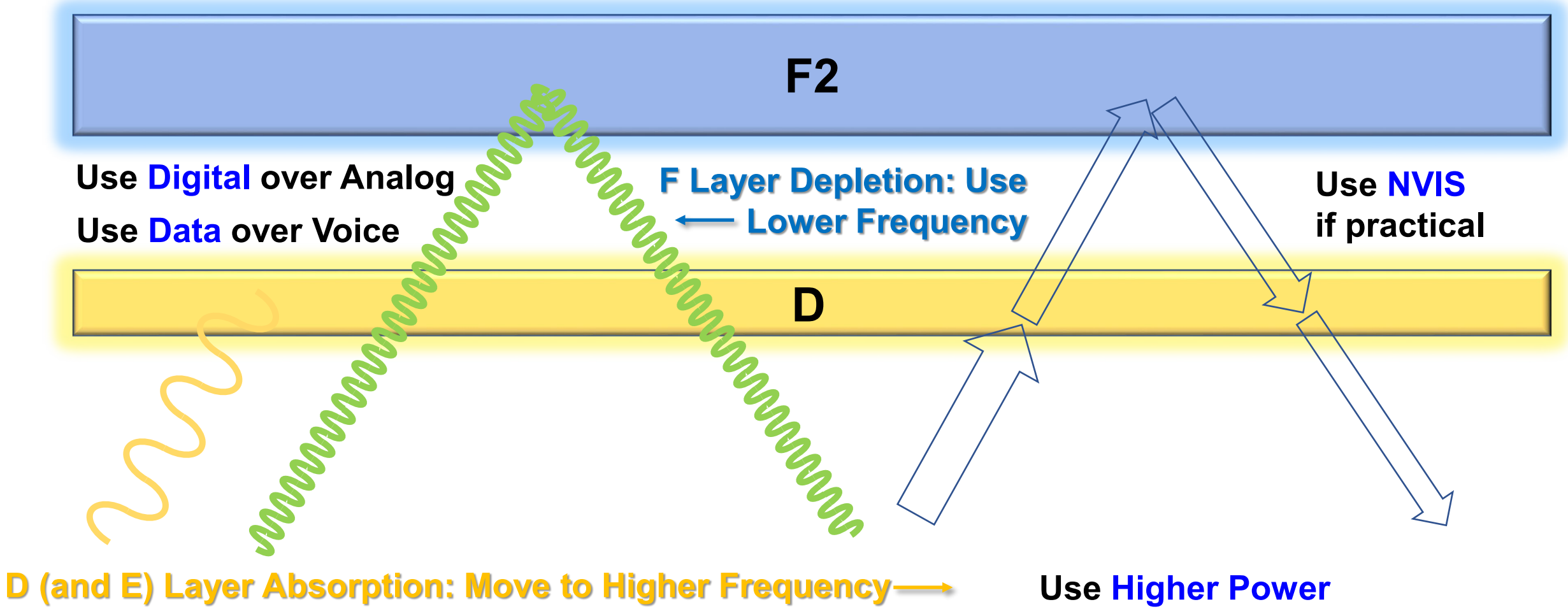
Extent varies with storm intensity

If storm arrives late afternoon, may not see effects until after sunrise of next day

Downwelling of ions pushed out of F Layer can enhance HF skywave equatorward and distant from the aurora for ~2 hours

NOT TO SCALE

Mitigation Techniques



Mitigation Techniques (Continued)

Use Networks

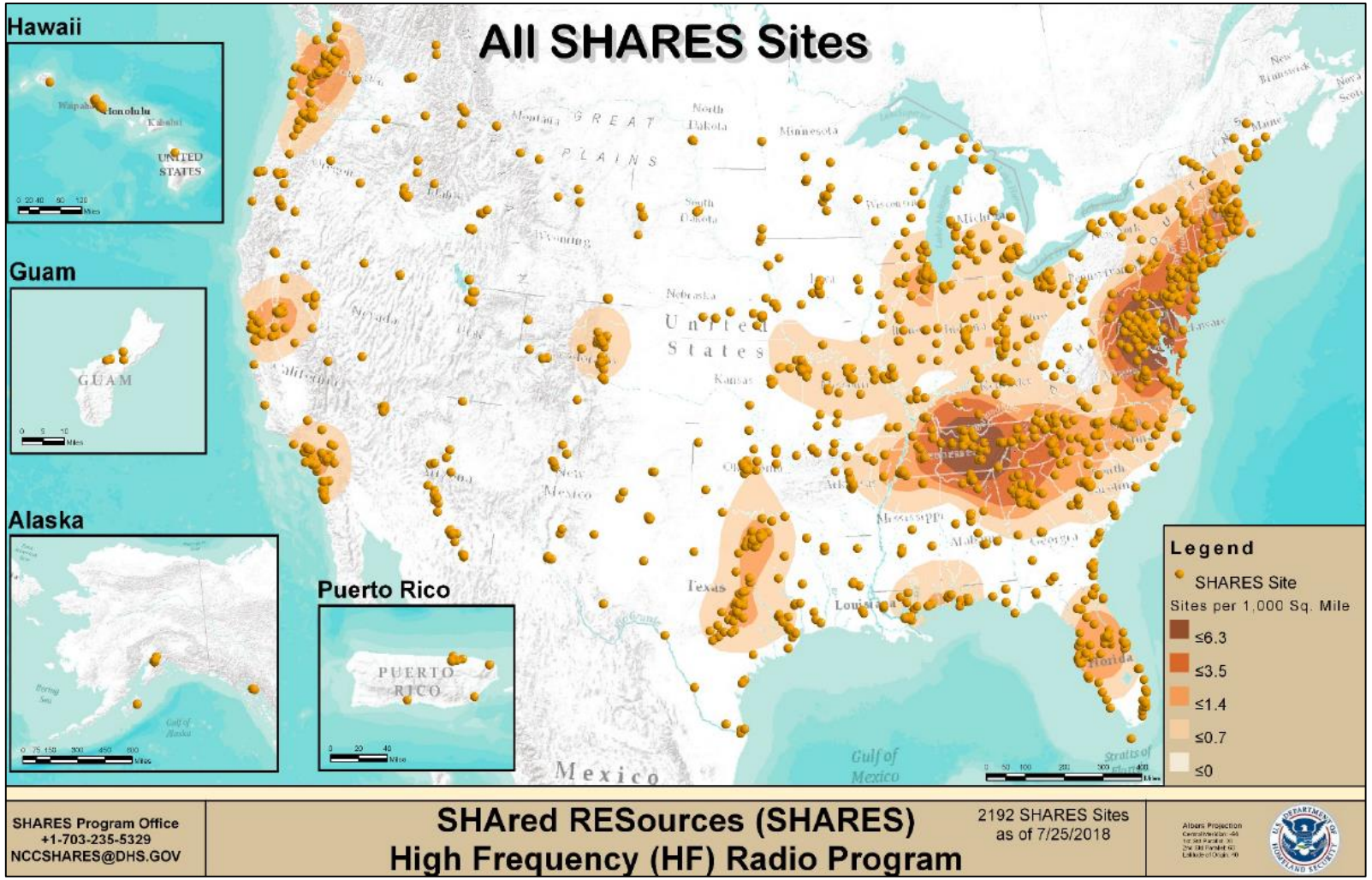
- **Station Relay**
  - If origin and destination stations cannot talk directly, manually pass traffic between stations that can talk.
- **Internet Connected**

← *(Example)*
WINLINK
Global Radio Email
Live System
Information

Mitigation Techniques (Continued)

The more stations available in a network, the higher the probability of successfully passing traffic.

SHARES is a federal program where federal, state, territorial, tribal, and local governments—and some private sector companies—share HF frequencies and resources.

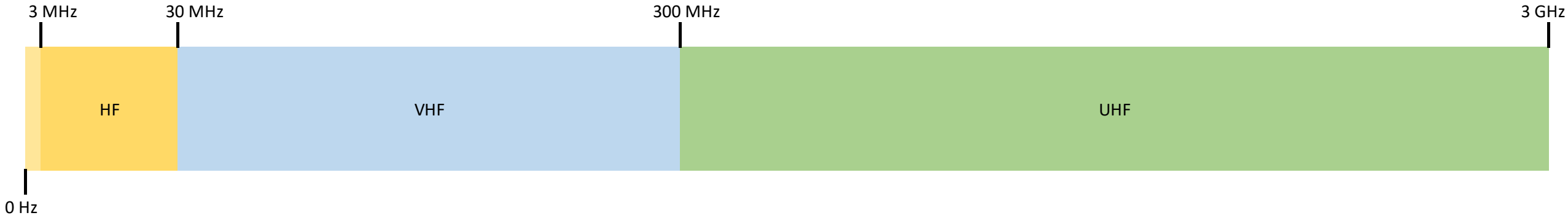


Applying a Risk Profile for HF Skywave

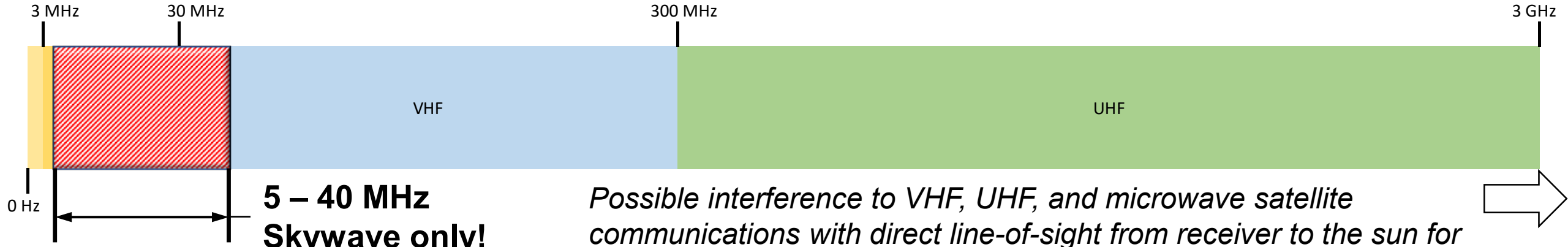
Worst Case	Analog Voice	Single Frequency	Single Station Pair	Low Power	Low Skill
Hurricane Watch Net (2017)	Analog Voice	Single Frequency	Station Relay	High Power	High Skill
		7.268 MHz & 14.325 MHz (40m Band, 20m Band)	~50 Stations in Net		
FEMA PR/USVI	Digital Voice (and data)	Automatic Link Establishment	Station Relay	High Power	Medium Skill
		> 40 Channels from 2 MHz to 28 MHz	Used Near Vertical Incidence Skywave for intra- and inter-island HF		
US Government (e.g. SHARES, COTHEN)	Digital Voice (and data)	Automatic Link Establishment	Networked Stations	High Power	Medium Skill
Amateur Austin, TX	Digital Data	Multiple Frequencies	Networked Stations	High Power	High Skill

[Not a] Radio Blackout Event

Radio Spectrum



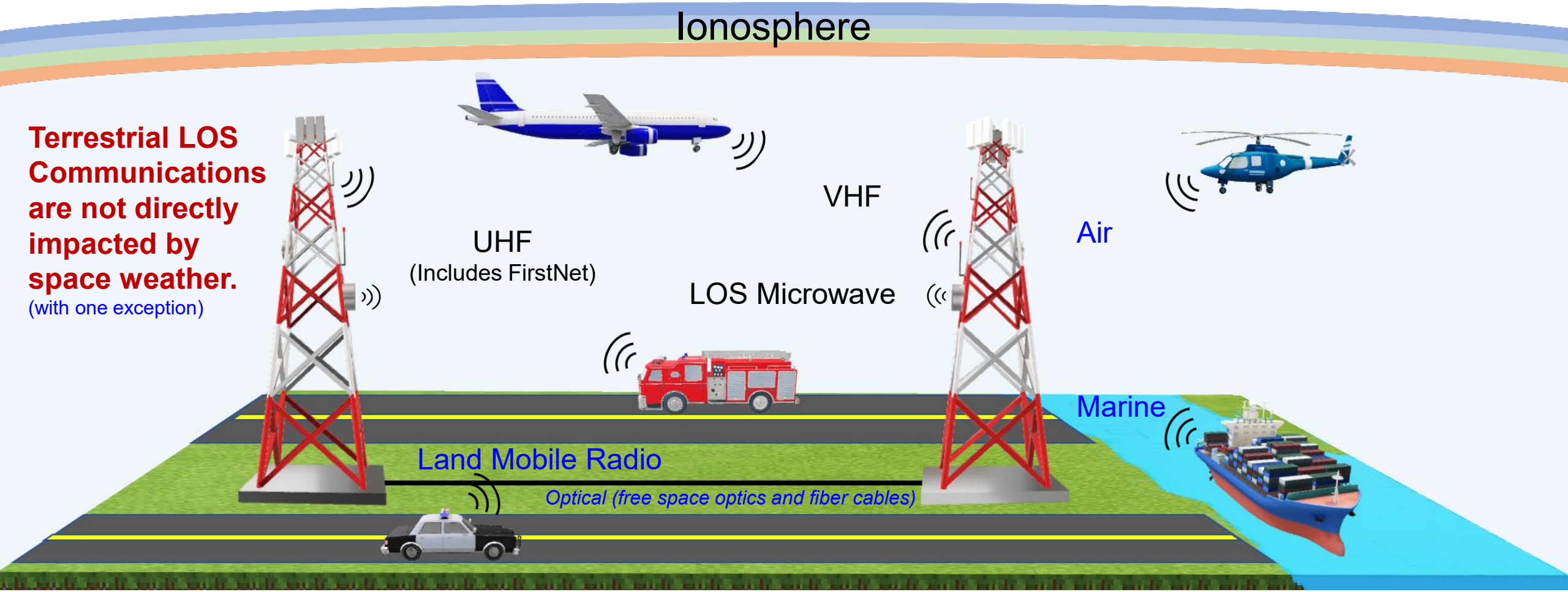
Solar Flare "Radio Blackout"



5 – 40 MHz
<u>Skywave</u> only!

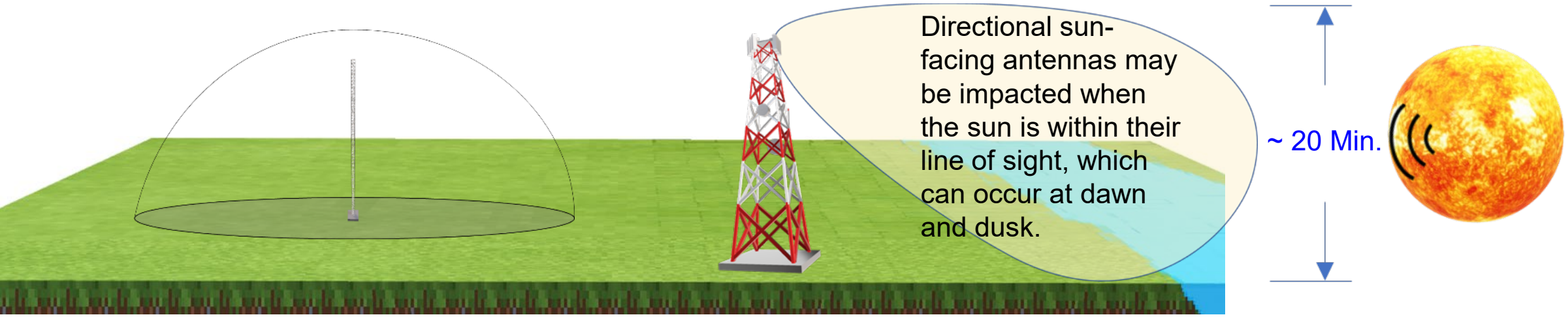
Possible interference to VHF, UHF, and microwave satellite communications with direct line-of-sight from receiver to the sun for seconds up to ~15 minutes

Terrestrial Line-of-Sight (LOS) Radio

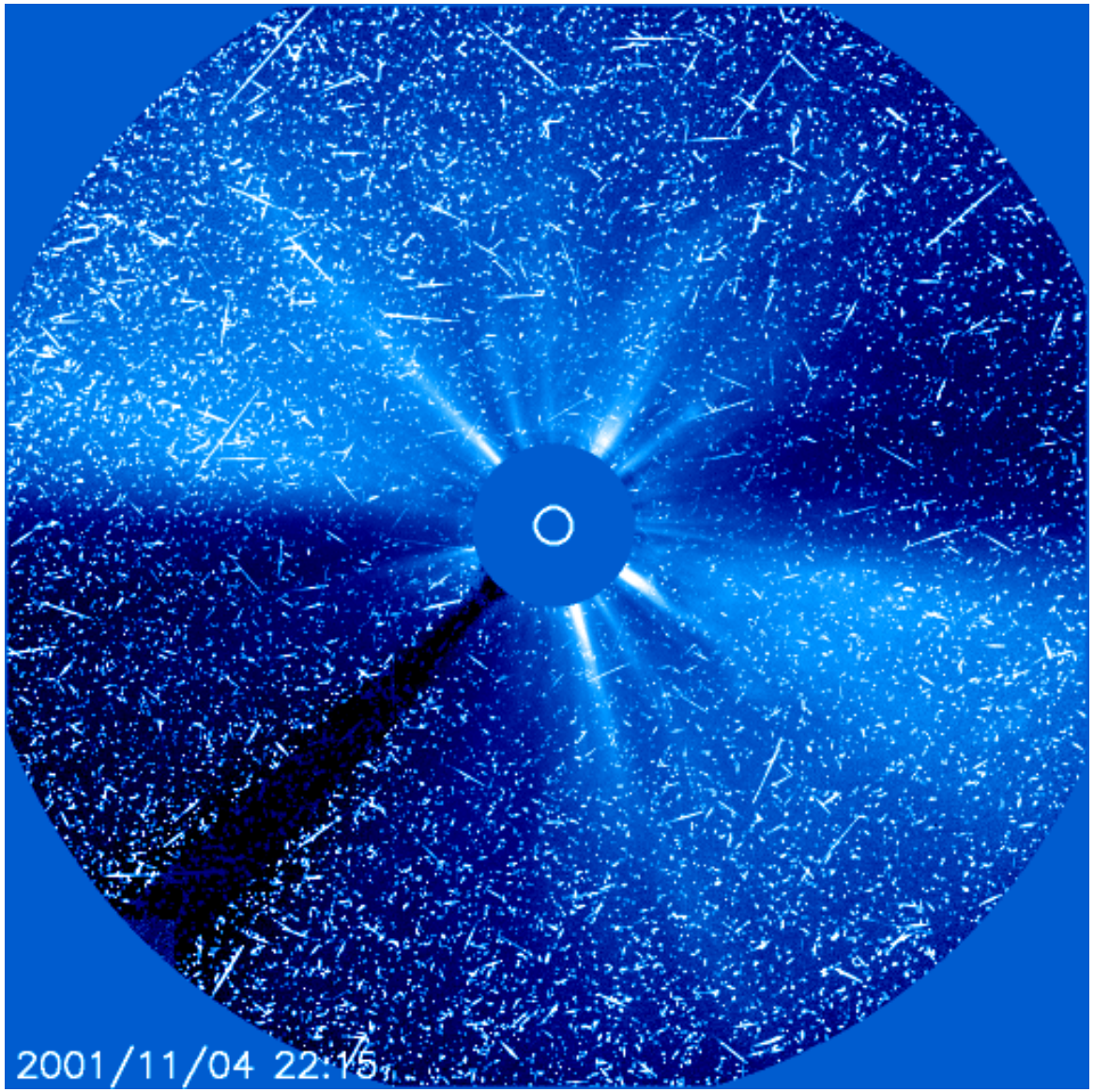


Solar Radio Bursts (the exception)

Omnidirectional antennas likely not impacted — unless transmitting and receiving antennas are on a direct line of sight with the Sun when a SRB occurs.

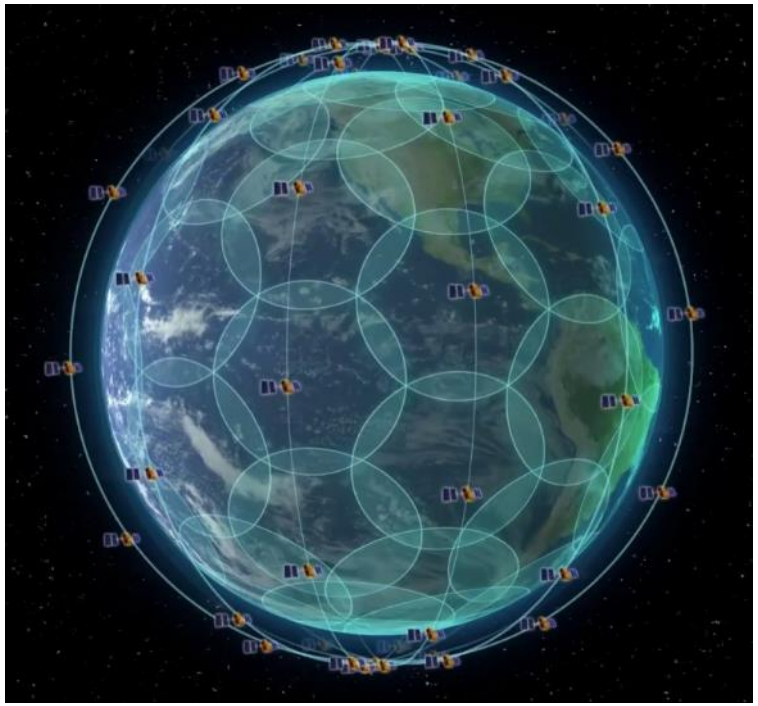


Satellite Communications

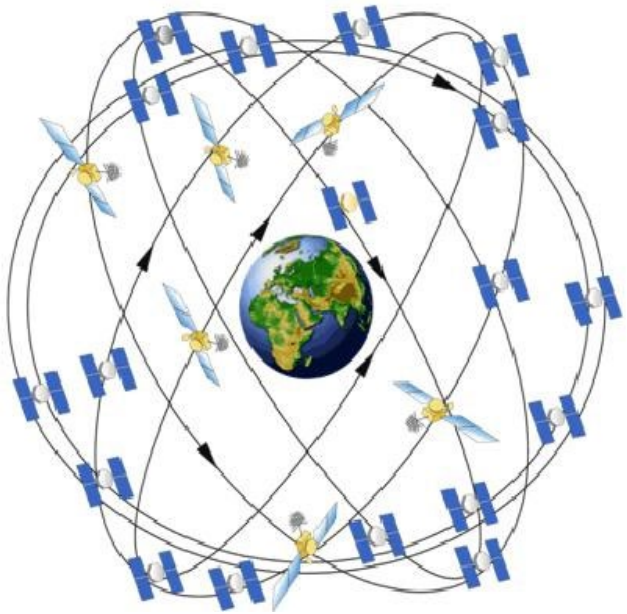


Satellite Basics - Orbits

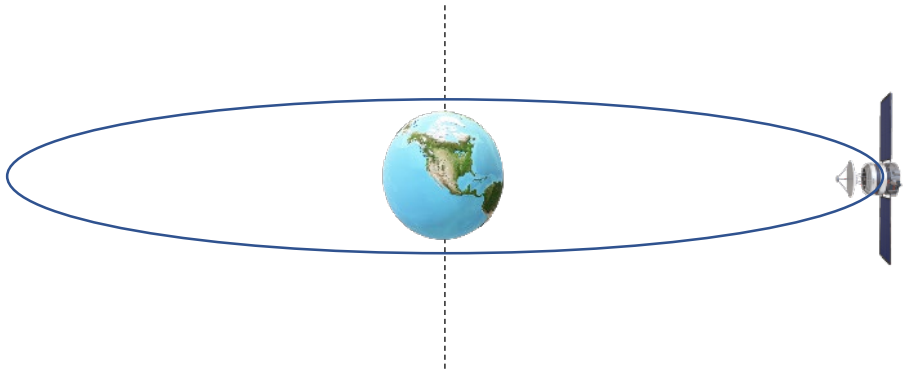
Low-Earth Orbit (LEO)
~180 – 2,000 km
~110 – 1240 miles



Medium-Earth Orbit (MEO)
2,000 – < 35,786 km
~1,240 – < 22,236 miles



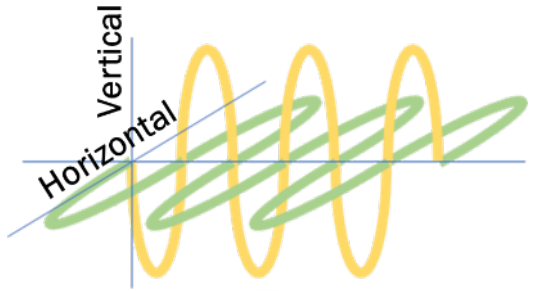
Geostationary Orbit (GEO)
35,786 km
22,236 miles



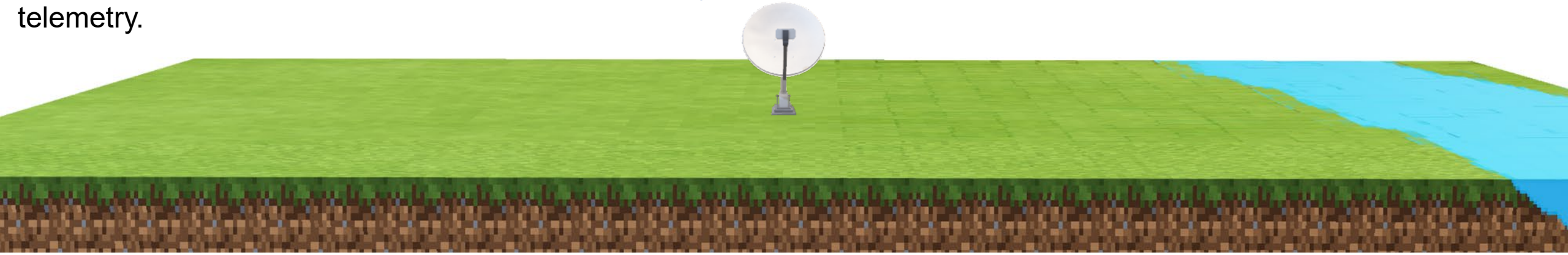
Satellite Basics - Frequencies

VHF	UHF	L Band	S Band	C Band	X Band	Ku Band	K Band	Ka Band	V Band
70-150 MHz	200-400 MHz	1-2 GHz	2-4 GHz	4-8 GHz	8-12 GHz	12-18 GHz	18-27 GHz	27-40 GHz	40-75 GHz

VHF and UHF are often used for satellite telemetry.

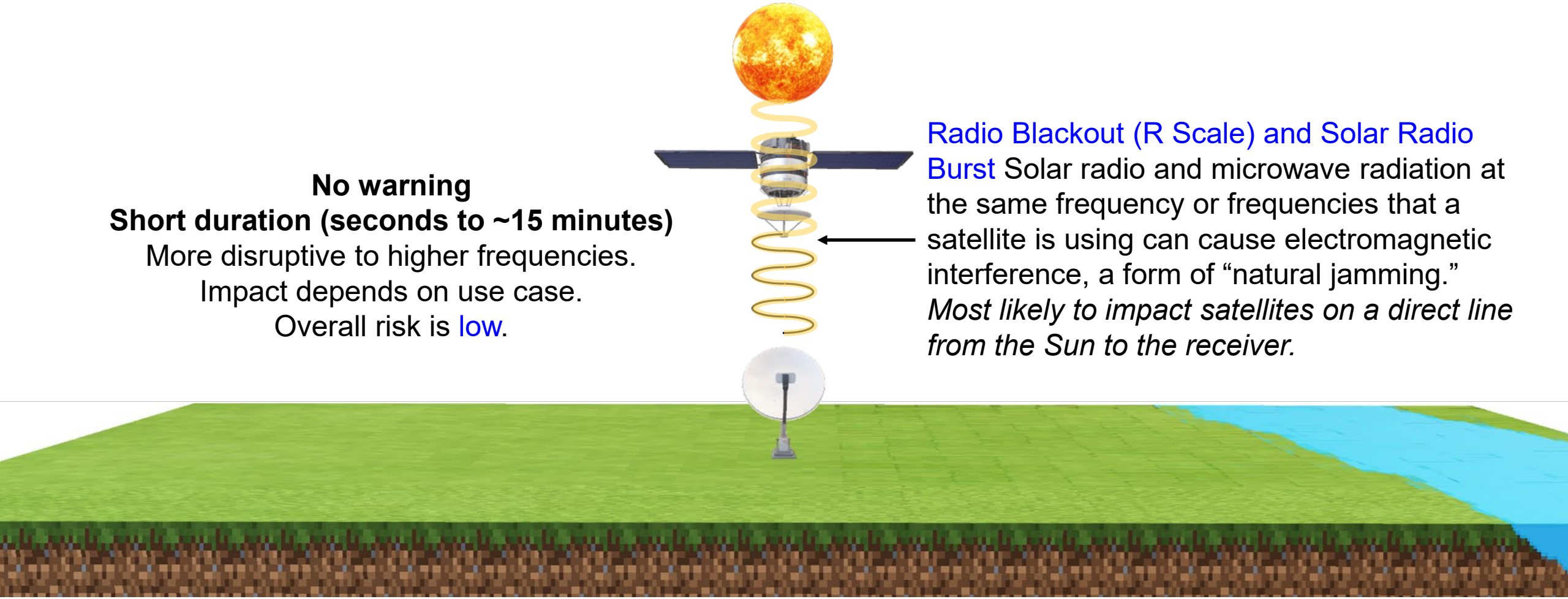


Polarization allows satellite providers to support two customers on the same frequency.



Electromagnetic Interference

No warning
Short duration (seconds to ~15 minutes)
More disruptive to higher frequencies.
Impact depends on use case.
Overall risk is low.



Radio Blackout (R Scale) and Solar Radio Burst Solar radio and microwave radiation at the same frequency or frequencies that a satellite is using can cause electromagnetic interference, a form of “natural jamming.” *Most likely to impact satellites on a direct line from the Sun to the receiver.*

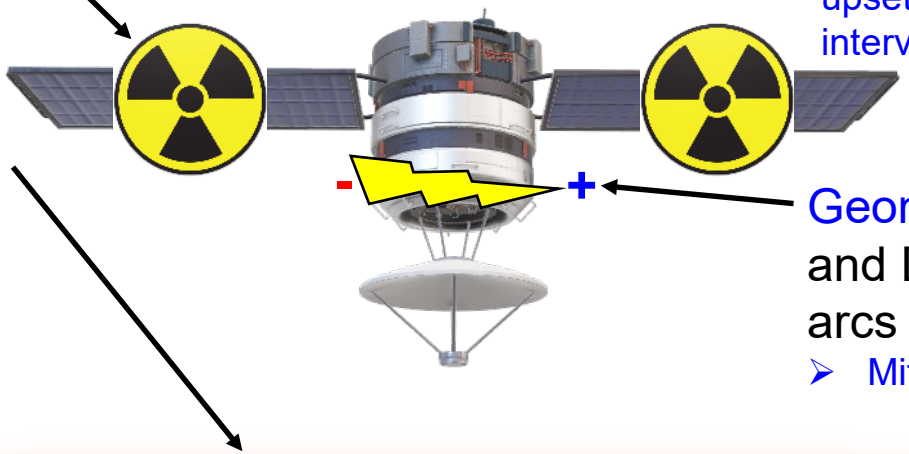
Satellite Physical Effects (and Mitigations)

Solar Radiation Storm (S Scale) Particles damage solar panels shortens useful life.

- Mitigated by proper design, quality control, and operational monitoring

Geomagnetic Storm (G Scale) Upper atmosphere expansion increases drag for **very**-low-earth-orbit satellites and debris.

- Not a significant issue for LEO satellite constellations above 400 - 600 km
- Mitigated by extra fuel reserve for station keeping as part of operational design
- New artificial intelligence can maneuver satellites to avoid collisions



Solar Radiation Storm (S Scale) Single Event Upset creates command or memory errors, usually temporary.

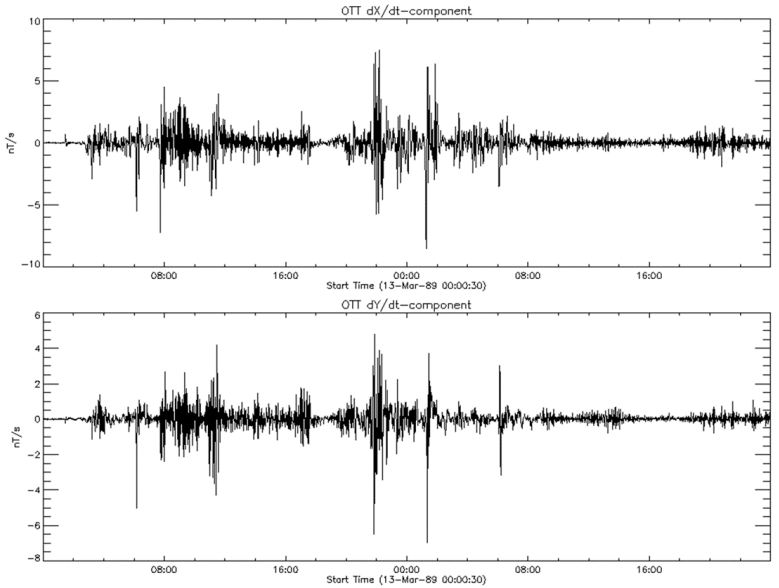
- New artificial intelligence can diagnose and fix upsets on the satellite with little or no human intervention

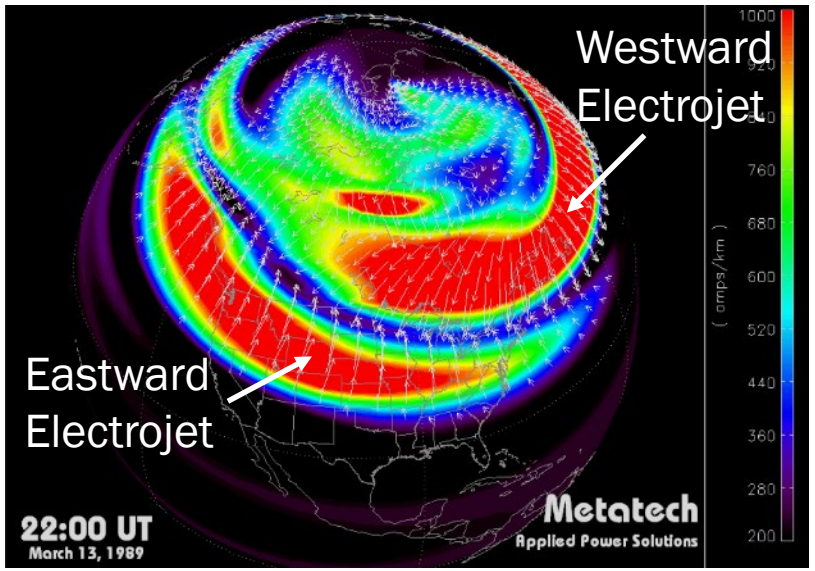
Geomagnetic Storm (G Scale) Surface and Deep Dielectric charging can cause arcs that can damage electronics.

- Mitigated by proper design and quality control

Scintillation and Frequency

VHF	UHF	L Band	S Band	C Band	X Band	Ku Band	K Band	Ka Band	V Band
70-150 MHz	200-400 MHz	1-2 GHz	2-4 GHz	4-8 GHz	8-12 GHz	12-18 GHz	18-27 GHz	27-40 GHz	40-75 GHz





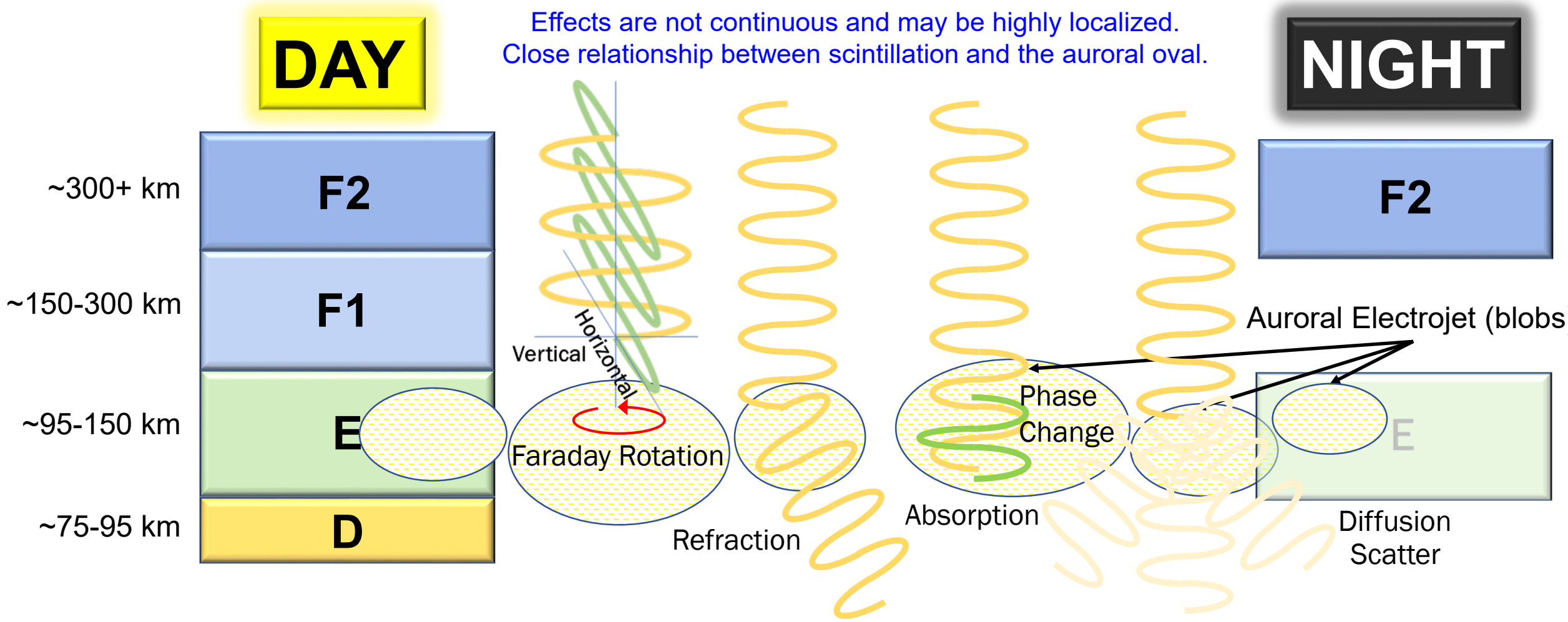
A curious thing about the telegraphers' experience is that it has been intermittent. For some periods the wires and instruments worked normally and then would start on a dance that puzzled the operators.

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.

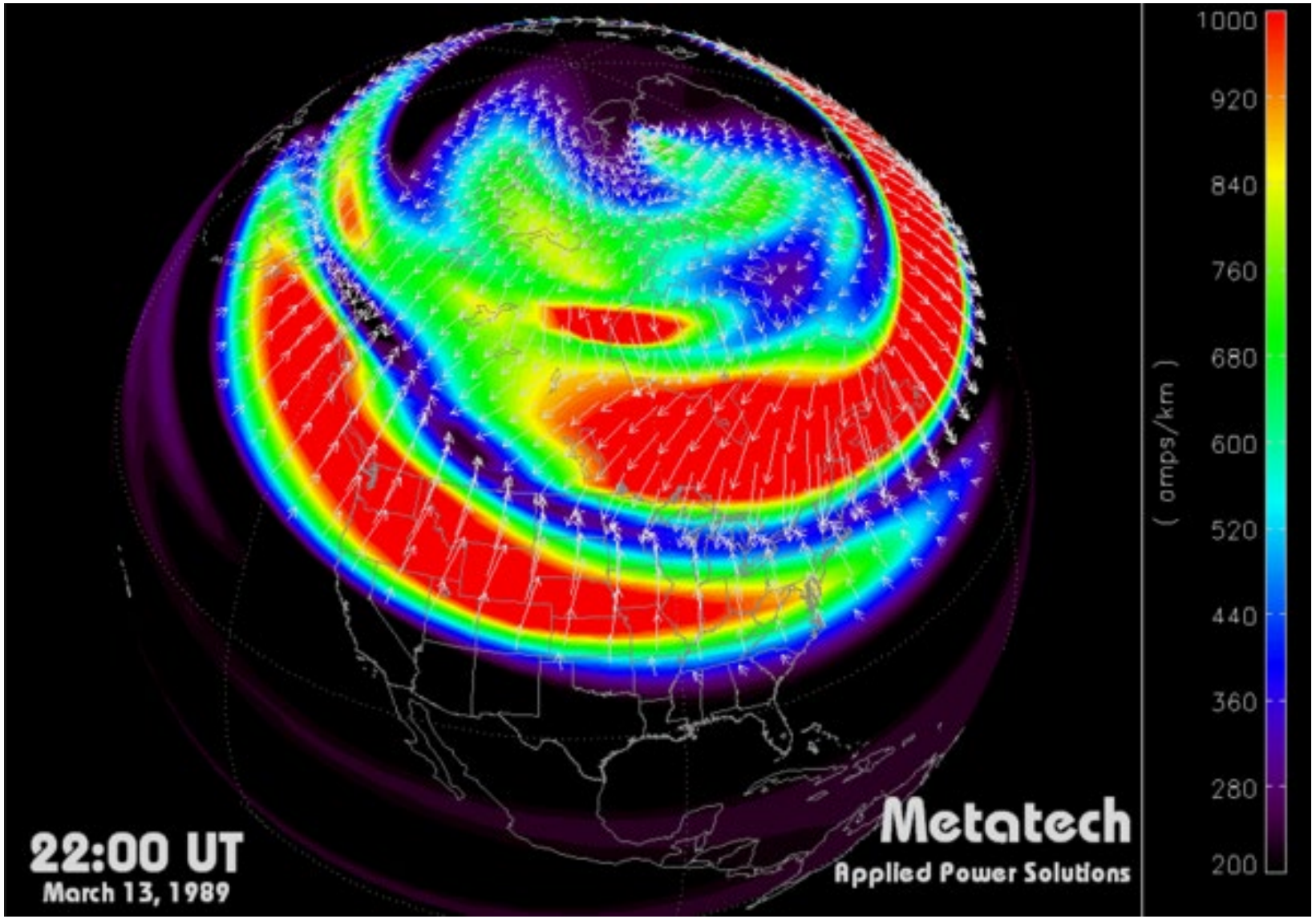
One feature was that while earth currents were disturbed, the wireless apparatuses remained unaffected.

The New York Times
Published: May 18, 1921

Scintillation Effects on SATCOM



Wireline Communications



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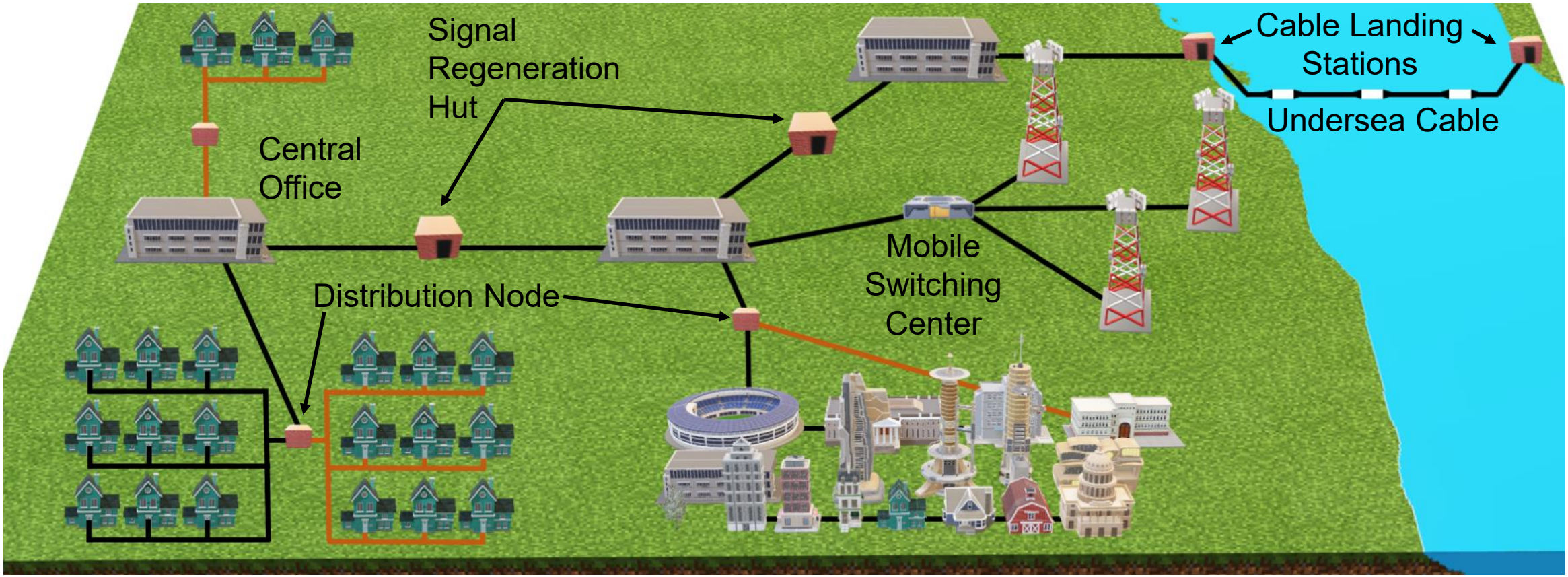
Terrestrial Wireline Basics - US

Fiber Optic Cable
Copper Cable

- Long haul cable ~88%-90% fiber optic
- Rural and “last mile” may still be ~40%-45% copper



- Fiber Optic Cables on land do not conduct electricity (mitigation)
- Damaging geomagnetically induced currents (GIC) require long-distance conductors (10s to 100s of km/mi)

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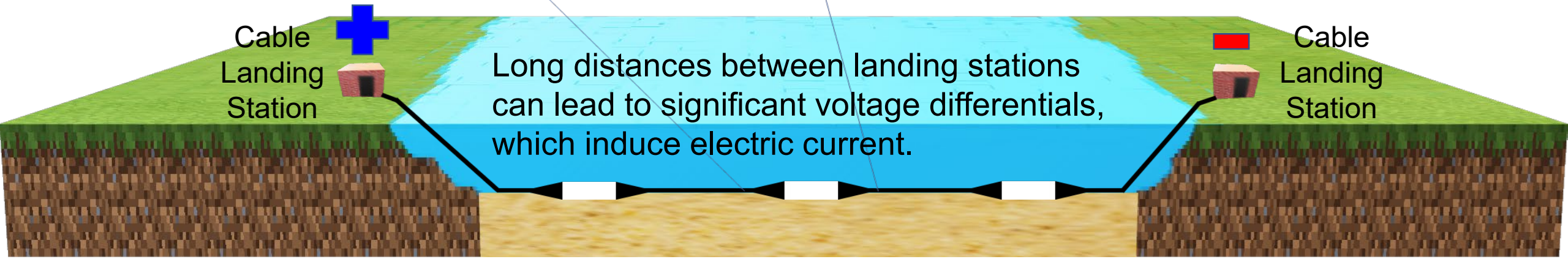
GIC and Undersea Cables

Undersea Repeaters regenerate optical signals approximately every ~40-70 kilometers.

Repeaters require power, which is provided by copper conduit built into the undersea cable.

- Copper conduit is susceptible to geomagnetically induced currents
- Research into vulnerability is ongoing and depends on cable length, geographic orientation, and electrical architecture



Risk currently unknown

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Conclusion

Radio

- Effects ionospheric skywave radio (HF). Not a total Radio Blackout!
- Mitigation is possible.
- Line-of-sight radio not effected, except for specific Solar Radio Burst cases.

Satellite

- Move to lower orbits and higher frequencies is changing the risk profile.
- Even in extreme storms, C-band and above not effected by scintillation.
- Concern for changes in orbital debris orbits.

Terrestrial Wireline

- Limited impact possible for legacy long-distance copper cables on land.
- Unknown risk for submarine cables.

Mark MacAlester
Communications Liaison
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CISA
CYBER+INFRASTRUCTURE

For more information:
cisa.gov

Questions?
Email: mark.macalester@hq.dhs.gov

Mark MacAlester
Communications Liaison
May 6, 2021

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