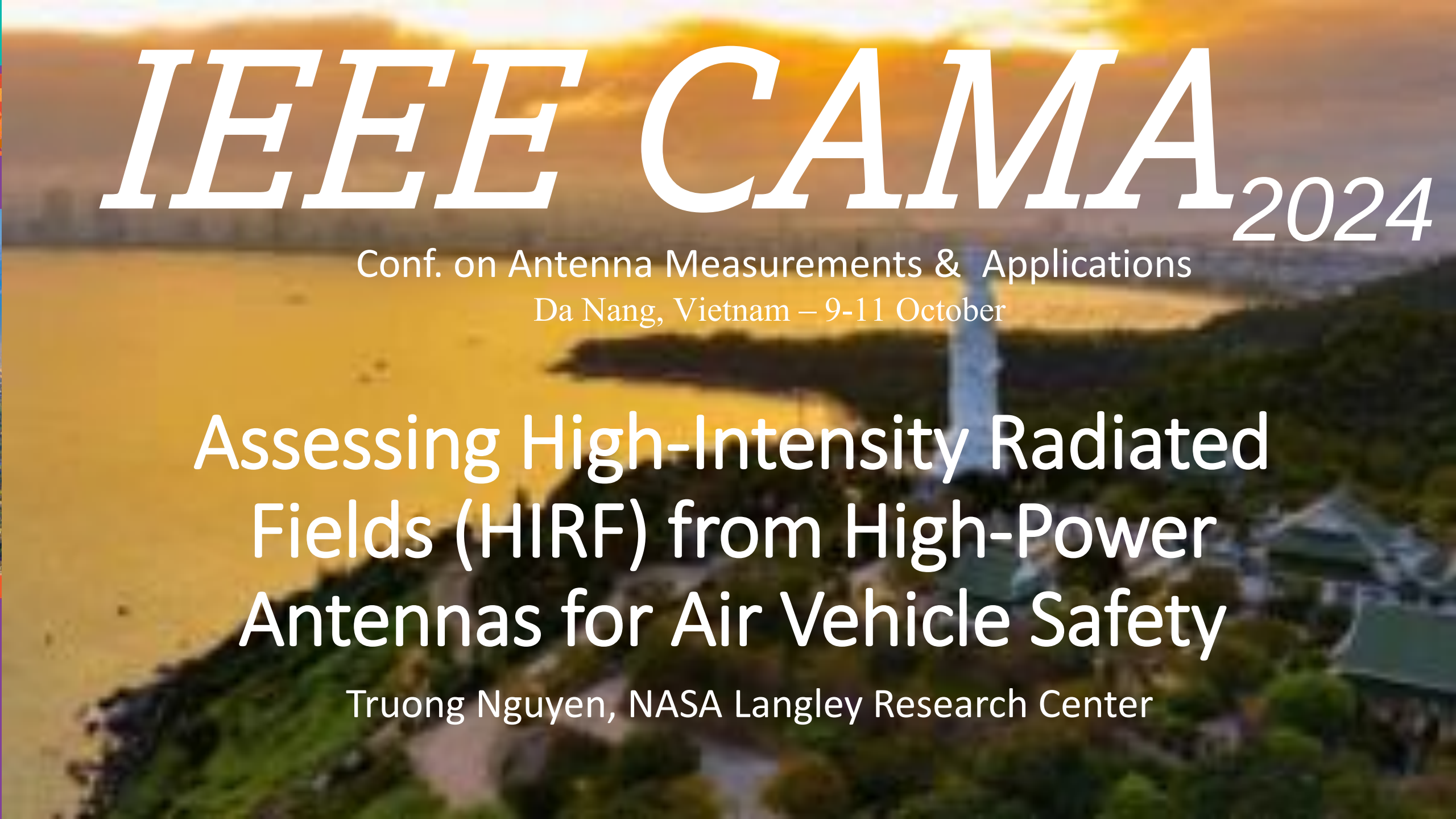
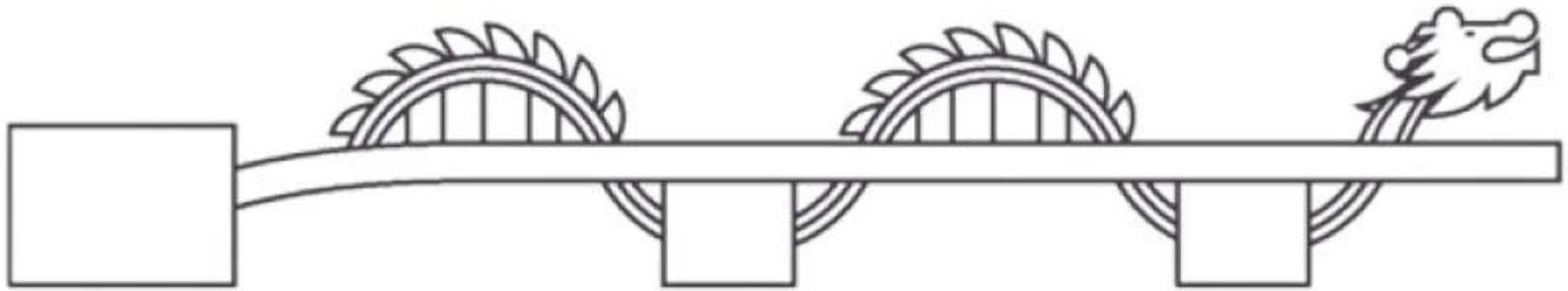


Assessing High-Intensity Radiated Fields (HIRF) from High-Power Antennas for Air Vehicle Safety

Truong Nguyen, NASA Langley Research Center



2024 IEEE CAMA
Da Nang, Vietnam

Outline

- Background & Motivation
- **Part 1**: **Map-based HIRF Avoidance Approach**
  - Presented at the 2023, 2024 Digital Avionics Systems Conference (DASC)
- **Part 2**: **Urban HIRF Environments** &
  - Minimum HIRF Tolerance Recommendation for AAM Vehicles

Background & Motivation

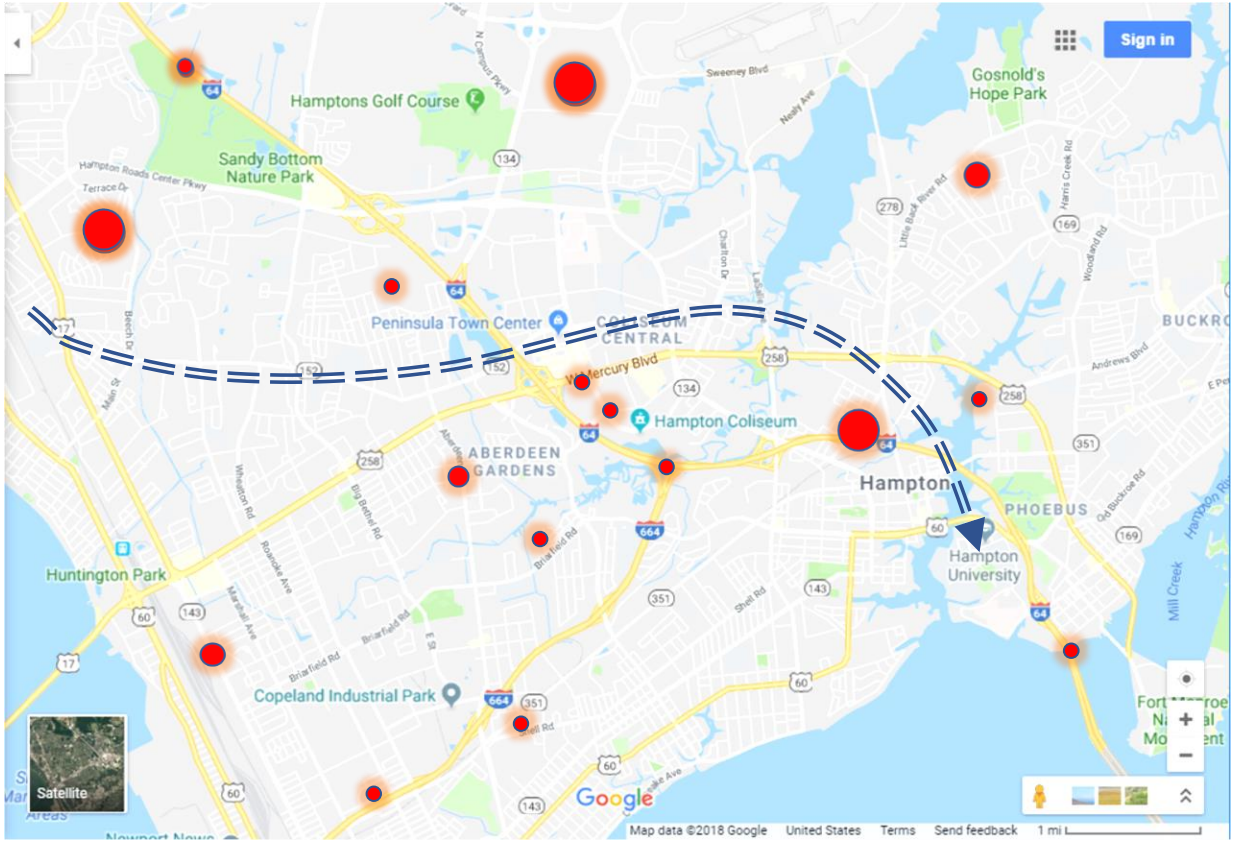
- Air vehicles are regularly exposed to High-Intensity Radiated Fields (HIRF)
  - HIRF sources:
    - Cellular towers, AM/FM/TV towers, satellite uplink, radar, communication radios…
  - HIRF can cause interference or even damage to aircraft systems
  - There are existing HIRF standards to protect Rotorcraft and Aircraft
  - Rotorcraft environment worse than for aircraft
- UAM/AAM/UAS vehicles may operate similarly to rotorcraft
  - Urban Air Mobility (UAM)/ Advanced Air Mobility (AAM)/ Unmanned aircraft systems (UAS)
  - Expected to be certified similarly to rotorcraft
  - Have large windows and lack of metal skin for shielding,
- **Problem**: Concerns about HIRF protection cost, size, and weight
- **Goal**: Develop a suitable approach to reduce the costs for HIRF Protection and Certification

Proposed Solution

- Reduce vehicle HIRF tolerance level to reduce vehicle cost
- Use a Map-based avoidance approach

This solution needs:

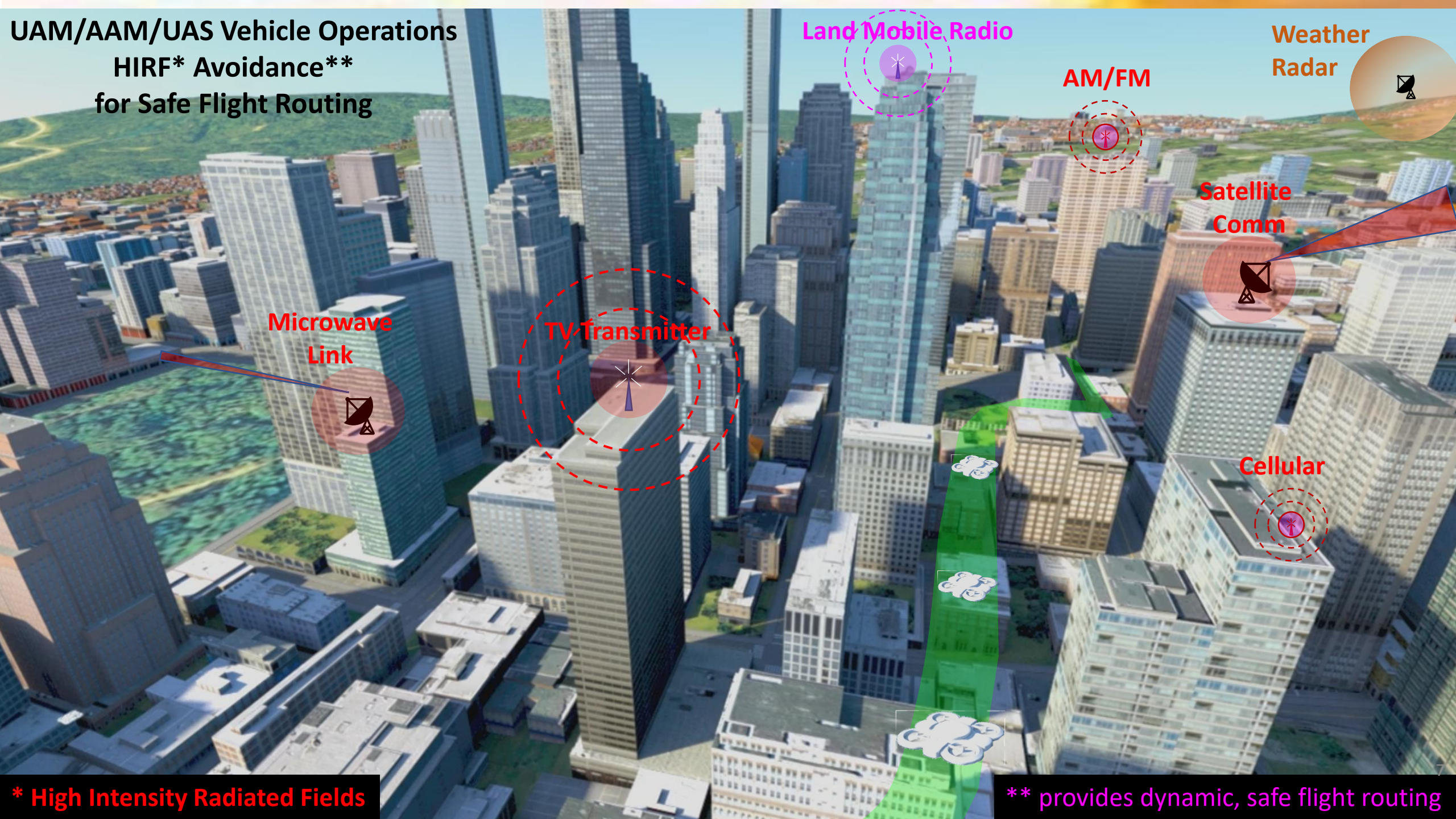
- To understand the HIRF environments in urban areas
- Optimize the tolerance level



"Keep-out" zones, with field strength potentially exceeding the UAV's tolerant levels

Urban Air Mobility (UAM) and AAM Concepts

Illustration by NASA's Aeronautics Research Mission Directorate


UAM/AAM/UAS Vehicle Operations
HIRF* Avoidance**
for Safe Flight Routing
Land Mobile Radio
AM/FM
Weather Radar
Satellite Comm
Microwave Link
TV Transmitter
Cellular
* High Intensity Radiated Fields
** provides dynamic, safe flight routing

Aircraft and Rotorcraft HIRF Environments

TABLE 3 - Certification HIRF Environment (HIRF Environment I)

FREQUENCY	FIELD STRENGTH (V/M)	
	PEAK	AVERAGE
10 kHz - 100 kHz	50	50
100 kHz - 500 kHz	50	50
500 kHz - 2 MHz	50	50
2 MHz - 30 MHz	100	100
30 MHz - 70 MHz	50	50
70 MHz - 100 MHz	50	50
100 MHz - 200 MHz	100	100
200 MHz - 400 MHz	100	100
400 MHz - 700 MHz	700	50
700 MHz - 1 GHz	700	100
1 GHz - 2 GHz	2000	200
2 GHz - 4 GHz	3000	200
4 GHz - 6 GHz	3000	200
6 GHz - 8 GHz	1000	200
8 GHz - 12 GHz	3000	300
12 GHz - 18 GHz	2000	200
18 GHz - 40 GHz	600	200

TABLE 2 - ROTORCRAFT SEVERE HIRF ENVIRONMENT (HIRF ENVIRONMENT III)

FREQUENCY	FIELD STRENGTH (V/m)	
	PEAK	AVERAGE
10 kHz - 100 kHz(1)	150	150
100 kHz - 500 kHz	200	200
500 kHz - 2 MHz	200	200
2 MHz - 30 MHz	200	200
30 MHz - 70 MHz	200	200
70 MHz - 100 MHz	200	200
100 MHz - 200 MHz	200	200
200 MHz - 400 MHz	200	200
400 MHz - 700 MHz	730	200
700 MHz - 1 GHz	1400	240
1 GHz - 2 GHz	5000	250
2 GHz - 4 GHz	6000	490
4 GHz - 6 GHz	7200	400
6 GHz - 8 GHz	1100	170
8 GHz - 12 GHz	5000	330
12 GHz - 18 GHz	2000	330
18 GHz - 40 GHz	1000	420

Part 1:Map-based HIRF Avoidance Approach

Solution: Provide a **map of HIRF avoidance zones**, tailored for each AAM vehicle

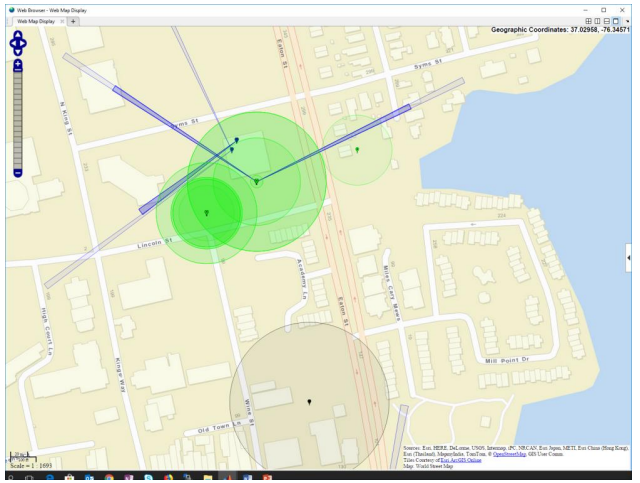
(A) **Transmitter Power** - (B) **Propagation Loss** (HIRF Map) < (C) **Vehicle Tolerance**

(A) Fixed-transmitter databases

(B) "HIRF Map" to be used in **flight-path planning**

(C) Vehicle's HIRF tolerant level

- User defined
- Higher tolerance ➔ Smaller HIRF zone



- **This approach requires knowledge of transmitters (frequency, location, power)**

E CAMA Vietnam

Calculate HIRF Zones

$$E = \frac{1}{R}\sqrt{30PG}$$

$$R = \frac{1}{E}\sqrt{30PG}$$

E = E-field tolerance level
R = Stand-off distance
P = Radiated Power
G = Antenna Gain
EIRP = PG = Eff. Isotropic Radiated Power

Assumptions:

- Use the worst-case power and gain data, to be conservative
  - In the Far-field
  - Ignore antenna pattern (use the worst case)
  - No high-order effects (reflection, diffraction)
  - No cumulative effect
- **The HIRF zone is a circular region with a radius R**
  - Angular range is incorporated if known
  - R is scaled for elevation angle if known

Benefits

- **Advantages**
  - Faster and cheaper to design, build, test, and certify
    - Avoid designing/certifying to the globally-defined worst-case environment
  - Suitable for AAM, VTOL vehicles
  - Can handle higher-power transmitters than in standard

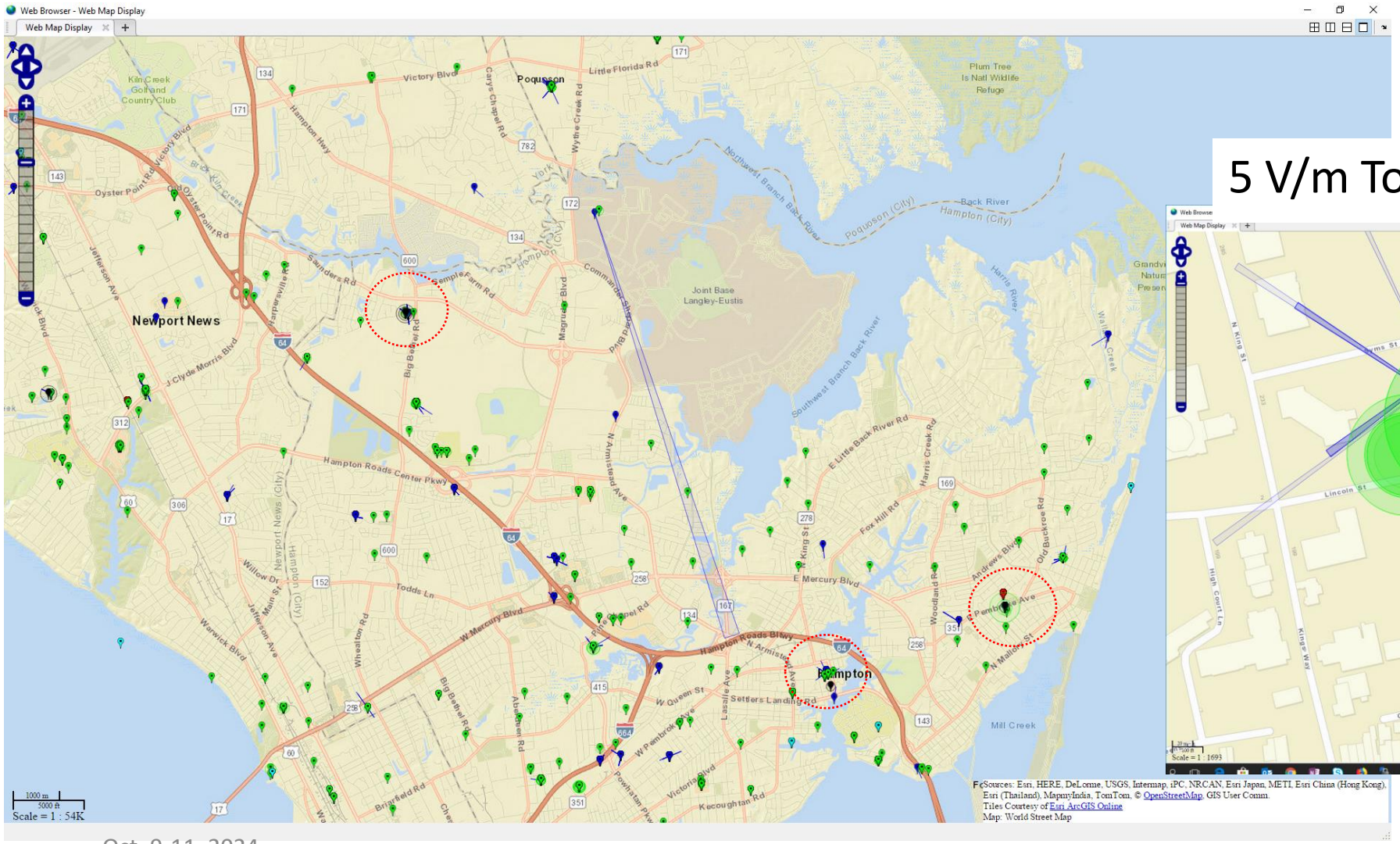
- **Disadvantages**
  - Slightly more complex flight planning
  - Transmitters databases unique to individual countries
  - Uncertainties in the transmitter databases
    - Unknown transmitters (i.e. government & military sites)
    - GPS accuracy
    - Deactivated transmitters

Credits: NASA Langley

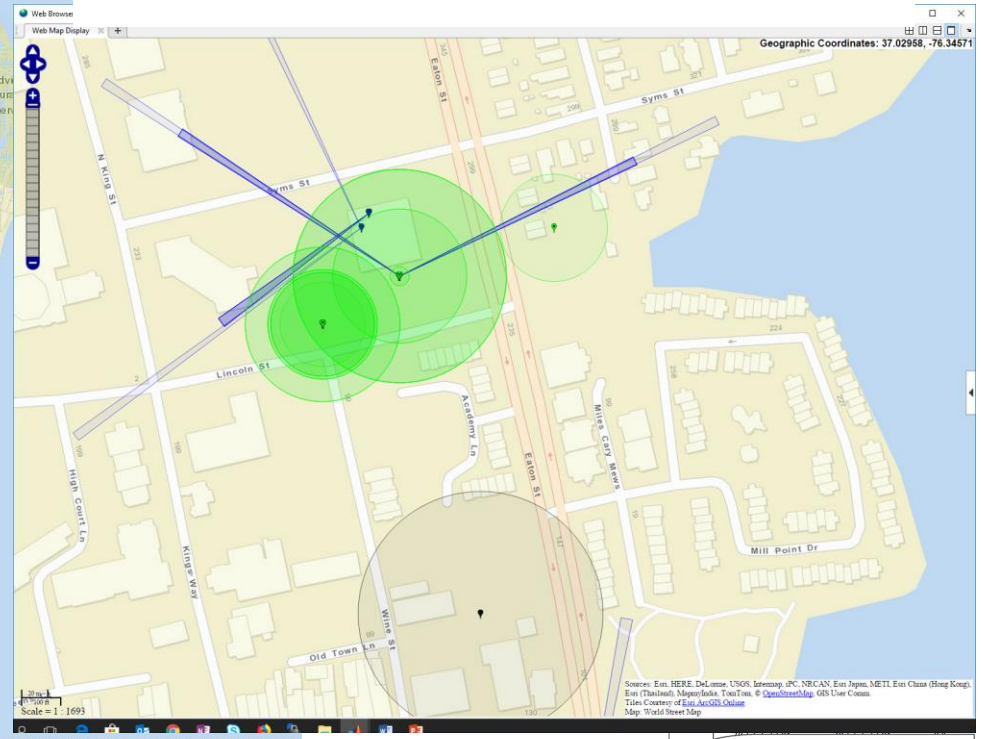
ULS HIRF-Map Example

FCC ULS Transmitters

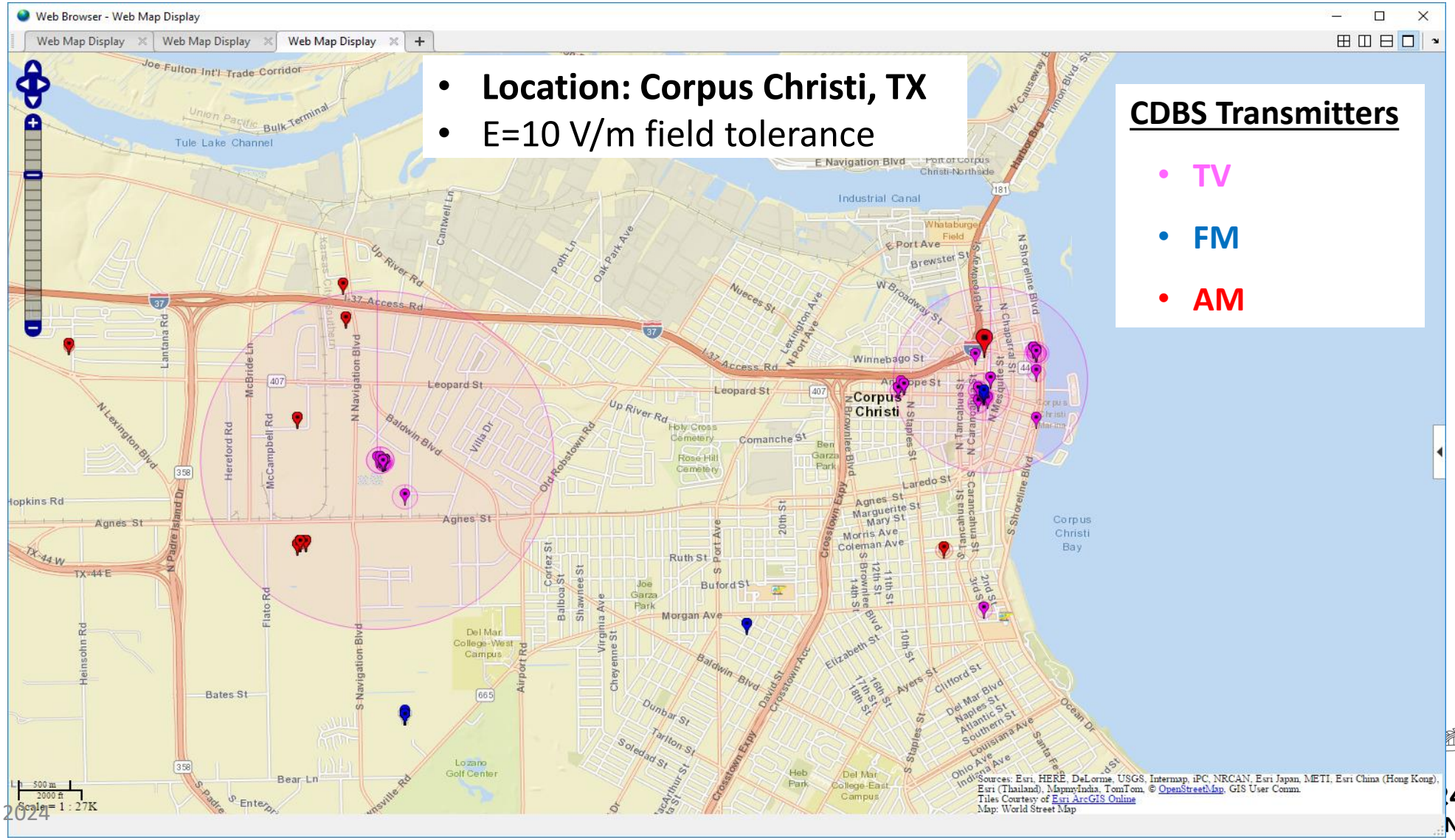
- Cellular
- Microwave
- Land Mobile
- Coastal and Aviation Ground
- Paging



5 V/m Tolerance Level

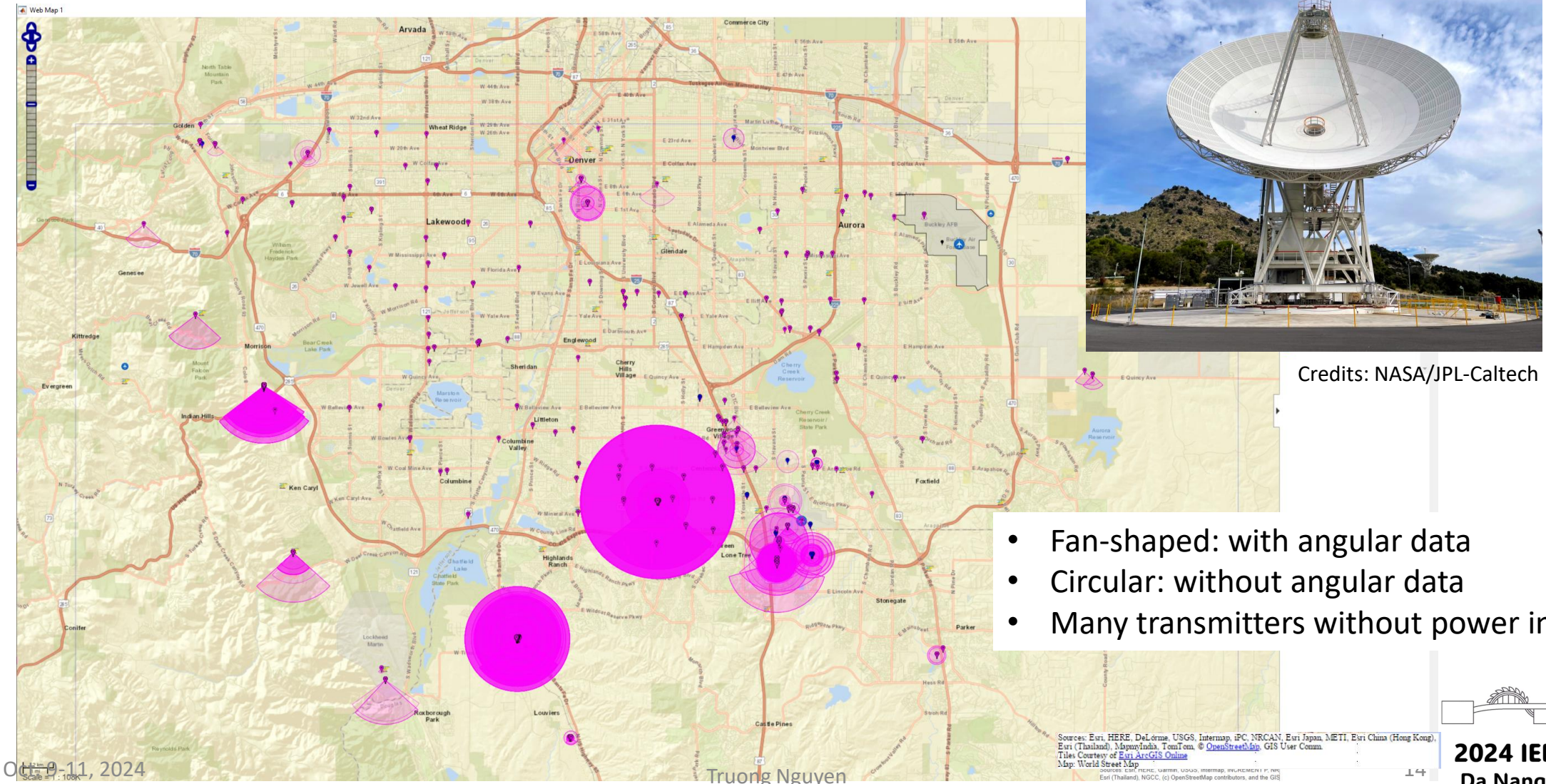


CDBS Example



IBFS Example

- 50 V/m, Denver, Colorado



Credits: NASA/JPL-Caltech

- Fan-shaped: with angular data
- Circular: without angular data
- Many transmitters without power info

Part 2:

Urban HIRF Environment

SAE ARP5583: Rotorcraft HIRF Assumptions

3.4.1 Assumptions for the Calculation of the Rotorcraft Severe HIRF Environment: The Rotorcraft Severe HIRF environment is derived from a worst case estimate of the electromagnetic field strength levels in the airspace in which rotorcraft flight operations are permitted. The worst case estimate considers transmitters in the following groups and rotorcraft to transmitter distances:

a. Airport/Heliport environment: The rotorcraft on the ground may be subjected to emitters having unique separation distance and geometry due to local terrain and runway/taxiway layouts. Because of these conditions, minimum separation distances for each category of emitter were specified as follows:

100 feet slant range for fixed transmitters within a 5 nautical mile boundary around the runway, with the exception of airport surveillance radar and air route surveillance radar; for these two radar types a 300 foot adjusted slant range was used.

50 feet slant range for mobile transmitters, including transmitters on other aircraft, and 150 feet slant range for aircraft weather radar.

b. Non-Airport/Non-Heliport Ground environment: These sources include airport emitters while the rotorcraft is in flight:

All transmitters, 100 feet slant range.

100’ minimum separation distance from HIRF sources!

Approach – Urban HIRF Environment

- **Determine Power Envelopes from government databases**
  - **No military or airport transmitters**
- **Compute Field Strength at 100’ distance (outside of airport)**
- **Compare with HIRF Standard**
- (Optimize tolerance levels by drawing HIRF zones on Map and)

- Use New York City as a representative urban area

Transmitter Databases

- **FCC (Federal Communications Commission)**

- **ULS**: **Cellular, Land-Mobile Radio, Microwave, Paging, Coastal & Aviation Ground,…**
  - The Universal Licensing System
  - **75 KW EIRP Max (cellular), 57.5 KW EIRP (Microwave) ***

- **CDBS**: **AM, FM, TV**
  - The Consolidated Database System → Licensing and Management System (LMS)
  - **8.2 MW EIRP Max***

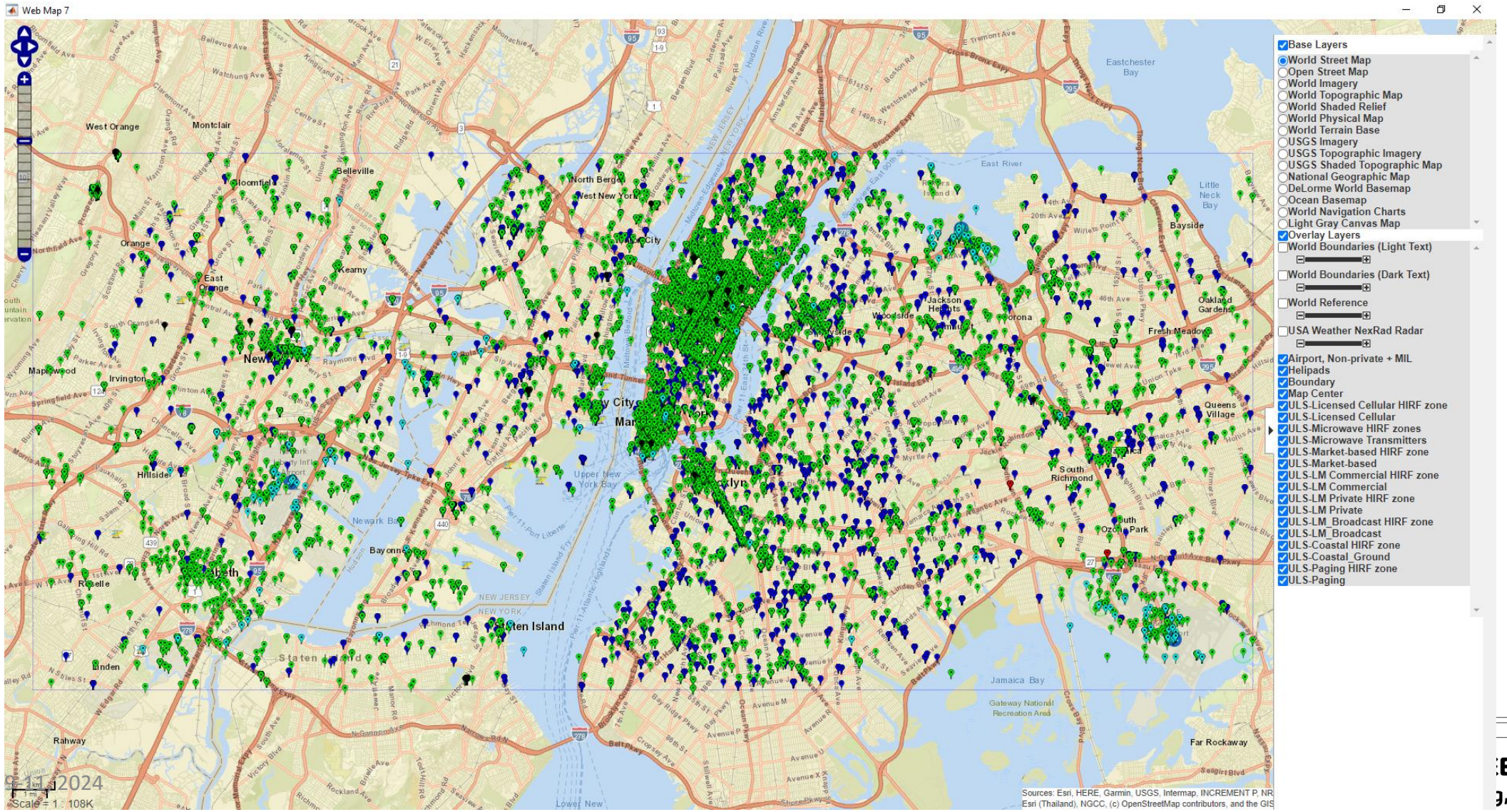
- **IBFS**: **Satellite Earth Station** (uplink)
  - The International Bureau Filing System → International Communications Filing System (ICFS)
  - **1.26 GW EIRP Max***

- **NOAA Weather Radar**: **25 GW EIRP Max**

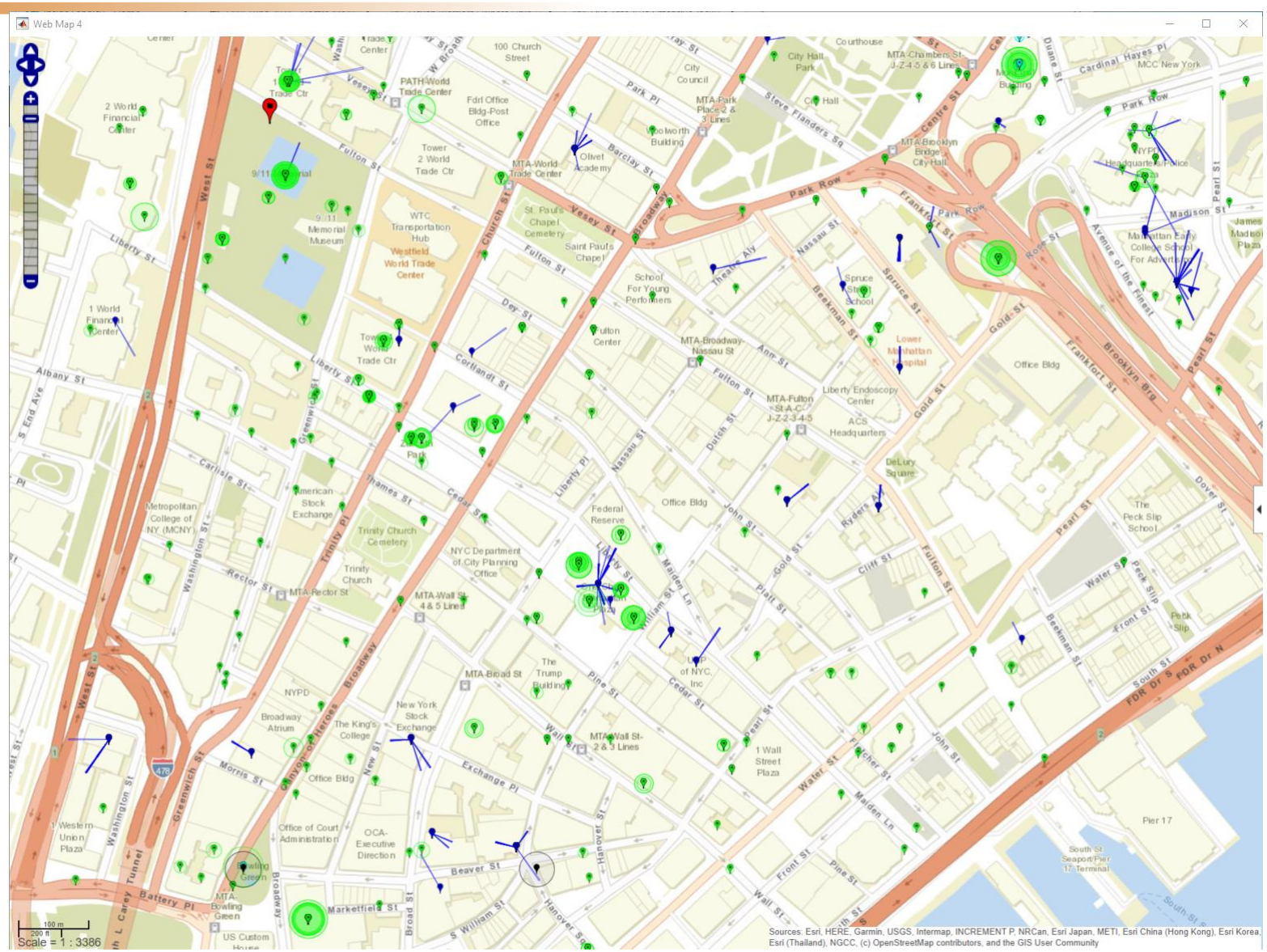
- **NTIA & FAA data** not publicly available
  - Stay out of airports and government facilities for now * From data for the New York City
- **Mobile transmitters** not considered

ULS Transmitters, Manhattan, New York

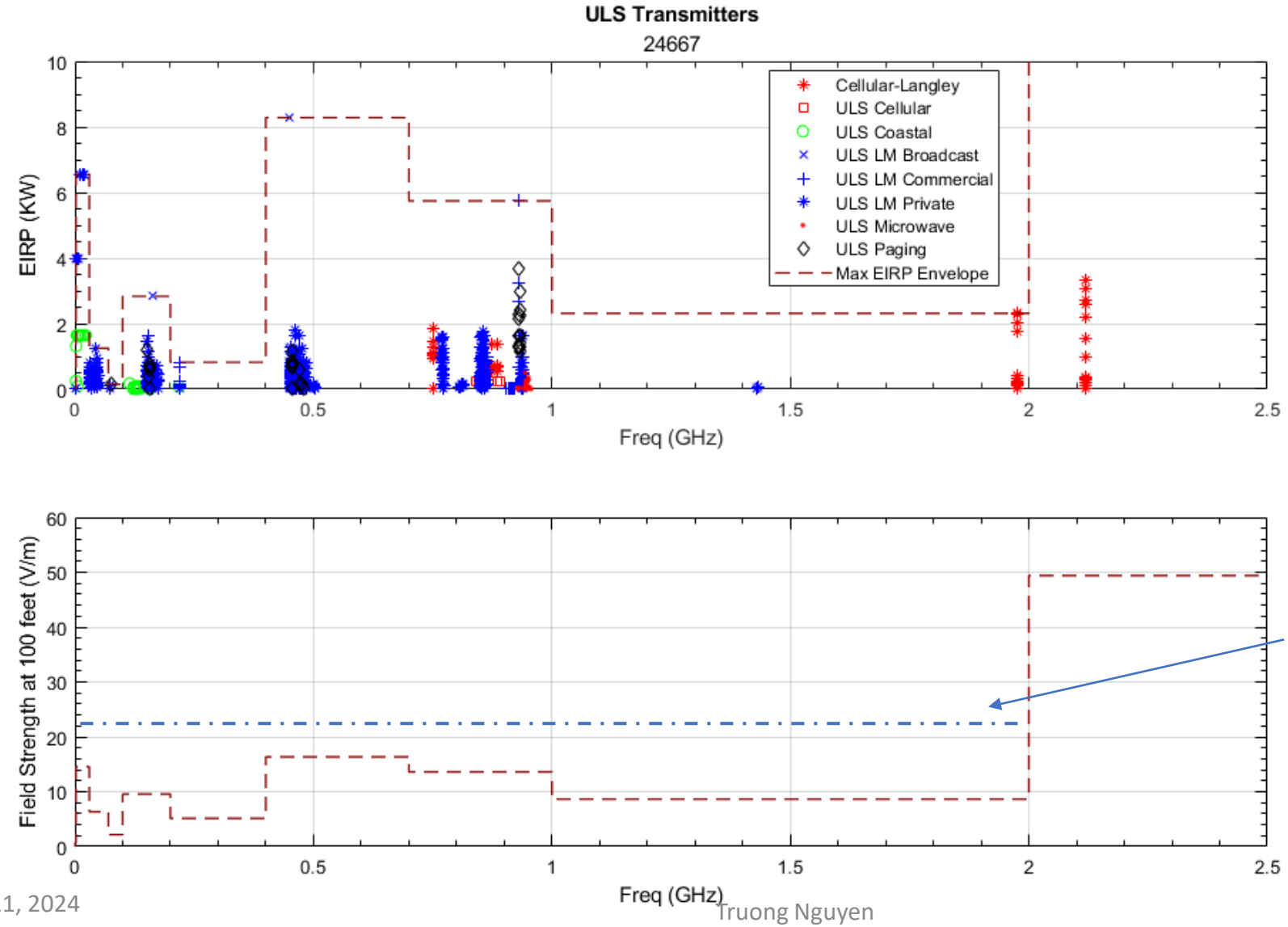
Transmitter record counts = ~ 25,000



ULS HIRF Map Example - 10 V/m Tolerant Level



ULS Baseline Threshold (NY City)
EIRP & E Field – to 2.5 GHz



Recommended HIRF Threshold for ULS:

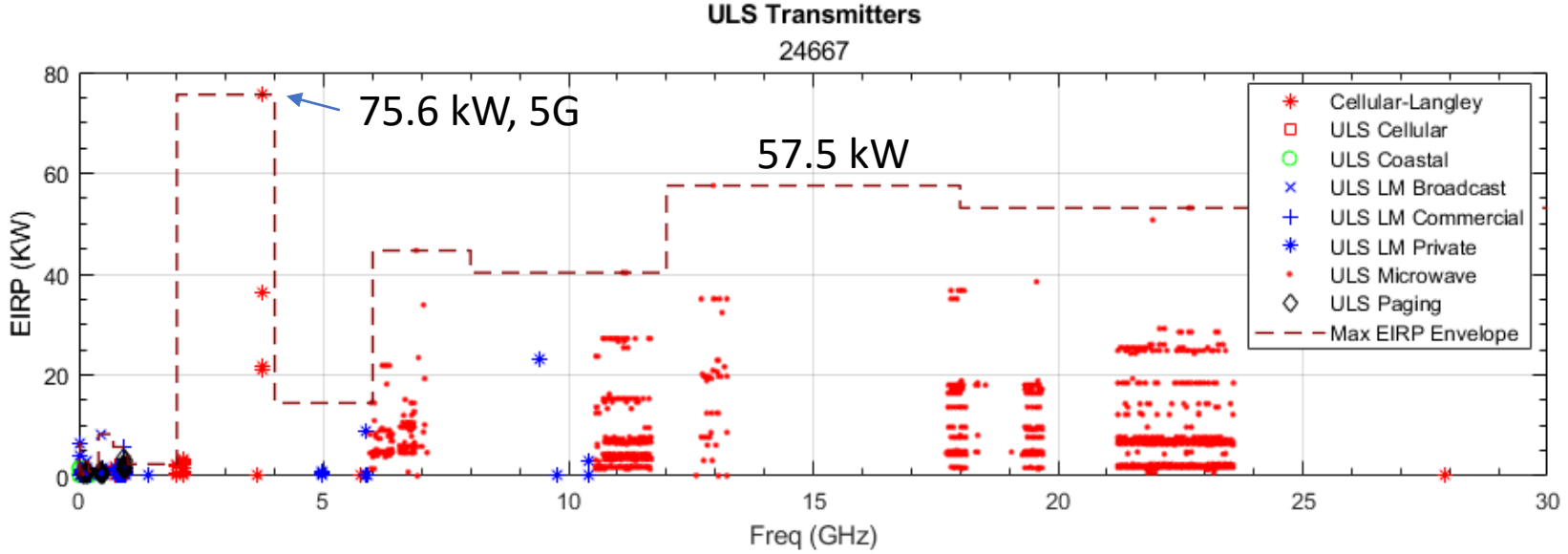
- **>25 V/m , F < 2 GHz**
- **>50 V/m , F > 2 GHz**

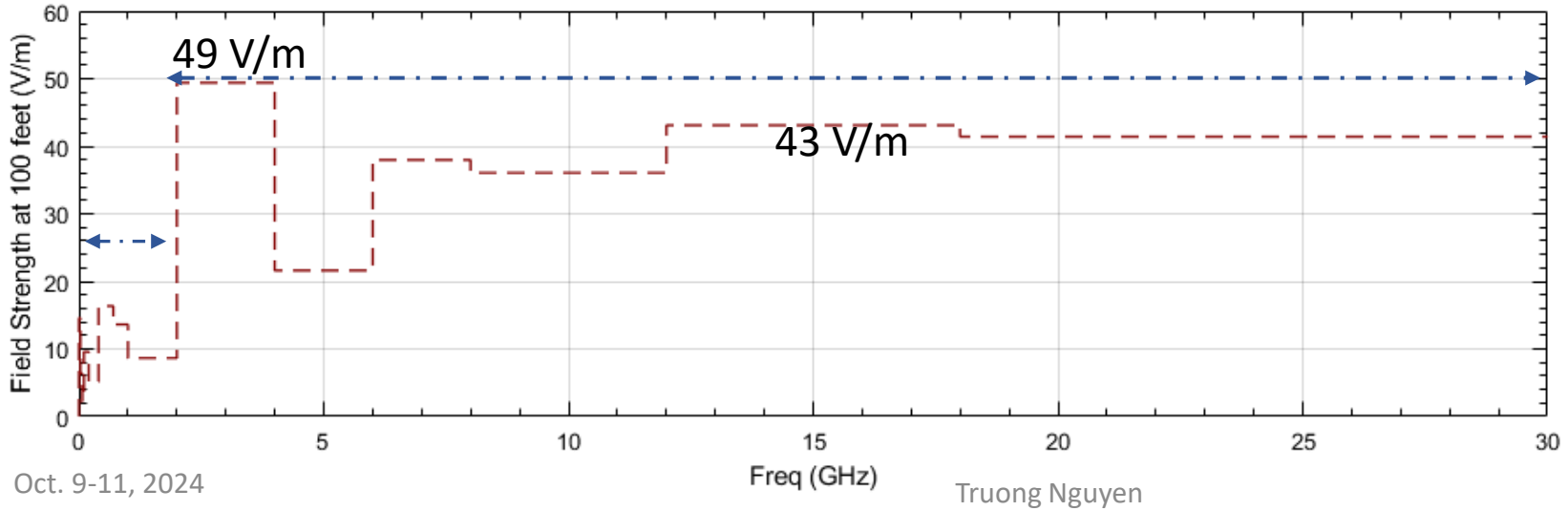
Transmitters:

- 24,667 data records
- 5,786 unique Call Signs

Suggested tolerance = 25 V/m

ULS Baseline Threshold (NY City) EIRP & E Field – to 30 GHz





Recommended Baseline Thresholds from ULS Data:

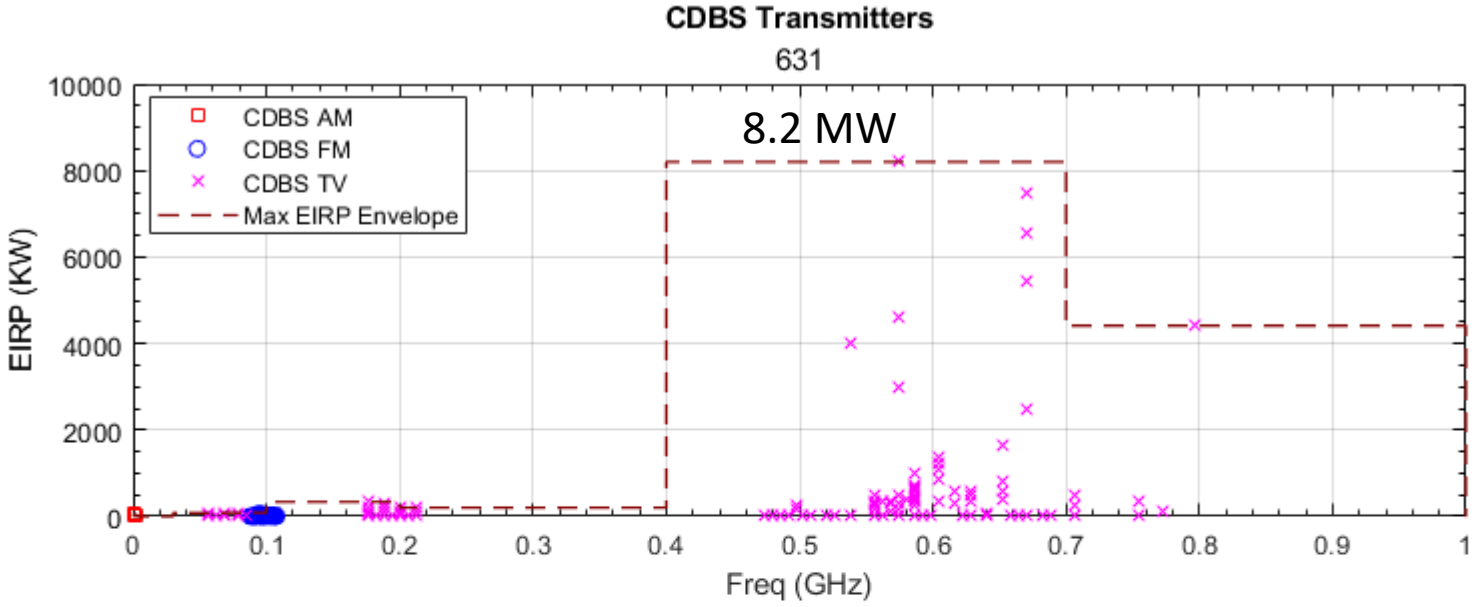
- **> 25 V/m , F < 2 GHz**
- **> 50 V/m , F > 2 GHz**

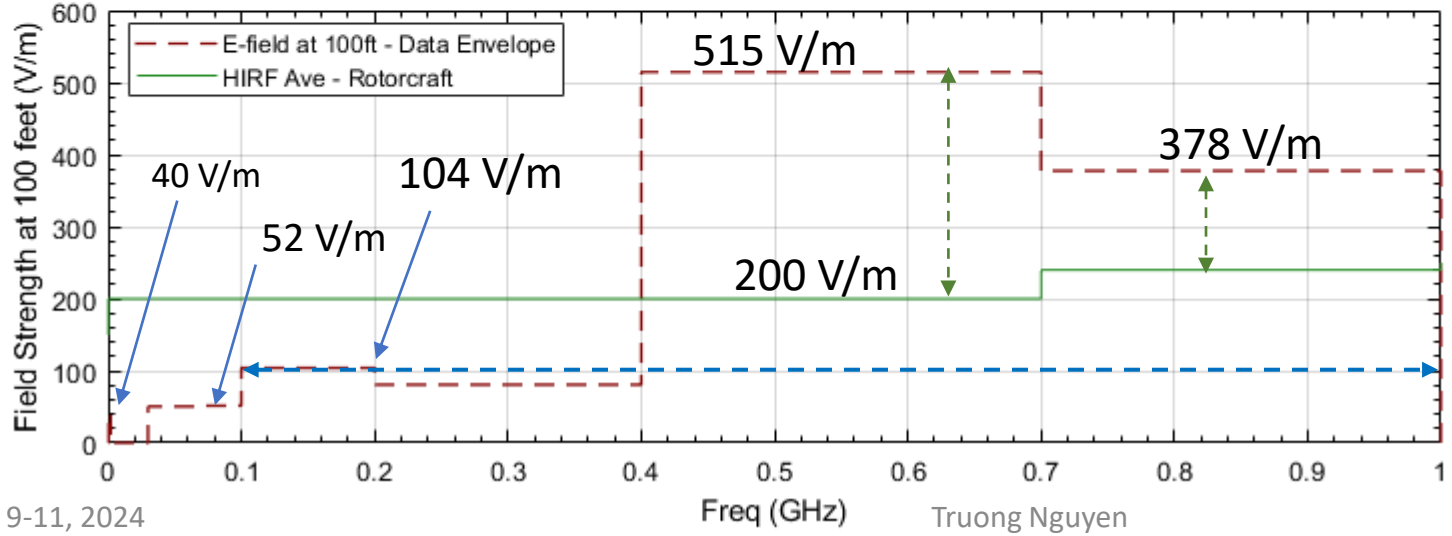
Transmitters:

- 24,667 data records
- 5,786 unique Call Signs

- LM Private Data above 1 MW eliminated,
- 1 data point > 46 MW eliminated

CDBS - EIRP & E-field (NY City)





Max EIRP:

- AM: 50 KW
- FM: 65.6 KW
- TV: 8.2 MW

The current standard is insufficient!

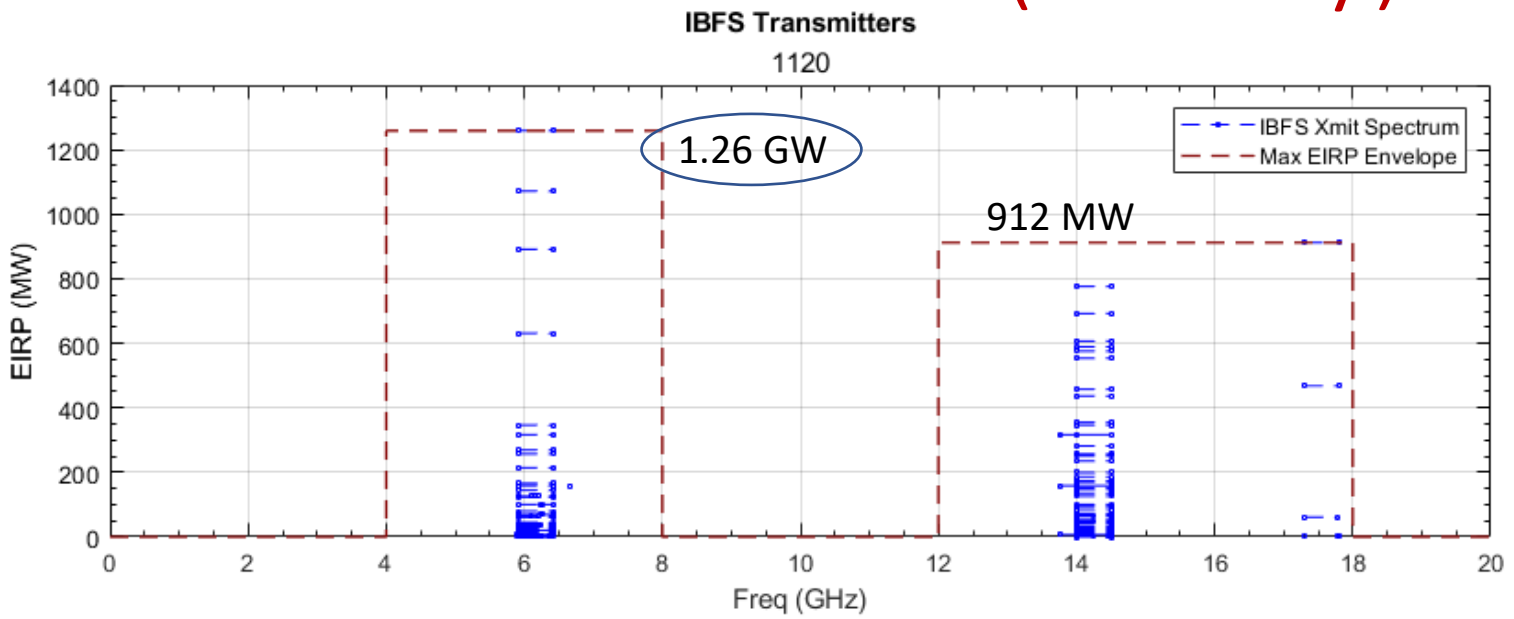
Tolerance Recommendation:

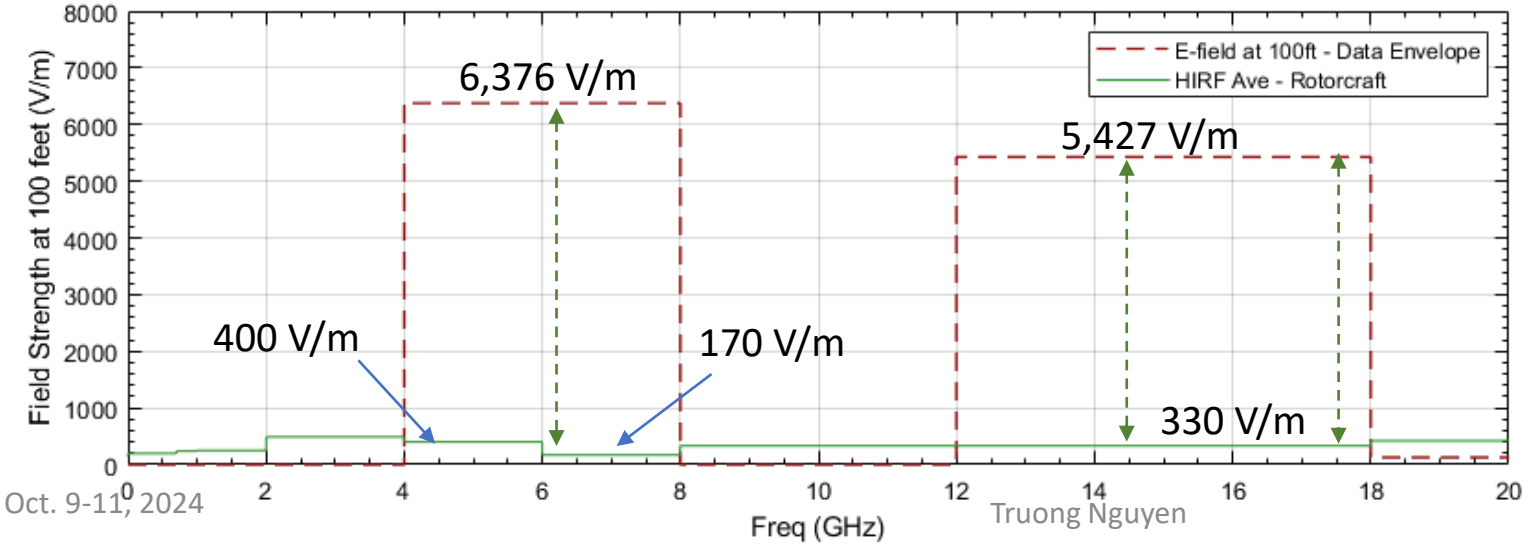
- **40 V/m,** for AM band
- **55 V/m,** 30 MHz – 100 MHz
- **100 V/m,** F > 0.1 GHz

Transmitters:

- 631 data records
- 107 unique Call Signs

IBFS - EIRP & E Field (NY City)





- Compare against HIRF Ave. limit
- Current requirements not sufficient!
- ➢ **Recommend:**
  - **500 V/m + use Map**

Transmitters:

- 1120 data records
- 121 unique Call Signs

Credits: NASA/JPL-Caltech

IBFS – FCC Transmitter Data Example

FCC IBFS Call Signs: E920377*, E900089*

*Licenses expired

A) Site Location(s)

#	Site ID	Address	Latitude	Longitude	Elevation (Meters)	NAD	Special Provisions (Refer to Section H)
1)	1	830 FOUNTAIN AVENUE BROOKLYN, KINGS, NY	40° 39' 33.0" N	73° 52' 5.0" W	4.9	UNK	

C) Frequency Coordination

#	Frequency Limits(MHz)	Satellite Arc (Deg. Long.) East Limit	Satellite Arc (Deg. Long.) West Limit	Elevation (Degrees) East Limit	Elevation (Degrees) West Limit	Azimuth (Degrees) East Limit	Azimuth (Degrees) West Limit	Max EIRP Density toward Horizon (dBW/4kHz)	Associated Antenna(s)
1)	5925.0000 - 6425.0000	60.0W	136.0W	40.9	12.3	159.2	251.0	-0.6	1

E) Antenna Facilites

Site ID	Antenna ID	Units	Diameter (Meters)	Manufacturer	Model Number	Site Elevation	Max Antenna Height (Meters)	Special Provisions (Refer to Section H)
1	1	1	13.0	DIA	1300DLM-C	4.9	14.1 AGL/ 19.4 AMSL	

Max Gains(s):53.3 dBi @ 4.0000 GHz 56.7 dBi @ 6.0000 GHz

H. Special and General Provision

2810 The grantee shall maintain on file with the Commission's current list or plan of the precise frequencies in actual use at this station, specifying for each such frequency: the r.f. center frequency, polarization, emission designator, EIRP (dBW), EIRP density (dBW/4kHz), and receiving earth station(s). This list or plan may be submitted either on a station -by-station basis or on a system-wide basis, and shall be updated within seven days of any changes in frequency usage at this station. Temporary usage of frequencies for periods of less than seven days need not be notified to the Commission if accurate station records are maintained of the times and particulars of such temporary frequency usage.

B) Particulars of Operations

The General Provision 1010 applies to all receiving frequency bands.
The General Provision 1900 applies to all transmitting frequency bands.
For the text of these provisions, refer to Section H.

#	Frequency	Polarization	Emission	Tx/Rx Mode	Max EIRP /Carrier	Max EIRP Density	Asso Ante
1)	5925.0000 - 6425.0000	H,V	2M50F9D	T	78.40	51.40	1
2)	5925.0000 - 6425.0000	H,V	36M0F9W	T	91.00	51.40	1
3)	5925.0000 - 6425.0000	H,V	36M0G7W	T	91.00	51.40	1
4)	5925.0000 - 6425.0000	H,V	10M0G7W	T	85.40	51.40	1
5)	5925.0000 - 6425.0000	H,V	7M40G7W	T	84.10	51.40	1
6)	5925.0000 - 6425.0000	H,V	1M34G7W	T	76.50	51.40	1
7)	5925.0000 - 6425.0000	H,V	500KG7W	T	72.40	51.40	1
8)	5925.0000 - 6425.0000	H,V	250KG7W	T	69.40	51.40	1
9)	5925.0000 - 6425.0000	H,V	48K0G7W	T	62.20	51.40	1
10)	5925.0000 - 6425.0000	H,V	400KF9W	T	71.40	51.40	1
11)	5925.0000 - 6425.0000	H,V	200KF9W	T	68.40	51.40	1
12)	5925.0000 - 6425.0000	H,V	50K0F9W	T	62.40	51.40	1

EIRP Unit in dBW
91 dBW = 1.26 GW
for a single carrier

NOAA Weather Radars

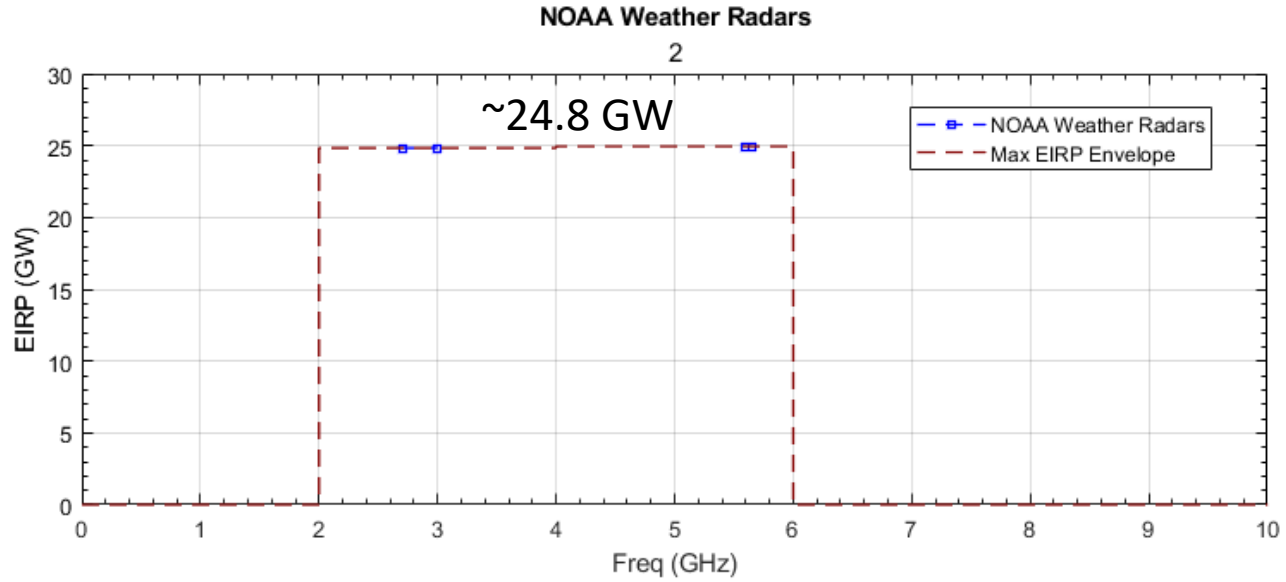
NEXRAD: Next Generation Weather Radar
TDWR: Terminal Doppler Weather Radar

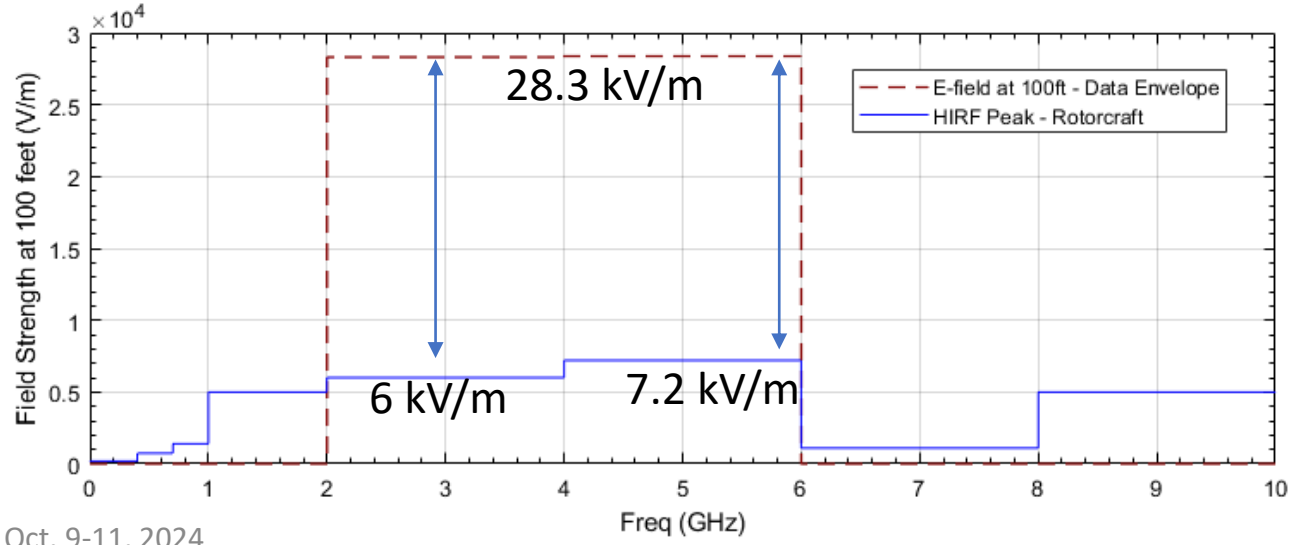
➔ Effective Isotropic Radiated Power (**EIRP**) = **~ 25 billion watts (peak), ~46 MW (ave.)**

	NEXRAD (WSR-88D) #160	**TDWR** #46
• **Frequency**	**2700-3000 MHz**	**5600-5650 MHz**
• **Peak Power**	**700 kW***	**250 kW***
Average Power	300-1300 W	
Antenna Gain	45.5 dB	50 dB
• **EIRP (Peak)**	**103.95 dBW (24.83 GW)**	**103.97 dBW (24.83 GW)**
EIRP (Ave)	76.64 dBW	
Beam Width	0.925 degrees	0.55 degrees
Pulse Width-max	1.57 & 4.7 microsec	1.1 microsec

*Cable loss is installation dependent. 0 dB is assumed to be conservative

NOAA Weather Radars – EIRP & E-Field

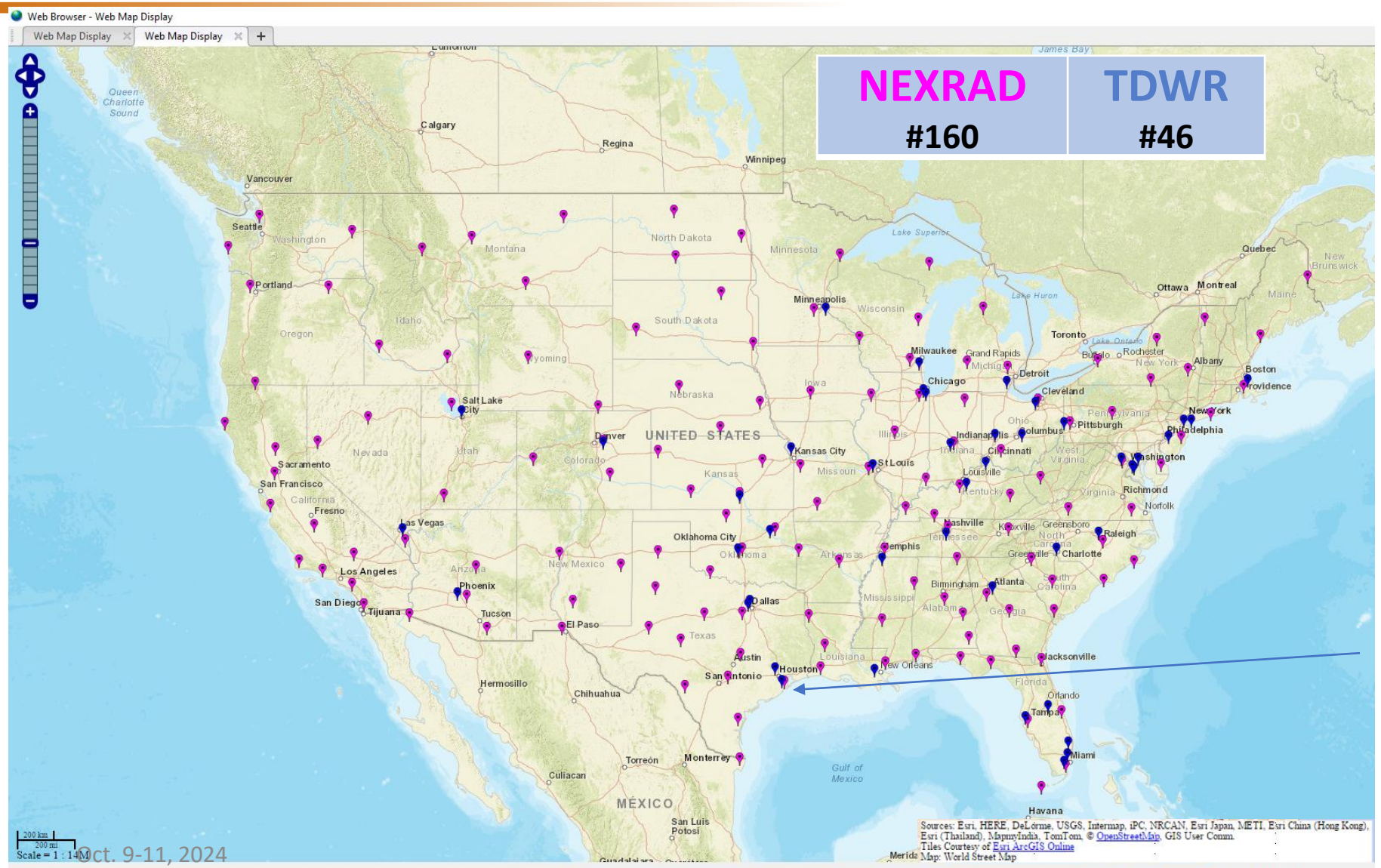




- Current requirements not sufficient!
- Radars are outside of urban areas

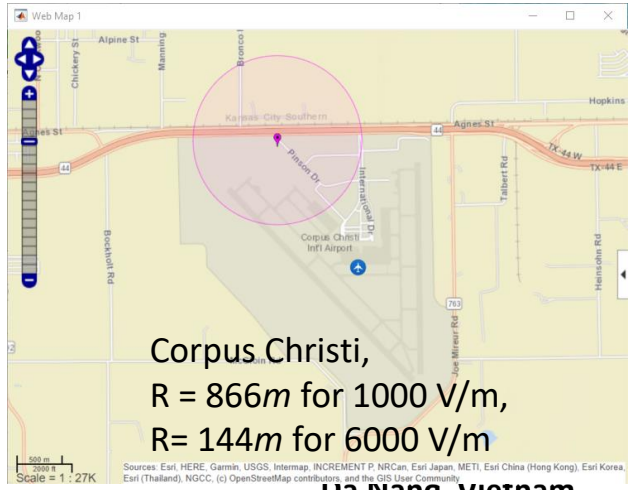
- **Recommend:**
  - **Only 1000 V/m Peak and use Map**
    → R = 866*m*

NOAA Weather Radars HIRF zone at 1000 V/m



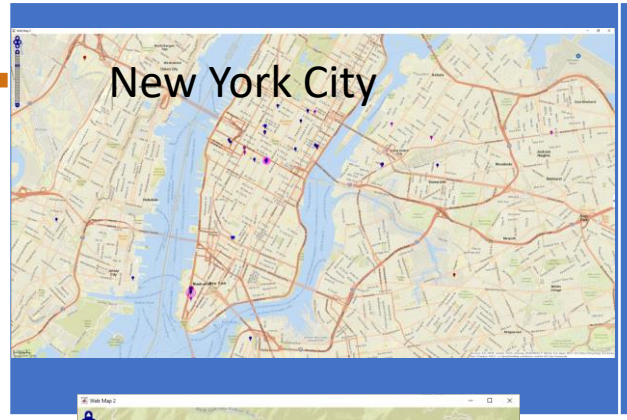
	NEXRAD (WSR-88D)
Frequency	2700-3000 MHz
Peak Power	700 kW
Power Gain	45.5 dB
Beam Width	0.95 degrees
Pulse Width-max	4.7 msec

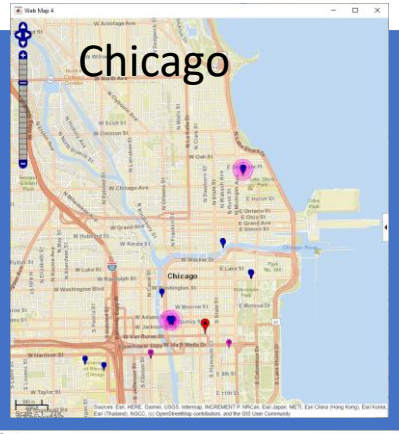
	TDWR
Frequency	5600 -5650 MHz
Peak Power	250 kW
Power Gain	50 dB
Beam Width	0.55 degrees
Pulse Width-max	4.7 msec

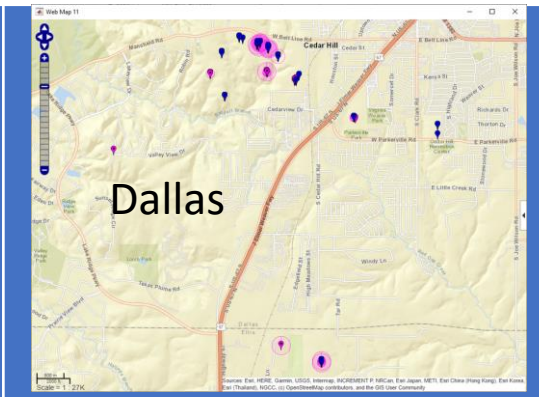


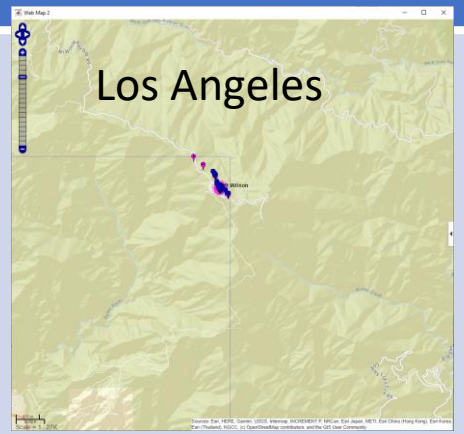
NOAA Weather Radar HIRF zones at 1000 V/m

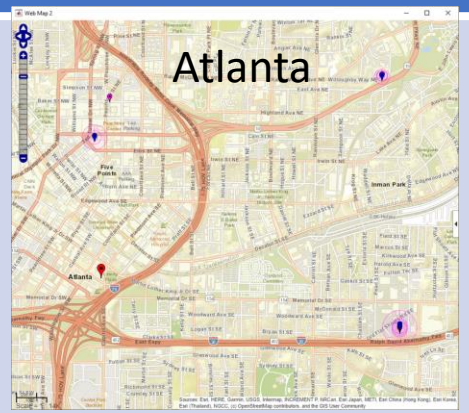
Other Cities – CDBS (105 V/m) & IBFS (500 V/m)

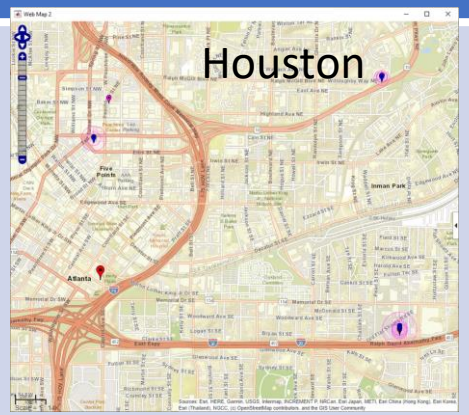


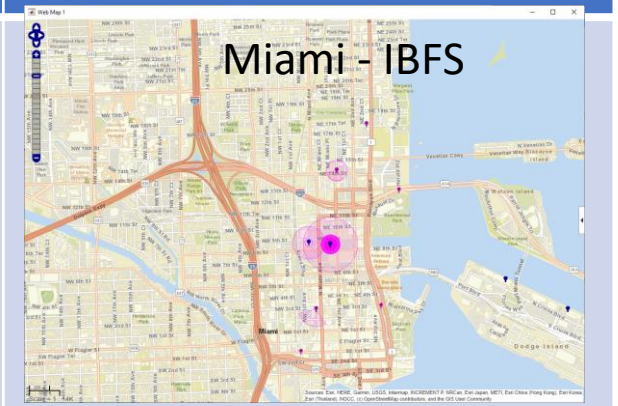


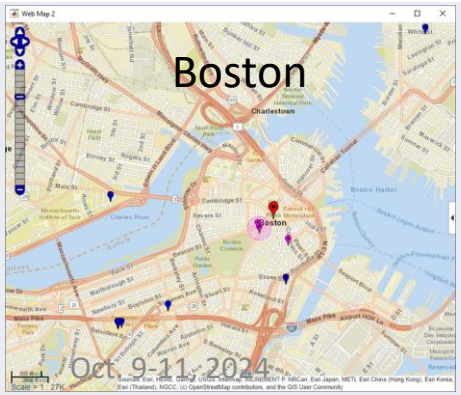


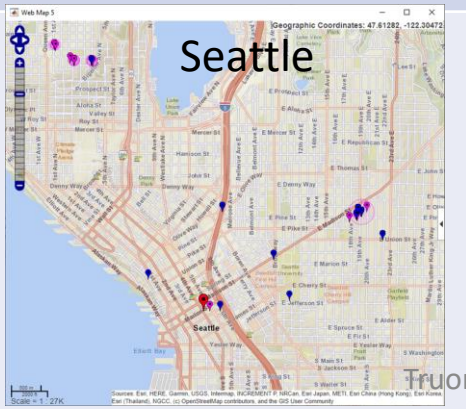


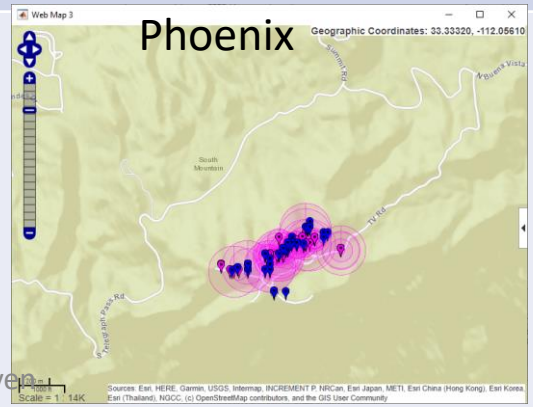


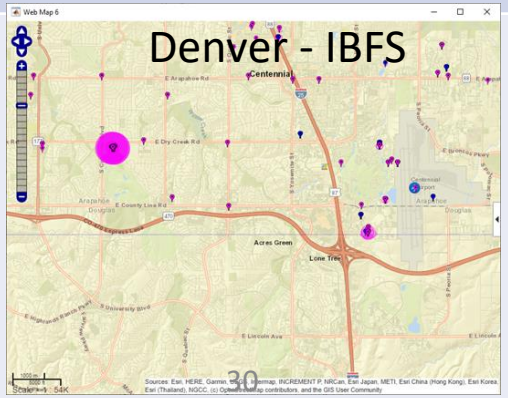












12 Cities - ULS Worst-Case Environments

Map Areas: 40x40 km to 40x80 km

Band	Freq. Range	HIRF Standard	New York	Chicago	San Francisco	Los Angeles	Dallas	Houston	Atlanta	Miami	Boston	Seattle	Phoenix	Denver	Max	Min. Recom. Threshold
1	10 kHz - 100 kHz	150													0	25
2	100 kHz - 500 kHz	200					1				13	1			13	25
3	500 kHz - 2 MHz	200	1	2	1	1	2	1	1	1	13	1	1	1	13	25
4	2 MHz - 30 MHz	200	15		18	7	13	7	7	7	7	18	1	10	18	25
5	30 MHz -70 MHz	200	6	4	4	5	5	4	4	4	5	4	5	4	6	25
6	70 MHz - 100 MHz	200	2	2	2	4	4	4	3	1	2	2	2	3	4	25
7	100 MHz -200 MHz	200	10	7	6	9	10	10	8	10	8	7	6	7	10	25
8	200 MHz - 400 MHz	200	5	5	5	4	4	5	4	5	3	5	2	1	5	25
9	400 MHz -700 MHz	200	16	7	14	14	10	36	7	8	8	17	8	10	36	25
10	700 MHz - 1 GHz	240	14	14	11	14	13	17	48	13	14	14	14	17	48	25
11	1 GHz - 2 GHz	250	9	9	9	9	9	9	9	9	9	9	9	9	9	25
12	2 GHz - 4 GHz	490	49	49	49	49	49	49	49	49	49	49	49	49	49	50
13	4 GHz - 6 GHz	400	22	20	16	27	115	~~788~~	16	17	0	16	38	32	115	50
14	6 GHz - 8 GHz	170	38	25	33	34	40	51	27	46	24	555	45	44	555	50
15	8 GHz - 12 GHz	330	36	38	~~161~~	52	30	~~738~~	30	~~1598~~	36	~~2278~~	75	48	75	50
16	12 GHz - 18 GHz	330	43	34	41	51	36	34	36	34	160	34	37	40	160	50
17	18 GHz - 40 GHz	420	41	40	44	46	29	24	24	24	35	35	41	36	46	50
# Records			24,667	8,834	7,651	97,640	12,227	12,311	7,603	5,662	9,227	17,151	34,316	9,196		

Shaded: Use HIRF Map to avoid HIRF Sources

12 Cities - CDBS Worst-Case Environments

Band	Freq. Range	HIRF Standard	New York	Chicago	San Francisco	Los Angeles	Dallas	Houston	Atlanta	Miami	Boston	Seattle	Phoenix	Denver	Max	Min. Recom. Threshold
1	10 kHz - 100 kHz	150														
2	100 kHz - 500 kHz	200														
3	500 kHz - 2 MHz	200	40	18	38	40	40	18	40	40	40	40	40	28	40	40
4	2 MHz - 30 MHz	200														
5	30 MHz -70 MHz	200	50	43	73	48	73	13	73	13	68	73	73	0	73	75
6	70 MHz - 100 MHz	200	52	51	76	178	73	73	73	47	73	73	73	32	178	75
7	100 MHz -200 MHz	200	104	76	129	95	73	73	73	21	36	129	129	69	129	75
8	200 MHz - 400 MHz	200	81	57	129	93	129	0	129	0	0	129	129	0	129	75
9	400 MHz -700 MHz	200	515	515	515	373	515	56	378	28	515	230	515	75	515	100
10	700 MHz - 1 GHz	240	378	515	487	365	515	29	515	0	515	515	515	515	515	100
11	1 GHz - 2 GHz	250														
12	2 GHz - 4 GHz	490														
13	4 GHz - 6 GHz	400														
14	6 GHz - 8 GHz	170														
15	8 GHz - 12 GHz	330														
16	12 GHz - 18 GHz	330														
17	18 GHz - 40 GHz	420														
# Records			631	421	381	629	645	262	420	189	382	302	448	236	645	

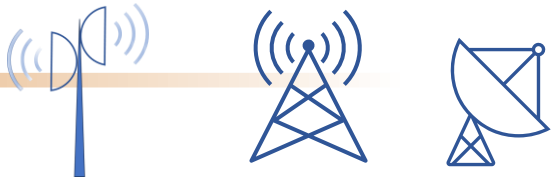
Shaded: Use HIRF Map to avoid HIRF Sources

12 Cities - IBFS Worst-Case Environments

Shaded: Use HIRF Map to avoid HIRF Sources

Band	Freq. Range	HIRF Standard	New York	Chicago	San Francisco	Los Angeles	Dallas	Houston	Atlanta	Miami	Boston	Seattle	Phoenix	Denver	Max	Min. Recom. Threshold
1	10 kHz - 100 kHz	150														
2	100 kHz - 500 kHz	200														
3	500 kHz - 2 MHz	200														
4	2 MHz - 30 MHz	200							~~4023~~					127	127	75
5	30 MHz -70 MHz	200												127	127	75
6	70 MHz - 100 MHz	200														
7	100 MHz -200 MHz	200							18						18	
8	200 MHz - 400 MHz	200														
9	400 MHz -700 MHz	200			7		7					7			7	
10	700 MHz - 1 GHz	240														
11	1 GHz - 2 GHz	250					1								1	
12	2 GHz - 4 GHz	490		288	5427	1108	39	0	31	715	136	71	0	80	5427	250
13	4 GHz - 6 GHz	400	6376	5683	6943	6600	4514	5748	5183	6832	4656	5427	4311	4949	6943	250-500
14	6 GHz - 8 GHz	170	6376	5683	6943	6600	4514	5748	5183	6832	4656	5427	4311	4949	6943	250-500
15	8 GHz - 12 GHz	330		1756		2783	2689		1011						2783	250
16	12 GHz - 18 GHz	330	5427	2848	5243	6303	5065	5748	6376	4949	3087	5065	4023	6676	6676	250-500
17	18 GHz - 40 GHz	420	127		2369	5365	5521	216	359			4672	675	2538	5521	250
# Records			1,120	1,215	1,865	2,751	1,369	1067	2,545	2,206	288	601	525	1,058		

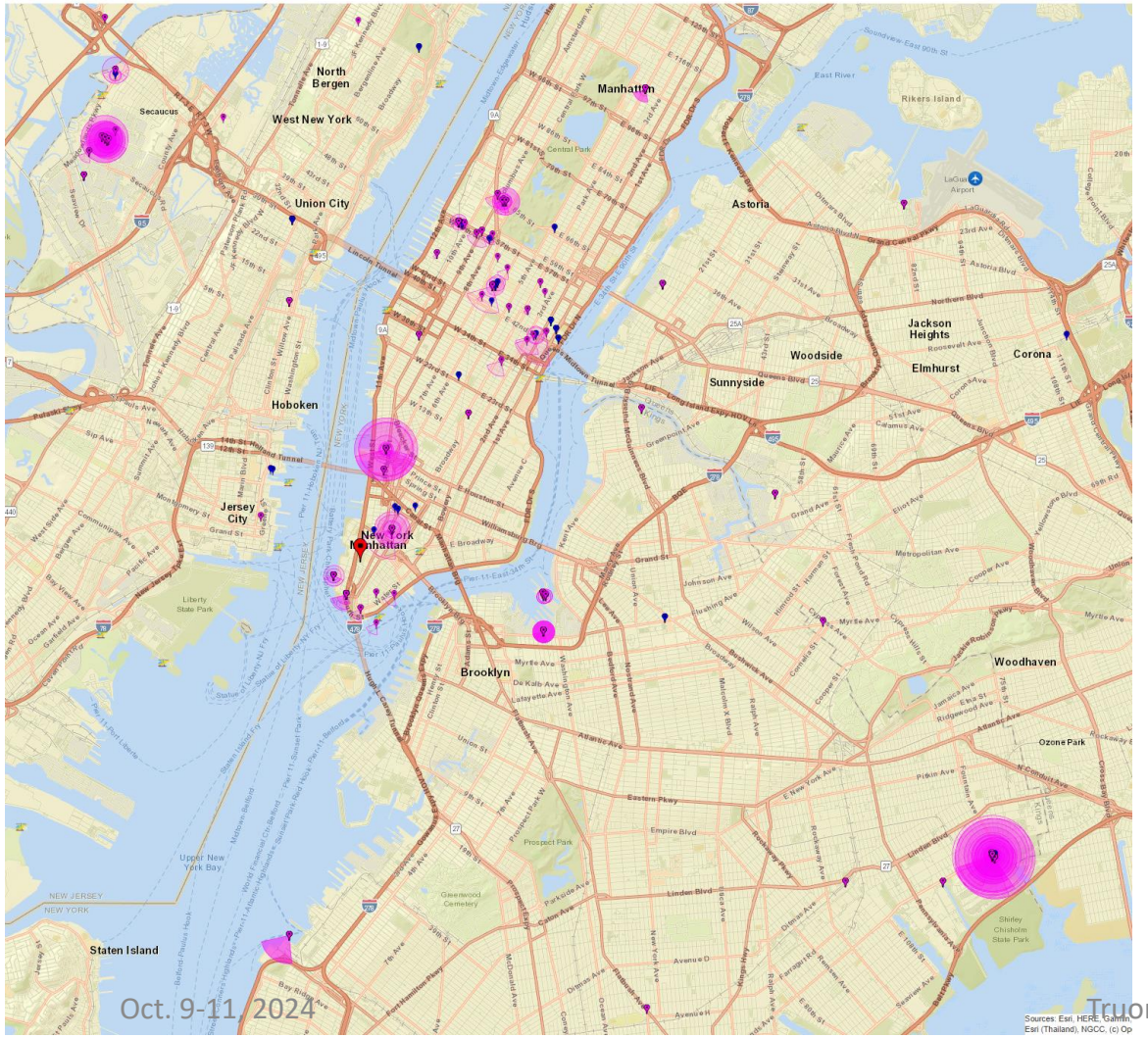
Combined Field Environment - HIRF Ave.



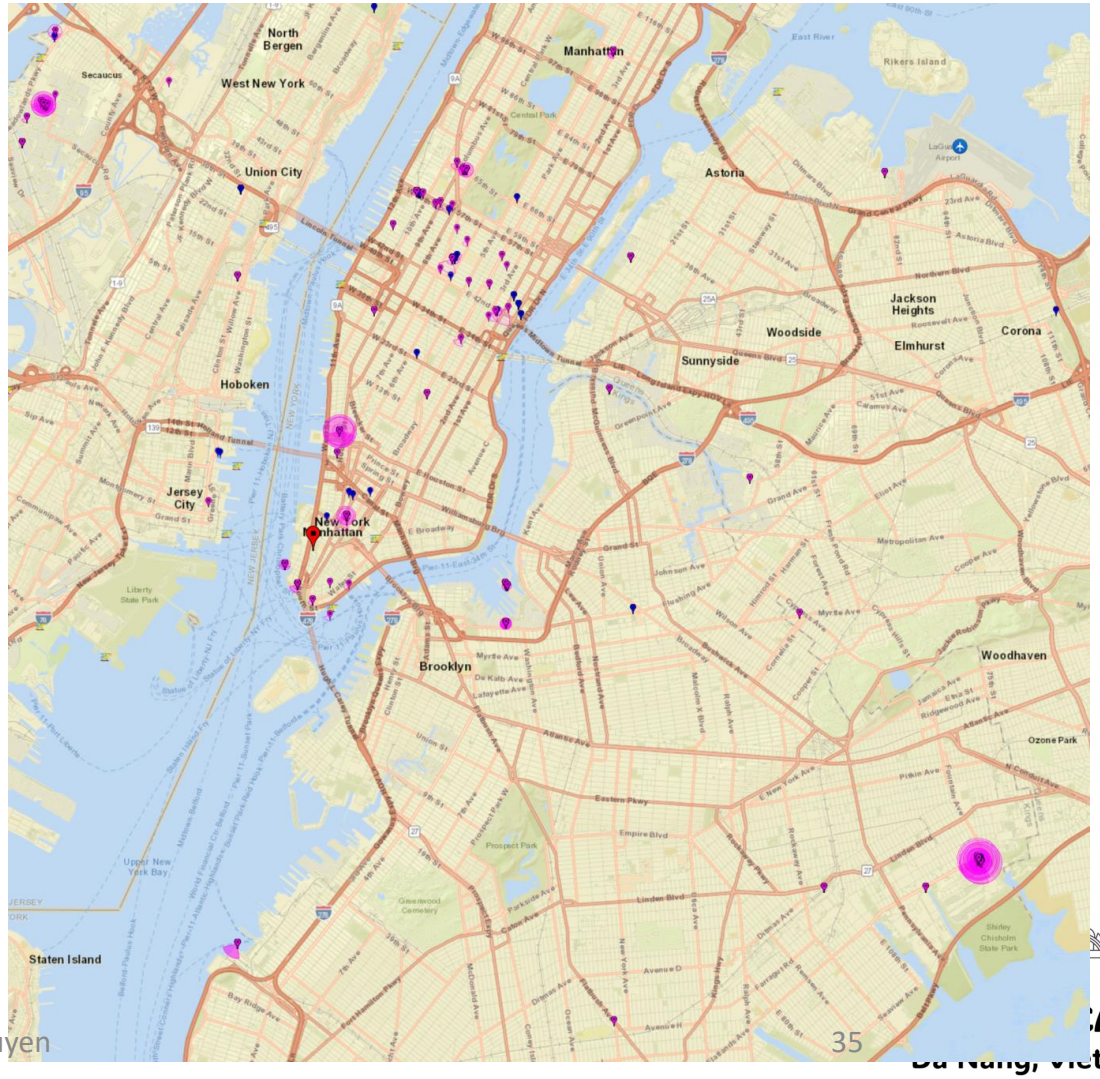
HIRF Band	Freq. Range	HIRF Standard	Max Field Environments			Recommended Min. Tolerance			Combined Threshold
			ULS	CDBS	IBFS	ULS	CDBS	IBFS	
1	10 kHz - 100 kHz	150				25			25
2	100 kHz - 500 kHz	200	13			25			25
3	500 kHz - 2 MHz	200	13	40		25	40		40
4	2 MHz - 30 MHz	200	18		127	25		75	75
5	30 MHz -70 MHz	200	6	73	127	25	75	75	75
6	70 MHz - 100 MHz	200	4	178		25	75		75
7	100 MHz -200 MHz	200	10	129	18	25	75		75
8	200 MHz - 400 MHz	200	5	129		25	75		75
9	400 MHz -700 MHz	200	36	515	7	25	100		100
10	700 MHz - 1 GHz	240	48	515	0	25	100		100
11	1 GHz - 2 GHz	250	9		1	25			25
12	2 GHz - 4 GHz	490	49		5427	50		250	250
13	4 GHz - 6 GHz	400	115		6943	50		250-500	250-500
14	6 GHz - 8 GHz	170	555		6943	50		250-500	250-500
15	8 GHz - 12 GHz	330	75		2783	50		250	250
16	12 GHz - 18 GHz	330	160		6676	50		250-500	250-500
17	18 GHz - 40 GHz	420	46		5521	50		250	250

IBFS – HIRF Avoidance Comparison

For 250 V/m Tolerance Threshold



For 500 V/m Tolerance Threshold



Findings & Conclusions

- **The existing HIRF requirements are**
  - **Far insufficient against satellite dishes (> 4 GHz)**
  - **Slightly insufficient against TV stations**
- The HIRF requirements can be lowered using the HIRF-Map approach
  - Level optimized using HIRF avoidance zones on HIRF-Map

Contact Info

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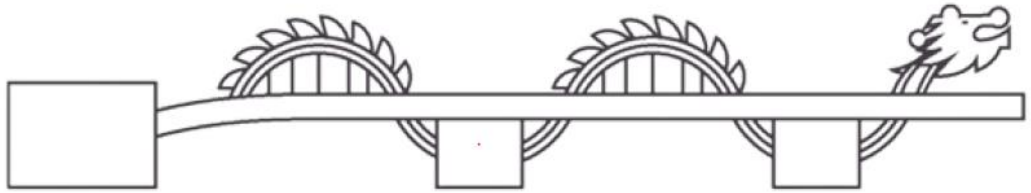

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Map Attributions

- *Google Maps*
- *Matlab WebMap*
- *Sources for WebMap: Esri ArcGIS Online (Tiles), Esri, HERE, DeLorme, Garmin, TomTom, USGS, Intermap, iPC, INCREMENT, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, OpenStreetMap, the GIS User Community, MapmyIndia, GEBCO, FAO, NPS, GeoBase, IGN, KadasterNL, DigitalGlobe, Earthstar Geographic, CNES/Airbus DS, GeoEye, USA FSA, Getmapping, Aerogrid, IGP, swisstopo, and others.*
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