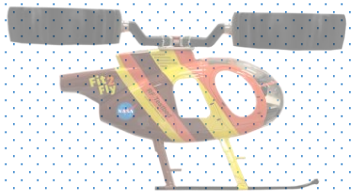


A HIRF-Map Certification Approach

For UAM, AAM, and UAS Vehicles

Truong Nguyen, NASA Langley Research Center

EMA Expo 2024

Jan. 29 – Feb. 2, 2024

Golden, Colorado

Work Sponsored by NASA

System-Wide Safety (SWS) Project

Electrified Powertrain Flight Demonstration Project

Sponsors

- **System-Wide Safety Project**
  - **Goals**:
    - **Explore, discover, and understand how safety could be affected by the growing complexity of advanced aviation systems**.
    - Develop and demonstrate the research tools, innovative technologies, and operational methods that will **proactively mitigate potential risks** to maintain the aviation industry's unparalleled safety record.
  - Part of the Airspace Operations and Safety Program (AOSP) within the NASA Aeronautics Research Mission Directorate (ARMD).

- **Electrified Powertrain Flight Demonstration Project**
  - **Goals**:
    - Conduct **ground and flight tests of electrified aircraft propulsion (EAP) technologies** to enable a new generation of electric-powered aircraft
    - Introduce **EAP systems to the U.S. commercial fleet** by conducting at least two flight demonstrations
  - Part of the Integrated Aviation Systems Program (IASP) within ARMD

Outline

- **Map-based HIRF avoidance**
  - Approach
  - Examples
- **Combining Map-based approach with traditional approach**
  - **Minimum HIRF tolerance recommendations**
    - Based on FCC's and NOAA's transmitters databases
  - Deficiencies in current HIRF standard levels

Background

UAM:	Urban Air Mobility
AAM:	Advanced Air Mobility
UAS:	Unmanned Aircraft Systems

- Aircraft, rotorcraft, and other air vehicles may be exposed to very **high EM field environments (HIRF)**
    - HIRF Susceptibilities **could lead to catastrophic events**
    - Digital upset, equipment reset, damage to hardware/ICs, loss of communication/data, analog measurement errors…
- Existing HIRF standards were **based on the worst-case environments** worldwide
- **Rotorcraft environment worse than aircraft**
    - Operate close to ground transmitters
    - Can hover in front of transmitters
    - Resulting in very severe HIRF test levels
- **UAM/AAM/UAS vehicles may operate similarly to rotorcraft**
    - Require testing to the same HIRF levels as for rotorcraft
    - Vehicles often lack metal skin for shielding
- **Concerns about HIRF protection cost, size, and weight for UAM/AAM/UAS vehicles**

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

Urban Air Mobility and AAM Concepts

Illustration by NASA's Aeronautics Research Mission Directorate

Aircraft and Rotorcraft HIRF Environments

- **14 CFR 27—AIRWORTHINESS STANDARDS**

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

Proposed Map-Based Solution

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

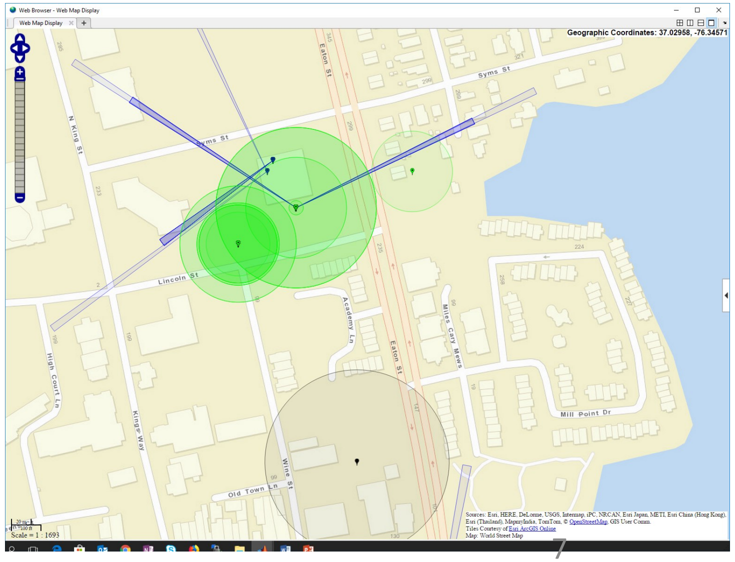
(A) **Transmitter Power** - (B) **Propagation Loss** (HIRF Map) < (C) **Vehicle Tolerance**

(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)**

Illustration of Flight Planning

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

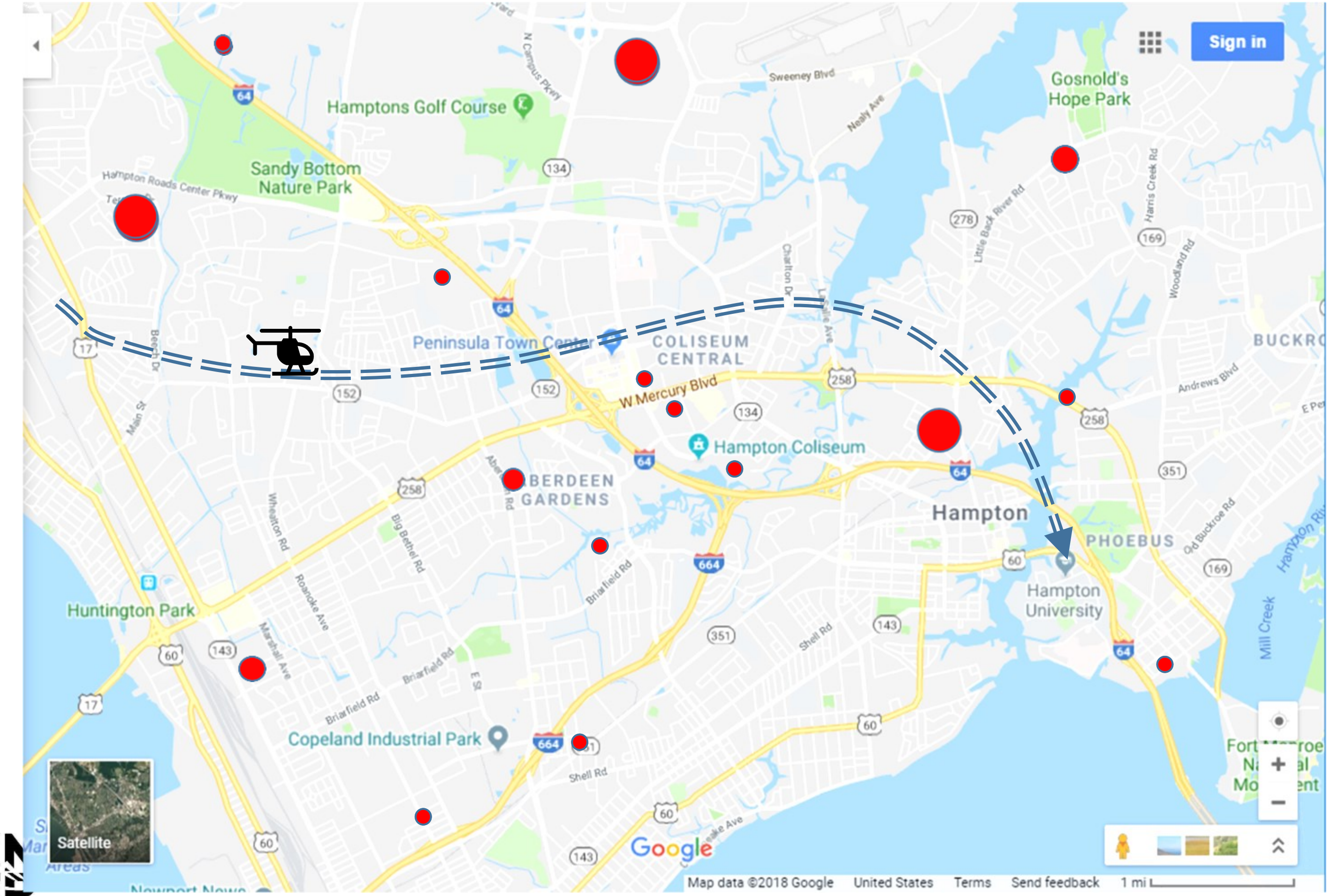


Illustration only. Not actual transmitters

- 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
  - …

Benefits

- **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/should be used in combination with the existing approach (more later)

- **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

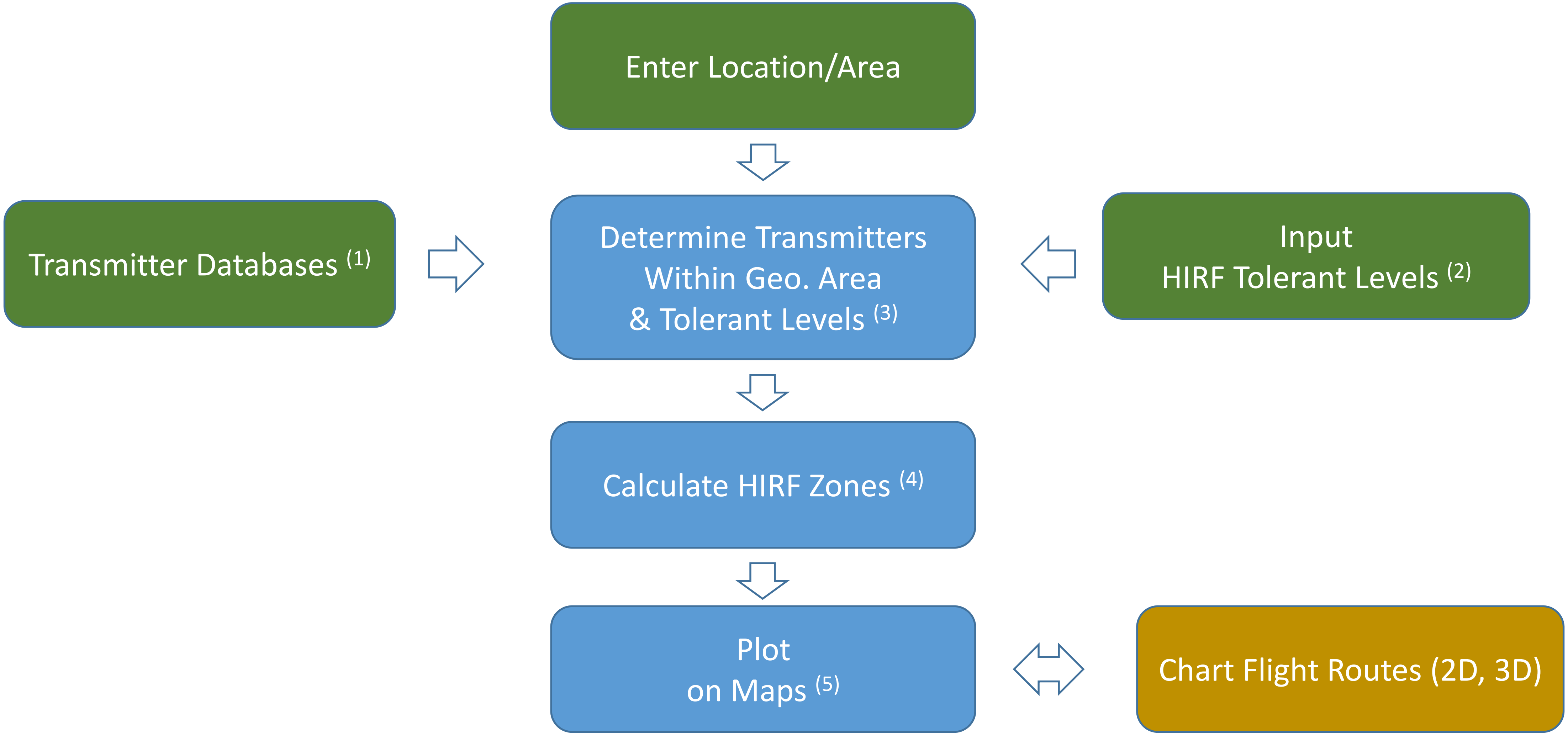
Proof-of-Concept

Proof-of-Concept: To develop a HIRF-Map tool, and to identify key issues

The HIRF-Map Tool is developed in Matlab

- **Import Databases** (FCC, NOAA,…)
  - Limit transmitters to those 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 WebMap**
- **Add flight paths**

Implementation



(1) Fixed Transmitter Databases in the U.S.

Databases Incorporated

- **FCC** (Federal Communications Commission)
- **NOAA weather radars**

  (National Oceanic and Atmospheric Administration)

Other Databases

NTIA Databases

(National Telecommunications and Information Administration)

- Transmitters operating in spectrum reserved for federal use
- GMF → EL-CID
- Not publicly accessible

FAA (Federal Aviation Administration)

- Info on Airport radars & others
  - Air Route Surveillance Radar
  - Airport Surveillance Radar
- Not publicly accessible

FCC License Databases

- **CDBS** Consolidated Database System
  - AM, FM, TV stations licenses
- **IBFS** International Bureau Filing System
  - Satellite Earth Stations (SES), Satellite Space Stations
- **ULS** Universal Licensing System
  - A collection of databases of less powerful transmitters
  - Some cellular tower data, microwave links, land mobile radios,…

ULS - Fixed Transmitters

- **Cellular**
  - FCC Database Incomplete!
  - Private Data by mobile carriers: Proprietary, incomplete
- **Market Based**
- **Microwave** Link
- **Land Mobile -**
  - Commercial
  - Private
  - Broadcast
- **MDS / ITFS**
  - Multipoint Distribution Service (MDS)
  - Instructional Television Fixed Service (ITFS)
- **Marine Coastal and Aviation Ground**
- **Paging**

NOAA Weather Radars

TDWR (Terminal Doppler Weather Radar)
NEXRAD (Next Generation Weather Radar)

	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**
EIRP (Ave)	76.64 dBW	
Beam Width	0.925 degrees	0.55 degrees
Pulse Width-max	1.57 & 4.7 microsec	1.1 microsec

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

(2) HIRF Tolerant Level

- **User defined!**
  - **Verified through testing/analysis**
  - Levels should be much lower than existing requirements
  - Unique to vehicle
- 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)	
	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

Note: In later discussions, uniform field tolerant levels across all frequency segments are assumed for discussion simplicity

(3) Transmitter Data Mapping & Usage

Transmitter Data	Used for
Frequency	Map to one of Frequency Bands
Modulation Types (AM, FM, phase, pulse-width/position, single-side bands with full/suppress carrier, vestigial sideband,…)	Map to CW, AM, Pulse
Power, Gain	Calculating HIRF zone radius
GPS Location	Plot on Map
Transmitter Type & details	Marker, colors, Pop-ups
Angular Range, Beam Elevation	Plot on Map (circular or angular sector)
Antenna height	Future 3D mapping

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
[illegible]	5000	330
12 GHz - 18 GHz	2000	330
18 GHz - 40 GHz	1000	420

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

(4) Calculate HIRF Zones

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

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

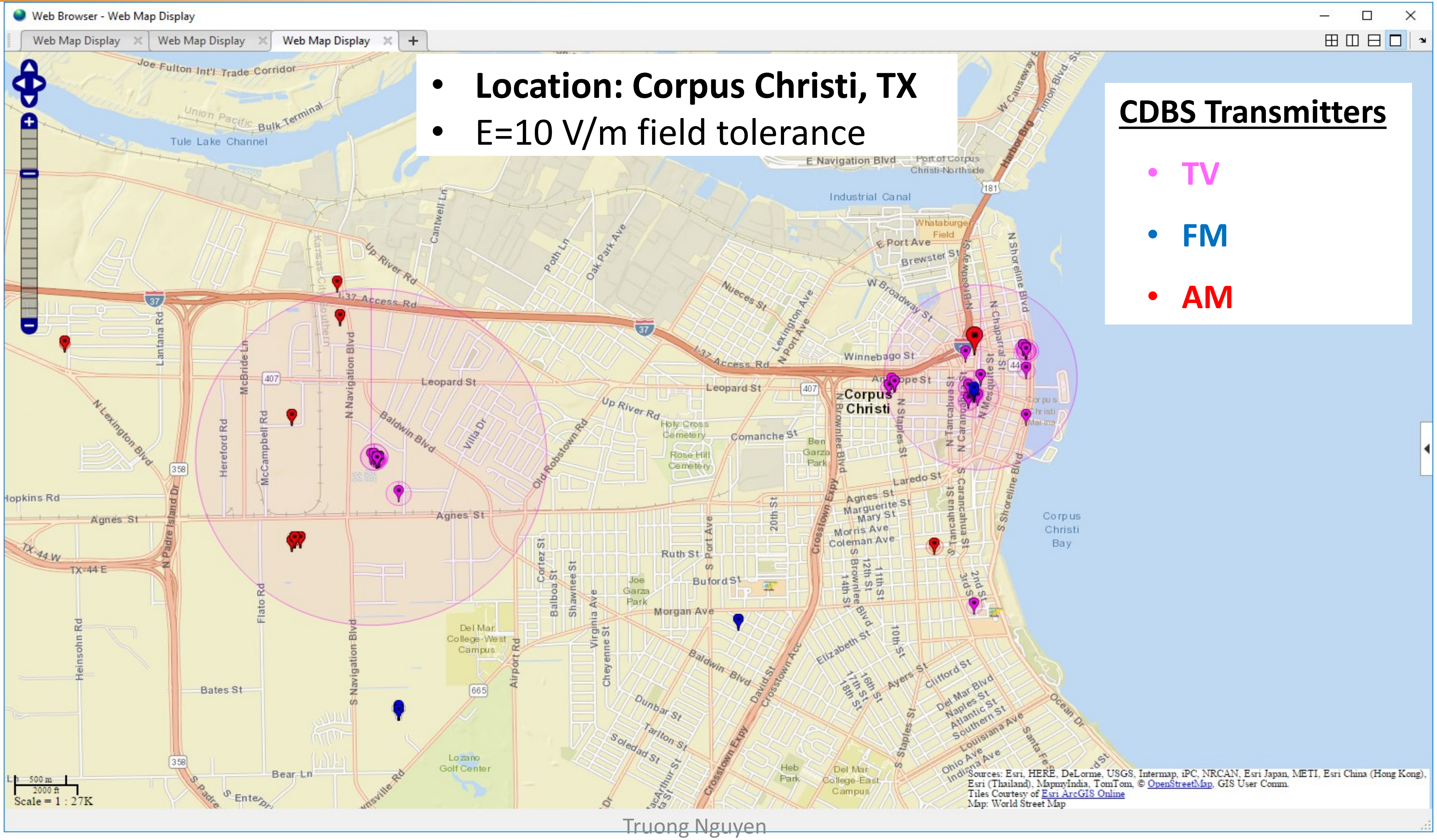
E = E-field tolerance level
R = Stand-off distance
P = Radiated Power
G = Antenna Gain
EIRP = PG = Eff. Isotropic Radiated Power

- The worst-case data is assumed, to be conservative
  - Ignore antenna pattern
- **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

(5) Plot HIRF Map

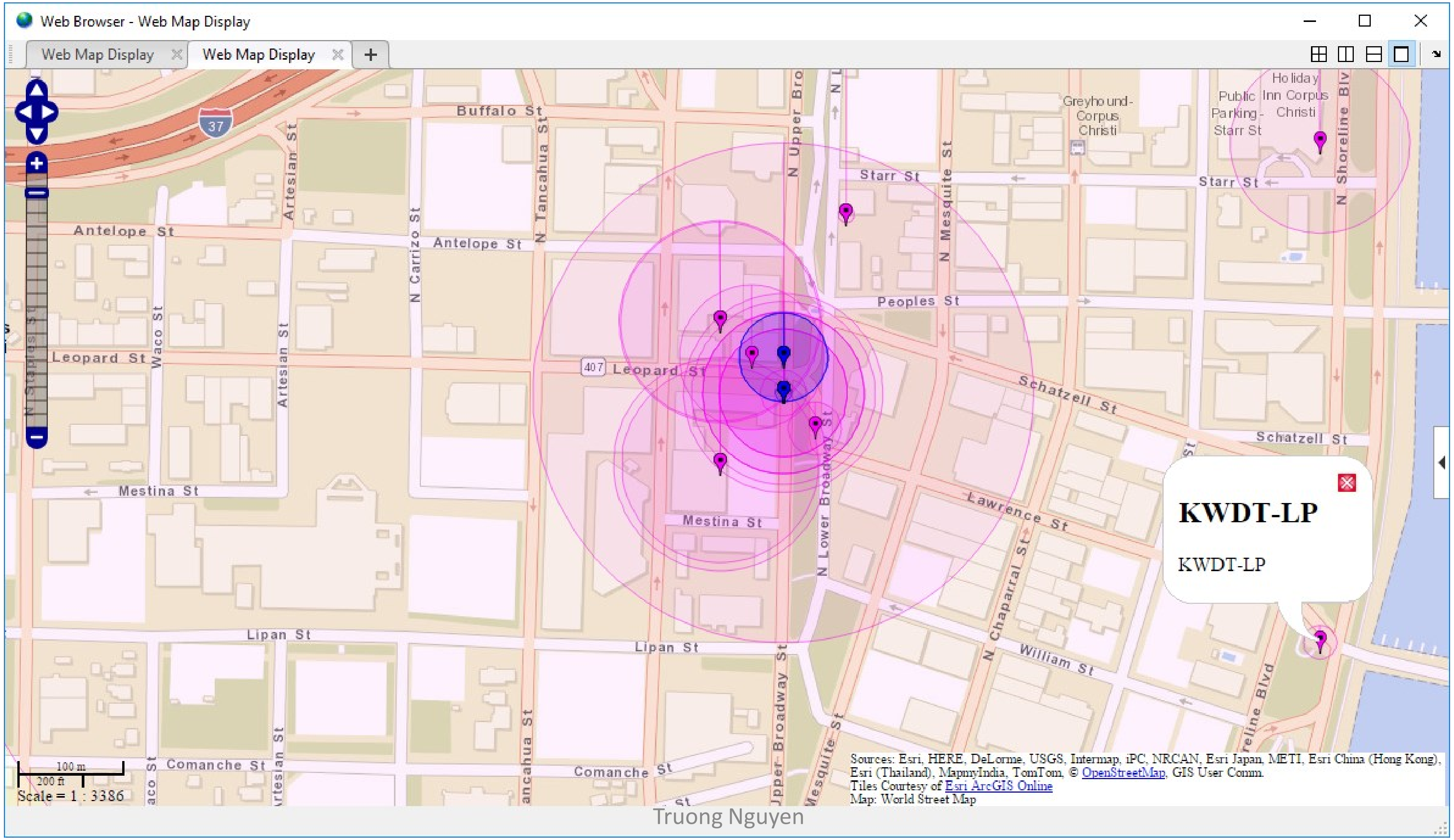
- **Used Webmap Tools in Matlab**
- **Ignore cumulative effects** from multiple carriers (similar to the existing HIRF standards assumption)
- **Ignore high-order effects** (ground bounce, multi-paths, diffractions)
- Display **HIRF zones for each carrier**
  - Darker shades → higher number of carriers
  - **Circular zones** for most transmitters
  - **Angular sectors** for microwave and satellite base station if data is available
- Also includes additional map info:
  - Airport and helipad locations
  - Military base boundaries

CDBS Database Example



CDBS Database Example

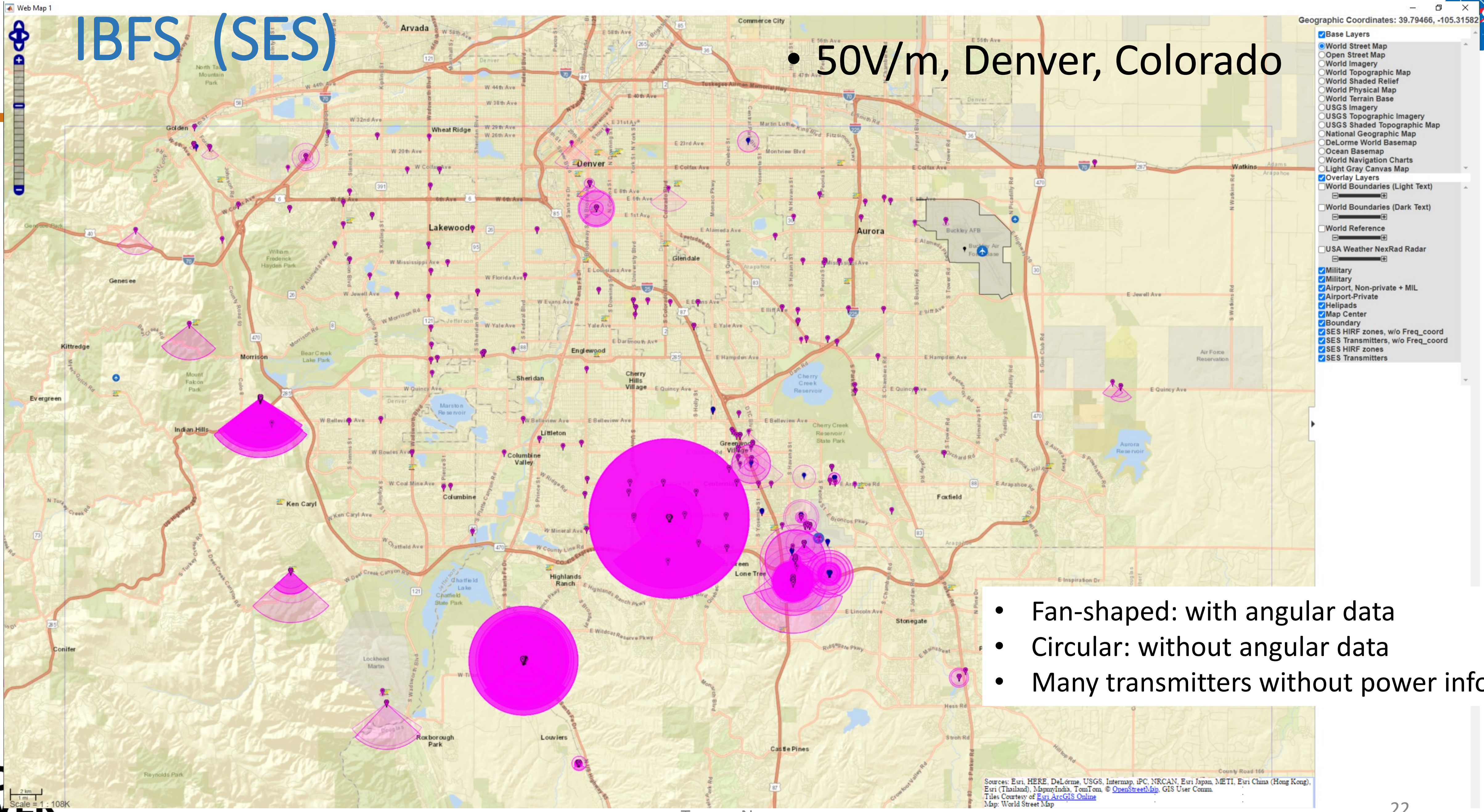
- HIRF zones for TV and FM Radio stations
- Multiple carriers



Truong Nguyen

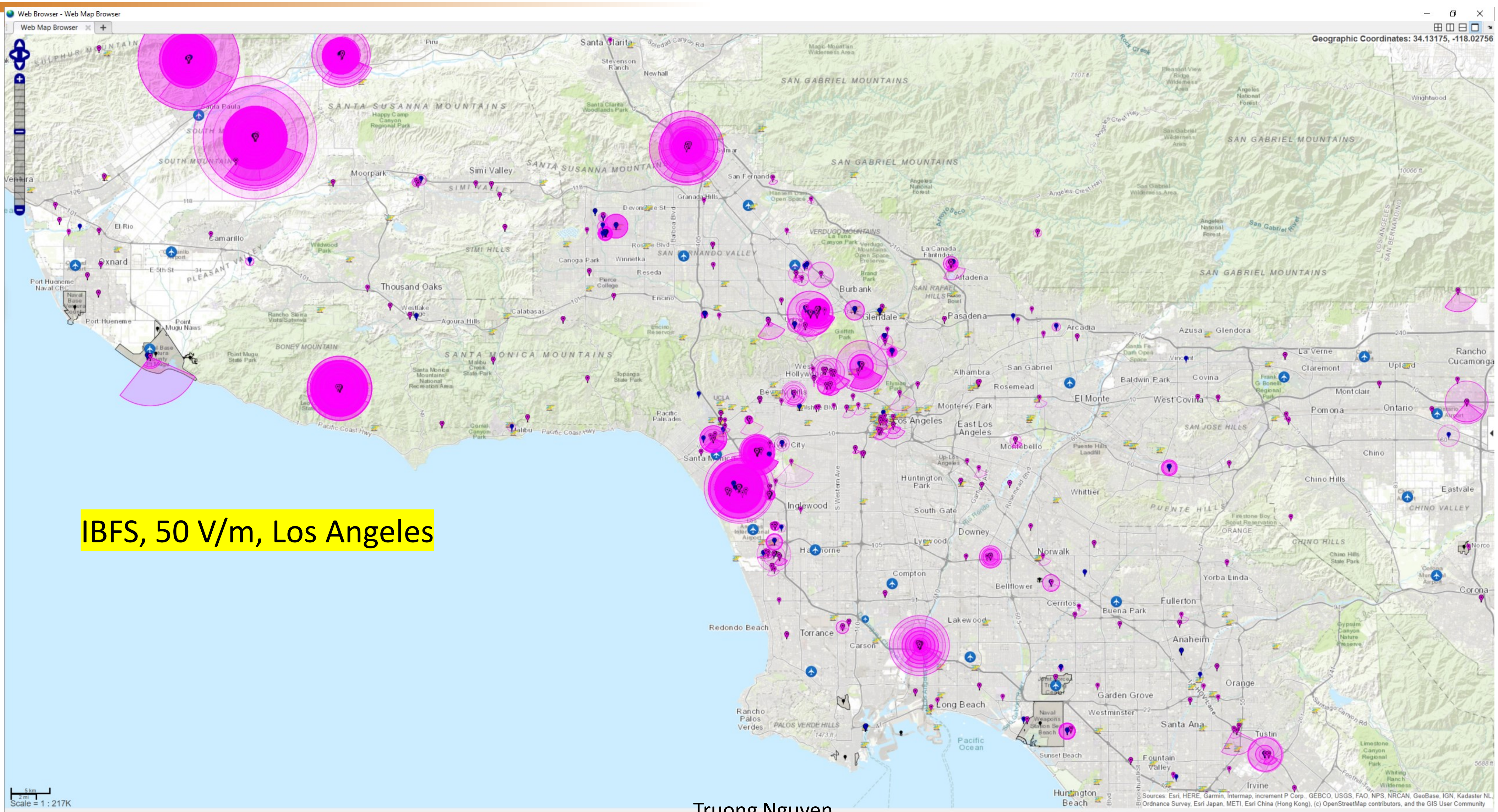
IBFS (SES)

- 50V/m, Denver, Colorado

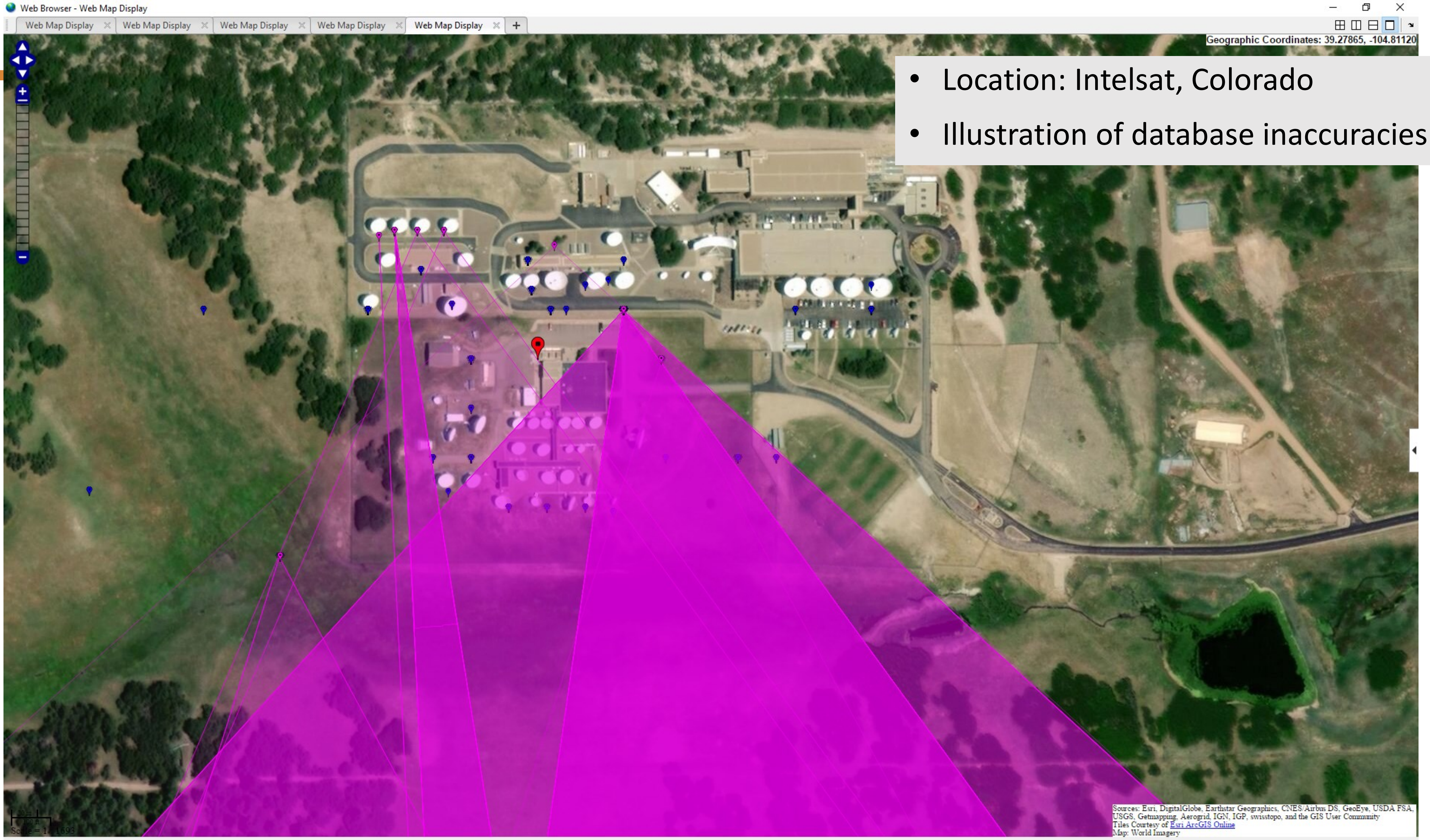


- Fan-shaped: with angular data
- Circular: without angular data
- Many transmitters without power info

IBFS, 50 V/m, Los Angeles Areas

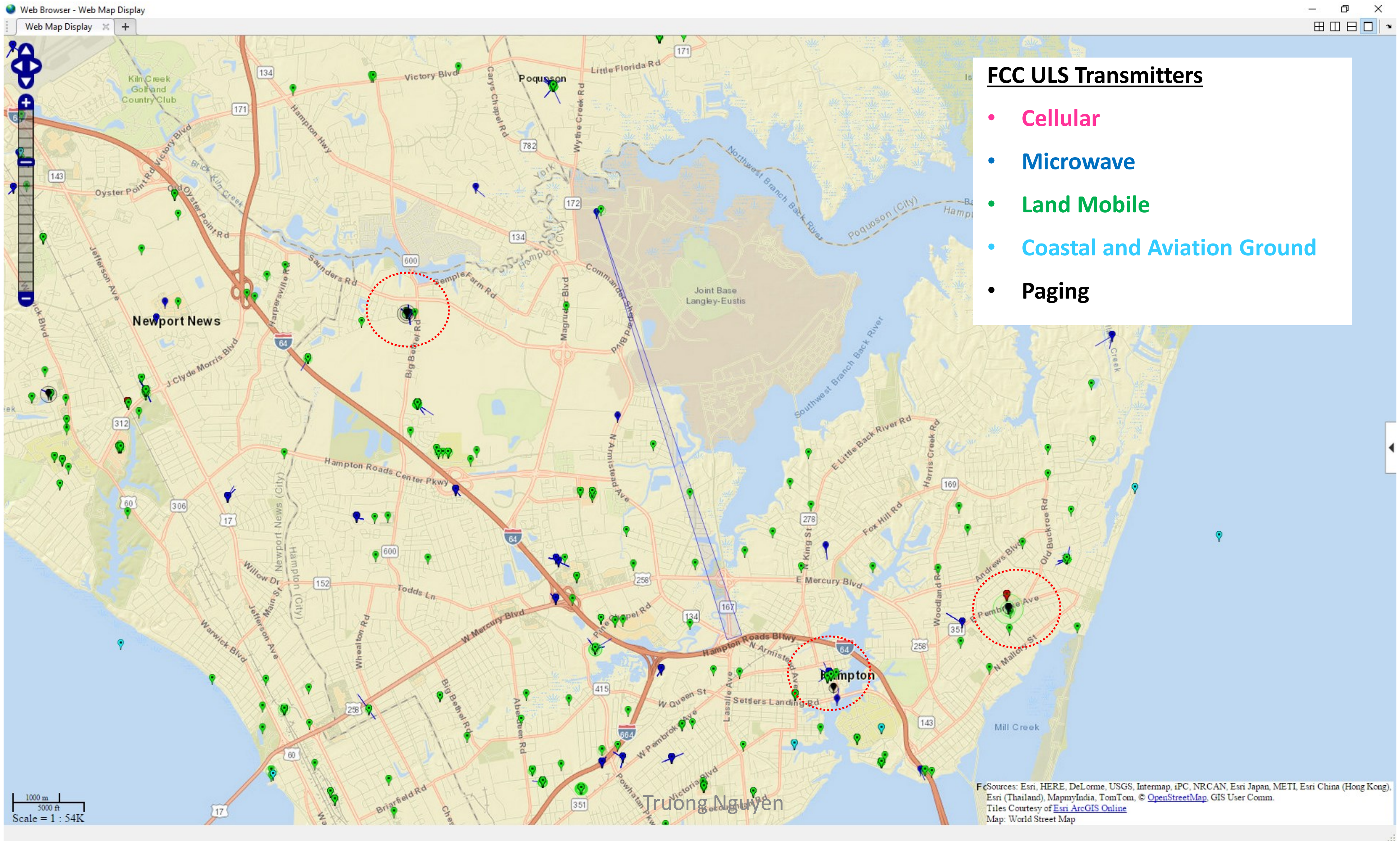


IBFS: Satellite Earth Stations

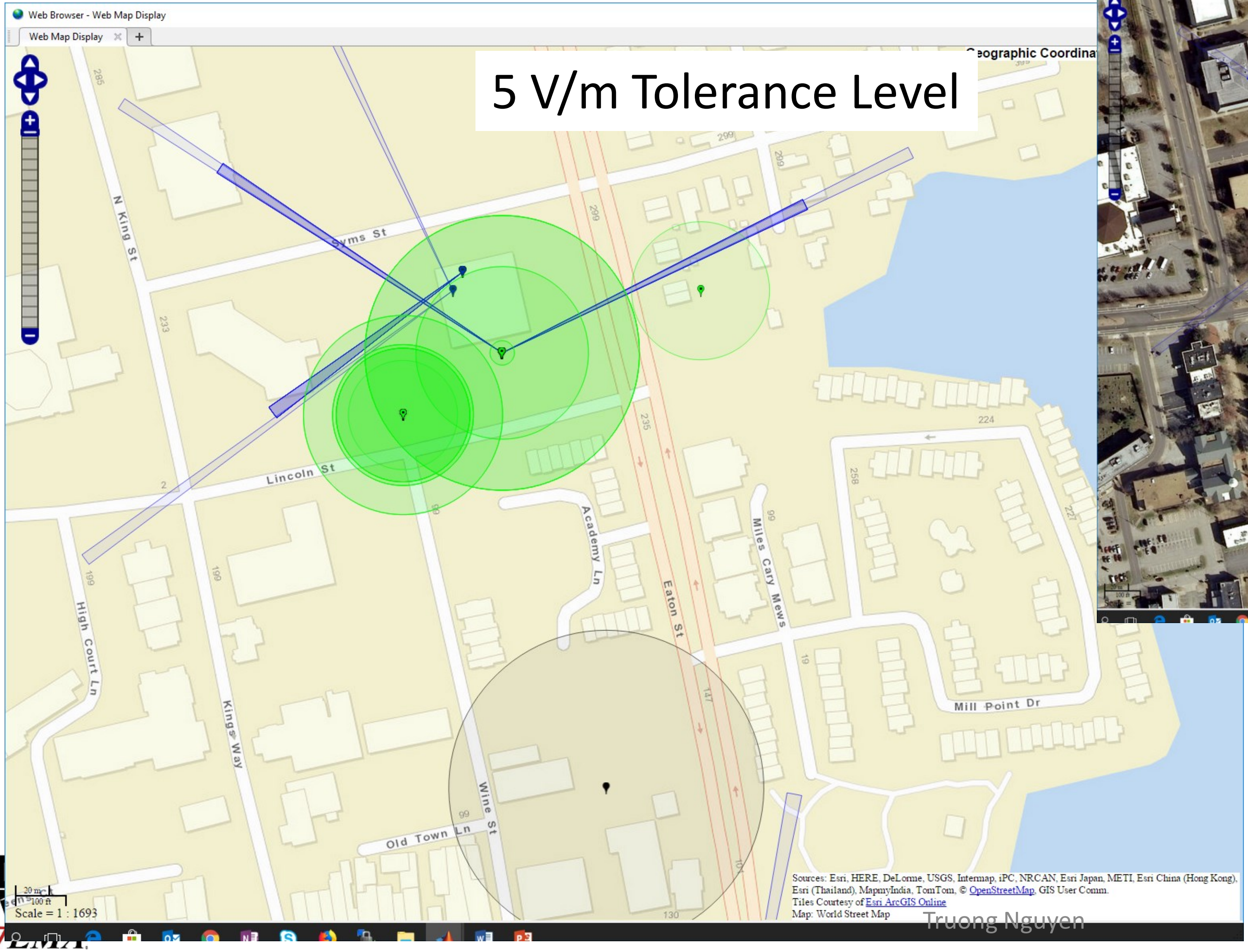


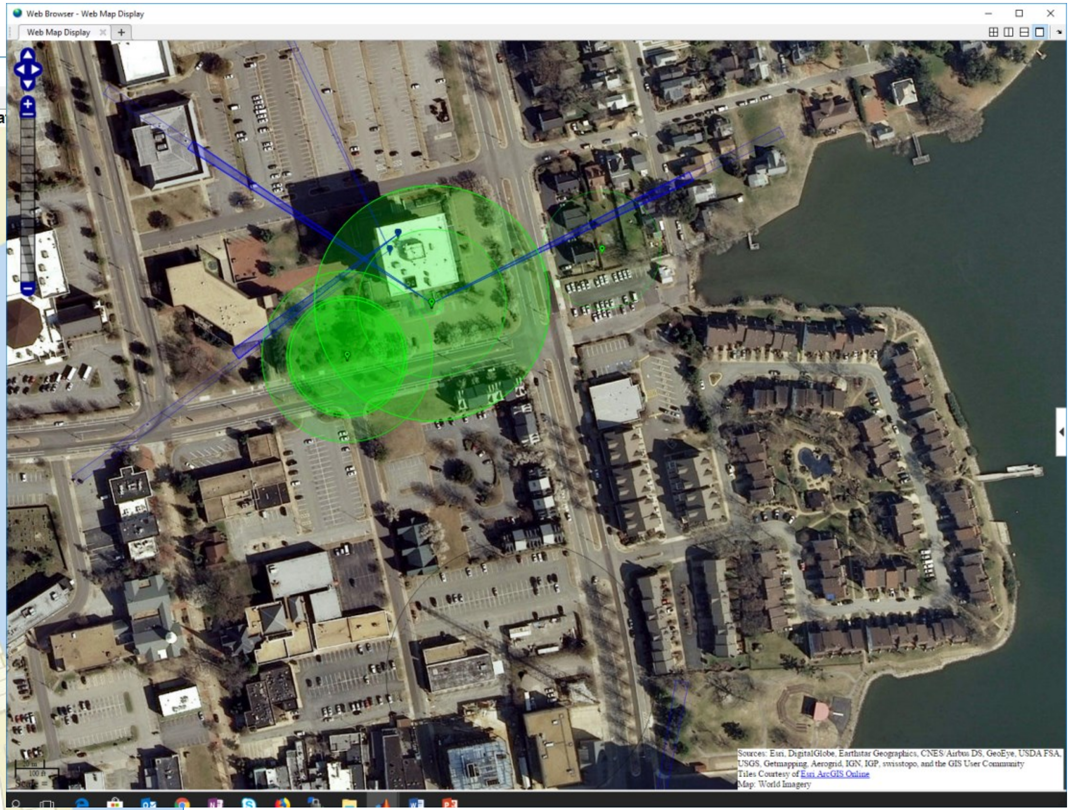
- Location: Intelsat, Colorado
- Illustration of database inaccuracies

ULS Database Example



ULS Transmitters HIRF Zones, Hampton, VA





FCC ULS Transmitters

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

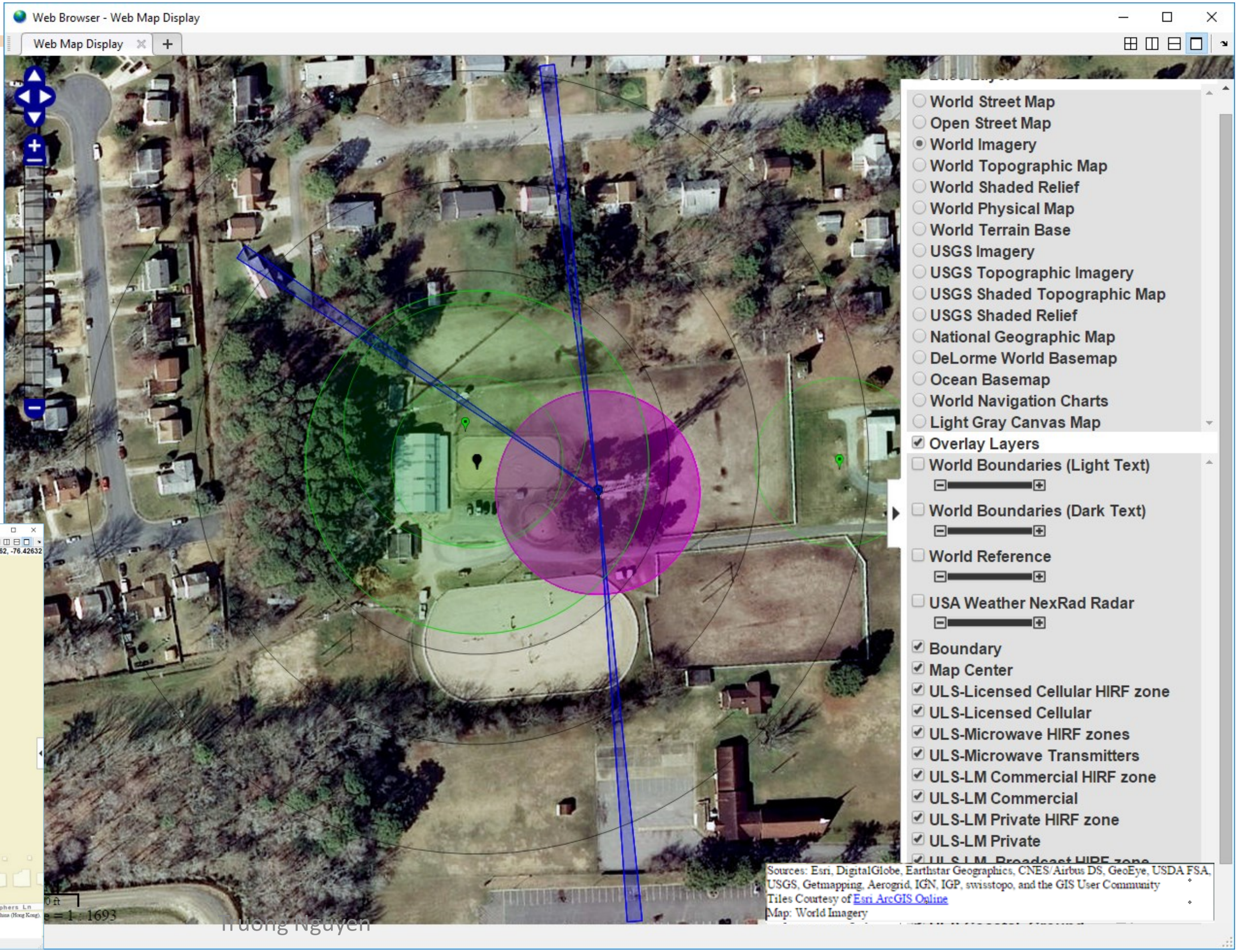
Truong Nguyen

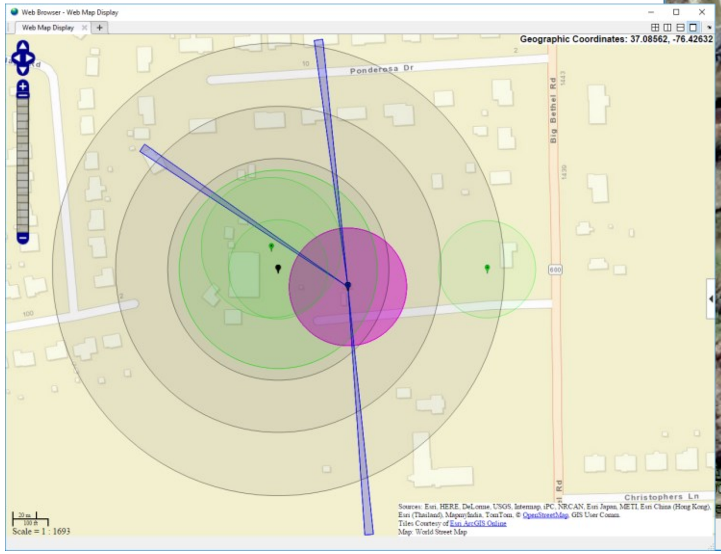
ULS Transmitters HIRF Zones Example

Location: Hampton, VA
Vehicle Tolerance Level: 2 V/m

FCC ULS Transmitters

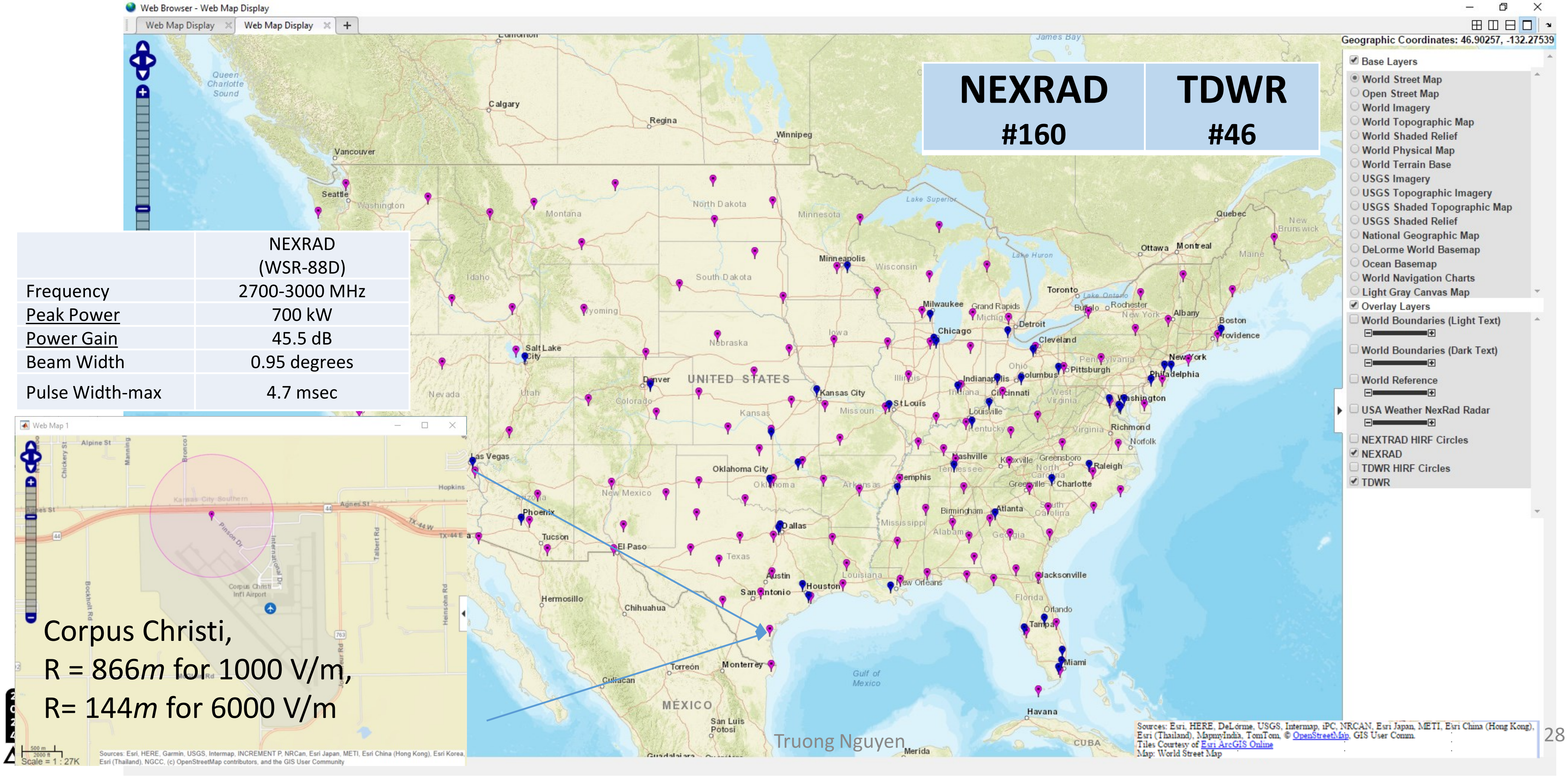
- Cellular
- Microwave
- Land Mobile
- Coastal and Ground
- Paging





Truong Nguyen

NOAA Weather Radars



NEXRAD	TDWR
#160	#46

	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

Corpus Christi,
R = 866*m* for 1000 V/m,
R= 144*m* for 6000 V/m

Findings

- ULS Databases:
  - Numerous low-power transmitters in a small region
  - Accurate GPS data
  - ➔ Recommend a default minimum HIRF tolerance

- GPS accuracy of CDBS and IBFS databases could be improved
  - Some **GPS data rounded**–
    - Accuracy can be off ~30 meters
  - **GPS location of the facility**, instead of the antenna
- Many SES have no transmitter power info

Map-based HIRF Approach with Recommended Minimum HIRF Tolerant Levels

- Use data for **New York City** as an example
  - More locations to be added
- Consider transmitter databases:
  - ULS (Small transmitters)
  - CDBS (AM, FM, TV)
  - IBFS (Satellite Earth Stations)
  - NOAA Weather Radar

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.

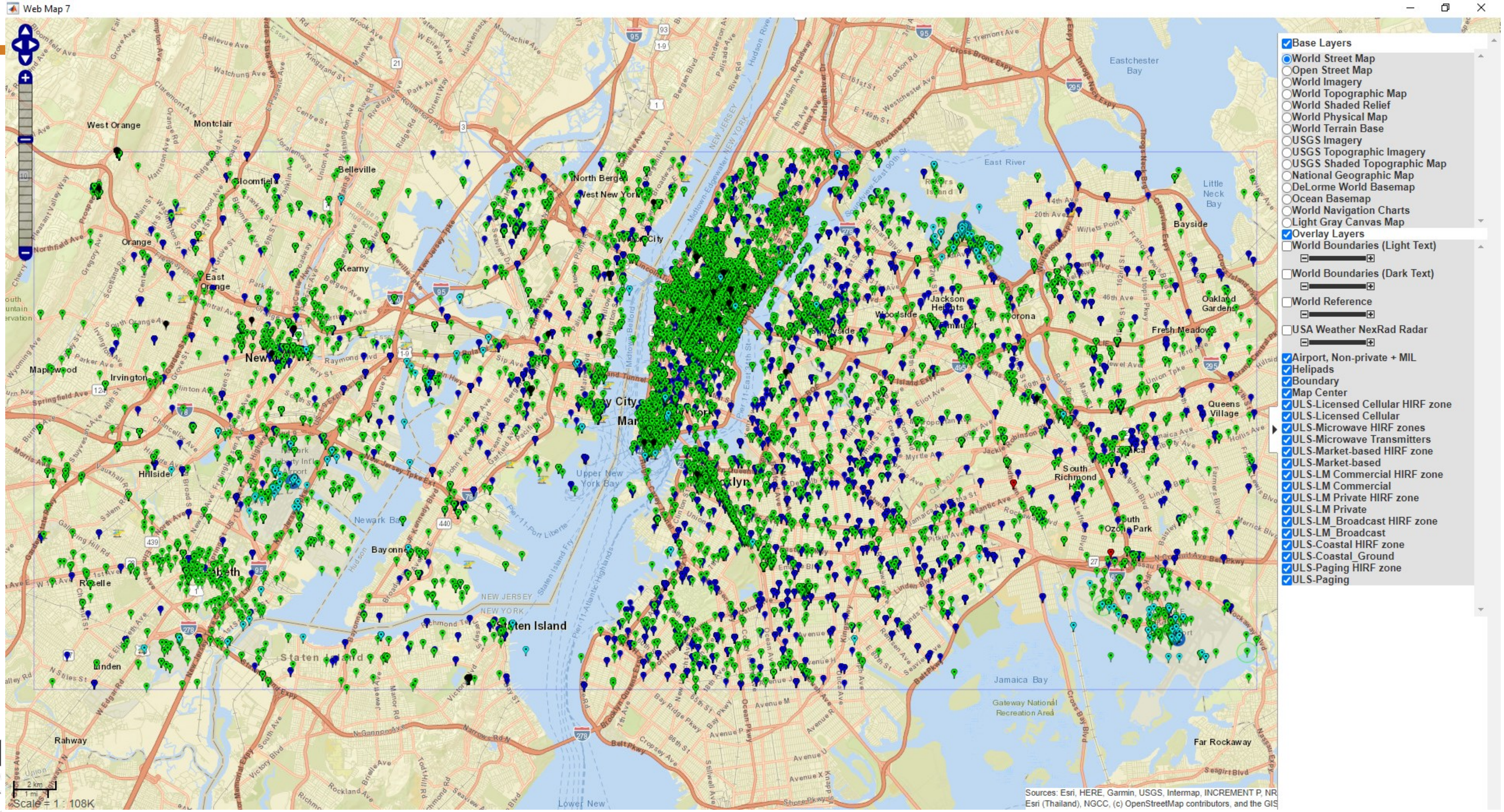
50 feet slant range for mobile transmitters, including transmitters on other aircraft, and 150 feet slant range for aircraft weather radar.

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

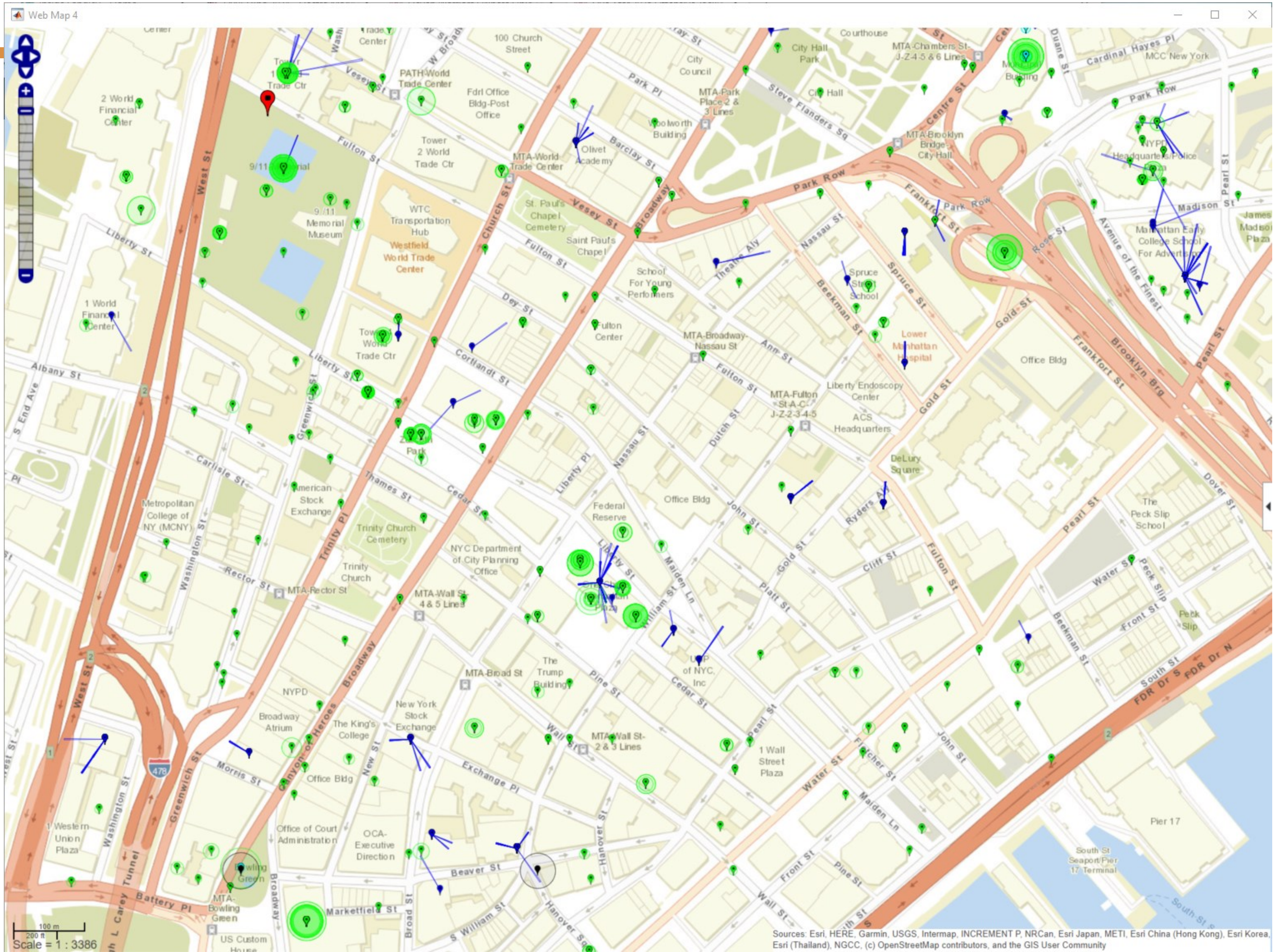
All transmitters, 100 feet slant range.

100’ minimum separation distance from HIRF sources!

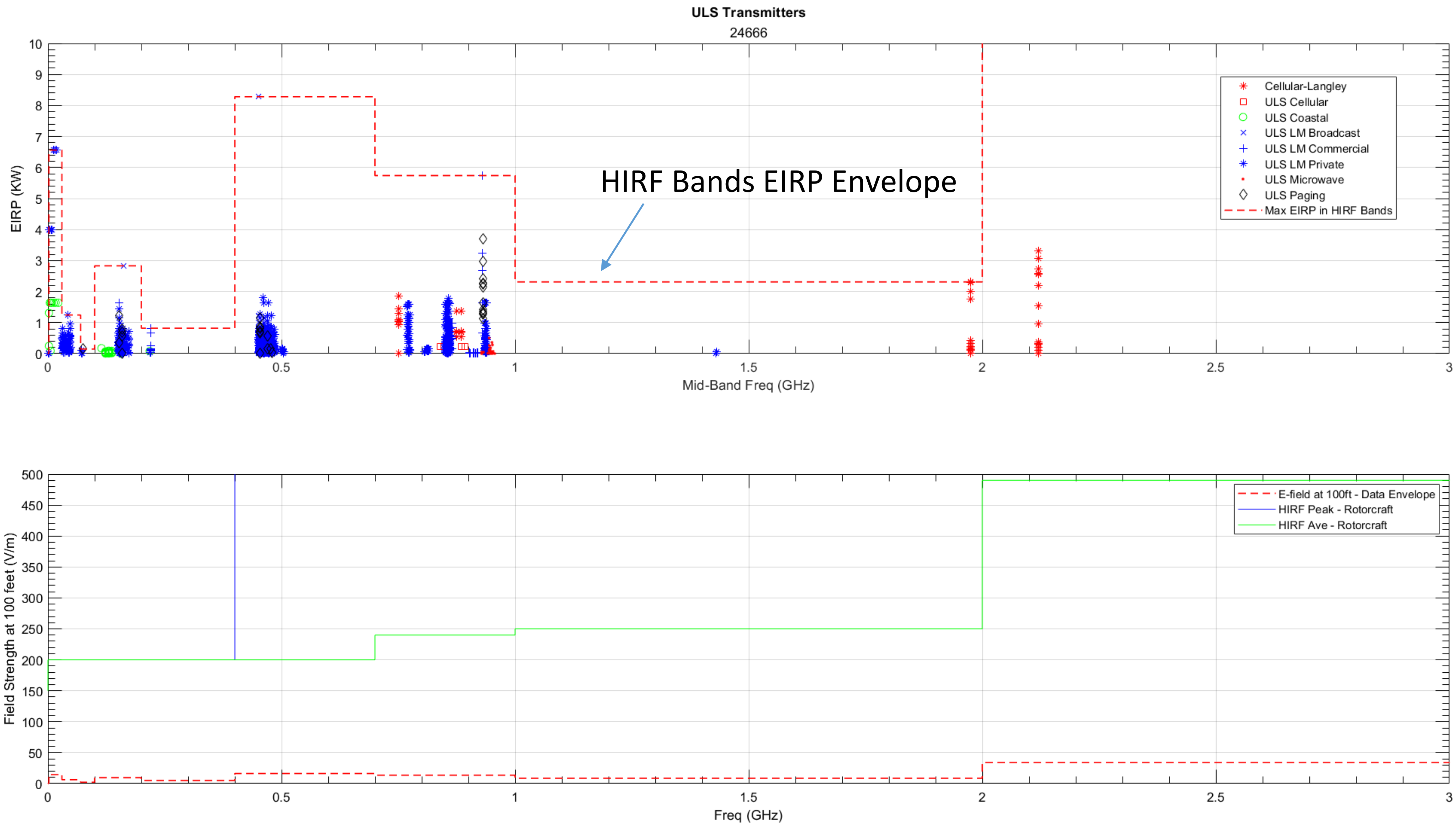
ULS Transmitters, Manhattan, New York



ULS HIRF Map - 10 V/m Tolerant Level



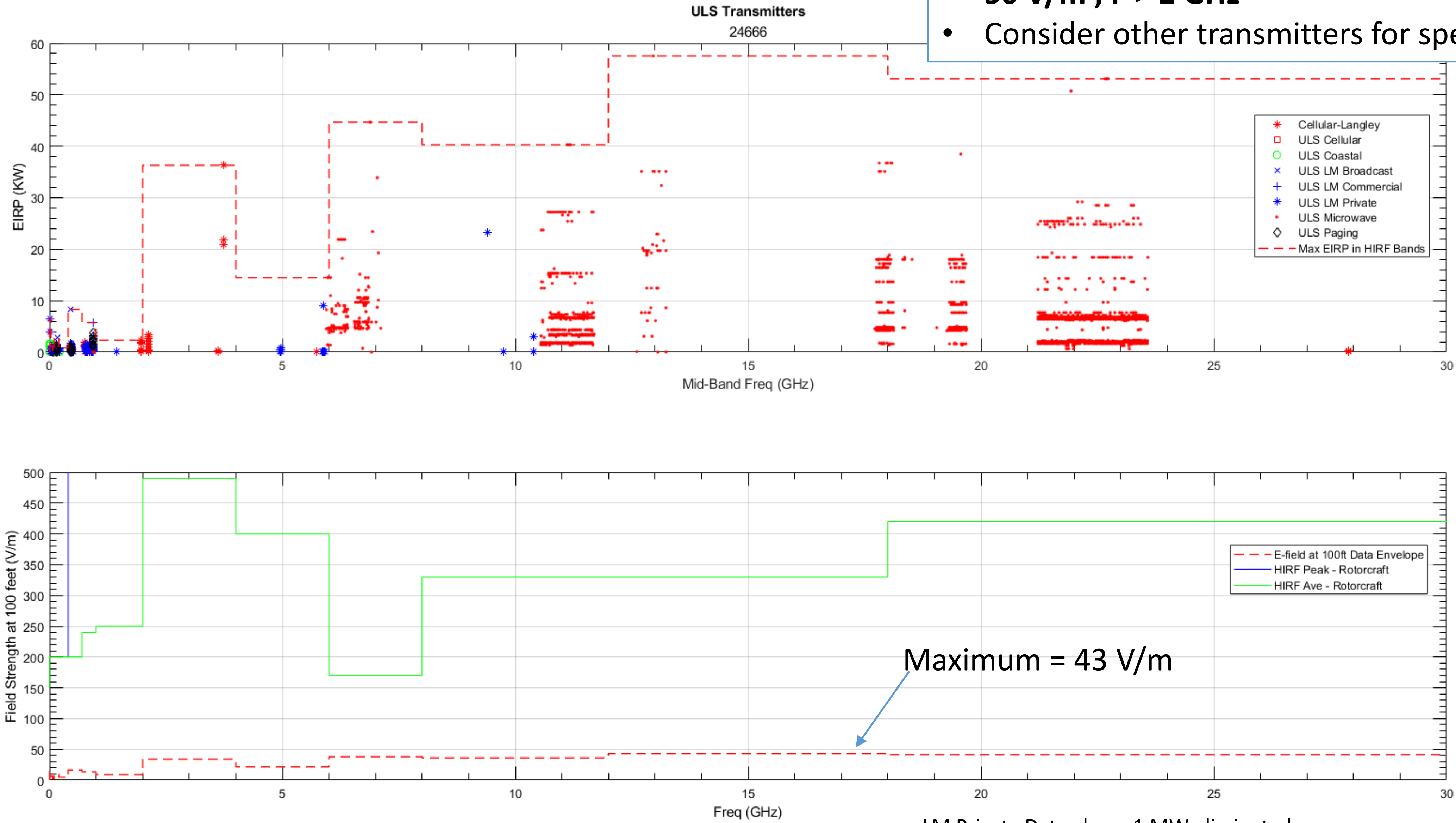
ULS Transmitters below 3 GHz



ULS Transmitters – to 30 GHz

Recommended HIRF Levels for ULS:

- **25 V/m , F < 2 GHz**
- **50 V/m , F > 2 GHz**
- Consider other transmitters for specific freqs



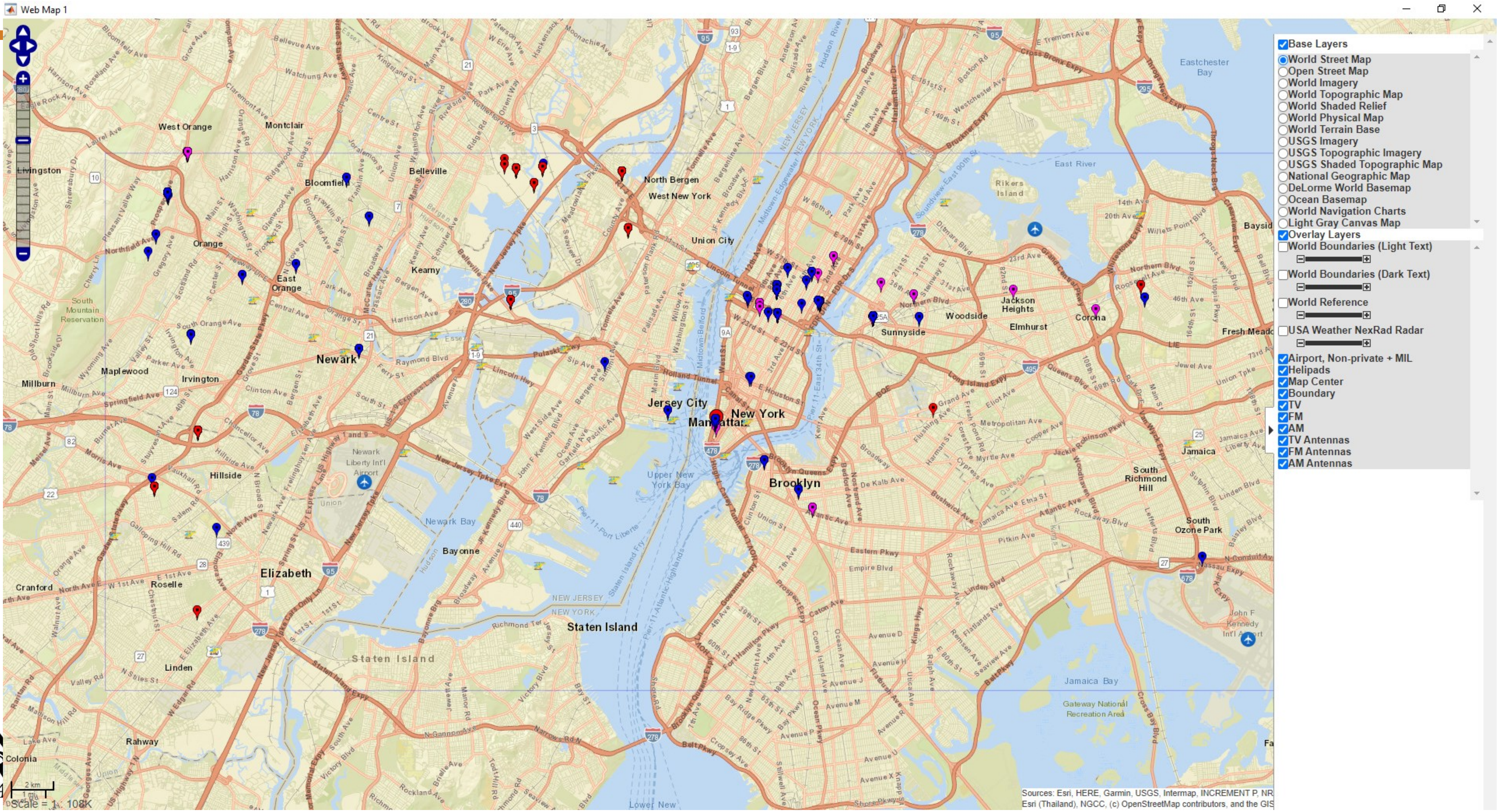
- LM Private Data above 1 MW eliminated,
- 1 data point > 46 MW eliminated

Recommended Minimum Field Tolerant Levels for ULS Transmitters

- **25 V/m (< 2GHz)**
- **50 V/m (> 2 GHz)**
- Based on 100' Separation Distance, per HIRF standard for rotorcraft
- Location : New York City, Area 40 km x 120 km, Map Center: World Trade Center

F1_GHz	F2_GHz	EIRP_kW	E_field
1e-05	0.0001	0	0
0.0001	0.0005	0	0
0.0005	0.002	0.0164	0.72773
0.002	0.03	1.6406	7.2786
0.03	0.07	1.2464	6.3442
0.07	0.1	0.14711	2.1795
0.1	0.2	2.8306	9.5607
0.2	0.4	0.24941	2.8379
0.4	0.7	8.282	16.354
0.7	1	5.74	13.614
1	2	2.3121	8.6406
2	4	36.308	34.241
4	6	14.454	21.605
6	8	44.668	37.979
8	12	27.237	29.657
12	18	57.544	43.107
18	40	53.108	41.412

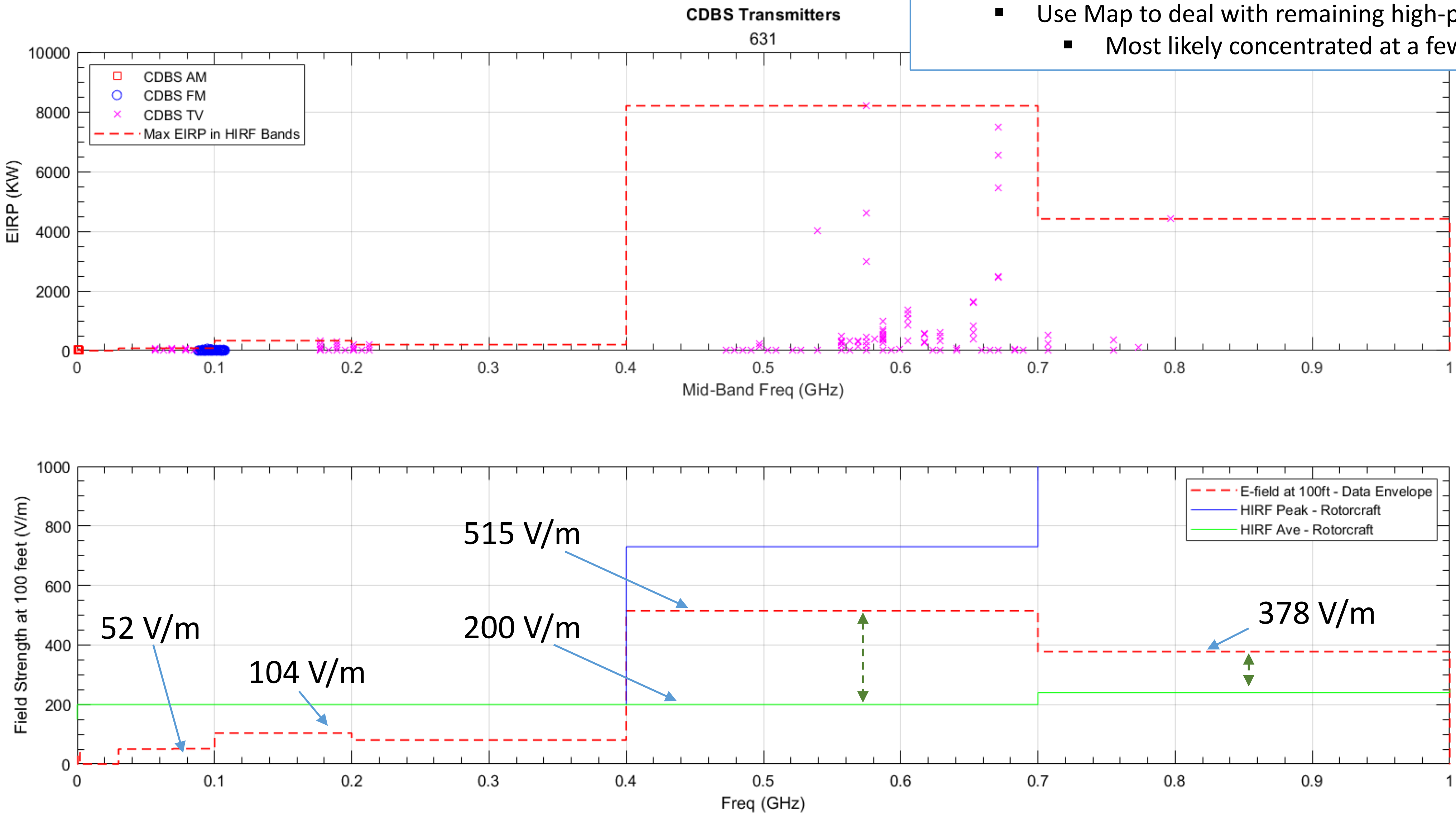
CDBS Transmitters, Manhattan, New York



CDBS Transmitters

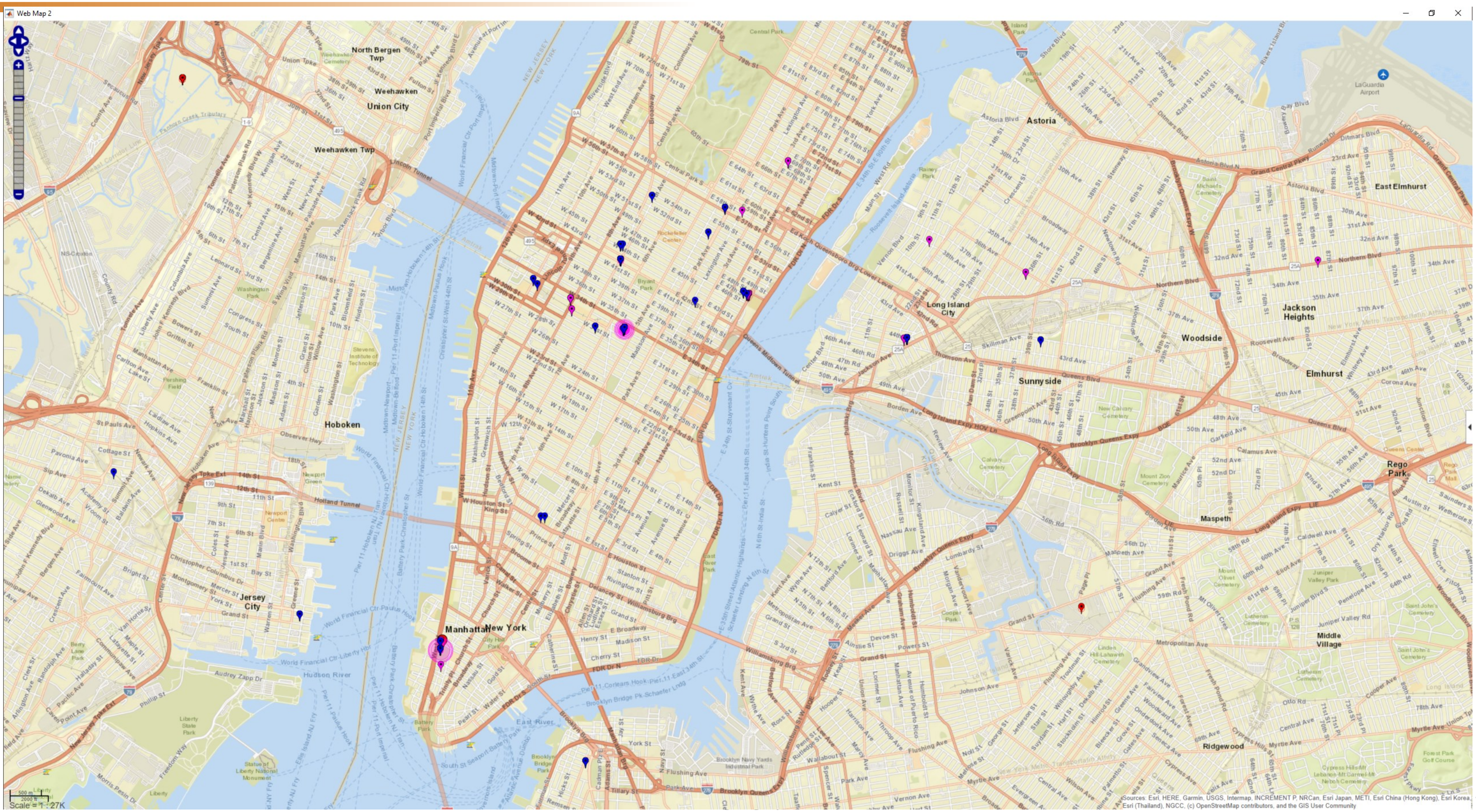
TV transmitters > 8 MW

- Maximum Field = ~515 V/m @ 100’
- **Recommendation:**
  - **105 V/m would tolerate most CDBS transmitters**
  - Use Map to deal with remaining high-power sources
    - Most likely concentrated at a few tall towers



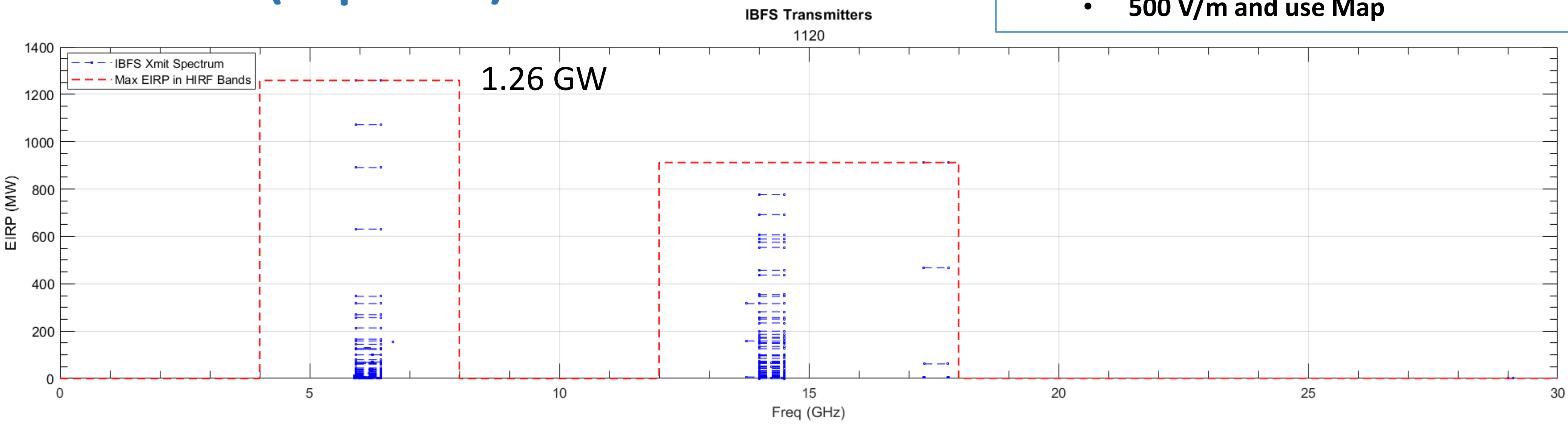
HIRF Zones - CDBS transmitters at 100 V/m tolerant level

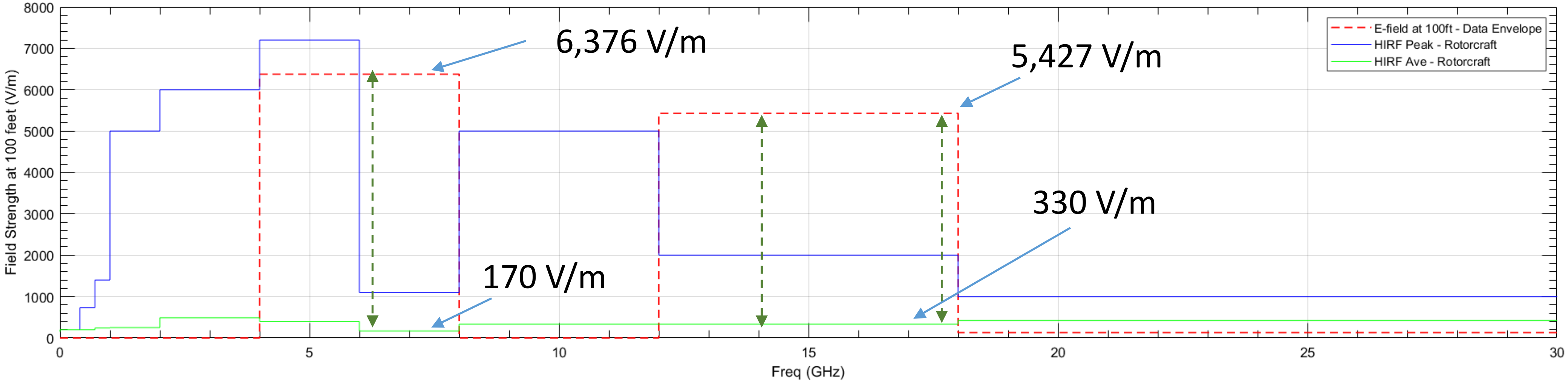
HIRF zones become small at 100 V/m



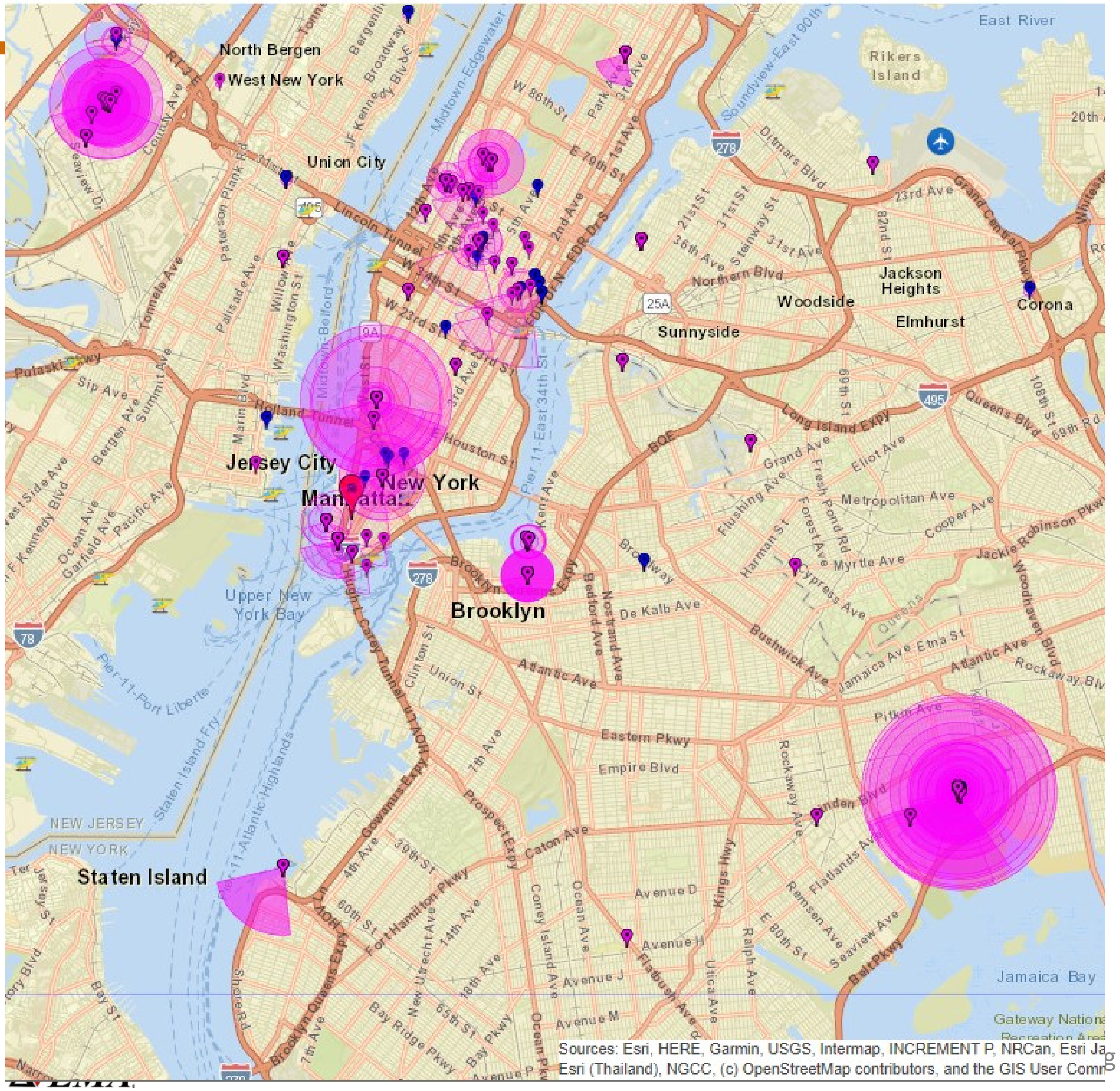
IBFS SES (Uplink) Transmitters

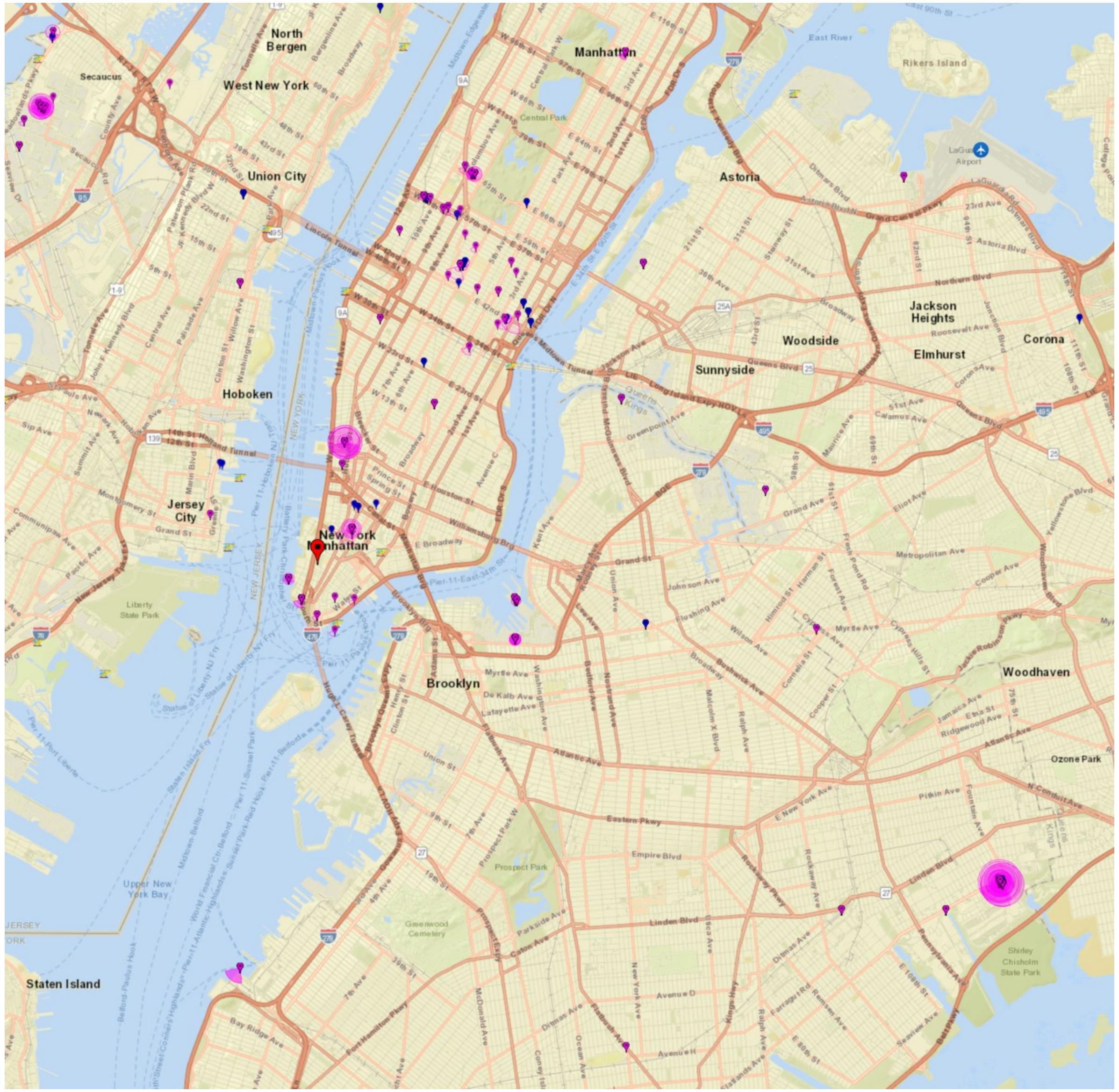
- Compare against HIRF Ave. limit
- Current requirements not sufficient!
- **Recommend:**
  - **500 V/m and use Map**



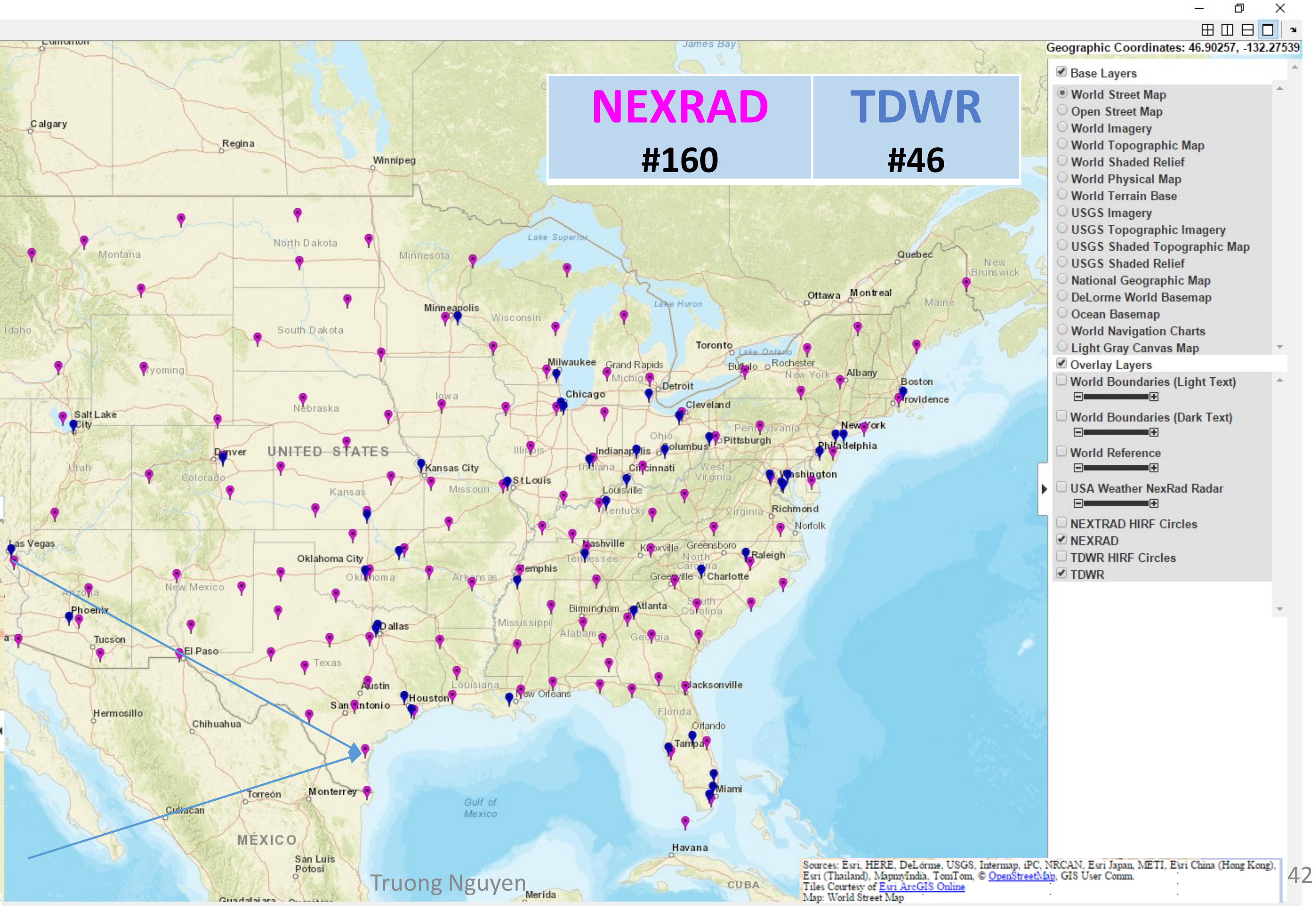


IBFS – HIRF Radius, 100 V/m & 500 V/m Tolerance Levels

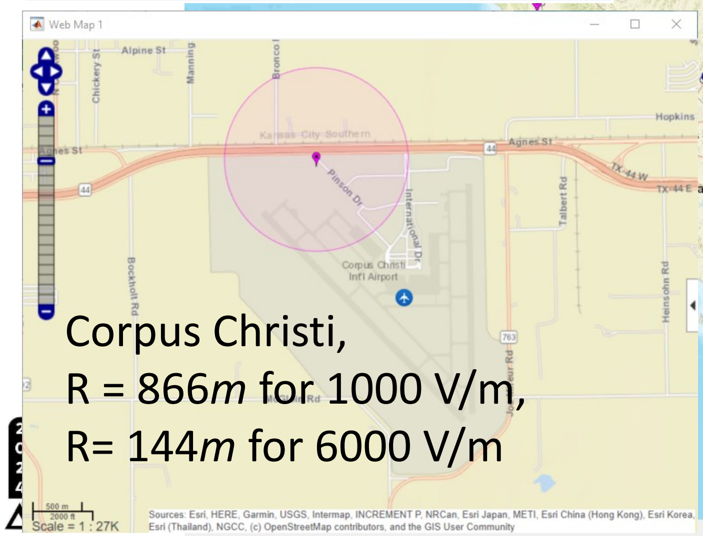




NOAA Weather Radars HIRF zone at 1000 V/m



	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

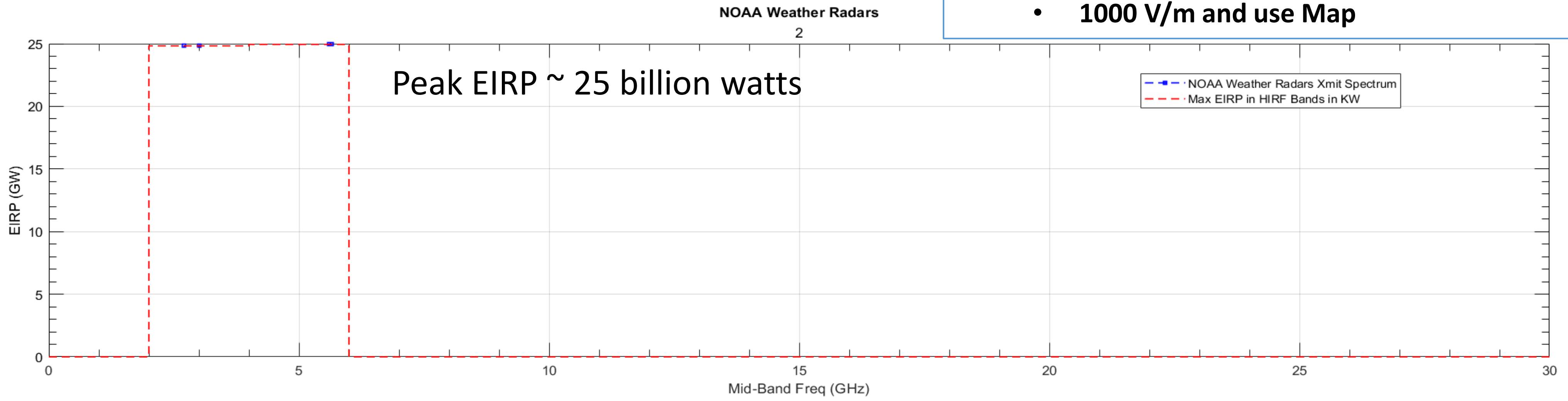


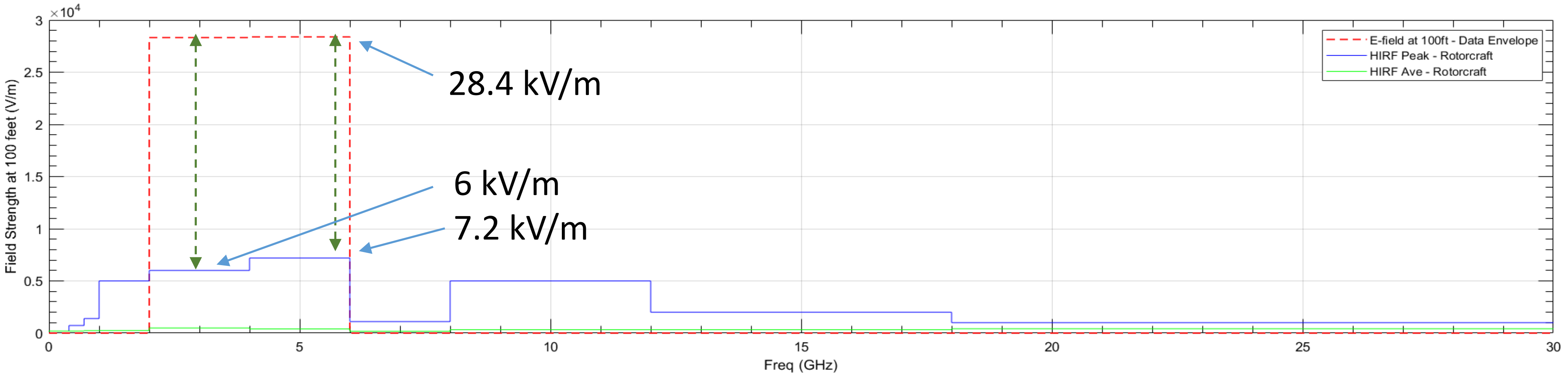
Corpus Christi,
R = 866*m* for 1000 V/m,
R= 144*m* for 6000 V/m

Truong Nguyen

NOAA Weather Radar – Peak Field Level at 100' distance

- Current requirements not sufficient!
- **Recommend:**
  - **1000 V/m and use Map**

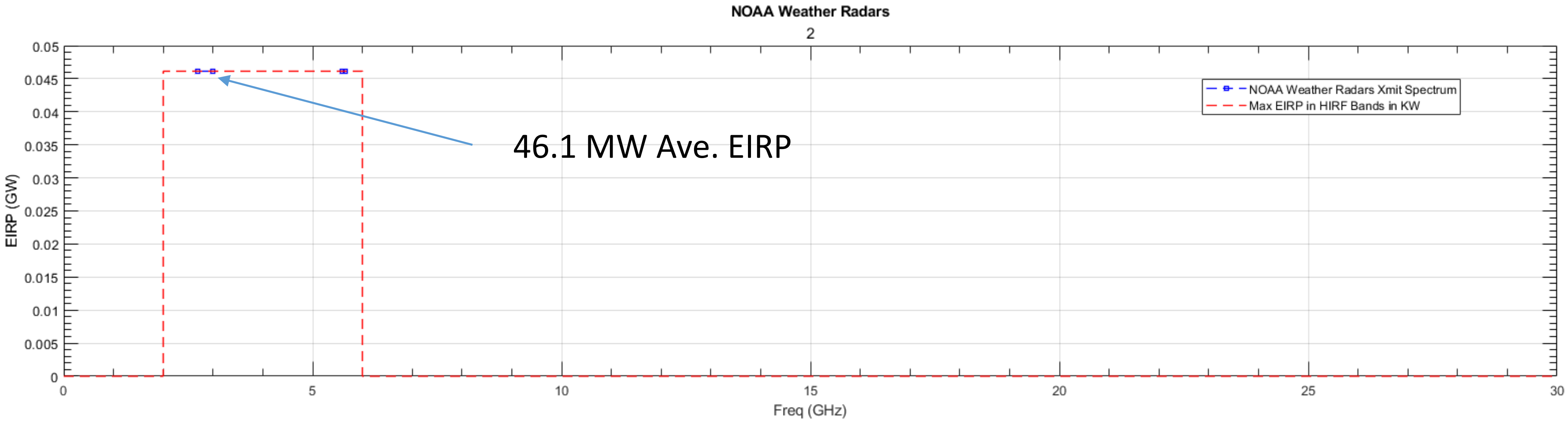


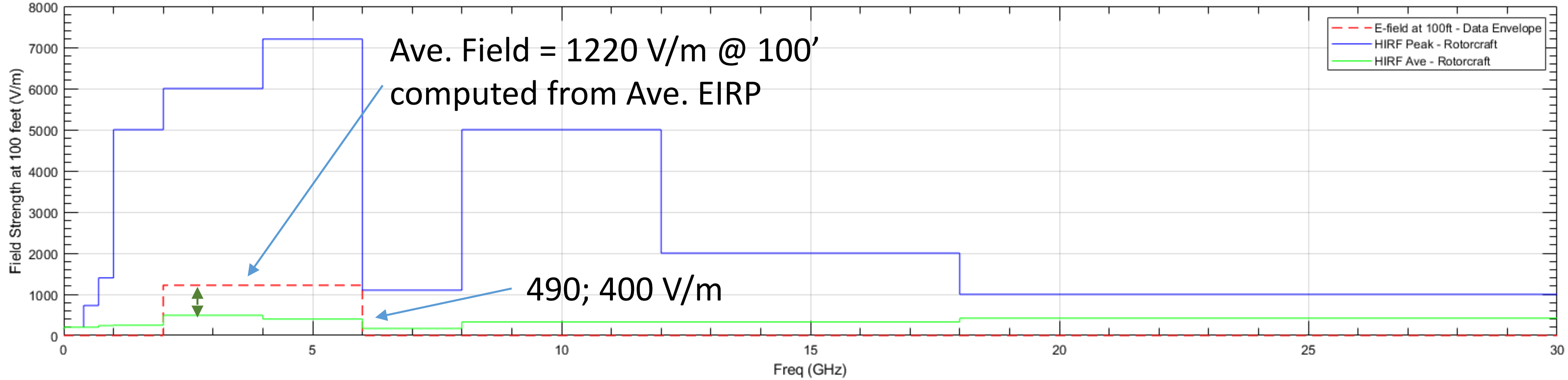


NOAA Weather Radar HIRF zones at 1000 V/m

R = 866*m* for 1000 V/m,
R = 124*m* for 7000 V/m

NOAA Weather Radar – Ave Field Level at 100’ distance





Preliminary - Recommended Field Tolerant Levels for AAM vehicles

- Recommended HIRF **Ave. Levels** based on ULS, CDBS, and IBFS:
  - **25 V/m** Freq < 2 GHz (Band Driver: ULS)
  - **50 V/m** 2 GHz - 40 GHz, except as noted below (ULS)

  - **55 V/m** 30 MHz – 0.1 GHz (CDBS)
  - **105 V/m** 0.1 GHz – 0.4 GHz (TV)
  - **100-200 V/m** Freq: 0.4 GHz – 1 GHz, **plus map** (TV)
  - **500 V/m** 4-6 GHz, 6-8 GHz, and 12-18 GHz, **plus map** (IBFS)
- Recommended HIRF Levels based on NOAA Weather Radar
  - **Peak:** **1000 V/m**, 2-4 GHz, 4-6 GHz, **plus map**
  - **Ave:** **100 V/m**, **plus map**
- Stay 100’ slant distance away from RF sources per assumption
- Keep out of Airports/Heliports and Military Bases
  - Unless location and frequency are known, and
    - Transmitter power < 77.4 KW levels
      - 77.4 KW EIRP corresponds to 50 V/m @100’
    - Use HIRF Map’s separation distances for higher power sources

Suggested Minimum HIRF Levels

HIRF Field levels in red are inadequate for 100’ separation. Actuals are in Blue

		Original HIRF Levels in V/m		Suggested Min. Tolerance Level (V/m)	
HIRF Bands	Freq. Range	Rotorcraft Peak	Rotorcraft Ave	Peak	Ave
1	10 kHz - 100 kHz	150	150		25
2	100 kHz - 500 kHz	200	200		25
3	500 kHz - 2 MHz	200	200		25 (ULS)
4	2 MHz - 30 MHz	200	200		25 (ULS)
5	30 MHz -70 MHz	200	200		55 (CDBS)
6	70 MHz - 100 MHz	200	200		55 (CDBS)
7	100 MHz -200 MHz	200	200		105 (CDBS)
8	200 MHz - 400 MHz	200	200		105 (CDBS)
9	400 MHz -700 MHz	730	200 (515)		105 + Map (CDBS)
10	700 MHz - 1 GHz	1400	240 (378)		105 + Map (CDBS)
11	1 GHz - 2 GHz	5000	250		25 (ULS)
12	2 GHz - 4 GHz	6000 (46,130)	490 (1220)	1000 + Map (NOAA)	50 (ULS), *(100 + Map (NOAA))?*
13	4 GHz - 6 GHz	7200 (46,130)	400 (6376)	1000 + Map (NOAA)	500 + Map (IBFS)
14	6 GHz - 8 GHz	1100	170 (6376)		500 + Map (IBFS)
15	8 GHz - 12 GHz	5000	330		50 (ULS)
16	12 GHz - 18 GH	2000	330 (5246)		500 + Map (IBFS)
17	18 GHz - 40 GHz	1000	420 (127)		125, or 50 + Map (ULS)

Conclusions

- **The HIRF-avoidance approach appears technically feasible**
- **Use HIRF-Map** to address higher-power sources
  - Recommend a minimum default tolerance level
    - To reduce the size of avoidance areas
    - Remove smaller transmitters from considerations
- **Existing HIRF requirements are inadequate in some cases**
  - For CDBS, IBFS (SES), and NOAA weather radar transmitters (at 100')
- **Avoid airports and military/government installations for now** unless transmitter databases are available

Recommendations

- **Incorporate additional databases** if available
  - Airport Surveillance Radar, Air-Route Surveillance Radar,…
- Perform similar analyses for other major cities
  - To determine the recommended minimum tolerance
- Consider mobile sources (other vehicles)
- **Work with the FCC to improve CDBS and IBFS GPS accuracy**
  - As FCC licenses are renewed periodically

Recommendations

- **Establish a standard subgroup** to develop further, and coordinate with national authorities (FAA, NTIA) on sensitive transmitter databases access
  - **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

The End

System-Wide Safety (SWS) Project

Electrified Powertrain Flight Demonstration Project

Illustration by NASA's Aeronautics Research Mission Directorate