



Digital Avionics Systems Conference

San Diego, CA, USA - September 29 - October 3, 2024

HIRF Tolerance and Avoidance for Advanced Air Mobility Vehicles

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Outline



- Background & Motivation
- **Part 1: Map-based HIRF Avoidance Approach**
 - Limit vehicle exposure to HIRF
 - Presented at 2023 Digital Avionics Systems Conference (DASC)
- **Part 2: HIRF Environments & Minimum HIRF Tolerance Recommendation for AAM Vehicles**
 - Drive vehicle design/test requirements

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 aircraft → Severe HIRF test levels**
 - Vehicles operate close to ground transmitters
 - Can hover in front of transmitters
- **UAM/AAM/UAS vehicles may operate similarly to rotorcraft**
 - **Urban Air Mobility (UAM)/ Advanced Air Mobility (AAM)/ Unmanned aircraft systems (UAS)**
 - Maybe required testing to the same HIRF levels as for rotorcraft
 - Vehicles often lack metal skin for shielding

Problem: Concerns about HIRF protection cost, size, and weight

Goal: Develop a suitable approach to reduce the costs associated with HIRF Protection and Certification

Urban Air Mobility (UAM) and AAM Concepts



Illustration by NASA's Aeronautics Research Mission Management



Aircraft and Rotorcraft HIRF Environments

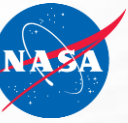
TABLE 3 - Certification HIRF Environment (HIRF Environment I)

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

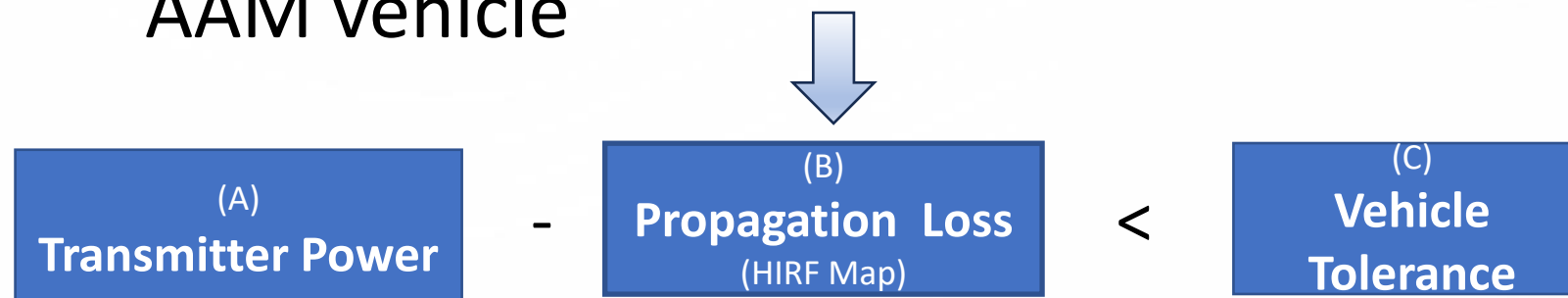
TABLE 2 - ROTORCRAFT SEVERE HIRF ENVIRONMENT (HIRF ENVIRONMENT III)

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) 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)**

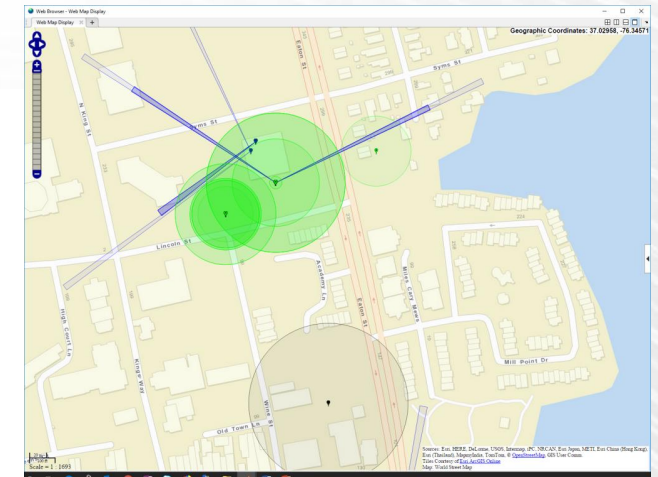
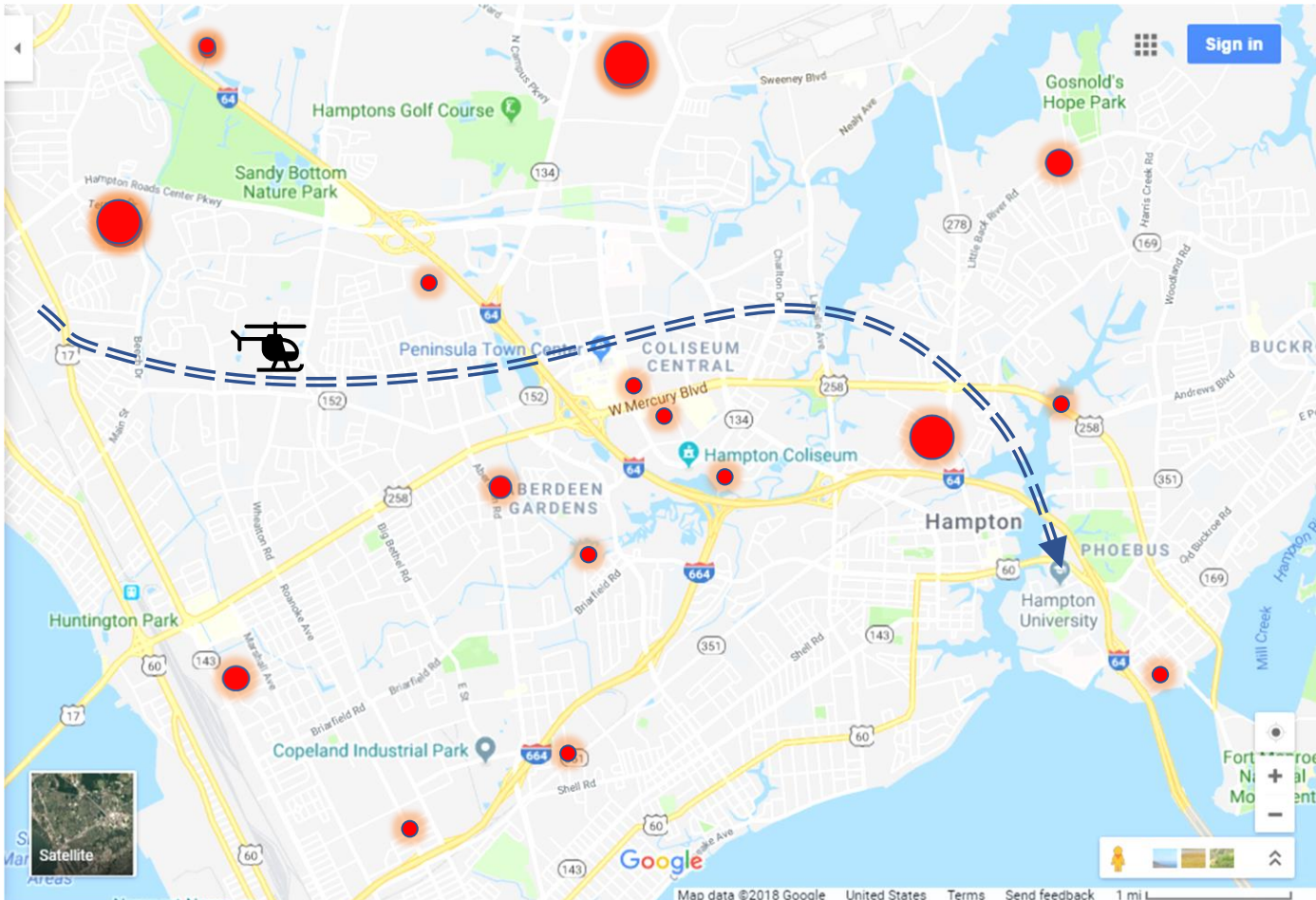


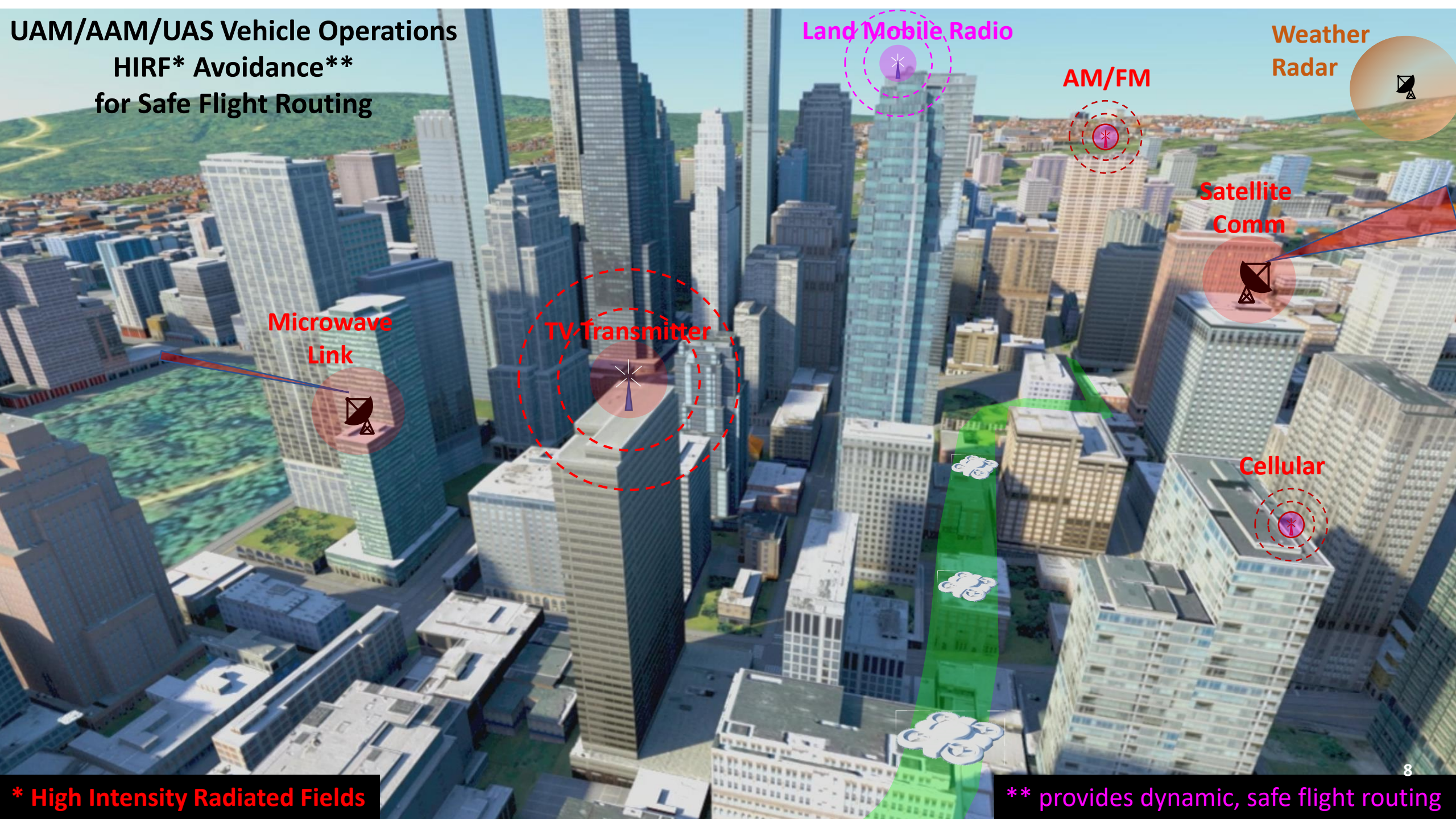
Illustration of Flight Planning

“Keep-out” zones, with field strength potentially exceeds the UAV’s tolerant levels



- HIRF Sources may include:
 - AM, FM, TV antennas
 - Satellite comm. antenna
 - Cell-tower antennas
 - Commercial radios
 - Land Mobile radios
 - Maritime Coast
 - Aviation
 - Radar (weather,...)
 - Airport transmitters
 - ...

UAM/AAM/UAS Vehicle Operations HIRF* Avoidance** for Safe Flight Routing



Land Mobile Radio

Weather Radar

AM/FM

Satellite Comm

Microwave Link

TV Transmitter

Cellular

* High Intensity Radiated Fields

** provides dynamic, safe flight routing

- **Advantages**

- Avoid designing/certifying to the globally-defined worst-case HIRF environment
- Faster and cheaper to design, build, test, and certify
 - Possible whole-vehicle HIRF testing in test chambers
- 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



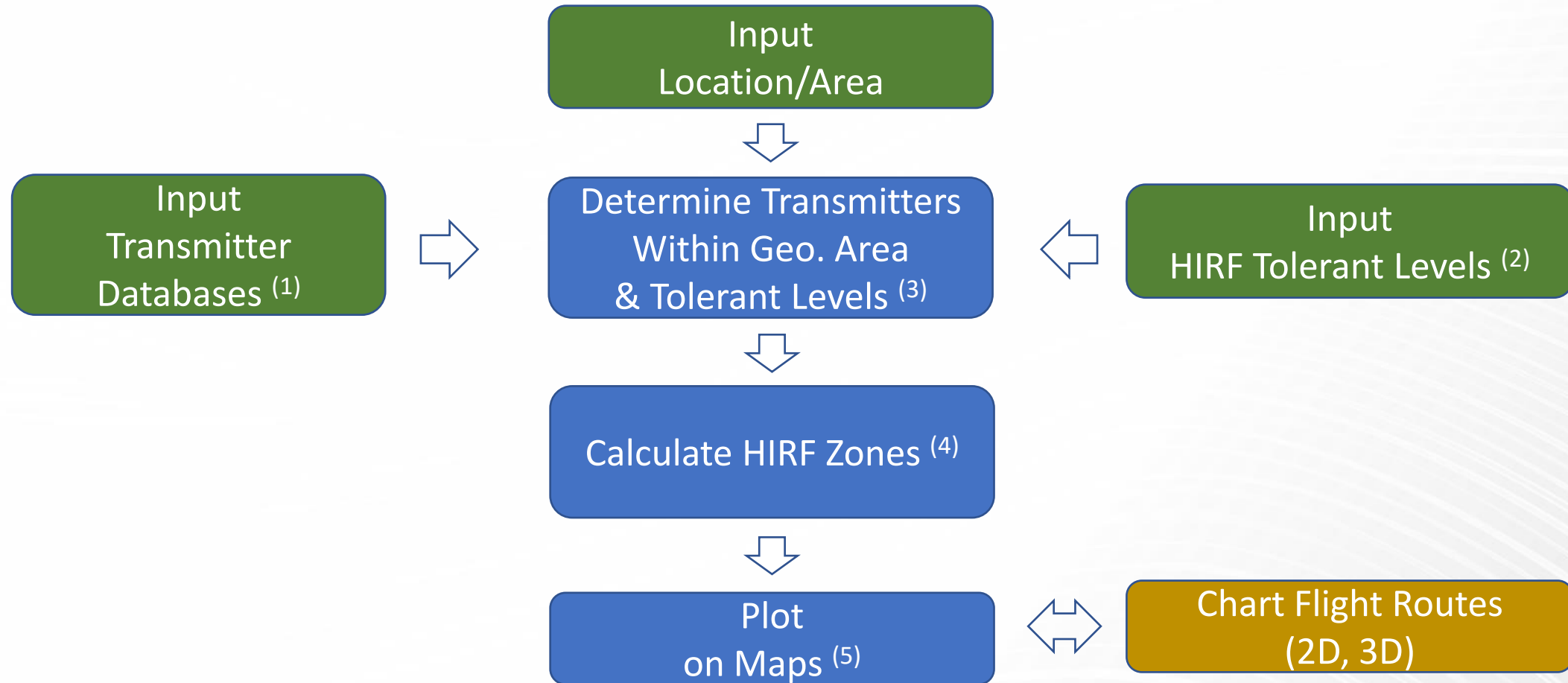
Credits: NASA Langley



Proof-of-Concept

- To develop a HIRF-Map tool, and to identify key issues
- **The HIRF-Map Tool developed in Matlab**
 - **Import Databases** (FCC, NOAA,...)
 - Limit transmitters to within geographical zone
 - **Calculate the HIRF zone** for each transmitter/carrier
 - From user-defined HIRF tolerant levels
 - Use worst-case power and gain data
 - **Overlay HIRF zones on Web Map**
 - **Add flight paths**

HIRF-Map Implementation



(1) 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



(2) HIRF Tolerant Level

- **User-defined!**
 - **Verified through testing/analysis**
 - Unique to vehicle
 - Expect levels to be lower than existing requirements
- Vary with frequency
 - Enveloped into 17 band segments, similar to table ->
- Modulations simplified to CW, AM, and Pulse to match standards

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

FREQUENCY	FIELD STRENGTH (V/m)	
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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

(4) 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:

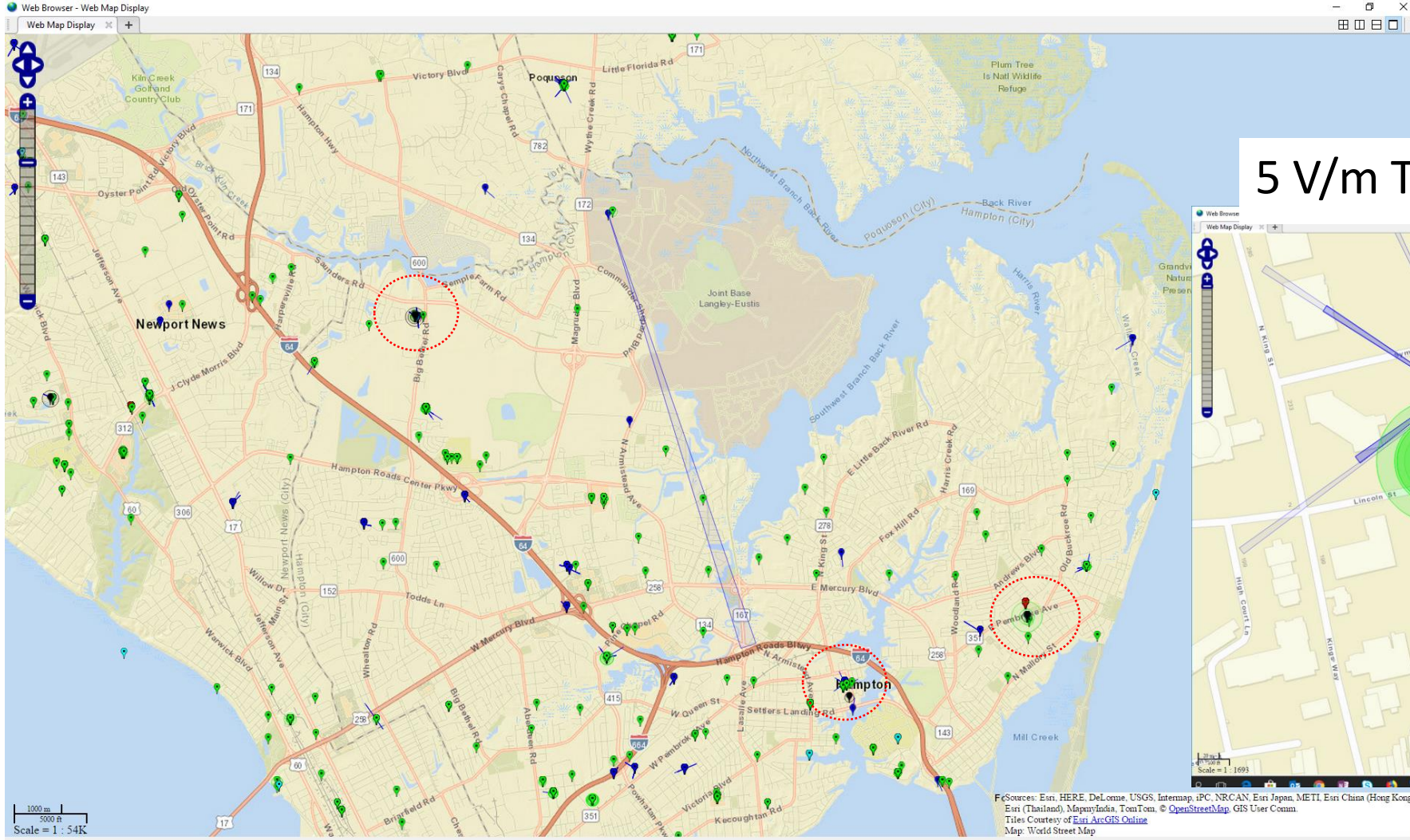
- Use the worst-case power and gain data, to be conservative
 - In the Far-field
 - Ignore antenna pattern (use the worst case)
 - No high-order effects (reflection, diffraction)
 - No cumulative effect
- **The HIRF zone is a circular region with a radius R**
 - Angular range is incorporated if known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

ULS HIRF-Map Example

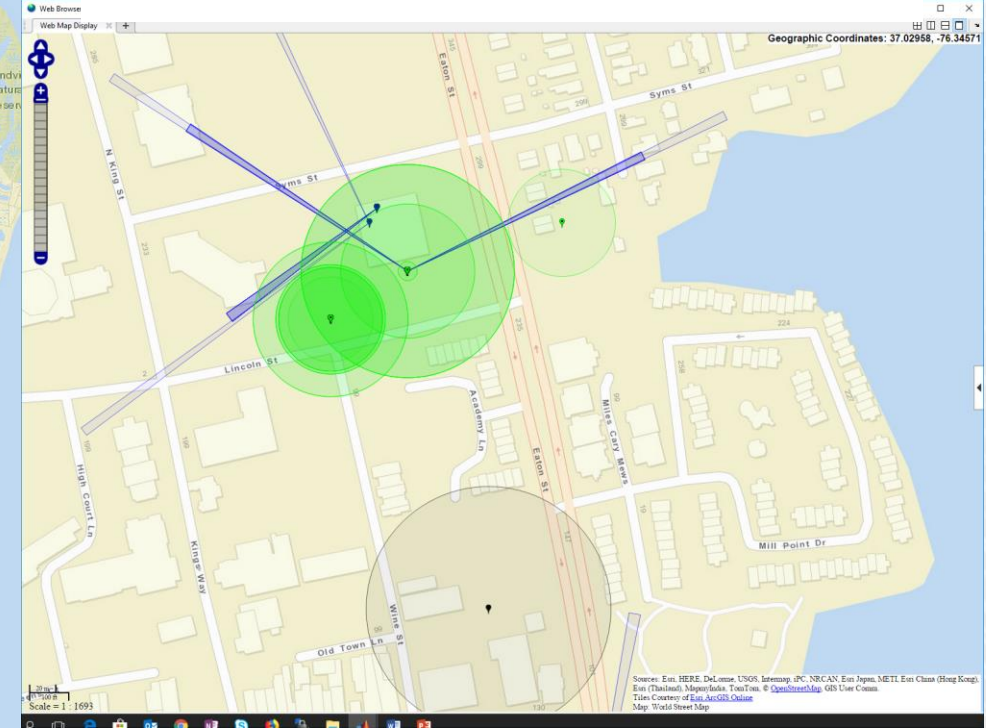


FCC ULS Transmitters

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



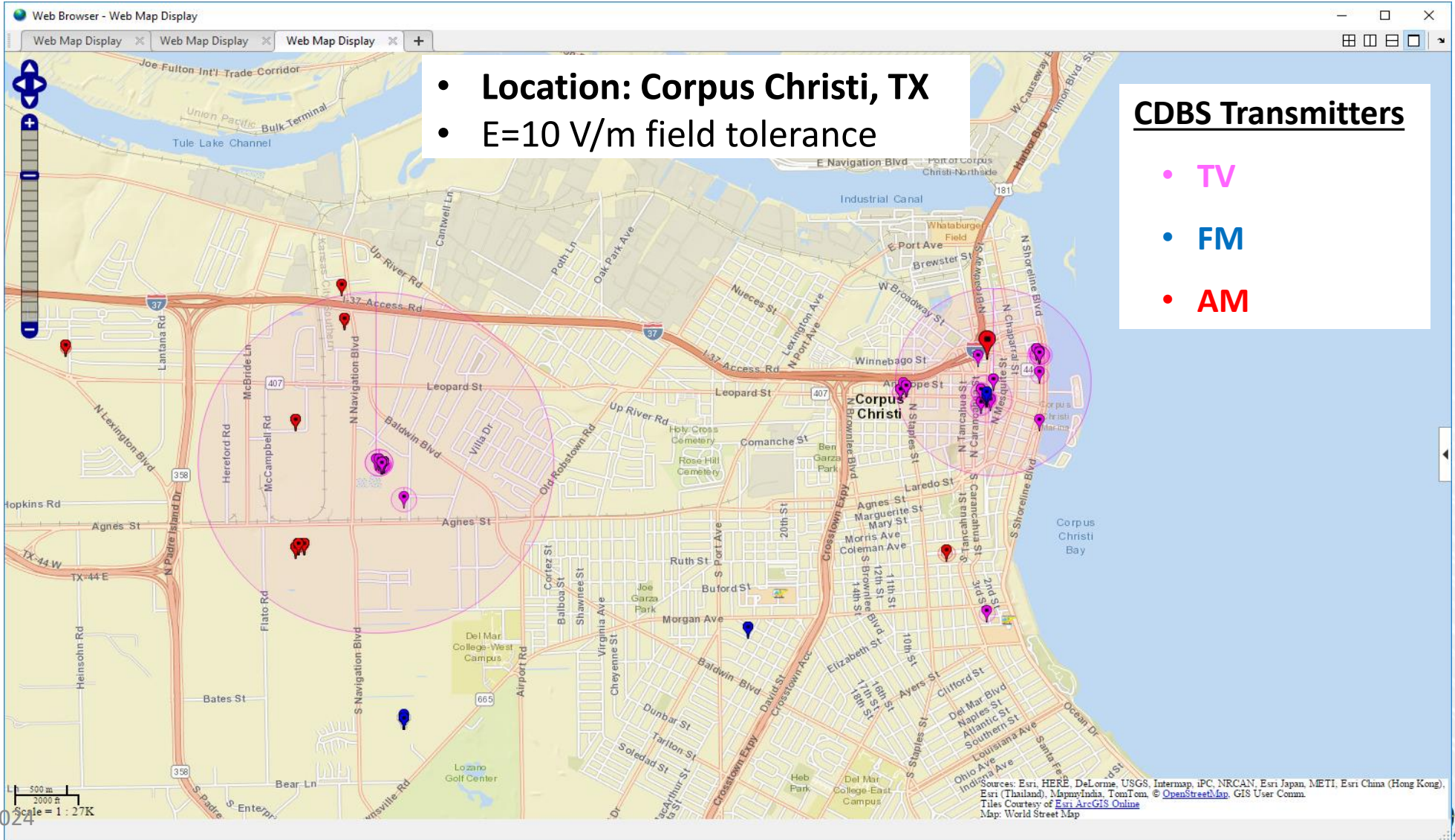
5 V/m Tolerance Level



Sources: Esri, HERE, DeLorme, USGS, Intermap, iPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong),
 Esri (Thailand), Swire, Swire, Swire, Swire, Swire, Swire, Swire, Swire, Swire, Swire, Swire, Swire, Swire,
 Tiles Courtesy of Esri, AerialGIS, OpenStreetMap, GIS User Community
 Map: World Street Map



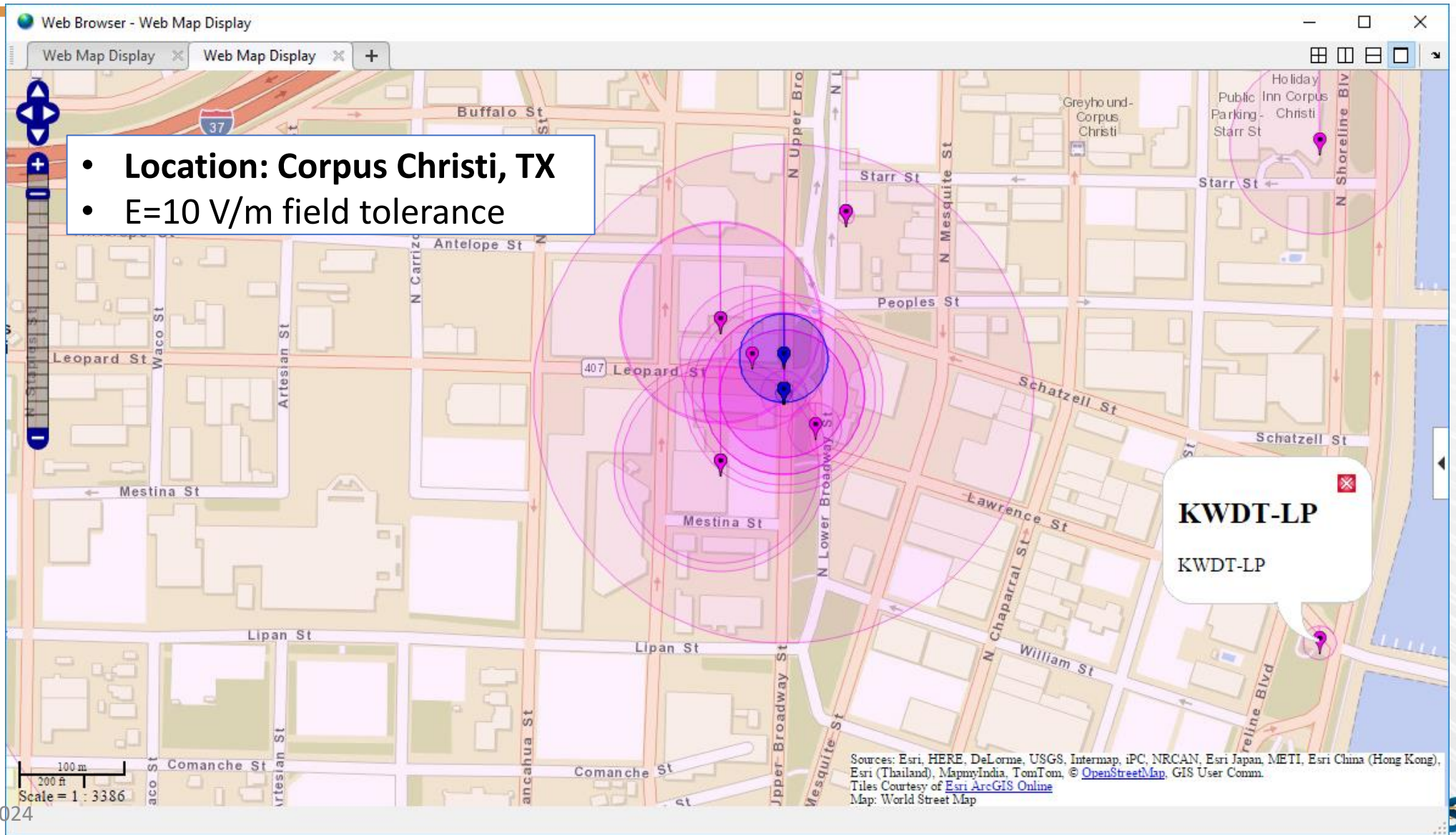
CDBS Example



CDBS Example



- HIRF zones for TV and FM Radio stations
- Multiple carriers

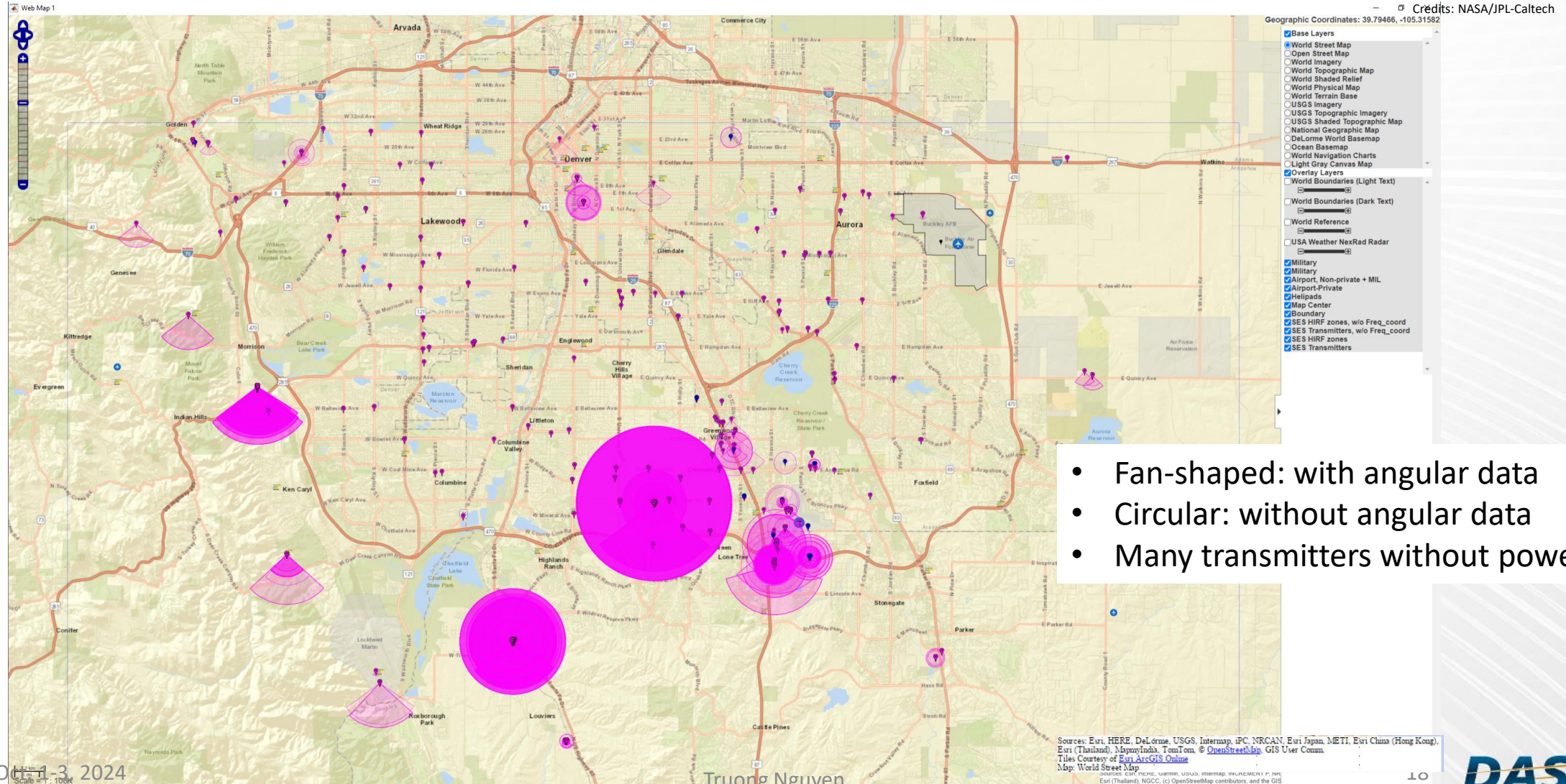




IBFS Example



• 50 V/m, Denver, Colorado



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

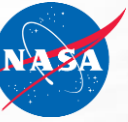
Sources: Esri, HERE, DeLorme, USGS, Intermap, IPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Swire, (Thailand), Mapbox, Terra, © OpenStreetMap, GIS User Comm. Tiles Courtesy of Esri, ArcGIS Online Map: World Street Map Sources: Esri, HERE, DeLorme, USGS, Intermap, IPC, NRCAN, Esri Japan, METI, Esri China (Hong Kong), Swire, (Thailand), NGCC, © OpenStreetMap contributors, and the GIS



Part 2:

HIRF Environment & Minimum Tolerance Recommendation

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

Observation:

- ULS transmitters are numerous and widespread in frequency. Lower-power

Approach:

1. **ULS:** baseline threshold based on **the max power envelope**
2. **CDBS, IBFS, and NOAA:**
 - **Tolerance Level based on acceptable HIRF avoidance zone size/density**
 - Use HIRF-Map to cover the remaining deficiencies
 - Non-urban transmitters can have larger avoidance zones
3. Combine the thresholds (maximum) in each HIRF-band
4. New York City as a representative urban area

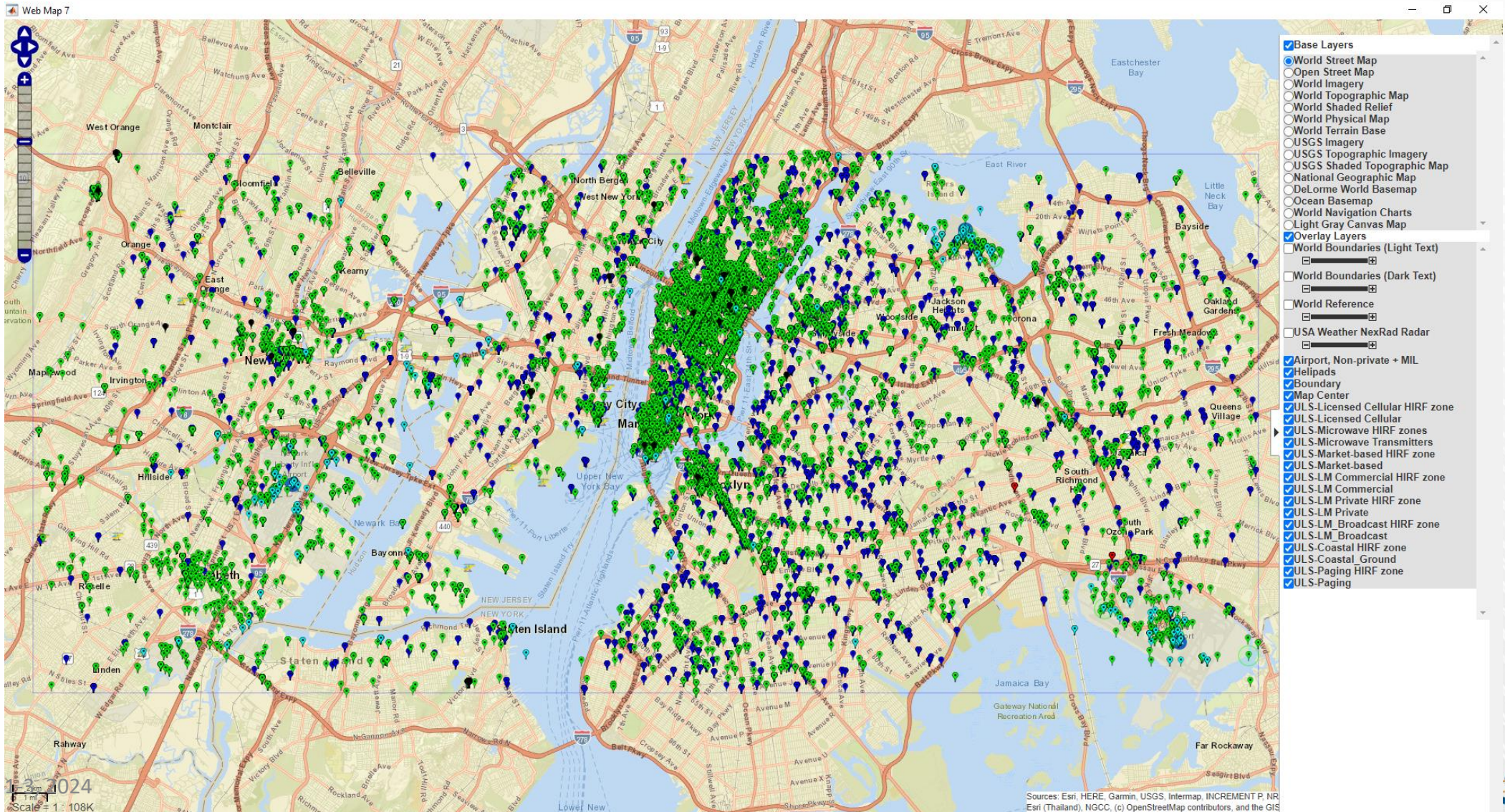




ULS Transmitters, Manhattan, New York



Transmitter record counts = ~ 25,000

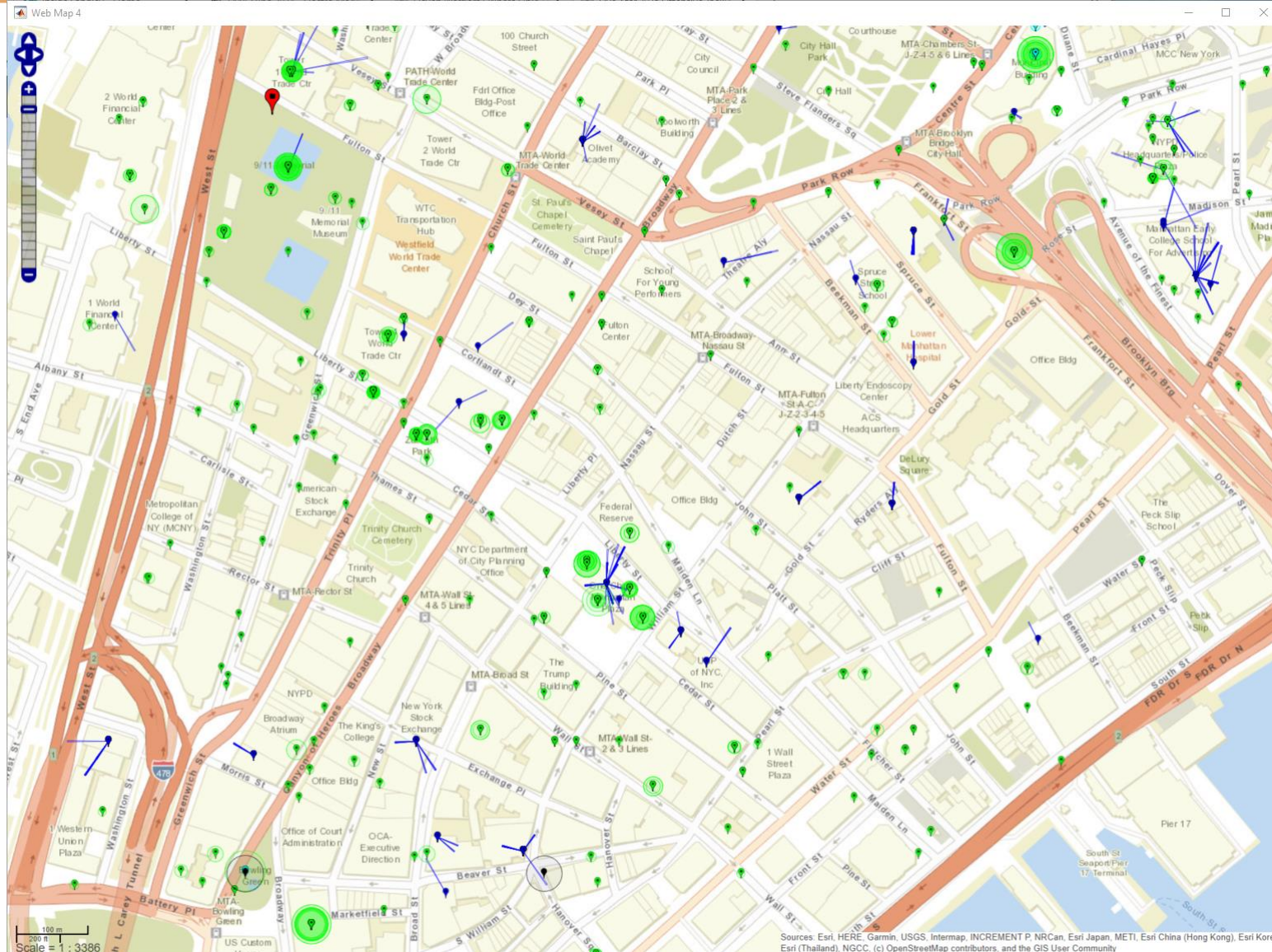


Oct. 13, 2024





ULS HIRF Map Example - 10 V/m Tolerant Level



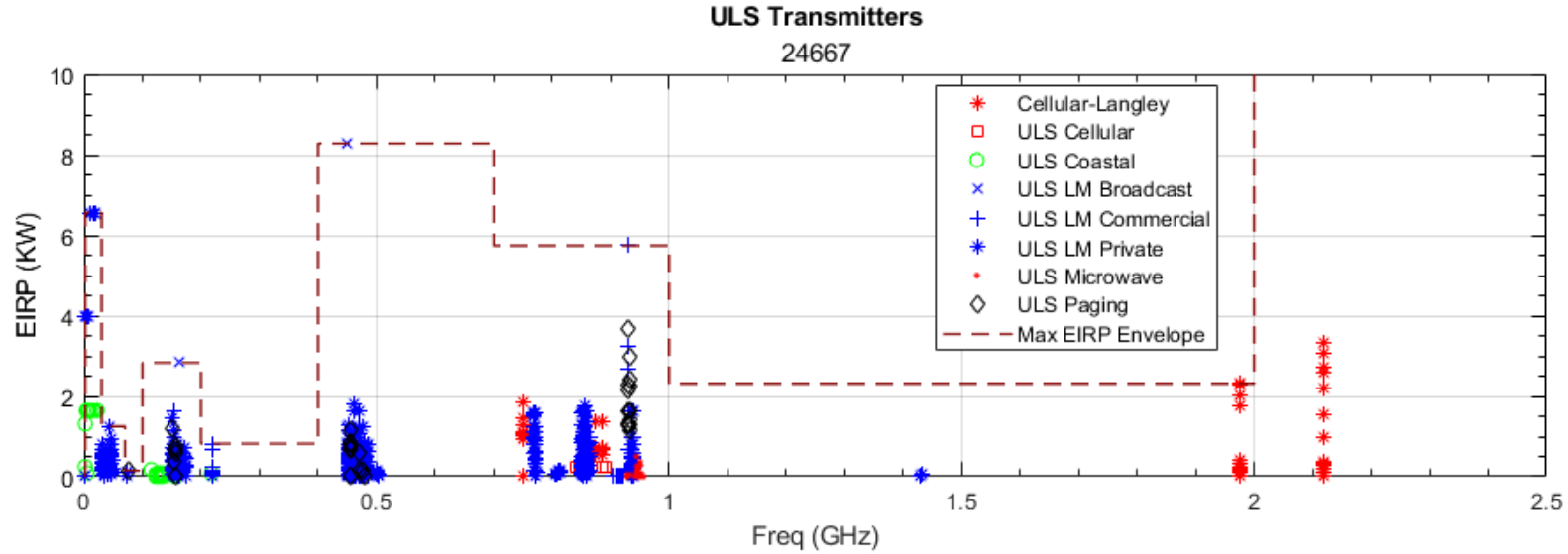
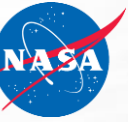
Oct. 1-3, 2024

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

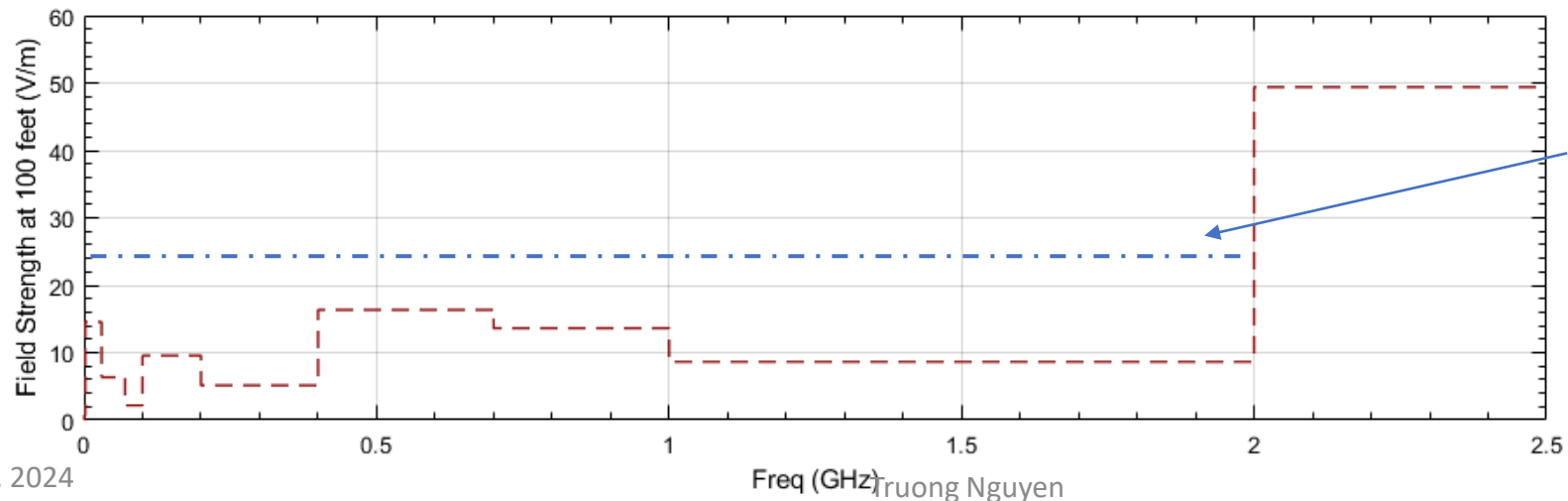


**Recommended HIRF
Threshold for ULS:**

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

Transmitters:

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



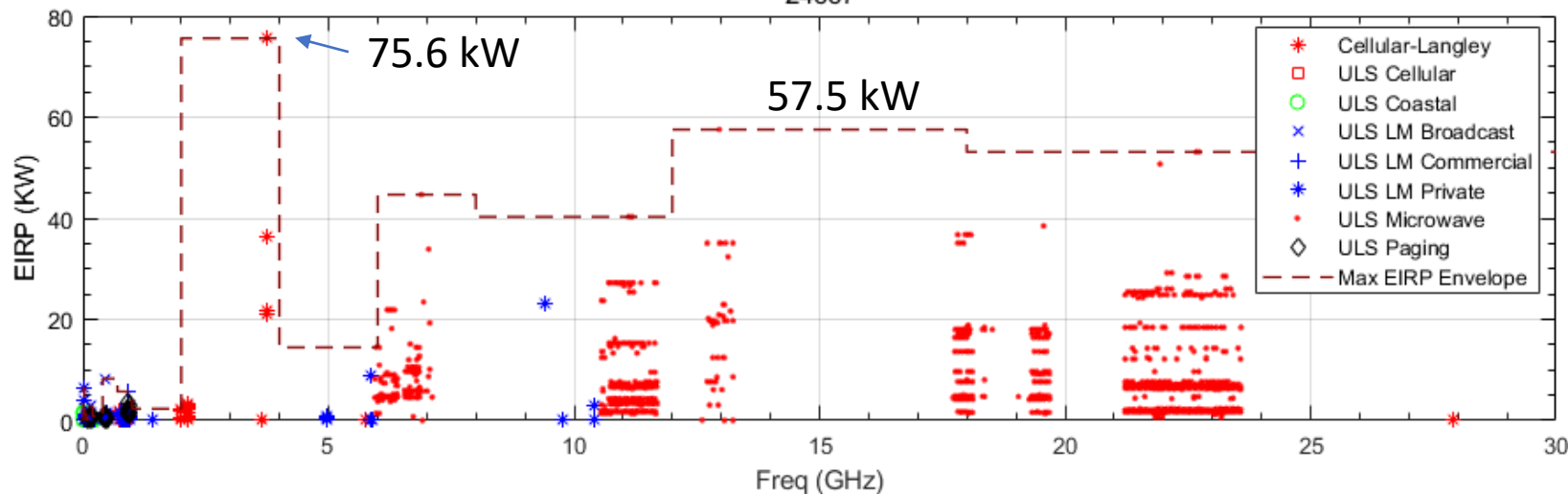
Suggested tolerance = 25 V/m



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

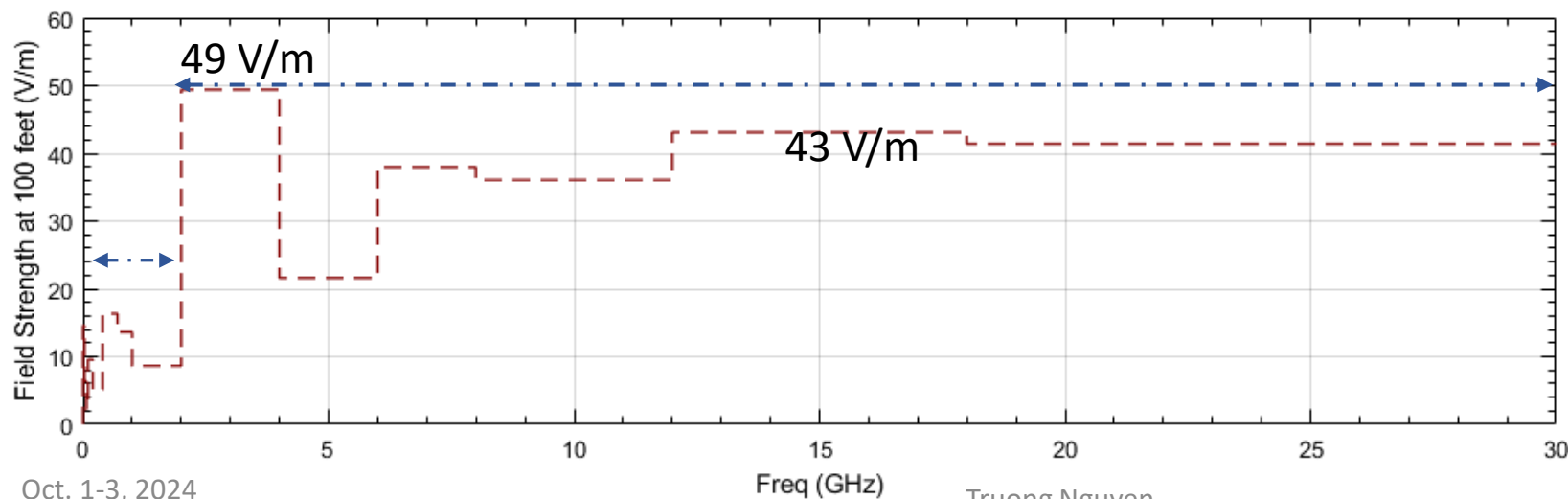


ULS Transmitters
24667



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

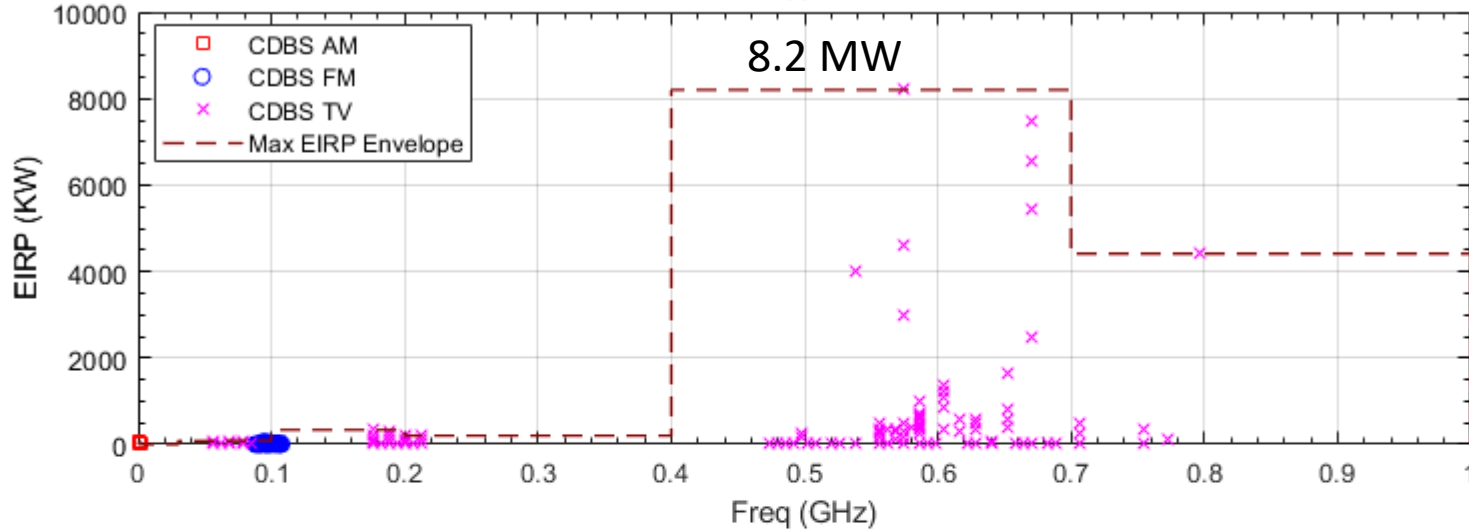
- LM Private Data above 1 MW eliminated,
- 1 data point > 46 MW eliminated



CDBS - EIRP & E-field (NY City)



CDBS Transmitters
631



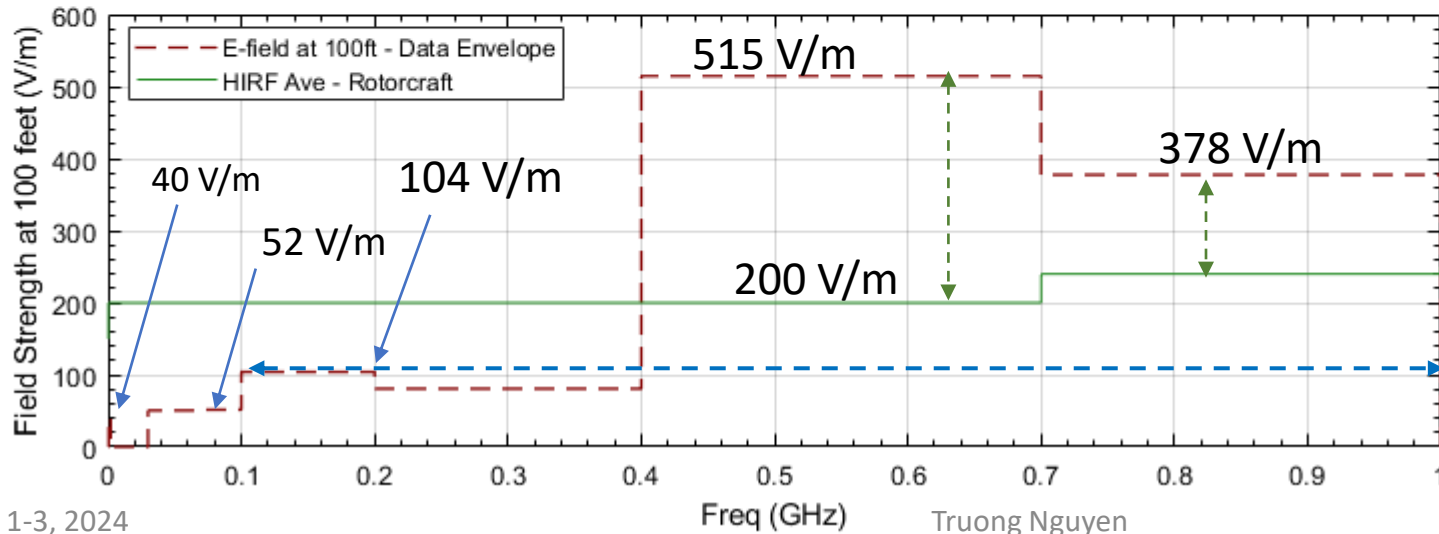
Max EIRP:

- 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:

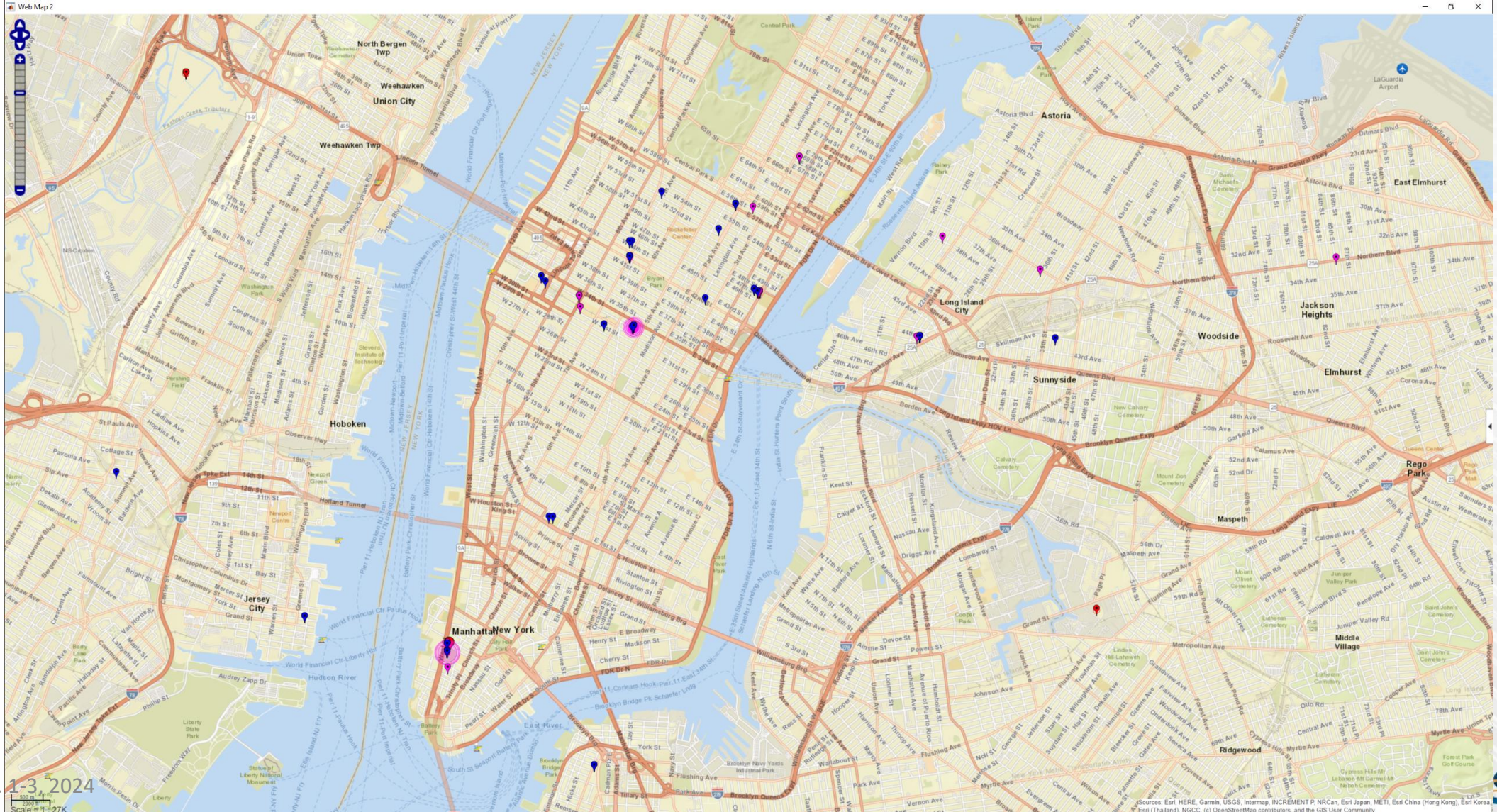
- 631 data records
- 107 unique Call Signs



CDBS HIRF Zones - 100 V/m Tolerance Level



NY City



Oct. 1-3, 2024



Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

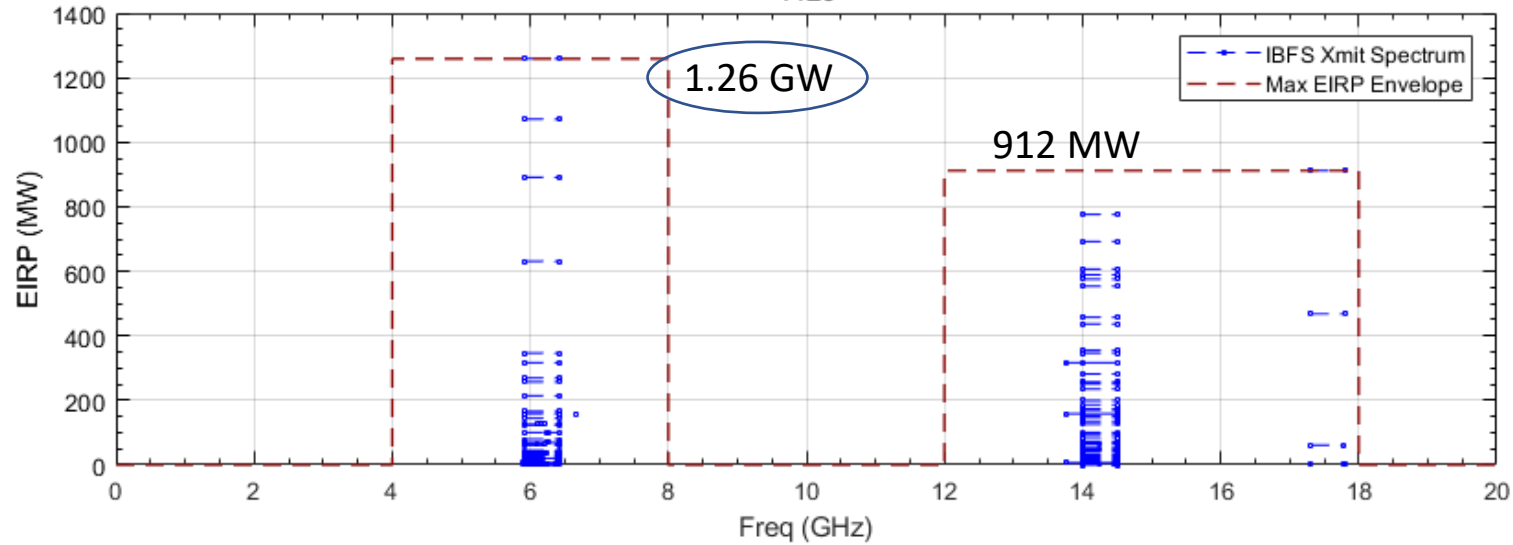


IBFS - EIRP & E Field (NY City)

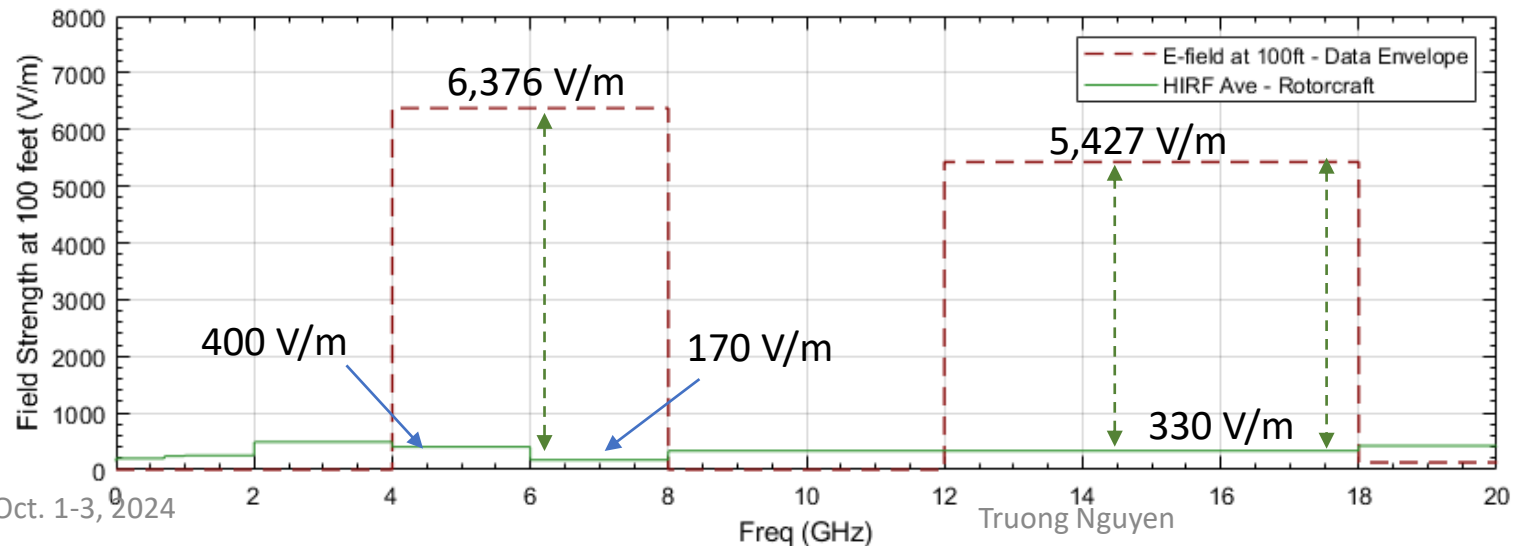


IBFS Transmitters

1120



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



Transmitters:

- 1120 data records
- 121 unique Call Signs



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

E) Antenna Facilities

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

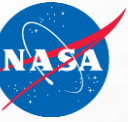
The General Provision 1010 applies to all receiving frequency bands.
 The General Provision 1900 applies to all transmitting frequency bands.
 For the text of these provisions, refer to Section H.

#	Frequency	Polarization	Emission	Tx/Rx Mode	Max EIRP /Carrier	Max EIRP Density	Assoc Antenna
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

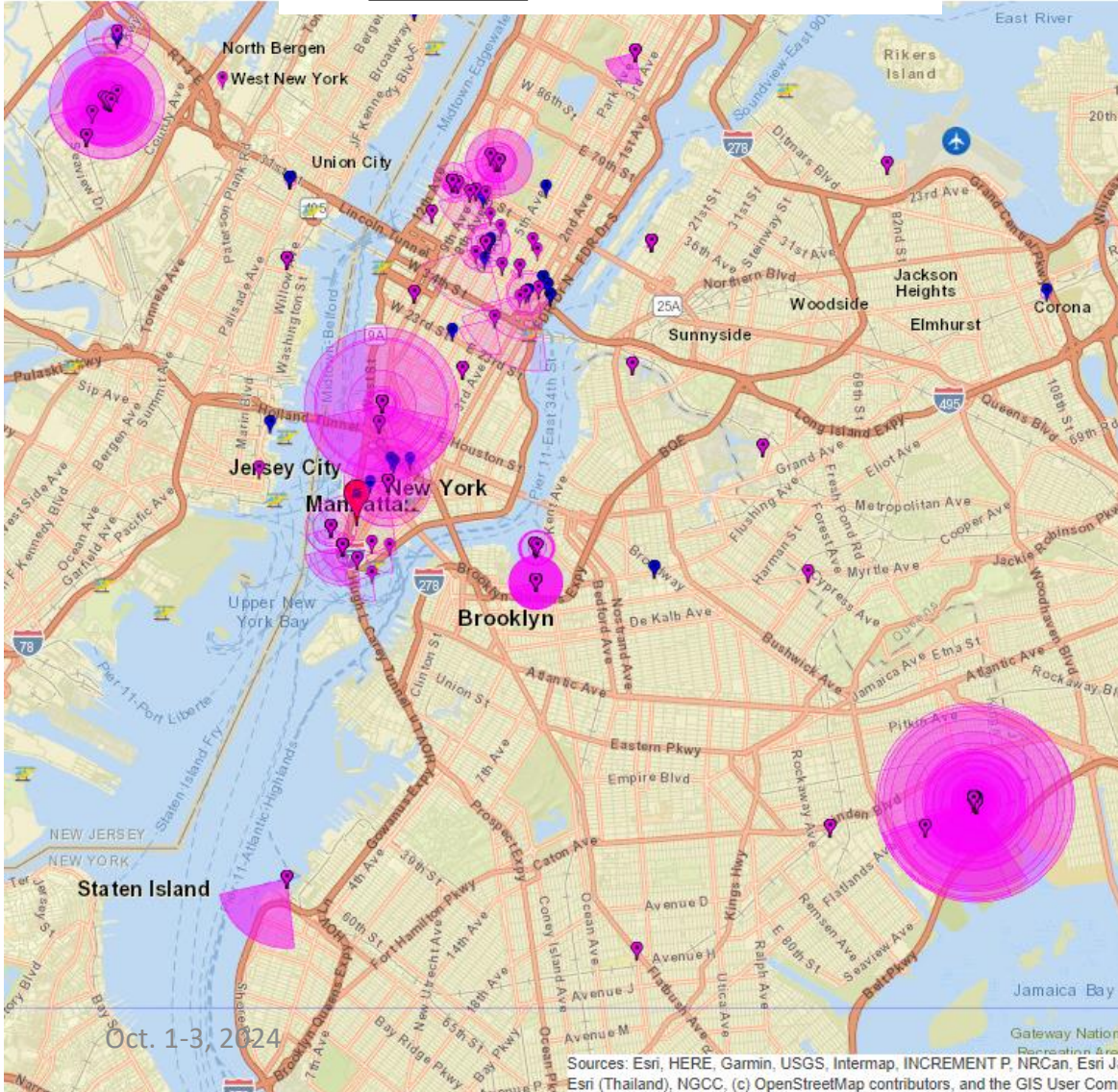
EIRP Unit in dBW
 91 dBW = 1.26 GW
 for a single carrier



IBFS – Tolerance Level Comparison



For 100 V/m Tolerance Threshold ■ NY City



- HIRF zones too crowded, leaving too little space for vehicles to operate around!



Credits: NASA/JPL-Caltech

Oct. 1-3, 2024

Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Ja Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Com

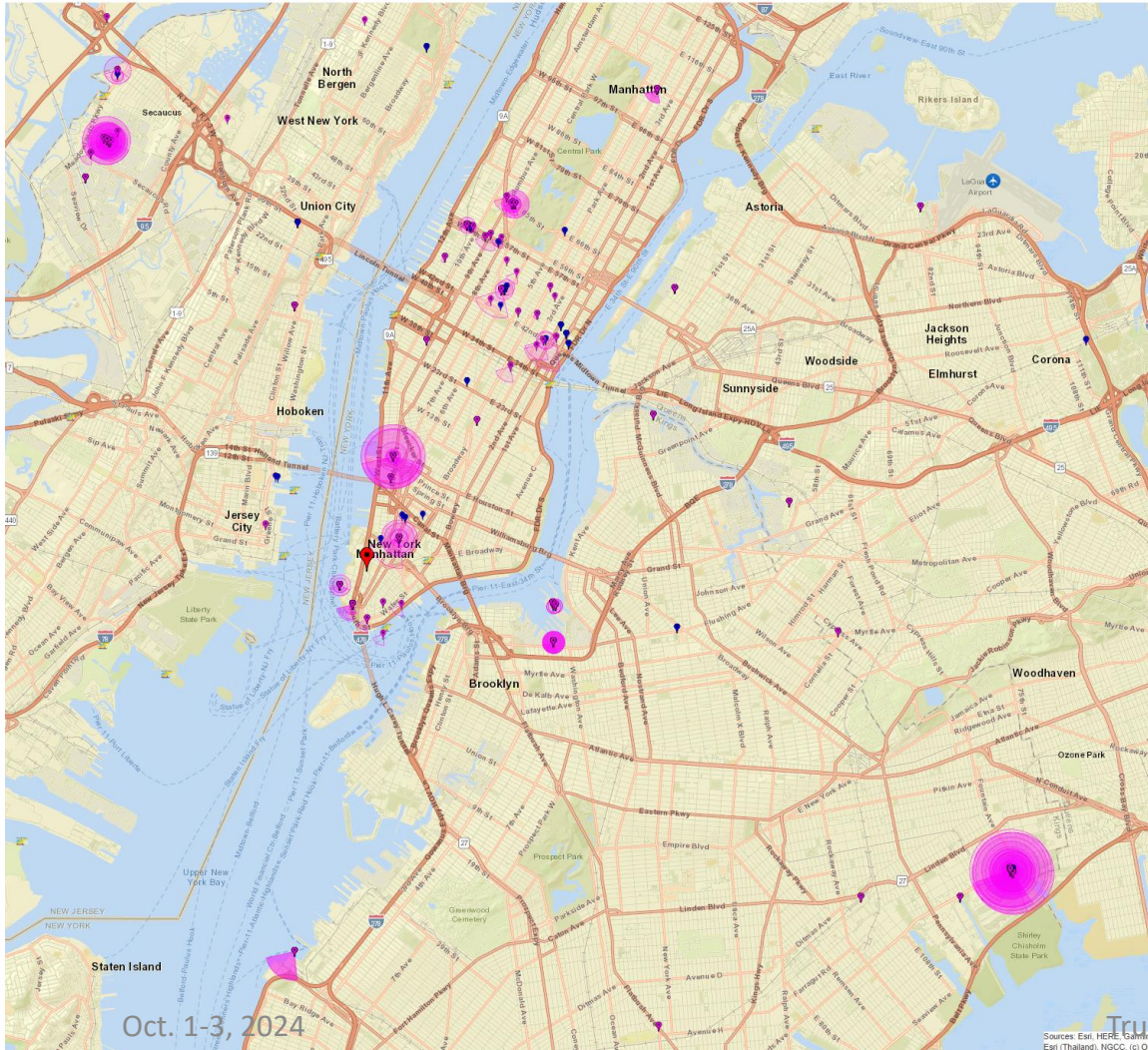
g Nguyen



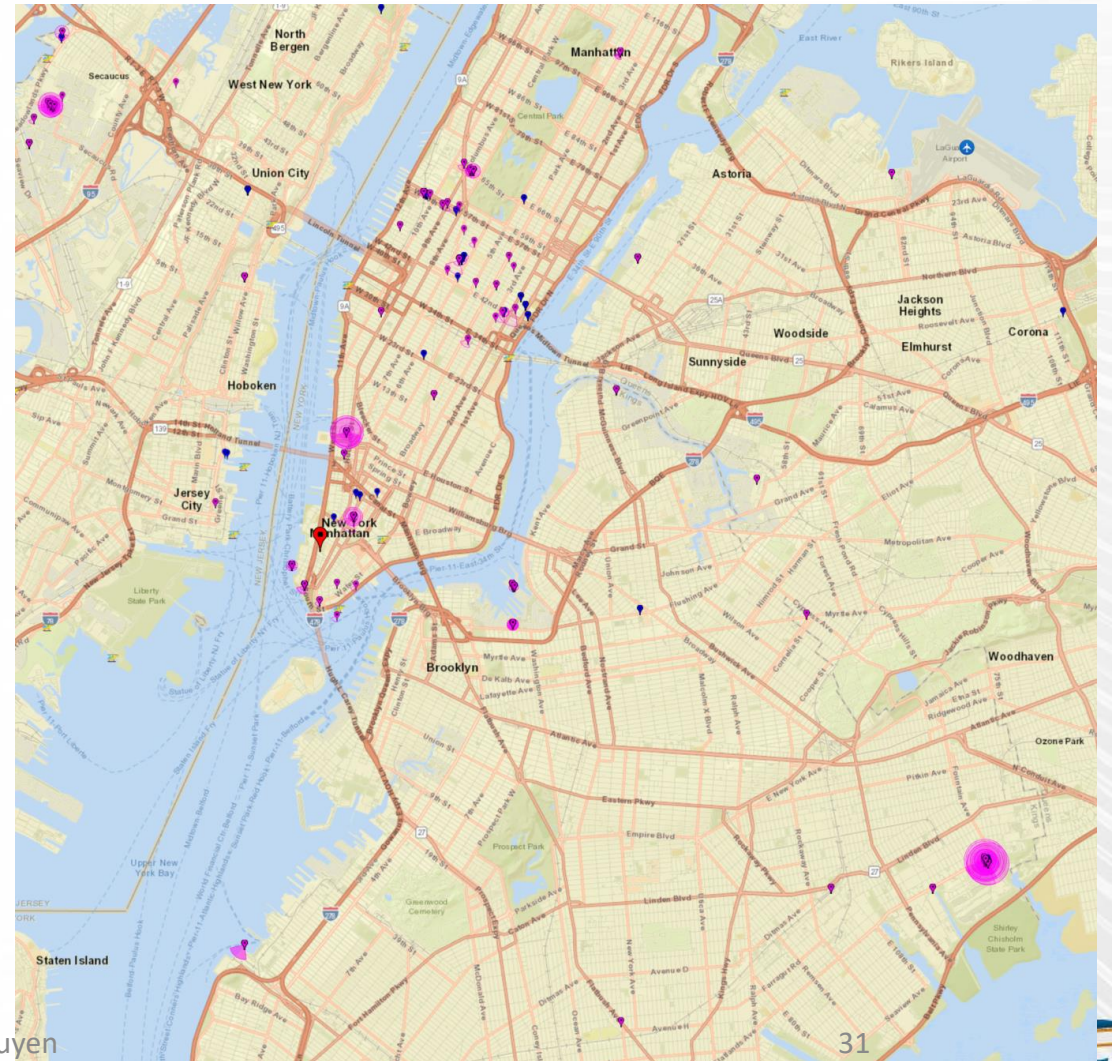
IBFS – HIRF Avoidance Comparison



For 250 V/m Tolerance Threshold



For 500 V/m Tolerance Threshold



NOAA Weather Radars

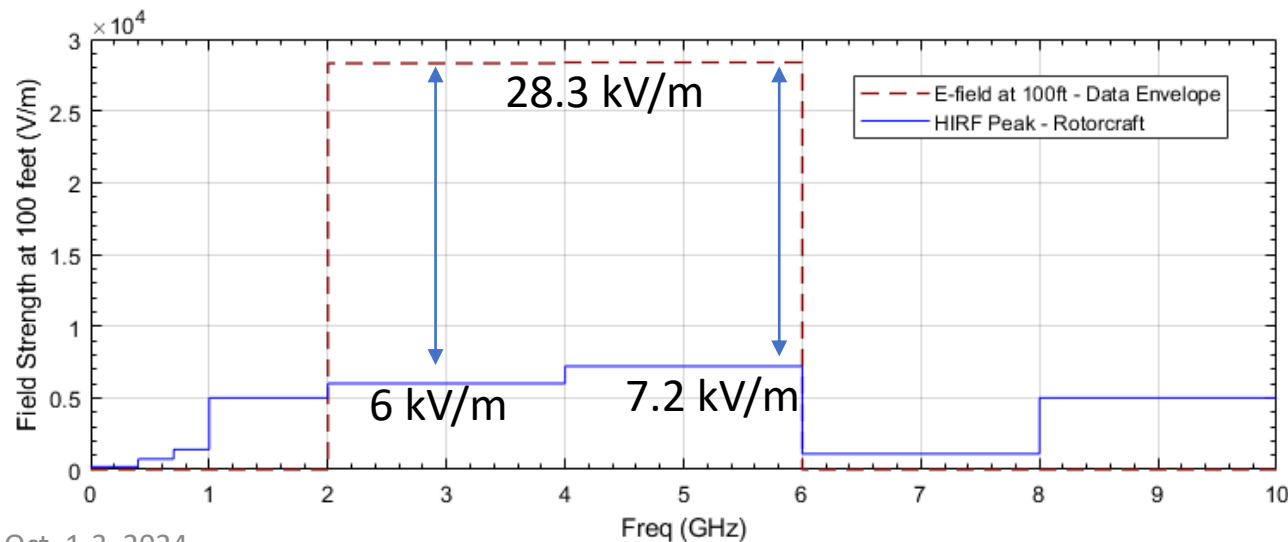
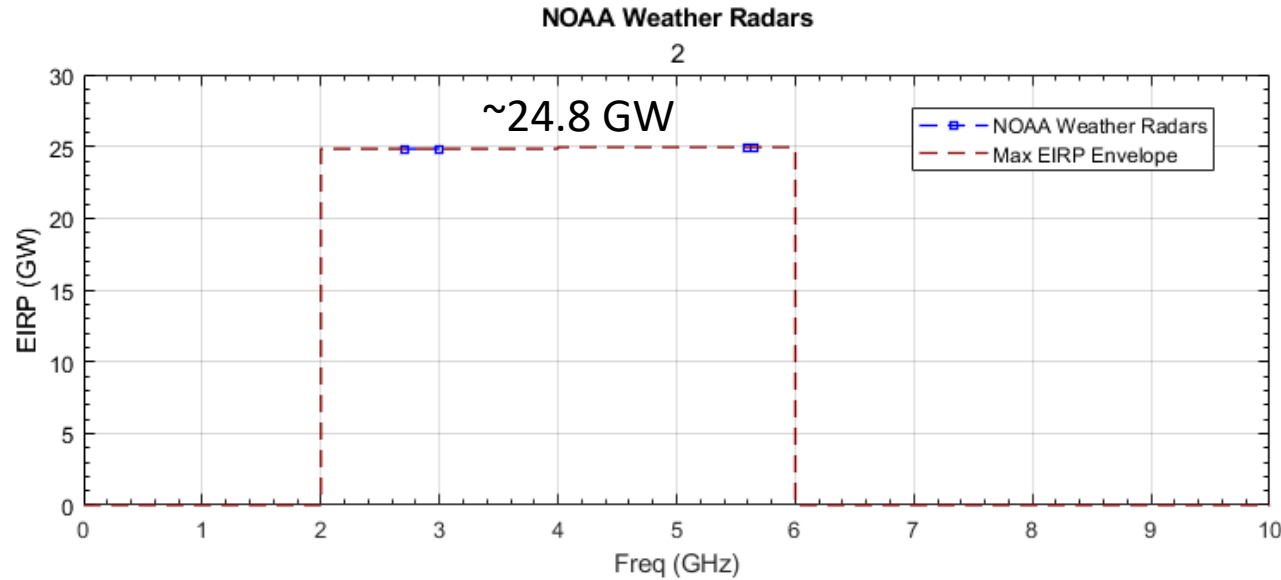


NEXRAD: Next Generation Weather Radar
TDWR: Terminal Doppler Weather Radar

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

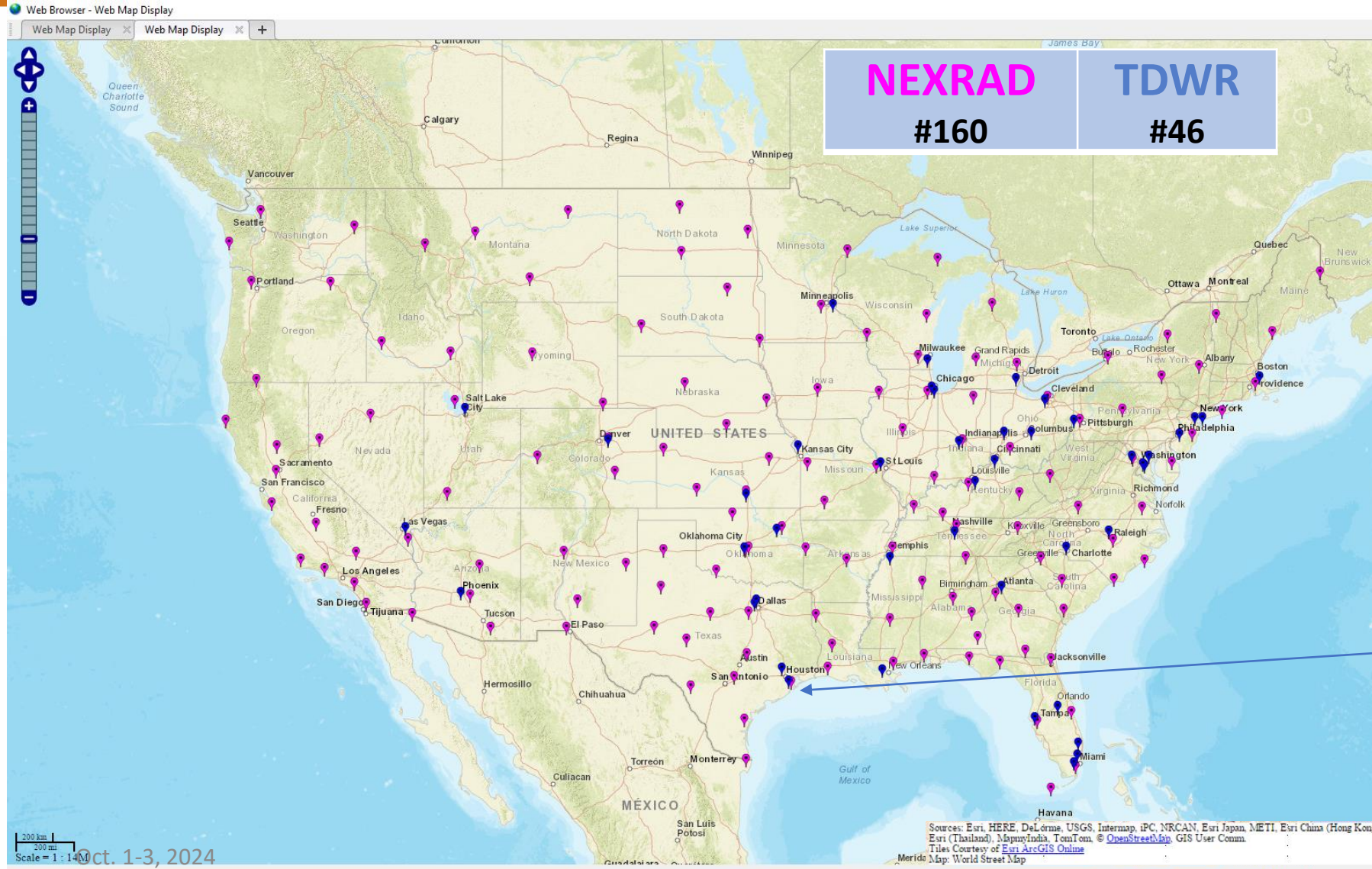
	NEXRAD (WSR-88D) #160	TDWR #46
• Frequency	2700-3000 MHz	5600-5650 MHz
• Peak Power	700 kW*	250 kW*
<i>Average Power</i>	300-1300 W	
<i>Antenna Gain</i>	45.5 dB	50 dB
• EIRP (Peak)	103.95 dBW (24.83 GW)	103.97 dBW (24.83 GW)
<i>EIRP (Ave)</i>	76.64 dBW	
<i>Beam Width</i>	0.925 degrees	0.55 degrees
<i>Pulse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

NOAA Weather Radars – EIRP & E-Field



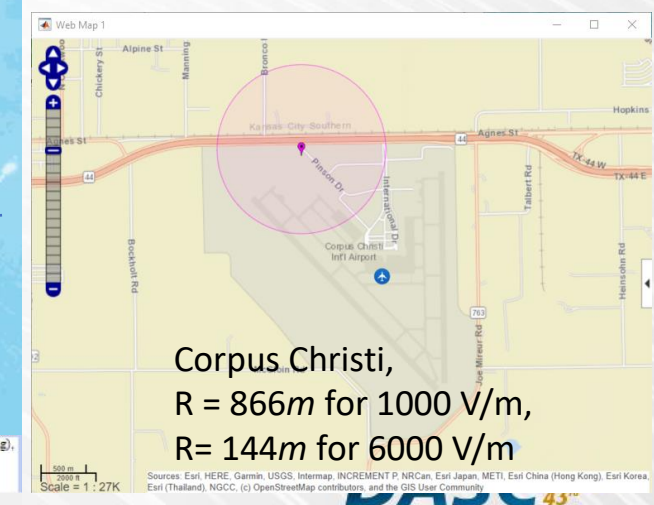
- Current requirements not sufficient!
- Radars are outside of urban areas
- **Recommend:**
 - **Only 1000 V/m Peak and use Map**
 $\rightarrow R = 866m$

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

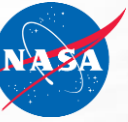


Oct. 1-3, 2024

Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NF Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS



Suggested Field Tolerant Levels for UAM/AAM vehicles (NY City)



- Recommended HIRF Ave. Level based on ULS, CDBS, and IBFS:

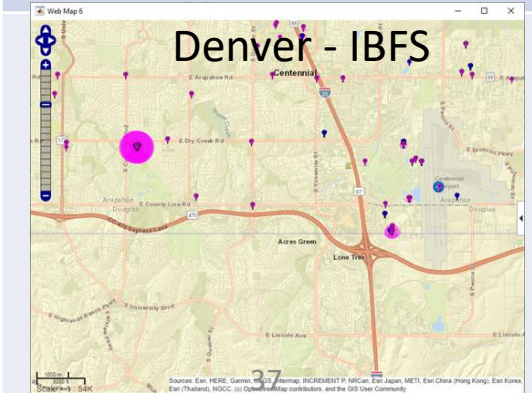
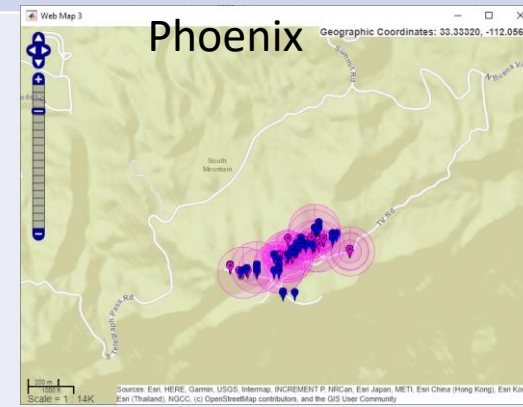
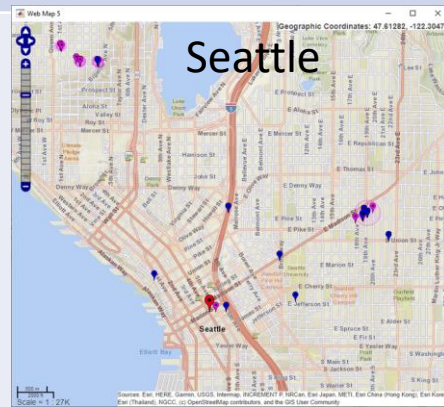
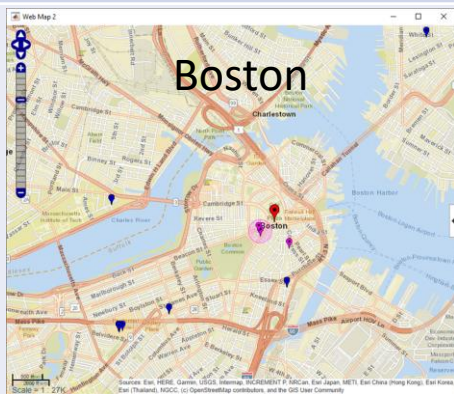
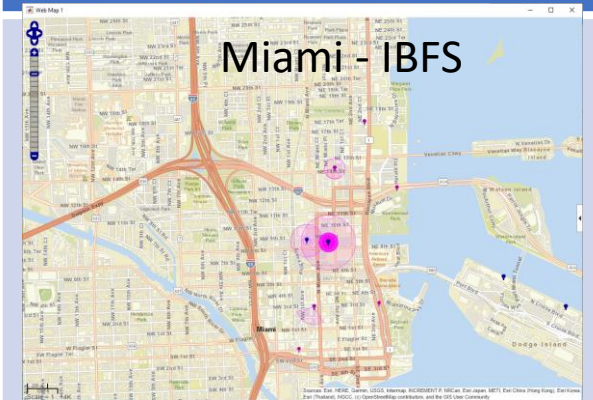
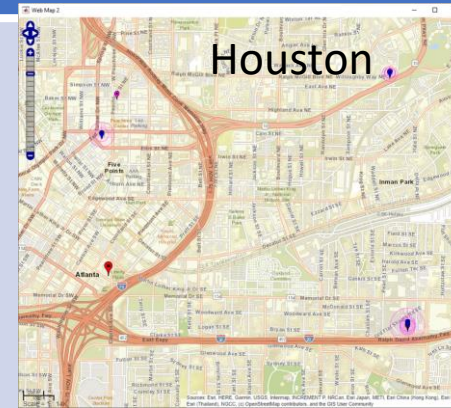
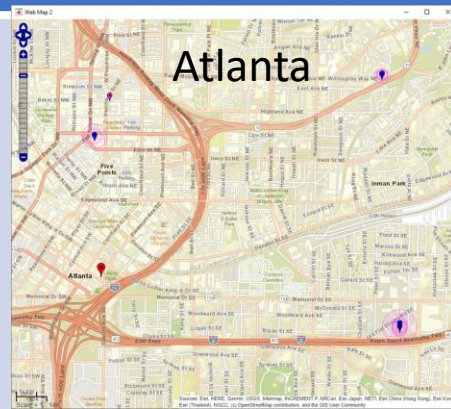
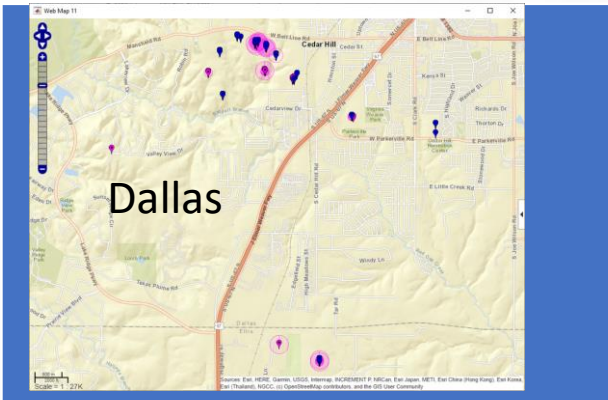
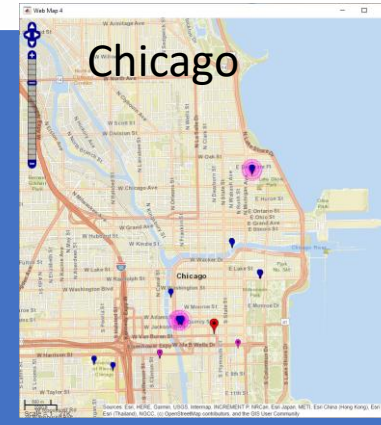
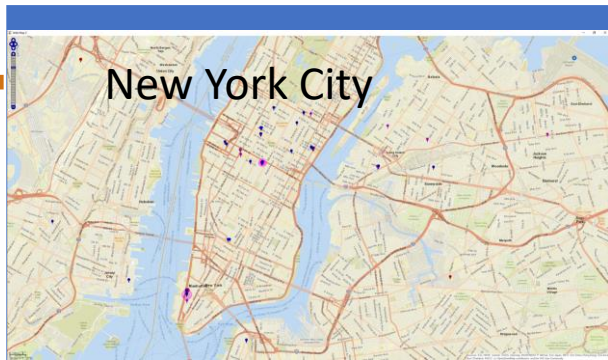
Baseline →	○ 25 V/m	Freq < 2 GHz	(Band Driver: ULS)
	○ 50 V/m	2 GHz - 40 GHz, except as noted below	(ULS)
CDBS Correction →	○ 55 V/m	30 MHz – 0.1 GHz	(CDBS)
	○ 100 V/m	0.1 GHz – 0.4 GHz	(TV)
	○ 100 V/m	Freq: 0.4 GHz – 1 GHz, plus map	(TV)
IBFS Correction →	○ 250-500 V/m	4-6, 6-8 GHz, and 12-18 GHz, plus map	(IBFS)

- Recommended HIRF Levels based on NOAA Weather Radar

Weather Radar →	• Peak: 1000 V/m,	2-4 GHz, 4-6 GHz, plus map
	• Ave: 50 V/m,	plus map

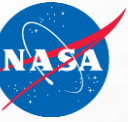
- Stay 100' slant distance away from RF sources per assumption
- Keep out of Airports/Heliports and Military Bases
 - Unless location, frequency, and EIRP are known
 - Note: EIRP = 77.4 KW corresponds to 50 V/m @100'

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

Truong Nguyen



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	



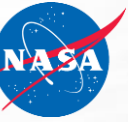
Modified!

Shaded: Use HIRF Map to avoid HIRF Sources

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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 Thresholds Summary – HIRF Ave.



Actual thresholds are to be determined through vehicle testing.

Shaded: HIRF Map must be used

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





Findings & Conclusions

- **The HIRF-avoidance approach appears technically feasible!**
- **HIRF-Map** is only needed for higher-power sources
 - With the minimum recommended thresholds
- **The existing HIRF requirements are insufficient**
- The recommended tolerance lower than standard below 4 GHz
 - Equal or slightly higher than standard above 4 GHz for some bands
 - Due to IBFS transmitters threats not addressable with the current standard
- **Avoid airports and military/government installations for now, unless transmitter data are available for consideration**



Recommendations

- **Incorporate additional databases** if available
 - FAA, NTIA,...
 - Airport Surveillance Radar (ASR), Air-Route Surveillance Radar (ARSR),...
- Consider **mobile sources** in the baseline threshold
 - Portable Electronic Devices (T-PEDs)
 - Other air vehicles
- Work with the FCC to improve **CDBS and IBFS GPS data accuracy**
 - As FCC licenses are renewed periodically



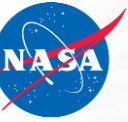
Recommendations (Cont.)

- **Establish a standard subgroup** to develop further, and
 - **Establish a Gate-keeper**
 - **An authorized entity** for sensitive data
 - Provide HIRF Maps capabilities for **government and airport sites**, or
 - **Provides sanitized data**
 - **Sanitized data expected form:**
 - **Frequency:** Fit frequency to one of the **frequency segments (FS1 - FS17)**
 - **Power Level:** Round up to one of the **power band segments (TBD)**
 - **Modulation:** Down-select to **CW, AM, or Pulse classification** only
 - **GPS Location:** **Approximated location**, and include uncertainty figure for map purposes



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.*
- *The OpenStreetMap license is available at: <https://www.openstreetmap.org/copyright>*



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The End

System-Wide
Safety (SWS)
Project

Electrified
Powertrain Flight
Demonstration
Project



Illustration by NASA's Aeronautics Research Mission Directorate